

FTD-MT- 65-57

#65-64797
AD624820

TRANSLATION

MANUFACTURE OF BASIC COMPONENTS AND ASSEMBLIES
OF AIRCRAFT ENGINES

By

M. I. Yevstigneyev, I. A. Morozov, et al.

CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION	
Hardcopy	Microfiche
\$ 8.25	\$ 225.52890
ARCHIVE COPY	

code 1.

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO



DEC 21 1965
RECEIVED
TSA

This document is a machine translation of Russian text which has been processed by the AN/GSQ-16(XW-2) Machine Translator, owned and operated by the United States Air Force. The machine output has been post-edited to correct for major ambiguities of meaning, words missing from the machine's dictionary, and words out of the context of meaning. The sentence word order has been partially rearranged for readability. The content of this translation does not indicate editorial accuracy, nor does it indicate USAF approval or disapproval of the material translated.

EDITED MACHINE TRANSLATION

MANUFACTURE OF BASIC COMPONENTS AND ASSEMBLIES
OF AIRCRAFT ENGINES

BY: M. I. Yevstigneyev, I. A. Morozov, et al.

English Pages: 517

TM5500657

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

Tekhnologiya Aviadvigatolestroyeniya

M. I. Yevstigneyev, I. A. Morozov, A. V. Podzey,
A. M. Sulima, I. S. Tsukanov

IZGOTOVLENIYE OSNOVNYKH DETALEY I UZLOV AVIADVIGATELEY

Pod redaktsiyey dokt. tekhn. nauk,
prof. A. V. Podzeya

Dopushcheno
Ministerstvom vysshego i srednego
spetsial'nogo obrazovaniya RSFSR
v kachestve uchebnogo posobiya
dlya aviatsionnykh vuzov i fakul'tetov

Izdatel'stvo
"MASHINOSTROYENIYE"

Moskva - 1964

Pages 1-456

Automation of Working of Housing Parts.....	365
4. Inspection of Housing Parts.....	366
Chapter IX. Production of Heads of Combustion Chambers of Liquid-Fuel Engines.....	370
1. Design, Specifications and Materials.....	370
2. Construction of Technological Process.....	373
3. Basic Operations of Working Combustion Chamber Heads..	375
Manufacture of Domes.....	375
Manufacture of Casing.....	380
Welding and Soldering of an Assembly.....	382
4. Inspection of Combustion Chamber Heads.....	386
Chapter X. Production of Fuel Injectors.....	388
1. Design, Specifications and Materials.....	388
2. Construction of Technological Process.....	393
3. Fulfillment of Basic Operations of Production of Injectors.....	396
Casing of Two-Component Injector of a Liquid-Fuel Rocket Engine.....	396
Casing of GTE Injector.....	398
Atomizer.....	400
Swirl Vane.....	401
4. Automation of Production of Fuel Injectors.....	403
5. Inspecting Injectors.....	409
Chapter XI. Manufacture of Pipelines, Flexible Hoses, and Bellows.....	412
1. Manufacture of Pipelines.....	412
2. Manufactured Pipelines and Branch Pipes from Sheet Material.....	431
3. Manufacture of Flexible Metallic Hoses.....	434
4. Manufacture of Bellows.....	438

Treatment of Teeth with Novikov-Type Engagement.....	259
4. Checking of Gears.....	261
Chapter VI. Manufacture of Annular Parts.....	272
1. Obtaining Blanks.....	273
2. Machining.....	283
Chapter VII. Working Parts and Units Made from Sheet Material.....	285
1. Design, Specifications and Material.....	285
2. Construction of Technological Process.....	288
3. Execution of Basic Operations.....	289
Blanking.....	289
Shaping Parts from Sheet Material.....	293
Machining After Forming.....	309
Joining Parts in Assemblies.....	315
Welding of Assemblies.....	315
Soldering Assemblies.....	324
Machining Assemblies.....	325
4. Inspection of Parts and Assemblies from Sheet Material.....	327
Chapter VIII. Production of Housing Parts and Assemblies.....	329
1. Design, Specifications and Materials.....	329
2. Construction of Technological Process.....	337
General Principles.....	337
Plans of Working.....	340
3. Fulfillment of Basic Operations for Working Housings.....	347
Large-Dimension and Thin-Walled Housings.....	347
Housings of the Pump and Turbine of Turbopump Units...	358
Medium-Dimension Housings of Box-Like Form.....	360
Small Housing Parts.....	363

TABLE OF CONTENTS

U. S. Board on Geographic Names Transliteration System.....	vii
Designations of the Trigonometric Functions.....	viii
Preface.....	1
Introduction.....	4
Chapter I. Machining of Shafts.....	7
1. Construction, Technical Specifications, and Materials.....	7
2. Construction of Technological Process.....	9
General Positions.....	9
3. Execution of Basic Operations for Machining of Shafts.....	15
4. Automation of Processes for the Manufacture of Shafts.....	29
5. Checking of Shafts.....	33
Chapter II. Production of Wheel.....	35
1. Construction, Specifications and Materials.....	35
2. Construction of Industrial Process.....	40
General Premises.....	40
3. Fulfillment of Basic Operation of Machining of Wheels.....	46
4. Checking Wheels.....	59
Chapter III. Working of Blades.....	63
1. Design, Specifications and Materials.....	63
Accuracy of Working.....	68
Blade Materials.....	70
2. Construction of Manufacturing Process.....	72
Rotor Blades of GTE Turbine.....	72
General Positions.....	72
Small-Size Blades.....	79

BLANK PAGE

Cast Blades.....	80
Single-Channel Cooled Blades with Deflector.....	81
Multichannel (Honeycomb) Cooled Blades.....	83
Blades of GTE Turbine Nozzles.....	84
Casting of Blanks.....	84
Machining.....	88
Blades of Turbines of Turbopump Units (TPU).....	89
Blades of GTE Axial-Flow Compressors.....	90
Peculiarities of Working Compressor Blades of Titanium Alloys.....	95
3. Increase of Operation Life and Reliability of Work of Blades by Industrial Methods.....	98
4. Execution of Basic Operations of Working Blades.....	105
Working of Base and Root Surfaces.....	105
Turbine Rotor Blades.....	105
Blades of Nozzles.....	112
Rotor Blades of Compressor.....	112
Stator Blades of Compressor.....	115
Preliminary Working of Tip.....	116
Turbine Rotor Blades.....	116
Blades of Nozzles.....	120
Rotor and Stator Blades of Compressor.....	121
Finishing of the Tip of Turbine and Compressor Blades.....	124
Grinding of Tip.....	124
Polishing.....	136
Working of Tip by Electrical Methods.....	141
5. Automation of Production of Blades.....	150
Automatic Transfer Machines for Producing Compressor Blades.....	150

Working of Blade Tips on Machines with Programmed Control.....	160
6. Checking Blades.....	162
Chapter IV. Production of Impellers.....	177
1. Construction, Technical Specifications, and Materials.....	177
2. Construction of Technological Process.....	181
General Positions.....	181
3. Execution of Basic Operations for the Production of Impellers.....	186
4. Checking of Impellers.....	204
Chapter V. Production of Gears.....	208
1. Design, Technical Specifications, and Materials.....	208
2. Construction of the Technological Process.....	212
General Position.....	212
3. Execution of Basic Operations for the Production of Gears.....	220
Treatment Before Cutting of Teeth.....	220
Cutting the Teeth of Spur Gears.....	223
Gear Planning.....	223
Gear Milling.....	225
Gear Shaping.....	231
Cutting of Teeth on Machines of High Productivity.....	236
Cutting the Teeth of Bevel Gears.....	238
Teeth-Finishing Operations.....	244
Shaving.....	244
Grinding of Teeth.....	246
Lapping of Teeth.....	252
Polishing of Teeth.....	255
Tooth Knurling and Pressing.....	256

Chapter XII. Manufacture of Parts and Assemblies from Plastics.....	450
1. Design, Specifications and Materials.....	450
2. Setting up the Technological Process.....	461
3. Fulfillment of Basic Operations.....	470
Chapter XIII. Manufacture of Fuel Elements of Nuclear Power Plants.....	484
1. Construction, Engineering Factors, and Materials.....	484
2. Construction of Technological Process.....	491
3. Carrying Out of Basic Operations of Manufacture of FE.....	503
4. Protective Arrangements for Work with Radio- Active Materials.....	508
5. Inspection of FE.....	511
Literature.....	513

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А	<i>а</i>	A, a	Р	<i>р</i>	R, r
Б	<i>б</i>	B, b	С	<i>с</i>	S, s
В	<i>в</i>	V, v	Т	<i>т</i>	T, t
Г	<i>г</i>	G, g	У	<i>у</i>	U, u
Д	<i>д</i>	D, d	Ф	<i>ф</i>	F, f
Е	<i>е</i>	Ye, ye; E, e*	Х	<i>х</i>	Kh, kh
Ж	<i>ж</i>	Zh, zh	Ц	<i>ц</i>	Ts, ts
З	<i>з</i>	Z, z	Ч	<i>ч</i>	Ch, ch
И	<i>и</i>	I, i	Ш	<i>ш</i>	Sh, sh
Й	<i>й</i>	Y, y	Щ	<i>щ</i>	Shch, shch
К	<i>к</i>	K, k	Ъ	<i>ъ</i>	"
Л	<i>л</i>	L, l	Ы	<i>ы</i>	Y, y
М	<i>м</i>	M, m	Ь	<i>ь</i>	'
Н	<i>н</i>	N, n	Э	<i>э</i>	E, e
О	<i>о</i>	O, o	Ю	<i>ю</i>	Yu, yu
П	<i>п</i>	P, p	Я	<i>я</i>	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere.
 When written as ѣ in Russian, transliterate as yě or ě.
 The use of diacritical marks is preferred, but such marks
 may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH
 DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	\sin^{-1}
arc cos	\cos^{-1}
arc tg	\tan^{-1}
arc ctg	\cot^{-1}
arc sec	\sec^{-1}
arc cosec	\csc^{-1}
arc sh	\sinh^{-1}
arc ch	\cosh^{-1}
arc th	\tanh^{-1}
arc cth	\coth^{-1}
arc sch	sech^{-1}
arc csch	csch^{-1}
—	
rot	curl
lg	log

This book, which is a training aid for students of aviation higher educational institutions and departments, presents the technological processes of manufacture of the critical components and assemblies of aircraft engines. It considers their design features, technical specifications for manufacture and materials, construction of technological processes, methods of executing basic operations, and checking methods.

The book will also be useful to engineers and technicians of the aviation industry.

Critics: the "Aircraft Engine Production" chair of the Kuibyshev Aviation Institute and Docent G. P. Zhadin.

Editor: Engineer M. A. Kolosov

PREFACE

The training course "Technology of Aircraft Engine Construction" consists of five sections:

1. Design fundamentals of technological processes of machining.
2. Design fundamentals of accessories.
3. Methods of treating surfaces.
4. Manufacture of components and assemblies of aircraft engines.
5. Assembly of aircraft engines.

The first three sections, which constitute the stablest part of the course and are common for various specialties, are presented in the textbook of V. P. Firago.*

This book is a training aid for the fourth section of the course and it includes questions of the technology of manufacture of basic components and assemblies of the engines of contemporary flight vehicles.

The fifth section is presented in the training aid by V. N. Belikov and A. N. Nikitin.**

*V. P. Firago. Design Fundamentals of Technological Processes and Accessories, Methods of Treating Surfaces, Oborongiz, 1963.

**V. N. Belikov and A. N. Nikitin. Assembly of Aircraft Engines, "Machine Building," 1964.

BLANK PAGE

All the material of this book is divided into 13 chapters; in each of them, groups together the components and assemblies which are similar with regard to technological criteria.

The authors have used the experience of Soviet plants, materials of scientific research institutes, reference sources, and also their own pedagogic and industrial practice.

In every chapter of the book the following order of presentation of the material has been adopted:

1. Construction of components or assemblies and the technical specifications for their manufacture and materials.
2. General considerations on the construction of the technological process.
3. Execution of basic operations.
4. Checking the basic elements of components or assemblies.

The authors have attempted to expound the material in concise form by omitting questions that are already known to students from courses taken or adjacent disciplines and by concentrating attention on questions of the manufacture of components and assemblies of objects of new aviation materiel.

As compared to the aid which was published in 1957, this book introduces considerable changes with respect to the contemporary state of the technology of aircraft engine construction. In particular, the subject of piston motors is left out and sections referring to the production of jet engines are considerably expanded.

The chapters of the book are not identical in volume. Thus, for instance, the production of blades, gears, components, and assemblies from sheet material is allotted the most attention and the corresponding chapters have a larger volume than the chapters that refer to other components. This is explained both by the variety of shapes

and forms of the indicated components and assemblies, so also by the complexity of the technology of their manufacture, including the most various methods of treatment.

Chapters I, VI, and VII were written by Prof. A. V. Podzey, Chapters VIII, X, and XI by Docent M. I. Yevstigneyev, Chapters IX and XIII by Docent I. A. Morozov, Chapter III by Docent A. M. Sulima, Chapters II, IV, and V by Docent I. S. Tsukanov, and Chapter XII was written jointly by Docents M. I. Yevstigneyev and I. S. Tsukanov.

In the review and examination of the manuscript, valuable remarks were made by Docents G. P. Zhadin, A. S. Shevelev, I. A. Ivanshchenko, V. M. Shmanev, V. P. Aleksandrov, V. T. Dundikov, and Yu. V. Yanitskiy. The authors express their sincere gratitude to all these persons.

The authors would gladly welcome all remarks and wishes both on the substance of the expounded questions, and also of a methodological nature, and ask that they be sent to the "Machine Building" publishing house at Moscow, I-51, Petrovka, 24.

INTRODUCTION

Improvement of the basic parameters of an aircraft engine, i.e., increase of power (thrust) and service life, lowering of specific fuel consumption, mass, and overall dimensions, is closely connected with raising the quality of its component and assemblies. High accuracy in the thinness of walls (delicacy) of components, the exclusively high requirements for their surface quality and the physico-mechanical state of the material, the wide use of heat-resistant and light alloys, and the application of the latest methods of production of blanks and components are the characteristic features of contemporary aircraft engine construction.

Even on comparatively small scales of production for obtaining blanks, such forms of hot working as drop forging, pressure molding, drawing, coining, and so forth, capable of ensuring specified location of fibers in the blank and given degree of deformation, are applied. Smith forging in aircraft engine construction is applied quite rarely. Many components are made by different methods of precision casting. The high requirements for the quality of the material force the application of special forms of checking which are founded on the use of isotopes and ultrasonics.

Almost all basic components of engines are subjected to thermal or thermochemical treatment, whose place in the technological process usually is determined by a large number of considerations (requirements for quality of the component, the possibility of carrying out machining, and others).

For guarantee of the required accuracy of machining during the design of technological processes, special attention should be given to the selection of bases, and also to the methods of installation of components. For the same purpose, the surface of components is frequently processed several times. In selecting methods of treatment, especially in finish machining, it is necessary to consider the possibility of the appearance of work hardening and residual stresses which can noticeably affect the performance of components and service life of an engine.

The components of aircraft engines require thorough treatment even of unmated surfaces. This is caused by the tendency to increase the fatigue strength of components and their corrosion resistance. For the same purpose, different methods of hardening technology and also coating and chemical treatment are being used more frequently.

The production of aircraft engines is connected with large difficulties due to the application of difficult-to-process heat-resistant alloys in them. Components made from these alloys are processed at lowered cutting rates, but the stability of the tool still remains very low. This makes tool economy difficult, especially if the necessity of application of a shaping tool is considered.

Many components and assemblies of contemporary aircraft engines are made from sheet material. They are presented with very high requirements with respect to quality of material, airtightness, and

strength of seams; the surfaces of these components and assemblies cannot have any defects in the form of flaws, cracks, and so forth. The high requirements force the continuous improvement of processes of cold pressing and drawing, and the application of new methods of hot working, welding, and soldering.

The production of aircraft engines differs also by special thorough checking. All critical components and assemblies, as a rule, are subjected to a hundred-percent overall check. The quality of the material, correctness of form, dimensions, mutual location of surfaces, quality of surfaces, weight balance, and also the quality of connections, especially permanent ones, are checked.

While allotting considerable attention to the quality of components and assemblies, at the same time it is necessary to consider the economics of production, seeking high performance and low cost of engines. This problem is solved by means of improvement of technological processes and utilization of the most rational forms of organization of production. Thus, for instance, treatment of blades, which each engine uses a great deal of, even on small scales of engine turnout, it is profitable to organize according to the principle of mass production.

MT-65-57

Manufacture of Basic Components
and Assemblies of Aircraft
Engines, Technology of Aircraft
Engine Construction, Machine
Building Publishing House,
Moscow, 1964.

Pages: Cover-456

C H A P T E R I

MACHINING OF SHAFTS

§ 1. CONSTRUCTION, TECHNICAL SPECIFICATIONS, AND MATERIALS

Critical shafts of aircraft engines work with large loads and at high speeds. The necessity of decreasing mass leads to complication of the form of shafts and forces them to be made hollow and thin-walled.

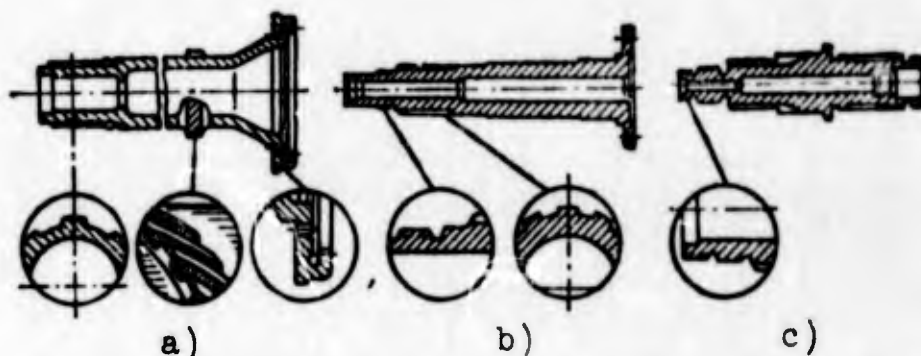


Fig. 1.1. Shafts of aircraft engines. a) turbine shaft; b) reduction gear shaft; c) turbo-pump assembly shaft.

The most complicated shafts to manufacture are those of turbines, compressors, reduction gears, and turbopump assemblies (Fig. 1.1). The external surfaces of these shafts constitute different combinations of smooth journals, splines, threads, gears, flanges, and so forth. Flanges of certain shafts (for instance, turbine and reduction gear shafts) frequently have internal or face splines of different form, and furthermore, holes under the fastening bolts.

The form of axial holes is stipulated basically by the conditions of uniform strength of the component. Therefore, they are straight, stepped, spherical, and other forms. Most shafts, besides axial ones, still have radial holes for feeding oil from the internal cavity to the external contact surfaces.

The difficult conditions of work of shafts determine the high requirements for accuracy of their machining; namely:

1. Working journals must be processed through the 1st to the 2nd class of accuracy.

2. Deviation of form of working journals is allowed within the limits of 0.005-0.02 mm.

3. Accuracy of nonworking journals - 3-4th class.

4. Accuracy of axial holes - 3-4th class.

5. Accuracy of matched holes - 1-2nd class.

6. Accuracy of thread - 1-2nd class (for threads).

7. Accuracy of splines - 2nd class.

8. Run-out of working journals relative to one another is allowed within the limits of 0.01-0.04 mm.

9. Mutual run-out of working and nonworking journals is allowed within the limits of 0.05-0.2 mm.

10. Purity of treatment of working surfaces - 7-10th class.

11. Purity of treatment of nonworking surfaces - 5-7th class.

Certain shafts must be statically and dynamically balanced with high accuracy.

The working surfaces of shafts frequently carburized to a depth from 0.7 to 1.2 mm. Hardness of carburized surfaces - HRC \geq 58. In certain cases the working surfaces of shafts are nitrated. The depth of the nitrated layer varies from 0.6 to 0.9 mm, and the hardness is

HRC \approx 65. Thermally improved shafts (subjected to hardening and tempering) must have a hardness of up to HRC42.

Defects of the surface layer (cracks, nadsirs, scratches, and burns) on critical shafts are not allowed. However, sometimes it is difficult to be free of small hairline cracks of metallurgical origin. The limits of permissibility of such a defect usually are indicated in the technical specifications.

The material used for shafts of aircraft engines is high-quality steel. Most frequently applied are chrome-nickel steels 18KhNVA, 12KhNZA, and 40KhNMA which, after hardening and tempering, obtain the following mechanical qualities: $\bar{\sigma} = 100-115 \text{ kg/mm}^2$ ($\approx 100 \cdot 10^7 - 115 \times 10^7 \text{ newton/m}^2$), $\delta = 11-12\%$, HB390 ($d_{10/3000} \approx 3.1 \text{ mm}$).

Shafts of single-action engines use a less expensive steel, for instance, 38KhA and steel 45.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

General Positions

Blanks of shafts (Fig. 1.2), as a rule, are obtained by stamping, transverse rolling, and on large scales of production, by rotary

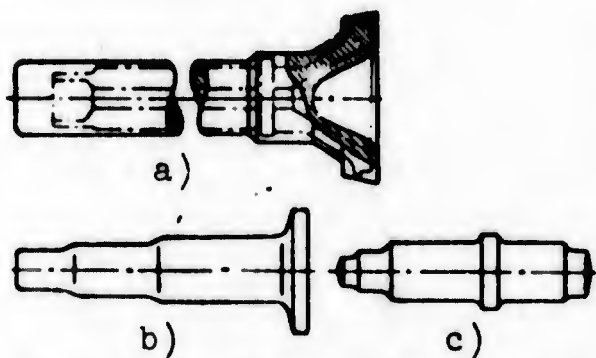


Fig. 1.2. Shaft blanks. a) turbine shaft; b) reduction gear shaft; c) turbopump assembly shaft.

pressing. Blanks are stamped under a hammer, on presses, or on forging machines. Disassembly of stamps, depending upon the form of blank, can be along or across the axis of the shaft. Transverse disassembly is possible usually in those cases when the shaft has a flange on its

end, and the rest of it is smooth or stepped with a gradual (from the flange) decrease of diameters of steps. With transverse

disassembly, a hole can be obtained on the large end (at the disassembly), especially if the blank is forged on a forging machine. However, this is done when the diameter of the hole is sufficiently great.

Drafts for holes are taken within the limits of $10-15^{\circ}$, and for external surfaces, $3-7^{\circ}$. All transitions of the blank must be smooth and the direction of the fibers should correspond to the configuration of the shaft. Blanks of very critical engine shafts are selected according to the first check group.* In these cases, from every blank an end 70-75 mm long is cut off for manufacture of samples for mechanical tests, and the blank is correspondingly made longer. Allowances for machining, depending upon the form and dimensions of the shaft, vary from 6 to 12 mm on the diameter; they are determined by means of calculation, using corresponding norms.

Blanks of shafts which are obtained by rotary pressing are the most similar in configuration and dimensions to the finished component. This method consists in periodic pressing and extruding in steps cut from the rod of a cylindrical blank in special dies. The large number of pressings following one after the other (approximately in 0.01 sec) plastically deform the blank, decreasing its cross section and forcing the metal to flow in an axial direction.

The blanks enter the machine shop in normalized state with a hardness of HB190-270, cinder should be removed from them (by etching or other methods), and external defects should be removed if the depth of their bedding does not exceed half the allowance on a side.

Machining of shafts is usually divided into three stages: roughing, finishing, and final treatment.

*Individual acceptance with respect to mechanical qualities is provided for.

Roughing results in equal distribution of allowances for subsequent treatment and it removes surface defects. It is conducted under stress conditions which are limited by the allowed shaft deformations under the action of forces of cutting and fastening. On considerable scales of production, heavy-duty high-power and rigid machines are more frequently used here.

During finishing, significantly smaller allowances are removed than during roughing. The conditions here are designated and less stressed to avoid deformations of both the entire shaft, and also its surface layers. In serial production on this stage, heavy-duty multiblade machines and lathes are used, frequently equipped with copying device. The basic purpose of this stage is to obtain a shaft with small allowances for final treatment. In addition, the errors must be corrected here after the first stage of machining and warping after heat treatment.

During final treatment it is required to obtain the assigned precision and surface purity; therefore, the conditions in which there can appear considerable errors due to deformations are impermissible here. The biggest specific weight on this stage is the processing on grinding machines; furthermore, different methods of finishing are applied (honing, superfinishing, and polishing). On the same stage, as a rule, threads, small splines, and other surfaces are processed, which could be damaged if they were processed earlier.

In the construction of a process for machining a shaft, such a sequence is usually maintained so that on the last stages the internal surfaces would be processed earlier than external ones. This is stipulated by the fact that concentricity of the external and internal surfaces is simpler to ensure if in the beginning the internal

surfaces were processed, using them then as adjusting bases for processing the external surfaces.

There are, however, cases when it is necessary to reject this rule and finally process holes at the end of the technological process. This in particular is the case if the shaft has inserts made from a soft metal (for instance, from plumbous bronze); the use of the finally processed holes of the inserts as an adjusting base could lead to nadirs during installation on a mandrel.

Considerable attention during the designing of a technological process is given to the selection of the site of heat treatment. Thermally improved shafts, for instance, may be subjected to hardening and tempering both before machining, and also after its first stage. In the first case, obviously, it is not necessary to transport the shafts from the machine shop to the heating shop and back; the duration of the processing cycle is thereby reduced. However, this is not always possible; in the presence of large allowances for processing, there arises the danger of nontempering of shafts. Such shafts are first roughed, and then subjected to heat treatment.

For shafts that have separate carburized sections, the site of heat treatment in the technological process depends basically on the method of protecting the uncarburized surfaces.

Aircraft engine construction employs the following methods of protection:

1. Copper plating of uncarburized surfaces before carburization (thickness of copper layer from 0.02 to 0.04 mm).
2. Increase of allowance on uncarburized surfaces, which is removed after carburization, but before hardening.
3. Combination of the first and second method, which includes copper plating of surfaces with increased allowance that is removed

after hardening of the component (double protection).

The last method permits the complete avoidance of carburization of surfaces, an increase of whose hardness is absolutely impermissible. In the application of the first and the last method of protection, copper plating, carburization, hardening, and tempering is conducted usually before finishing, but after the carburized surfaces are prepared for final treatment.

In the second method, the external surfaces of the shaft are carburized around after the carburized surfaces are prepared for final treatment, while the uncarburized ones are treated with increased allowances. Hardening and tempering are carried out after removal of these allowances before the finishing stage of treatment. Obviously, with the second method the cycle of treatment is longer than with the first, since the component must be sent from the machine shop to the heating shop twice. Therefore, such a method is not applied if possible.

In the solution of the question concerning selection of a method of protection from carburization, we are guided by the following considerations.

If a local increase of hardness is allowed on carburized surfaces, then the first method is applied. If the component has a surface, an increase of whose hardness is absolutely impermissible (threads, small splines, spots where small holes must be drilled after tempering, and so forth), then the third method is applied. Finally, if during machining (finishing or final) of uncarburized surfaces by a metal cutting tool it is necessary to pass sections of carburized surfaces, then the second method is applied.

Model Processing Plans

Thermally-improved shafts

1. Heat treatment (normalization).
2. Facing and centering.
3. Turning of outer surfaces under a support (if the shaft is long).
4. Roughing stage:
 - a) drilling of axial hole;
 - b) boring of hole, turning of center faces;
 - c) cutting of sample for testing (for shafts of first check group);
 - d) machining of external surfaces.
5. Heat treatment (hardening and tempering).
6. Restoration of center bases.
7. Grinding of journals under support (if shaft is long).
8. Finishing stage:
 - a) boring of hole;
 - b) machining of external surfaces;
 - c) milling of grooves, flats, and other similar external surfaces;
 - d) drilling of radial holes.
9. Final stage:
 - a) polishing of hole;
 - b) boring or grinding of hole sections with high accuracy;
 - c) grinding of external surfaces;
 - d) cutting of splines;
 - e) threading;
 - f) polishing of external surfaces;
 - g) finishing of working surfaces.
10. Final check.

Hardening and tempering of shafts having diameter less than 50 mm and with small allowances on all steps is produced before the first stage. If shafts have small length, for instance up to 500 mm, then they are not centered, and the rough stage starts from hole processing.

Carburized shafts

1. Heat treatment (normalization).
2. Facing and centering.
3. Machining of external surfaces under support (if shaft is long).
4. Roughing stage:
 - a) drilling of axial hole;
 - b) boring of hole, turning of center faces;
 - c) cutting of sample for testing (for shafts of the first check group);
 - d) machining of external surfaces;
 - e) grinding of carburized hole sections;
 - f) grinding of external carburized surfaces.
5. Copper plating of uncarburized surfaces.
6. Carburization, hardening, and tempering.
7. Dressing and stripping of hole base faces.
8. Grinding of journals under support (if shaft is long).

Model Processing Plans (Continued)

9. Finishing stage:
 - a) boring of hole;
 - b) machining of uncarburized external surfaces;
 - c) cutting of splines, milling of fillets, and so forth;
 - d) drilling of radial holes.
10. Final stage of treatment:
 - a) polishing of hole;
 - b) grinding of carburized hole sections, restoration of base surfaces;
 - c) grinding of external necks;
 - d) grinding of splines;
 - e) threading;
 - f) polishing of external surfaces;
 - g) finish trimming of external working surfaces.
11. Final check.

Sometimes shafts are copper-plated around, and from carburized surfaces copper is removed by grinding, i.e., copper plating is produced before operation "e" and "g" of the roughing stage.

§ 3. EXECUTION OF BASIC OPERATIONS FOR MACHINING OF SHAFTS

Facing and centering. Facing, depending upon the dimensions of the shaft and the production scales, is done on lathes or horizontal milling machines. During facing on lathes the blank is placed in a chuck, while on milling machines, it is placed in a device with adjusting clamp prisms. After facing, centering is carried out. The blank can be centered on general-purpose machines (turning lathes, drills, turret lathes) and on centering machines of type 283 from the Kirov plant or type FTs-1 and FTs-2.

Large blanks are usually centered manually on mark or on a conductor with the help of an electric drill or on radial drilling machines.

In small batch and piece production, centering with the help of a spiral drill and countersink is employed. However, for small and medium shafts, in serial production it is better to employ combined center drills. Such drills permit the obtainment of center holes in one pass.

In multiple production, for centering of small shafts they usually employ milling-centering machines (Fig. 1.3) which permit facing and centering from one place. In all methods of executing the operation the center holes should ensure equal allowance distribution and at the same time serve as a reliable support during installation of the shaft.

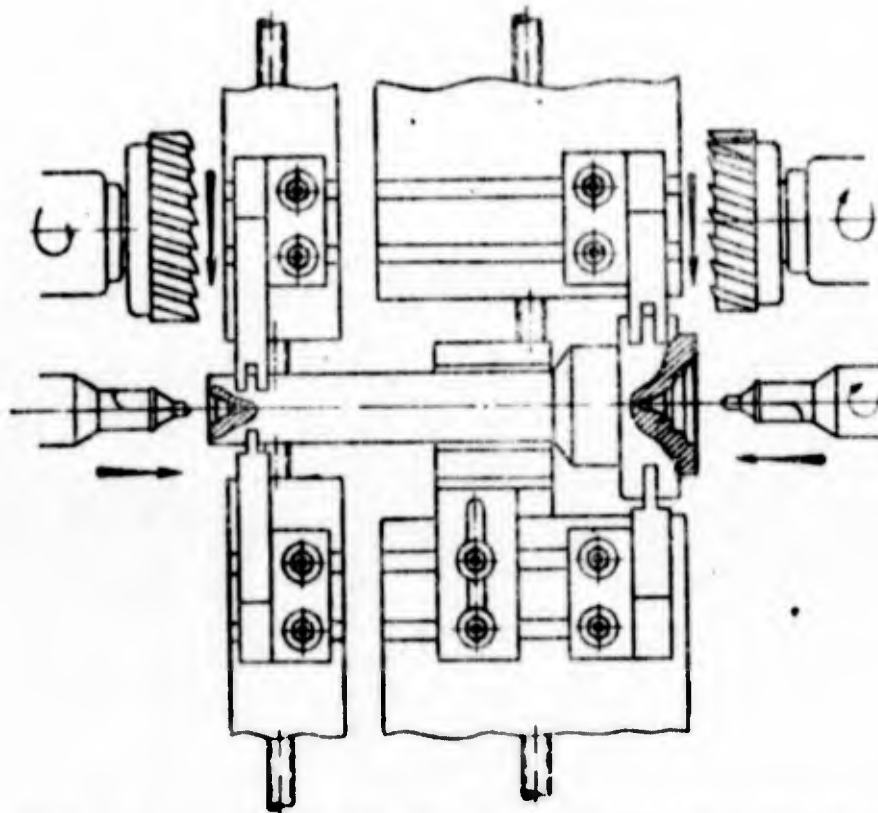


Fig. 1.3. Working zone of milling-centering machine.

Hole processing in solid material. Holes of short shafts are processed most frequently on turret lathes. On these lathes it is possible, besides a hole, to further process the external surfaces of the free end. The correct position of a short shaft can be easily attained by installation of it in a chuck without supports.

Figure 1.4 shows the set-up of a turret lathe for processing a short shaft. The sequence of processing is designated by numbers.

Shafts with a large ratio of length to hole diameter are especially difficult to machine. The holes of such shafts are

processed both from one side (through), and also from two sides by two simultaneously operating cutting tools. The second method is more productive, but with it there is the possible formation of a transition step in the middle of the shaft.

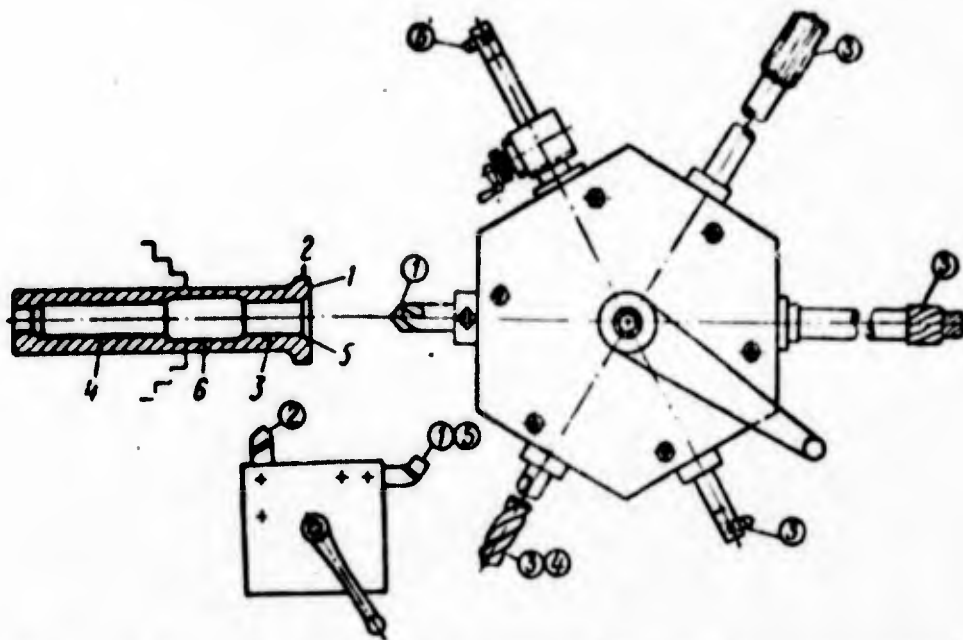


Fig. 1.4. Set-up of turret lathe for processing holes and external surfaces of a shaft.

For processing holes of long shafts they use drills for deep drilling or boring heads. Working with drills for deep drilling, and also with flat drills is produced on horizontal drilling machines, for instance, type 2953, from "Krasnyy proletariy" ["Red Proletarian"] plant.

Before treatment with long drills, for decreasing their withdrawal the front part of the hole is bored for guiding the drill. After drilling, an allowance of about 1 mm is left on the side for counterboring and reaming. During deep drilling, a liquid coolant and lubricant (sulfurized oil) is fed under high pressure (30-40 atm(tech) $\approx 30 \cdot 10^5 - 40 \cdot 10^5$ newton/m²), which facilitates shaving removal from the hole cavity. However, when carrying out the operation, the drill must always be removed from the hole a few times and

it should be cleaned from shavings, which lowers the productivity of the machining. Drilling is done with small feeds (0.03-0.06 mm/rev) at a cutting speed up to 50 m/min. Recently, a more productive method of making deep holes with hollow boring heads has been employed. The diagram for processing with such heads is shown in Fig. 1.5.

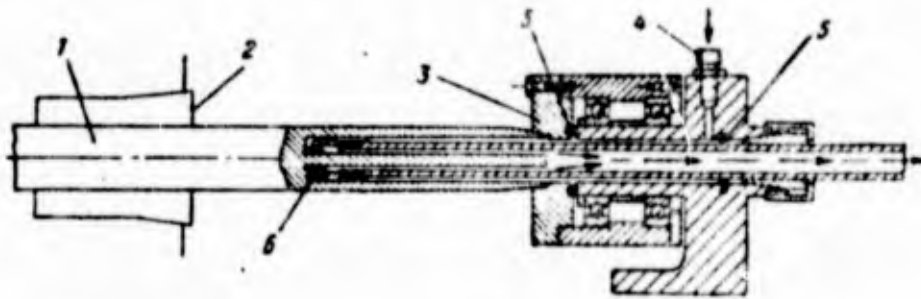


Fig. 1.5. Diagram for making a hole with boring heads.

Shaft 1 is placed on one side in chuck 2, and the other side, the face, rests in cone recess 3 of the revolving part of the device. During the operation, the shaft revolves, and the boring head with cutters 6 moves in an axial direction (axial feed). The liquid coolant and lubricant is fed under large pressure through nozzle 4 into the cavity between the hole of the shaft and the external surface of the boring bar. Cooling the cutting edges of the tool, the liquid emerges with shavings through the hole of the head and the boring bar as shown by the arrows. Leaks are avoided by the employment of seal 5 in the device.

Boring heads are single-, double-, and multi-cutter, depending upon hole diameter. Figure 1.6 shows a single-cutter head for processing shafts with holes from 18 to 30 mm. The head is equipped with guide slots.



Fig. 1.6. Single-cutter boring head.

Boring of holes. Rough boring of stepped holes of long shafts is produced most frequently on turret lathes. For finish boring of holes which have a complex form, copying machines or machines with programmed control are employed. The application of such machines permits an increase in the accuracy and productivity of machining.

After finish boring, separate sections of holes which have an accuracy above the third class are processed on lathe or internal grinders. An example of shaft installation is shown in Fig. 1.7.

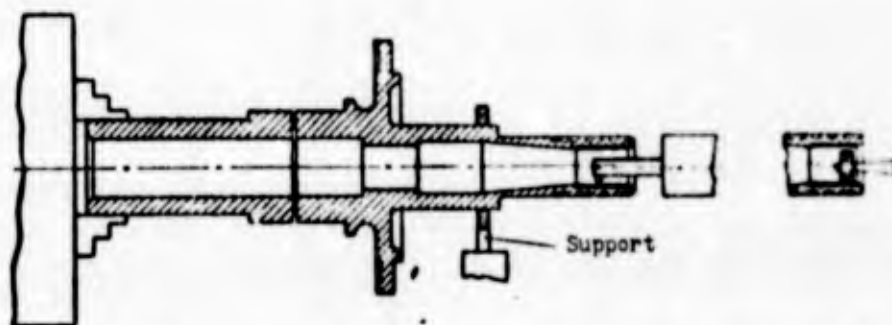


Fig. 1.7. Diagram of shaft installation for making a precision hole.

Turning of external surfaces. Rough turning of external surfaces of shafts is most frequently produced on semiautomatic multi-cutter lathes (for instance, on type 1730 lathes of the "Krasnyy proletariy" Plant, type 116 of the Orzhonikidze Plant, and others).

The shaft is placed on centers and secured in a center chuck.

Heavy shafts (shafts of turbines, reduction gears, and others) are secured in a three-jawed chuck around an external surface (for instance, around a flange). Sometimes, for reliability of fastening

on the surface of the flange, the flats (to the depth of 0.5-0.7 of the allowance) under the chuck jaws are removed. If the flange has holes, then they are used for connecting the shaft with the chuck dog.

Finish turning of external surfaces for long shafts is produced on multi-cutters or lathes with the application of supports for decreasing the camber of the part. During turning on lathes, just as during boring, a wider application has been obtained copying devices with servo-systems. As already mentioned, the application of such devices permits a considerable reduction in the time and labor of the set-up and an increase in the accuracy and conditions of machining.

In the diagram of the hydraulic device (Fig. 1.8) the body of copying fixture 4 is made in the form of a cross slide to which

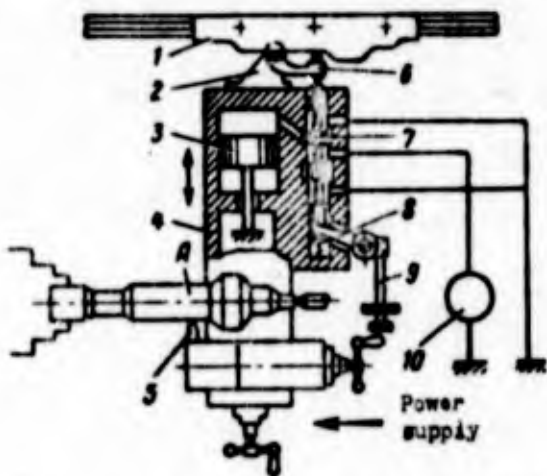


Fig. 1.8. Hydraulic copying device attached to lathe.

cutter 5 is attached. The slide moves about fixed piston 3. On the axis of bracket 2 lever 6 turns with the copying pin. A spring, acting upon valve 7, ensures contact between the pin and master form 1. Oil is injected by pump 10. Adjusting

shifts are made by rotation of shaft 9 which acts upon lever 8. The described fixture can be placed on the machine at an angle of 45° . It is then possible to bore flat faces perpendicular to the axis of the shaft.

Devices with pneumatic control and with electric control are also employed. Figure 1.9 shows the diagram of a device that is included in the lathe diagram. From electric motor 8 rotation is

imparted to electromagnetic clutches 6 and 7. One clutch controls the motion of the cutter in a longitudinal direction, while the other controls its motion in transverse direction. If the contacts of copying instrument 1 are closed, then current goes through the circuit: from generator 3 across coils 4 and 5 and contacts 1 to ground 2, i.e., motion is connected, "to the left," for instance. When the copying pin rests in the copying recess or in the longitudinal limiter, contacts 1 are disconnected and the current is interrupted. The action of the spring of the slide contact closes the circuit of the magnetic clutch of transverse movement, "reverse" for example, and the cutter will leave the part or cut the face. If the pin does not come in contact with the limiter, then the spring will lock contacts 1 and longitudinal motion will start again. On the bed behind the machine there is a bar on which the limiters are placed. When the copying pin rests in the limiters the contacts are opened, longitudinal feed is turned off, and transverse feed is turned on. With the use of the considered copying devices it is possible to attain a second class machining precision.

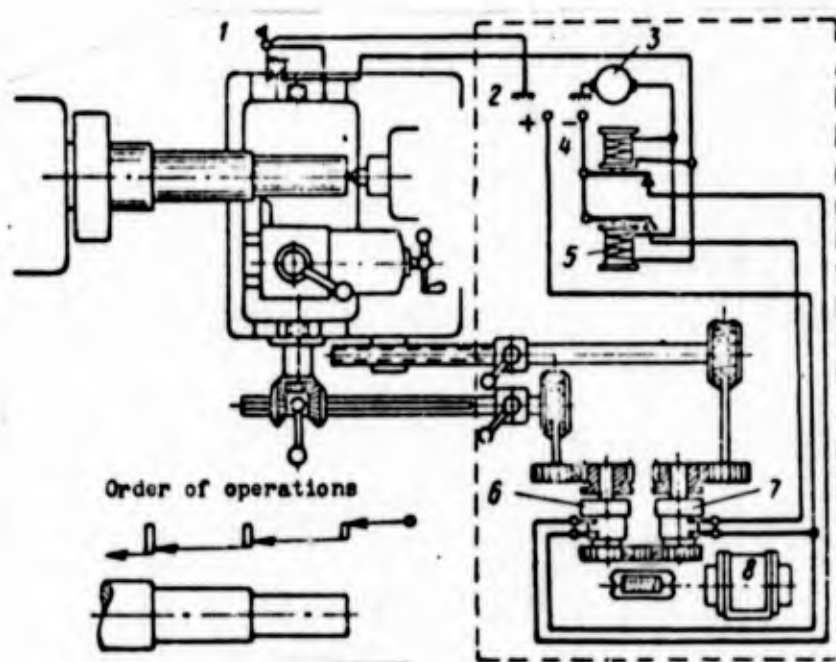


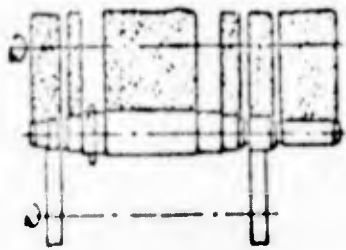
Fig. 1.9. Electric copying device attached to lathe.

The described set-ups are applicable also for machining shaped surfaces (both external and internal).

Automation of operations with the help of copying devices permits multiple-machine service.

The range of application of copying devices is quite wide, since during readjustments for other operations it is frequently necessary to replace only the master form.

Sometimes, especially on transfer machines, finish turning of shaft journals is replaced by rough grinding on a centerless grinding



machine. Instead of two multi-cutter lathes, which are intended for finish turning, sometimes one centerless grinding machine that operates according to the diagram shown in Fig. 1.10 is

Fig. 1.10. Diagram of rough grinding of shafts.

set up.

Grinding of journals. In the process of

machining shafts, for the obtainment of the specified accuracies of form and dimensions, journals are sometimes ground a few times. The required location of external journals relative to the internal surface can be attained only when the fit of the shaft on the mandrel is made with minimum clearance. For this purpose, tapered and expanding mandrels are employed. The most convenient in practice turned out to be expanding mandrels with a layer of water (Fig. 1.11) which ensures fast and accurate installation. Expansion of the thin-walled part of the mandrel is carried out by means of pressure on the plastic of rod 1 while driving home screw 2.

Shafts are sometimes placed on center plugs which are pressed into holes around their ends.

Shafts with holes of small diameter, as a rule, are placed with their faces on the centers. For exact mutual location of journals

with respect to holes, the faces should be strictly concentric with the holes, which is attained by their joint machining.

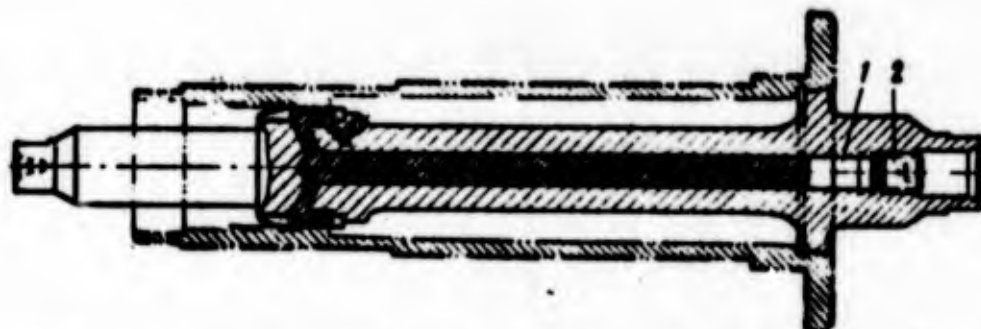


Fig. 1.11. Mandrel for shaft installation for machining the top.

Journals are usually ground from one set-up, which ensures their coaxiality. Grinding of journals is divided into preliminary and final. Short journals are usually ground by the transverse feed of a wheel whose width is no less than the length of the journal. With such a feed, the wheel is guided not only around the cylindrical part, but also around the end. For obtaining smooth transitions, the edge of the wheel is further guided around the radius. The most frequently used wheels are those with ceramic bonds.

The dimensions of ground journals are sometimes checked with the help of devices which measure the play. The most progressive is the active method of checking in which the size of processed journals is checked by devices which automatically control the work of the machine. Application of this method increases the quality of machining, decreases rejects, and raises the productivity of grinding operations.

From the large variety of arrangements of devices for active checking, the most frequently applied are those which are founded on the principle of component measurement (there are arrangements which work on the indirect method principle; their action is based on control of the tool).

Figure 1.12 gives devices which work on the principle of "skipping" and "with falling contact." In both set-ups a lever system is

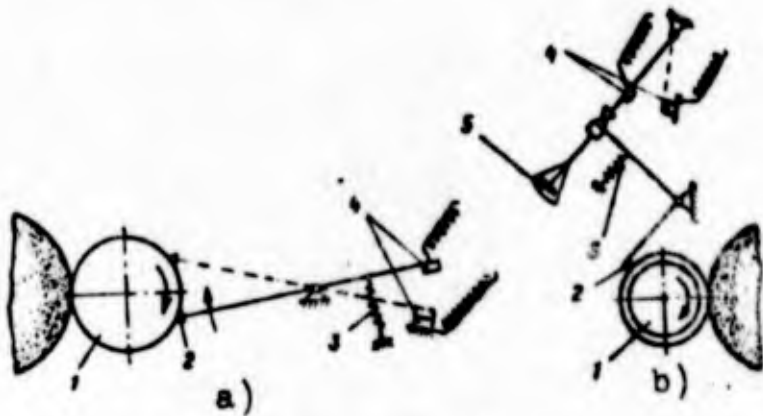


Fig. 1.12. Diagrams of devices for controlling the dimensions of journals in the process of machining. a) device that works on the "skipping" principle; b) device "with falling contact." 1) article; 2) feeler; 3) spring; 4) contacts; 5) indicator.

used. The operations terminate with the closing of the contacts which are electrically connected with the mechanisms for turning off the feed and stopping the machine. This occurs at the moment when the processed necks attain their specified dimensions. The advantages

of the described arrangements consist in the simplicity of the mechanism. However, these arrangements have the deficiency that they noticeably react to deformation of the machine and the component. The accuracy of machining with their use is 10-15 μ .

The most perfect devices are those which have inductance pickups. Such an arrangement is shown in Fig. 1.13. The device consists of

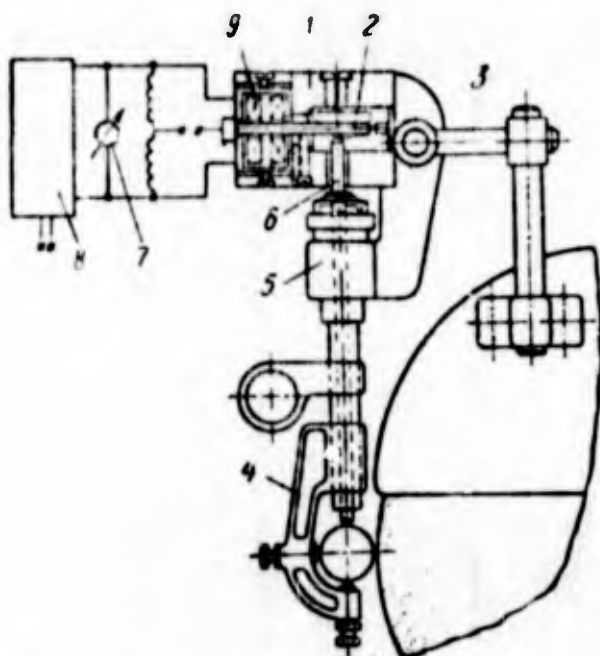


Fig. 1.13. Checking equipment with inductance head.

inductance head 1, measuring spindle 6, and support bracket 4, all mounted in body 5 which is connected to the machine with the help of hinge system 3. When changing a dimension, the action of the measuring spindle moves armature 2. Inductance is then changed, and consequently the amount of current in coil 9 also changes. The electrical device has amplifier 8 and an intermediate

relay, with whose help the mechanism for turning off the machine is set into motion. Observation of the change in size of a component is done on the scale of galvanometer 7 with a scale value of 2μ . The accuracy of machining with the use of this device is $5-7 \mu$. The latest designs of devices with inductance pickups are universal and permit the measurement of necks of different diameters.

At present, devices have been developed for cylindrical grinders which reduce losses of additional time during the machining of stepped shafts. These devices facilitate delivery to the specified size, owing to which an inadequately qualified worker can execute operations of high-precision grinding. By the force applied to the handle the grinder can judge the yield of metal and thereby attain maximum productivity. When the handle reaches the rest, this means that the specified diameter has been attained and machining should terminate.

This automatic device is combined with the dressing mechanism that is located behind the grinding wheel, which permits the grinder to establish the amount of diamond feed before each pass. Change in the diameter of the grinding wheel is noted on a special board from which the appropriate command is given for correcting the position of the wheel.

Machining of splines. Straight-sided and involute splines are usually milled on horizontal spline milling machines of the "Komsomolets" type, model 5U34, with a hob by the generating method. Splines of critical shafts are ground after milling (in the finish stage) taking an allowance of $0.3-0.5$ mm on the width of the spline. Grinding of straight-sided and involute splines is produced on type 352 spline grinders. This is most frequently a shaping operation (around the cavity between splines). The abrasive wheel is guided around the form with the help of counterrecoil rollers with slow

rotation of the wheel or with diamonds by means of straightening fixtures, i.e., pantographs, at working speeds.

Both in milling, and also in the grinding of splines, the shaft is placed with its hole on a center mandrel or directly on center chamfers. In order to avoid rotation of the shaft in the process of grinding or during division, clamps are employed which connect the shaft (mandrel) with the spindle of the machine. Installation of the shaft frequently is difficult to carry out on a surface, relative to which the exact location of splines is specified; therefore, the operation of grinding of intermediate bases is presented with higher requirements, considering the possible error due to mismatch of bases.

End splines are usually cut on milling machines or special spline planers which are equipped with precision dividers.

Internal involute splines (for instance, on the flange of a turbine shaft) are cut on gear shapers by the generating method, similar to how it is done for internal gears (see Chapter V). Special-purpose machines with horizontal spindles which have recesses for location of the shaft are suitable for this.

Treatment of spherical surfaces. Spherical surfaces of small diameter are turned by form tools, and spheres of large diameter, by ordinary cutters with the help of rotary fixtures. The rotary fixture is placed on the lathe carriage in such a manner that the axis of rotation of the cutter holder passes through the center of the processed sphere.

Grinding of spherical surfaces is carried out on circular grinding machines. The abrasive wheel is guided around the radius of the sphere. Sometimes, the sphere is ground with a cup wheel that is secured to the spindle of the head that is attached to the circular grinding machine. The diagram of grinding with a cup wheel is shown

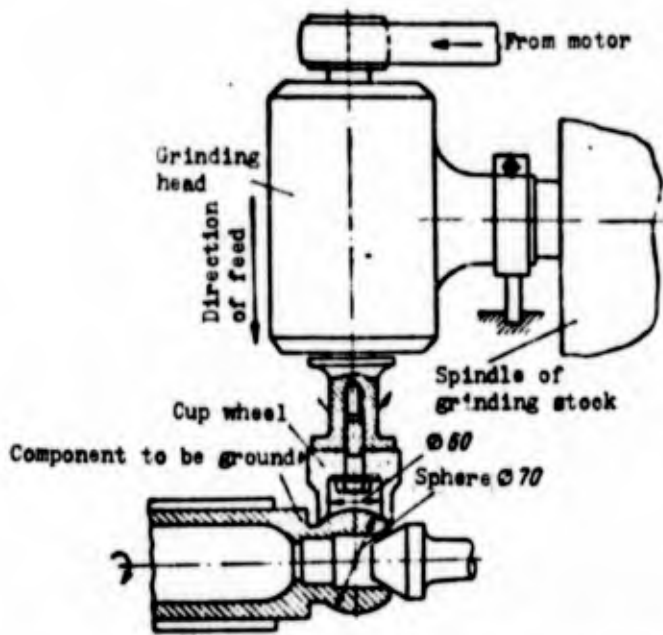


Fig. 1.14. Grinding of a sphere with a cup wheel.

in Fig. 1.14. There are also other diagrams for the treatment of spherical surfaces by turning and grinding.

Threading. Threading is accomplished at the end of the last stage. Fine threads are ground directly on a smooth surface by multiple-thread or single-thread (precision thread) wheels, while coarse threads are milled at first and then ground by single-thread

or multiple-thread wheels.

Finishing of smooth shaft journals. In the operations of journal finishing a high degree of surface purity is attained. Before finishing, the journals must be treated with precision, since the finishing methods do not correct the errors of shape and dimensions to a sufficient extent. Finishing is produced by grinding with abrasive belts, lapping, and also by superfinishing. The latter method is the most perfected. Figure 1.15 gives the design of an insert attached to a head, with whose help superfinishing is accomplished. Fine-grained abrasive bricks, together with the body of the head, accomplish from 200 to 1000 axial oscillatory motions per minute with an amplitude of 2-4 mm. The pressure of the abrasive bricks on the processed surface does not exceed 2 kg/cm^2 ($\approx 2 \cdot 10^5$ newton/m²). The speed of rotation of the component is about 40 m/min. Surface purity after finishing corresponds to the 10th class.

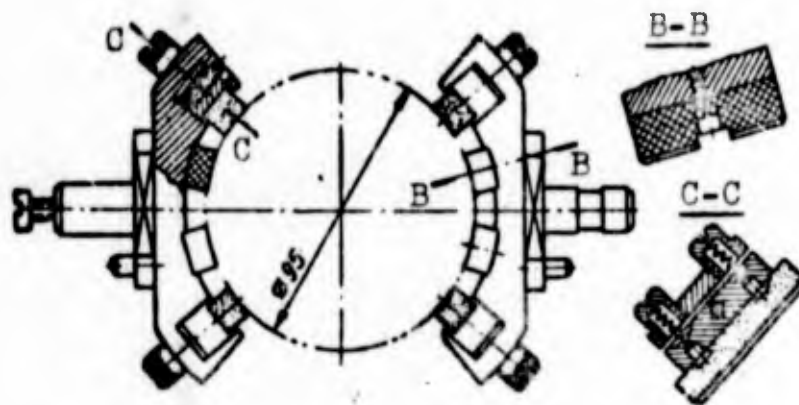


Fig. 1.15. Head for superfinishing of shaft journals.

Surface hardening of journals. For increasing their fatigue strength, the journals of shafts are sometimes roller burnished. Special attention is given here to the condition of hollows. The regimes for such treatment are usually selected experimentally.

Finishing of holes. Most frequently for clean finishing of holes internal grinding and also honing is employed. For instance, we know of the use of honing for finishing a shaft hole with a diameter of about 100 mm and a length of more than 8 m with an allowance of 0.6 mm; the process of finishing is about 1 hour long. Long abrasive bricks, evenly pressed to the surface of the hole, accomplish rotary and reciprocating motions. Owing to this, the abrasive grains of the bricks are subjected to the action of forces that are directed to different sides, as a result of which they are heated, and there then occurs self-sharpening of the tool.

Sometimes nonporous bricks with a strong bond are employed, and also cast-iron bricks with crushed diamond. Owing to their high strength and ability to hold the abrasive grains for a comparatively long time, a higher processed surface can be obtained. In certain cases, for finishing of holes it is possible to employ lapping with cast-iron laps.

§ 4. AUTOMATION OF PROCESSES FOR THE MANUFACTURE OF SHAFTS

Recently, on large scales of production, automation has been attempted for certain technological processes. In this respect the operations are set up better in electrical machine construction and motor and tractor construction for the manufacture of stepped shafts of small and medium dimensions, similar to the shafts of turbopump assemblies.

During the machining of these shafts, the transfer machines have provisions for single adjusting bases. These bases are the face surfaces and center holes; therefore, processing on these machines usually begins with facing and centering. For combined treatment of these surfaces milling-centering machines of type MR-77 and MR-78, and others are employed. The last machine has two tool heads, each of which contains a drill and a hard-alloy facing tool. The heads can contain turning tools, chamfering tools, and others. Thus, on these machines, simultaneously with facing and centering, end journals can be processed. Blanks for this process are placed in prisms that are based around the external surfaces.

Lathe treatment on the line is performed on multi-tool lathes or copy lathes from the "Krasnyy Proletariy" Ordzhonikidze Plant, the Vitebsk Plant, and others. Selection of a machine for the line is of great importance. It is known that during the treatment of a shaft the biggest load is carried by the longitudinal turning tools. Usually, if the shaft is insufficiently rigid, single-tool copy lathes (copying devices) are used. In another case it is possible to use multitool lathes. Besides these considerations, the simplicity of the layout is also considered. In connection with this, there has been a recent tendency to use copying machines for finish turning

which have high speeds, with the provision to employ a highly productive cutting tool. Multi-tool lathes have been used for rough finishing, when the main part of the total allowance is removed and high accuracy is not required.

For the purpose of further increasing the productivity of lathe treatment of shafts the latest copy lathes equipped with several carriages are also used.

For loading of copy lathes there have been developed normalizing devices and conveyer. Most frequently these devices have two mechanical arms apiece, one of which is used for loading and the other for unloading.

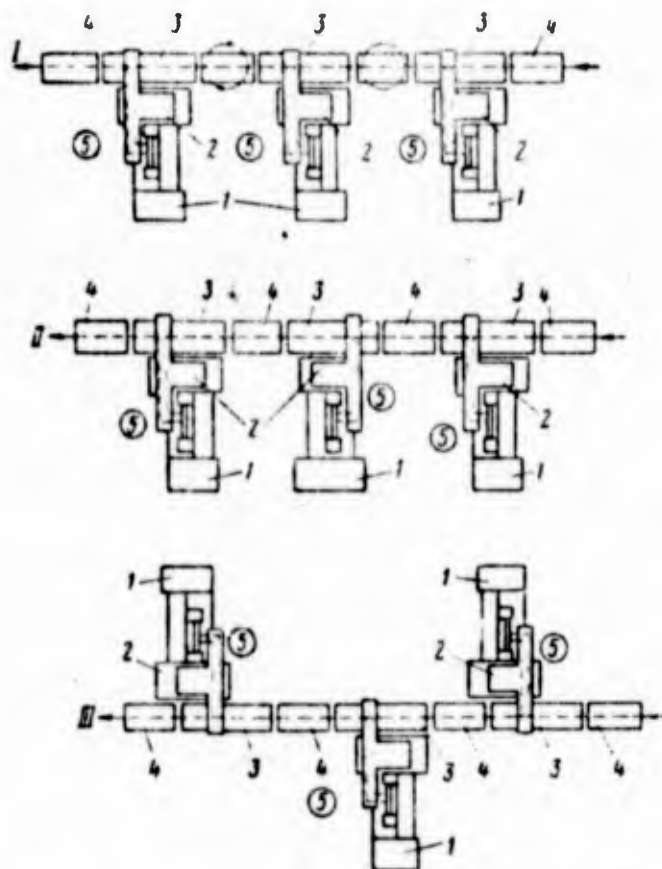


Fig. 1.16. Layouts of copy lathes in the automatic section. 1) copy lathe; 2) standard loader-unloader; 3) conveyer; 4) bin; 5) work site.

Copy lathes can be loaded also through the spindle. Layouts of lathes on a transfer machine are indicated in Fig. 1.16.

Lathe treatment of stepped shafts is also performed on automatic single-spindle vertical machines with programmed control.

Grinding of shafts on the line is produced on circular grinders or centerless grinders (see Fig. 1.10). The circular grinder model 3V153, has two grinding stocks and can process journals up to 80 mm wide and up to 140 mm in diameter by in-feed grinding. The model 3Sh153 is intended for treatment of wider journals, i.e., up to 150 mm. In-feed grinding reduces the time of treatment by approximately 1.5 times as compared to longitudinal grinding. The conveyers on the grinding section and several other machines are similar to those shown in Fig. 1.17.

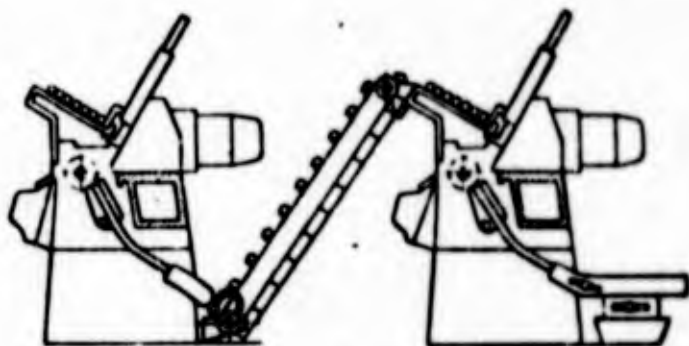


Fig. 1.17. Conveyance of shafts from section to section.

Holes in shafts are processed usually on unit drilling machines built into the line.

Splines on shafts can be processed not only by milling, as shown earlier, but also by planing, broaching, and cold rolling. Figure 1.18 shows the diagram for broaching, and Fig. 1.19 represents the diagram for rolling splines.

Broaching is produced with two block broaches with subsequent rotation (division) of the blank. This method is employed to process both open, and also blind splines with a tool outlet. In the last case a copy straight-edge is used, which controls the radial position

of the broaching tools. Recently, processes of obtaining splines by plastic deformation without the removal of shavings have become wide-spread.

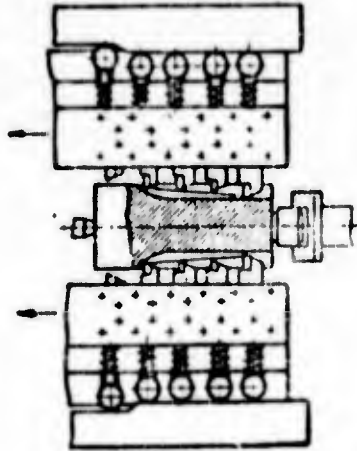


Fig. 1.18. Broaching of straight-block splines with two block broaches.

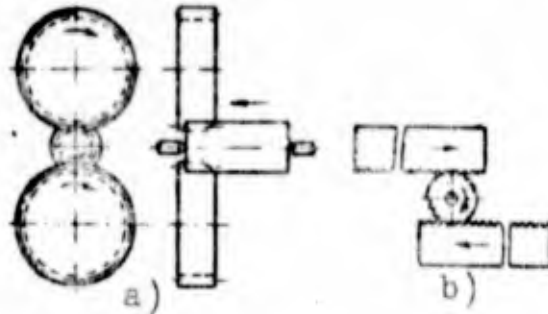


Fig. 1.19. Diagram for rolling involute splines. a) circular rollers; b) rods.

Cold rolling is produced by rollers, rods, and shaper heads. Shafts with rolled splines are more durable than those with cut ones, by approximately 25-40%.

During rolling, axial movement of the blank is forced; the rollers have a partition. The distance between rollers is established beforehand and is not changed during the entire process. Shafts with a hardness not over HB220 are subjected to cold rolling.

The method of rod rolling requires relatively simple equipment, but the manufacture of rods presents definite difficulties. The

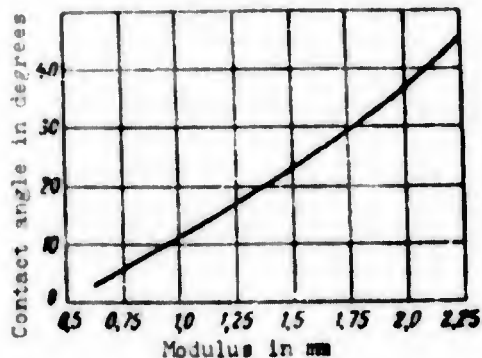


Fig. 1.20. Recommended minimum values of contact angle for cold rolling of involute splines.

accuracy of treatment with rods is approximately the same as in the treatment with rollers. For cold rolling of involute splines by rods or rollers there are definite limitations (Fig. 1.20).

After rolling, the external diameter of splines is somewhat increased, which as a rule is considered by the size being

rolled. In some cases the external diameter of splines is ground. Grinding of spline shapes is a very time-consuming operation; therefore, for increasing productivity it is expedient to simultaneously grind several cavities.

Threads on the transfer machine, just as in the usual case, are processed on thread-millers, rollers, or thread-grinders. Loading and unloading of components at separate work sites is carried out with the help of feeders of the type shown in Fig. 1.21. Transportation of components is produced usually on the level of centers of machines from the front side of the line. The conveyer consists of a round rod with a ratchet device. The rod picks up reciprocating movement from an hydraulic mechanism. Opposite every position there are feeders which load and unload the components.

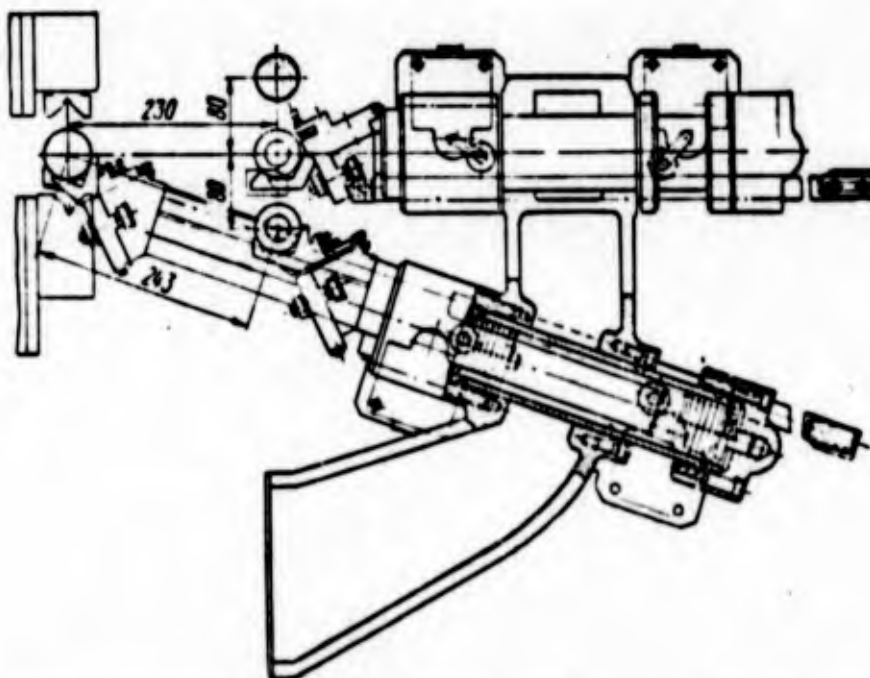


Fig. 1.21. Feeder with loading and unloading arm.

§ 5. CHECKING OF SHAFTS

Diameters of shaft journals are checked by calipers and micrometers; diameters of holes are checked by feelers and indicators for internal measurement; the male threads are checked by calipers, rings,

and micrometers; the female threads are checked by thread feelers.

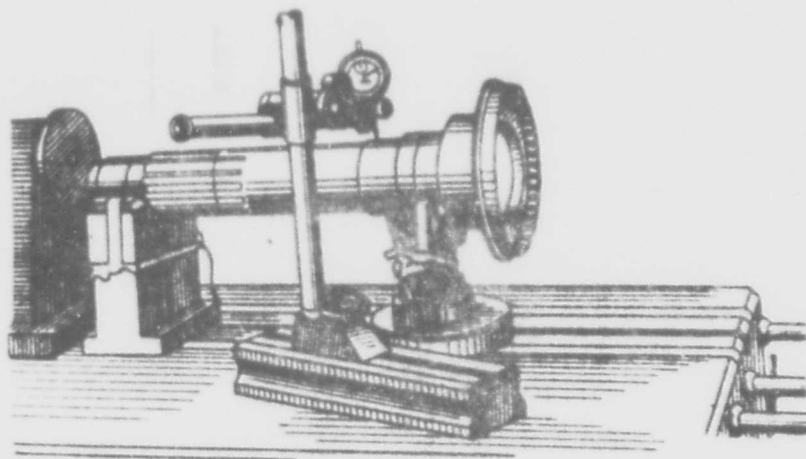


Fig. 1.22. Check of run-out of external journals.

Figure 1.22 gives the diagram for checking the run-out of the external journals of a turbine shaft.

CHAPTER II

PRODUCTION OF WHEEL

§ 1. CONSTRUCTION, SPECIFICATIONS AND MATERIALS

Disks of turbine and axial-flow compressors of gas-turbine engines and of turbopump units of liquid-fuel rocket engines are basic components of jet engines.

Wheels of gas turbines (Fig. 2.1a and b) work under the most severe regimes; stresses in them reach 5000 kg/cm^2 ($\approx 5000 \cdot 10^5 \text{ newton/m}^2$); therefore, they most frequently do not have any hole and are made in a block. Turbine wheels are made from high-alloy steels EI415, EI481, EI395, heat-resisting alloys EI437b, EI617, etc. Surfaces of wheels are carefully processed; they should not have surface scratches and sharp transitions, in order to avoid concentration of stresses. Around circumference of wheels there are located straight or canted grooves for attaching blades with a fixing or normal fir-tree type. Centering of wheels with shafts or with respect to one another (in turbines of two or more cascades) is produced by precise cylindrical shoulders — outboard O and inboard I. They are connected by bolts or cylindrical pins through holes A. For transmission of torque there are also used toothed blade rims C.

Holes for pins A get final processing in the unit.

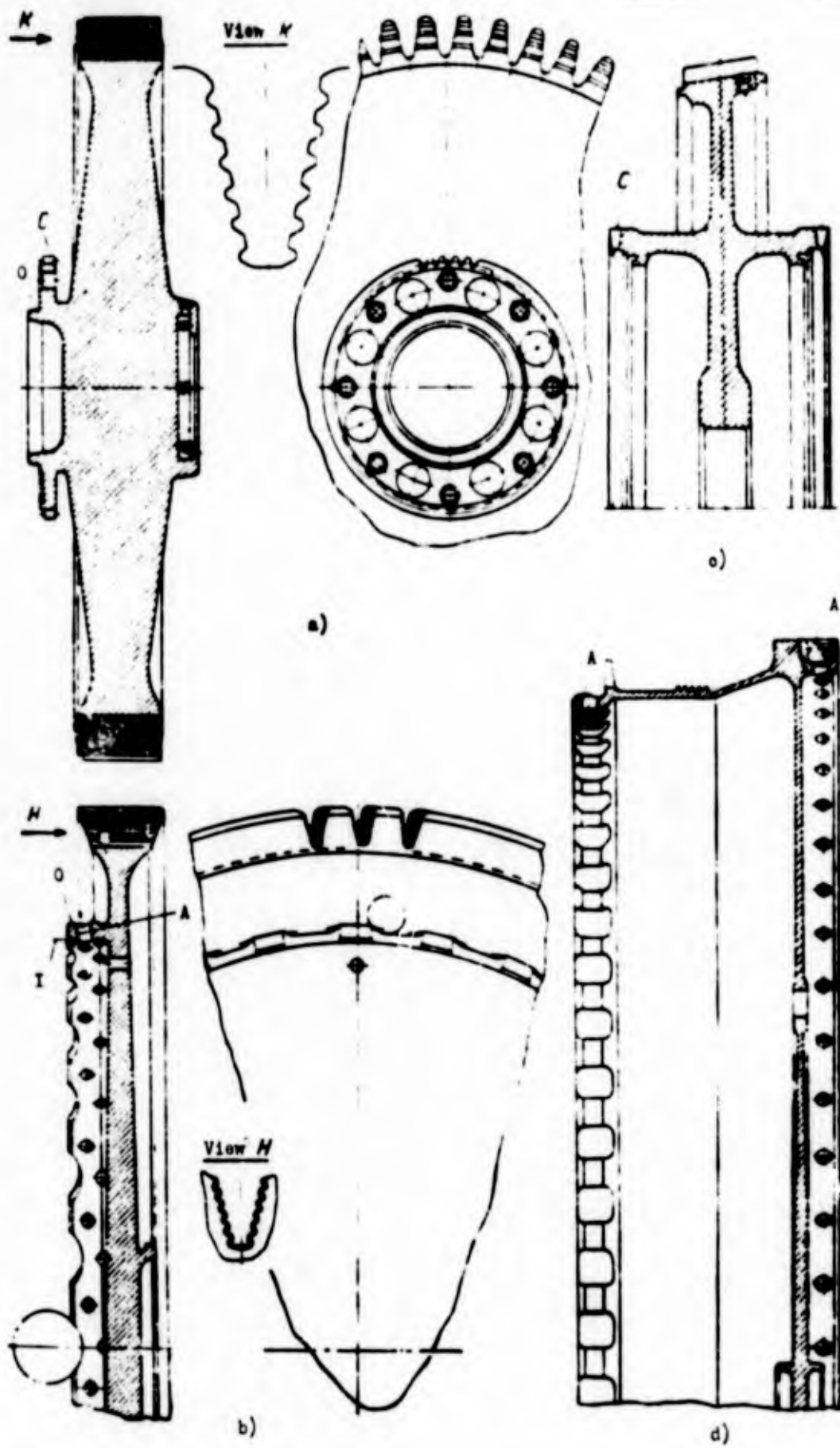


Fig. 2.1. Wheels. a and b) of turbine; c and d) of axial-flow compressors.

Wheels of axial-flow compressors (Fig. 2.1c, d) depending upon method of connection in rotor can have dovetail splines C (Fig. 2.1c), holes with pins A (see Fig. 2.1d) or be bolted. Grooves for fixing blades in disks of aluminum alloys have dovetail shape (Fig. 2.2a), and in steel ones, there are of fir-tree type (Fig. 2.2b). With respect to the axis of the wheel grooves are usually canted.

Compressor wheels are made from aluminum alloys AK4-1 and AK6-1 and from steels 18KhNVA, OKhN3M, 30KhGSA, EI961, and others.

Wheels of turbopump units are centered with shafts by precise cylindrical holes (or shoulders) B (Fig. 2.3a), by shaped or splined holes. Splines are made both in body of the wheel itself and also in holes of steel sleeves (Fig. 2.3b).



Fig. 2.2. Shape of grooves in compressor wheels. a) "Dovetail," b) fir-tree.

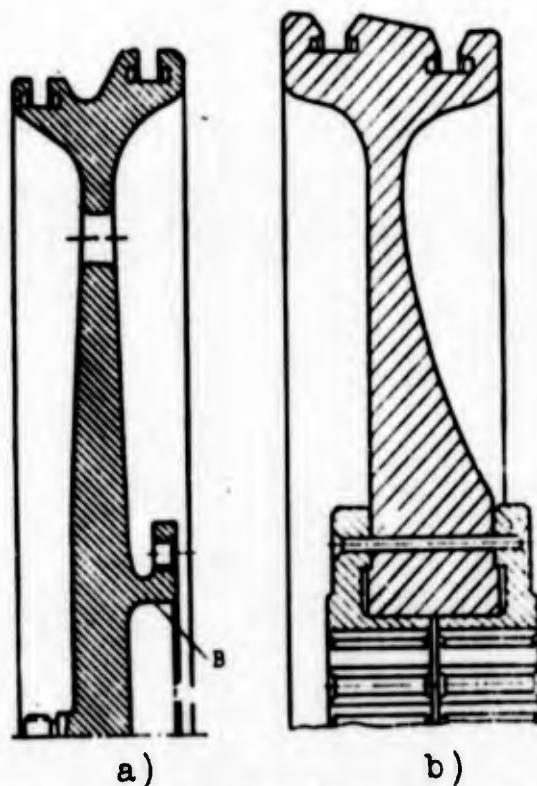


Fig. 2.3. Wheels of turbo-pump unit turbine. a) flanged; b) splined.

Wheels are fastened to shafts by bolts, threaded pins screwed into flanges, a central nut on threaded end of shaft, and also by welding.

Welding can be seam (Fig. 2.4a), flash butt (Fig. 2.4b) or friction (Fig. 2.4c).

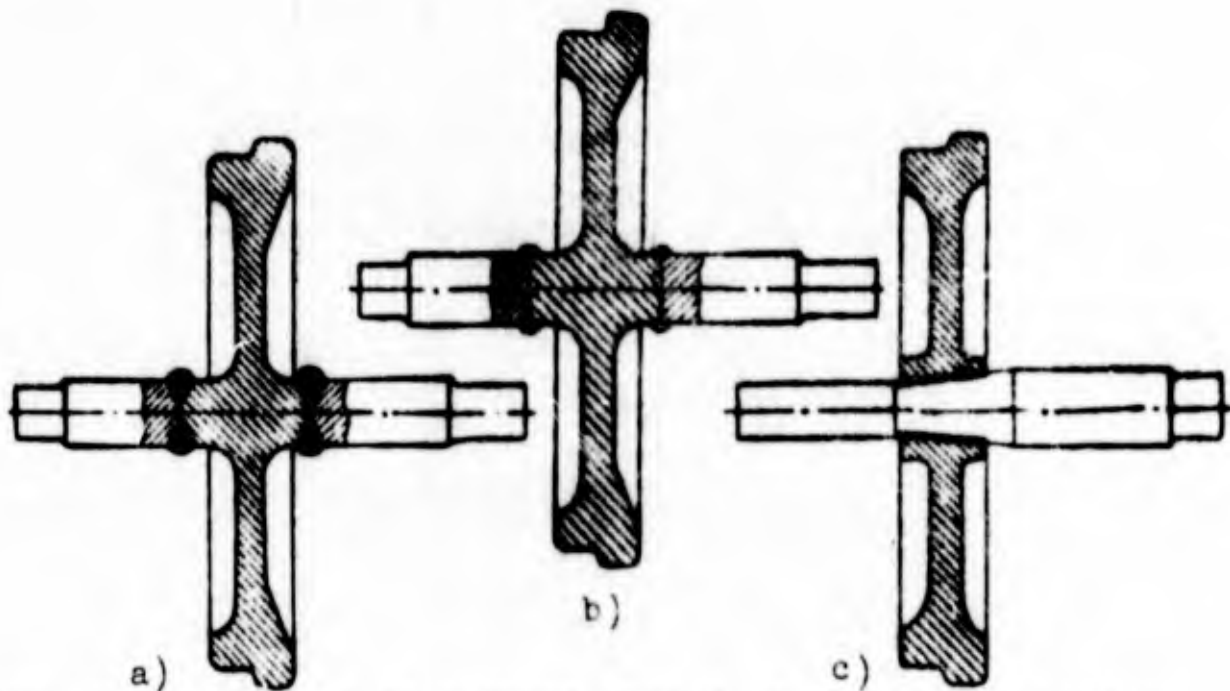


Fig. 2.4. Welding of turbine wheels of turbopump units to shafts. a) seam; b) flash butt; c) friction.

Connection of wheel of turbopump unit to blades is either detachable or permanent. In detachable connection the fixing for blades can be, for instance, annular grooves of T-shape (see Fig. 2.3), rectangular shape with chamfers on lateral faces or fir-tree grooves similar to how this is done for turbine wheels of gas-turbine engines.

Permanent connection of wheel with blades is carried out by welding or soldering. In case of welded joint on outer circumference of wheel in construction there is provided annular flange, on both sides of which there are drilled deep welding faces. In certain cases small turbine wheels for turbopump units are constructed in a single whole with blades and annular shrouds on the periphery.

Depending upon operating temperature and stresses wheels of turbopump units are made from aluminum alloys AK4, AK6-1, steel Zh-1, 30KhGSA and from heat-resisting alloys of type VLR-20, ZhS3. Small

wheels are cast in one piece with blades. End surfaces of all wheels are profiled.

Accuracy of processing of wheels is characterized by following specifications:

Accuracy of working of surfaces

1. Seating shoulders.....2nd, 3rd class
2. External diameters.....3rd, 4th class
3. Rectangular splines U_3/S_1X
or U_3/S_2Xper All-Union Government Standard 1139-58
4. Diameters of labyrinth shoulders.....2nd, 3rd class
5. Tolerance for width of groove of dovetail type in average section (within one wheel).....+0.02-0.03 mm
6. Tolerance for width of fir-tree groove (on rollers).....+0.05-0.02 mm
7. Tolerance for width of T-shape groove.....0.03 mm
8. Tolerance for spacing between teeth in fir-tree fixing.....0.02 mm

Accuracy of mutual location of surfaces

1. Permissible run-out of outer surfaces relative to fitting places.....0.05-0.1 mm
2. Permissible displacement of axes of holes for pins relative to their nominal positions.....0.2-0.4 mm
3. Permissible difference of circumferential spacing between blades grooves.....0.2-0.3 mm
4. Misalignment of axis of groove per 100 mmto 0.2 mm
5. Difference of spaces between end splines.....to 0.02 mm
6. Run-out of end splines.....to 0.05 mm
7. Run-out of faces of wheel relative to fitting places.....to 0.05 mm

Cleanness of processing

1. Fitting places and grooves.....7th, 8th class
2. Non-working surfaces.....6th, 7th class

Static balancing of wheels is done with precision of 5g on a 100 mm arm. Dynamic balancing is usually done after assembly of rotor.*

*V. N. Belikov and A. N. Nikitin, "Assembly of aircraft engines," "Machine building," 1964.

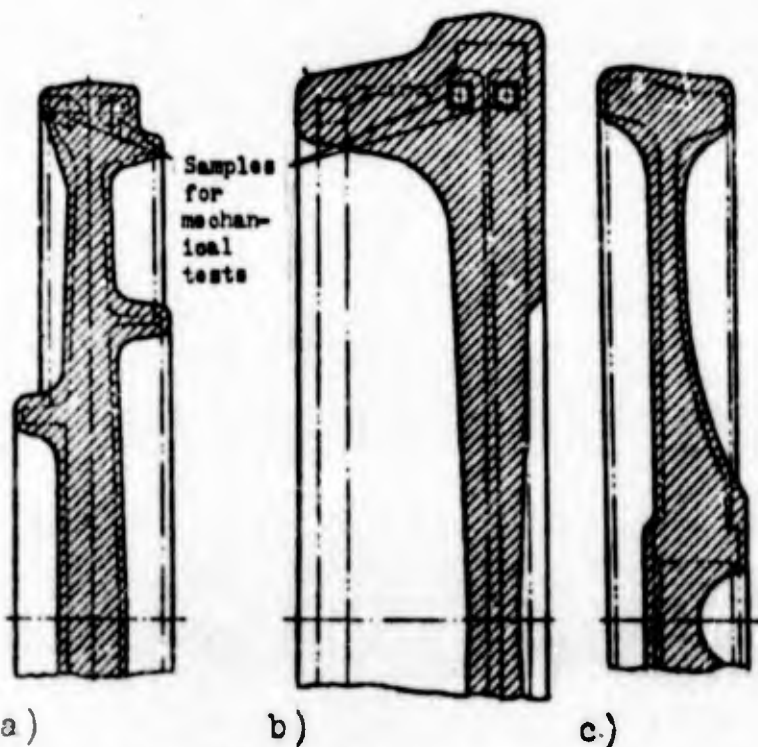
Wheels are subject to heat treatment by hardening and tempering (aging). Material of wheels is usually taken from II check group.

Surfaces of compressor wheels are oxidized, anodized, and surface of wheels of turbopump units, furthermore, are further passivated in bath with potassium bichromate to increase anticorrosive properties.

§ 2. CONSTRUCTION OF INDUSTRIAL PROCESS

General Premises

Wheel blanks (Fig. 2.5) are stamped in closed dies with heavy hammers. The large diameters of wheels when there is a relatively



a) b) c)
Fig. 2.5. Wheel blanks. a) for turbine; b) for compressor; c) for turbine of turbopump unit.

thin crosspiece between the rim and nave do not permit one to obtain a blank with small margins. In certain places the margin for treatment attains 10-12 mm.

Blanks are delivered in annealed or normalized state. Hardness of turbine wheel blanks, for instance, made of steel EI415, is HB270-180. At supplier-factory one of blanks from

every melt is cut into samples for mechanical tests. After quenching of samples in oil at a temperature of 1030-1060°C and tempering at a temperature of 650-680°C with cooling in air, mechanical properties should be as follows:

ultimate strength.....	above 90 kg/mm ²	(≈90·10 ⁷ newton/m ²)
yield point.....	above 75 kg/mm ²	(≈75·10 ⁷ newton/m ²)
elongation.....		12%
hardness.....		HB.340-285

Stress-rupture strength at a temperature of 500°C and with constantly applied load of 35 kg/mm² (≈35·10⁷ newton/m²) should be at least 100 hours.

Macrostructure of blanks, revealed in fractures and pickled templets, should not have to have flakes, shrinkage pores, bubbles, stratifications, cracks, nonmetallic inclusions, visible to the naked eye. There also are not allowed silvery spots of slate-type and intergranular fractures. On surfaces of blanks there should not be seams, overlaps, cracks, foreign inclusions, and other defects connected with disturbance of continuity of material. As for wheel blanks of turbopump single-action engines, requirements are less rigid.

Blanks of turbine wheels of turbopump units, made in one piece with blades from steels or heat-resisting alloys (for instance, ZhS3, and others), are cast in wax patterns in a vacuum chamber. Blade wheels from aluminum alloys can be cast with required accuracy in investment molds by centrifugal method with vacuum compaction of metal.*

To check continuity of material of turbine and compressors wheels ultrasonic flaw detection is widely used.

As it is known, ultrasonic oscillations (with frequency above 20 kilocycles) are distributed according to laws of geometric optics. Thanks to high directivity of ultrasonic waves they are frequently called beams. When these beams strike the interface of two media on the perpendicular there occurs partial reflection of the oscillations.

*Method of casting parts by wax patterns is given in Chapter III.

The portion of energy reflected is greater than the acoustic resistance of these media. Acoustic resistance of air is slight ($41 \text{ g/cm}^2 \text{ sec} \approx 41 \cdot 10^2 \text{ newton/m}^2 \cdot \text{sec}$), therefore, to transmit ultrasound in for any considerable distance is impossible. Acoustic resistance of metals is great ($1.5 \cdot 10^6$ to $5.0 \cdot 10^6 \text{ g/cm}^2 \text{ sec}$ or $\approx 1.5 \cdot 10^8$ to $5 \cdot 10^8 \text{ newton/m}^2 \cdot \text{sec}$); therefore, absorption of ultrasonics in them is comparatively small. Thus, if beams of ultrasound are directed into the metal, in the absence of stratifications in their path they will be reflected from the bottom and will go in the opposite direction. In the presence in the path of beams of stratifications, for instance, air bubbles, beams will be reflected earlier than from the bottom, and will give additional (besides bottom) splash on screen of oscillograph. For catching of splashes there has been built ultrasonic flaw detection and corresponding equipment.

In Fig. 2.6 is given block diagram of pulse flaw detector 86IM-2. Two seeker heads with quartz plates touch surfaces of part, on which

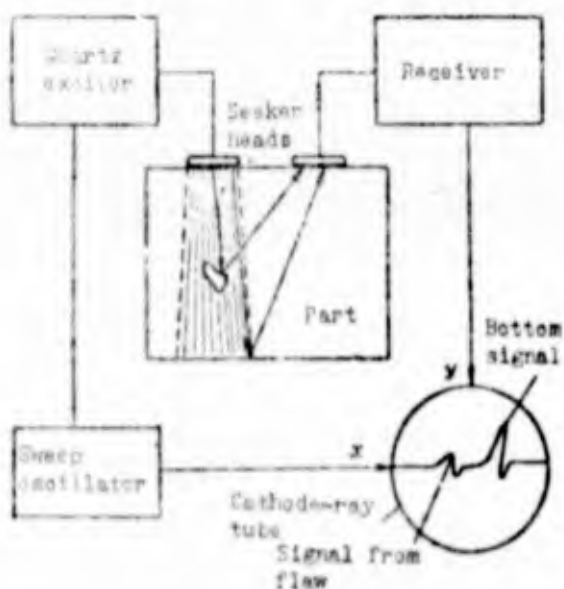


Fig. 2.6. Block diagram of ultrasonic flaw detector 86IM-2.

there was preliminarily placed a film of oil with acoustic resistance $125,000 \text{ g/cm}^2 \text{ sec}$ ($\approx 125 \cdot 10^5 \text{ newton/m}^2 \text{ sec}$). Ultrasonic oscillations are sent by one head into depth of metal in the form of a slightly divergent beam. Reaching a stratification or the opposite wall (bottom), pulses are reflected. Part of reflected energy reaches receiving head, the quartz plate of which will convert reflected elastic oscillations into electrical one. In receiving

channel these oscillations are amplified and further pass to screen of

oscillograph in the form of scanning. Since starting of scanning is produced at the time of supply of pulse by exciter of quartz, by position of bottom signal and signal from defect relative to beginning of scanning it is possible to judge depth at which defect is located.

There also exist pulse flaw detectors with one seeker head, but range of measurement of defects in depth is limited. During use of one-head flaw detectors it is difficult to reveal defects lying at a depth of 10 mm.

Ultrasonic check is usually produced after roughing, when cleanness of surface corresponds to approximately fourth class. Roughed around wheels, passed by ultrasonic check, are then subjected to heat treatment. Wheels from alloy AK6-1, for instance, harden at a temperature of $530 \pm 5^{\circ}\text{C}$ in water, heated to $70-90^{\circ}\text{C}$. Time of exposure of wheels during heating is about 5 hours. Aging occurs at a temperature of $190 \pm 10^{\circ}\text{C}$ for 15 hours with air cooling.

Wheels of steel 30KhGSA are hardened at $880 \pm 10^{\circ}\text{C}$ in oil. Time of exposure in furnace is about an hour. Tempering is at $580 \pm 20^{\circ}\text{C}$ for 2 hours with cooling in water.

Wheels of steel EI481 are hardened in electric furnaces, where they are first heated for 3 hours to 850°C , kept at this temperature for some 2 hours; then temperature in furnace is raised to 1000° and, keeping wheels about an hour at this temperature, they heat them further to $1140 \pm 10^{\circ}\text{C}$. Exposure at 1140°C is about 1.5 hours. Wheels are cooled in running water. Aging of disks of steel EI481 is for 30-35 hours (at a temperature of 660°C - 16 hours; at 800°C - 16-20 hours). Wheels are cooled in air.

After heat treatment wheels may have warping, sometimes attaining 1 mm on the face; therefore, allowance for machining after roughing should not be less than 2-3 mm to the side.

Machining after heat treatment starts with preparation of fastening bases. The most convenient bases for treatment of wheel are flat butt surfaces and a central hole (wheels of gas-turbine engine and turbopump unit compressors) or seating shoulders (turbine wheels of gas-turbine engines).

Simultaneously, with undercutting of butts they usually turn to the middle, the rim along the outboard diameter. Big wheels are turned on vertical lathes or facing lathes. Holes in bosses are drilled on radial-drilling on a jig.

End shaped surfaces of wheel are usually worked from each side separately on lathes with hydraulic duplicating lathes. More productive and exact working is simultaneous machining of two faces on special bilateral hydraulic duplicators with a central drive.

Faces of wheels of large diameters are worked several times in different operations, in order to avoid considerable deformations. Sometimes before final working of faces wheels from aluminum alloys are subjected to stabilizing tempering, which promotes decrease of warping of wheels after final working of faces. Fastening bases before final working of faces have to be restored.

Working of grooves, holes and splines is usually done after final working of faces, using their flat part as a support. The sequence of working such surfaces is not of great importance.

Annular blades grooves in wheels of turbopump units are machined by form tools on lathes. Axial or slanted grooves in wheels of gas-turbine engines, as a rule, are broached. In small scale production such grooves are permitted.

Anodizing or oxidizing of wheels is done both at the end of the industrial process and also after final working of faces. The last variant is sometimes applied in manufacture of compressor wheels from

aluminum alloys.

Holes A for pins (see Fig. 2.1) are finally drilled during assembly.

Sample Working Plans
Wheels for gas-turbine engines

1. First roughing of faces.
2. Ultrasonic check (turbines wheels).
3. Rough working. There are working external surface and faces, notches or central hole is reamed depending upon construction of wheel.
4. Heat treatment.
5. Treatment of base surfaces: faces, fitting shoulders, top, central hole or holes in bosses.
6. Treatment of end fittings.
7. Milling of fillets or grooves.
8. Restoration of bases.
9. Final treatment of faces, top and precise fitting surfaces.
10. Polishing of non-working surfaces.
11. Machining of grooves.
12. Drilling of holes.
13. Cutting of splines.
14. Benchwork.
15. Static balancing.
16. Final check.
17. Anticorrosive treatment (anodizing or oxidizing).

Wheels for liquid-fuel rocket engines with flange or with splines:

1. Rough treatment of top, hole and faces.
2. Heat treatment* - hardening and tempering.
3. Treatment of base surfaces, faces of fitting shoulders and central hole (all surfaces besides profiled faces).
4. Machining of shaped surfaces on faces from a copy.
5. Pressing of bushings into central hole and fixing of them in wheel.
6. Grinding or sharpening of base surfaces - shoulder hole, faces, flange, sleeve and rim.
7. Preliminary machining of top of wheel and machining of annular groove for fixings.
8. Preliminary and final milling of insert grooves.
9. Trimming and setting of insert and driving of pin.
10. Broaching of spline hole in sleeve or in the wheel itself.
11. Final machining of top and cutting of annular grooves for fixings.
12. Drilling and countersinking of holes in flange, in hub and cutting of threading.

*Wheels of AK4 and AK6 are hardened before roughing.

13. Stripping and removal of insert.
14. Polishing of holes in hub.
15. Static balancing.
16. Final check.
17. Oxidizing or anodizing.

§ 3. FULFILLMENT OF BASIC OPERATION OF MACHINING OF WHEELS

Lathe working. Lathe working occupies a considerable place of total labor-consumption of wheel manufacture. The most realistic means of increasing productivity and accuracy of lathe working is concentration of operations and application of high speed attachments, ensuring rigid positioning of the piece. Concentration of operations, as it is known, decreases number of installations and during treatment of such heavy parts as wheels of turbines and compressors of contemporary gas-turbine engines, eases labor of workers.

During roughing of big and heavy wheels of turbines and compressors on vertical-lathes or facing lathes they position piece by external diameter or by protruding (convenient for positioning and fastening) shoulders. In Fig. 2.7 is shown positioning in holder for treatment

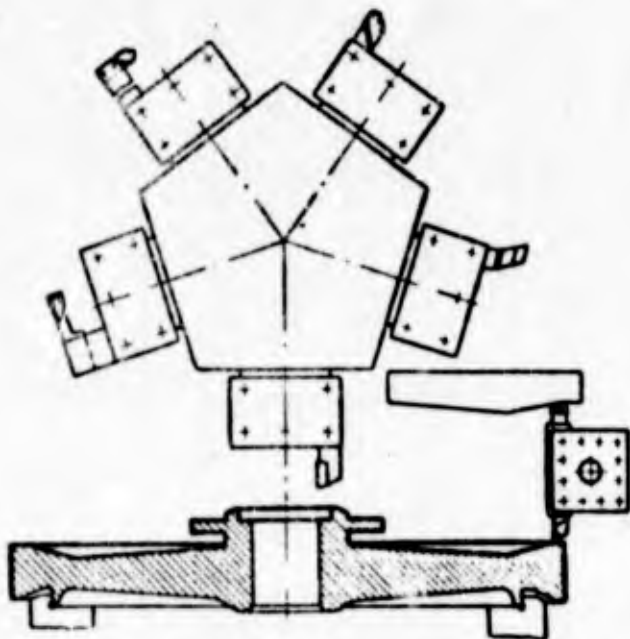


Fig. 2.7. Treatment of turbine wheel on turret lathe.

of several surfaces on one side of a wheel on a vertical-lathe. On edges of turret head are placed cutters, equipped with a hard alloy. Simultaneously with working of external diameter by cutter, fastened in cross support, they machine fittings of end from a duplicate, fixed on the motionless part of the machine. First the wheel is machined on one side, and then after turning — on the other. Treatment on a

turret lathe does not permit obtaining of assigned accuracy; therefore

finishing of surfaces is usually done separately on a facing lathe or on large lathes. Profiled face surfaces of wheel are usually machined on each side separately on lathes with a hydroduplicator.* More productive and exact is simultaneous machining of two faces on two-way hydroduplicators with central drive and with fastening of worked disk by its rim (Fig. 2.8). A special device on machine permits one to position wheel blank so that allowance from both sides will be identical.

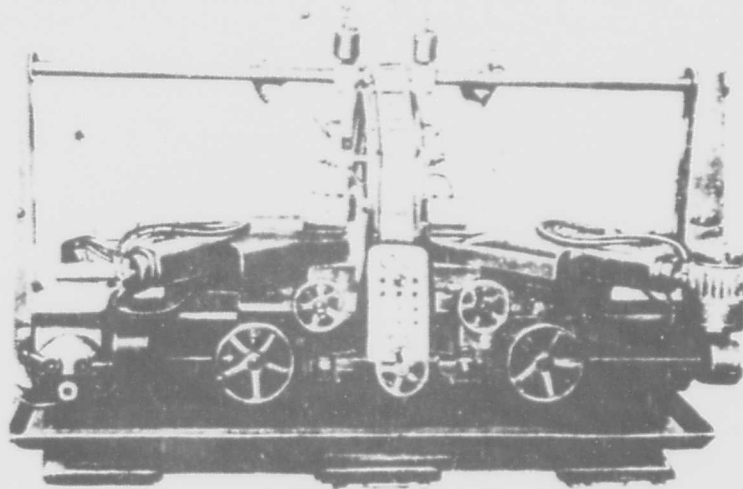


Fig. 2.8. Simultaneous machining of two faces of wheel on hydraulic copying lathe.

**GRADING NOT
REPRODUCIBLE**

During clean machining of wheels on lathes the part is often positioned with truing of worked side by indicator to run-out of 0.02-0.03 mm. This is done also for purpose of completely equal distribution of allowance. Furthermore, accurate adjustment ensures more equal distribution of mass of wheel and subsequently permits reducing balancing time.

Small turbine wheels, and in particular wheels of turbopump units,

*Diagrams of hydraulic copying lathes are considered in Chapter I.

are worked on lathes and turret lathes. Working of shaped faces is produced in separate operations using the same copying lathes as during working of large wheels.

Wheels with hole in center are best positioned in attachments with a hydrolayer (Fig. 2:9). The part is centered by thin-walled sleeve 3, and clamped by nut 2. Pressure on plastic during turn of screw 1 is limited by screw stop 5. Rim of wheel rests on several added supports 4, stopped by a plunger under pressure of plastic during screwing in of the same screw 1. Such positioning is especially convenient if faces of rim and of hub of wheel are not located in the same plane.

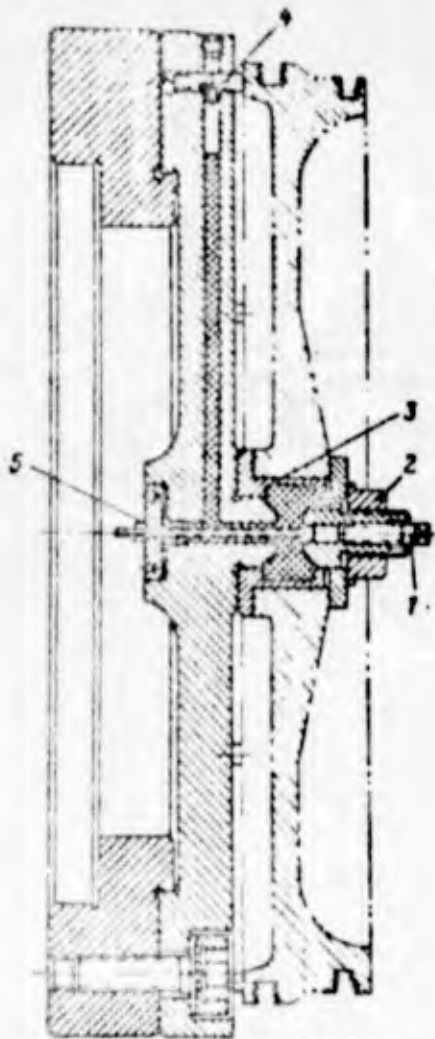


Fig. 2.9. Positioning and fastening of wheel of turbine of turbopump unit in lathe attachment with hydrolayer.

Annular grooves (Fig. 2.10) are machined by set of special cutters on precision lathes. During clean machining they use measuring squaring tools and in first passages cut both grooves simultaneously. They calibrate grooves by identical form tools in order: first left, then right. With well set-up production lateral face of T-shaped grooves can be worked simultaneously by two left, and then two right tools.

Rough cutting of grooves is usually done in a separate operation.

Lathe working of compressor wheel, done in a single piece with blades, consists of two stages. In first stage they work body of the wheel itself, and in the following stage they work the convex and concave surfaces of blades. Butt and cylindrical inboard and outboard

surfaces are machined just as on wheels without blades. The most

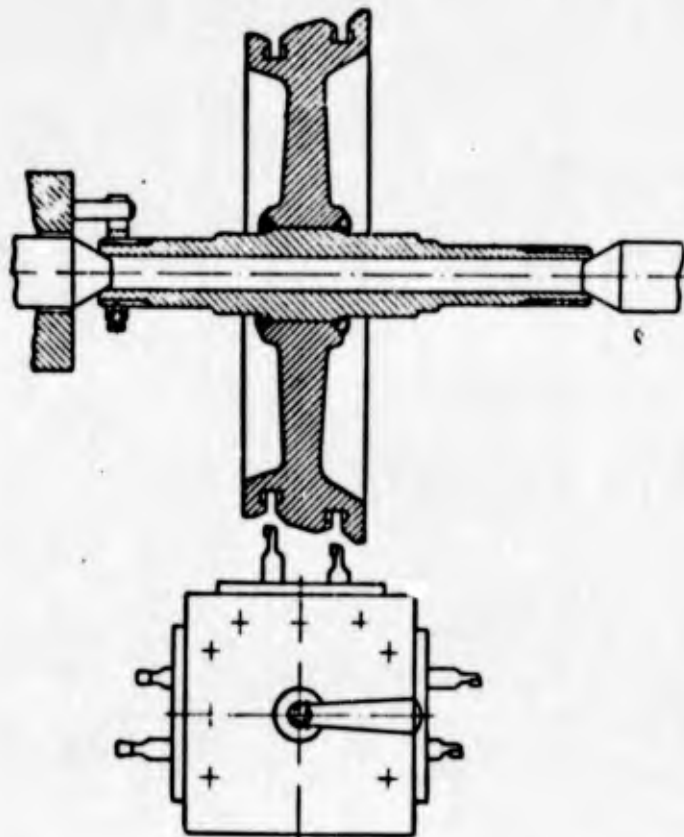


Fig. 2.10. Machining of T-shaped annular grooves in wheels of turbopump units.

labor-consuming operations are machining of convex surface and boring of concave surface of blades. If back and bucket are formed by cone surfaces, then they are worked just as blade of unshrouded impeller (Chapter IV). Noncircular surfaces of blades with twisted profiles are worked on lathes with help of three-dimensional master form. Working of blades from form is complicated by the fact that during machining of back or boring of bucket it is necessary to revolve the

wheel together with dividing attachment about the axis of the machine. Backs and buckets of such blades are worked in separate operations.

Working of Blades. Blades made in one piece with wheel from difficult-to-machine metal can be worked by electromachining and electrochemical methods. Recently these methods have been used in such cases with increasing frequency. With their help it is possible to work blades in a solid blank and, all the more so, in a blank with intervals between blades. In a solid wheel they first take out intervals by electromachining (Fig. 2.11), then back and bucket of blades are worked electrochemically using electrodes of corresponding shape.* If blank is obtained by casting and has intervals between blades,

*Application of electroerosional and electrochemical methods of working blades is presented in detail in Chapter III.

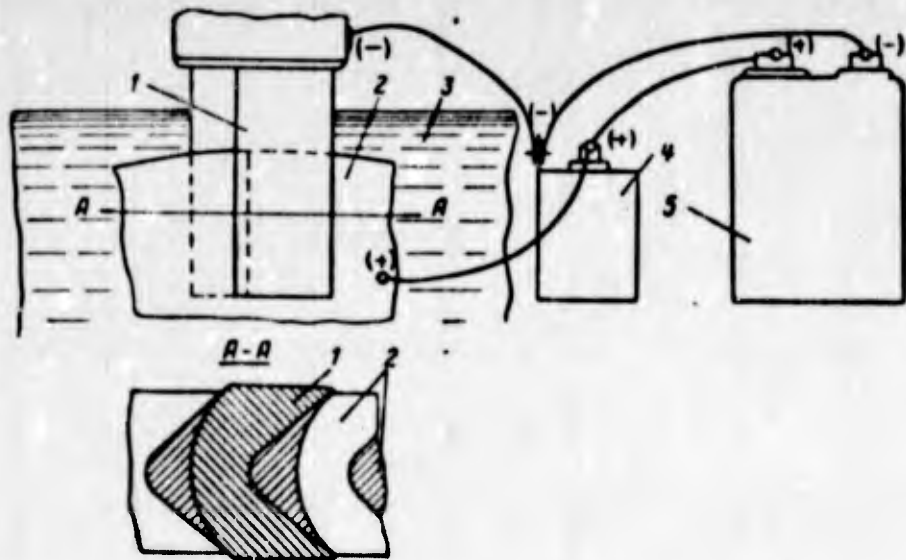


Fig. 2.11. Working wheel blades by electro-erosional method. 1) electrode-tool; 2) turbine wheel; 3) kerosene; 4) capacitors; 5) rectifier.

manufacture is simplified; in this case it is not always necessary to pretreat blade by electro-machining.

Working of

Grooves. Grooves for attaching blades in wheels of compressors and turbines, de-

pending upon scale of production, are worked in two or one operations.

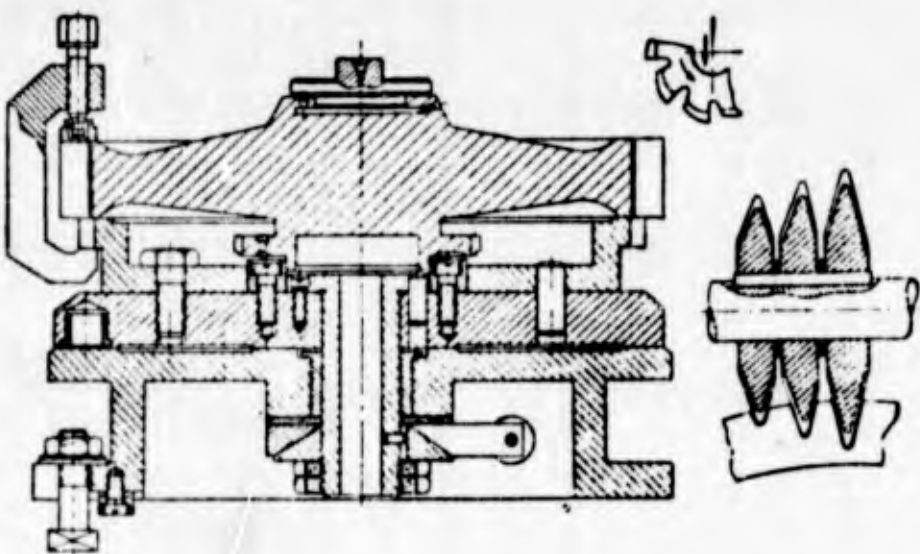


Fig. 2.12. Milling of grooves by a set of milling cutters.

For small scales of production they apply the first variant: grooves are first milled, and then broached. First operation is performed on horizontal milling or gear milling machines by method of division without

peening. Selection of these machines is determined by the fact that big wheels are more easily positioned on them. Fir-tree grooves in turbine wheels are premilled on trapezoidal form by one milling cutter or by a set of two or three milling cutters (Fig. 2.12). In case of a set of two or three milling cutters allowance by depth is evenly distributed among them.

Trapezoidal grooves on contour can be worked on gear milling machines by hobbing cutters by rolling method. Lateral form of tooth of milling cutter in this case will be a complex curve, which is determined by calculation or graph.*

Broaching of fir-tree grooves after milling is produced by several broaching by diagram shown in Fig. 2.13. After grooves are chamfered by milling 1, there is produced first broaching with removal of allowance 2, then by two broaching they machine fir-tree teeth by form 3 and 4. Last broaching removes upper face.

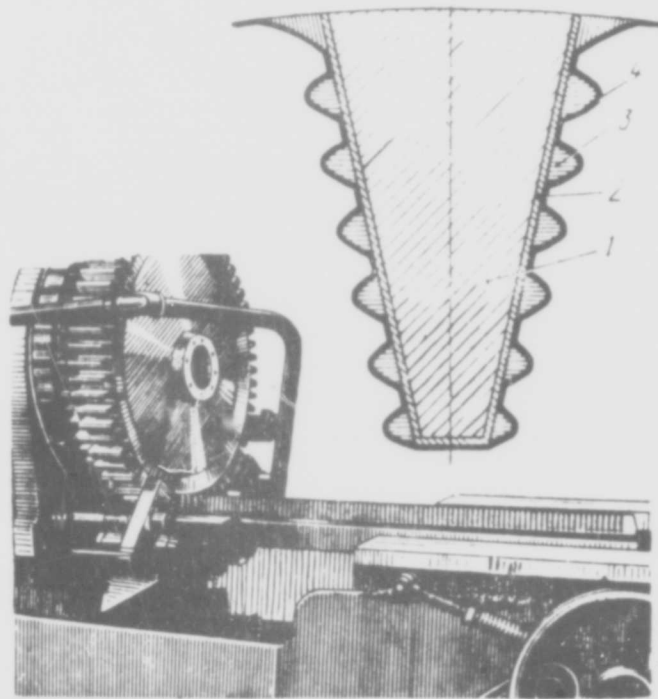


Fig. 2.13. Working grooves on horizontal broaching machine and diagram of broaching. 1) allowance, taken by milling; 2-4) allowance, taken by consecutive broachings.

*For detail see I. A. Frayfel'd, Tools working by rolling method, Mashgiz, 1948.

In large lot production fir-tree grooves in wheels are completely machined by broachings without preliminary milling. Working is conducted on horizontal or on vertical broaching machines (Fig. 2.14).

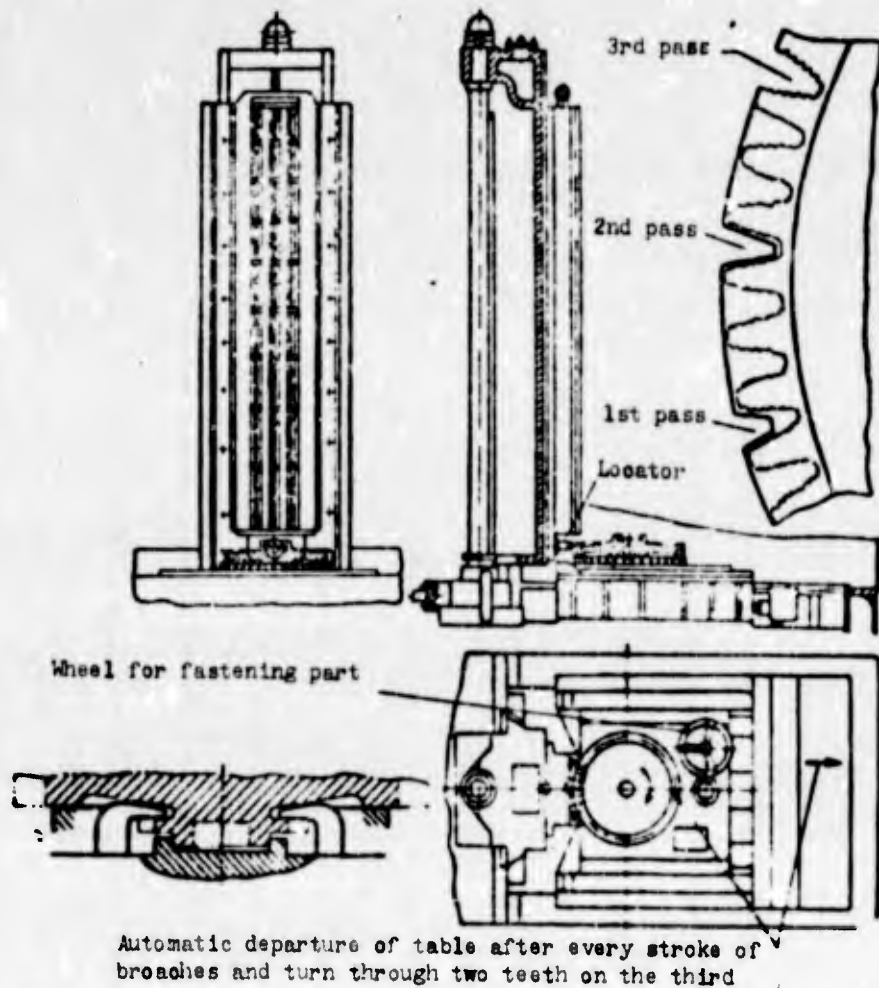


Fig. 2.14. Broaching of wheel grooves on vertical broaching machine MP-15.

Special attention is drawn to working of "fir tree" teeth, which are first broached in step form, but then (next broach) are calibrated in contour.

For broaching part is positioned in special dividing attachment (Fig. 2.15) having in horizontal broaching machines, besides centering and clamp members for wheel, also guide member for broaching, which is sometimes called an adapter. Productivity of operation of broaching grooves can be considerably increased, if simultaneously in one stroke of slider we work several broaches. Such a scheme is applied usually only on vertical broaching machines, which moreover occupy smaller

area as compared to horizontal broaching machines. Difficulties with use of such machines are connected usually with cleaning broaches of shavings.

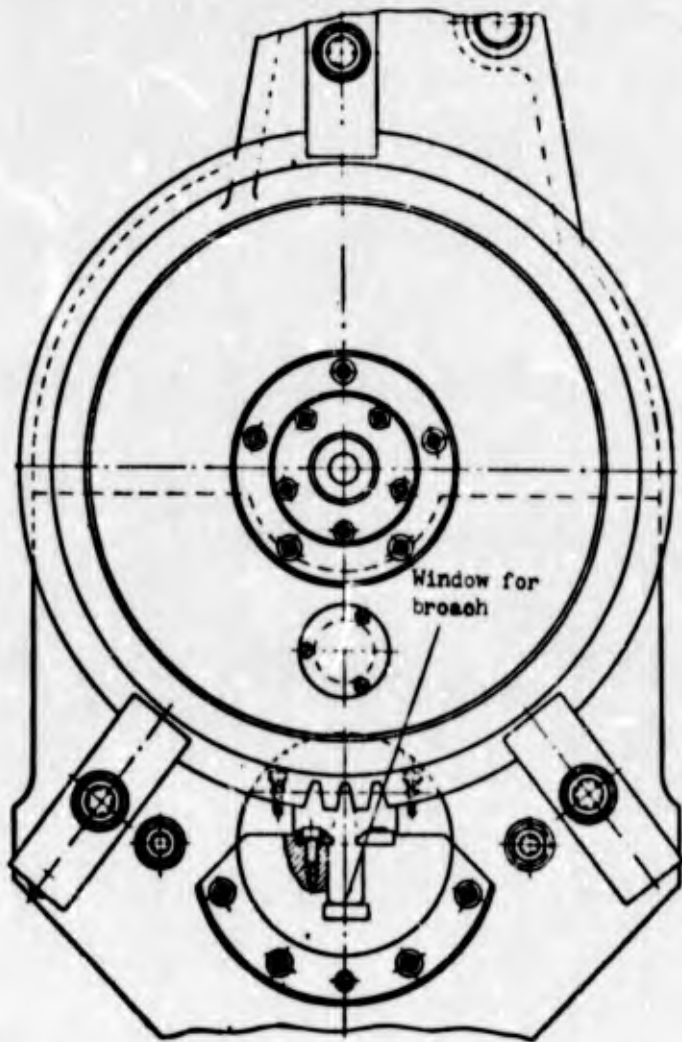


Fig. 2.15. Attachment for horizontal broaching machine for broaching disk grooves.

fastened to slider of machine.

In compressor wheels grooves are usually made tapered. During broaching of such grooves they use dividing attachments, adjusting members of which are correspondingly inclined to plane of table of machine.

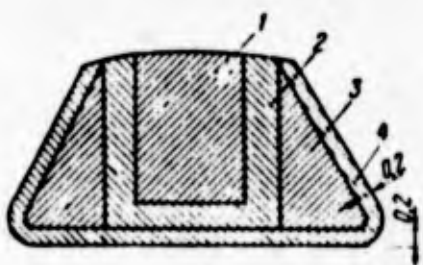


Fig. 2.16. Diagram of broaching of a groove of dovetail form.

In spite of shown deficiencies, vertical broaching machine in operation is very convenient because motion of slider downwards (working stroke) and upwards (idling) are automatic. Also there can be automated (usually manual) division of wheel to following position at the end of idle motion of slider.

Broaches for vertical broaching machine are made up of separate short sections, assembled in a body, which is

Broaching of tapered groove in form of a dovetail is produced in one pass by set of separate broaches (sections). Diagram of broaching of such a groove is shown in Fig. 2.16. Numbers 1, 2, 3 and 4 designate allowance consecutively taken by set of

broaches.

Positioning bases during broaching are usually outer or inner shoulders, serving as centering bases during assembly of wheels with shafts or other wheels. In wheels of compressors, centered in assembly by butt splines, for adjusting base we take the holes.

Fastening of disks in attachments is produced by screw clamps through holes, located in center or on hub. If there are no holes, the wheels are fastened by hooks to inboard side of flange. In the absence in wheels of holes and flanges the wheels are fastened by several (4-5) U-type screw clamps (see Fig. 2.14), in turn changing position along rim during their approach in process of division, up to broach.

Grooves in wheels made from difficult-to-work metals can be obtained electrochemically (Fig. 2.17). The tool here is a hollow electrode, having shape of profile of groove to be worked. Electrode can be made from brass or other conducting material not subject to corrosion in solution of table salt (steel 1Kh18N9T, etc).

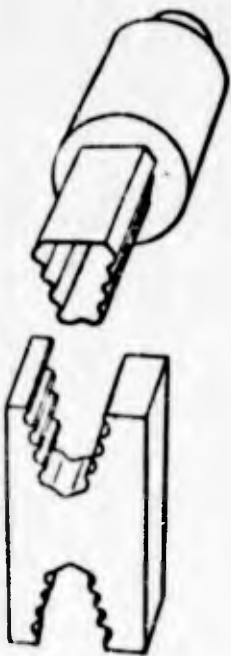


Fig. 2.17. Shaped electrode and form of groove, worked by electrochemical method.

For rough working of groove electrode is made of brass plate. During finishing of profile of groove plate is made of small thickness and is fastened to a profile rod made of a dielectric. Cutting of groove is carried out by feeding electrode in direction of groove axis. Minute particles of metal taken from wheel are washed away by stream of electrolyte, passing under pressure through holes of electrodes. After passage through clean electrode there is attained groove precision by width of up to 0.05 mm.

Final calibration of grooves and skinning of

surface layer, formed as a result of electrochemical treatment in salt electrolyte, is produced by brief piercing on low-power horizontal hydraulic press.

Such profile piercing has five-six teeth with coated (electro-erosionally) hard alloy.

During electrochemical working of grooves metallic parts of dividing attachments must be protected from corrosion by salt solution of electrolyte.*

Involute splines are cut on gear-slotting machines of large dimensions with positioning of part on special attachment (Fig. 2.18). If wheel does not have hole in center it is necessary to use as adjusting bases its outer surface and face on the side, opposite the flange. Necessary concentricity of shoulder A and dividing circumference of splines during basing of disk by external diameter, carried out with precision of 3rd class, is attained by alignment of wheel by indicator previously ground shoulder A.

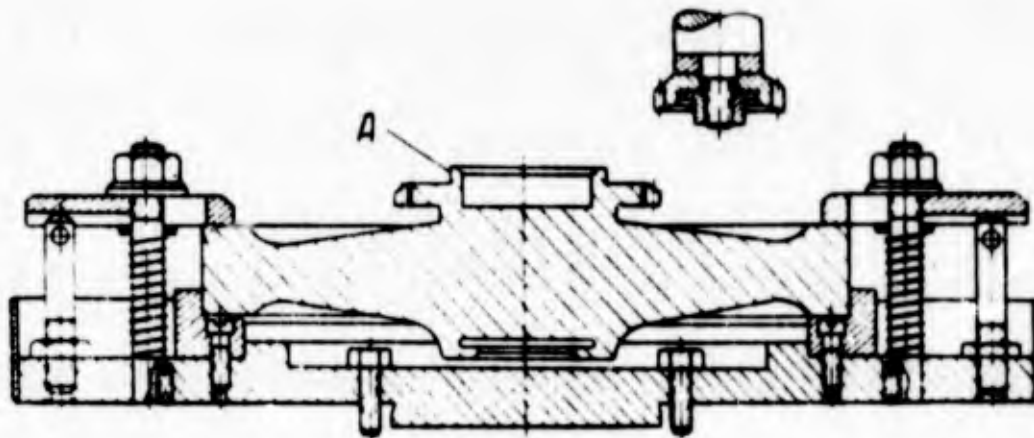


Fig. 2.18. Slotting of flange splines on gear slotting machine.

Cutting of end splines. End splines on drums of compressor wheels are cut by milling, round broaching and planing.

*Features of electrochemical working are presented in Chapter III.

They mill splines on horizontal milling machines by disk milling cutters; here there are used dividing attachments with high precision of division by step (up to 0.015-0.02 mm).

Broaching of end splines is performed by round broaches on semi-automatic spline broaching machine PShN (Fig. 2.19). On horizontal

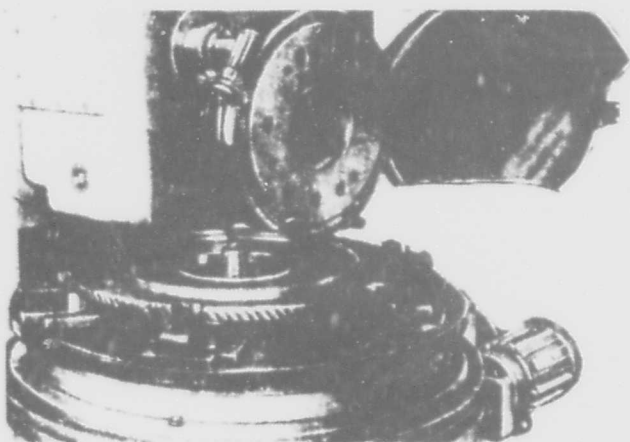


Fig. 2.19. Broaching of end splines on round broaching machine.

spindle of machine there is fixed round broach, and on the dividing table of machine is the part being worked.

Precise positioning of wheel with respect to center on attachment is ensured by unclasp rod with hydrolayer.

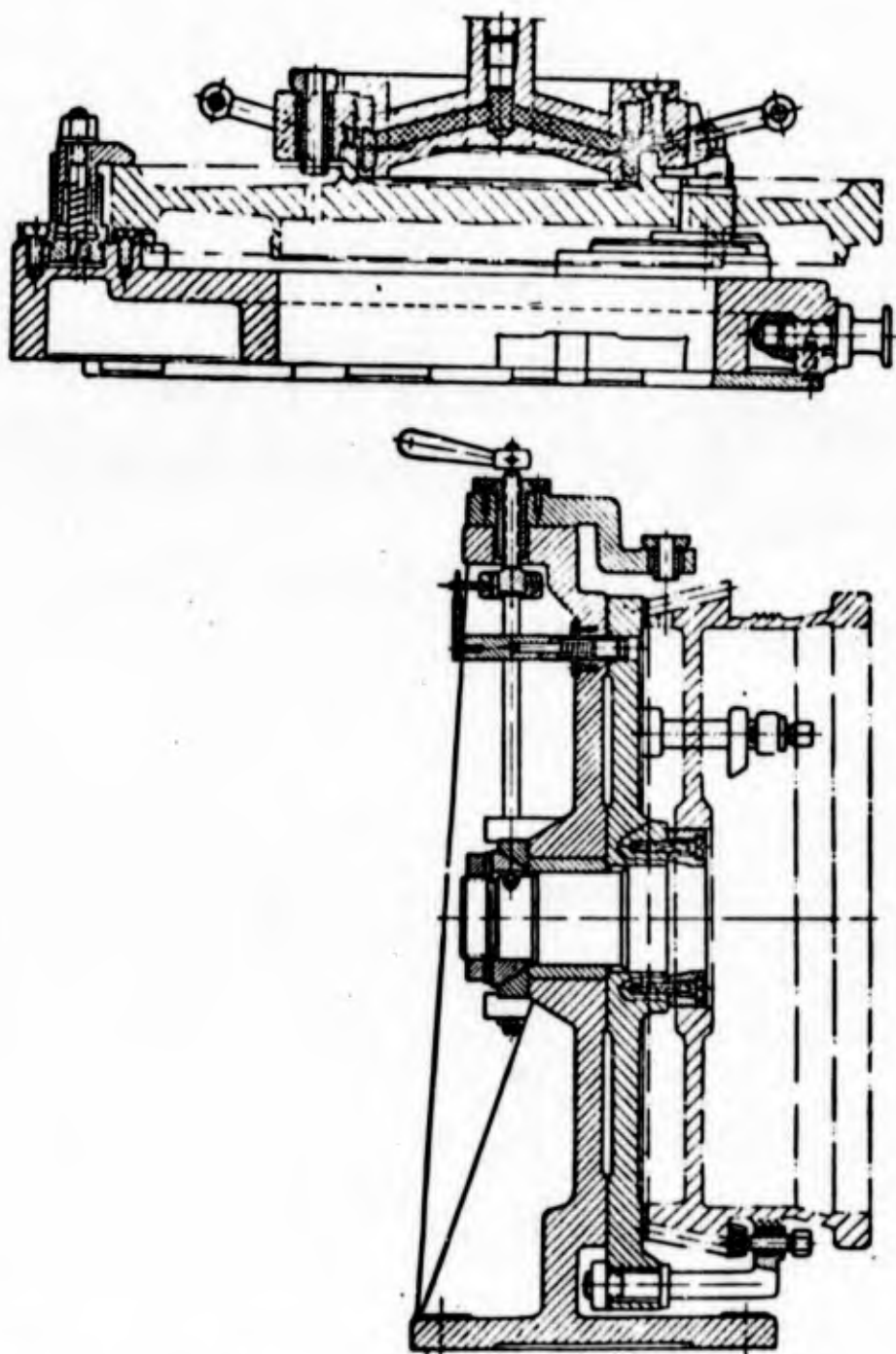
Semiautomatic work of machine is composed of following motions: broach continuously spins about its axis and during set-up of machine can shift vertically; round table of machine accomplishes reciprocating motions in direction of axis of worked groove. Turn of table to following division is carried out at the time, when free interval on broach drawing occupies position above processed part.

Broach has 15 cutting and 2 calibrating sectors of 11 teeth each. Drop between teeth (rise) varies from 0.05 mm at the beginning to 0.025 mm in the last cutting teeth.

Planing of end splines is possible with one tool on a cross-planer in dividing attachment, but productivity with such method will be low. Best results can be achieved during planing on semiautomatic multiblade gear-shaper PShKh-1. On this machine planing is carried out by twelve

consecutively fixed cutters without return strokes. On section of passage of each tool through cavity a special device, a Nichomedes conchoid, on machine transforms rotary motion of cutter into rectilinear.

Drilling of Holes. In view of cumbersomeness and heaviness of wheels holes in them are drilled, as a rule, in positioners, secured to table of machine.



Holes, located on the same circumference, are drilled on ordinary single-mandrel vertical boring machines in positioners with turning or dividing devices. Holes, located on different circumferences, are drilled in positioners on radial-drilling machines or on vertical machines, but with the help of a multi-mandrel head.

Constructions of positioners for drilling of holes in wheels are shown in Fig. 2.20.

Fig. 2.20. Positioners for drilling holes in wheels.

Grindling of fitting shoulders. In Fig. 2.21 there are given examples of positioning of wheels for grindling of precision fitting

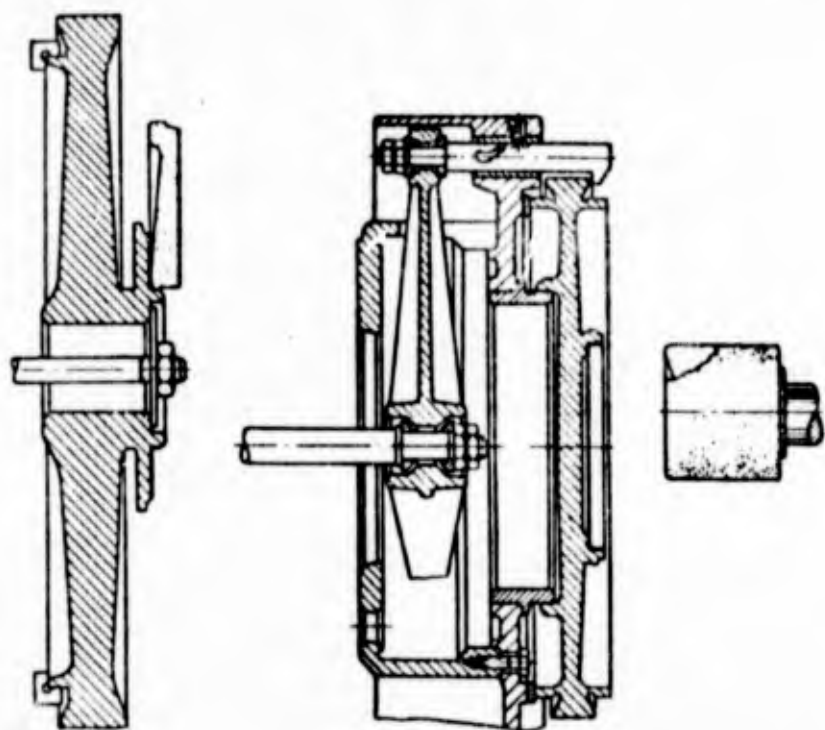


Fig. 2.21. Grindling of precise fitting shoulders.

shoulders. In order to obtain required precision of location of processed shoulders with respect to other surfaces, the latter are used as positioning base. During grinding at first they grind that shoulder, which is the most convenient for positioning. Frequently the shoulder is ground after installation of

wheel with alignment of it with respect to surface, relatively to which location of shoulder is assigned.

Operations of coatings. Most wheels of turbines, compressors and turbopump units are oxidized or anodized. Steel wheels are oxidized chemically or electrolytically.

During chemical alkaline oxidizing in water solutions (bluing) part is dipped in concentrated boiling solution of caustic soda and mineral oxidizers in the form of chile saltpeter or sodium nitrate.*

After exposure for 20-40 minutes there forms a thin oxide film of black color.

Electrolytic oxidizing is carried out by means of anodizing in

*Ya. V. Vayner and M. A. Dasoyan. Technology of electrochemical coatings, Mashgiz, 1962.

alkali solutions for 5-8 minutes at solution temperature of about 50°C. Cathode material is lead.

Anodizing is what we call electrolytic process of oxidizing of aluminum and its alloys. They anodize in chromic, sulfuric, and oxalic acid electrolytes. As a result of anodizing on surface of part there will form a durable, porous (porosity up to 20%) oxide film with unlimited growth in thickness. On boundary between porous film and metal there will form solid very fine glass-like film of great hardness.

Strength of bonding of oxide film is very high. To separate film from metal mechanically is impossible. Heat resistance of oxide film reaches 1500°C.

§ 4. CHECKING WHEELS

Checking of wheels is simply checking dimensions, form and quality of basic surfaces and their mutual location. Methods of checking surfaces of simple form do not differ at all from methods of checking other parts. Here they apply various gauges, patterns and other normal tools. The most complex and labor-consuming operations in checking wheels are operations checking the grooves.

Fir-tree grooves are checked on a projector and on a microscope by indicator instruments, rollers gauges and on pneumatic instruments (Solex).

On projector with magnification 1×50 there is checked radial displacement of one side of groove relative to other and smoothness of radius linkages. This check is conducted in two grooves, broached in samples by one set of broaches. One groove is broached before beginning of broaching of grooves in turbine wheel, and second is broached after termination of broaching of all grooves in the lot of wheels.

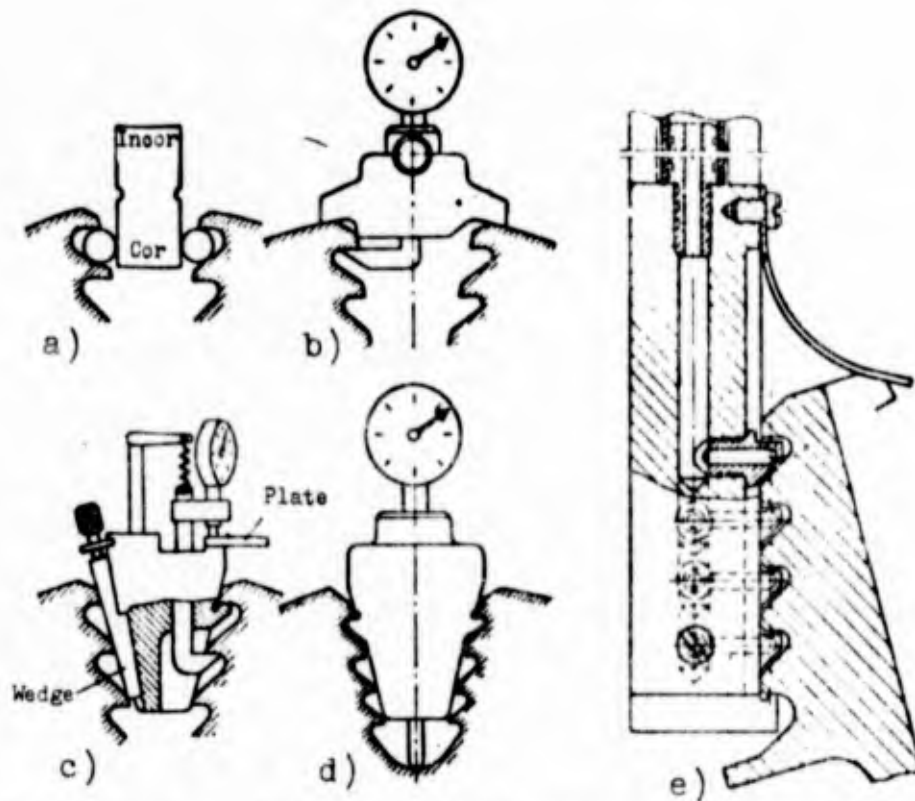


Fig. 2.22. Diagram of checking of fir-tree groove. a) width of groove by rollers; b) thickness of shelf; c) spacing between teeth; d) depth to base of groove; e) spacing on pneumatic meter.

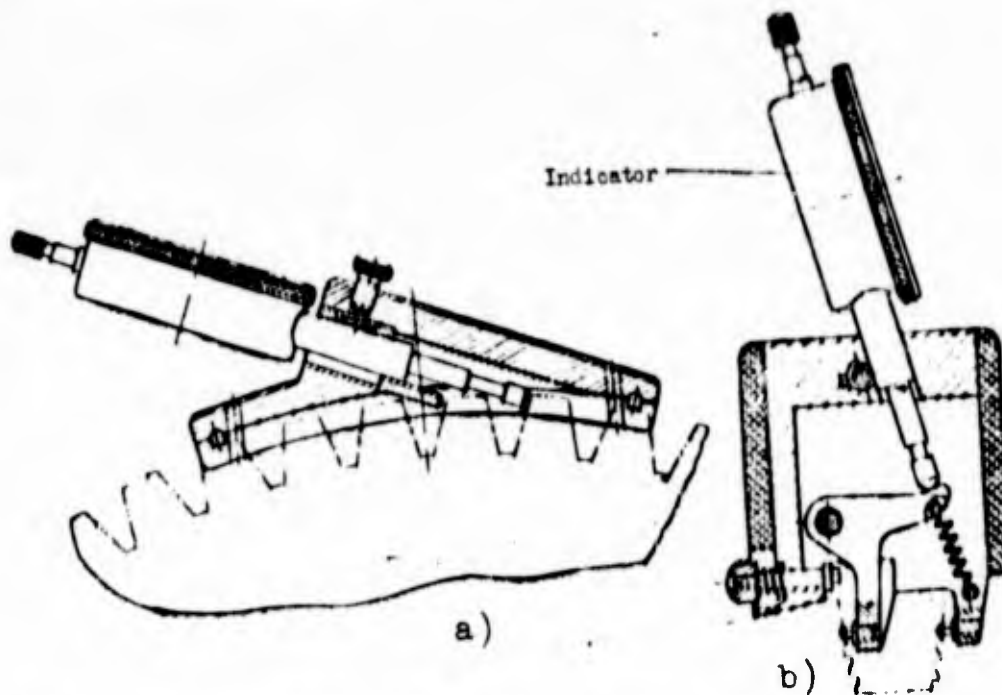


Fig. 2.23. Check of spacing between grooves. a) Rectilinear ones; b) Fir-tree.

On microscope they check angles of profiles and spacing between teeth. With help of instruments or check attachments (Figs. 2.22, 2.23) they check: thickness of first tooth or dimension to shelf,

spacing between teeth, depth to base of groove, spacing between grooves on circumference, location of groove with respect to axis of wheel and with respect to radius. They also check misalignments of groove by four indicators with their legs resting in gauge tightly inserted in groove. Furthermore, indicator instruments check spacing on circumference between trapezoidal grooves before broaching the fir tree. All indicator instruments are tuned by standards.

Grooves of dovetail type are checked for width, parallelism of sides at given height h , for spacing between grooves, location of grooves with respect to axis and radius of wheel and for angle of inclination.

Width and nonparallelism of groove sides at height h is checked by flat two-rollers gauges (Fig. 2.24) at two extreme points of groove

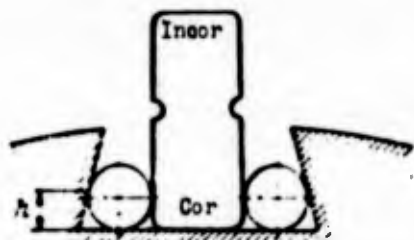


Fig. 2.24. Check of width of grooves of dovetail type.

(at ends). Gauges are made in a set with difference in thickness of 0.01 mm. Deviation of grooves in circumferential spacing is checked by pedometers of type shown in Fig.

2.23.

Conicity of base of groove and its radial location with respect to axis of wheel are checked on complex checking attachment. Besides this, in practice there are used indicator checking instruments by which they simultaneously check width of groove at height h and its angle of inclination (Fig. 2.25). Indicator, connected with lever of right roller, shows deviation of width of groove from proper value. Misalignment of groove is shown by the other indicator, touching face of wheel a certain distance from a support, also pressed to the face of the wheel. In production practice angle of inclination of groove is usually checked occasionally in central measuring laboratory, and there is ensured by positioning of

attachment on broaching machine. They also check run-out of involute splines relative to centering shoulder of turbine wheel.

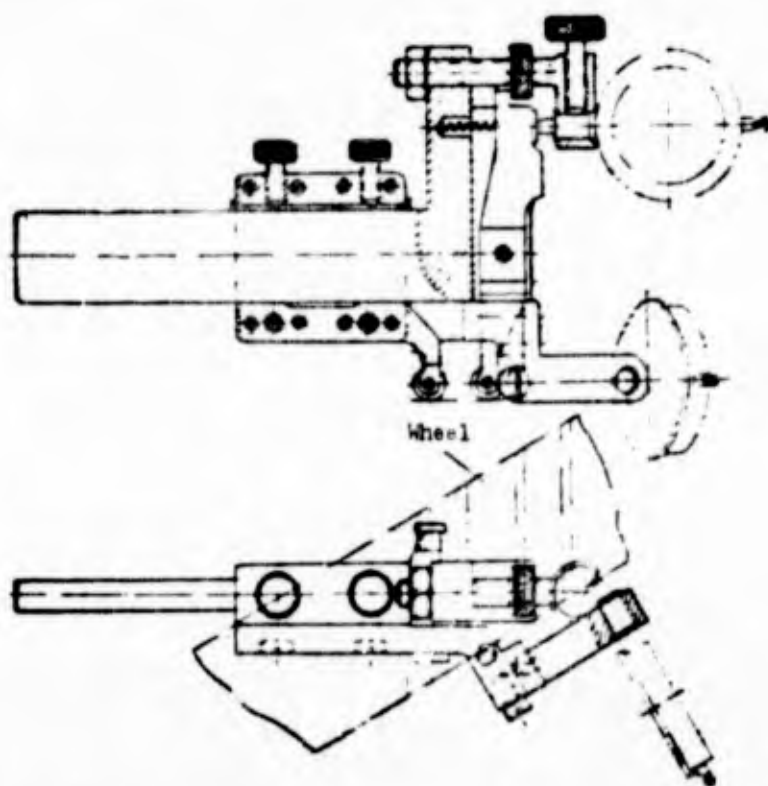


Fig. 2.25. Instrument for checking width of groove and direction of it with respect to face of wheel.

CHAPTER III

WORKING OF BLADES

§ 1. DESIGN, SPECIFICATIONS AND MATERIALS

Blade of jet engines are divided into rotor (rotating) and guide stator and nozzle (motionless). They are solid, with channels for cooling, and hollow. By method of manufacture blades are divided into formed (forged, pressed and stamped), cast and welded or soldered.

Basic structural members of a blade are the tip and the root section - root.

Blade tip has a complex three-dimensional shape with constant or variable cross sections profiles along its length. Sections may be turned relative to one another, forming twist of tip. Convex side of tip is generally called the back, and the concave side is called the bucket. Edge of tip toward entrance of gas we call inlet (nose), and the opposite edge, outlet (trailing).

Tip of rotor blades of gas-turbine engines (Fig. 3.1) has variable section and twist, reaching 60° .

Back and bucket of tip in section are usually outlined by a curved of variable radius. Such profile of the blade tip is given by coordinates of separate points. Sometimes surface of bucket has cylindrical or conical form with smooth transition in plane.

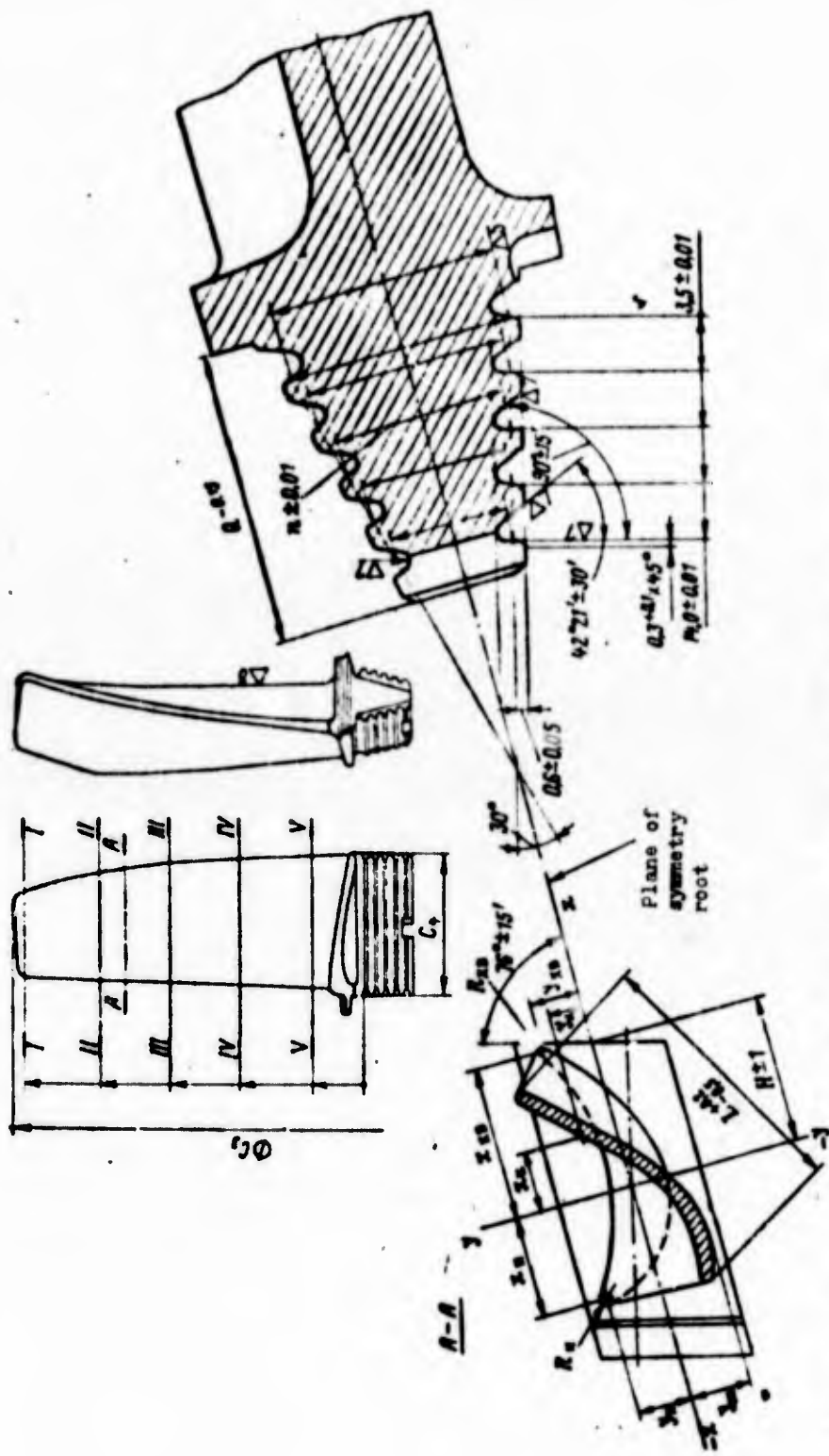


Fig. 3.1. Rotor blade are of turbine of gas turbine engine.
 [K = bucket; H = [?]; CH = [?]; XB = root.]

Tip of turbine nozzle blades has sections, constant or variable along the blade, with angle of twist of up to 10° . Such blades are made without a fixing or with two fixings (Fig. 3.2).

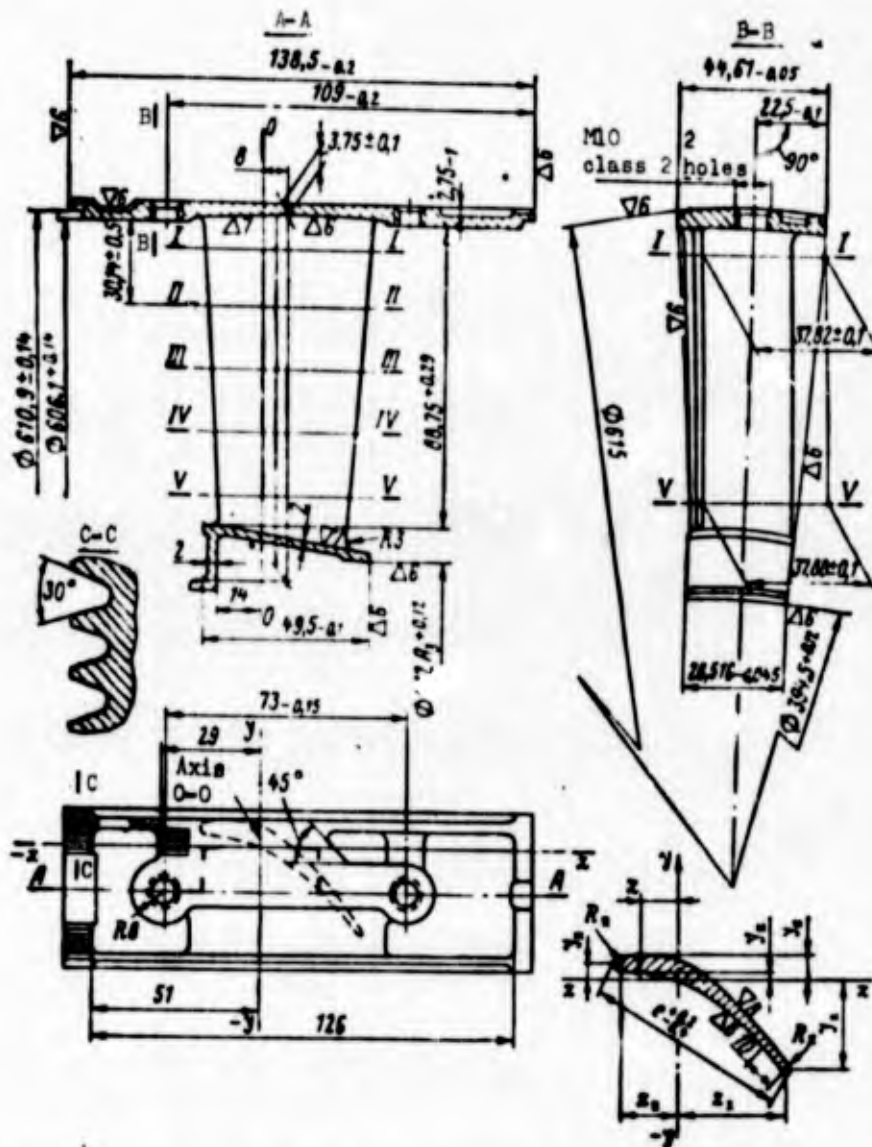


Fig. 3.2. Blade of turbine stator of gas-turbine engine. [κ = bucket; η = [?]; c = back; x = root.]

For turbopump units of liquid-fuel rocket engines the tip of the rotor and nozzle blades is of complex profile, analogous to blades of turbines of gas-turbine engines, or has constant shape of sections its whole length and no twist (Fig. 3.3).

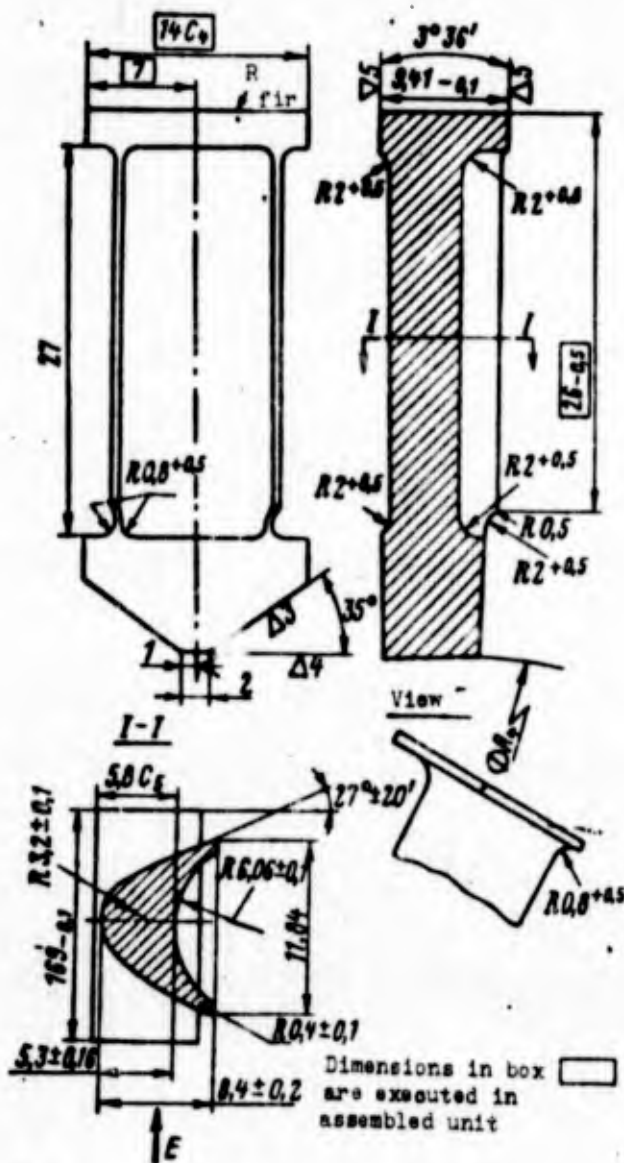


Fig. 3.3. Rotor blade of turbine of turbopump unit.

Tip of rotor (Fig. 3.4), stator and guide (Fig. 3.5) blades of compressor is of more complex shape than for turbine blades; sections and radii of curvature the length of the blade vary, and angle of twist reaches 60° .

Removable connections are executed with the help of roots of different design. Basic shapes of roots are the following: fir-tree, dovetail, T-shape, bulb, forked, mushroom-shaped, and others.

Fir-tree root is most frequently met in turbine rotor blades; and dovetail type is met in rotor blades of axial-flow compressors.

Roots of T-shaped, forked and bulb type most frequently occur for blades of turbopump units.

Blades, combinable with bodies by means of welding, soldering and sockets, do not have roots (rootless).

Accuracy of Working

Accuracy of working of basic surfaces of blades of turbines and compressors is characterized by following data:

Blade Fins.

1. Deviations of form of contours of bucket and back of tip in design sections from assigned allowable is from 0.1 to 0.3 mm.

2. Deviations of maximum thickness of profile of tip from nominal value - not more than 0.2 mm.

Tolerance for thickness of outlet edge - 0.1-0.4 mm.

3. Tolerance for angle of twist of tip in cross sections - $\pm 15'$.

4. Displacement of contours of bucket and back from nominal position in direction, perpendicular to plane of symmetry of root: for rotor blades of turbines of GTE - 0.2-0.6 mm; for blades of compressors - 0.1-0.4 mm.

5. Tolerance for thickness of wall of tip of cast hollow blades - ± 0.3 mm.

6. Cleanness of working of blade tip - 8-10th class.

Surface of tip of blades made from aluminum alloys is subjected to chromate of anodization, and those made of steel often get chrome- or nickel-plating.

To increase heat resistance nozzle and rotor blades of a turbine are coated with heat-resistant enamels, and sometimes are subjected to calorizing or chrome-calorizing.

Blade Roots.

Fir-Tree (see Fig. 3.1):

1. Spacing of teeth execute with tolerance 0.01-0.02 mm.
2. Tolerance for thickness of root on center line of teeth (fitting dimension) - 0.02-0.06 mm.
3. Tolerance for radius of linkage between adjacent teeth - 0.05-0.1 mm.
4. Angle between working (support) surface of tooth and plane of wedge composes $90-104^{\circ}$ with tolerance of 10-30'.
5. Angle between teeth ($42^{\circ}-55^{\circ}$) is maintained with accuracy of $\pm 10'$ to $\pm 40'$.
6. Cleanness of working surfaces of root - 7th class.

Dovetail (trapezoidal, Fig. 3.4):

1. Dimensions of fitting surfaces - 2nd accuracy class.
2. Tolerance for angle of fitting surfaces - 4-8'.
3. Accuracy of location of root with respect to profile of tip - ± 0.2 mm.
4. Displacement of base of root relative to outlet edge is allowed within limits ± 0.1 mm.
5. Cleanness of working of surfaces: root - 7th class, others - 6th or 5th class.

Shelved with journals (see Fig. 3.5):

1. Dimensions of shelves - with accuracy of 2nd or 3rd class, less frequently of 4th accuracy class.
2. Diameter of journals usually of 2nd or 3rd accuracy class.
3. Thread of journals and holes - 2nd class.
4. Nonparallelism and nonperpendicularity of surfaces of shelves and journals allowed is not more than 0.05-0.1 mm.

5. Cleanness of worked surfaces -7th or 6th class.

Prismatic:

1. Tolerance for thickness of root (fitting dimension) - 3rd accuracy class.

2. Displacement of profiles of tip and upper root (small root) relative to lower root allowed is not more than 0.15 mm.

3. Cleanness of working of these surfaces - 6th or 7th class.

Additional specifications.

Tolerance for mass of each rotor blade of GTE turbine is set up to 5% of its nominal mass.

For rotor blades of GTE turbine they also set lower permissible limit of frequencies of 1st bent form. Thus, for turbine rotor blades of one small-lot-produced motor frequency of natural oscillations of 1st tone should be: 1600-1950 cps (Stage I), 1020-1200 cps (Stage II), 630-700 cps, (Stage III), 435-475 cps (Stage IV), 230-270 cps (Stage V).

Blade Materials

Exploitational conditions of work of blades present to materials from which they are prepared very high requirements.

Material of blades should possess sufficient strength, plasticity, creep resistance, fatigue limit, corrosional stability, erosion resistance and as small a sensitivity to notches as possible. Besides, material should be easily worked by cutting and pressure. Alloys of cast blades should possess high casting qualities, and of welded blades, good weldability.

For rotor blades of GTE turbines there are basically applied heat-resisting alloys, containing nickel, chromium, tungsten,

molybdenum, titanium and tantalum. Most widely applied is nickel-chromium-titanium wrought alloys EI437B, EI617, and others.

At present in connection with increasing temperatures before a turbine for rotor blades they are applying more heat-resisting wrought and cast alloys.

Quality of alloy is improved, if it is produced in a vacuum. Fusion in a vacuum ensures more thorough control of alloy composition, frees it from harmful impurities and improves characteristics at high temperatures.

Casting alloys are more heat-resistant than forging ones, since at very high temperatures structure of cast alloys better sustains load than homogenized ones, obtained from hot working. For this reason both here and abroad there are constant attempts to use casting alloys for rotor blades of turbines.

Of great interest are metals, having a higher melting point, of which the most promising are chromium, molybdenum, niobium and tungsten.

For nozzle blades of GTE turbines we basically apply casting alloys on a nickel base: ZhS3, and others.

They are trying to use for turbine blades ceramic materials on an aluminum oxide base with different metal oxides or their carbides. These materials are outstanding in high heat resistance, almost constants mechanical properties up to temperature of 1000°C and low specific weight.

However, certain unsatisfactory characteristics of them (for instance, low thermal strength, brittleness), and also technological difficulties of manufacturing parts from these materials with high precision hamper their application.

For rotor and nozzle blades of turbopump units of liquid-fuel

rocket engines of single action they apply forging aluminum alloy AK4, structural and heat-resistant steels brands 30KhGSA, 1Kh18N9T, EI69, and also heat-resisting alloys on a nickel base VL7-20.

Blades of an axial-flow compressor work at comparatively low temperatures; therefore, material for them are aluminum alloys: AK4, AK6, VD-17 structural and heat-resistant steels: 30KhGSA, 18KhNVA, Kh17N2, 30Kh2N28A, EI961.

They make blades of the supersonic and last stages of compressor from steel.

For compressor blades they also find application of alloys of titanium - VT3-1, VT10.

There are attempts to apply for compressor blades glass-fiber reinforced plastic materials, possessing high strength for low weight, high corrosion resistance and relative insensitivity to surface damage, and also possibility of complicated shaping. Mechanical strength of plastic reaches 63 kg/mm^2 ($\approx 63 \cdot 10^7 \text{ newton/m}^2$); maximum operating temperature is still limited to $250\text{-}300^\circ\text{C}$.

§ 2. CONSTRUCTION OF MANUFACTURING PROCESS

Rotor Blades of GTE Turbine

General Positions

Blanks. Blanks for blades from forging alloys are obtained by drop forging, pressing (pressing), rolling and milling, seeking longitudinal location of fibers of material. The most usual method is forging of blanks (Fig. 3.6), which is usually performed on forging presses with force of 1500-4000 T ($\approx 15\text{-}40 \text{ Meganewtons}$) in open or closed dies.

For more or less considerable scales of production they try to obtain forged blanks with small allowances for working. Applying so-called "flashless die" forging, it is possible to decrease allowance for working to 1.0-1.5 mm and considerably reduce total labor-consumption in manufacture of blades. Distinction of method of "flashless die" forging from usual methods is more rigid apportioning of metal of initial blank.

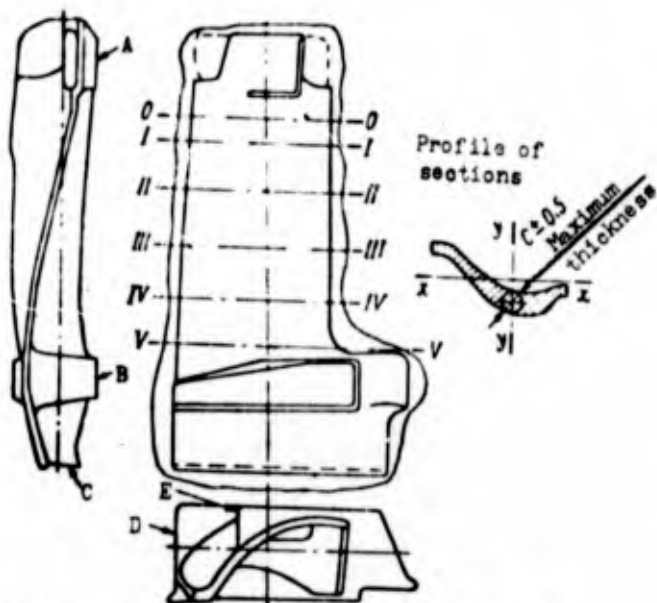


Fig. 3.6. Forged blank of turbine rotor blade. Specifications: 1. Drop forged slants 1° . 2. There is allowed displacement of dies along axis xx of not more than 0.5 mm and longitudinal displacement up to 0.8 mm. 3. Nonplanarity of surfaces A and B, not more than 0.5 mm. 4. A, B, C, D and E - base surfaces for machining.

In selection of allowance for machining of rotor blades it is possible to be guided by the given data from NIAT [Scientific Research Institute of Technology and Organization of Production of the State Committee of the Council of Ministers USSR for Aviation Material].

Blanks of turbine blades with constant profile the length of the tip can be obtained by extrusion. Such a method ensures obtaining of blade blanks with minimum allowances

and longitudinal direction of fibers. Extrusion of blanks can be produced on standard forging and extruding equipment: hydraulic, mechanical or frictional presses, on horizontal-forging machines, and others. Extruded material is heated to temperature, close to

Length of blade tip, mm	Allowance on side, mm	
	tip	root
Below 50	0.8-1.0	1.5
From 50 to 100	1.0-1.5	1.5
From 100 to 200	1.5-2.0	2.0

upper limit of forging range. It is recommended to apply induction heating. To avoid breaks of metal at thin edges in connection with their faster cooling in construction of die there are "pockets," ensuring certain thickening of edges. Unnecessary metal, filling pockets, is removed by machining.

To produce a blade with variable profile the extruded blank is subjected to cold rolling. Between operations of rolling of blank it is necessary to anneal in order to remove of internal stresses.

Blade blanks from casting alloys are obtained by casting from wax patterns. Castings have allowance for tip of 0.3-0.6 mm on the side of grinding and polishing and for root, 0.8-1.2 mm on a side. At very tip of blade is a boss, utilized as positioning base during working checking of blade.

Small lot manufacture of turbine blades from castings is more economical, than from forged blanks. During vacuum melting and casting of blanks the secondary metal does not oxidize, and this permits us to use taps (flow gates, vents, etc.) and, thereby, to lower consumption of metal. Prime cost of manufacture of blades is lowered here by up to 60%.

Bases. Complex shape and insufficient rigidity of the part hamper reliable fastening of blade and stability of positioning.

Working of tip and root of blades more frequently is carried out with part positioned on flat bases (Fig. 3.7) located on root in direction of back and bucket and on industrial boss. For fixing there are used holes in boss and the face of the root toward outlet edge.

Such bases are more convenient, ensure reliable fastening and stability of positioning.

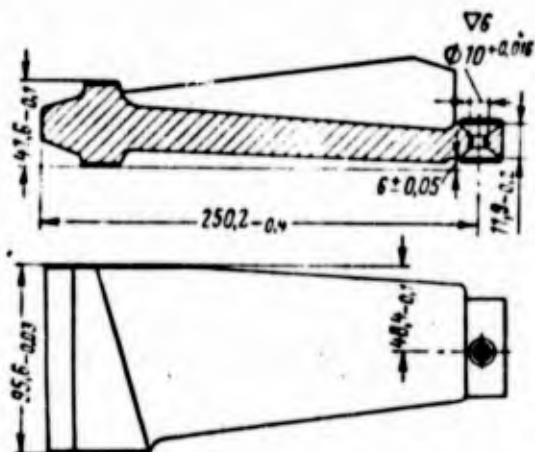


Fig. 3.7. Flat base surfaces of turbine rotor blade.

Back of blade usually is worked on duplicating machines (lathe, milling, grinding).

Bucket of fin is reamed, milled, ground. When sections of bucket are formed by circular arcs, working is simplified and necessity for copying machines disappears. Working of bucket of more complex profile, for instance,

formed by surfaces of two cones, of variable radii in combination with tangent planes, etc., we produce on duplication machines.

Cleanness of surfaces, assigned by specifications for profile of root, is attained by milling, broaching or grinding; and for tip, by polishing.

Labyrinth grooves on ends of blade roots are finally worked after installation of blade on wheel, i.e., assembled. This the most simple method of guaranteeing high accuracy of mutual location of surfaces, belonging the two joined parts.

In order that blackness does not remain during working of blade fin from blanks with small allowances (for grinding), adjusting base should ensure exact and definite position of the part. Several variants of solution of this problem are known. In foreign practice, for instance, they use as positioning base three center holes: one on end of blade tip and one each on flat lateral faces of root. Positioning base is used in all operations of machining and during checking of blade. During preparation of flat bases it is very important, that allowances for working of blade are distributed evenly. This is attained now by application of device of automatic

distribution of allowance (model ART-1).*

Positioning of blade in space is carried out by method of automatic search in a selected number of degrees of freedom (up to six). As criterion of optimum location of blades in an ARP device there is selected maximum of the least deviations of dimension of part from dimension of the standard or blueprint. In device there is used electrical single-channel automatic optimizer, controlling shifts of blade.

Device consists of two parts. First is located in cabinet and contains unit for forming of criterion, optimizer, switching unit and power unit. Second part consists of platforms for installation of blade with mechanisms for shifting it in the needed number of degrees of freedom and a clamp for installation of inductance pickups (miniature with large stroke of rod) on surface of blade tip. Before beginning of work they set up transducers (up to 28) on standard blade or calculation points of blueprint. Blade or its blank as a result of process of automatic searching is located equidistant to contour of standard blade with precision of 0.05 to 0.2 mm. Upon completion of searching there is automatic stop.

Time of search for most advantageous position of blade in industrial conditions is on the average 12-30 seconds.

If blade has impermissible deviations from form, the system automatically rejects it.

The ARP unit can be either directly built into machine, or to work as self-contained unit.

*Design was developed by D. T. Vasil'yev, Candidate of Tech. Sciences, jointly with colleagues of Institute of Automation and Telemechanics of Academy of Sciences of USSR.

Another problem, encountered during working of blades from blanks with small allowances, is to avoid warping of part after removal of even a comparatively thin layer metal. Warping occurs as a result of redistribution of residual stresses, appearing in the course of cutting. Practically this problem is solved by selection of corresponding conditions of working and application of jet cooling,* and in certain cases also by correction of supports of attachments, when for fastening of blade there is created certain stress, counteracting expected flexure after working. This last method sometimes finds application in attachments for machining the back.

During development of industrial process of manufacture of turbine blades one should consider peculiarities of heat-resisting alloys. These alloys are very difficult to work by cutting, especially intermittent cutting. If workability of steel 45 by contemporary hard-alloy tools is taken as 100%, the relative workability of heat-resisting alloy EI437 is only 4% EI617 - 2%, ZhS6 - 1.4%.

Heat-resisting alloys, possessing high strength in combination with great viscosity, are inclined to considerable hardening, and this leads to growth of cutting forces, heating of tool, and as a result - rapid wear of it.

One of basic directions of improving conditions of cutting during working of heat-resisting alloys is improvement of materials of cutting tools. However, other measures are also necessary. Investigations and experiments of plants, for instance, established that prolonged stability of tools during intermittent cutting of

*Stream of liquid is fed from below into slot between piece and rear margin of tool under pressure of 10-20 atm(tech) ($\approx 10 \cdot 10^5$ to $20 \cdot 10^5$ newton/m²). Diameter of hole of injector is about 0.5 mm.

certain heat-resistant alloys on a nickel base can be obtained only with working by a tool of high-speed cutting steels R18, R9K5, RK10, R9F5, R18F2M, SK8. Here there are assumed very low speeds of cutting - of the order of 3-6 m/min. As lubricant coolant best is a five percent emulsion (All-Union Government Standard 1975-53) pressure-fed. Working should be done only with a sharp tool (permissible wear on rear edge for milling cutters (0.2-0.3 mm, and for cutters 0.3-0.5 mm).

Workability of heat-resisting alloys can also be noticeably improved by proper heat treatment.

Considering that heat-resisting alloys can be worked only at relatively low speeds of cutting, it is expedient to expand application of processes of grinding, and also electrical methods.

Turbine blades for the contemporary jet engine are one of the mass-produced parts; therefore, production of them is organized on continuous-flow principle with application of highly productive machines and highly effective methods of working.

Sample Working Plan

Forged blank.

1. Cutting of burr.
2. Working of base surfaces on industrial boss and of butt section (milling and grinding of planes, drilling and countersinking of hole in industrial boss).
3. Rough working of tip and edges (milling of edges and bucket machining of back).
4. Restoration of positioning bases (grinding of base planes of industrial boss and butt on side of back and bucket).
5. Finishing (grinding) of bucket and back.
6. Preliminary milling of wedge.
7. Polishing of tip for etching.
8. Etching and checking for external defects of material of blade (cracks, lumps, pores, nonmetallic inclusions, hairline cracks, etc.).
9. Milling of wedge and profile of root.
10. Final grinding and polishing of tip.
11. Grinding of faces and shelves of root on side of bucket and back.

Sample Working Plan (Continued)

12. Cutting off of industrial boss.
13. Final check.
14. Grinding of blade face of set of blades (assembled).
15. Check of frequency of fundamental tone of flexural oscillations of blades.

At present there have been developed model industrial processes of manufacture of blades. Their introduction with standardized equipment permits us to considerably reduce periods of preparation for production of new motors, cost of manufacture of industrial equipment and labor-consumption of production of blades, and also to increase quality and stability of their manufacture.

Small-Size Blades

Length of tip of such blades is 30-80 mm, accuracy of manufacture of tip is within limits ± 0.05 mm. Small-size blades usually have shrouding on tip.

To ensure given accuracy of tip by present methods of machining is very difficult; it is usually achieved by manual trimming. For mechanization of working of the blade most promising are electrical methods of working: electroerosional (removal of basic allowance) with subsequent electro-hydro-polishing.

Model industrial process of manufacture of small-size turbine blades with application of electrical methods of working:

1. Exact forging of blank with allowance to the side of 0.5-0.8 mm. For tip and 1.0 mm for root.
2. Milling of inlet and outlet edges.
3. Equal distribution of allowance in tip with filling of blade by light alloy, in holder.
4. Milling and grinding of base surfaces of root and upper shelf on side of bucket, back, inlet and outlet edges, faces of root and shelf.
5. Milling of wedge and fir-tree profile of root.

6. Grinding of bevels of root and shelf on the side of outlet and inlet edges.
7. Smelting of alloy and removal of blade from holder.
8. Electroerosional working of tip on multiposition semiautomatic machine.
9. Electro-hydro-polishing of tip on multiposition installation.
10. Grinding of inlet and outlet edges.
11. Hydroabrasive polishing of tip before etching.
12. Etching and check for defects of material.
13. Hydroabrasive polishing of tip.
14. Polishing of inlet and outlet edges by abrasive tape.
15. Grinding of labyrinth on upper shelf.
16. Final check.

Cast Blades

Blanks of average-dimension cast (solid) turbine blades have allowance on the side for tip 0.3-0.6 mm and for root 0.8-1.2 mm. On castings at end of tip they provide boss, which is used as auxiliary base during working of tip.

During manufacture of cast blades it is expediently first to finally work lock and boss on tip of blade, and then from root and boss work the blade. Root and boss are worked in special attachment — holder (Fig. 3.8). Blade in holder is positioned by extreme sections

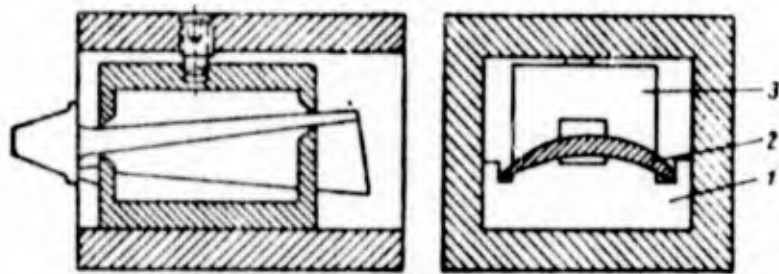


Fig. 3.8. Holder for working root of cast turbine blades. 1) fixed base element; 2) blade; 3) clamp number.

of bucket on profile positioning members (trenches), is secured from the back and filled with fusible wood alloy.

With such positioning they work face, wedge and fir-tree profile of root, and also surface of boss on tip of

blade. After working holders with blades are dipped in bath with hot water to extract alloy.

After grinding and polishing of tip they cut off industrial boss, grind the face of blade in a false wheel, and polish the tip.

Single-Channel Cooled Blades with Deflector

Flow chart of manufacture of hollow single-channel cooled turbine blades from forging alloy EI929 with deflector of alloy EI617 is shown in Fig. 3.9.

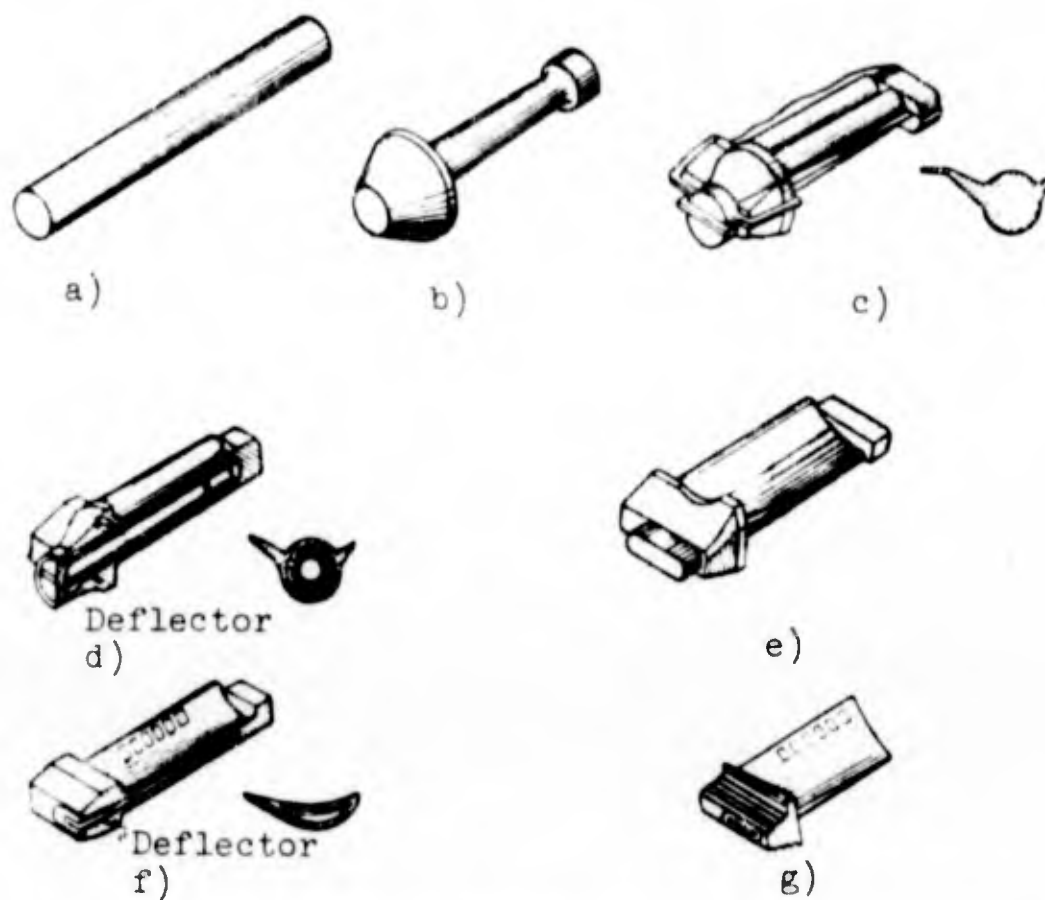


Fig. 3.9. Diagram of manufacture of hollow single-channel cooled turbine blades. a) initial blank; b) heading and turning of rod; c) drop forging of intermediate blank; d) machining and assembly of blank with deflector and fillers; e) drop forging of blade; f) machining and etching out of filler; g) final machining.

Deflectors – hollow thin-walled solids of revolution with external annular grooves (Fig. 3.10) – serve to guide and distribute air coolant, fed into cavity of blade. Metallic fillers are fastened in deflector by argon arc and electric-contact spot welding.

Hollow intermediate blank of a blade, assembled with deflector and fillers, proceeds to hot stamping, during which there are created channels for passage of air coolant (Fig. 3.11). Then fillers are etched out.

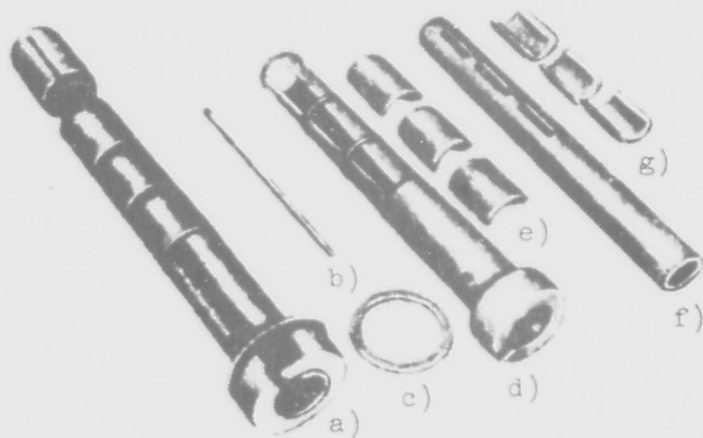


Fig. 3.10. Deflector and fillers. a) deflector together with fillers; b) wire filler; c) washer filler; d) deflector; e) filler inserts; f) filler tube.

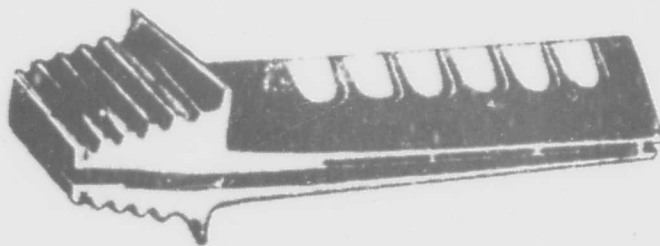


Fig. 3.11. Fully worked turbine blade with one-sided forged deflector.

Allowances for machining are: on profile of blade 0.8 mm to the side, on inlet and outlet edges 2 mm and for root, 3 mm to the side.

Industrial bases are subjected to machining (planes of shelves of root and boss on the side of back and bucket), root, tip, recesses on outlet edge. Then on outlet edge by electroerosion method there are processed slots (matching number of grooves) for exit from cavity of blade, without affecting deflector.

Location of deflector in cavity of blade and marking of depth of electroerosional treatment of slots are checked on X-ray photographs of forged pieces.

Multichannel (Honeycomb) Cooled Blades

In blades of given construction cooling channels are located in the surface and at edges of tip; thickness of crosspieces between channels and thickness of walls is at least 1.0 mm. Blank for these blades is a flashless die forging with allowance for working of tip of 0.5 ± 0.1 mm to the side and $1.5^{+0.2}_{-0.1}$ mm in width of tip and root. Presence of burr in blank greatly deforms channels located at blade edges.

Flow chart of manufacture of multichannel cooled blades is shown in Fig. 3.12.

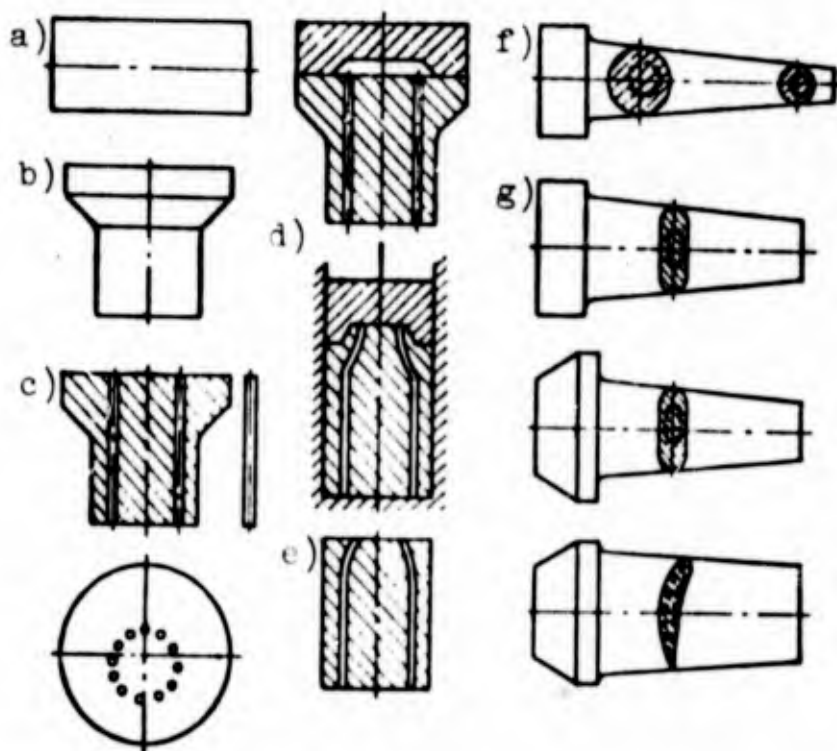


Fig. 3.12. Flow chart of manufacture of a multichannel (honeycomb) cooled turbine blade. a) initial cylindrical blank; b) heading; c) working of holes and investing of them with filler; d) forging of mushroom-like blank into cylinder; e) segment of upper part; f) extrusion of cone blank; g) closed impression die forging for six transitions.

Filler is etched out from channels in alkaline bath (70% NaOH and 30% saltpeter) at 500-550°C for 35-50 hours. Tip is polished and etched for detection of macrostructure at the end of manufacture. Airtightness and carrying capacity of channels of blade are checked by kerosene under pressure of 1.5 atm ($\approx 1.5 \cdot 10^5$ newton/m²).

Blades of GTE Turbine Nozzles

Most widespread are blanks of GTE nozzle blades, manufactured by precision casting in investment patterns. Such castings almost do not need machining; utilization of material comprises about 90%, which has special significance for such expensive materials as alloys ZhS3, and others.

Process of manufacture of cast nozzle blades consists of two basic stages:

- a) obtaining exact casting;
- b) machining.

First stage is most labor-consuming and crucial.

Casting of Blanks

Casting by investment patterns is one of the most highly effective methods of production of complex machine parts which require precision and cleanness of cast surface.

Essence of process consists in the following: from fusible organic materials in a die-mold we obtain model and cover it with special silicate dressing, which upon drying will form a crust on the pattern. Then the pattern is placed in a flask with molding sand and all this is set in a furnace for smelting of model compound and heat treatment at high temperature in order to turn silicate covering into a durable ceramic shell. Place occupied earlier by model will form a cavity, in which they pour metal of the blank.

Cast blanks of blades are knocked from flasks, cleaned and after thorough check are subjected to heat treating.

Technique of manufacture of castings of blades by investment patterns has many variants both in fulfillment of basic operations, and also in composition of model and mold materials.

Models of blades are molded in special built-up cast molds, usually steel. Dimensions of working part of cast molds should consider shrinkage of model composition and metal of casting during cooling.

Cast molds are sometimes manufactured by electroplating, plating halves of specially prepared aluminum blade with layer of copper 0.8-1.3 mm thick on a nickel underlayer. Then copper-plated blade, after washing and drying, is plated with copper or steel to layer 2-2.5 mm thick. After etching out aluminum blade in boiling alkaline bath and removal by electrolytic means of layer of nickel the obtained crown is filled from non-working side with aluminum or zinc alloy in special metallic form, thus obtaining cast mold.

Working cavity of cast molds is nickel plated, which increases its strength.

Such method ensures obtaining of dimensions of cast forms of 2nd or 3rd accuracy class.

Material for preparation of pattern masses are paraffin, stearin, rosin, cerezine, polystyrol, bee wax, plastic.

Most frequently blade models are first coupled, and then already coupled models are assembled in block of four to six models with common flow gate.

Process of manufacture of ceramic shell consists of coating models with ceramic dressing, sprinkling with sand, and drying first in air, and then in atmosphere of ammonia.

For preparation of ceramic dressing they apply Marshalite,* quartz sand and ethylsilicate.**

Ceramic shell is formed from five successively applied layers.

For this blocks of models are dipped two or three times in bath of ceramic dressing. Then over them they sprinkle quartz sand for best bond between layers and prevention of cracking. Thickness of dressing is 1-1.5 mm.

After natural drying of blocks in hood for 2 hours, there follows accelerated drying for 40-50 minutes in ammonia gas environment. Remaining layers are applied analogously.

They check drying of each layer of dressing by submersion of test model in hydrolyzed ethylsilicate, after which dressing should not remain or be cracked.

Model blocks are molded in rigid flask; filler is usually molding sand, consisting of aluminous cement, Marshalite and quartz sand.

After drying of flask in air from form the pattern material is etched by heated air, vapor or in special thermostats. Sometimes etching of pattern material is combined with drying and even with calcination. In this case utilization of worked pattern material is completely eliminated, since the material burns in the furnace.

After etching of pattern material forms are first dried, then calcinated in electric furnaces at a temperature of 300 - 900°C with slow, stepped increase of temperature for 13-16 hours.

*Marshalite - ground quartz sand, sifted through sieve No. 270.

**Ethylsilicate - $\text{Si}(\text{C}_2\text{H}_5\text{O})_4$, ethyl ether solution of orthosilicic acid.

Metal for nozzle blades is smelted in arc or induction high-frequency electric furnaces. Induction furnaces ensure minimum waste of elements, and consequently also large constancy of chemical composition of alloy, best control of metallurgical process during smelting of alloy.

Filling of molds with metal can be done by several methods: free filling, compressed air pressure, in vacuum, on centrifugal machine.

Free filling of molds with metal is the most widespread in plant practice. Alloy, heated to temperature of overflow, is poured into molds, which are preheated to 600 - 800°C.

Filling of molds with metal under pressure of compressed air increases density of castings, improves filling of mold.

Filling under vacuum (with rarefaction in mold of approximately 100 mm or ($\approx 136 \cdot 10^2$ newton/m²) improves filling of mold with metal, since it permits removing from it of gases and air.

Filling of molds on centrifugal machines ensures high degree of packing of metal in mold.

Castings are subjected to heat treatment to eliminate residual stresses appearing during cooling of castings (from alloys LK4, VL7-45U), and also to produce mechanical properties, assigned by specifications (alloy ZhS3, and others).

After heat treatment castings pass to sand-blasting treatment and inspection.

By investment patterns there may also be cast hollow, cooled blades (Fig. 3.13). Technology in this case is basically the same as during casting of monolithic blades. Distinction is only that during manufacture of investment pattern of hollow blade inside it is necessary to place a ceramic rod.

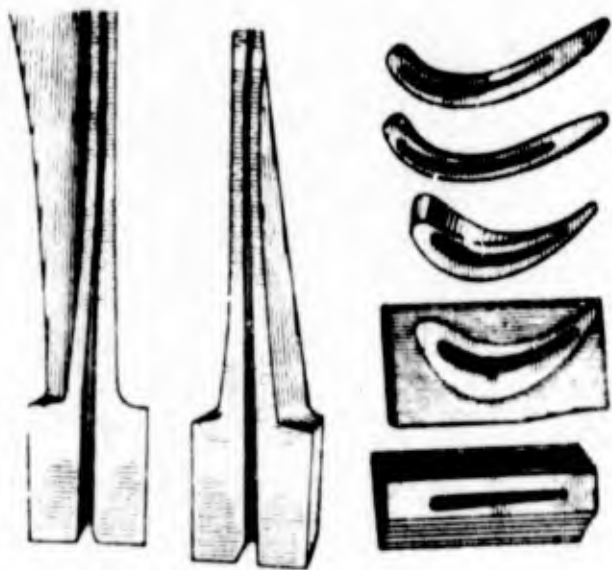


Fig. 3.13. Sections of cast blank of hollow blade.

Rods are prepared from fire-proof material (silicon carbide with admixture of Marshalite) bonded by ethylsilicate.

Forged rod after calcination is dipped in fixing agent (75% hydrolyzate and 25% ethyl cellulose). Then rod is checked by patterns in assigned sections. Deviations in profile should not exceed 0.15-0.2 mm to the side. For pattern material they use

water-soluble carbomide (urea with boric acid or potassium nitrate (MB-97-3)). Pattern material is removed from shell in running water at 50-60°C.

In other respects process of manufacture of hollow casting differs little from technique of casting a solid blade (forging of model, covering by ceramic mass, etching out of pattern material, packing of molds, heat treatment and filling). Ceramic rod from cavity of casting is removed by pneumatic chisel with subsequent leaching of ceramics residue from windows of blade by melted caustic and washing.

Machining

Machining of nozzle blade made of heat-resisting casting alloys includes grinding and polishing of tip and working of surfaces of lower and upper roots.

Heat-resisting casting alloys from which nozzle blades are made have low workability with a metal tool, especially alloys of type ZhS3; therefore, they are chiefly ground. Grinding is conducted by abrasive wheels EB-46-60, ST-ST3 with abundant cooling by soda water.

In contemporary industrial processes most operations in working blade tip are mechanized and are executed on copying-polishing machines.

Industrial process of machining turbine nozzle blades (see Fig. 3.2) is constructed in following sequence. Initially with respect to bucket and inlet edge they grind and rub side cavities of shelves of upper and lower roots which are basic base planes for all subsequent working of blades. Then there follows working of remaining surfaces of root: grinding of heel, shoulders, drilling of holes, cutting of threading, boring of shank, and other surfaces. Then they grind back and bucket, and finally fit their profile and polish.

Blades of Turbines of Turbopump Units (TPU)

For high-temperature TPU turbines (working on basic components) rotor blades (see Fig. 3.3) are most frequently united with wheel by welding (electric arc, friction) or are cast in a single whole with the wheel. Blanks for welded blades are precision castings, obtained by casting in investment patterns.

Only surfaces of shroud shelf and butt part are machined. Positioning base is surface of back, clamping is in bucket. Steam surfaces of blade after casting are not worked.

Working of castings starts with milling of traces of flow gates and feeders on shroud shelf and butt part. Blades are fixed in multiposition attachments. Then they grind four lateral planes of shroud shelf and butt of blade on side of back, bucket, inlet and outlet edges. After which set of blades is assembled on one wheel in special attachment, ensuring tight adjoining of one to another, and they drill butt part of blade for welding.

For TPU blades, working with steam-gas, in case of considerable scales of production, blade blanks are obtained by rolling or

forging — without allowance for tip working. Root of blade is processed on base of tip — by broaching. In conditions of small-lot production bars are the blanks.

Blades of GTE Axial-Flow Compressors

Blank. Blanks of rotor and stator blades of compressor are:

- 1) bars, cut from strip of rectangular section, sometimes subjected to bending in stamp for formation of blade twist;
- 2) rough forgings with allowance in tip of 2.0-3.5 mm;
- 3) forging with small allowance in tip 0.3-0.5 mm;
- 4) forging with subsequent stamping without allowance for tip;
- 5) exact casting with allowance for tip of 0.2 mm.

Blanks for blades in the form of bars and rough forgings are used in small scale production.

In machining of blades in this case of great importance are operations of milling of tip on duplicating milling machines. Labor-consumption in machining such blanks is very considerable.

In large scale production blades are manufactured from forgings with small allowance for tip or from forgings with subsequent stamping.

As distinguished from rough forgings, blanks with small allowances are forged in two or three forges (depending upon dimensions) with drop hammers. Before stamping in initial blank they ram on root on horizontal-forging machine. Initial blank in the form of rod is rigidly inspected for mass, so that forging is obtained as far as possible without burr. Allowance toward tip of blade, where thickness of blade is too small, is sometimes increased to 0.6-0.8 mm in order to soften impact of stamps and to prevent their excessive wear, and also prevent formation of cracks in blade. By such a technique there can be obtained blanks for blades of steel, aluminum and titanium alloys.

Forging with subsequent calibration (stamping) is the best method of obtaining complex three-dimensional shape of blade tip. Such method of manufacture of precision blank solves basic problem of production of blades -- obtaining of profile of tip with final dimensions, required shape and almost without further machining with the exception of rounding of edges and polishing of blade tip.

Process of forging with subsequent calibration is the most perfected for blades of aluminum alloys. Technological process of obtaining blanks from alloy VD17 is given in Table III.1.

Tip is calibrated in two operations. Part proceeds to first calibration directly after second forging from the same heating, after which part proceeds to hardening. Second and final (cold) calibration is produced no later than 3-5 hours after hardening (before aging). In final calibration on tip they leave allowance (for filling of metal) of 0.1-0.3 mm depending upon dimensions of blade.

Calibration ensures obtaining of blank with allowance for maximum thickness of tip within 0.2 mm. Allowance for root is: for base -- up to 2.5 mm, for lateral surfaces -- up to 1.5 mm.

For steel blades process of obtaining blade blank by forging with subsequent calibration is like the considered one and consists of following stages:



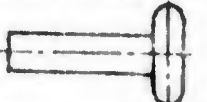
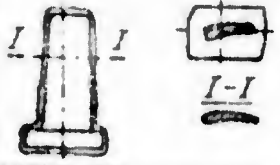
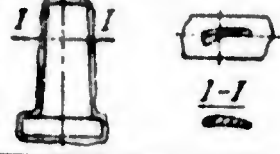
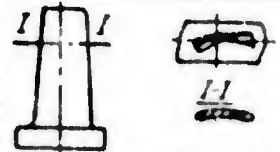
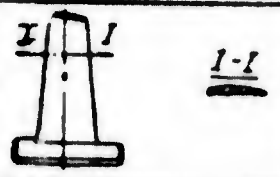
- 1) cutting of initial blank from rod;
- 2) fullering on forging hammer;
- 3) forging -- shaping of blank on forging hammer;
- 4) exact forging of blank before calibration;
- 5) calibration of blank with allowance for grinding.

Basic difficulty in obtaining blanks by forging with subsequent calibration is providing production by stamps. Durability of stamping stamps is approximately the following:

for blades from aluminum alloys - up to 8,000 pieces,
for steel blades - up to 2,500 pieces.

Obviously, it is possible to solve question of what procurement to use - calibrated or forged (with allowance in first) - only after corresponding economic calculation, considering also local potentialities.

Table III.1

No. of operation	Name of operation	Sketch of operation	Equipment
1	Initial rod-blank		
2	First heading		Horizontal forging machine
3	Second heading		Horizontal forging machine
4	First forging in heated forge up to $t = 200^{\circ}\text{C}$		Hammer
5	Second forging		Hammer
6	Cutting off of burr		Stamp
7	First stamping		Hammer
8	Hardening		Furnace
9	Cold stamping		Hammer
10	Inspection of blank		

Of considerable interest also is the method of producing blanks for compressor blades by hot extrusion with subsequent rolling,

developed by TsNIITMash [Central Scientific Research Institute of Technology and Machine Building]. Essence of given process is that heated initial cylindrical blank is clinched and then is extruded with formation of root and tip of constant profile without twist.

After second heating blank passes through rollers, which give tip required profile and twist with machining allowance of 0.3-0.5 mm to the side. Advantages of given method: complete automation, high productivity, equipment consuming, less power metal economy of metal for blade blanks.

Castings of compressor stator blades are obtained by casting in investment patterns with tip allowance of 0.2 mm to the side.

Process of machining of compressor blades is determined by type of blade and form of blank.

Working of blades from forged blanks, having passed through calibration, is greatly simplified and leads basically to machining of root surfaces, polishing tip and patching edges. The root is best worked by broaching. However, machining of root of rotor blades is hampered by the fact that tip of blade with complex three-dimensional shape possesses low strength. Difficulties arise in positioning the part in attachments, and also there is danger of deformation of tip in the course of working. In this case of decisive significance is selection of bases.

Bases. As bases for working the root of rotor blades of a compressor there are (Fig. 3.14) surface of bucket A, nose at point B and upper plane of root in direction of inlet edge at point C. Fastening of blade is produced on back D. Support during broaching is carried out in preliminarily milled face of root on side of outlet edge.

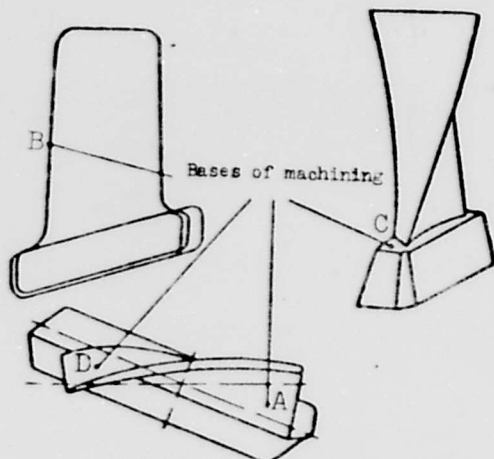


Fig. 3.14. Bases during broaching of root.

Machining. Process of machining

steel rotor blades from calibrated stamping consists of following basic stages:

1. Heat treatment of blank — hardening and tempering.
2. Working of primary base surfaces: inlet and outlet edges, end of root.
3. Working of root — broaching or milling.

4. Grinding of tip.
5. Cutting of industrial allowance.
6. Polishing of tip.
7. Final check, including magnetic.
8. Zinc-coating, nickel plating or chrome plating.

Polishing of tip — completing operation in manufacture of blade in serial and mass production — is carried out by abrasive tapes on vibration polishing machines, and in small-lot and unit production the tip is preliminarily polished with felt, and then felt wheels, covered with paste GOY.

For blades of aluminum alloys flow chart of machining remains the same, with the exception of operations of grinding the tip and cutting off the allowance.

At present most plants manufacture compressor rotor blades from forgings with tip allowance of 1.5-2.0 mm.

Working by cutting of stainless steels in many respects is similar to working of heat-resisting steels and alloys. Predominant

operation during machining of compressor blades is milling. Regrinding of milling cutters made of high-speed cutting steels (R18, R9K5) for working of blades of stainless steels is produced during blunting on trailing edge of 0.3-0.8 mm.

Bases for working of blades from a bar (in small scale production) are holes and center indentations on faces of blank. Machining of surfaces of tip and root in this case consists of numerous and labor-consuming milling operations.

The industrial process of working aluminum stator blades with journals from a forging consists of following basic operations:

1. Blank - forging with tip allowance 15-2.0 mm a side.
2. Heat treatment of blank - hardening and aging.
3. Working positioning bases - undercutting faces and drilling center holes.
4. Roughing of journals and shelf - machining of journals, undercutting of faces (milling of sides of shelf).
5. Rough milling of tip.
6. Restoration of positioning bases (centering of faces of journals).
7. Finishing of journals and undercutting of their faces.
8. Clean milling or broaching of sides of shelf.
9. Clean milling of tip.
10. Thread rolling.
11. Polishing of tip, shelf, journals.
12. Final check.
13. Anodization.

If blank of such blade is a forging stamping with subsequent calibration, the process of machining is simplified - tip of blade is only polished, and operation of tip milling drops.

Peculiarities of Working Compressor Blades of Titanium Alloys

Blanks of blades from titanium alloys are manufactured by forging with subsequent correction in calibrating stamp. Tip allowance remains in range of 1-3 mm. Blanks are subject to heat treatment

and pickling.

Base during machining of tip is root and machining boss at tip of blade (auxiliary positioning base), located in plane of root.

Root of dovetail type and boss are worked in special holders, allowing displacement and misalignment of blank of not more than 0.05 mm. Root of blade is broached. Broaches are made from high-speed cutting steels R18 or R9F5.

Tip of blade is worked on duplicating milling machines by milling cutters, equipped with plates of hard alloy VK4 or VK8 with cooling by 5% emulsion (All-Union Government Standard 1975-53) with speed of cutting 40 m/min and of feed 100-200 m/min for one or two passages.

After milling blade tip is polished on polishing mandrels by felt wheels, rolled by abrasive grains, thereby removing allowance to 0.1 mm. Preliminary polishing for trimming profile is carried out by grain KZ-46-60. Before pickling tip is polished by grain KZ-100-220, ensuring cleanness of surface to 8th class.

Hard abrasive wheels are not applied for polishing, inasmuch as in this case in blade tip there could appear residual tensile stresses and microcracks, sharply lowering limit of endurance of blades.

Pickling of blade tips for inspection of magnitude of grain is produced in bath with reagent R-77 for 10-20 sec with subsequent thorough neutralization in soda water and washing in running water.

Blade tip after polishing is strengthened by hydraulic shot-peening, which increases fatigue strength.

Tip hardening is produced by cast-iron shot of diameter 0.5-0.8 mm with emulsion of hydraulic shot-peener, whose principle of action is based on ejection. Blades, fixed by roots in adapters,

accomplish rotary (~ 20 rpm) and reciprocating (20-50 mm/min) motion with respect to nozzles. Nozzle-ejectors are located on bottom of chamber a distance of 200-250 mm from axis of rotation of blades. Upon feeding air from network of pressure 1-1.2 atm(gage) ($\approx 1 \cdot 10^5$ to $1.2 \cdot 10^5$ newton/m²) in ejector there is created rarefaction and into it there are sucked shot and liquid, forming a powerful stream of the shot, the air, and the liquid.

Small-size blades are worked simultaneously 5 pieces at a time by three to six nozzles per blade for 15-35 min. Large dimension blades are work hardened one at a time by 15 nozzles for 40-45 min.

Conditions of hardening of blades of titanium alloys were determined experimentally during one-way blow-past of flat titanium plates.

Cleanness of surface of blade tip before work hardening corresponds to 8th class; after blow-past of shot cleanness worsens to 6th class; therefore, tip is again polished by felt wheel with abrasive paste on it (grain 320) or abrasive paper KZ-80-320 on vibrating burnishers ensuring required tip surface cleanness of 8th class.

Most promising is grinding and polishing of blades of titanium alloys by water-resistant abrasive belts on abrasive belt grinders.

Recently there has been conducted work in manufacture of hollow straightening blades from sheets of titanium alloys.

Flow chart of manufacture of hollow footless stator straightening blade is shown in Fig. 3.15. Blade consists of two halves - back and bucket of blade - welded at front and trailing edges. Blanks of back and bucket are cut from strip of alloy OT4 1.5 mm thick, on guillotine shears; then they are molded on a hydraulic press, ensuring required profile and twist of blade tip. Shape of blanks are thermally

fixed for 50 min in neutral medium of argon at a temperature of 680° - 700° C. After seam welding of edges there is applied repeated heating to eliminate stresses, caused by welding. Then edges are ground and polished.

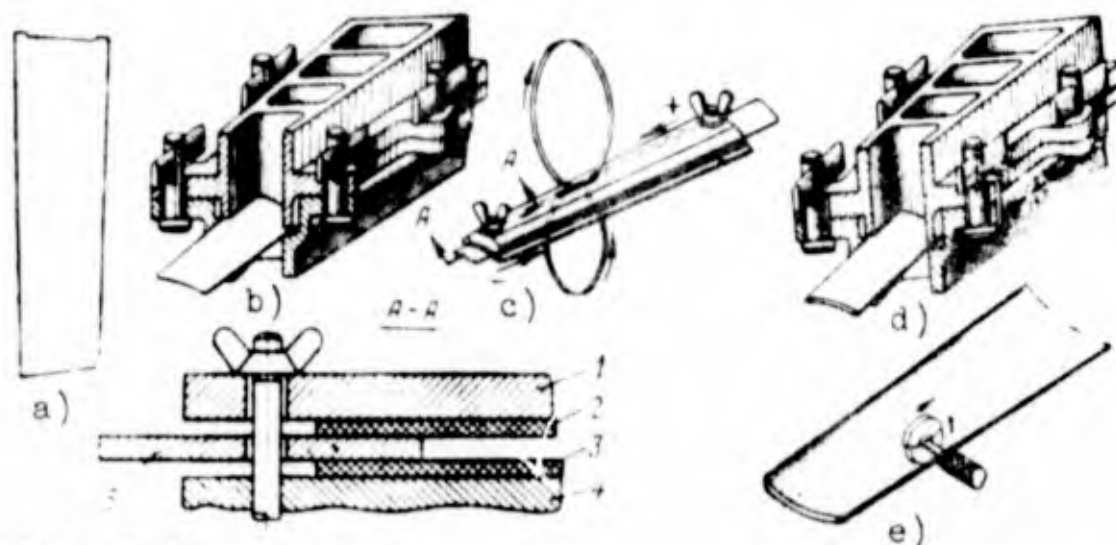


Fig. 3.15. Flow chart of manufacture of hollow rootless stator blade of compressor from sheet of OT4. a) initial blank; b) molding and thermal fixing; c) roll welding of edges; d) thermal fixing after welding; e) finishing of edges. 1) cover plate; 2) back of blade; 3) bucket of blade; 4) base; 5) insert.

§ 3. Increase of Operation Life and Reliability of Work of Blades by Industrial Methods

Rotor blades of turbine work at high temperature in a subversive gaseous environment. In material of blades there appear high stresses of variable character. Besides tension from centrifugal forces, bending and torsion from gas flow, material of blades experiences secondary stresses from vibration loads, the amplitude and frequency of which changes in a wide range.

Practice of operation of jet engines shows that operation life and reliability of blades of engines depend not only on material (chemical composition, structure, heat treatment), structural shape and dimensions of part, but also to a very great degree on a series of technical (quality of surface) and operational factors. State

of surface layer of part, usually with traces of machining, damaged grains and other stresses concentrators, renders very great influence on stress-rupture and fatigue strength of a part.

Not long ago efforts of technologists to increase fatigue and stress-rupture strength of surface layer were directed mainly at improving cleanness of surface. At present it has been established that stress-rupture strength, the appearance and development of fatigue cracks is conditioned not only by microroughness of surface, but also the physico-mechanical state of the surface layer (its structure, residual stresses, etc.).

In practice of aircraft engine construction there have found application technological methods of increasing heat resistance, stress-rupture and fatigue strength of blades, promoting increase of their operation life and of the operational reliability of the engine.

Mechanization of operations of finishing is one important factor, affecting increase of operational reliability of blades. Mechanization of finishing operations promotes increase of quality of blades. To achieve higher accuracy and cleanness of working, for instance, in existing technological processes final working of back of blade is executed in two operations: preliminary and final grinding on abrasive-belt grinders KhSh-186, and polishing — on vibration polishers of model VPL-4.

Selection of methods and conditions of working of blades should be made from conditions of guaranteeing their maximum strength. Investigations established that work hardening and residual stress in surface layer depend on methods and conditions of machining. With increase of speed of cutting depth and degree of work hardening

decrease. With increase of feed and especially of blunting of cutting tool depth and degree of work hardening increase. Residual stresses in existing methods of working by cutting (besides grinding and polishing by abrasive belts) are basically tensile; their magnitude is greater, the higher temperature in the cutting zone. For instance, in surface layer of tip of turbine blades made from alloy EI867 during grinding by ceramic wheels and polishing by flexible polishing wheels there appear residual tensile stresses of $35-70 \text{ kg/mm}^2$ ($\approx 35 \cdot 10^7$ to $70 \cdot 10^7$ newton/m²). Grinding and polishing by abrasive belt in the same blades creates in this layer compressive stresses of $80-40 \text{ kg/mm}^2$ ($\approx 80 \cdot 10^7$ to $40 \cdot 10^7$ newton/m²).

It is also known that work hardening and residual stresses render substantial influence on fatigue and stress-rupture strength of blades. During work of blades in conditions of high temperature (700° and above) and its prolonged influence work hardening and residual stresses lower limit of endurance and stress-rupture strength. Compressive residual stresses at temperatures up to 600°-700°C promote increase of fatigue strength (compressor blade).

Thus, knowing character of dependences of strength characteristics of blade materials on quality of surface, it is possible in every concrete case to designate the optimum methods and regimes of working of blades for strength specifications.*

During work of turbine blades in region of comparatively low temperatures, of the order of 600°-700°C, working hardening increases resistance of heat-resisting alloys to fatigue breakdown. With increase of temperature during operation and increase of duration of

*At present there exist recommendation on selection of methods and regimes of treatment of blade tips.

service life work hardening starts to lower limit of stress-rupture and fatigue strength, more strongly the higher the temperature and the greater the degree of work hardening.

Influence of residual stresses on strength of blade depends on their sign. Tensile stresses in surface layer of blades are harmful, since, being added to operating stresses of the same sign, they increase total tension of blade. Compressive residual stresses may be useful, increasing fatigue limit. However, effectiveness of compressive residual stresses depends on temperature and time of its action during operation. At a temperature above 700° - 800° C with passage of time there occurs relaxation of stresses, and there also may be redistribution of residual stresses with change of their sign on surface of blades.

From this there also follows the expediency of wider application for turbine blades of electrical methods of working (electrohydro-polishing and electropolishing), in which in surface layer there are practically no work hardening and residual stresses.

For compressor blades (especially from alloys of titanium), and also fir-tree roots of turbine blades, working at lower temperatures than blade tip, from considerations of strength one should apply strengthening working (shot peening, hydraulic tumbling, hydroabrasive working, rolling by rollers or balls), creating in surface layer of blades compressive stresses, with condition of preservation of cleanness of surface not below 8th class.

The English firm Bristol strengthens surface layer of tip of compressor blades in the following way. After machining blades are subjected to ordinary shot peening for removal of tensile and creation of compressive stresses in surface layer. Then tip of

blade is polished and work hardened by peening with glass balls, in order to remove tensile stresses appearing in process of polishing. For this they use glass balls with dimensions 0.013-0.053 mm and 0.035-0.07 mm. Work hardening of blades is produced in chamber with help of pistol-type attachment into which there are fed compressed air and glass balls.

After dry peening by glass balls depth of working hardening in blade tip is 0.1-0.25 mm, cleanness of surface corresponds to 8th or 9th class.

Additional tempering after polishing of tip of turbine blades is used to decrease residual stresses, appearing in blade in process of its manufacture. Conditions of heat treatment are established for each alloy separately from conditions of obtaining favorable diagram of distribution of residual stresses and lowering of work hardening. Thus, for instance, for alloy EI617 we have heating in argon to temperature of 950° with exposure in furnace for 2 hours and subsequent aging at a temperature of 800° for 8 hours.

Heat-resistant protective coatings are used to protect surface layer of turbine blades from oxidation and depletion of alloying elements in conditions of prolonged operation. Magnitude of depletion layer of turbine blades from alloy EI437b after operating time of 600 hours is 30μ. As a result of changes occurring in microstructure of surface layers, stress-rupture and fatigue strength of blade is sharply lowered, inclination to crack-formation increases, erosional destruction is facilitated, etc.

For protection of surface of blades they apply:

- a) coating with enamel EZh1000;
- b) diffusion protective coatings;

c) plasma metallizing.

Heat-resistant enamel coating should have durable cohesion with metal, protect metal from corrosion and surface active materials, be elastic and resistant to thermal shocks, increase oxidation resistance and heat resistantness of blades. Thickness of coating — 40-60 μ .

Charge for manufacture of enamel consists of sand, boric acid, barium carbonate, calcium carbonate, titanium dioxide and zinc oxide. Components are thoroughly mixed, melted, and from obtained mass they prepare granules (frit). Granulated mass with admixture of fireproof clay is subjected to grinding in ball mill. Crushed mass with water (dross) is used for coating blades.

Before coating surfaces are degreased by phosphoric acid and roasted at a temperature of 700° for 3 min. Coating is applied by means of submersion of blade in dross or spraying in an electrostatic field. After application of dross blades are dried and roasted in a furnace at 1030°-1050° for 10-12 min or by currents of high frequency.

Diffusion protective coating is one of the most promising methods. Strength of cohesion of diffusion coatings with basic metal as a result of penetration of applied substance in crystal lattice of protected material considerably exceeds cohesion of other forms of coatings. Furthermore, gradual decrease in concentration of applied substance in depth of coating creates a less sharp change of properties during transition from coated metal to external surface of diffusion layer. For turbine blades of interest is diffusion calorizing, chrome plating, chromecalorizing, molybdenum plating and tungsten plating.

Diffusion calorizing of surface of turbine blades made from nickel-chromium alloys has rather wide application in plant practice. Also used in practice is diffusion chrome plating.

Firm AVRO (United States) applies this method in manufacture of nozzle blades from cobalt-based alloy.

For diffusion chrome plating blades are dipped into retort, filled with mixture of chromium powder, catalyst and inert substance, which prevents sintering of metal, thereby improving condition of circulation of gases in mass of mixture. Retort is heated in furnace and after completion of diffusion cycle it is cooled.

Coatings attain optimum properties with thickness of layer of 0.05-0.08 mm.

To increase wear-resistance of surfaces of blade roots they have recently begun to apply metal spraying by various metals. This is

done with help of plasma-arc torches, developing, as it is known, very high temperature, at which many metals are evaporated. American firm General Electric, for instance, has constructed special installation for metallizing (Fig. 3.16), in which burners are located distance of 70-75 mm from blades. According to firm

optimum layer of coating 0.02-0.07 mm thick can be obtained in just a few seconds, and life of blade with this layer is considerably increased.

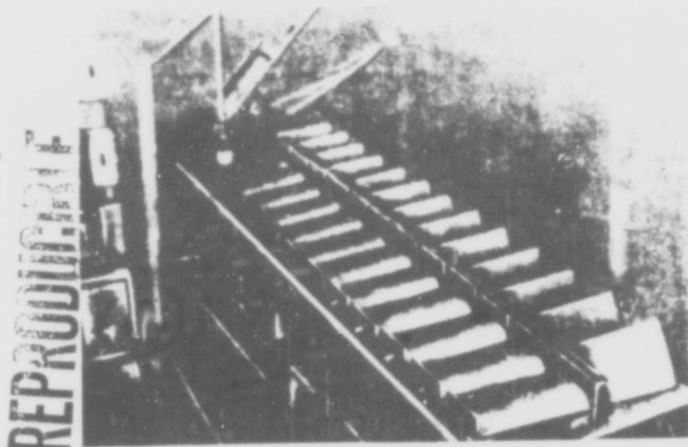


Fig. 3.16. Experimental line of firm "General Electric" for plasma metallizing of blades.

§ 4. EXECUTION OF BASIC OPERATIONS OF WORKING BLADES

Working of Base and Root Surfaces

Turbine Rotor Blades

Base planes on setting boss and root part of blade (Fig. 3.10) are milled, broached and ground. Methods of working should ensure sufficient cleanness of working (6th or 7th class), accuracy of dimensions (3rd to 5th class) and mutual location of planes (parallelism and perpendicularity of planes).

Milling with subsequent grinding are considered basic methods of working setting bases of turbine rotor blades.

During working they try to apply the most productive methods of milling, for instance, simultaneous milling of several parts by a set of milling cutters, continuous milling by face and end mill on vertical-milling machine with round table or on machines of drum type. Simultaneous working of lateral base sides of blades on duplex longitudinal-milling machine is shown in Fig. 3.17. After milling flat sides are usually ground on vertical surface grinding machines, for instance model 3A-756.

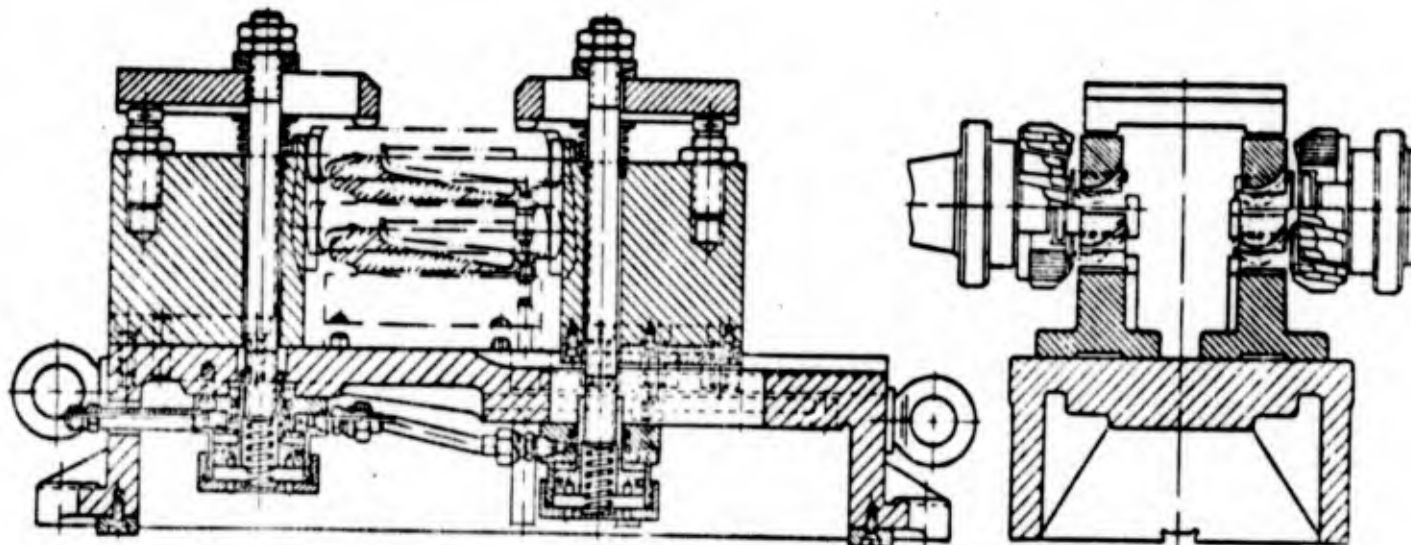


Fig. 3.17. Milling of lateral faces of rotor blades on duplex longitudinal-milling machine.

In model technological process there is anticipated following order of working of base planes. After cutting burr they grind (preliminarily and finally) base planes on back side on root section and setting boss. Then, they simultaneously broach or grind (separately) base planes on bucket side. Then, on a positioner they drill and counterbore hole in setting boss (Fig. 3.18), grind lateral planes on side of inlet and outlet edges. Operations of grinding are executed on vertical surface grinding machines.

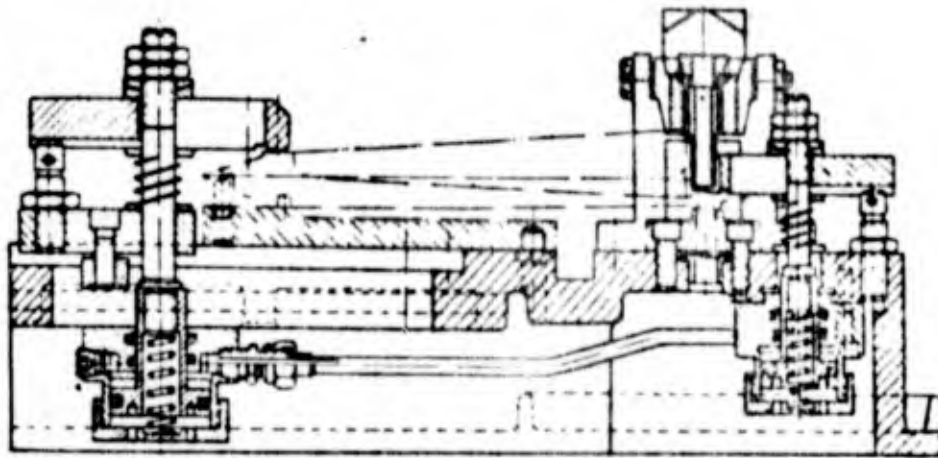


Fig. 3.18. Positioner for drilling and reaming of base hole.

After working of bases they mill inlet and outlet edges, chamfers of bucket and back at root and rough the blade tip. Completing roughing of tip, they again grind or broach base planes on the side of back and bucket in root part and setting boss (reduction of setting bases).

For working bases of blanks with small tip allowances at present they have created special milling-drilling semiautomatic machines with electronic device (ARP) for equal distribution of allowance.

By working of roots it is necessary to give root section not only required form, but also to ensure correct location of root with respect to tip.

Fir-tree root is worked in two stages: first they mill or broach

wedge, and then work root profile.

Milling of root key is executed in two operations: preliminarily and finally. They position and fasten blade in attachment on flat bases (Fig. 3.19).

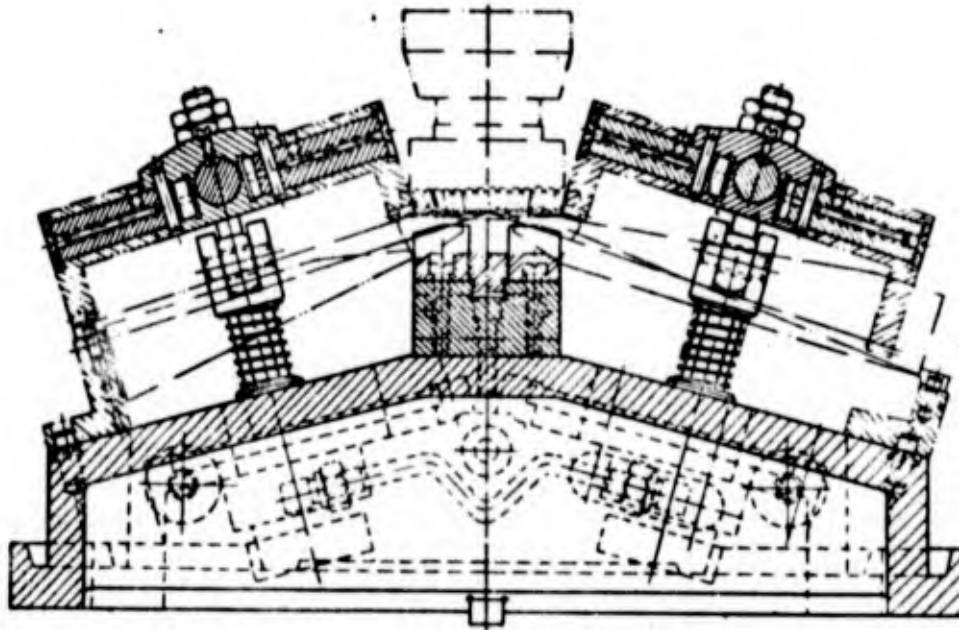


Fig. 3.19. Milling of root key.

During broaching both sides of key are processed simultaneously. Final working of chamfers now is usually combined with working of root profile, but sometimes they are milled on horizontal-milling machine by combined milling cutter (two special angular milling cutters).

Fir-tree profile of root is processed by milling, grinding, broaching, or a combination of these working methods.

Milling is the simplest method of working fir-tree profile of root, not requiring special and complex equipment, which explains its wide application in factories.

Working is conducted (Fig. 3.20) by forming cutter of closed profile by passing method on horizontal-milling machines of increased rigidity. Blades are positioned and fastened on flat bases in holders (Fig. 3.21). Holder with blade is fastened in attachment fixed on

table of machine. Operation is executed in two transitions: first they mill one side of root profile, then holder with worked part is turned around in attachment, and they work the other side. Fir-tree roots of blades of small and average dimensions are milled in one passage, large dimension blades are milled in two passages (preliminary and final).

For blades from alloy of type EI-437 in most plants there is applied cutting speed of 8-10 m/min, feed speed of 12-25 mm/min with cooling by 10 percent emulsion. Regrinding of milling cutters is forced and is produced after working 6-8 blades. Passage milling improves quality of worked surface of teeth (it lowers roughness, work hardening and residual stresses) and increases life of milling cutters. Cleanness of working - 8th class.

High precision of relative location of both sides of root profile is best attained with simultaneous working of both sides of root on mills of type DF-392 (duplex), GF-609 and GF-643 (quarto).

Grinding of fir-tree roots is fairly widespread. This is caused by impairment of workability of blade materials, connected with increase of their heat resistance.

They grind profile by single or multiple-thread profile wheel on general-purpose or specialized machines.

As abrasive there is applied artificial corundum of grain size 60-100 with ceramic bond of hardness SM2 or SM1.

During grinding of blade root on usual surface grinder, cooling may be insufficient, and there may appear grinding cracks. In certain cases besides cooling, introduced by usual means, they fed supplementary liquid coolant to grinding wheel through annular groove in its fitting hole. Such cooling is the most effective. To avoid obstruction of pores of grinding wheel one should equip machine with additional filter.

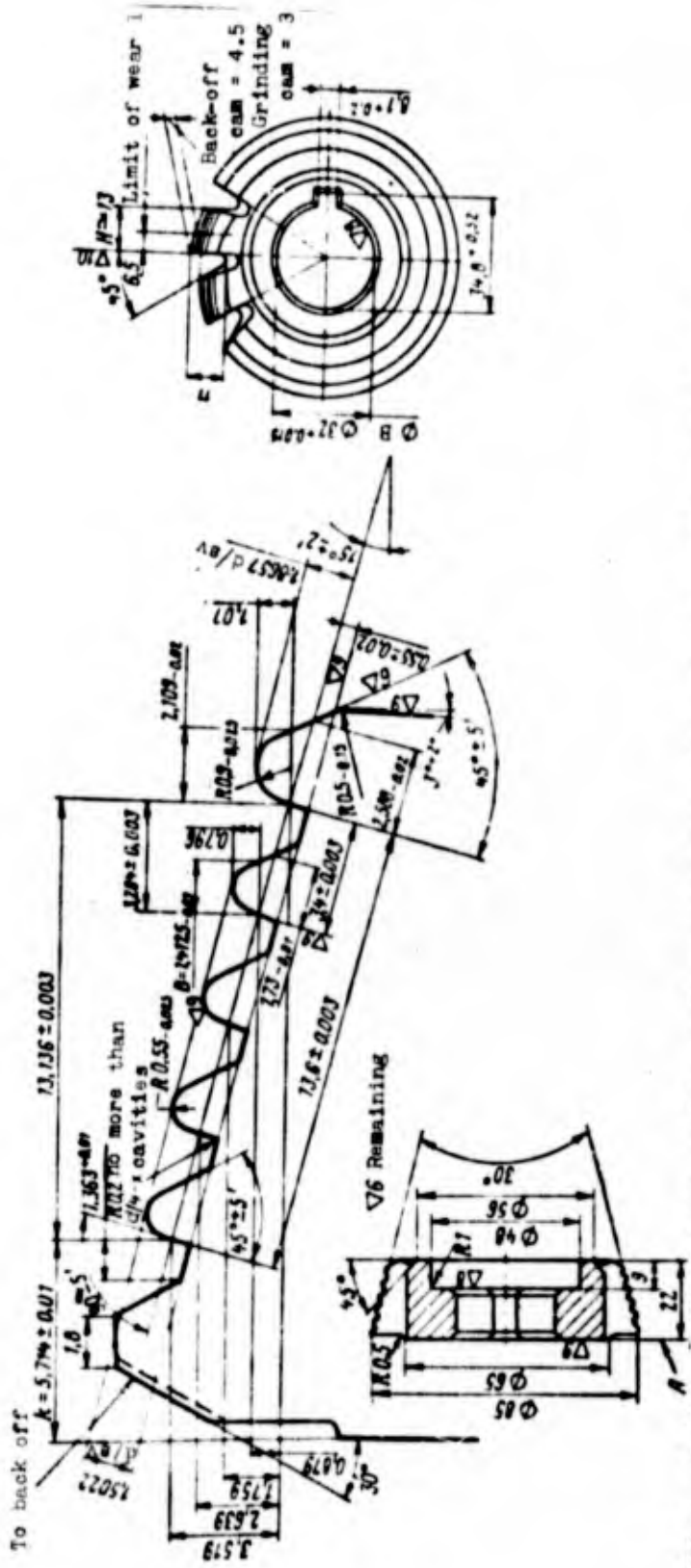


FIG. 3.20. Milling cutter for working fir-tree root profile.

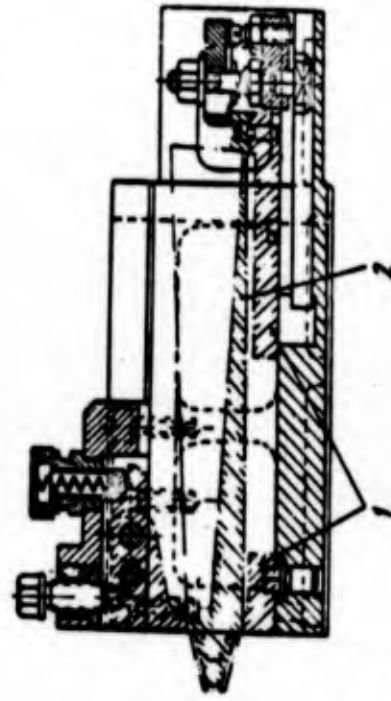


Fig. 3.21. Unified holder for positioning blade during milling of root. 1) removable elements; 2) worked part.

Semiautomatic grinder model MSh-122 is intended for simultaneous grinding from two sides of the fir-tree profile of the root of large-dimension turbine blades (length up to 400 mm). Grinding of blade root can be produced on virgin material or after preliminary milling. Cooling is by sulfurized oil.

Grinding of the fir-tree root of cast turbine blades usually is produced in two transitions: preliminary grinding with removal of allowance 1-2 mm and final, with removal of allowance to 0.7 mm. Roots of blades from alloy type ZhS3 are ground by wheels EB60SM2K and EB60Sm1K, they are replaced after working 1-2 blades. Conditions of grinding: wheel speed 25-30 m/sec, longitudinal feed 15 m/min, transverse feed of wheel (on incision) during preliminary grinding 0.02-0.03 mm/double stroke and during final grinding - 0.005-0.01 mm/double stroke.

To avoid cracks roots of cast blades are ground without cooling.

In certain plants after grinding the bottom of first groove of fir-tree herringbone blade root is work hardened by roller.

Broaching of fir-tree turbine blade roots is done on vertical-drawing and horizontal-broaching machines. For this operation it is more expedient to use vertical-broaching machines with two sliders and a multiposition table. In this case during working stroke of one slide there is produced resetting of blade and preparation for working by second broach, fastened to second slider, which leads to considerable reduction of auxiliary time.

By broaching they successively work wedge of root and fir-tree profile. Fir-tree profile of root is broached by different methods (Fig. 3.22). By generating plan (Fig. 3.22a) fir-tree profile is broached in one stroke of broach with minimum-possible rise on tooth of broach of 0.01-0.02 mm. To decrease influence of elastic

deformations of worked material on precision and cleanness of worked

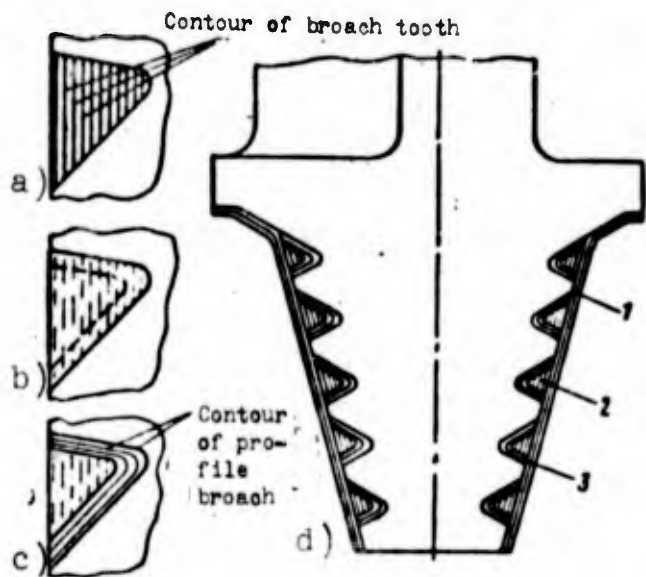


Fig. 3.22. Plans for broaching fir-tree profile of turbine blade root. a) generating plan of cutting in one passage; b) generating plan of cutting (preliminary and final); c) generating plan of cutting (preliminary) and profile (final); d) plan for broaching fir-tree root.

surfaces the root profile is broached by generating plan in two transitions: preliminary and final (Fig. 3.22b). Fir-tree root is broached also by profile plan of cutting, but most frequently, by a combined plan: preliminarily by generating plan, and finally by profile plan of cutting (Fig. 3.22c), which ensures higher precision of root. Accuracy of profile in this case is determined by calibrating teeth of broach.

Blade is fastened by flat bases in attachment with high speed clamp, and root is broached simultaneously from two sides. Broach is composed (up to five sections) of steel P18. Step of cutting teeth 10-15 mm. Broaching is done at comparatively low speeds of cutting 0.5-2.0 m/min, rise per tooth 0.01-0.03 mm.

Average life of broach is not more than 2000-2500 blades till complete wearing out. Cleanness of treated surface is of 8th or 9th class.

Broaching gives high productivity and precision. Decrease of heating of material during broaching as compared to milling and grinding promotes lowering of magnitude of residual tensile stresses in teeth of blade root.

Blades of Nozzles

Surfaces of shelves of upper and lower roots of cast nozzle blades are worked by grinding on general-purpose and special surface grinding machines. In first operations blades usually are positioned by surface of bucket in attachment of holder type.

Special surface grinding machines for working bases of nozzle blades, for instance model BS-200, have electronic device (ARP) for equal distribution of allowance between back and bucket. Presence of ARP in machines gives possibility of applying blank with small tip allowances.

Rotor Blades of Compressor

Working a root of dovetail type. Working of blanks of rotor blades usually starts with working of root. The most productive and economic method of working a root is broaching. By broaching they work all surfaces of root in one setting. Blade is set in holder on back (sometimes on bucket) with support in inlet face of root, surface of boss and underside of root. They fasten blade on bucket side.

During broaching of root there is adopted following cutting plan (Fig. 3.23): first they work face I, then bottom II and, finally,

lateral surfaces III. Combined broach consists of five sections; position of each section can be regulated in the body.

During broaching of roots of blades of steels and aluminum alloys they apply following regimes: speed of cutting

2-5 m/min, rise per tooth 0.02-0.05 mm;

as lubricant-coolant they apply for

aluminum alloys kerosene with addition of

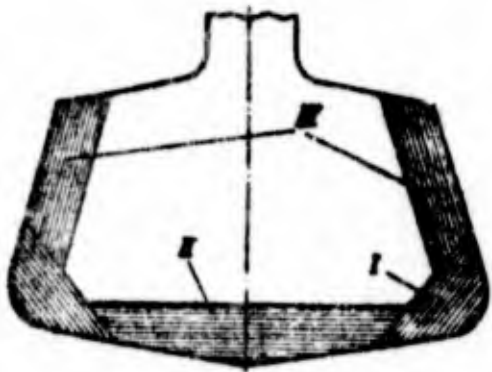


Fig. 3.23. Plan for broaching root of dovetail type.

5% sulfurized oil or 2.5% oleic acid, and for steels — an emulsion. The clean shavings from broaches most frequently by a stream of lubricant-coolant during reverse stroke of broaches.

Roots of compressor rotor blades are broached on horizontal (models 7510, 7520), vertical (model MP-23) and on specialized horizontal continuous action broaching machines (model MP-57) the S. M. Kirov plant in Minsk.

Application of vertical-broaching machines ensures considerable economy of production space and ensures condition for process automation of root broaching.

Horizontal-broaching semi-automatic machine MP-57 has a turning table with two positions — working and loading — and a device ensuring continuous motion of carriages, on which blocks of broaches for working of root, are fixed.

Root of dovetail type is worked on this machine in two positions: first they broach profile of root (lateral surfaces, face and bottom), and then its ends (chamfers) and groove.

During working of root in loading position of turning table they produce removal and installation of parts.

Cleaning shavings from broaches is by hydraulic jet, consisting of a tube, to lateral part of which there are screwed 15 caps with holes.

Fir-tree roots of steel compressor blades are worked basically by broaching.

Auxiliary setting base (boss on tip of blade) usually is worked in two operations: first they mill face of boss, and then drill center of it.

Face of boss is milled on vertical or longitudinal duplex mill simultaneously for two blades. Blade is set in attachment by bucket

profile on support points with bottom of root resting on adapter. Blade is fastened by profile of back.

Center drilling of boss is executed on vertical boring machine. Blade is fastened in positioner by its root. It is most expedient to combine operations of milling tip and centering in one, executing it on semiautomatic milling-centering machine.

In large-lot and mass production working of roots and setting boss of rotor blades is planned on transfer machines.

After working root and setting boss, depending on design of blades, they execute such operations as milling of chamfers (faces) and grooves of roots (set of milling cutters on horizontal mill), drilling of two holes in bottom of root, etc.

Inlet and outlet edges of blades of lengths up to 300 mm with angle of twist to 50° are preliminarily milled on semiautomatic copying machine, model FK-300.

Preliminary milling of inlet and outlet edges normal to profile in sections of compressor rotor blades of lengths up to 600 mm with angle of twist to 60° is carried out on semiautomatic copying machine, model KA-75. Machine is made on the basis of horizontal-mill, model 6N83. Working is produced by cylindrical milling cutters with screw teeth.

Blade and copy are set in chucks of headstock and through center holes are supported by tail-spindles of tailstocks.

Profile of edge is reproduced by hydraulic servo system, controlling vertical shift of console with table.

To obtain an edge, normal to profile in every section, blade automatically turns according to longitudinal feed of milling cutter.

Stator Blades of Compressor

For stator blades with journals they first mill butts of journals, and then center them. Butts are milled by set of two milling cutters on horizontal-mill, and centers are bored on vertical boring machines by positioner.

Milling of butts of journals and their centering is more expediently produced on milling-centering commercial semiautomatic machines, ensuring equal distribution of allowance between back and bucket.

Journals are turned and ground (for steel blades) relative to centering faces.

Lateral surfaces of shelves are usually milled on horizontal-mills by set of two milling cutters. Blade is set in attachment (Fig. 3.24) on plane of shelf, centered by surface of journals and is clamped on centering face or on surface of blade.

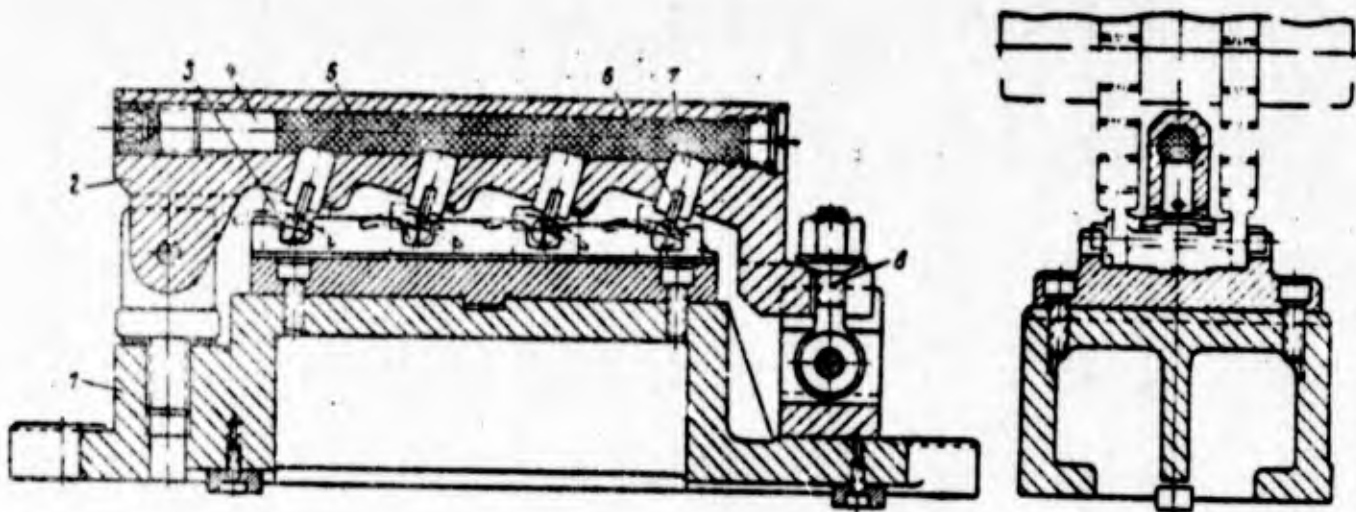


Fig. 3.24. Attachment for milling shelves of stator blades for compressor. 1) body; 2) swing strip; 3) worked blade; 4) plunger; 5) hydrolayer; 6) clamp; 7) plunger; 8) swing bolt.

Threading on ends of journals is rolled or milled on thread-milling machines.

Preliminary milling of inlet and outlet edges for stator blades

of compressor is produced on semiautomatic copying machines FK-300 and KA-75.

Preliminary Working of Tip

Turbine Rotor Blades

Surfaces of bucket and back are processed separately. Due to low rigidity of part these surfaces are usually worked in several operations.

Working of back. Back is usually turned on vertical duplex semiautomatic copying-lathes, models of MK-54 and MK-56 of plant

"Red Proletarian" (Fig. 3.25), having mechanical system of copying. Worked blades in by twos are set on mounting, connected with spindle of machine. Each spindle has its own support and works on a closed cycle, upon completion of which it automatically stops. Feed circuit for each support is independent. Support group consists of

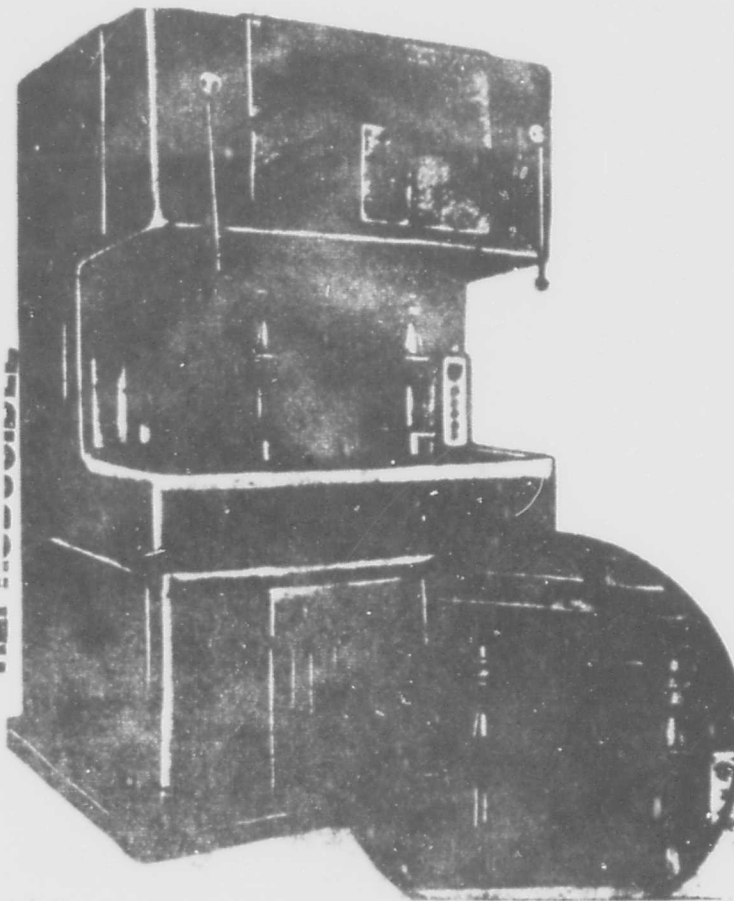


Fig. 3.25. Semiautomatic duplex copying lathe, model MK-56.

carriage, support and pumping tool clamp.

Assigned profile of part will be formed as a result of turn of tool clamp from three-dimensional copies, secured on shafts of spindle group.

Machines of MK-54 and MK-56 have found wide application for roughing and finishing of back, ensuring precision of profile to 0.2-0.25 mm. These machines also permit working of chamfers in root of blade on the back side. Deficiency of machines of this plan during working of back is change of angular position of cutter relative to worked surface in wide range (i.e., angle of cutting), disturbing normal conditions of cutting. For this reason on machines MK-54 and MK-56 it is impossible to work tip of a blade with large angle of twist (more than 25°).

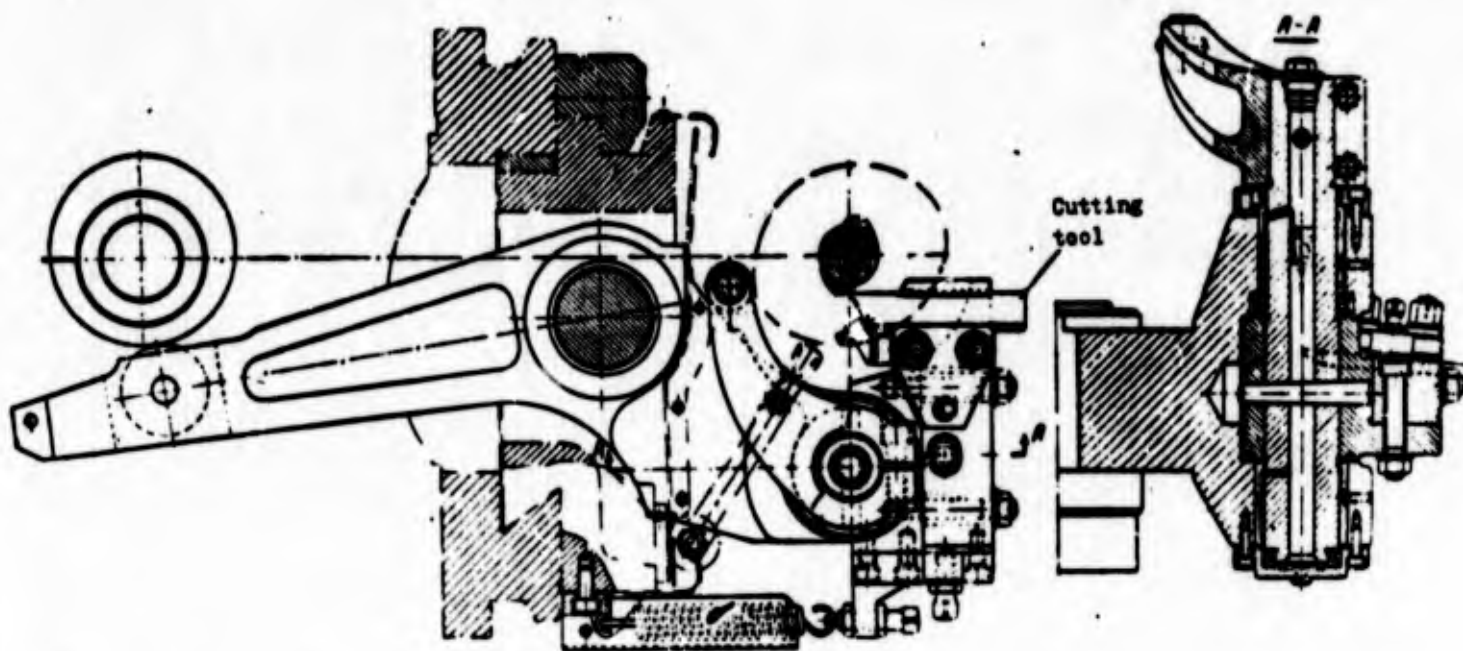


Fig. 3.26. Plan of copier of machine MK-56.

To keep angle of cutting constant in plan of copying lathe MK-255 there is an additional copy, controlling oscillation of cutter holders (Fig. 3.26). However, such a correcting device decreases rigidity of system, which leads to lowering of productivity and

accuracy of working of contour of back, and worsening of cleanness of surface. Therefore, in those cases when profile of tip of blades allows application of rigidly fixed tool, they prefer to work them on machines without correcting devices.

During manufacture of blades from alloys with poor workability by blade tool it is expedient to replace clean turning of back of blade on machines MK-54 and MK-56 by grinding on copying-grinding machines, of models KhSh-65 and KhSh-117.

Working of bucket. Both roughing and finishing of bucket is usually produced by milling with cylindrical milling cutter on copying-

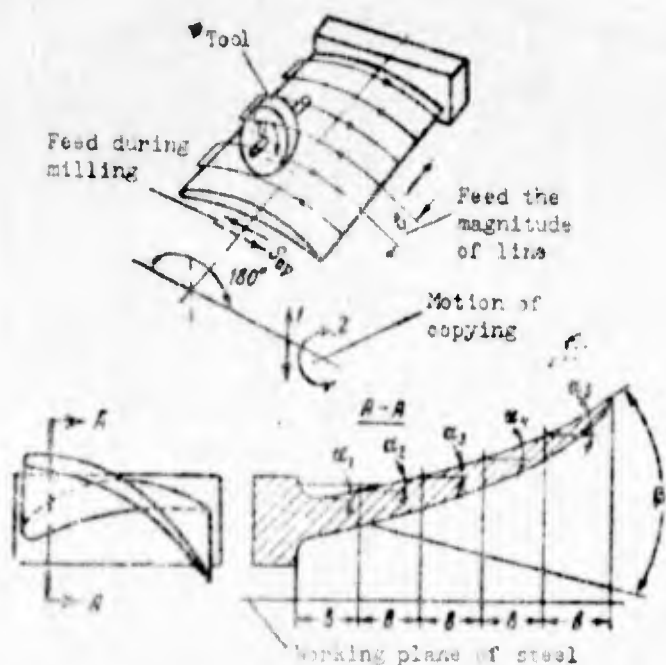


Fig. 3.27. Plan for working back of blade on duplicating mill OF-31 M. [np = trans = transverse?]

mills of type OF-31 and OF-31M by method of wide transverse line (Fig. 3.27). This method is based on condition that curvature of any section of worked surface along axis of part is small, and longitudinal generatrices of profile in any selected magnitude of line are near to a straight line, forming with horizon angle ($\alpha_1; \alpha_2; \alpha_3$, etc.) of not more than 20° . The maximum total angle of inclina-

tion of longitudinal generatrices to one another should not exceed 40° .

Machine of model OF-31M has horizontal location of spindle.

Basic copying motions of machine are: vertical shift of blank with respect to milling cutter, turn of blank around axis of cross-bar, ensuring engagement of worked section of profile of tip with cutting edge (generatrix) of milling cutter. This motion is caused

by the fact that longitudinal generatrices of profile of tip may be inclined to horizon, and axis of milling cutter is always horizontal.

Motion of copying of machine is carried out by table, which shifts in vertical guide together with cross-bar. Motion is imparted to table by rods of two hydraulic cylinders, controlled by copier, located on carriage.

Copier consists of two servo systems. Tracking elements of both systems are two independent rollers, spaced a distance apart, corresponding to width of milling cutter, and they follow during working along boundary curves of worked section.

Each roller gives command to corresponding cylinder of copying system. Here, identical shift of pistons of both cylinders corresponds to vertical forward motion of table. Larger shift of one of rods during simultaneous work of two cylinders corresponds to rise of table and simultaneous turn of it about axis of cross-bar.

After rollers of copier pass along whole profile of worked line, there occurs shift of carriage the magnitude of a line and then working of the following, second line.

Control of carriage motion by magnitude of line is carried out by servo device "line."

On machine three cycles of automatic work are possible:

1) two-way cycle - milling of blank is carried out with movement of table to the left and to the right;

2) cycle of passage milling - cutting is carried out during movement of table to the right; during movement of table to the left motion is accelerated;

3) cycle of encounter milling - cutting is carried out during movement of table to the left; during movement of table to the right motion is accelerated.

Bucket is milled on machines OF-31M by lines from 10 to 40 mm depending upon angle of twist of tip. Magnitude of pitch on tip, appearing during working by lines, depends on correctness of selection of width of milling cutter and accuracy of operation of copy valves. Pitch usually should not exceed 0.05-0.15 mm.

Machine ensures precision of tip working of up to 0.15 mm and roughness of surface within 5th class.

Blades of Nozzles

Preliminary working of tip of nozzle blades is basically carried out by the same methods and on the same equipment ^{as/} turbine rotor blades.

For nozzle blades of forged alloys (EI437A, and others) back and bucket are worked separately. Bucket or back are usually milled by cylindrical milling cutter by method of transverse line on duplicating mills of type OF-31M and FT-250. If profile of bucket is formed by rectilinear generatrices, they work it by cylindrical milling cutter by transverse line the length of tip of blade (width of milling cutter is up to 200 mm) without rocking on semiautomatic copying duplex mill of type FT-250. Back of tip is sometimes worked on copying lathes MK-56.

Tip of nozzle blades from casting alloys, as a rule, is ground by abrasive wheel or abrasive belt.

For rootless nozzle blades, having constant profile the length of blade, back and bucket are ground separately on surface grinding machines with copier of type MSh-81 and MSh-82. Tip is ground along blade by profile wheel of width 125 mm, which is guided by special profile cutter.

Tip of two-root nozzle blades is preliminarily ground either by abrasive wheel on copying-grinding machines KhSh-117 and KhSh-123 (only back is worked) or abrasive belt on copying-grinding machines

KhSh-185M (for bucket), KhSh-186 and MV8851A (for back).

Rotor and Stator Blades of Compressor

Milling. Preliminary working of tip of rotor and stator blades of compressor is executed in most cases by milling. Basic methods of milling of compressor blade tips are the following.

Circular milling of a blade tip by narrow transverse lines (width of line up to 15 mm) is produced on specialized or turret lathes (Fig. 3.28).

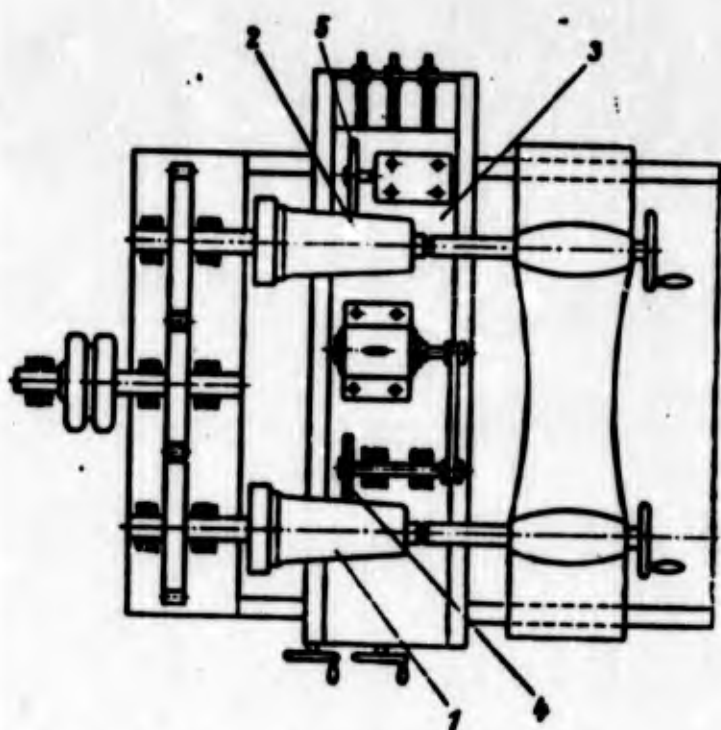


Fig. 3.28. Diagram of milling of tip of blade by narrow transverse lines.

Worked blade 1 and copy 2, located on the same axis or parallel, rotate with identical speed. On transverse carriage 3 of longitudinal support there are fixed milling head with three-sided milling disk 4 and stanchion with roller 5, accomplishing reciprocating motions in transverse direction during continuous longitudinal movement of support.

Conditions of milling of tip of blades from aluminum

alloys are the following: cutting speed 200-250 m/min; feed 0.05 mm/tooth; for steel blades conditions, accordingly, are 20-30 m/min and 0.05-0.2 mm/tooth.

Method of circular milling by narrow helical transverse lines is widely applied in factories. Its basic merit is the simplicity of the copier. During circular milling warping of tip considerably decreases, since tip is worked from one installation and allowance is

taken from both sides of tip simultaneously and more or less uniformly. By given method it is possible to work blade with great twist.

However method of circular milling also has essential deficiencies:

1) it requires gap-free engagement of gears; appearance of gap sharply lowers precision of profiling;

2) twisting of tip of blade from force of cutting affects precision of working.

To decrease influence of twisting working of long tip of blade should be conducted simultaneously from two sides;

3) low productivity;

4) for one turn of blade speed of tracking and magnitude of feed per tooth very in considerable range, thereby worsening quality of surface layer and roughness of worked surface.

Separate milling of bucket and back of tip of blade by wide transverse lines on copying milling machines of type OF-31M. Width of line, determining number of passages, and consequently also productivity of work of machine, depends on shape of blade. The greater the twist of the tip, the narrower the line. Surface of back or bucket are most frequently milled in several transverse lines.

Separate milling of bucket and back of fin of blade by narrow transverse lines. This method of copying is used as the basis for eight-and four-spindle duplicating milling machines of type 8KFL and 4FKL and practically does not differ at all from separate milling by wide lines.

Separate milling of bucket and back of tip of blade by longitudinal lines is done on four-spindle semiautomatic copying machine of type 4FPL-M by milling disk, located at an angle of 45° to worked surface.

In machine 4FPL-M there is applied hydraulic system of copying. Copying motion is vertical shift of table relative to cutting tool.

Advance during milling is carried out by transverse motion of block with milling heads along its guides. Advance on line occurs automatically by longitudinal shift of table and is ensured by mechanism of line advance.

Width of longitudinal line is determined by profile of tip of blade and has different values in various sections of tip depending upon its curvature.

Circular milling of blade tips by longitudinal lines is executed on machines of firm Exello and similar ones. Milling disk, located at an angle of 45° , moves along axis of blade tip. After every line mechanism of machine turns blade for milling of following line until full turn of blade is completed. Milling continues during forward and reverse motion of carriage of machine with blade.

Separate milling of back and bucket of blade gives possibility of introducing additional supports under the side of tip not being machined, thereby increasing its rigidity.

Deficiencies of methods of separate milling are warping of blade tip, which appears during one-sided alternating removal of allowance from blank, and also additional error of working, connected with re-setting of blade from one setting base to another.

Semiautomatic copying-mills of models FSL-1 and KA-65 are more productive and free from above deficiencies for simultaneous working of bucket and back, including slanting sections for root of rotor and stator blades of compressor.

FSL-1 -- eight-spindle mill; back and bucket are milled by longitudinal lines simultaneously for 4 blades of lengths up to 300 mm with angle of twist up to 30° .

KA-65 — four-spindle machine is intended for simultaneous working of back and bucket of two large blades, of lengths up to 600 mm with angle of twist up to 60° .

Finishing of the Tip of Turbine
and Compressor Blades

Grinding of Tip

In the typical existing technological process after roughing of tip they anticipate grinding in two operations — preliminary and final. Then profile of tip at root is finished (manually) on polishing mandrels and finally the grind back and bucket by abrasive belt. Surface of back and bucket for turbine rotor blades are ground separately.

Grinding of back of tip of blade by abrasive wheel. Non-ruled surface of back of blade tip is worked by a wide profiling disk on copying-grinders of type KhSh-65, KhSh-117 and KhSh-123 of Kharkov Machine-tool Plant.

These machines work by method of rolling: assigned form of surface will be formed as the envelope of the series of consecutive positions of profile of tool. Profiles of tool and worked part here are interlinked.

Profile of back of tip is ground by incision of wide abrasive wheel (Fig. 3.29), kinematic connected worked piece by gear ratio of 2:1 or 4:1. Every section of surface of back is worked by a corresponding section of the wheel. On machine it is possible to simultaneously work two (gear ratio 1:2) or four (gear ratio 1:4) blades, depending upon their form. Worked blades are fastened on mounting, which is set in centers of machine. Machine has longitudinal feed, and a special mechanism serves for profiling of wheel.

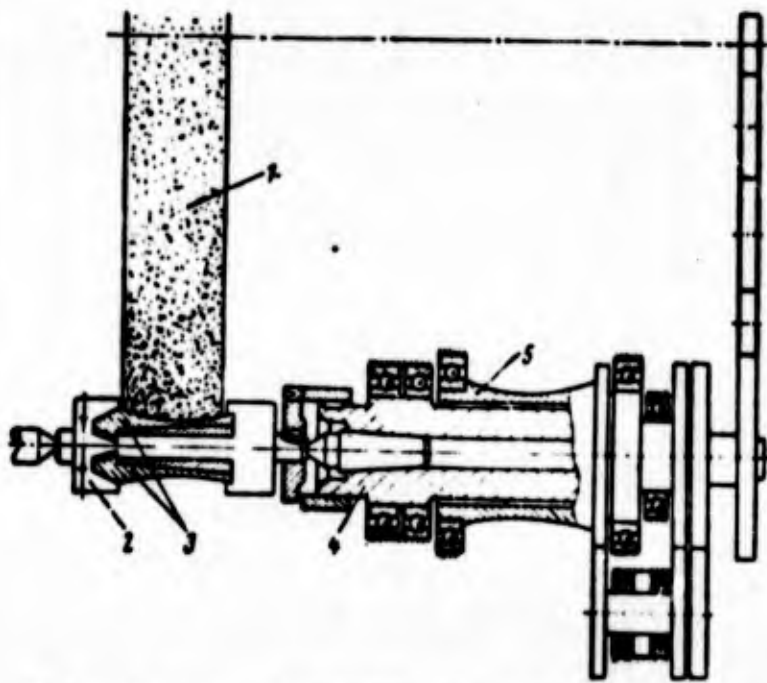


Fig. 3.29. Diagram of conjugate grinding of back of blade tip on machines of type KhSh. 1) three-dimensional grinding abrasive; 2) mounting; 3) blades; 4) spindle of headstock; 5) three-dimensional master form.

Three-dimensional master form, designed only for profiling of wheel, is ground by method of reverse copying from standard blade, fixed on the mounting (Fig. 3.30). For this on mounting 3 they set standard blades 2, press to them thrust blade 4 of arc-shaped profile, corresponding to average radius of abrasive wheel 8 of the head, which produces master form 1.

During rotation of mounting and longitudinal shift of table thrust blade 4 obtains necessary motions, which through lever 5,

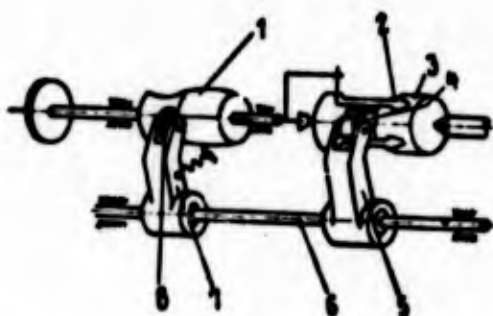


Fig. 3.30. Profiling master form of machine of type KhSh. 1) master form; 2) standard blade; 3) mounting; 4) thrust blade; 5) lever; 6) shaft; 7) lever; 8) abrasive wheel for grinding master form.

shaft 6, lever 7 are transmitted to abrasive wheel 8. In process of grinding master form mounting 3 should rotate about form with gear ratio 1:2 or 1:4.

After termination of working of master form abrasive wheel of head is replaced by tracking roller, diameter and radius of curvature of which are equal to diameter and radius of curvature of abrasive wheel of head. In place of thrust blade 4 they set hard-alloy roller or diamond for profiling the wheel (Fig. 3.31).

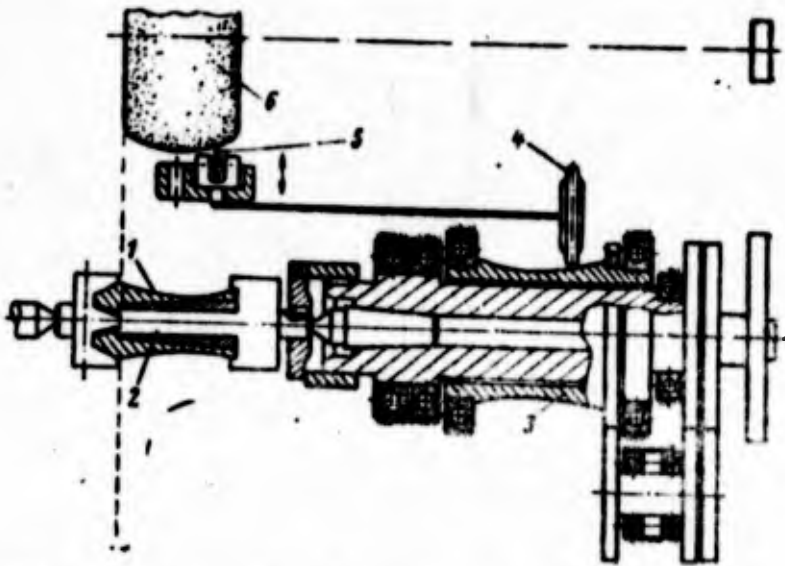


Fig. 3.31. Profiling of abrasive wheel. 1) blade; 2) mounting; 3) master form; 4) roller; 5) hard-alloy roller or diamond; 6) abrasive wheel.

During rotation of master form and longitudinal shift of table with profiling mechanism roller 4, resting on form 3, transmits to governing tool 5 motions, necessary for profiling of abrasive wheel 6.

Profile of form, just as of abrasive wheel, corresponds to only one blade.

Machines KhSh-117 and KhSh-123 ensure high productivity, cleanliness of worked surface of 6th class and precision of profile of back 0.2-0.3 mm.

Deficiencies of these machines are the following:

1) during grinding by wide wheel there appears large centrifugal force, which lowers accuracy of working of tip of blade;

2) complexity of finishing of master form during setting up of machine;

3) on sections of blade tip, where curvature of profile of back is small and is almost a straight line (at trailing edge), abrasive wheel crumbles more rapidly than on curved sections. This is explained by the fact that rectilinear section of blade tip corresponds to smaller length of arc on grinding wheel than curved section.

Irregularity of wear of abrasive wheel causes its frequent truing.

For grinding by wide abrasive wheel of back of rotor and stator blades of compressor the Kharkov Machine-tool Plant created semi-automatic grinding copier, model KhSh-116. Diagram and principle of its work are analogous to machines KhSh-117 and KhSh-123.

Grinding of tip by abrasive belt. Final grinding of tip of turbine rotor blades is produced by abrasive belt on copying belt grinders.

Grinding by abrasive belt has a series of advantages as compared to grinding by abrasive wheel:

1) elastic abrasive belt ensures uniform removal of allowance over all the ground shaped surface of part;

2) speed of belt does not depend on wear, whereas during wear of abrasive wheel its diameter decreases, which affects precision and effectiveness of working;

3) working surface of belt can be several larger than working surface of wheel, which gives possibility of increased productivity and improved cooling conditions;

4) grinding by abrasive belts with cooling by mineral oil and emulsion in most cases is accompanied by appearance in surface layer of part of compressive residual stresses, whereas during grinding by wheels there chiefly appear tensile residual stresses;

5) replacement of belts is easier and simpler than replacement of wheel; belts are safe to use.

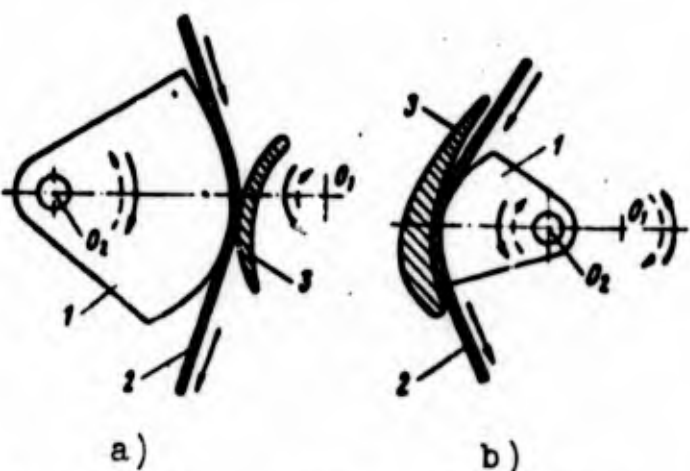


Fig. 3.32. Diagram of grinding of blade tip by abrasive belt. a) working of back; b) working of bucket; 1) cam; 2) abrasive belt; 3) blade.

Surfaces of tip are ground by belt by method of rolling with help of copying cams (Fig. 3.32). Rolling of tip of blade by cam is produced either by oscillation of part and cam about fixed axis, or as a result of planetary motion (oscillation) of part about fixed cam.

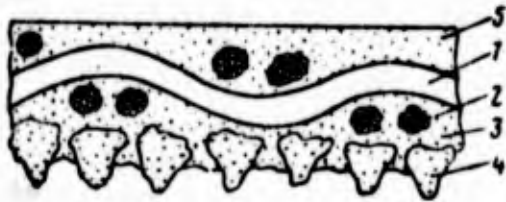


Fig. 3.33. Diagram of structure of abrasive belt with electrostatic application of grains (per K. S. Mitrevich). 1) base; 2) weft; 3) glue bonding; 4) abrasive grains; 5) dressing.

Abrasive belt (Fig. 3.33) consists of a fabric (serge, diagonal [?], coarse calico) base, to one side of which is glued abrasive, and other is impregnated with dressing. Material of abrasive grains is artificial corundum (white - EB or normal - E).

During manufacture of water-resistant tapes they apply for bond synthetic resins on a phenol base, various varnishes (YaK-1, nitroglyptal No. 754, and others), liquid glass.

Most widely used in blades are close-grained belts, for which thickness of layer is 1.5-2 times diameter of grain.

Granularity of abrasives is selected according to allowance and required cleanness of working. Thus, for clean grinding they apply belts with granularity 14-120 (most frequently with granularity 46-60). For final grinding and polishing they use a belt of granularity 120-320. During working by belts there is attained cleanness of 7th or 8th class.

During grinding of alloyed and heat-resisting steels optimum speed of belt is 25 m/sec, specific pressure 2.5-3.0 kg/mm² ($\approx 2.5 \cdot 10^5$ to $3 \cdot 10^5$ newton/m²).

Life of abrasive belt, depending upon adopted conditions and conditions of working, is 2-3 hours. The most intense removal of metal is observed, moreover, in first 30 minutes of use of belt.

Grinding of blade tips by abrasive belts is done by two methods:

a) separate grinding of surfaces of back and bucket by wide abrasive belt;

b) simultaneous two-side grinding of surfaces of blade tip by narrow abrasive belt.

Separate grinding by wide abrasive belt of surfaces of back and bucket is the more productive method. However, in connection with large liberation of heat during grinding by wide belt and deformations of blades during separate treatment of surfaces of tip, this method is inferior in accuracy to working by method of grinding of blade tip by narrow abrasive belt.

Wide abrasive belt is most frequently used to grind back of blades on machines of type KhSh-185, the bucket on machines of type KhSh-186 of Kharkov Machine-tool Plant, and also on machines of Moscow Plant of Jig Boring Machines of type MV-8850 for bucket and MV-8851A for back. Diagram of machine KhSh-185M is shown in Fig. 3.34. Holder with blade is fastened to Table 3, fixed on carriage 2. Carriage accomplishes rectilinear reciprocal motion, imparted by eccentric mechanism 1 of worm gear through pull rod and levers. On rear end of table is fixed gear quadrant, engaged with rack, mounted on corner iron. Abrasive belt 4 envelopes fixed master form 5, having mirror image of form of bucket of blade. When worked blade is brought toward fixed cam belt will cut into part and starts process of working the bucket, in the course of which to blade there is imparted complex motion, consisting of reciprocating motion of carriage 2 and motion of rolling on initial circumference of gear quadrant, imparted to Table 3.

Endless abrasive belt is set in motion by drive pulley 6, which is rotated by electric motor. Position of guide pulleys 7 and 8 is adjusted in such a way as to remove possibility of abrasive belt running off cam during grinding.

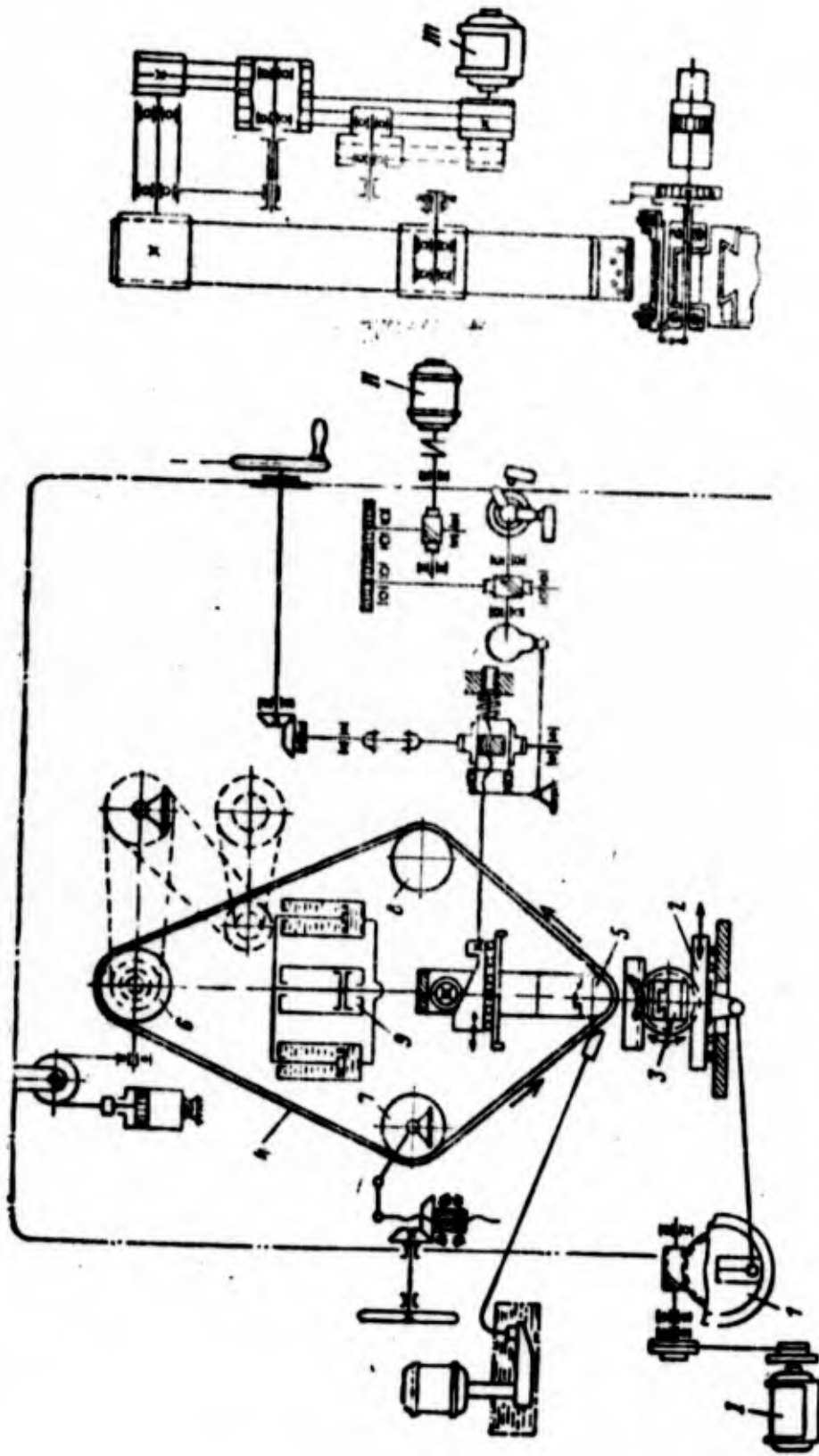


Fig. 3.34. Schematic of machine KhSh-185M. I) electric motor for drive of feed mechanism; II) electric motor for automatic feeding of master form; III) electric motor for drive of abrasive belt.

Advance of master form on worked blade can be manual or automatic. Fast advance and removal of cam is produced by pneumatic cylinder 9, with hydraulic damper to guarantee smoothness of motion of fast advance and removal of the form. Control of fast advance of master form is carried out by two-way stop-cock.

In machine there is provided supply of liquid coolant between blade and belt, and also feed of air under pressure to reverse side of belt through ducts in the master form for improvement of conditions of sliding of abrasive belt over surface of the form.

Narrow belt grinding is by two methods — transverse or longitudinal lines.

During grinding by transverse lines (circular grinding) blade rotates rapidly about its axis and slowly shifts in longitudinal direction. In second method blade rapidly shifts along axis with respect to belt and rotates slowly (feed) after passage of each line. Productivity of grinding by transverse lines is higher than by longitudinal ones, and more considerable than larger curvature and angle of twist of the tip profile. However, accuracy and cleanliness of worked surface here will be worse due to large forces of inertia of fast-rotating blade, leading to its deformation during working.

Tip of blades are ground by narrow belt on transverse lines on belt copying machines of models KhSh-126; KhSh-126A, ShPL-300 and ShPL-600, and on longitudinal lines on machines LSh-1, LSh-1a, Sh-2.

On machine LSh-1 (Fig. 3.35) they finally grind profile of tip of one- and two-root compressor and turbine blades with length of tip up to 200 mm and twist up to 30° .

Worked blade is fastened by root in attachment, fixed on spindle of machine, second tip is supported by revolving center or clamp

mounting of tailstock.

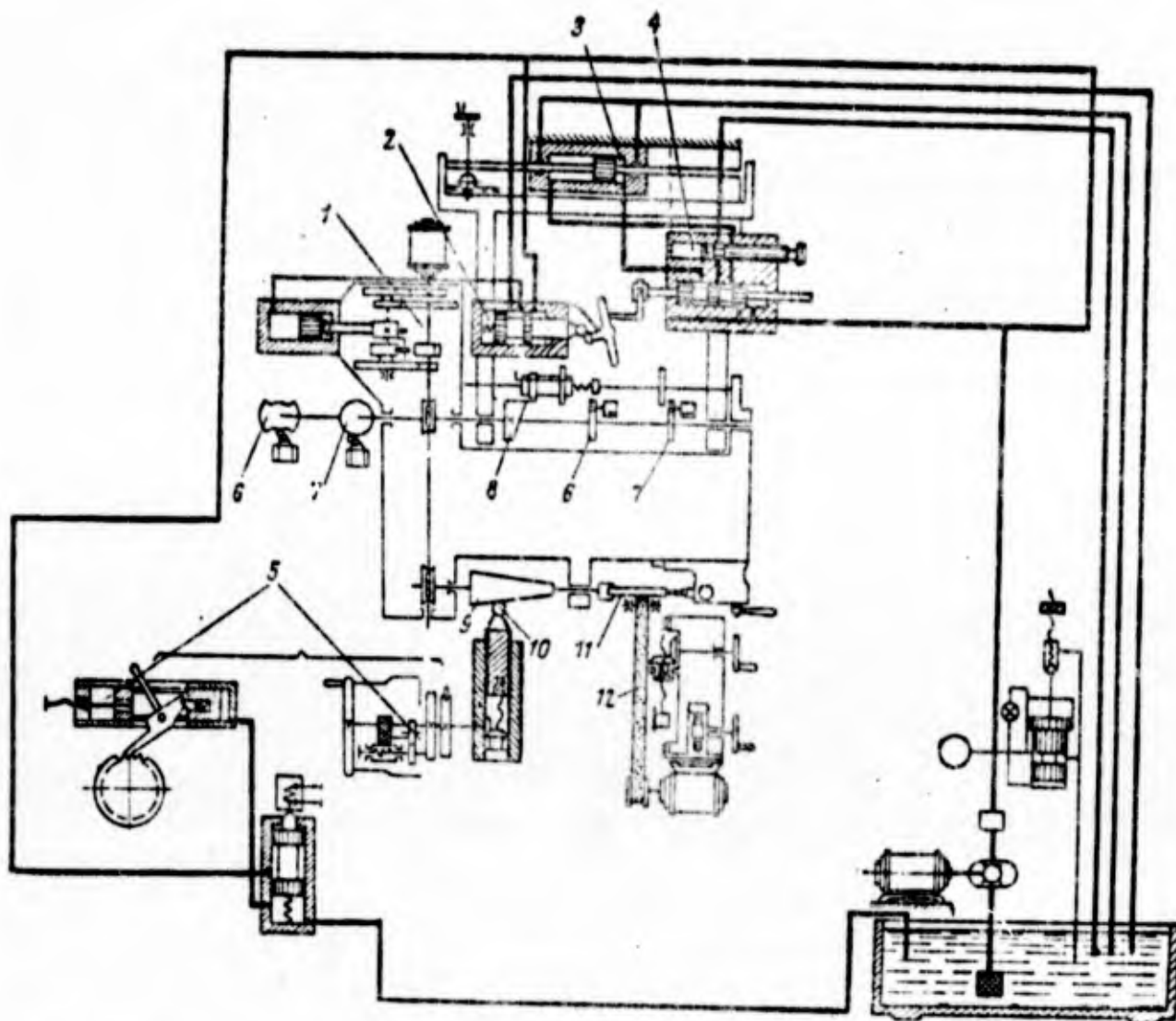


Fig. 3.35. Belt grinding copying machine of model LSh-1. 1) mechanism of line feed and bypass; 2) line feed valve; 3) hydraulic cylinder for longitudinal shift of table; 4) reverse valve; 5) feed mechanism for incision; 6) master form of bypass; 7) form for incision; 8) butt form for working chamfer at root; 9) three-dimensional master form; 10) working roller; 11) worked blade; 12) abrasive belt.

Blade, on same axis with master form 9, accomplishes with its reciprocating motions along axis, simultaneously shifting in direction, perpendicular to axis.

Mechanism of line advance 1 automatically ensures at the end of every movement turn of blade (master form) one step (line).

During work of machine form shifts relative to tracking roller 10, rigidly secured in feed mechanism 5, and forces copying mechanism

together with worked blade to accomplish oscillatory motions, thereby reproducing on blade tip assigned profile.

Uniform rotation of spindle does not ensure constancy of magnitude of feed during working of whole perimeter of contour of blade tip: on section of back and bucket of feed is greater than during working of nose and trailing edges. Irregularity of feeds leads to increased wear of abrasive belt on nose and trailing edge sections. For this reason edges are not worked on machines LSh-1: during passage of edges above belt blade and form are turned faster by special bypass mechanism.

Allowance to the side during preliminary grinding by abrasive belt on machines LSh-1 is from 0.05 to 0.2 mm, and during final grinding to 0.04 mm.

Recommended conditions of grinding for turbine rotor blades from alloys EI617, EI867 and EI929 by abrasive belts STEB46-60 or SUEB46-60 are the following: speed of belt - 25-30 m/sec; speed of piece - 10-14 m/min; angular feed on line 36'-54', transverse feed - 0.07-0.12 mm/turn of blades. Tip is ground with abundant cooling by transformer oil with addition 3-5% oleic acid. Accuracy of grinding profile of tip is up to 0.05 mm; cleanness of surface is 7th class; deformations of blade tip are slight.

Basic deficiency of machine LSh-1 is its low productivity. For instance, time of grinding a blade of steel EI961 with length of tip up to 100 mm and width 40 mm is about 15 minutes.

Principle of work of machines LSh-1a and LSh-2 is the same as machine LSh-1. They are intended for working profile of tip of rotor and stator blades of a compressor. On machine LSh-1a the grind tip of blades up to 200 mm long with angle of twist up to 30°, and on machines LSh-2, of blades up to 300 mm long with angle of

twist up to 50° . Width of abrasive belt on machines LSh-1, LSh-1a is 15 mm, and on LSh-2, 25 mm.

On machine KhSh-126 they grind profile of tip, including chamfered sections and edge of rotor and stator blades of a compressor of lengths up to 250 mm with angle of twist up to 50° . Abrasive belt 20-50 mm wide is applied.

Basic motions of machine are:

1. Motion of abrasive belt from individual electric motor.
2. Rotation of blade from hydraulic motor with variable angular speed within one turn of blade.
3. Longitudinal shift of blades from hydraulic cylinder.
4. Transverse feed (incision), carried out by turn of profiled cam.
5. Turn of belt to profile of blade, carried out from master roller with help of hydraulic device.
6. Removal of blade from belt after termination of cycle of work of machine.

Machine ensures accuracy of grinding of profile of tip of 0.15-0.2 mm and cleanness of surface of 7th class.

Tape-grinding copying semiautomatic machine, model ShPL-300 is intended for circular grinding of profile of tip, including chamfered section and edges, of rotor and stator blades of compressor of lengths up to 300 mm with angle of twist up to 60° .

Grinding is conducted by narrow abrasive belt during passage of worked contour around on a spiral.

Basic motions are: reciprocating shift of table, rotation of piece and incision feed, carried out from hydraulic drive.

In machine there is used mechanical system of copying (inter-connected master forms) by closed kinematic circuit, ensuring

simultaneous commands to profiling motion, so also to motion of turn of roller of abrasive belt (Fig. 3.36).

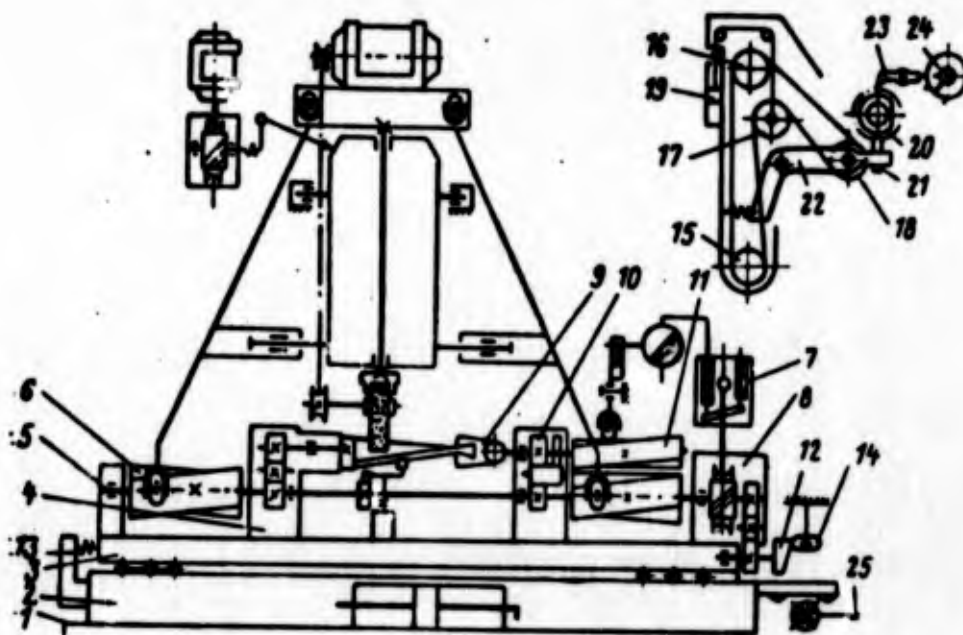


Fig. 3.36. Schematic of machine ShPL-300.

On machine 1 in longitudinal guides there shifts table 2 with carriage 3. On carriage are fixed stanchion 4, in which there is mounted shaft 5, bearing master form 6. Shaft is rotated by hydraulic motor 7 through reductor 8 and transmits it to blade clamp mechanism 9 through gears 10. Auxiliary form 11, synchronously rotating with shaft 5, serves to provide variable angular speed of rotation of blade. Simultaneously cam 12 rotates, which during grinding presses chamfer of root by spring 13 to roller 14, rigidly joined with bed, and imparts to carriage reciprocating motion toward the chamfer.

Grinding head is carried out in the form of a frame. On its left side are mounted four rollers: drive 15, intermediate 16, tightening 17 and working 18.

Abrasive belt is stretched by hydraulic cylinder 19. Feed for cutting is carried out automatically in each reverse of table. Feed mechanism is a profiled cam 20, to which there is pressed thrust

21, secured to lever 22, bearing working roller. The cam is turned by ratchet 23 from servomotor 24. Manual feed can be carried out by turning of handle of crank united to servomotor.

Machine is equipped with device for active control during grinding. Upon removal of all allowance electromechanical transducer sends command to stop machine.

Grinding of profile of tip of bigger compressor blades (with length up to 600 mm) is anticipated on belt grinding semiautomatic copying machine, model ShPL-600. Tip is worked (like machine ShPL-300) on transverse line by narrow abrasive belt, having lined contact with worked surface the width of belt (20-60 mm) with periodic turning of blade.

Polishing

Tip of any blade after grinding is thoroughly polished to produce assigned surface cleanness (8th to 11th class), minimum depth of work hardening and minimum residual stresses in surface layer, which promotes increase of useful life and reliability of work of blades in operating conditions.

For finishing of blade tips they apply the following forms of polishing: mechanical, abrasive-liquid and electrolytic.

Mechanical polishing. At present the most promising method of mechanical polishing is vibrating contact polishing by abrasive belt of compressor blades on machines LVP-3, VPL-3c and VPL-4, and of turbine blades on machines LVP-4.

Machine LVP-3 (Fig. 3.37) is intended for simultaneous polishing of back and bucket of rotor and stator blades of compressor, including oblique chamfer at root of blades of length up to 200 mm with angle of twist up to 25° . Polishing is carried out by complex vibrating motion of blades between two fixed abrasive belts, which

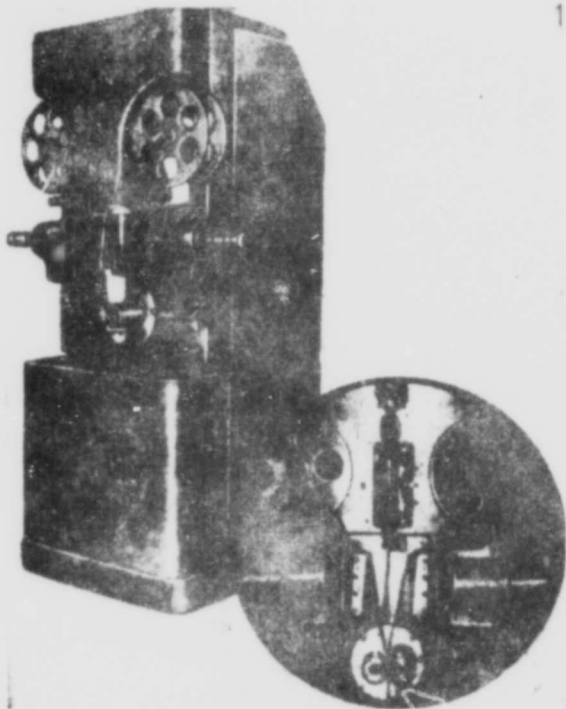


Fig. 3.37. Semiautomatic vibrating contact belt polisher LVP-3.

blade is fixed by root in spring sponges of adapter 9, which are unclasped by plunger 8 under action of oil, fed under high pressure from multiplier 7. Upon starting of machine, under action of a solenoid the piston of four-way valve 12 moves downwards, pump 2 is simultaneously turned on, feeding oil from tank 15 through filter 3 and reduction valve 1 to the valve and further through throttle 14 and valve 13 parallel to it. From here part of oil proceeds through reduction valve 4 to cavities I and IV of cylinders of hydraulic vises 11, and also to upper cavity of multiplier 7. Under pressure of oil the vises, through rubber blocks 10, press abrasive belt to blade. At the same time piston of multiplier moves downwards, pressure in hydraulic cylinder 8 drops, and spring sponges of adapter by their own elasticity clamp blade roots. The other part of oil through valve 6 enters cavity of left cylinder of belt feed, accomplishing

are pressed to tip by blocks, prepared from rubber of brand 922 and Shore hardness 55-65.

Profile of blocks corresponds to profile of back and bucket of blade.

Abrasive belts, reeled from bobbins, are drawn by special feed device. Belt feed devices are rotated by rack, moving under action of two hydraulic cylinders. Rollers can revolve only in one direction, from right to left.

Diagram of machine is shown in Fig. 3.38. Worked

idle motion of rack; roller of belt feed here does not rotate.

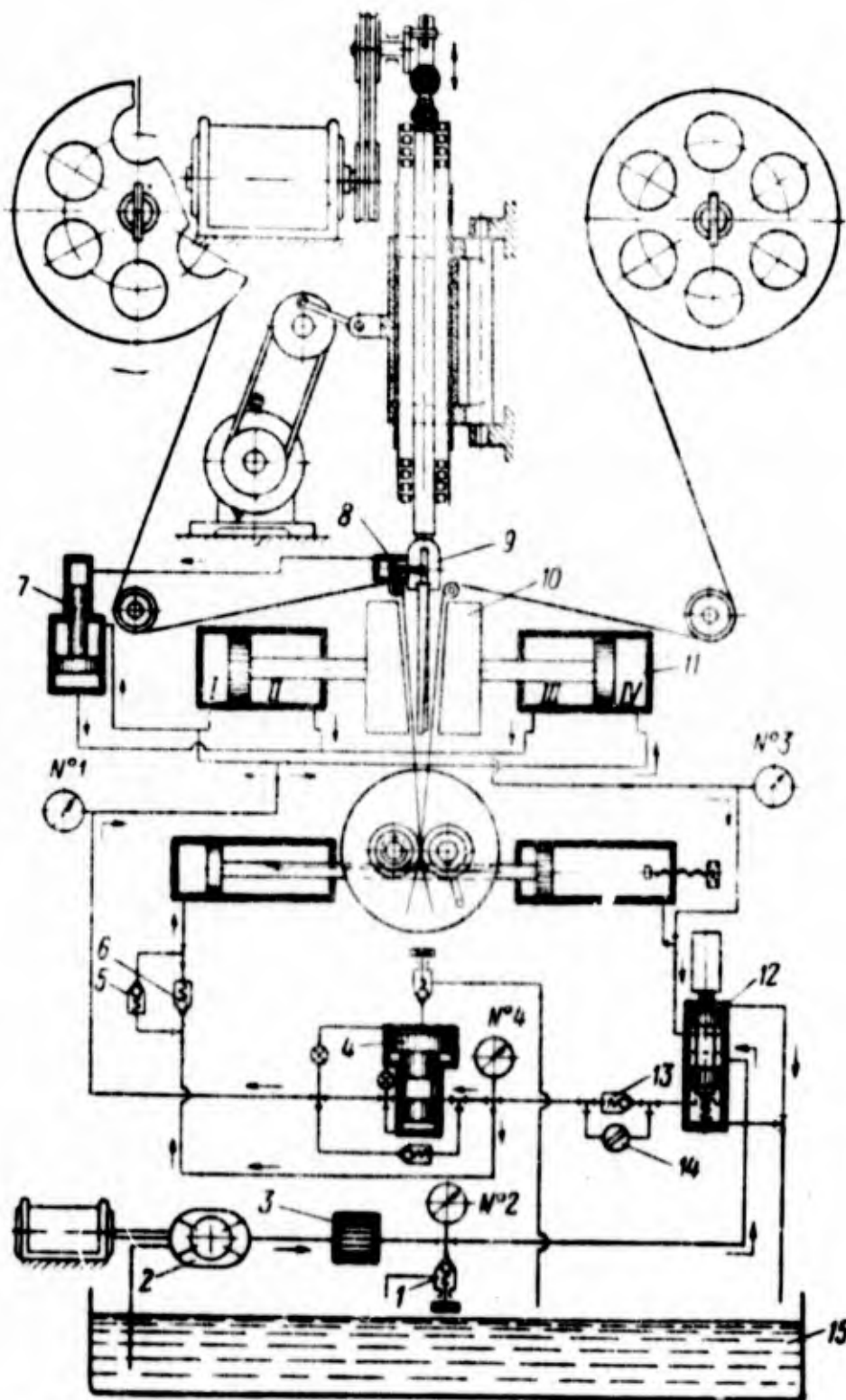


Fig. 3.38. Diagram of machine LVP-3.

Some 1-2 seconds after compression of vises timer switches on electric motors for drive of blade. After termination of polishing this relay de-energizes solenoid of valve 12, piston of valve shifts upwards. Here, oil enters cavities II and III of cylinder of

hydraulic vises, blocks move aside, liberating tip of blade. Simultaneously oil is fed into lower cavity of multiplier 7, thanks to which plunger 8 unclamps sponge of adapter and liberates root of blade.

The most effectively polishing of tip of steel compressor blades is in three transitions. In first transition they use abrasive belt E70, for second transition, belt E150. Both belts are on paper basis (All-Union Government Standard 6456-62). Third transition is produced by tape E220 on a fabric base (All-Union Government Standard 5009-62) with paste of GOI. Total removal of metal from thickness of tip (in the three transitions) is 0.04-0.05 mm.

Productivity of machine with three transitions is 15-20 blades per hour.

Machines LVP-3 ensure uniform quality of finishing of blade tips, eliminate burns and distortion of tip profile, occurring during manual polishing.

Principle of work of other polishing vibrating-contact machines is the same as for machine LVP-3.

Abrasive-liquid polishing. Abrasive-liquid (hydroabrasive or liquid) polishing is used mainly for polishing or "revivifying" blades (during preparation of surface of blades for pickling, before and after luminescent check, to remove scale, etc.). Application of hydroabrasive polishing permits mechanizing of process of finishing and improvement of condition of labor in these operations.

Hydroabrasive polishing can be conducted in different ways. To worked surface under pressure of up to 6 atm(tech) ($\approx 6 \cdot 10^5$ newton/m²) they direct stream of liquid, consisting of mixture of oil or emulsion with abrasive powder — carborundum or artificial corundum. Abrasive liquid can also be fed on part through slits of rapidly revolving

drum (rotating method). It is possible also to polish, revolving processed part in the liquid with abrasive.

Polishing is based on disintegration, filling and smoothing of ridges in processed surface under action of blows of particles of abrasive, having speed of 50 m/sec or greater. Presence of liquid promotes acceleration of process due to chemical-mechanical influence on processed surface.

Polishing is done in chamber of special installation reminding one of sand-blasting apparatus. Processed blade is fixed in special holder with rubber insert for protection from abrasive polishing. Inside the chamber the holder with blade is established between head- and tailstocks. Spindle of headstock has drive from electric motor through reductor. Working fluid from tank by electric pump and flexible hose is fed to injector, to which there also proceeds compressed air.

For polishing the whole length of blade tip carriage with secured injector accomplishes reciprocating motions. Liquid with abrasive in tank is continuously mixed by mixer.

Abrasive liquid is usually composed of 25-50 parts by weight of abrasive grain and 75-50 parts by weight of soda emulsion.

Productivity of liquid polishing for a given metal depends on air pressure and speed of stream, magnitude of grain and concentration of abrasive in liquid, angle and distance of nozzle from processed surface. With increase of magnitude of grain, air pressure and speed of stream productivity increases. Optimum air pressure, depending upon magnitude of grain, varies from 1 to 10 atm(tech) ($\approx 1 \cdot 10^5 - 10 \cdot 10^5$ newton/m²); with granularity of abrasive M28-M20 air pressure is approximately 4 atm(tech) or $\approx 4 \cdot 10^5$ newton/m²; with granularity 100-120 - pressure is 5-8 atm ($\approx 5 \cdot 10^5$ to $8 \cdot 10^5$ newton/m²). Angle of

direction of stream $15-45^{\circ}$; nozzle is located 50-100 mm from processed surface.

Cleanness of surface treated by hydroabrasive method depends on cleanness of initial surface and granularity of abrasive and does not depend on time of polishing. Usually cleanness of surface after polishing is improved as compared to initial state by one class.

In surface layer of blade subjected to hydroabrasive polished, there appear residual stresses of compression.

During abrasive-liquid polishing of blades there are no micro-crack and burns of material, characteristic for mechanical polishing, since process of hydroabrasive polishing occurs in intensely cooled medium. The mat surface of parts, treated by hydroabrasive polishing, facilitates manifestation of different surface defects of material.

Deficiency of liquid polishing is irregularity of removal of metal, preventing wider use of this process.

Working of Tip by Electrical Methods

One promising direction in increasing productivity during manufacture of blades is application of electrical methods of working: electroerosional roughing and electrochemical dimensional machining of blade tips. Effectiveness of application of electrical methods for working tips is caused by poor workability of heat-resisting steels and alloys by cutting.

Electroerosional working. Process of electroerosional (electric pulse) working consists of consecutive excitation of electric discharges between surface of electrode-tool and worked part. Under influence of pulse electric discharges from worked surfaces part of the metal is removed. Workability of material here is determined by its thermal and physical properties and almost does not depend on structure at all. Metal removed from surface is determined by energy,

liberated in working zone. Rate of removal during working of heat-resisting alloys EI437 and EI617, and also aluminum and its alloys is 30-50% higher than for carbon steels. Specific rate of removal for heat-resisting blade alloys per 1 cm² worked surface composes 35-60 mm³/min, which permits us to obtain speed of working of blade by depth of 0.35-0.6 mm/min.

Electroerosional working of blade tips permits us simultaneously to work profile of bucket and back (Fig. 3.39). Initial bank is a

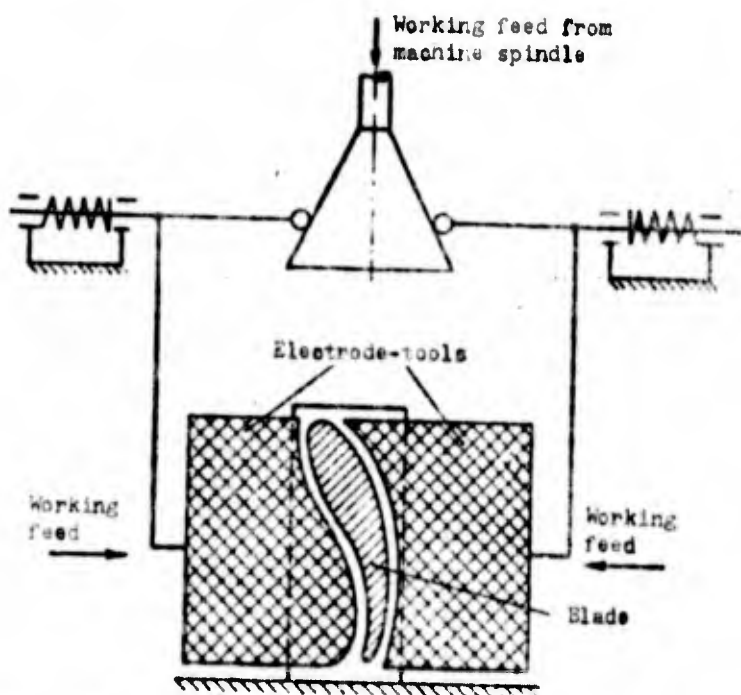


Fig. 3.39. Diagram of electroerosional working of blade.

forged blade with preliminarily treated base surfaces, having allowance for electroerosional treatment by tip profile of 1.5-2.5 mm. Working of blades is carried out on specialized machines of type ME-8 and general-purpose copying-piercing machines of models 473, 4724 and others. Electrode-tool for working profile of tip is usually made from carbonic material

EEG or coke-graphite composition ARV, having very low wear (0.2-1% of volume of metal, removed from worked part) and low manufacture cost.

Working profile of electrode-tools is equidistant curve to reverse image, respectively, of back and bucket of blade, removed from them a magnitude, equal to sum of magnitudes of interelectrode gap, maximum height of microscopic unevennesses and allowance for final working of blade tip. Magnitude of interelectrode gap, depending upon current, is 0.13-0.18 mm. Coke-graphite materials

are well worked by metal-cutting tool. In conditions of experimental plants shaped part of electrodes is prepared by bench work from patterns. In small lot production profiles of electrodes are prepared on copying machines. One electrode without additional correction can work up to 25-30 blades.

As working medium on machine ME-8 they apply transformer (All-Union Government Standard 982-56) or solar oil. During working there occurs contamination of oil by products of erosion and increase of its viscosity, lowering productivity and stability of process. State of working fluid is checked for its viscosity. Replacement of working fluid is made at viscosity above 1.8-2.0 centistokes ($180-200 \text{ m}^2/\text{sec}$) ($t = 50^\circ$). Consumption of working fluid is on the average about 0.6-0.85 litres per kilowatt hour (3600 kilojoule), of energy introduced to working zone.

Electrical conditions of treatment are set by two parameters: average current and idling voltage of generator. Working of blade tips made from heat-resisting alloys usually is produced at idling voltage $U_{\text{idle}} = 20-25 \text{ v}$ (but not below 12 v, since here productivity and stability of process is sharply lowered) and average current intensity $I_{\text{av}} = 3 \text{ to } 150 \text{ amperes}$.

Precision of working is determined basically by electroerosional wear of electrode-tool.

Roughness of surface after electric pulse treatment sharply differs from surface, treated by cutting, and corresponds approximately to 1st to 3rd class. Unevennesses of surface have form of irregularly located holes, the quantity and dimensions of which depend on parameters of electrical conditions.

Surface layer after electric pulse working is part of dissolved metal not removed from surface. It forms as a result of contact of

metal dissolved under action of electrical pulse with working fluid.

Presence in heat-resisting alloys after electroerosional working of changed surface layer 0.15-0.3 mm thick with defects in the form of microcracks and pores lowers their strength characteristics, especially fatigue strength. For this reason such a method of working can be applied only as a preliminary one, with obligatory subsequent removal of changed surface layer. Allowance for subsequent working should be two-three times larger than magnitude of modified layer.

With decrease of electrical conditions cleanness of surface is improved, and thickness of modified layer decreases.

Residual stresses in surface layer increase with increase of depth of modified layer.

After preliminary electric pulse working blades are ground and polished by abrasive belt.

In a series of plants after electric pulse working they practice electrochemical working of tip of turbine rotor blade with subsequent vibration polishing by abrasive belt. Electrochemical working permits complete removal of modified surface layer, formed after electric pulse working in rough conditions. Allowance, left here for electrochemical treatment, comprises 1.5-2.5 mm to a side.

Electrochemical working. Process of electrochemical working, sometimes called electrohydro working, is based on use of phenomenon of dissolution of surface of anode in process of electrolysis. Essence of given method (Fig. 3.40) consists in a stream of electrolyte, flowing with great speed (27-45 m/sec) in gap between cathode (electrode-tool) and surface of anode (blade, during transmission of current of great density intensely dissolving metal from surface of anode (blade).

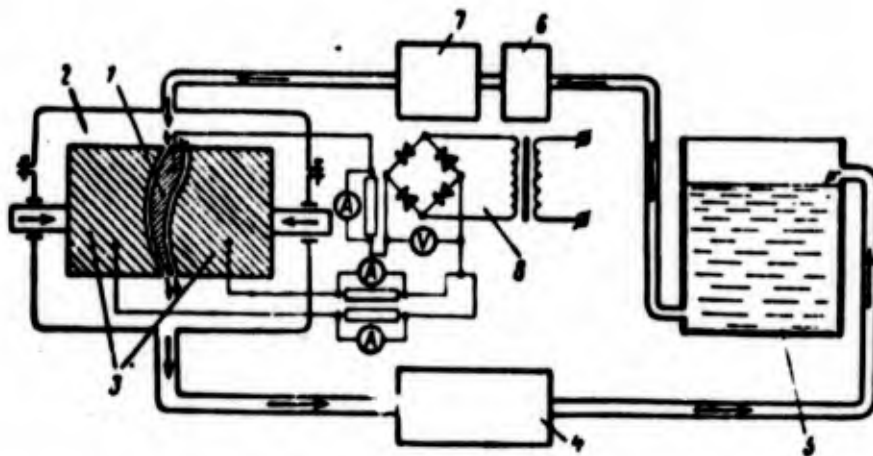


Fig. 3.40. Diagram of installation for electrochemical working of blade tip (EGU). 1) worked blade; 2) working chamber; 3) electrode-tools; 4) centrifuge; 5) tank with electrolyte; 6) heat exchanger; 7) pump; 8) rectifier.

With small distances between electrodes and blade (0.1-0.08 mm) there occurs copying of profile of cathode on anode. The great density of current, which can reach 70-100 amp/cm² or more, promotes increased intensity of removal of metal from anode (blade). Intense circulation of electrolyte between blade and cathode ensures removal of products of anode dissolution, cooling of electrodes and mixing of electrolyte.

Electrochemical treatment of profile of tip of turbine rotor blades is produced on an electro-hydraulic installations (EGU).

Initial blank in certain plants is forged blade with preliminarily worked inlet and outlet edges and base surfaces and allowance for tip profile of 1.5-2.5 mm a side.

Electrodes are made from stainless steel 1Kh18N9T or from brass of LS59 by method of reverse copying from a standard blade with application of reverse polarity on electro-hydraulic installation or by mechanical metal-working. Electrodes in process of work practically do not wear out.

As electrolyte in electro-hydraulic installations they use 10-15% water solutions of chlorine salts, most frequently table salt

(sodium chloride).

Profile of tip of blades from heat-resisting alloys can be worked in conditions: current density 15 amp/cm^2 , voltage fed to worked blade 12 v; density of electrolyte 1.073 g/cm^3 , pressure of electrolyte up to 10 kg/cm^2 ($\approx 10 \cdot 10^5 \text{ newton/m}^2$), temperature of electrolyte $20\text{-}30^\circ\text{C}$.

Rate of removal of metal during electrochemical working of heat-resisting alloys is proportional to current density.

Accuracy of parts depends basically on uniformity of distribution of allowance on surface of worked blade, precision of manufacture of electrode-tool and uniformity of flux distribution of electrolyte around worked surface. By this method it is possible to work blade with thickness of inlet and outlet edges up to 0.15 mm. Roughness of surface of turbine blades, worked by electrochemical method, corresponds to 7th or 8th class.

In many heat-resisting alloys (EI437B, EI617, and others) after electrochemical treatment there is observed corrosion in grain faces a depth of up to 0.03 mm. Depth of corrosion in grain faces is inversely proportional to current density at the end of working. Corrosion of layer is eliminated by subsequent treatment by vibration contact, electrolytic or hydroabrasive polishing.

Microhardness of surface layer in blades treated by electrochemical method does not differ from hardness of initial metal. In surface layer after electrochemical treatment there are also absent residual stresses, since process of electrochemical treatment is not accompanied by plastic deformations and liberation of heat.

Working tip of turbine rotor blade (length up to 250 mm) with allowance up to 2-3 mm a side takes 12-17 minutes. Power of installation for working one blade is approximately 75-100 kilowatt.

During electrochemical working of blade tips there is no necessity for complicated copying metal-cutting machines, a cutting tool of high-quality high-speed cutting steels. Time of preparation of production during transition to manufacture of blades of other structural forms is sharply reduced.

Electrolytic polishing. Electrolytic polishing is one of the varieties of electrochemical treatment of metals, using dissolution of surface layers of anode in process of electrolysis. During anode dissolution of metal in corresponding electrolyte on surface of polished part there will be formed a viscous film of salts, protecting microcavity from action of current and not preventing dissolution of projections, as a result of which roughness of surface is smoothed (polished).*

Microroughnesses of electropolished surface are in direct dependence on initial state of surface and quality of polished metal. The higher the initial cleanness of surface, the faster and better is the electropolishing. To obtain by electropolishing cleanness of surface of 10th or 11th class (All-Union Government Standard 2789-59) requires preparation of initial surface by 7th or 8th class. Structural discontinuity or presence in metal of nonmetallic inclusions (slag, oxides, sulfides, breaks of structure) sharply show up during electropolishing. Polyphase alloys complex in structure, polish worse than pure, uniform, single-phase metals and alloys.

Dissolving surface layers of riveted metal, smoothing roughness of surface, removing or redistributing residual stresses in surface layer caused by preceding working, electropolishing improves

*L. Ya. Popilov. Electrical and ultrasonic working, Mashgiz, 1960.

operational properties of processed parts: corrosional stability of surface is noticeably increased, stress-rupture fatigue strengths increase. However, here one should consider that electropolishing does not impart to metal additional strength, but only creates conditions allowing fuller realization of potential strength, determined by nature of metal. Observed increase of strength is the result of improvement of microgeometry of surface due to removal of plastically deformed surface layer and sections of concentration of stresses. At the same time incorrect conditions of electropolishing can sharply lower strength due to corrosion of metal boundaries.

Electropolishing is used in series of domestic and foreign engine-building plants. For instance, in factory of firm Rolls-Royce (England) completing operation of manufacture of turbine blades is electropolishing of the tip.

Technological process of electropolishing of the tip of turbine blades is as follows. Blades to be polished are thoroughly degreased. Unpolished sections of blade are protected by layer of varnish. Then blade is set in special attachments (suspension), which are suspended in electrolyte on cross beams which are the anodes.

Polishing of blades from most nickel alloys is usually produced in sulfur-phosphorous or sulfur-phosphorous-chromium electrolytes, consisting of a mixture of sulfuric and orthophosphoric acids and mixture of crystalline chromium anhydride.

Electrolyte is filled in bath of sheet lead or heat-resistant vinyl plastic. Bath is equipped with preheating (vapor or electrical) and ventilation device.

Electropolishing of blades is produced in conditions: temperature of electrolyte 15-30°C, current density 40-80 amp/inch². Duration of treatment depends on magnitude of polishing allowance. During

electropolishing from worked surface there is removed layer of metal up to 0.05 mm.

As source of direct current for electropolishing they most often use standard low-voltage generators, produced for electroplating purposes, solid-state (selenium or copper-oxide) and mechanical rectifiers.

During electropolishing of blades there is nonuniform removal of metal on separate surfaces of tip (on edges a greater removal than on middle of contour of tip) which to considerable measure limits its wide application in engine-building plants.

§ 5. AUTOMATION OF PRODUCTION OF BLADES

Large production of blades combined with raised requirements on their quality causes necessity of wide application during manufacture of blades of special and specialized machines and automatic transfer machines.

Complex mechanization and automation promotes increase of labor productivity, radical improvement and easing of working conditions, increase of quality, reliability and operation life of engines, eliminating the subjective factor during fulfillment of every operation of technological processes of manufacture of blades. Below are descriptions of technological processes of manufacture of blades on automatic, which have been introduced into production.

Automatic Transfer Machines for Producing Compressor Blades

Automatic transfer machines for manufacture of compressor and turbine blades both operative, and newly created, due to complexity of form of parts and required precision, are not constructed for whole complex of working -- from blank to ready article. They are designed for separate working of roots and tip. The first automatic lines were created for working root surfaces of blades of compressor simpler than the herringbone root of rotor blades: roots of dovetail type for rotor blades (automatic transfer machine AL-1), prismatic roots (AL-3), shelves and journals (AL-2), for stator blades.

Developing the technological process of working blades on a transfer machine, it is necessary to be guided by following basic propositions:

- 1) all operations of the transfer machine should be identical in time of fulfillment. If operations are different in time, the rhythm

of work of the line in this case will correspond to the most prolonged operation. Efficiency of an automatic transfer machine here will decrease;

2) conditions of cutting for operations of an automatic transfer machine are designated from the condition of obtaining life of cutting tool of not less than 7 hours, which ensures continuous work of line during replacement. If this condition is impracticable, they apply a tool with life of not less than 3.5 hours. For reduction of replacement time for blunted tool its correcting should be produced outside the line.

Automatic transfer machine AL-1 (Fig. 3.41) multirange, rectilinear type, consists of nine positions for serial-parallel working of root surfaces. Every position is equipped with automatic heads with corresponding tool caps or machines built into the line. Line has a rod pulsating conveyor, transferring holder with worked blade from one position of treatment to the next.

After fulfillment of all operations holder with worked blade proceeds to table, which lowers and transfers holder to return conveyor. By this conveyor blade holders pass to front table, lifting them to initial position. Blade is clamped in holder and is freed after working automatically. On line in rotation are 18 holders - 12 on upper and 6 on lower conveyor. There is foreseen checking enroute, excluding disturbance of switching sequence of separate mechanisms and preventing rejects. Signal equipment on main control panel gives possibility to rapidly detect place of damage. Every position of machine is supplied by individual set-up control panel. Upon necessity work of line can be stopped by pressing one of the emergency push buttons, located in several places of the line.

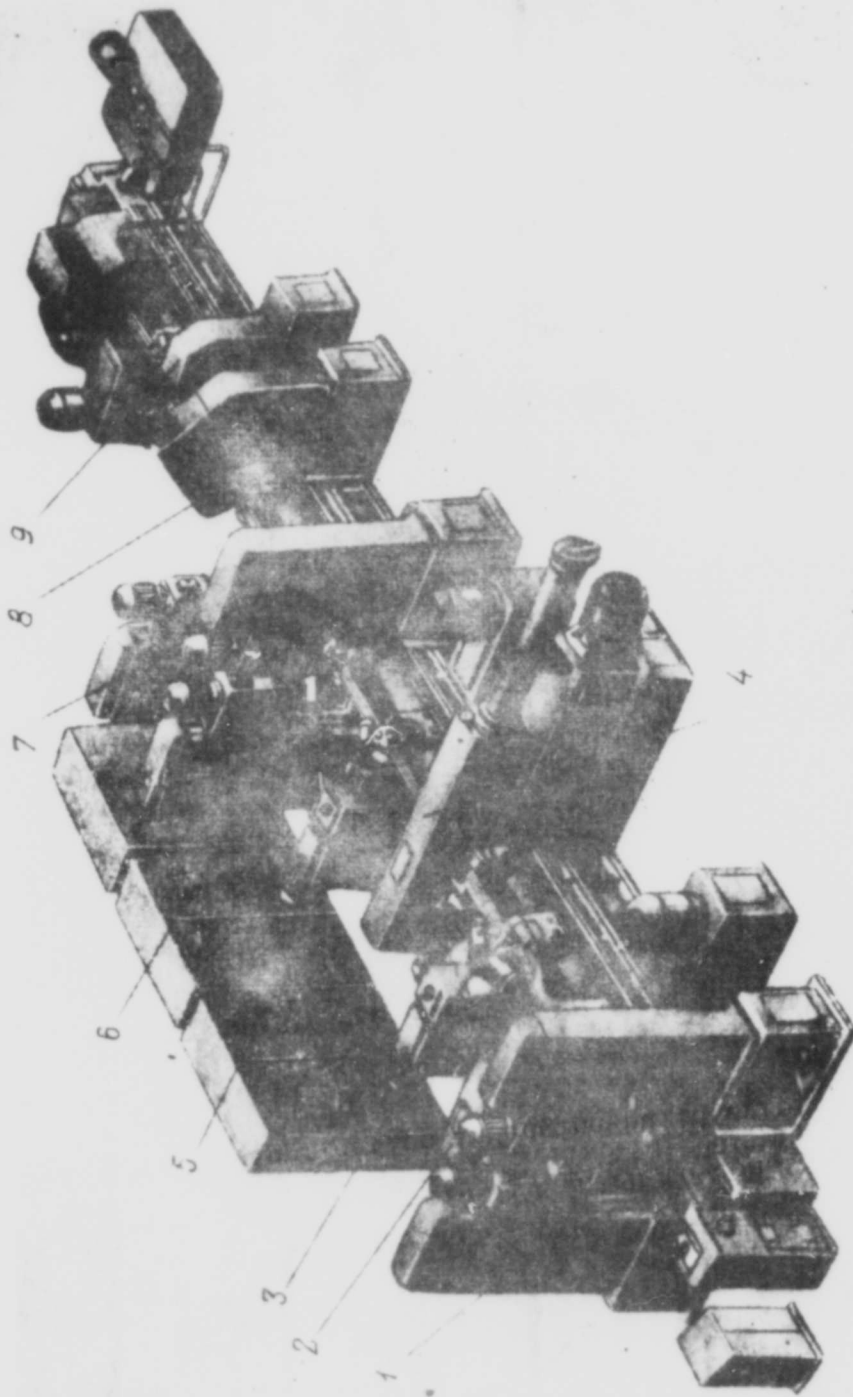


Fig. 3.41. Transfer machine AL-1 for working root of compressor rotor blade.

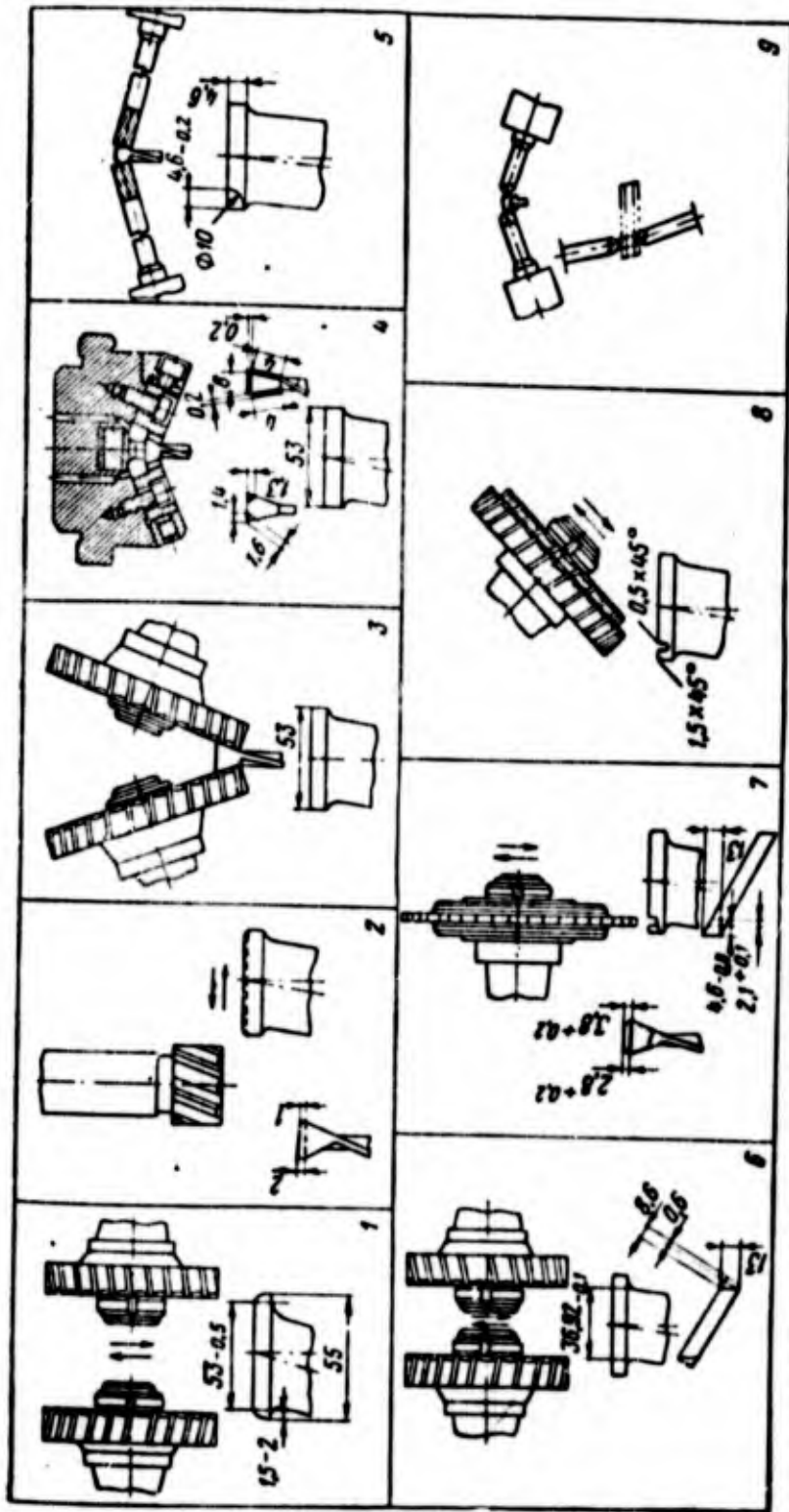


Fig. 3.42. Chart of working of root of compressor rotor blade on transfer machine AL-1.

By replacement of holders and, in separate positions, of the tool the line can be rapidly readjusted for working of roots of blades of dovetail type of other dimensions. This permits one to rationally load transfer machines even for relatively small program of engine production.

Drives of conveyors, lifting tables, mechanism of clamping blades in holder, and also locking and clamp of holders in working positions are carried out by hydraulic mechanisms.

On line there is foreseen cooling of tools. Shavings are removed by flow of liquid coolant under pressure. There is also foreseen checking of forced lubrication of guide beds, intermediate boxes, milling heads and reducers of power heads.

The blank of a blade for working on the line is a precision forging, prepared by coining without tip allowance. Root part of blade blank has allowance per side of up to 1.0 mm.

Flow chart of working of blade root is shown in Fig. 3.42.

Milling of root faces (pos. 1). Both faces are worked simultaneously. Heads for execution of given operation are placed on vertical brackets. Worked faces are used as support during subsequent broaching and uniform incision of teeth of broaches in the blank.

Milling of root bottom (pos. 2) is by end milling cutter of steel R18. Head is established on horizontal guide. Allowance left for subsequent broaching of bottom is 0.15-0.20 mm.

Milling of lateral faces of root (pos. 3) with allowance for broaching 0.15-0.2 mm a side. Head has special cap for two disk milling cutters.

Broaching of profile of root with removal of faces (pos. 4) is executed on built-in horizontal broaching machine by set of five

broaches, in one body. In the beginning forming broaches go into operation, then bottom and side. Wear of teeth of broach should not exceed 0.15 mm. After boring broaches are finished by rubbing.

Two flats on lateral faces of root (pos. 5) are milled by head with special cap for two milling cutters of diameter 10 mm. Flat. serve for fastening blades in wheel.

Final milling of facets of root at an angle of 30° (pos. 6) is produced analogously to milling of faces at pos. 1 in accordance with requirement of blueprint.

Groove in root (pos. 7) is milled with vertical shift of power head with disk milling cutter of steel R9K5 fixed in it. For greater rigidity in work the milling cutter is secured on mounting between two disks.

Two faces in cut of root (pos. 8) are milled by set of two disk milling cutters. Milling cutters are mounted on sleeve, thereby ensuring fast replacement and accuracy of their installation.

Edges in cut of root (pos. 9) are rounded by special head with two two-tooth milling cutters - counterbores - which accomplishing planetary motion.

Duration of the most labor-consuming operation of working a blade root on transfer machine AL-1 is 30 sec, and working cycle - 40 sec.

Later there were created analogous transfer machines AL-6 and AL-10 for working roots of compressor rotor blades. These lines, just as AL-1, are of rectilinear type with position machines standing separately, connected by conveyor systems for feeding holders with worked blanks and return of them to loading position. Transportation of holders is carried out in two planes.

Transfer machine AL-2 (Fig. 3.43) consists of nine machines and

is intended for working journals and shelf of stator blade of compressor.

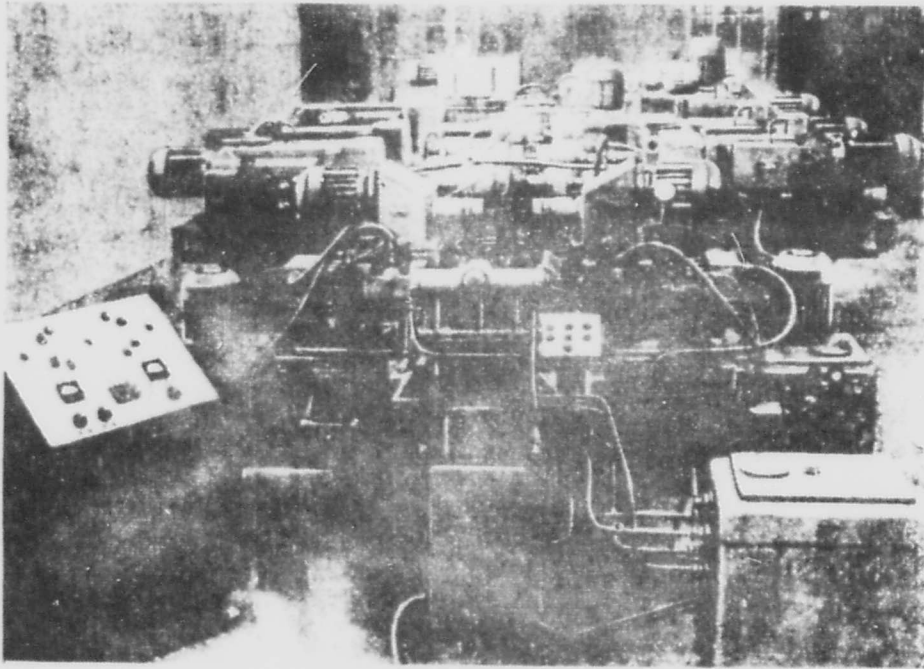


Fig. 3.43. Transfer machine AL-2 for working journals and shelf of a compressor stator blade.

Blanks are precision castings, obtained from investment patterns. At the beginning of the line in loading position, the blank is set in a holder, in which it is fixed by three points of the profile of the back, two points of nose and one point of shelf of root. Blank is clamped in holder automatically by hydraulic wrench.

Technological process of working root surfaces of stator blades is shown in Fig. 3.44.

Both faces of journals are finally worked by two disk milling cutters (pos. 1), then they preliminarily turn large and small journals (pos. 2), ream by shaped counterbore groove in bottom of lock of larger journal with simultaneous finished boring of small journal (pos. 3).

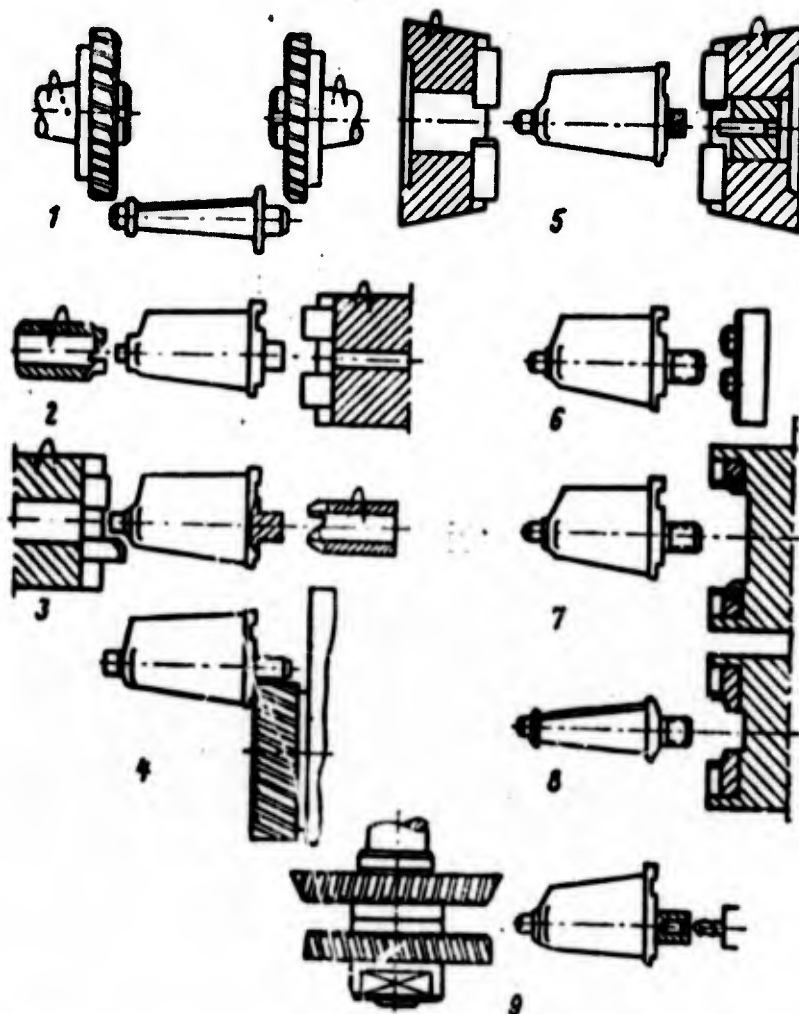


Fig. 3.44. Diagram of working of journals and shelf of stator blade of compressor on transfer machine AL-2.

Bottom of root is finally milled (pos 4) by power head, which, besides feeds in transverse and longitudinal directions, imparts to milling cutter circular planetary motion relative to axis of blade journal. During longitudinal motion of power head there occurs incision of milling cutter; subsequent working of bottom of root is conducted during circular (planetary) motion of tool.

Finally, they turn journal in pos. 5. In this operation in large journal there also is removed approach chamfer for rolling of thread, face is centered for checking of coaxialness of journals and position of root bottom after broaching, and on small journal there will be cut face and chamfer is removed.

Thread in large journal is rolled by thread-generating head with rollers (pos. 6). Counterrecoil tool is fed to part by threaded copy nut. Thread rollers are screwed in and out with identical speed.

Short shelves of root and chamfers on them are worked by broaching (pos. 7), consisting of two sections, established in common housing, secured on slide of machine.

On table of machine is fixed additional hydraulic cylinder, which, when holders are clamped on table, advances support mounted in the holder. Support is clamped to vertical unworked shelf of blade root. In course of machining it receives force of broaching, thereby ensuring constancy of position of worked shelves.

Long shelves of root and two wide chamfers are broached at pos. 8. The broach consists of two sections: for broaching of shelves and for broaching of wide chamfers. Sections of broaches are established in common body, secured on slide of machine. Broaching is conducted in vertical direction.

Drilling of hole in great journal and milling of chamfers on end of tip by two milling cutters is produced at pos. 9. After position machines there is fixed chamber for washing holders and a conveyor with table for lowering holder from plane of feed conveyor to plane of return conveyor. Rod of return conveyor moves holder with worked blades to lift table, which lifts them to loading position.

Rods of conveyor, tables for raising and lowering and clamp wrench work off of two hydraulic drives.

At the end of transfer machine are fixed two pump stations, feeding emulsion for cooling cutting tool and to chamber for washing parts. Lubrication of all moving parts of mechanisms of line is produced automatically.

Automatic transfer machine ALZL-1. Prismatic roots of guide blades of compressor are worked machine ALZL-1 (Fig. 3.45). Machining of root is produced in six successive operations:

- 1) milling of faces of blade;
- 2) milling of grooves in faces;
- 3) milling of wide planes of root;
- 4) milling of narrow planes of root;
- 5) calibration of roots in thickness by broaching;
- 6) washing of blade.

GRAPHIC NOT
REPRODUCIBLE

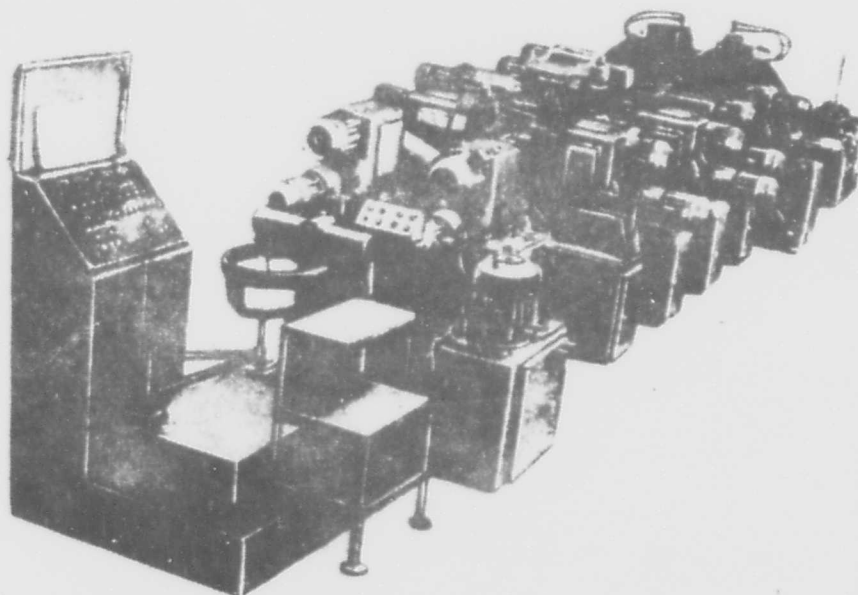


Fig. 3.45. Automatic model readjustable transfer machine ALZL-1 for complete working of surfaces of prismatic roots of compressor guide blades.

Productivity of line — 60 blades per hour.

Automation of production of turbine rotor blades is considerably complicated by high requirements for precision of roots of fir-tree profile and poor workability of heat-resisting blade alloys.

In spite of these difficulties, at present there is being conducted

intense work on creation of transfer machines for working turbine rotor blades. In creation of these lines they take for the basis model technological process of manufacture of turbine rotor blades.

In model process root and tip of blade are processed from basic setting bases. Model technological process consists of four basic stages:

- 1) machining of setting bases;
- 2) preliminary working of tip (bucket, back, edges, slanting sections, etc.);
- 3) working of root;
- 4) final finishing of tip.

Automation of first and third stages now is already fully possible. It is considerably more complicated to automate working of the tip.

One promising effort in creation of transfer machines for preliminary and final working of tip profile is application in technological processes of these lines of electrical methods of treatment.

Working of Blade Tips on Machines with Programmed Control

Application of machines with programmed control for working of blades permits us in short periods and without large expenditures to prepare a blade of any assigned profile. This is especially expedient in the creation and experimental finishing of engines.

At present there already are a number of models of such machines. Of considerable interest is semiautomatic four-spindle mill, model 4FPL-Pr (Fig. 3.46) with pulse system of programmed control (without feedback). Machine is intended for separate working of profile of back and bucket, including oblique chamfer at the root, of compressor

rotor and stator blades of up to 200 mm in length with angle of twist up to 30° .

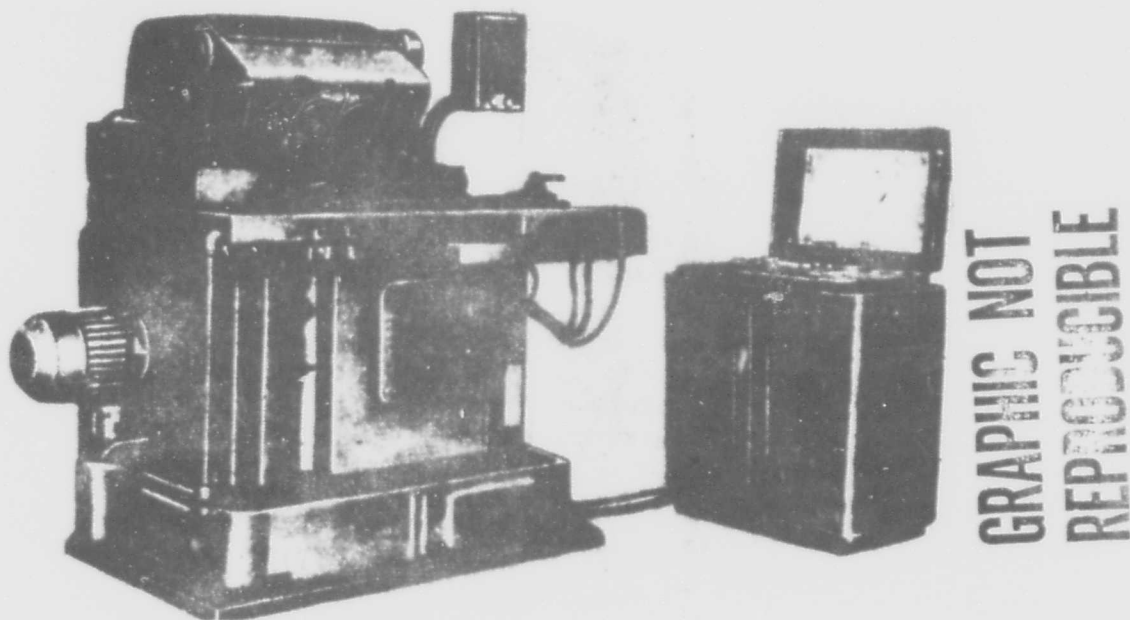


Fig. 3.46. Four-spindle semi-automatic mill with pulse system of programmed control, model 4FPL-Pr for separate working of the profile of back and bucket of compressor rotor and stator blades.

System of programmed control permits simultaneous shift in three coordinates, which gives possibility to carry out any technological variant of working. Machine is equipped with inductive system for fixing initial position in all three coordinates.

Programming of process of machining by an electron computer is conducted in following sequence. On the basis of drawing of blade and technological chart there is composed program sheet, including all data necessary for working of blade. By a punch these data are coded in system of computer. After that, on a general-purpose digital computer there are executed instruction, connected with determination

of paths of tool, and then on a specialized machine — an interpolator — on ferromagnetic tape there are recorded all data necessary for control of the machine. The work program is reproduced on control panel of machine by a reading device and, with help of step-by-step motors, through boosters and ball screw gauges it is transmitted to delivery mechanisms.

Upon completion of working magnetic tape automatically stops, and then is re-reeled to initial position.

There has also been created duplex semiautomatic mill, model FP-300, with phase system of programmed control (with feedback) for separate working of profile of back and bucket of compressor rotor and stator blades of up to 300 mm in length with angle of twist up to 50°.

Working of back and bucket of blade is produced by disk milling cutter, on longitudinal lines.

System of programmed control of machine anticipates work by program, recorded on ferromagnetic tape in the form of continuous phase-modulated signals. Motions of each of working organs are programmed on separate tracks. Calculation and recording of programs are produced both according to drawing on general-purpose digital computer "Ural" with special interpolator, having output to magnetic tape, and also directly on machine by a standard with help of electrohydraulic servo system.

§ 6. Checking Blades

Blades are checked both in the course of machining, and also after its termination. Checking of blades includes:

- 1) detection of external and internal defects of material;
- 2) check of cleanness of working in accordance with drafting requirements;

3) check of dimensions, shape of profiles of back and bucket, and also location of tip with respect to root;

4) check of dimensions of lock;

5) check of mass and frequency of natural oscillations of blades.

Detection of defects of material. Inspection for external and internal defects of material permits us to detect cracks and hairlines on surface, cavities, porosity, stratifications, alien inclusions and flocs in material. For this purpose we apply etching, magnetic and luminescent methods, color defectoscopy and ultrasonic method of inspection.

Magnetic powder method is based on attraction of particles of iron powder (or its oxides) to magnetic poles, formed in a magnetized part in places of disturbance of continuity. Settled powder makes previously invisible defects of metal well visible to the naked eye. According to the character of settling of powder one can determine not only location of defects, but also their approximate dimensions.

For realization of magnetic powder inspection we need special apparatuses (magnetic flaw detectors), in which set there are attachment for magnetization of checked blades (solenoid or electromagnet); device for dusting with powder or glaze with liquid, in which there is iron powder in suspension, and also attachment for demagnetization of blades after inspection.

Relative simplicity and rather high reliability of this method contributed to its wide introduction. However, application of this method is possible only during inspection of parts, made from materials, possessing magnetic properties.

Color and luminescent methods of inspection, being capillary methods, are used for detecting flaws, coming out of surface in parts

of different materials and, especially those not possessing magnetic properties.

Color method is based on use of properties of certain aniline dyes to penetrate into surface cracks and pores and to migrate from there on dried surface of the part.

For this to degreased surface of checked blade there is applied paint "Sudan IV," dissolved in benzene with transformer oil. Paint penetrates cracks and pores. Then surface of blade, from which (by rags, moistened in solvent), surplus of paint is removed, is covered by a film of white paint (zinc oxide, thinned in mixture of collodion, benzene and acetone). White paint soaks up and dissovses paint "Sudan", extracting it from cavities of defects, as a result of which the latter ones distinctly loom in the form of thin red lines on the white background, repeating outline of the defect. Color method is simple in application and does not require special equipment.

Luminescent method is more complicated and is more sensitive; it is based on ability of certain liquids to gleam upon irradiation by ultraviolet light.

The inspected part after thorough cleaning and degreasing is dipped in liquid and kept in it 10-15 min. Here the liquid, as also in color method, moistens not only surface, but penetrates into cracks and pores. Then they wash the part, removing liquid only from surface, while cavities of flaws remain filled. The part is dried, and its surface is "powdered" with a thinly dispersed "detecting" powder, possessing high absorptivity. Powder (magnesium oxide) extracts liquid from cavities of flaws to surface and moistened by it, adheres to surface. During subsequent blowing of part by air surplus of powder departs, and particles which adhere due to liquid outline

contours of flaws.

Presence of defects is established by inspecting part in dark place with ultraviolet illumination. Cracks and pores are revealed in the form of luminescent lines and spots.

As working fluid there is applied a mixture of 16% (by volume) aviation oil (All-Union Government Standard 1013-49) and 84% tractor kerosene (All-Union Government Standard 1842-52). This mixture gives a fairly bright bluish-white glow.

Luminescent method reliably reveals cracks, pores, pocks, oxidized scabs, impurities, etc., on the surface.

Ultrasonic method of inspection using surface waves permits one to detect surface cracks and metallurgical defects of material. Given method is applied usually for detection of cracks on inlet and entrance edges, and less frequently for those on surface of back and bucket appearing during manufacture and operation of blade.

This method is based on sounding the checked metal with brief pulses of ultrasonic oscillations, propagated on surface of blade, and catching of their reflections (echosignals) from flaws.

Inspection of blade edges is produced in the following way. Contact surface of head, covered with film of oil, is applied to edge of tip at the blade root in such a manner that ultrasonic waves are directed towards opposite end of blade tip (Fig. 3.47). The presence of defect is judged by the form of the oscillogram. If, during inspection on screen of flaw detector between initial and end pulses there are no intermediate pulses, this confirms absence of cracks on the inspected blade edge. Appearance of intermediate pulses on screen of flaw detector will indicate presence of obstacles, capable of reflecting ultrasonic waves during sounding of blades

GRAPHIC NOT REPRODUCIBLE

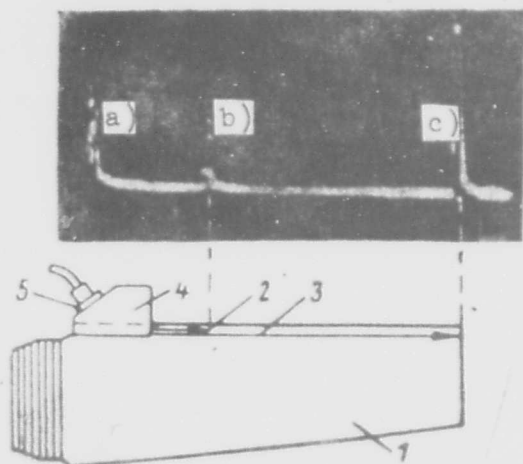


Fig. 3.47. Diagram of sounding of edge of blade. 1) blade; 2) crack; 3) beam of ultrasonic surface waves; 4) seeker head; 5) emitter; a) initial pulse; b) end pulse; c) pulse from defect.

along the edge (microcracking of surface layer, deep scratches on the tip edge fin, internal defects of material, etc.).

Cleanness of worked surfaces is checked by external inspection of blade by means of comparison with a standard.

Operations of inspection of basic dimensions and shape of the tip, the root, and their mutual location are the most labor-consuming.

Schemes of instruments used in these operations can be divided

into two basic groups: contactless — optical-projection; contact — mechanical, optical-mechanical, electrical, pneumatic and pneumo-hydraulic.

Checking of blade tip. Cross sections of blade tip are checked by optical contactless method on projectors. Of considerable interest is the projector of the Swiss firm Sip [? SIP (Société Genevoise d' Instruments de Physique)], working according to method of light section (Fig. 3.48). Method of light section gives possibility of obtaining on screen image of profile of section of fin with magnification of 20 or more. Blade is fastened by its root in vertical position, and its axis coincides with optical axis of instrument. Surface of blade is illuminated by six lamps 1 through six lenses 2, located around the section. For production of sharp image of profile of tip in checked section filaments of lamps are at focus of condenser

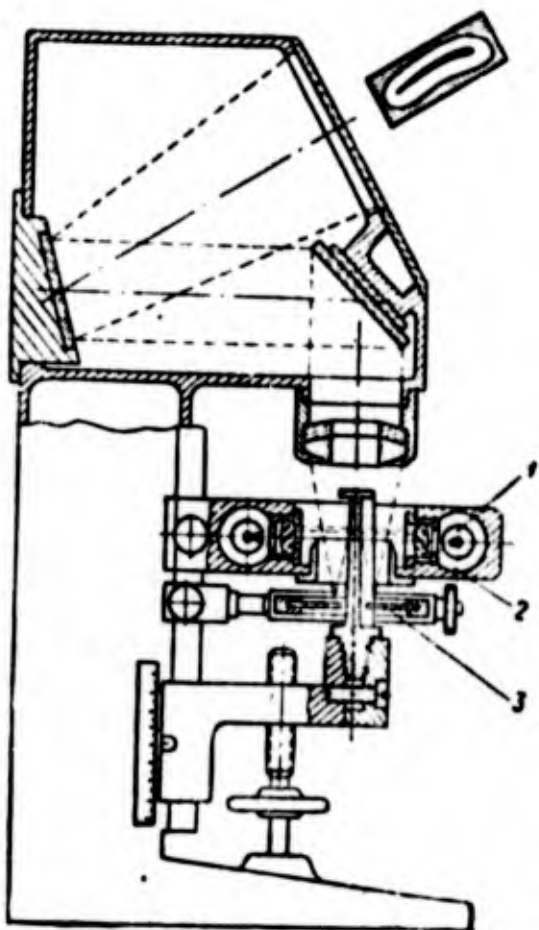


Fig. 3.48. Projector for checking blade tips.

of system of lenses, as a result of which beams of light are parallel. Section is projected on a screen.

The blade tip is coated with a layer of magnesium soot about 0.01 mm thick so that its surface refracts, and does not reflect the light beam. Two adjustable mirrors 3 serve to produce image of profile sections. Hollow (annular) lens permits one to check profile of cross section of blade tip of considerable length.

Optical method of light section is convenient for any blades in experimental production and in small lot plants.

Basic deficiencies of projection method of checking the tip profile are:

- 1) with increase of dimensions of blades and their image (to $\times 100$) size of screen sharply increases;
- 2) necessity of applying film of soot on surface of tip;
- 3) difficulty with fulfillment of exact drawing on colored glass with 30 and even 100 power magnification;
- 4) impossibility of use of these instruments directly at working stations in workshop.

Most widely applied in production are instruments, working by contact method (at separate points) with different reading devices. Such instruments are applied for checking elements of the tip and root of blades.

Instruments with indicators of dial-type are used for reading results of one or two simultaneously produced measurements. Instruments are set up from standards. Designs of instruments are not general-purpose and are intended for checking some given blade. They are simple and convenient in operation, but not very productive.

In small scale production profile of blade tip is usually checked by patterns. Deviations of profile of section of back or bucket from pattern are determined visually, by clearance or by a probe.

Check of tip by patterns is insufficiently productive, insufficiently objective (result of measurements depends on conditions of installation of patterns — misalignment of them, magnitude of force of clamp of pattern to tip), requires bulky pattern measuring equipment.

Large labor-consumption in checking mass parts is caused by application of multi-dimensional and highly productive instruments and measuring machines, in which all auxiliary motions are mechanized (clamping and feed of measuring elements, etc.).

Applied multi-dimensional instruments of contact type are divided into optical-mechanical and instruments with application of electric-contact, inductive and pneumatic-contact transducers. They tune such instruments by a standard blade.

Multi-dimensional instruments and measuring machines can be rapidly retuned for checking other blades. These instruments are equipped with corresponding elements for tuning. Field of their application is intermediate and final inspection. Base for fastening blade is root or center depressions, two of which are on lateral surfaces of root and one at end of tip. Among such instruments are general-purpose multi-dimensional, optical-mechanical instruments POMKL for simultaneous checking of tip profile, displacement of tip from

axis of roof, angle of twist and thickness of tip in cross sections of a compressor blade (Fig. 3.49).

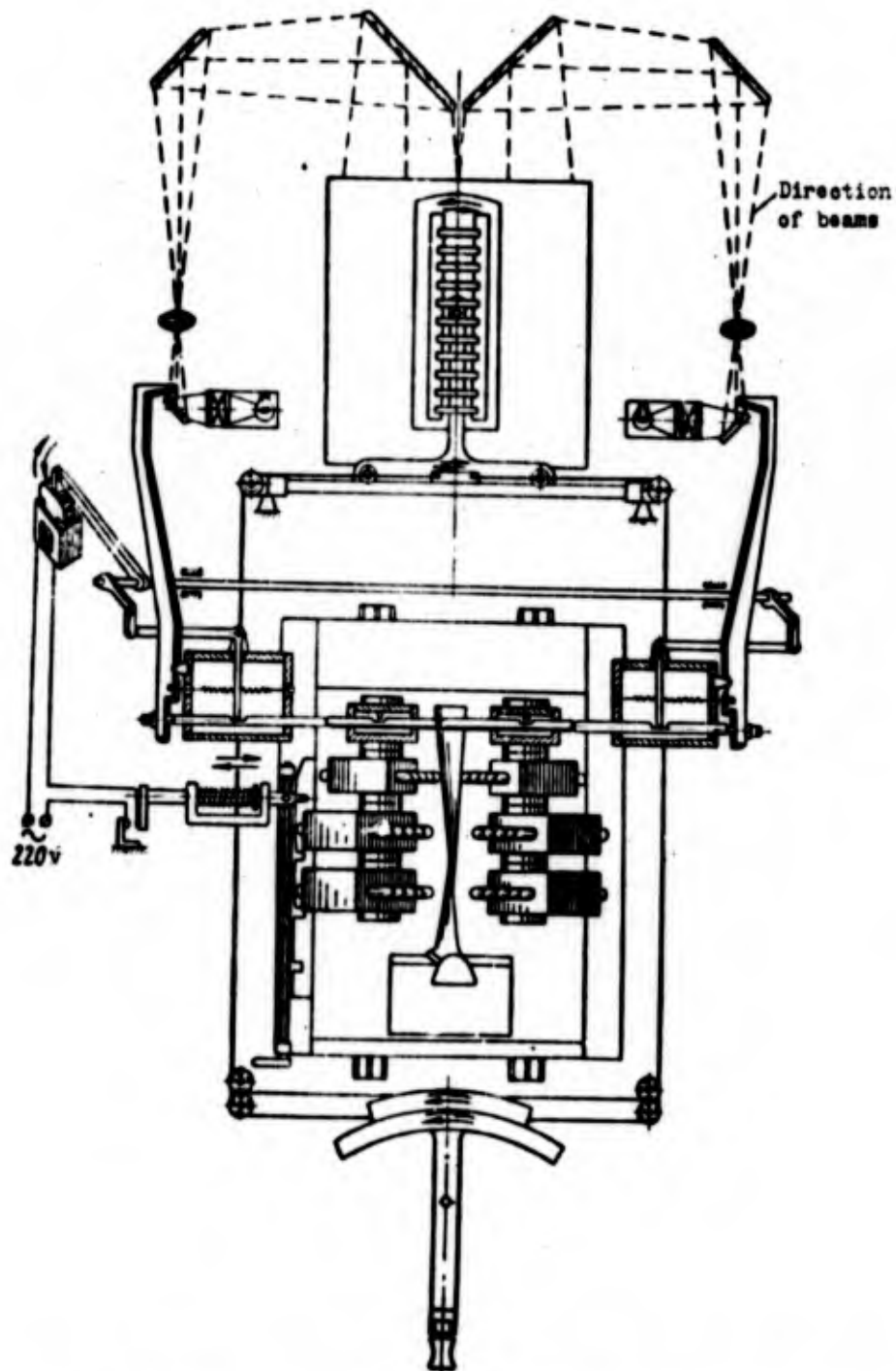


Fig. 3.49. Diagram of optical-mechanical instrument POMKL-4 for checking profile of tip of compressor blades.

Check of curved surface of section profile in instruments of type POMKL is carried out in the following way. On profile of checked section of blade tip there are established with defined spacing contact

rods. Free ends of rods by standard are brought to single plane of measurement. Deviations of tip profile from the assigned cause shift of contact rods, transmitted to measuring rods and then to levers with ratio 5:1. Ends of levers are projected on screen with magnification 10:1, thereby ensuring overall magnification of 50:1.

On screen they establish boundaries of field of tolerance, by which one can determine suitability of a checked blade.

Depending upon errors of profile in the checked section ends of levers on screen either deviate from base lines (during local errors of profile), are displaced parallel to base lines (upon displacement of whole section), or will be disposed on one straight line at an angle to the base line (in case of error in angle of twist).

Checked blade is secured in instrument by its root. Inspection is produced at points with spacing of 5 mm. Accuracy of measurement is 0.02 mm, productivity of inspection is up to 250 blades per hour.

Advantages of the instrument:

- 1) separation of error of the actual profile from displacement of whole section from axis of root and error of angle of twist;
- 2) practical nonwearability of master form or standard blades, serving only for tuning or checking contact measuring units;
- 3) absence of traces of meters on surface of blade.

There exist multi-dimensional measuring machines with electro-mechanical transducers. They measure simultaneously 28 points of blade for upper and lower limits of tolerance with help of signal lamp register. If blade is suitable in all parameters, then one lamp lights up ("suitable") in center of panel, and in case of defect there lights up yellow "+" or red "-" tube, corresponding to the given point. Measuring device is tuned to zero by two standard blades,

corresponding to upper and lower limits. Productivity of such machines is about 200 blades per hour.

Checking by limits with signal lamp register during multi-dimensional measurements of blades does not have wide usage. Absence of scale, showing magnitude of deviations of dimensions, is inconvenient for production, since it does not permit checking on the stability of the manufacturing process.

More convenient for production are multi-dimensional instruments with dial devices of pneumatic float type and pneumohydraulic micro-

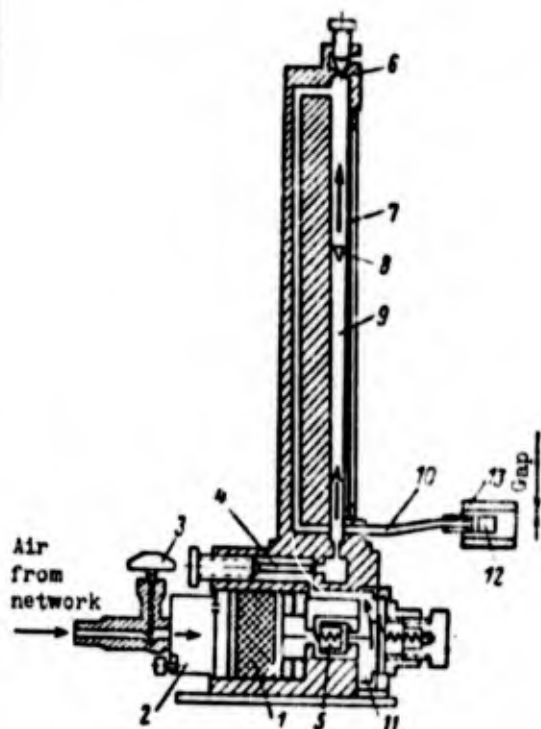


Fig. 3.50. Diagram of float-type pneumatic micrometer PPO-9M. 1) filter; 2) setting tank; 3) closing valve; 4) variable-area nozzle; 5) check valve; 6) nozzle of escape to atmosphere; 7) scale; 8) float; 9) indicator tube; 10) hose; 11) stabilizer; 12) measuring head; 13) part.

meters of panel type. Scales in such instruments are rectilinear, are located vertically, close to one another, and all checked tolerances can be reduced to one height of scale, limiting it from above and from below by two fat parallel lines. Emergence from tolerance limits can be easily noticed on any scale. As indicators for reading height of scales they apply either floats (pneumatic float meters), or colored liquid (pneumohydraulic meters).

Diagram of pneumatic float micrometer of type PPO-9M, developed by NIAT is shown in Fig. 3.50.

Work of this instrument consists of the following. Air from network, passing through settling tank and filter, enters pressure

stabilizer, whence through variable-area nozzle it is brought to indicator tube, measuring head (transducer) and through gap, formed between measuring nozzle and walls of part, it emerges into the atmosphere in the conical glass. Indicator tube there is a float, whose position depends on speed of air flow.

In foreign practice widely applied are multi-dimensional pneumo-hydraulic instruments of the English firm Sigma for checking blade tips, providing for simultaneous checking control of several elements of the tip in at least three sections.

Check of fir-tree root. In fir-tree root they check: thickness of root on center line of teeth, relative displacement of sides of profile, thickness of body of root in first and last grooves, height of root from axis of roller of first tooth to bottom of lock, height of tooth from center line of root, spacing of root teeth.

With small scales of production thickness of root with respect to center line of teeth is checked by rollers, set in grooves of root, measuring by micrometer or indicator bracket, tuned by standard. Accuracy of measurement is 0.02 mm; productivity is about 700 blades per hour.

More convenient in operation is indicator bracket, in which measuring tips are standard wires, fastened by springs. This ensures free setting of wires in cavity of tooth and rapid replacement of them when worn.

With sizeable scale of production there are applied multi-dimensional instruments with indicators of dial-type (Fig. 3.51). Checked blade 1 is inserted by root in "pike mouth" guide, along which there are placed self-adjusting indicator brackets. Cradle 2 is suspended above base 3 on two laminated springs 4, elasticity of

which forces roller 5 to enter cavity of blade root. On crade 2 is fastened a pair of laminated springs 6 of block 7, bearing roller 8. Roller is united to block 7 by a hinge. Spring 6 seeks to push roller 8 into opposite cavity of blade root. Arresters 9 and 10 separate blocks 11 and rollers 5 and 8, allowing the blade to freely stand on measuring positions. Along the instrument there are established as many brackets as cavities in the root profile. Thus, during inspection of the root the blade should be advanced from the first to the last bracket.

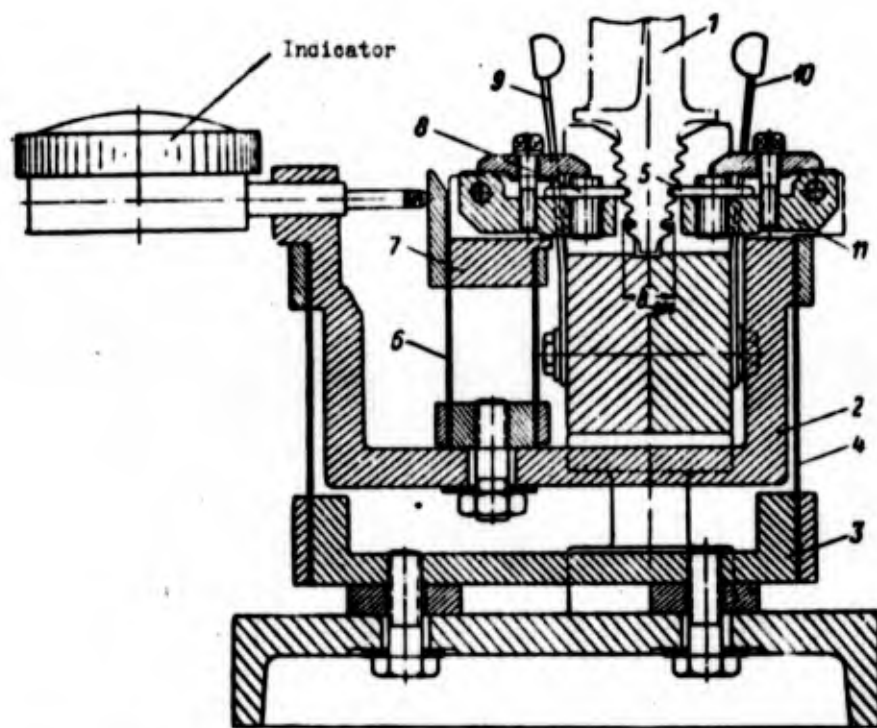


Fig. 3.51. Multi-dimensional indicator instrument for checking thickness of root with respect to center line.

Tuning of indicators on "zero" is produced by a standard.

In multi-dimensional instruments for inspecting fir-tree roots as meters they also use pneumatic-contact and inductance pickups.

Instruments for inspecting elements of a fir-tree root for the most part are pneumatic (UPYeZ-3 for checking misalignment of fir-tree

root, UTYeZ-3 for checking thickness of fir-tree root, ShYeZ for checking spacing of teeth, etc.).

Instrument for checking misalignment of teeth of fir-tree root of turbine blades UPYeZ-3 (Fig. 3.52) consists of a plate, pneumatic float-type meter, holder and measuring unit. Mutual displacement and crossing of profiles are checked by tubes 1-6. Others six tubes serve for checking misalignment of wedge and root relative to setting bases, displacement of base hole at end of tip with respect to end of root. Capacity of instrument is up to 300 blades per hour.

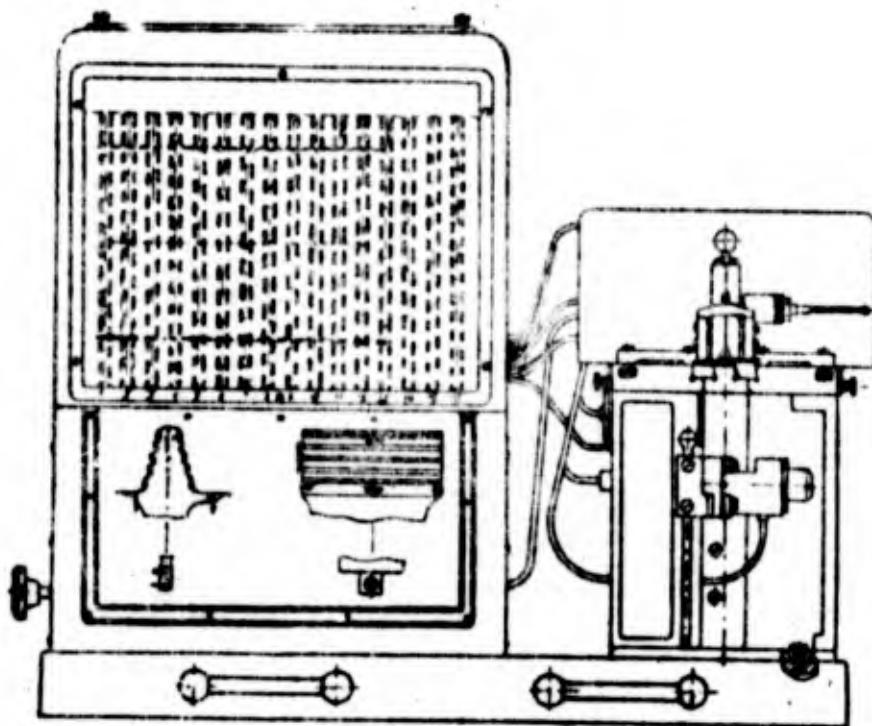


Fig. 3.52. Instrument UPYeZ-3 for checking misalignment of fir-tree root of turbine blade.

The fir-tree root of turbine blade on multi-dimensional instrument Sigma is checked by inductance pickups and galvanometers. Tuning to zero is produced from standard blade. Simultaneously, there are measured 13 dimensions and displacement of root with respect to the axis.

Checked blade is clamped by three centers in pneumatic holder. Forces of clamp in centers are calibrated.

Plan of instrument has several groups of transducers, which touch corresponding elements of blade root. Position of probe of transducer is fixed by a corresponding galvanometer.

Deficiencies of multi-dimensional instruments with inductance pickups are necessity to conduct observation of many galvanometer pointers simultaneously and the cumbersomeness of the panel.

Checking a root of dovetail type. For roots of this type they check thickness and angle of root, using general-purpose measuring and indicator instruments.

Instrument for checking thickness of root is shown in Fig. 3.53.

Checked blade is placed on table 1 of instrument and moves between rollers 2 and spherical support of rod 3. Roller 2 is motionless, and rod 3, shifting in sleeve, transmits change of dimension to measuring tip of indicator.

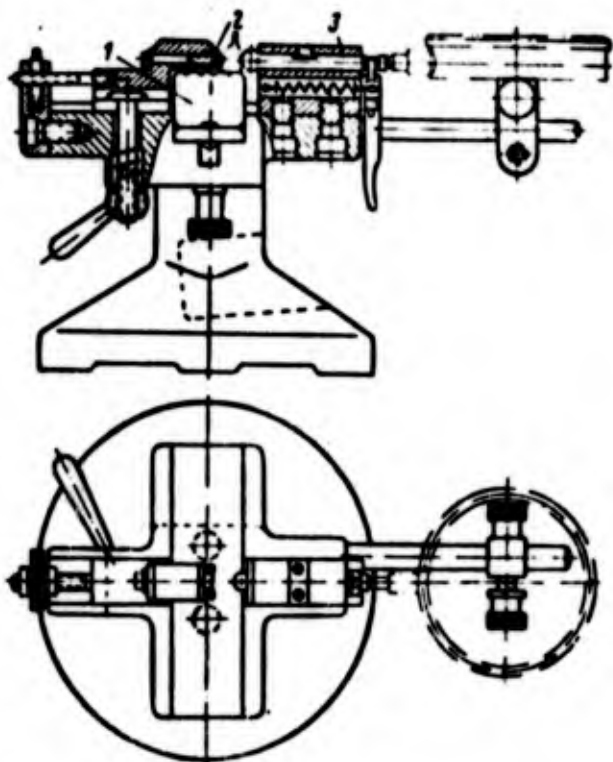


Fig. 3.53. Instrument for measurement of thickness of root of dovetail type.

Capacity of instrument is up to 700 blades per hour.

Angle of root is checked on instruments, in which as the meter they use inductance pickups or indicators of dial-type.

For checking roots of compressor blades they also apply highly productive pneumatic and electric-contact instruments.

Check of frequency of natural oscillations. Frequency of natural flexural oscillations of 1st tone of

turbine rotor blades is checked after their final working (clipping of end of tip and blades assembled and correcting of radii) on special vibration stands (Fig. 3.54).

Sound vibrations of oscillator 3 through amplifier 4 are fed to field coil 2 of electrodynamic vibrator 1. Oscillations of mobile

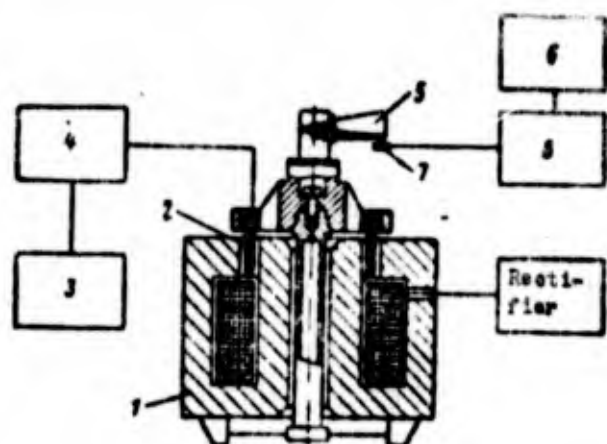


Fig. 3.54. Block diagram of installation for checking frequency of natural oscillations of blades.

coil of vibrator are transmitted to checked blade 5 through attachment in which it is fastened.

Upon coincidence of frequency of oscillations of vibrator and natural frequency of checked blade there appear resonance oscillations of great amplitude, but of the same frequency. These oscillations are perceived by capacitor pickup 7 and

are fed through amplifier 8 to oscillograph 6. Here, height of luminescent rectangle on screen of oscillograph will be at a maximum.

Check of frequency of natural oscillations of high forms of blades is produced just as check of frequency of 1st tone with this difference only, that after clamping the checked blade is lubricated by kerosene and has sand poured on it. Blade is tuned in resonance to maximum concentration of sand in nodal lines.

Mode of high-frequency forms of oscillations is put in specification sheet. Upon deviation of obtained modes from fixed the blade is rejected.

CHAPTER IV

PRODUCTION OF IMPELLERS

§ 1. CONSTRUCTION, TECHNICAL SPECIFICATIONS, AND MATERIALS

Impellers of aircraft engines are divided with respect to form into three types: unshrouded, i.e., intakes, semishrouded, and

shrouded. Semishrouded and shrouded impellers are one- and two-sided.

Unshrouded impellers, i.e., intakes (Fig. 4.1) consist of a hub with vanes that are open on the lateral sides. The hub has a central fitting hole (cylindrical or conical), a row of holes under the fastening pins, and holes under weight-bolts for balancing. The vanes of unshrouded impellers have complicated form with variable cross sections.

The convex part of the vane is called the back and the concave

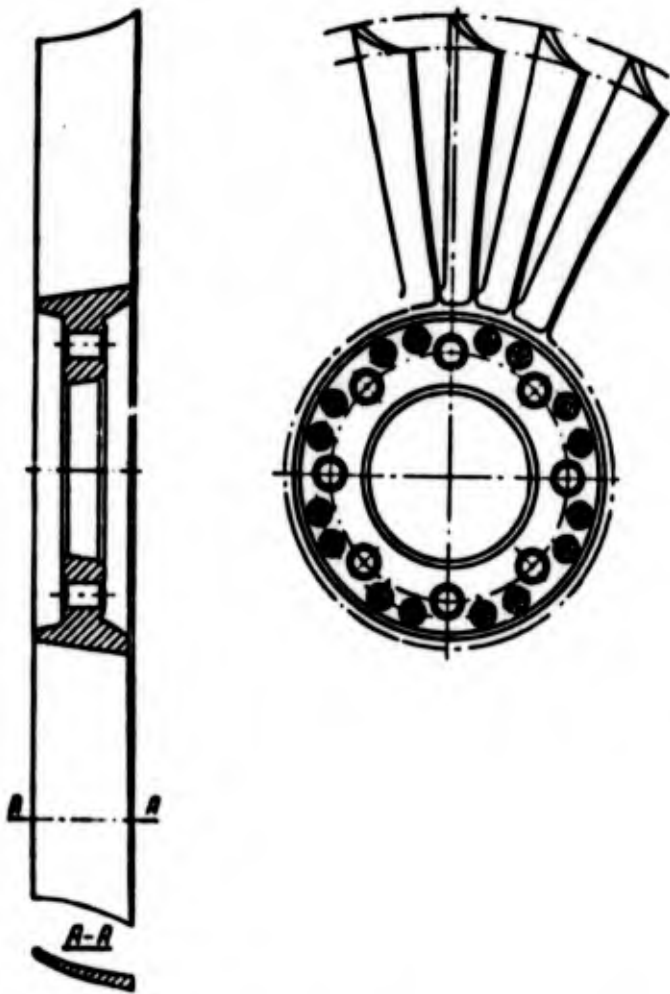


Fig. 4.1. Impeller intake of compressor.

part is known as the bucket. The leading edges of the vanes are pointed and sharpened around the radius. The trailing edges or ends of the vanes, for tighter attachment to the impeller, are not rounded, but are tapered with an undercut.

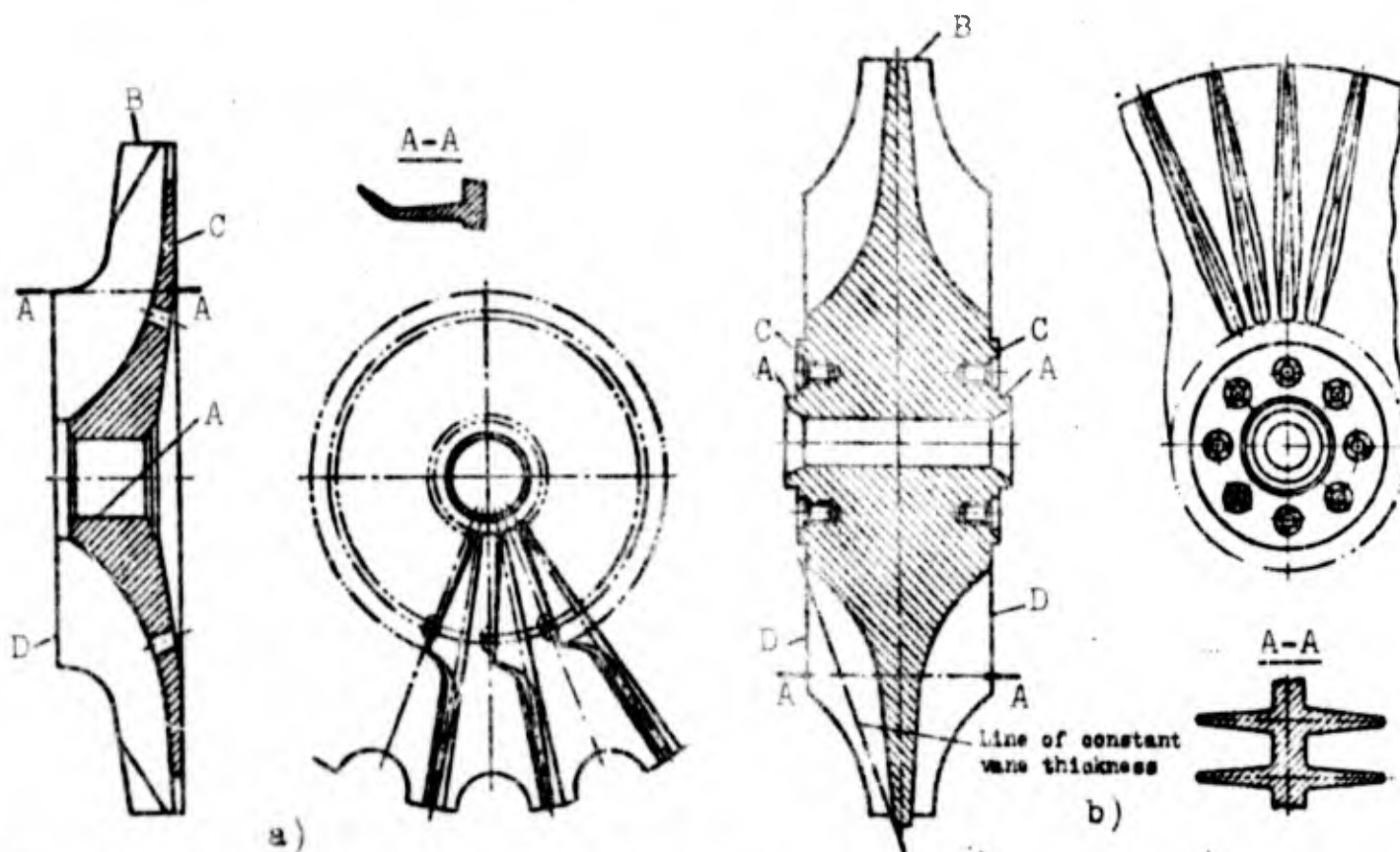


Fig. 4.2. Semishrouded impellers. a) one-sided; b) two-sided.

Semishrouded impellers (Fig. 4.2), besides the hub, also have a disk to which all vanes are attached by their trailing edges. Holes in the hubs of large impellers are usually smooth and cylindrical, while the hubs of small one-sided impellers are also splined. In one-sided impellers, the vanes sometimes have their own intake portion at the inlet. Vanes are straight and curvilinear. In certain designs of large two-sided impellers, half of the vanes (every other one) do not reach the hub. Vanes with a trapezoidal cross section have a straight slanted line of constant thicknesses.

Shrouded impellers can be one-sided integral units (Fig. 4.3a) and soldered (Fig. 4.3b), and also two-sided (Fig. 4.3c). All of

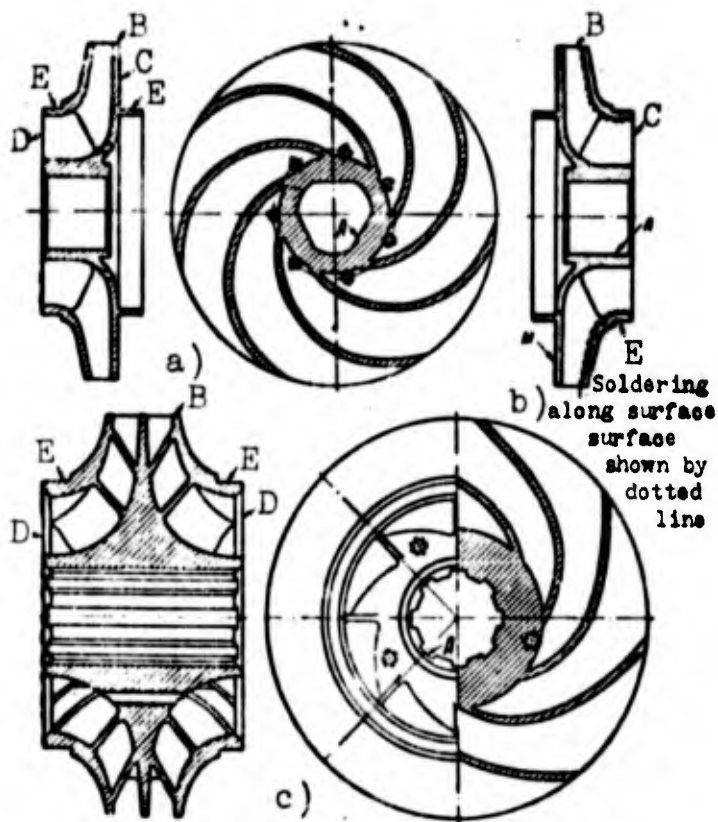


Fig. 4.3. Shrouded impellers.
 a) one-sided, one-piece; b) one-sided, soldered; c) two-sided.

them have curvilinear channels with variable cross sections from center to periphery. Holes in the hubs for the most part are splined, and they sometimes have flats at an angle of 120° (triangular). In shrouded impellers of turbopump assemblies on the side of the ends at the entry there are exact annular bands for the labyrinth seal.

The required accuracy of impellers is characterized by the following data:

Accuracy of Production.

1. Centering bands or fitting holes of the hub A — 2nd class; sometimes — 1st class.
2. External diameter B — 5th or 4th class.
3. Allowance on width of impeller — 0.2-0.4 mm.
4. Allowance on thickness of vanes — 0.2-0.3 mm.

Accuracy of Mutual Location of Surfaces.

1. Permissible run-out of external diameter B relative to fitting surfaces — 0.02-0.05 mm.
2. Permissible run-out of ends C and D relative to fitting surfaces — 0.02-0.04 mm.
3. Permissible unparallelism of ends (for two-sided impellers) — 0.02-0.04 mm.
4. Permissible run-out of disk end of one-side impellers — 0.03-0.04 mm.

5. Permissible angular displacement of vanes around their circumference from their nominal position - up to 10'.

6. Permissible run-out of "labyrinth" bands E relative to fitting points - 0.02-0.03 mm.

Purity of Treatment.

1. Vanes of unshrouded and semishrouded impellers: 7th-9th class.

2. Channels of shrouded impellers: 4th-6th class.

3. Fitting surfaces and labyrinth bands: 7th-9th class.

4. Nonworking surfaces: 5th-7th class.

Impellers are balanced statically to the state of neutral equilibrium.

Dynamic balancing is produced usually in unit with the shaft.

The material for the majority of critical unshrouded and semi-shrouded impellers is aluminum alloy AK6-1 with additions of chromium and titanium.

After heat treatment, i.e., quenching (heating to a temperature of 510° and cooling in water with a temperature of $20-40^{\circ}$) and aging (heating to a temperature of 155° with exposure of 10-15 hr and cooling in air) this alloy obtains the following mechanical qualities: ultimate strength 36-38 kg/mm² ($\approx 36 \cdot 10^7 - 38 \cdot 10^7$ newton/m²), elongation per unit length 5-10%, and hardness HB = 100-105.

During fatigue strength tests, samples with a load of 11 kg/mm² ($\approx 11 \cdot 10^7$ newton/m²) should be exposed for 20 million cycles.

Unshrouded one-piece impellers employ cast aluminum alloys AL, and sectional-soldered impellers use aluminum alloy AV, and also steel 30KhGSA, 35KhGSA, 1Kh18N9T, and others.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

General Positions

Blanks of unshrouded and semishrouded impellers (Fig. 4.4) are usually pressure-molded or forged by a hammer in dies. Blanks should

be given a shape that is similar to the shape of the component in order to obtain high quality of the material and decrease allowances in treatment. However, due to the complexity of form of components, small allowances cannot always be obtained, and in certain places (at the vane base) they reach 10-15 mm. For components that have sufficiently large holes, the blanks are made with recesses.

This is done mainly for the purpose of packing

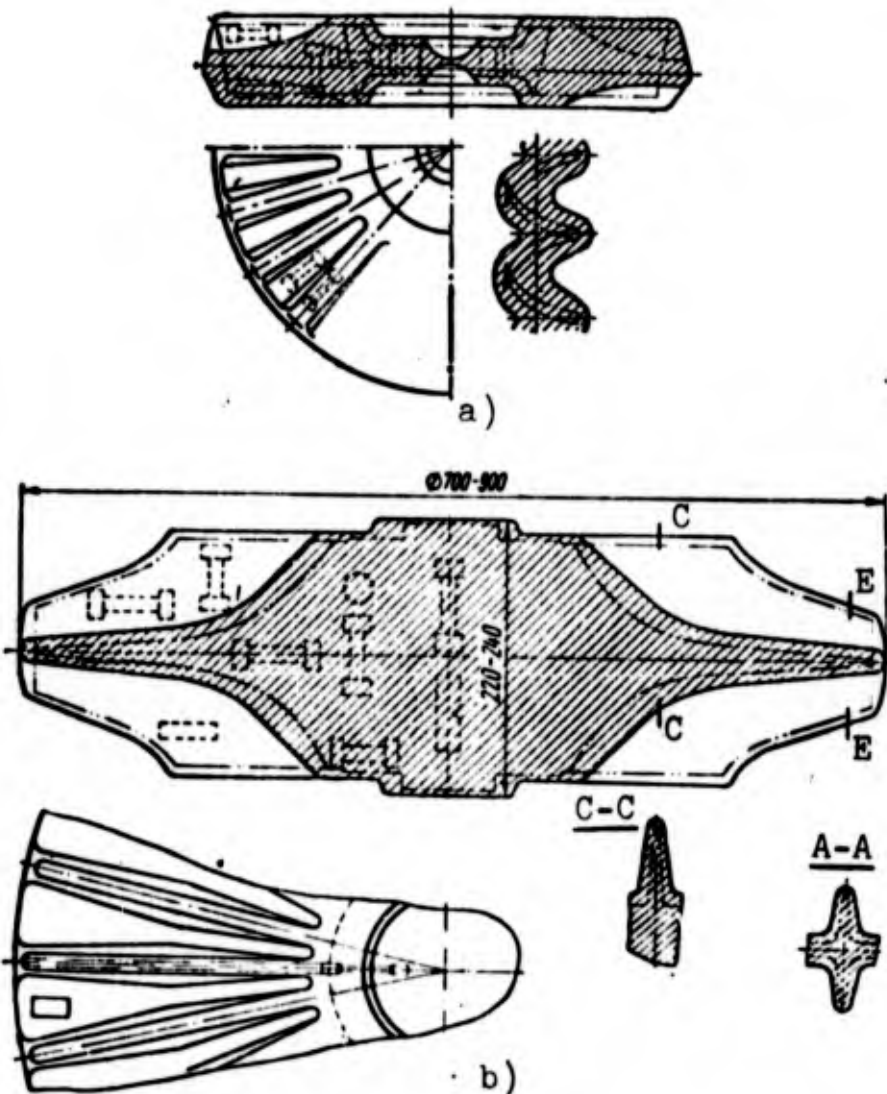


Fig. 4.4. Drop-forged impeller blanks. a) unshrouded; b) two-sided, semishrouded. Draft = 7° ; displacement along the line of disassembly not more than 2.5 mm; irregularity of vane spacing around external diameter ± 1 mm.

the metal in the most stressed spot of the component. After quenching, the blanks are put into the second control group, i.e., one component from the heat batch of one melt is cut into samples for mechanical tests. The layout of samples is shown in Fig. 4.4.

Blanks of shrouded impellers made from aluminum alloys (Fig. 4.5) are loam-cast, chill-cast, or shell-(skin) cast with precision cores under channels. Blanks made of steel and heat-resistant alloys are cast in wax patterns. These methods obtain castings of the highest quality.

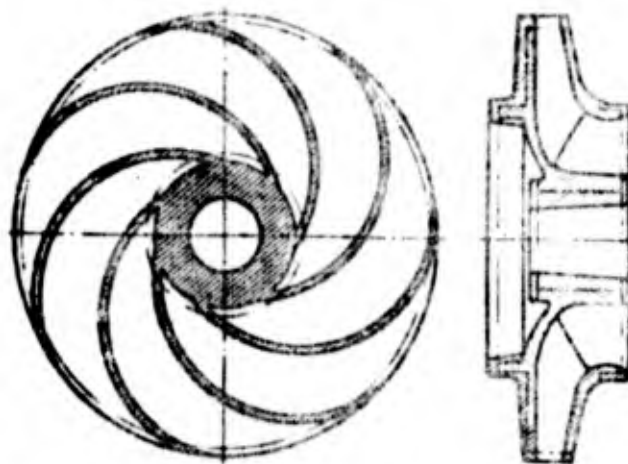


Fig. 4.5. Casting of shrouded one-sided impeller.

Shell (skin) loam molds are made in a precision metallic pattern consisting of two halves. Surfaces of the pattern are chrome-plated and polished. Each half is preheated to $200-250^{\circ}\text{C}$, then they are packed with finely-processed casting sand which is a mixture of quartz sand and powdered bakelite (6-8%). After exposure for 2 min, the halves are covered by a 10-12 mm thick skin of sand that has been sealed in melted bakelite. These skins, which are separated from the patterns, are dried in a furnace at 300°C and thus, hard and durable shells, are obtained from the two halves. Assembly of shells together, and also with the core and gating system, is produced with locator marks by means of gluing.

Inasmuch as closed channels are not subjected to any treatment other than dressing, and sometimes polishing, the requirements for their accuracy and surface purity in the blank are higher as compared

to other surfaces. Allowances for making holes, butts, and lateral surfaces should be sufficient so that it is possible to correct errors in the location of channels relative to these surfaces and to remove the defective layer. On mechanically processed surfaces the allowances for loam casting reach 10 mm, and in chill molds and in shell molds, about 3 mm on a side.

Machining of impellers can be divided into two stages: rough and finish. In the rough stage a large part of the allowance is removed, and machining is conducted with rather considerable forces of cutting and fixing of the component. In the finish stage a smaller portion (up to 30%) of the allowance is removed, and the impeller is given its final form. At the end of the finish stage the vanes are polished.

Selection of fixing bases for finish operations does not present any particular difficulties. The accuracy of location of all base surfaces of the component is usually specified with respect to the fitting surfaces. In most cases the fitting surfaces are sufficiently suitable to serve as fixing bases. If, however, the component's fitting position has the form of short band A (see Fig. 4.2b), then during final treatment the component is placed on central counter-sinks. On these bases the face and cylindrical surfaces, including seating bosses, are machined due to which the accuracy of mutual location of surfaces will be sufficiently high.

It is frequently difficult to select the primary fixing base. When making a central hole, the most reliable method would be fastening of the impeller blank around external surface B. However, the use of this surface as the primary base is possible only when the vanes or channels with respect to it are exactly located in the blank.

This is usually difficult to attain when obtaining a blank, and therefore, it is necessary to resort to the use of the lateral surfaces of vanes or webs in closed channels as fixing bases in the first operations. On the base of these surfaces the ends, central hole, and sometimes, the external surfaces B or E are machined. Then further machining is produced on the base of the machined surfaces.

The time and effort involved in operations for producing vanes of unshrouded, semishrouded, and sectional shrouded impellers is quite considerable; therefore, during treatment they sometimes use multi-position fixtures and multi-spindle machines. Machining of cast shrouded impellers, in which the channels are only dressed, is less labor-consuming.

Heat treatment of impellers made from aluminum alloys is usually produced before machining, with the exception of large, sectional-soldered impellers, and impellers with bent vanes. Such impellers are thermally treated after specified mechanical operations. For the purpose of direct heat treatment of material, large impellers are thermally processed after mechanical stripping operations, sectional-soldered impellers are thermally processed after soldering, and impellers with vanes are treated before bending the vanes. After quenching, all impellers are subjected to aging (in a furnace). Impellers with bent vanes are aged after the vane-bending operation.

The quality of the impeller material (presence of internal flaws) is checked after quenching and after a number of rough machining operations by ultrasound.*

*Explained in detail in Chapter II.

Model Plans for Treatment of Impellers

Open intake impellers (Fig. 4.1).

1. Turning of external diameter B and facing (fixing base).
2. Broaching of other face and boring of hole.
3. Drilling of holes under pins and reaming of two of them for fixation of angular position for subsequent installations.
4. Cutting of cavities between vanes for two intakes (left and right) simultaneously.
5. Restoration of bases (turning of faces, boring of central hole, and reaming of two holes under pins).
6. Milling of vane back and bucket.
7. Turning of top, facing, and boring of gooves on two sides.
8. Turning of vane back and boring of vane bucket.
9. Trimming and polishing of vane surfaces.
10. Drilling and countersinking of holes in hub.
11. Static balancing.
12. Final check.

After operations 6 and 10, operations processing the bottom of hub cavities are introduced.

Semishrouded impellers (Fig. 4.2). Treatment of one- and two-sided semishrouded impellers is similar to a certain extent. In the treatment of vanes of two-sided impellers it is necessary to execute all operations twice, i.e., for each side separately. The plan of operations should ensure that vanes from both sides are combined in circumference with the specified accuracy. The considerable weight of two-sided compressor impellers requires the construction of a technological process with the least amount of rearrangements.

Two-sided impellers.

1. Treatment of fixing bases — beads, faces, holes, and end planes.
2. Rough milling of vanes and webs between them.
3. Restoration of fixing bases — dressing of center faces.
4. Facing and beading.
5. Finish milling of vanes and webs between them.
6. Polishing of vanes and webs.
7. Drilling and threading.
8. Finishing of external surfaces.
9. Milling of vane bevels.
10. Final boring of central hole.
11. Polishing of bevels and hole.
12. Static balancing.
13. Final check.

Cast shrouded impellers (see Fig. 4.3a) (one-sided and two-sided).

1. Trimming of channels.
2. Facing and boring of holes.
3. Rough turning of external surface.
4. Broaching of splines.
5. Finish turning of external surface.
6. Turning of labyrinth bands.
7. Drilling of holes and threading in hub.
8. Trimming of channels.
9. Final check.

Soldered shrouded impellers (see Fig. 4.3b).

1. Turning of end and external surfaces and holes. Fixing ends and holes for the following operations are turned from one installation.
2. Rough milling of vanes and webs between them.
3. Finish (not final) turning of holes, ends, and external surfaces.
4. Finish milling of vanes and webs between them.
5. Polishing of vanes and webs.
6. Final facing of hub and vanes under soldering (on master form).
7. Check of adhesion of cover (turned on master form) to body of impeller in soldering spots. When clearances are more than 0.2 mm the cover must be fitted on the body of the impeller.
8. Laying and spot welding of solder lines to impeller and assembly with cover in fixture attachment (sometimes with a clamp at 4-6 points by electric welding).
9. Soldering in an electric furnace.
10. Mechanical and chemical cleaning of channels from excess solder and deposit.
11. Heat treatment - hardening and aging.
12. Trimming and prepolishing of channels.
13. Processing of hole and end on one side, and then top and end on other side.
14. Drilling, countersinking of holes, and threading.
15. Finishing of round hole by press fitting of a splined bushing or broaching (shaped or splined) of hole in the impeller itself.
16. Finishing of external diameter of channels and labyrinth bands on spline base.
17. Trimming of burrs, sharp edges, and washing.
18. Final check.

§ 3. EXECUTION OF BASIC OPERATIONS FOR THE PRODUCTION OF IMPELLERS

Treatment of base surfaces. Vanes or channels of impellers must be exactly located with respect to the design base surfaces. Therefore, during treatment of these surfaces the impellers are placed in the cavities between vanes or surfaces of channels (Figs. 4.6, 4.8, 4.9, and 4.10).

In unshrouded or one-sided semishrouded impellers, one of the ends and the external diameter are processed first. Then these surfaces serve as locating bases. Treatment is produced on lathes; the component is placed in the attachment (Fig. 4.6) on three or four rigid supports 1 which determine the position of the end,

and centered by spring locators 2 (floating bevels) placed between vanes. The component is pressed down to the rigid supports of the attachment by the center of the tailstock.

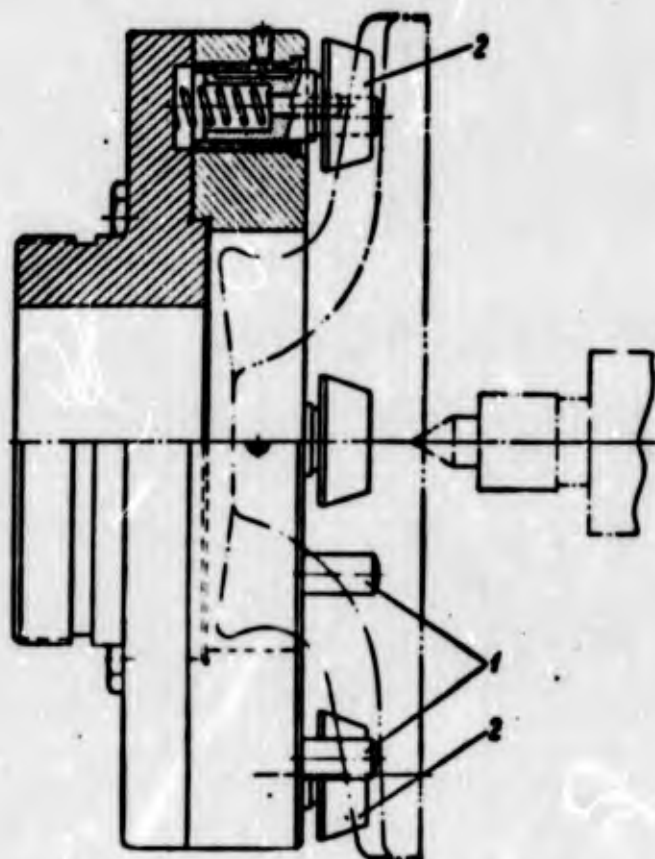


Fig. 4.5. Turning of external surface of impeller with installation of blank on floating bevels.

Fitting bases - hole and face - are processes on turning lathes or revolving lathes. The component is secured in the jaws of a self-centering chuck.

In order to obtain a hole of the 3-rd accuracy class, it is first drilled and then reamed. If an accuracy of the 2nd class is required, the small holes (to a diameter of ~ 30 mm) are reamed after boring, and the large holes are obtained by precision boring. In this operation the vane pattern is turned along its ends on vertical turret lathes. For this purpose the lathe is fitted with a copying attachment (Fig. 4.7) with a master form in the turret head.

Rough lathe treatment of shrouded cast impellers determines the accuracy of mutual location of the base surfaces of the component;

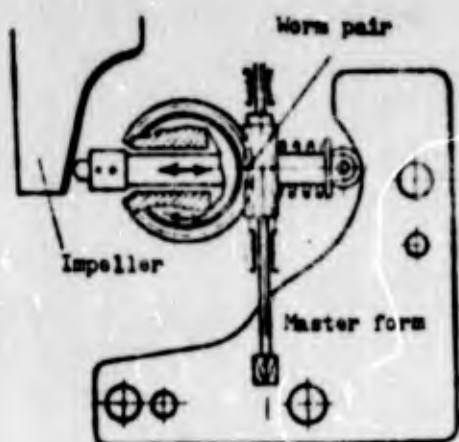


Fig. 4.7. Diagram of copy device for treatment of vane edges.

therefore, the selection of fitting bases in the first two lathe operations has a large value. The fitting base in the first lathe operation is the outlet portion of the three channels, with which the component is placed on wedge-shaped jaws of a special chuck (Fig. 4.8). Such installation ensures the exact location of the processed surfaces with respect to the channels which remain mechanically untreated in the finished

impeller. In this operation the inlet face and the ribbon are turned around the periphery, on which the component is placed in the second operation (Fig. 4.9). The attachment has three projections (fitting elements) and strips for attaching the component.

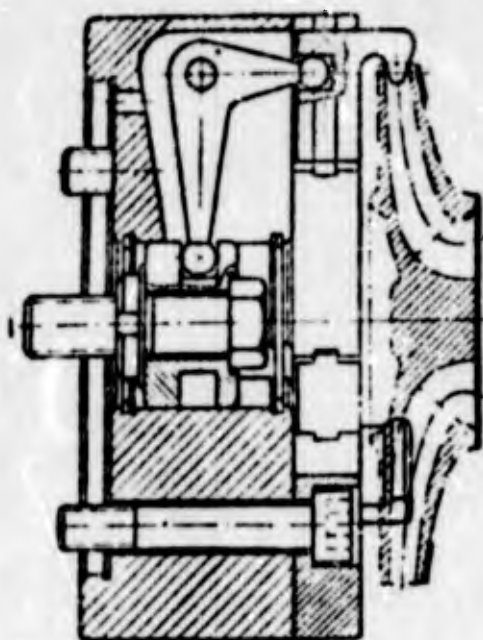


Fig. 4.8. Facing of shrouded impeller with channel centering.

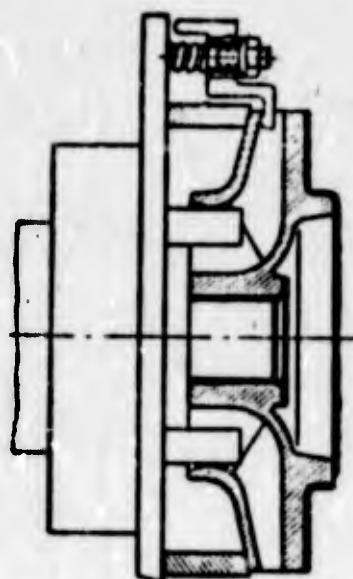


Fig. 4.9. Turning of faces, and external band, and boring of hole in shrouded impeller.

Rough lathe treatment of large, two-sided, semishrouded impellers is produced on vertical lathes (Fig. 4.10). The component is placed

with its vane ends on the annular support of a special attachment and centered with the lateral vane surfaces on six spring supports with spherical tips. When turning the external cylindrical surface, the component is bolted through the central hole. Then, before turning all other surfaces, the fastening is changed to three clamps on the periphery between vanes.

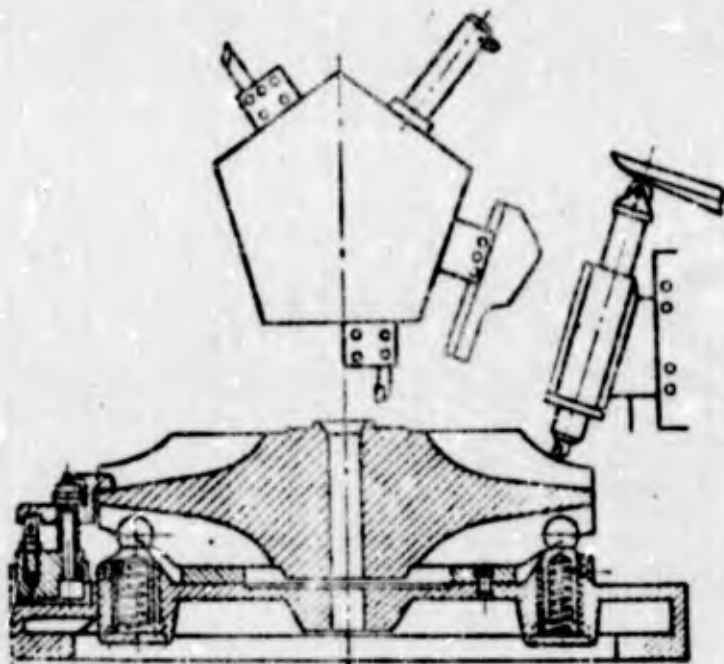


Fig. 4.10. Treatment of impeller on one side on vertical lathe.

The central hole is drilled before rough turning by a hollow countersink drill; control samples for mechanical tests are made from a cut rod. In the operation of finish turning, all faces, the base bead, and the vane contour are turned on one side.

The vane contour is turned on the master form which is secured on one of the faces of the turret head. The cutter for turning the contour is secured in a spring holder that is fixed on the transverse support of the machine. During treatment of the other side, the component is placed along the turned face and base band.

Treatment of vanes. Treatment of vanes is divided into rough and finish, and is produced in several operations.

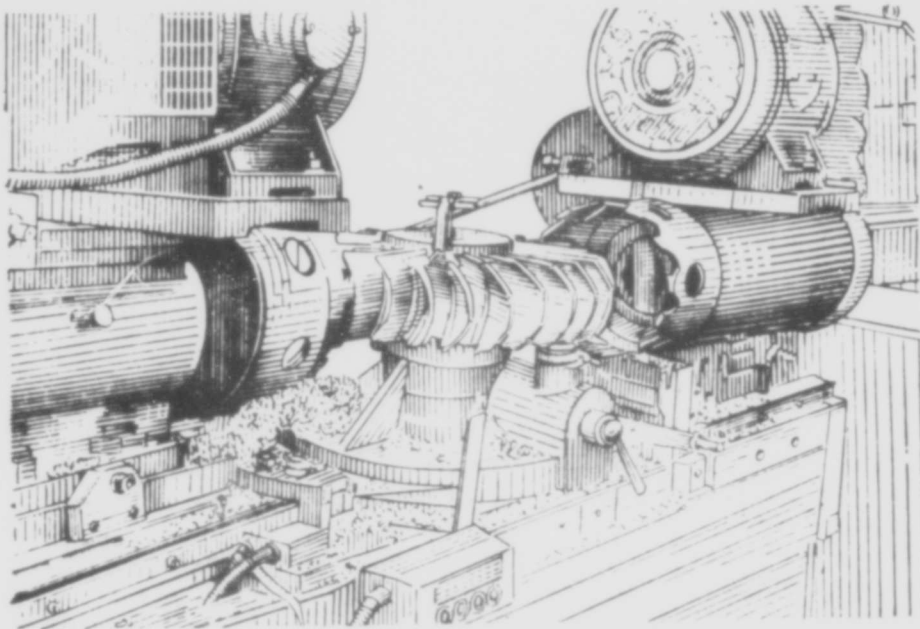


Fig. 4.11. Rough grooving of cavities with hollow countersinks.

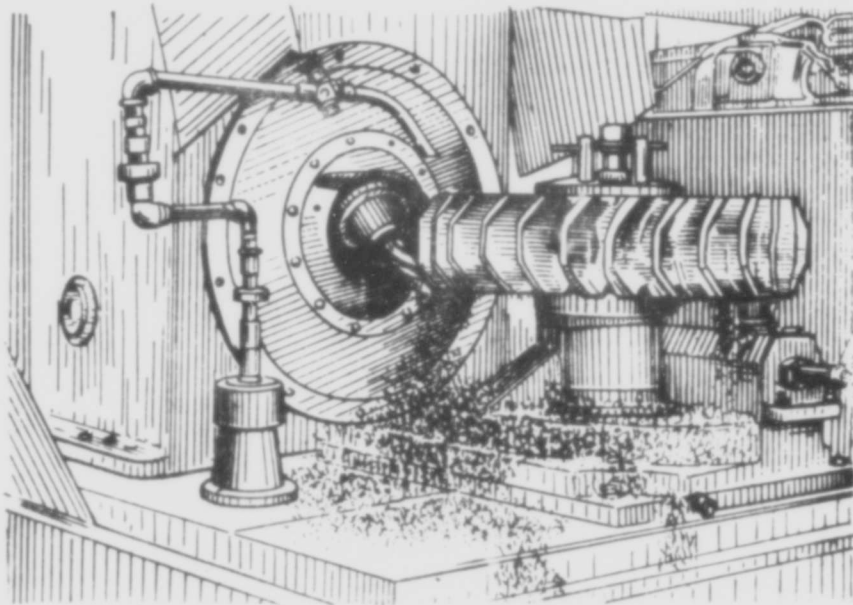


Fig. 4.12. Grooving of cavities with cone-type cutter.

Rough grooving of vanes of unshrouded intake impellers is produced in the beginning with hollow countersinks (Fig. 4.11) and then with cone-type shank cutters (Fig. 4.12). On the dividing attachment two components are secured simultaneously; they are fixed by their central hole with location through holes under pins which were preliminarily drilled and reamed.

Figure 4.11 shows a duplex milling machine which works with two hollow countersinks.* One countersink treats the back of the vane,



Fig. 4.13. Treatment of cavity base between vanes.

and the other, the bucket. Both countersinks move along the vane generatrix simultaneously. For the purpose of decreasing the stresses that appear during treatment, and approximation of radii of vane curvature to those specified, grooving is divided into two operations. In the beginning a cavity is grooved between vanes to half of the depth, and then, with a countersink of large diameter, the remaining part of the cavity is grooved. Further, the cavity is

grooved by a shank cutter (Fig. 4.12) to the entire depth. The surface at the vane base is processed by the same cone-type cutter in a separate operation (Fig. 4.13).

During finishing, the back and bucket are preliminarily and finally turned on specialized machines. The cutter is placed on these machines in a holder with a rack. During rotation of the spindle and longitudinal movement of the holder, the cutter describes the trajectory of the surface of a cone, in conformity with the form

*This tool is also called a cup cutter.

of the processed vanes. The rack of the holder is in contact with spur gears. Movement of the holder along its axis conforms to spindle rotation owing to the gears which constitute a kinematic circuit together with the rack transmission.

The intake is placed with its central hole on an hydraulic mandrel of the dividing attachment and fixed by rods through holes under pins. The hydraulic mandrel ensures high accuracy of installation of components.

The leading edge of the intake vanes is smaller than the trailing edge; therefore, from the back of the vane it is necessary to remove

a strip of complicated curvature.

This strip is milled on a vertical milling machine (Fig. 4.14). The component is placed on the revolving attachment which is placed on the table of the machine and moves with it in longitudinal and transverse directions.

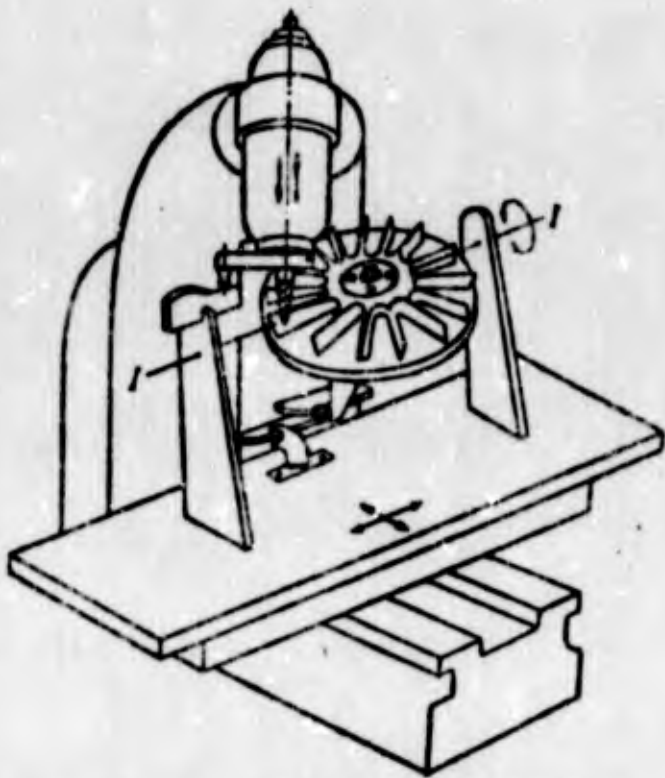


Fig. 4.14. Milling of leading edge of intake vanes by means of three master forms.

Treatment of the complicated surface of the strip is ensured by three master forms and an end form cutter. Two master forms are

fixed on one plane of the bed, and

the third is placed on the machine

table. One of the master forms, fixed on the bed, during longitudinal movement of the table, inclines the table of the attachment together with the impeller around axis I-I. The second master form moves the machine table in a transverse direction, and the third master form

moves the head of the spindle with the cutter in a vertical direction. The totality of motions of the impeller and form cutter around the three master forms obtains a strip surface of the specified form.

Vanes of one-sided semishrouded impellers are milled. Rough milling is produced on horizontal milling machines or on specialized milling machines of type GF114, GF115, and GF116, and others.

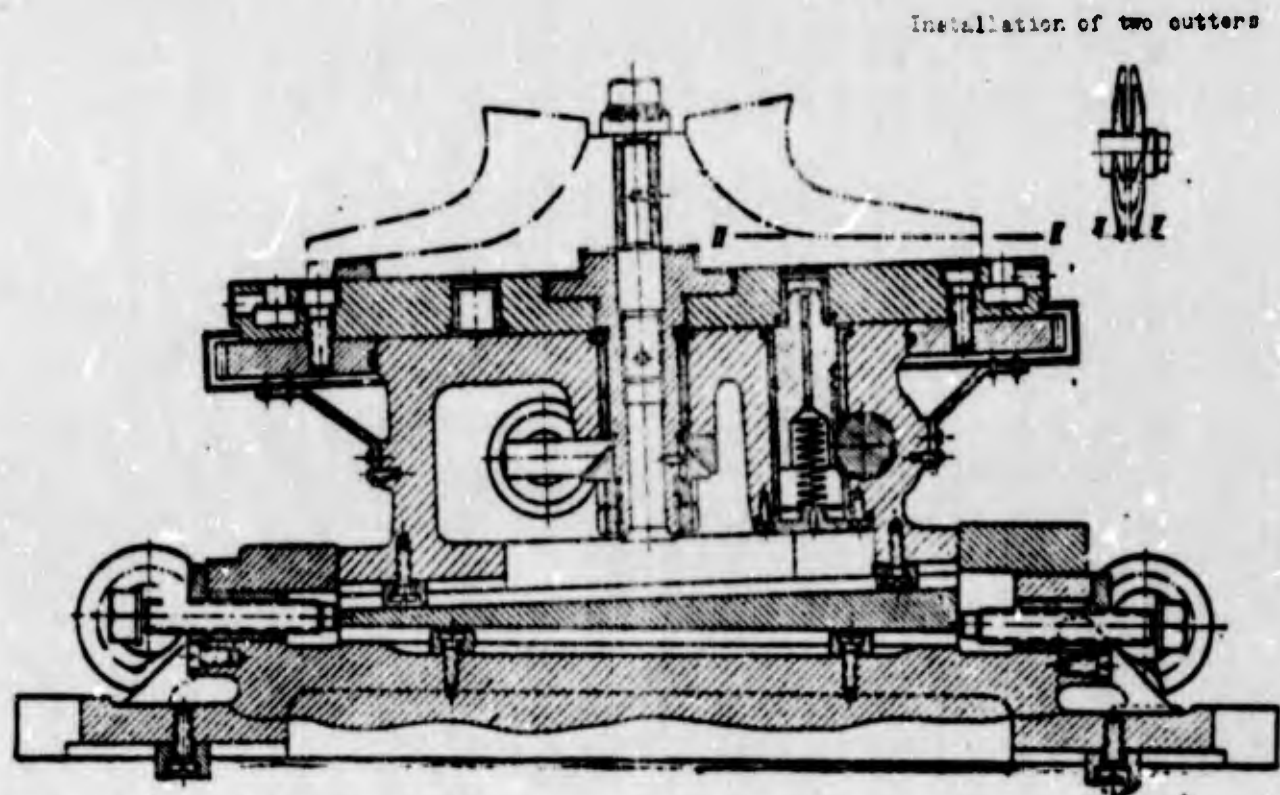


Fig. 4.15. Installation for milling vanes by two coupled cutters

The attachment on which the component is placed with its hole or seating boss is inclined with respect to the machine table so that the web between vanes is parallel to the plane of the table. Rough and finish milling of straight vanes with parallel lateral planes is produced by two cutters simultaneously with the help of a dividing attachment (Fig. 4.15). The radius of the cutters is equal to the radius of the web at the hub. Vanes of variable thickness with trapezoidal cross section are finish-milled by one cutter alternately on each side. After milling of lateral vane faces by paired cutters

or one cutter, the remaining untreated part of the web (bottom between vanes) is milled in the following operation, also on horizontal millers or specialized machines with the application of dividing attachments, i.e., chucks (Fig. 4.16).

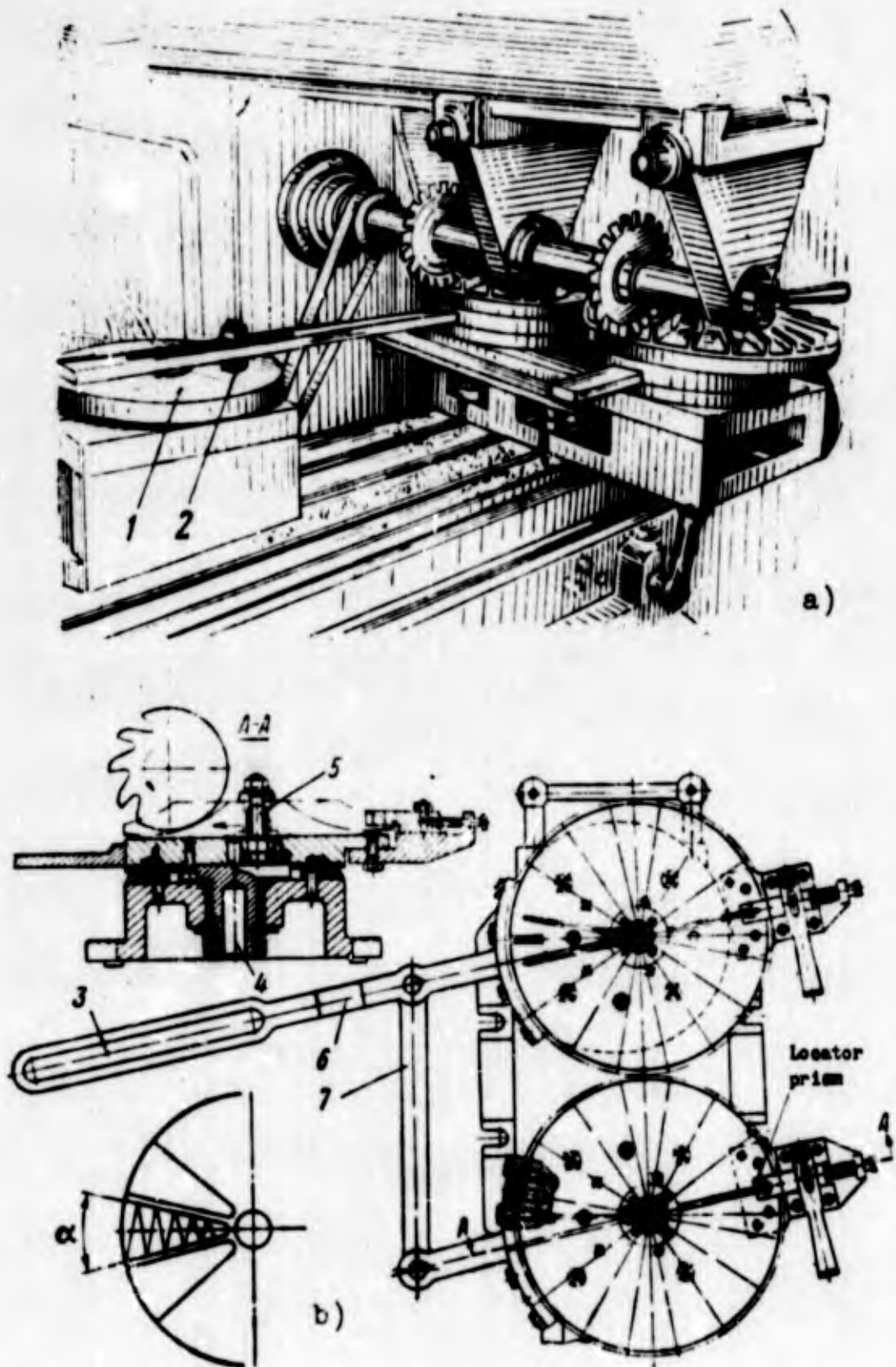


Fig. 4.16. Milling of webs between vanes on a two-position rocker attachment.

Rough milling of web is produced by one circular cutter which, moving through the base of the web to the center of the tilting impeller, makes a zigzag path between the vanes, as shown in Fig. 4.16b. On the lateral faces of the vanes, allowances for finish milling are left. The impeller is installed with its hole on pin 5, and is tilted around axis 4 to the magnitude of central angle α . Tilting occurs from disk 1, which revolves in one direction with pin 2 fixed on it eccentrically. Pin 2, moving through grooves 3, across lever 6 and transverse strip 7, simultaneously tilts both impellers at the indicated angle α . Longitudinal movement of the impeller on the cutters and their reverse movement is carried out by the mechanical motion of the machine table. Turn of the impeller (division) to the following position is done manually with the help of a locator prism. During finish milling of the web, contact of vanes with the ends of the cutter is not allowed.

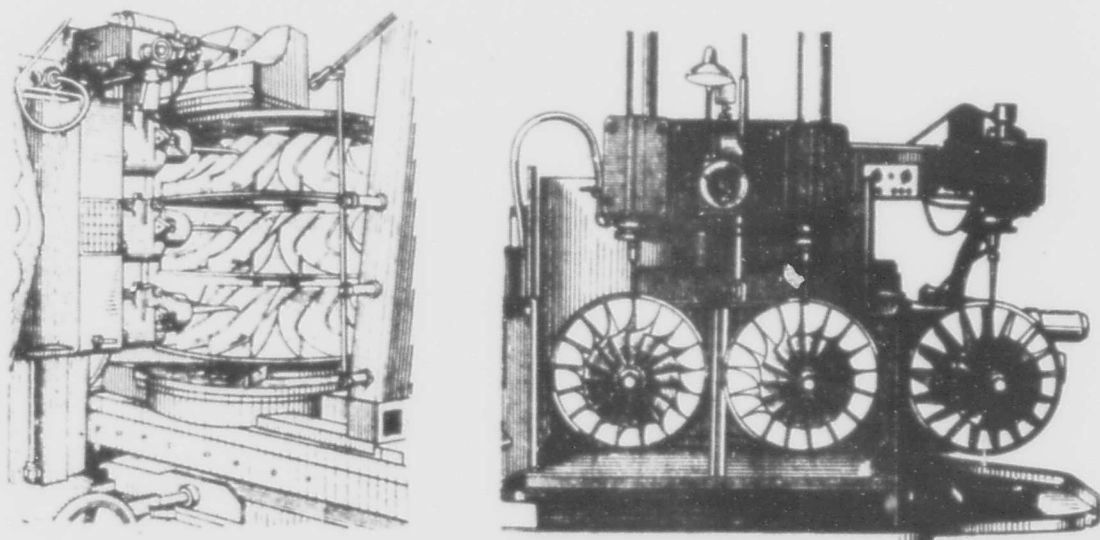


Fig. 4.17. Milling of impeller vanes on volume master form.

Impellers with sweptback vanes at the inlet are machined by the line method on copy milling machines with horizontal or vertical

location of spindles (Fig. 4.17). The intake portion can be formed by means of bending the vanes in stamps (Fig. 4.18). This operation is produced no later than 2-3 hours after hardening before aging, when the material still possesses good plastic properties. The die of this stamp, in the form of one or several wedges, is placed between the vanes and is secured in this position by a powerful clamp. The punch is secured on the upper mobile part of the press. The form of the punch and die is finally selected experimentally, taking into account the elastic release of the vanes after bending.

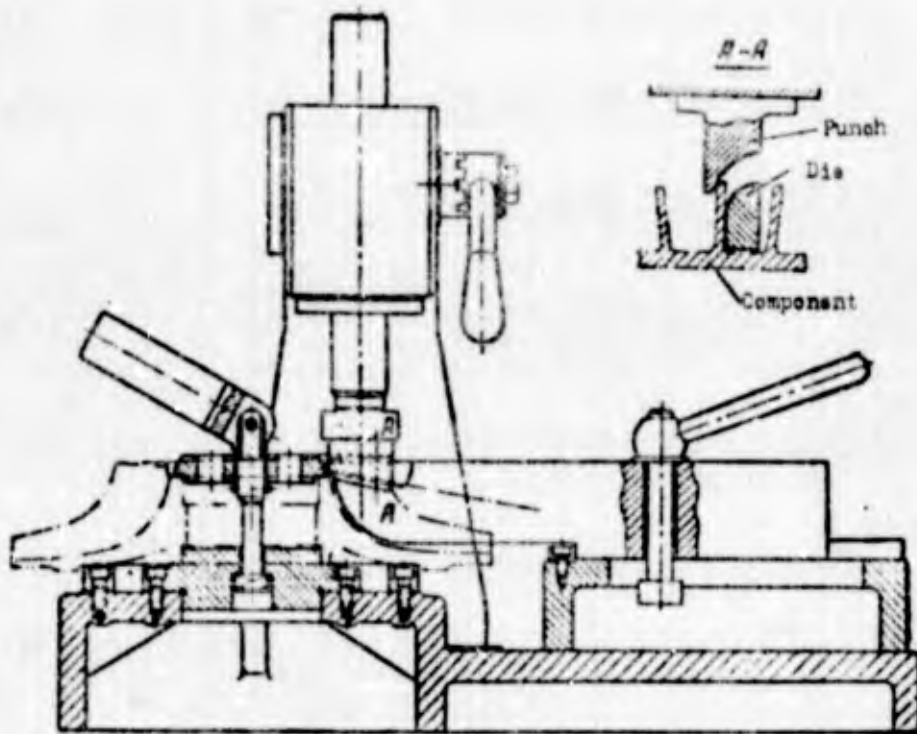


Fig. 4.18. Bending of vanes in stamp.

Straight vanes of two-sided impellers are roughed and finished also in different operations, on the same machines. Rough milling of vanes and the webs between them is produced simultaneously, using a special attachment.

Finish milling of lateral vane faces is produced by one cutter alternately from each side, using dividing attachments. After finishing of vanes, the web is finish-milled.

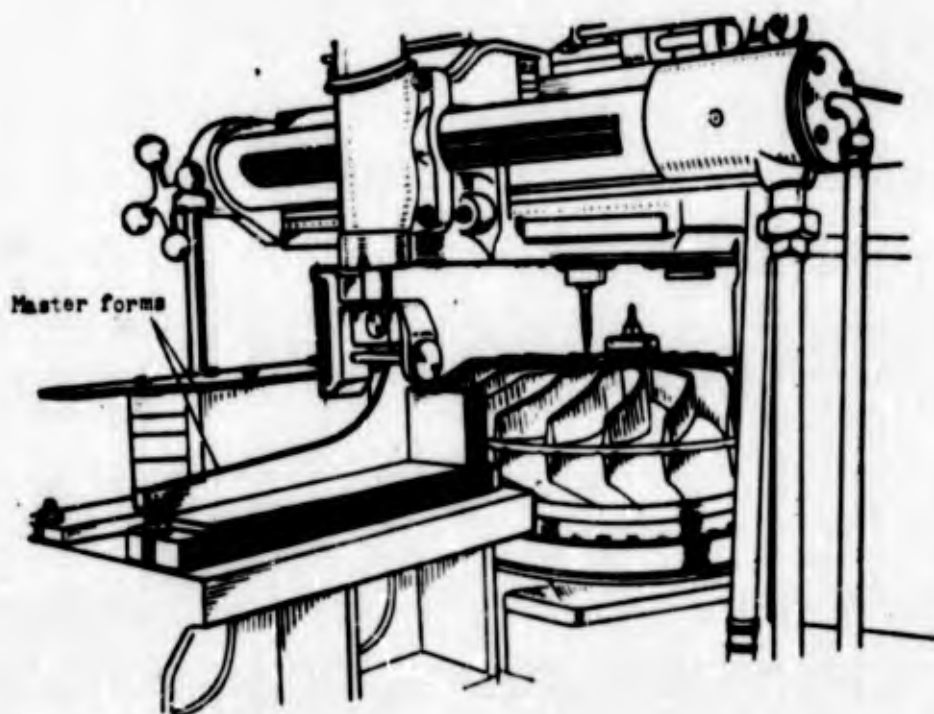


Fig. 4.19. Milling of curved vanes on vertical hydraulic copy milling machine.

Impellers with curvilinear vanes are machined in the same sequence as those with straight vanes. For facilitating rough milling of vanes in the beginning, if possible, straight narrow radial slots are made in the cavity between vanes on horizontal milling machines. Lateral faces of curvilinear vanes are rough- and finish-milled on copying machines with hydraulic servosystems and on machines with electronic control. Installation of the impeller and the diagram of treatment of vanes on the hydraulic copying machine is shown in Figs. 4.19 and 4.20. On this machine the lateral surfaces of curvilinear vanes are milled by a face cone cutter. The head with the cutter has transverse and vertical motions which are controlled by two valves of the hydraulic copying mechanism. The roller tips of valves 1 and 2 maintain constant contact with the flat master forms during longitudinal mechanical motion of the table together with the master forms and impeller. The vanes are alternately processed after every turn of the impeller in the dividing attachment.

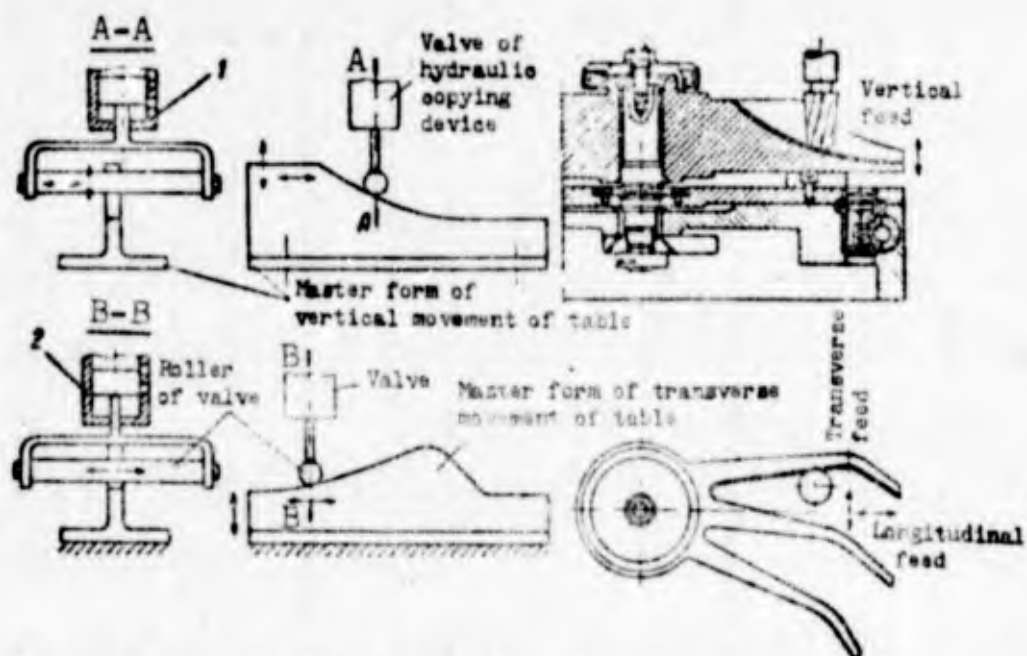


Fig. 4.20. Diagram of treatment of curved vanes on a hydraulic copying machine.

The right and left lateral faces of the vanes are milled in different operations, first one side of the vane, and then the other. The remaining untreated web (the interval between vanes) is milled by an end cutter by the line method on the same machines.

After treatment of the web by the line method, the surface is very rough. The productivity of this method is rather low. These circumstances must be considered in the determination of the allowance for subsequent treatment and the required quantity of machines.

Treatment of holes and threading. In the execution of these operations it is important to ensure the required location of the axes of exact holes with respect to the faces and axis of the component. Holes are drilled and countersunk on radial drilling machines with the help of plate jigs. The jig plate is placed on the face of the impeller and centered on the exact cylindrical band of the component with angular fixation on one of the vanes with the help of a prism.

The jig bushings for tool direction are quick-change. The thread is cut in the holes from the same installation, whereupon the

jig bushings are removed.

Assembly and soldering of shrouded impellers. Soldering of the cover to the body of the impeller is produced in electric furnaces by solder with an addition of flux. Before assembly for soldering, the clearance between the cover and the body of the impeller is checked, and then chemical purification (etching) and degreasing is produced. The clearance should be 0.1-0.2 mm for impellers having a diameter of 100-250 mm. If the actual clearance is larger than that shown, then the cover and the body are fitted in place. The mutually selected position of the cover and the body is fixed by marks.

Before setting in furnace, the body of the impeller is assembled with the cover and secured in a special attachment made from heat-resistant metal. The cover is secured to the body of the impeller either mechanically or by a clamp in several spots by electric welding.

The solder for aluminum impellers is Silumin or alloys on an aluminum base with the addition of copper and silicon. Selection of a hard solder for steel impellers depends on the material of the impeller and the specified seam strength.* Most frequently, solder Psr-25 is used, which contains 25% silver. Solder in the form of a narrow tape 0.1-0.2 mm thick is put between the surfaces to be soldered and fastened to the cover mechanically or by spot welding. Solder is also applied in the form of wire that is packed along the seam. A flux in the form of fine powder or paste is put on the heated impeller near the seam.

*More specific details of soldering may be seen in Chapter VII.

After soldering, the impeller is chemically and mechanically cleaned and thoroughly washed.

Final treatment of external surfaces. This operation is one of the critical ones in the technological process; upon its completion the basic requirements set up by the technical specifications must be satisfied. Final treatment is produced on turning lathes or turret lathes. The component is placed with its hole on a precision mandrel (hydraulic would be better). Surfaces that are stipulated by specifications of exact mutual location are processed on one installation (Fig. 4.21).

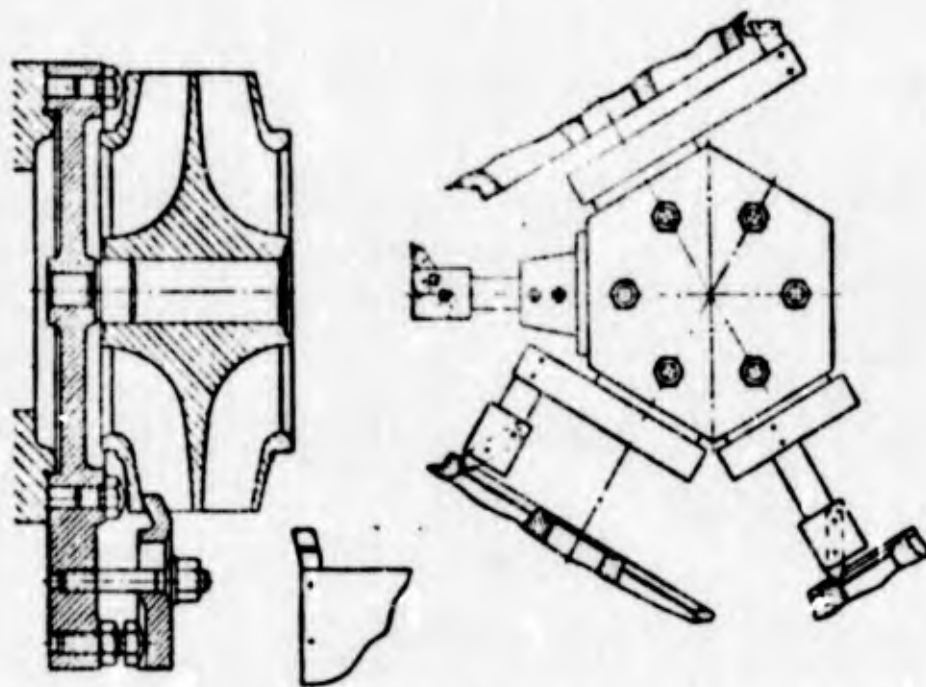
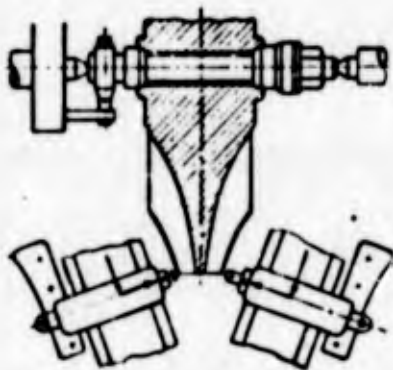


Fig. 4.21. Treatment of two-sided impeller on turret lathe.

Large, two-sided compressor impellers are placed on a mandrel by their center faces. Seating bosses and face planes are processed on two sides with one installation of the component, which gives the highest accuracy with respect to concentricity and interperpendicularity of impeller surfaces. Before machining the vane contour, in order to avoid rejects, the component is aligned on centering bands

with the help of an indicator. The vane contour is turned on the



master form simultaneously on two sides (Fig. 4.22). During machining of the external surfaces of the intake impellers there can appear strong vibration of vanes, in consequence of which the surface of treatment

is rough. In order to avoid this, on part of the support end of the attachment there is placed a rubber ring into which the ends (edges) of the vanes are pressed during fastening of the component.

Finishing of vanes and channels. Trimming and polishing of impellers are very labor-consuming and critical operations which affect the quality of work of vaned machines. Questions of mechanization of these operations, especially polishing, constantly attract the attention of technologists. Transitions on vanes and in channels are trimmed by cutters with the help of drills. On small scales of production, vanes are polished by felt polishing wheels with glued abrasive grain.

Heavy components usually are suspended from a long rope, which facilitates their feed to the polishing wheel. The operation is divided into transitions of rough and finish polishing. In rough polishing, felt wheels with an abrasive of medium granularity are employed, and in finish polishing, coarse calico wheels with a finer grain are used. The polishing operations are presented with high requirements both with respect to surface purity, and also accuracy, and its fulfillment is assigned to a skilled worker.

Work sites in the polishing section should be equipped with effective ventilation with suction directly at the place of treatment.

Metallic and abrasive dust should not enter the respiratory organs of the worker.

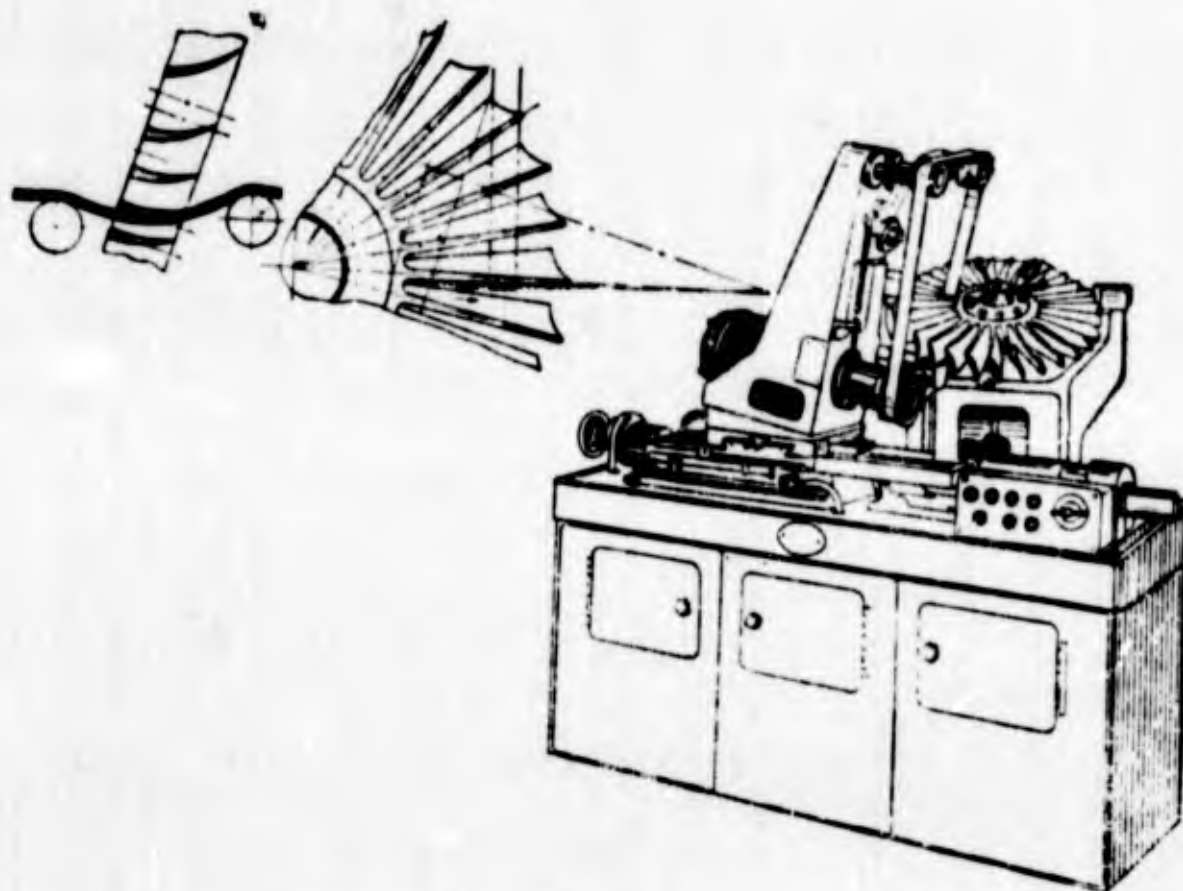


Fig. 4.23. Polishing of the back of an intake vane by means of an abrasive belt.

In batch production the polishing process should be mechanized. There exist different methods of mechanization, namely: vanes of unshrouded intake impellers are polished on special machines and installations; the back of the vane is polished by an endless abrasive belt (Fig. 4.23); the bucket is polished on a machine whose spindle is equipped with a circular cone polishing wheel.

Vanes of semishrouded impellers are polished in several operations. The polishing setup is similar to that of finish milling: the lateral faces of the vanes are polished first, and then the web is polished on rockers (Fig. 4.24). Rough polishing is produced by NIAT-10 elastic polishing wheels whose base is a thin steel disk

covered by a vulcanite bond with abrasive grains. To avoid pile-up of the web edge during polishing, a steel track is set before it at the inlet of the polishing wheel.

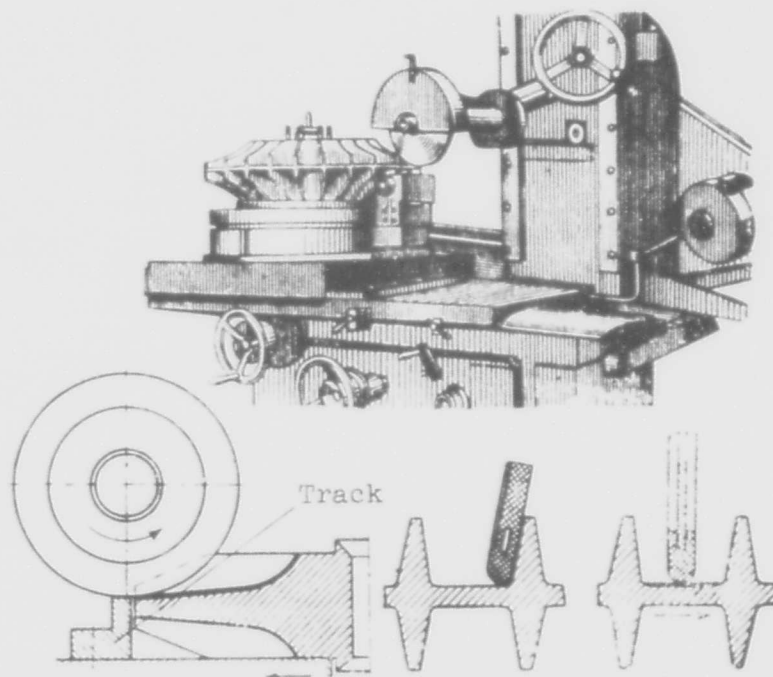


Fig. 4.24. Mechanical polishing of vanes and webs of semishrouded impeller.

Finish polishing is produced by the same arrangement, but by a felt polishing wheel with glued abrasive. In rough polishing with NIAT-10 polishing wheels, an abrasive with granularity of 50-40 is used; in finish polishing, a granularity of 12-10, whereby a purity of the 8th-9th class is attained.

Channels of shrouded impellers are trimmed by straight-sided milling cutters. There are no effective methods for polishing channels at this time. One of the high-priority problems of decreasing the volume of trimming operations is the obtainment of a casting with high surface purity of channels.

Balancing of impellers. Static balancing of impellers is produced on blades to the state of neutral equilibrium. Dynamic balancing is produced in the rotor unit. Best results from the point of view of decreasing motor vibration is given by two-stage balancing: first separate, i.e., for each component in the rotor unit, and then the entire rotor. During balancing, the metal is usually removed from the webs between vanes, and for intakes, it is removed from the surface of the back around the external diameter.* Before balancing, intake vanes are accelerated at the specified frequency of natural oscillations by means of removal of a thin layer of metal from the backs.

§ 4. CHECKING OF IMPELLERS

Frequency of natural oscillations of intake vanes is checked on a special vibration stand (Fig. 4.25).

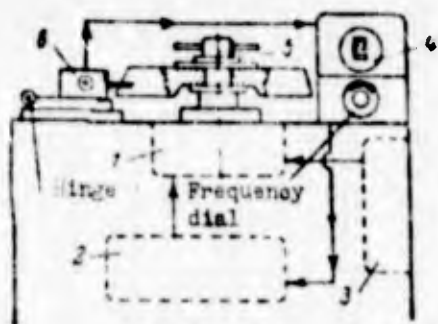


Fig. 4.25. Arrangement for checking the frequency of natural oscillations of intake vanes. 1) audio-frequency generator from 1500 to 2000 cps and vibrator; 2) low-frequency amplifier; 3) amplifier with rectifier for transducer; 4) cathode oscilloscope; 5) device for fastening component; 6) electrode capacitor transducer.

Audio-frequency from the generator is sent to the input of the amplifier, to whose output the field coil of the vibrator is connected. Oscillations of the vibrator are transmitted to a device with the component secured to it. Oscillations of the component are perceived by the electronic capacitor transducer which is connected to the

*For details concerning balancing, see the training aid by V. N. Blikov and A. N. Nikitin, *Assembly of Aircraft Engines, "Machine building,"* 1964.

the back of the vane with a clearance of 0.5 to 1 mm. Oscillations are converted into voltage which, after amplification, is sent to the vertical plates of the oscilloscope. On the screen of the oscilloscope there then appears an image in the form of a rectangle.

Upon coincidence of the frequency of oscillations of the generator (by means of turning the frequency dial) and the natural frequency of oscillations of vanes (resonance), the rectangle will have maximum height. Frequency of resonance oscillations is determined by the reading of the dial.

The frequency of oscillations is usually checked for all intake vanes, but for acceleration of the check a transducer is connected only to one vane. After reaching the resonance state of one vane, all remaining vanes are alternately resounded with help of a ball 5-6 mm in diameter. Upon contact of the ball (soldered on wire) alternately with all vanes, the tone of sound should be identical with the tone of the vane in which the transducer is located.

Check of run-out of exact surfaces, in accordance with the technical specifications, is one of the most critical operations. For

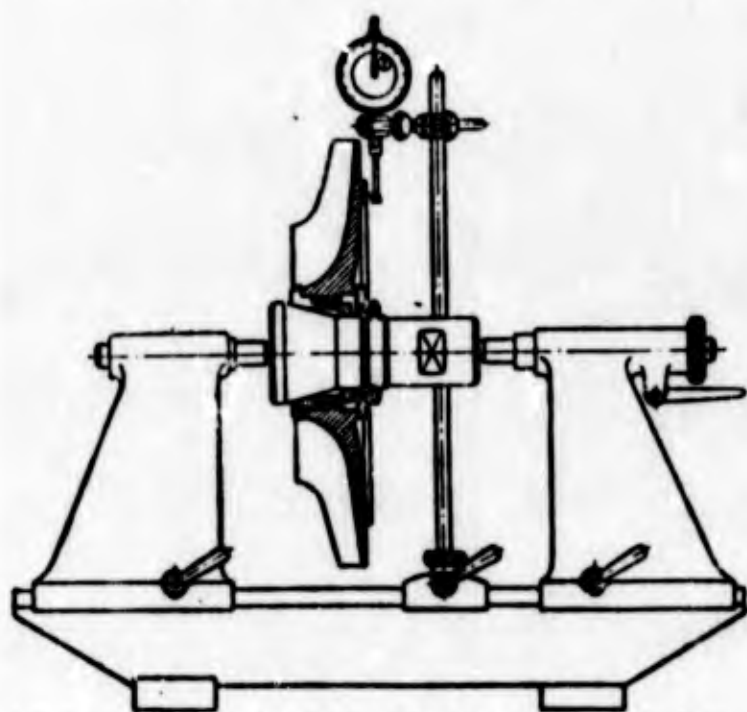


Fig. 4.26. Check of run-out of impeller surfaces.

this purpose, the impeller is placed on a center mandrel, and the magnitude of run-out is determined by the indicator (Fig. 4.26).

Angular location of vanes is checked with the help of templates and indicator instruments. The template is fastened to the impeller after one of the vanes is exactly combined

with its spokes. Further, by transferring the instrument, the displacement of the remaining vanes with respect to the template's spokes is checked. The template is placed through the hole or band of the impeller.

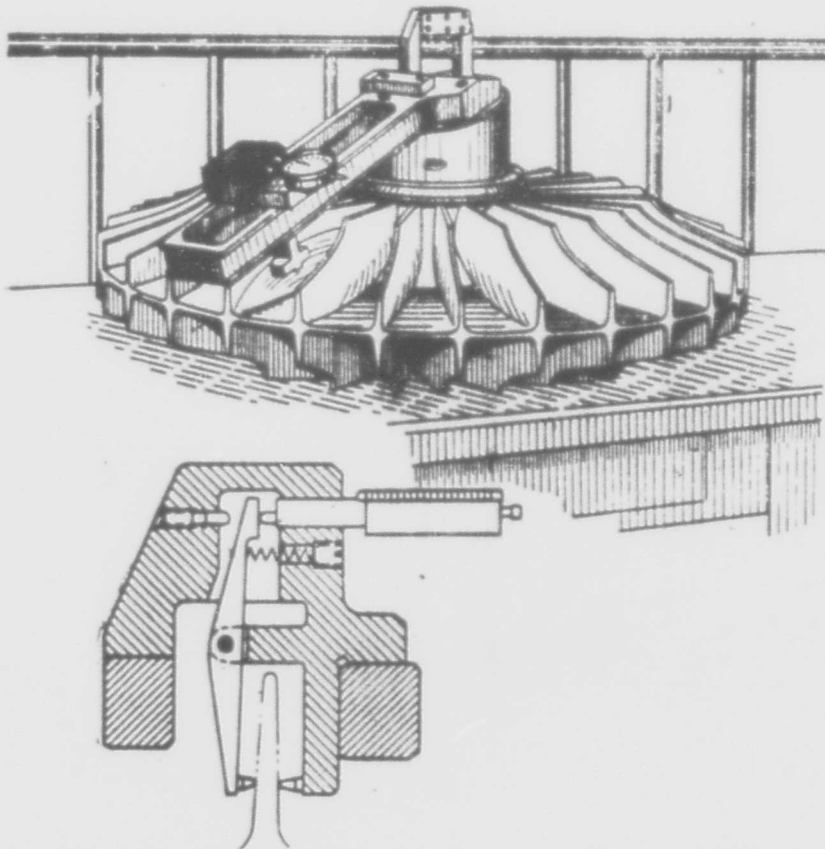


Fig. 4.27. Check of vane thickness along line of constant thickness.

Thickness of vanes is checked along the line of constant thickness (Fig. 4.27). The checking device with adjusting element (mandrel or ring) under the fitting of the impeller has guides for setting and moving the indicator device. The guides are inclined at an angle in the direction of the line of constant thickness. During the check for thickness, the instrument moves along the guide, the fixed needle instrument should be pressed to one side of the vane, and the needle

of the indicator lever slides along the line of the other side. The instrument is preliminarily tuned on a measuring plate.

Profile of vanes of unshrouded impellers (intakes) are checked by templates in three sections at different radii.

CHAPTER V

PRODUCTION OF GEARS

§ 1. DESIGN, TECHNICAL SPECIFICATIONS, AND MATERIALS

Critical gears of aircraft engines work with large loads at high speeds. This especially pertains to reduction gears of turboprop

engines, where the loads reach 700-800 kg ($\approx 7000-8000$ newton) per one centimeter of tooth length, and speeds from 70 to 80 m/sec. They must be light and reliable in operation. The necessity of decreasing mass leads to complication of the form of gears, and forces them to be made thin-walled and delicate. The form of certain gears is shown in Fig. 5.1.

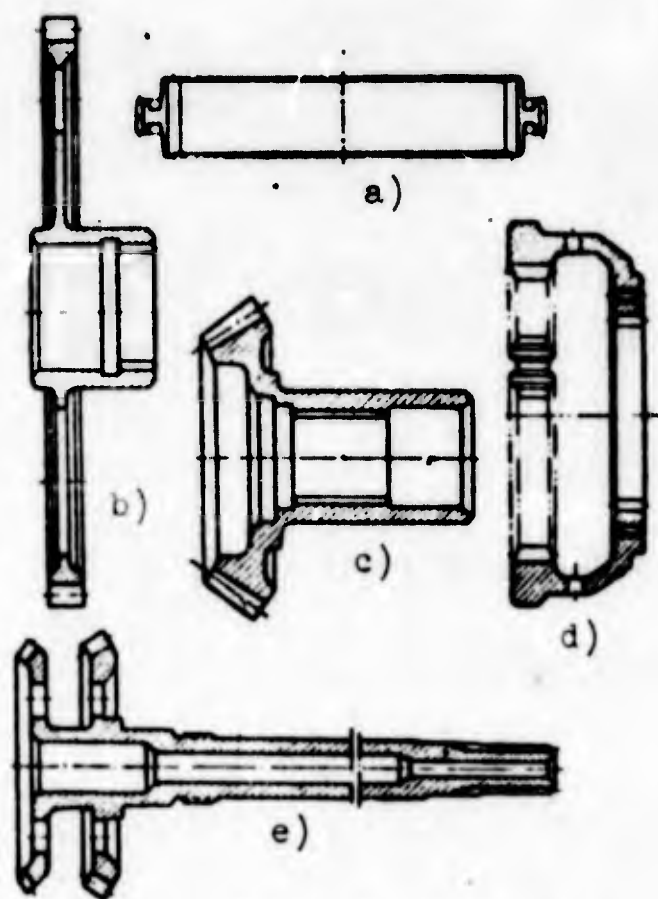


Fig. 5.1. Form of gears. a) crown without hub; b) crown with hub; c) bevel with shaft; d) bell; e) bevel block.

More often than others we encounter straight external spur and bevel gears. The locating (datum) surfaces of these gears are clearance or splined holes, and also

the journals on hubs and shafts, usually made according to the 2nd

accuracy class. Internal crown-spur gears are sometimes equipped with external involute splines (Fig. 5.1a).

The required quality of gears, which determines their, operational reliability, is ensured by the thoroughness of finishing, the application of alloyed steel, the appropriate heat treatment, and in certain cases, the improvement of the standard tooth profile (Fig. 5.2). Accuracy of manufacture is one of the decisive factors and is regulated by tolerances according to the following standards:

GOST 1643-56 for spur gears with moduli from 1 to 50 mm and pitch circle diameters up to 5000 mm;

GOST 1758-56 for bevel gears with moduli from 1 to 30 mm and pitch circle diameters up to 2000 mm;

GOST 3675-56 for worm gears with axial moduli (for unregulated location of gear and worm) from 1 to 30 mm and gear diameters up to 2000 mm, worms up to 400 mm, with moduli (for adjustable location of gear and worm) from 1 to 16 mm, and gear diameters up to 5000 mm.

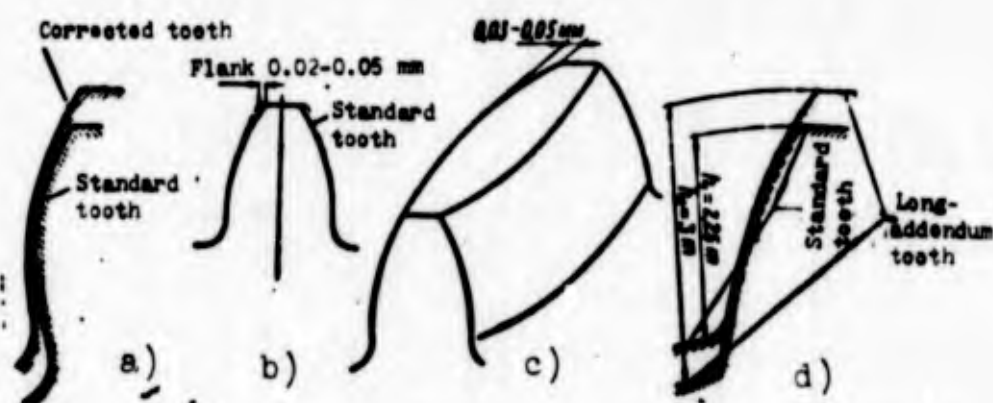


Fig. 5.2. Form of improved teeth. a) corrected tooth profile with positive shift; b) flanked tooth profile; c) elliptoid tooth; d) long-addendum tooth.

Besides those indicated, there is GOST 9178-59 for small-modulus spur gears with moduli to 1 mm and gear diameters to 500 mm.

In each of these GOST's 12° of accuracy are established, but allowances are not worked out for all degrees. Norms are established for every degree of accuracy: 1) kinematic accuracy; 2) smoothness of work of gear; 3) contact of teeth. Besides this, independently of the degree of accuracy, side play norms are established for different forms of couplings.

The accuracy of manufacture of spur gears is set by the degree of accuracy and the form of coupling with respect to side play and it is conditionally designated in the following way: St 7-Kh GOST 1643-56, which signifies: a gear of the 7th degree of accuracy with side play in the coupling Kh and according to GOST 1643-56.

If necessary, the accuracy of one gear can be specified by different degrees of accuracy; thus, for example, St 8-7-7-Sh GOST 1643-56, which signifies a gear of the 8th degree of kinematic accuracy, 7th degree with regard to smoothness of work, 7th degree with respect to contact of teeth, and with side play of coupling "Sh."

Parameters of kinematic accuracy:

kinematic error - ΔF_{Σ} ;

accumulated error of circular pitch - Δt_{Σ} ;

run-out of profiles - e_0 ;

oscillation of length of total normal - $\Delta_0 L$;

oscillation of center-to-center distance per gear revolution - $\Delta_0 \alpha$;

generation error - $\Delta \theta_{\Sigma}$.

Norms of smoothness of gear operation determine the magnitude of the components of total error of angle of gear rotation repeated in a full revolution. These norms contain the following errors:

profile - Δf ;

base pitch - Δt_0 ;

Table V. I

Brand of steel	State of Finished Component						
	Type of heat treatment	Temperature of heating °C	Cooling medium	$\bar{\sigma}^1$ Kg/mm ²	δ %	Hardness	
						core HB	surface HRC
<u>1. Hardened steel</u>							
37KhNZA ²	Hardening Tempering	820 525-575	Oil Air	115	10	352-415	—
40KhNMA ²	Hardening Tempering	850 580-620	Oil Water	110	12	293-375	—
18KhNVA ²	Hardening Tempering	860-870 150-170	Air Air	120-115	10-12	321-388	—
38KhA	Hardening Tempering	860 510-540	Oil Water	95	9	363-302	—
<u>2. Case-hardened</u>							
12KhNZA	Hardening Tempering	780-800 150-170	Oil Air	90	12	262-363	} After carburi- zing and hardening 58-62
18KhNVA	Hardening Tempering	840-850 150-170	Air Air	120-115	10-12	321-388	
18KhNVA	Austem- pering	840-860	Salt- peter 220 ± ± 20°	} 115	10	321-363	
	Tempering Sub-zero treatment Tempering	540-560 -60 to -70 150-170	Air Air				
<u>3. Nitrated steel</u>							
38KhMYuA	Hardening Tempering	930-950 610-650	Oil Water	100 ³	9	302-340	} After nitra- tion >70
38KhMYuA	Hardening Tempering	930-950 590-670	Oil Water	100	9	302-340	

¹Kg/mm² ≈ 10⁷ newton/m²

²Steels 37KhNZA, 40KhNMA, and 18KhNVA undergo high-temperature tempering after normalization at 650-670°C.

³Components made of steel 38KhMYuA with a cross-section more than 20 mm are quenched in water.

oscillation of center-to-center distance on one tooth - $\Delta_{\gamma\alpha}$;
circular pitch - Δt , and others.

Norms of contact of teeth determine the accuracy of fulfillment of relative dimensions of the contact spot in the teeth of matched gears. These norms contain the following parameters: dimension of surface of gear-contact pattern, misalignment of teeth, nonparallelism, misalignment of axes, and others.

Approximately the same norms of accuracy and side plays in teeth are introduced in the GOST's for bevel gears and worm gears.

On the basis of the indicated standards, in the aviation industry branch normal 341AT has been developed (in exchange for 107MT) for spur and bevel gears. According to this normal, accuracies St 5-4-4-Kh, St 6-5-5-Kh, St 7-6-6-Kh, and St 8-7-7-Kh are recommended for spur gears. For bevel gears, St 6-Kh, St 7-Kh, and St 8-Kh, with tooth surface purity for spur gears from the 10th to the 6th class and for bevel gears the 7th and the 6th class.

Gears of aircraft engines in most cases ^{are/} carburized or nitrated. Depth of the carburization layer is usually maintained at 0.7 to 1.2 mm, and the nitration layer from 0.3 to 0.6 mm.

The material for the gears is high-quality steel. The brands of steel, their mechanical qualities, and heat treatment data are given in Table V.1.

§ 2. CONSTRUCTION OF THE TECHNOLOGICAL PROCESS

General Position

Blanks of gears (Fig. 5.3), as a rule, are drop-forged in dies on horizontal forging machines, or on presses. The stock material is basic for all blanks. Die forging ensures direction of fibers in conformity with the form of the component. The position of the parting

line of the dies is determined by the form and dimensions of components. Blanks of crown and bell gears are drop-forged on the face, and the blanks of pulley blocks and certain gears with long shafts are die-forged, placing the parting line along the axis of the component.

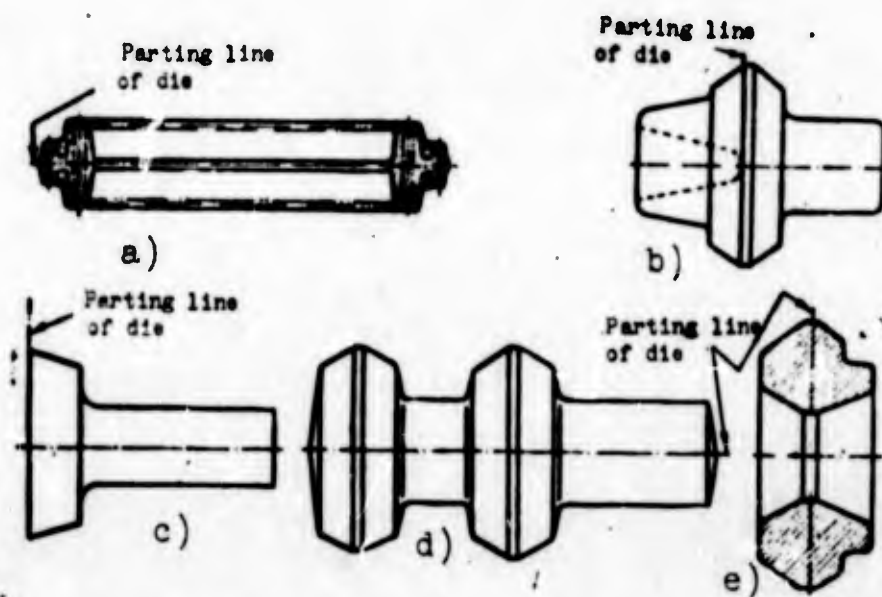


Fig. 5.3. Gear blanks. a, d, e) drop-forged in closed dies; b) forged on horizontal forging machine; c) upset in an open die on a press.

Blanks for large crown gear can also be obtained by the rolling method.* Blanks of gears with shafts (Fig. 5.3c) can be obtained by upsetting with electric heating. This method is sometimes called electro-upsetting. It has been used with success for the manufacture of blanks of various bolts, and also small blades (upsetting of locks), and other similar components. Electro-upsetting has been applied relatively recently, but, owing to its high productivity and operational convenience, this method is spreading quickly in industry.

For reducing machining and increasing the strength of gears, they have recently started making blanks with teeth. Such blanks

*Considered in detail in Chapter VI.

are made by centrifugal casting, drop die-forging, hot and cold rolling, and by pressure molding through toothed dies.

Gear blanks enter the machine shops in annealed form or normalized with scale removed. In certain cases, instead of the usual annealing, blanks are subjected to isothermal annealing. In such annealing, the hot blank taken from the die is exposed for a certain time at constant temperature in a salt bath. After isothermal annealing, the blank has no scale.

Allowances for treatment (determined according to norms) are usually within the limits of 4-6 mm at the diameter. For blanks made from nitrated steel (38KhMYuA) the allowances are increased by 2-3 mm. This is done to keep the alloyed elements from burning out during heating.

Machining of gears can be divided into three basic stages: rough, finish, and trimming.

The rough stage consists of stripping operations in which up to 60-70% of the entire allowance for treatment is removed. On this stage, equal distribution of allowances for further treatment is attained and surface defects of the blank are eliminated.

In the finish stage, up to 30% of the allowance is removed and the component is given its final form. This stage is characterized by the use of high-precision machines. The gear-cutting operations are included in the finish stage.

The trimming stage includes operations whose execution provides the specified accuracy and purity of working surfaces.

The sequence of operations within each stage is determined mainly by the selection of the setting bases. Crown and bell gears, for instance, are treated in each stage from the face and hole, and then the top and teeth are treated on the base of these surfaces.

However, in the last stage this rule is sometimes disregarded, and the holes are finally treated on the base of the working surfaces of the teeth. This, for instance, is the sequence followed in the treatment of gears having bronze bushings. The sequence here is changed due to the danger of damage to the bushing hole, which could occur during installation of the gear on a mandrel.

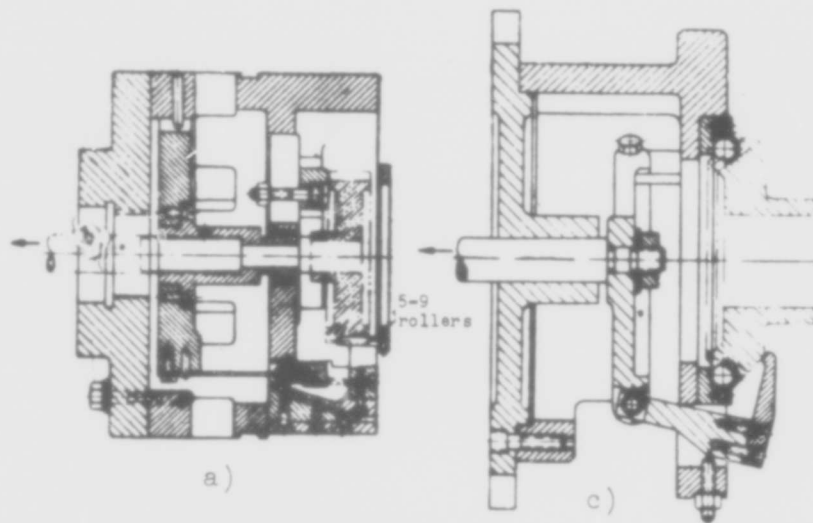
The same sequence is followed (hole is processed on tooth base) also after heat treatment, if the teeth are subsequently not processed (for instance, in many bevel gears), or if during subsequent treatment a small allowance is removed (usually in nitrated gears).

The use of teeth as a setting base for machining of a hole in these cases is stipulated by the necessity of correcting the errors in mutual location of teeth and locating surfaces which appear during heat treatment.

Installation of gears by their teeth is produced on rollers, balls, or toothed sectors in special chucks (Fig. 5.4). Installation of bevel gears with a large angle of initial taper is not always stable; therefore, in such gears, after heat treatment, they sometimes scrape the faces of the center holes with check of run-out along the tooth cavities. The corrected faces serve as the setting base for all subsequent operations.

Holes in disks, flats, and various extractions for lightening are processed usually in the second stage, i.e., before heat treatment. Splines, threads, and key grooves, to avoid damage, are processed after heat treatment. Metal-coating and oxidizing is produced after final check of components.

The place of heat treatment is determined by its form, and also the shape and dimensions of the gears. Large components, which are subjected to heat treatment, are hardened usually after roughing.



GEARING
 REPRODUCIBLE



Fig. 5.4. Chucks for installation of gears on cavities between teeth.
 a) roller for spur gears;
 b) sector for spur wheels;
 c) ball for bevel gears.

Before roughing, only gears of small dimensions with small allowances for treatment are hardened. In this case there is no danger that the component will not obtain complete heat treatment.

Very frequently, carburization and hardening of gears is produced after the second stage of treatment, whereupon certain surfaces can have an increased allowance for subsequent treatment. For instance, if the component has a surface with threads or small splines, then before carburization, besides copper plating, on these surfaces an increases allowance is left, which is removed after carburization, thus forming a surface on which it is possible to cut fine threads or splines without the risk of their breaking-off.

For decrease of warping, hardening of disks and other nonrigid

gears, and especially carburized ones, is produced in dies on a press (Fig. 5.5). The die, together with the pressed component, is lowered into the cooling medium, i.e., oil, during movement of the press.

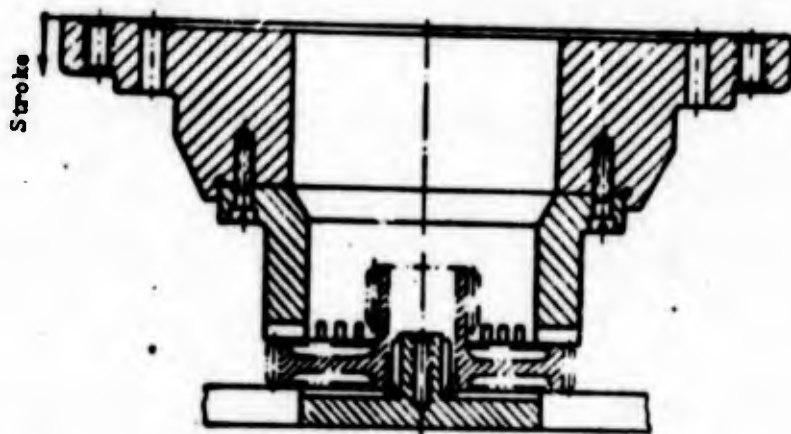


Fig. 5.5. Die for hardening of spur gears.

Large nitrated gears, in addition to the usual hardening and tempering in the blank or after the rough stage, are further subjected to stabilizing tempering after the finish stage. In this tempering the internal stresses which have formed during cutting in the operations of the finish stage are removed. Nitriding is usually done between preliminary and final grinding (or lapping) of teeth and in certain cases (when teeth cannot be ground), after shaving.

Grinding of teeth before nitration reduces the allowance for finishing operations and thus preserves high surface hardness. So that warping is minimum, it is recommended to employ the isothermal process of nitration at $520-540^{\circ}\text{C}$. In this process the surface quality of the components is usually higher than in the stepped process, although the furnace efficiency is lowered in this instance.

Model Plans for the Production of Gears

Carburized gears.

1. Heat treatment — normalization.
2. Rough stage of treatment:
 - a) roughing of end and hole;

- b) roughing of other end;
- c) roughing of top.
- 3. Finish stage of treatment:
 - a) turning of end and boring of hole;
 - b) exact boring or grinding of hole;
 - c) grinding of other end;
 - d) machining of top, hub, and disk;
 - e) treatment of holes and reliefs in disk;
 - f) cutting of teeth.
- 4. Copper plating of surfaces not subjected to carburization.
- 5. Carburization and hardening.
- 6. Stage of final treatment:
 - a) grinding of hole (or external surface of shaft);
 - b) turning under splines and threads;
 - c) cutting of splines;
 - d) threading;
 - e) finishing of teeth;
 - f) metal-working.
- 7. Final check.

Sometimes the gear is copper plated before cutting the teeth. However, this leads to lengthening of the cycle of treatment due to the additional transporting of components from shop to shop.

Nitrated gears.

- 1. Heat treatment - normalization.
- 2. Rough stage:
 - a) roughing of end and hole;
 - b) roughing of other end;
 - c) roughing of top.
- 3. Heat treatment - hardening and tempering.*
- 4. Finish stage of treatment:
 - a) turning of end and boring of hole;
 - b) exact boring or grinding of hole;
 - c) grinding of other end;
 - d) treatment of top, hub, disk;
 - e) treatment of holes and reliefs in disk;
 - f) cutting of teeth.
- 5. Stabilizing tempering.**
- 6. Treatment before nitration:
 - a) grinding of ends and holes;
 - b) grinding of gear teeth with allowance of 0.04-0.06 mm on a side.***
- 7. Tinning of surfaces not subjected to nitration, and parkerizing of open (untinned) surfaces.
- 8. Nitration.
- 9. Stage of final treatment:
 - a) grinding of hole (or external surface of shaft);
 - b) turning under splines and threads;
 - c) cutting of splines;

*For small gears it is produced before the rough stage.

**For small gears it is not produced.

***Sometimes it is replaced by shaving.

- d) threading;
- e) finishing of teeth;
- f) metal-working.

10. Final check.

The quality of treatment of gears depends not only on the plan and methods of treatment of separate surfaces, but also on the correct assignment of the magnitude of tolerance for treatment of teeth. Table V.2 gives the tolerances adopted in aircraft engine construction practice.

Table V.2. Tolerance for Teeth Thickness and Accuracy of Treatment of Gears with Modulus from 2 to 8 mm

Operation	Processed gears	Tolerance for tooth thickness, taken in the given operation, mm	Accuracy of treatment
Preliminary cutting of teeth (for gears with modulus more than 2.5 mm)	1. Spur 2. Bevel	-	7-8th degree
Final cutting of teeth	1. Spur 2. Straight-bevel	0.5-1.0	6th degree
Shaving of teeth	Spur with external and internal teeth	0.05-0.2	Increased by one degree
Preliminary grinding of teeth	Spur with external and internal teeth	0.2-0.3	No lower than the 6th degree
Final grinding of teeth after carburization and hardening	1. External spur 2. Internal spur 3. Straight-bevel	0.25-0.4	5th degree No lower than the 6th degree The same
Final grinding after nitration	1. External spur 2. Internal spur 3. Straight-bevel	0.08-0.12	5th degree No lower than the 6th degree The same
Lapping of teeth after carburization or nitration	1. Spur 2. Straight-bevel	0.02-0.04	No lower than the 6th degree

§ 3. EXECUTION OF BASIC OPERATIONS FOR THE PRODUCTION OF GEARS

Treatment Before Cutting of Teeth

Treatment before cutting of teeth basically gives the gears the form specified by the drawing. Special attention is given to the accuracy of surfaces which will serve subsequently as the setting bases. Sometimes with increased accuracy the surface of the external diameter of the crown is treated, although it also does not render an influence on the quality of coupling. Increased accuracy is necessary when this surface serves as the base during measurement of teeth, when it serves as the intermediate setting base for grinding of holes, or when in the installation of gears on gear-cutting machines it is necessary to resort to alignment along the external surface.

The basic operations preceding cutting of teeth are executed on turning lathes, multi-tool lathes, turret lathes, and surface grinders.

Turning lathes are used for the execution of operations, which consist of a small number of transitions: facing, boring of holes, machining of top, and so forth. Installation of the component, depending upon its form, can be carried out with the help of three-jawed self-centering chucks, in a chuck with tightened tail center, or on an alignment bar. Similar methods of installation are also employed in grinding operations.

On turret lathes they usually machine a large quantity of surfaces (Fig. 5.6) (figures indicate the sequence of transitions). The component, if it does not have considerable slopes, is set and secured, for instance, in a chuck along its hub. The hole is drilled first, then broached, and reamed twice. Thus, it is possible to make a very exact (up to the 2nd class) setting base with minimum withdrawal of

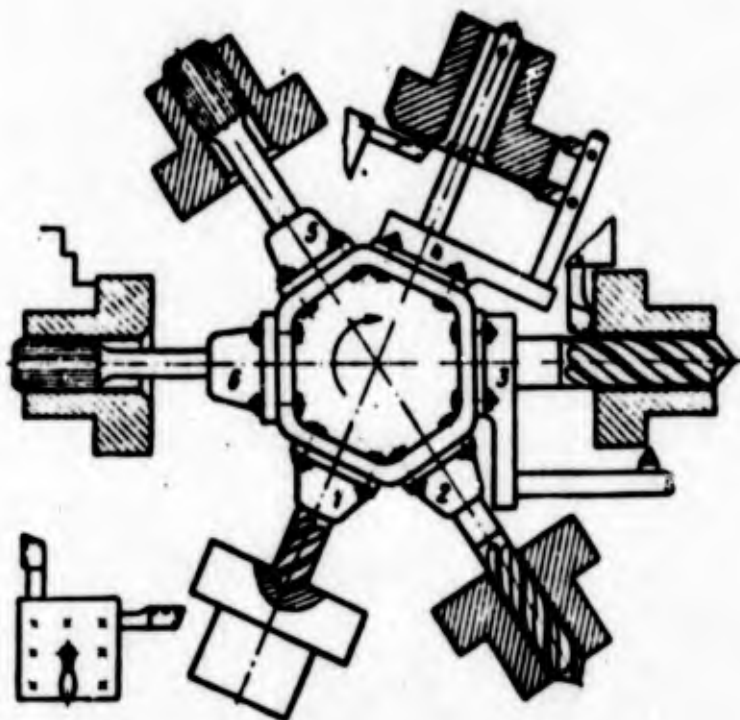


Fig. 5.6. Arrangement of turret lathe for machining a gear blank.

hole axis for subsequent operations. However, reaming of a hole in hard metals by reamers made from high-speed cutting steels and in holes with a diameter of more than 30 mm is impractical. In these cases they resort to exact boring or grinding. On turret lathes they produce both rough, and also finish machining, maintaining an accuracy of the 4th class.

Treatment of external surfaces and faces on large scales of production is executed on semiautomatic multi-tool lathes (models 1730 and

1721), copy machines 1722, semiautomatic multi-spindle model 1282, and on other similar machines.

Examples of treatment of external surfaces on semiautomatic multi-tool lathes are shown in Fig. 5.7.

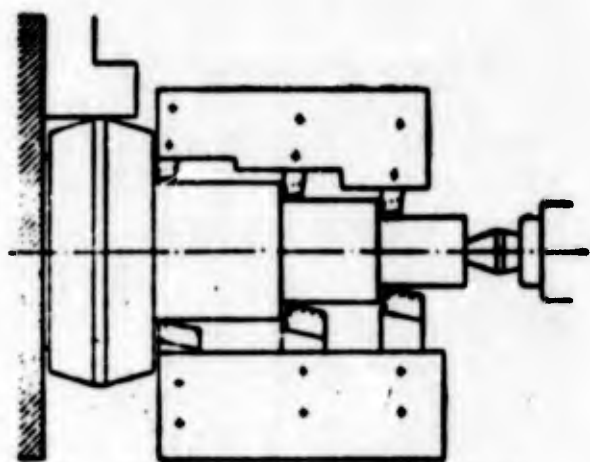


Fig. 5.7. Arrangement of semiautomatic multi-tool lathe for rough machining of blank.

In the arrangement of multi-tool lathes for machining of bevel gears special attention is given to the accuracy of treatment of the front and

rear bevels which will serve as the base for tooth measurement and adjustment of the gear-cutting machine. The accuracy of these surfaces is controlled by patterns.

On the same scales of production, for treatment of gears we frequently find the use of semiautomatic multi-spindle machines, type 1283, from the "Krasny proletariy" ("Red Proletarian") plant. On these machines it is possible to process gears with diameters up to 300 mm. Examples of arrangement are shown in Fig. 5.8.

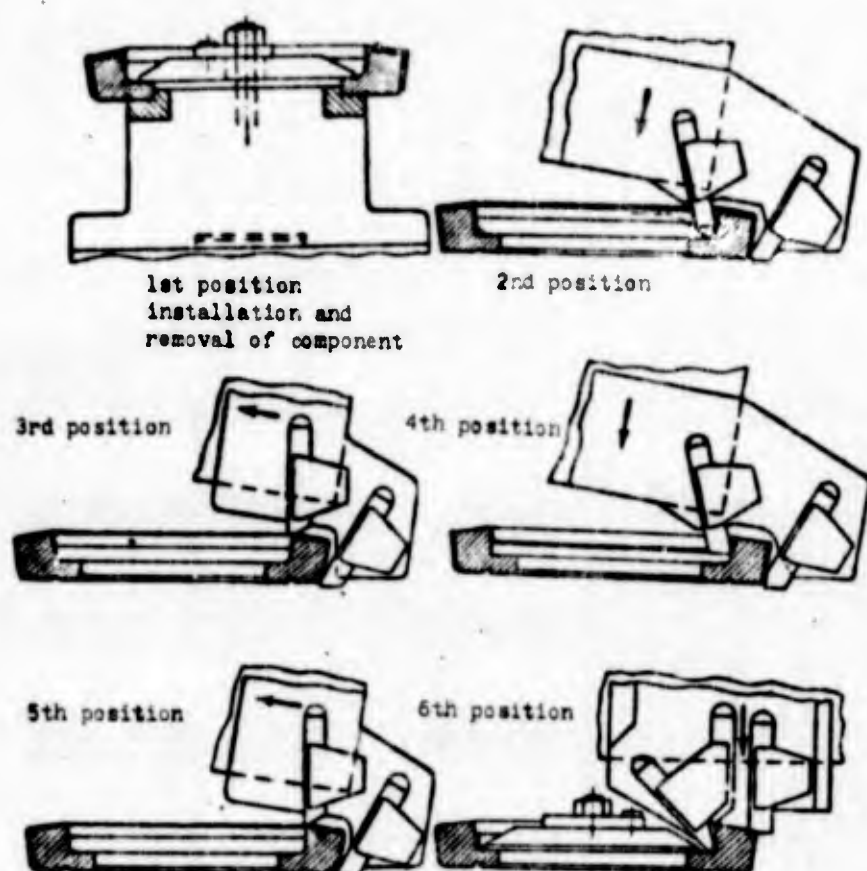


Fig. 5.8. Arrangement of semiautomatic six-spindle machine for machining of bevel gears.

For achievement of accurate installation of large and medium gears on gear-cutting machines, their holes or external journals must be ground together with the end in one operation. The gear is placed in a self-centering device on the external surface with support on the end. For accurate installation, as the support one should take the end which was turned in the preliminary operation after one installation with machining of the external surface. The second end is most frequently ground on surface grinding machines with installation

on the plane of the magnetic plate.

The external surface is ground on cylindrical grinders by placing the gear with its hole on a mandrel or on centers. A more exact fitting is attained by close installation on a cone or expanding mandrel, for instance, a hydraulic mandrel.

As a rule, gears are checked before cutting of teeth. Special attention is allotted here to the accuracy of location of the setting bases with respect to the external (or internal for internal gears) surfaces and support ends, which should be from 0.01 to 0.03 mm.

Cutting the Teeth of Spur Gears

In aircraft engine construction, the teeth of spur gears are cut according to the rolling method. Depending upon the form and dimensions of the gear, gear planers, gear millers, and gear shapers are employed for this purpose.

Gear Planning

Gear planing is a low-efficiency method of machining. In the cutting of gears by gear planing much time is expended for reconnection of the cutting tool (rack) in the process of rolling. Therefore, for spur gears with straight and slanted teeth, this method is rarely employed. It is usually applied for cutting double-helical gears with herringbone teeth. Cutting of double-helical gears on 515 "Komsomolets" machines or Parkinson machines (Fig. 5.9) is produced by two gear-shaper racks having 6-8 teeth with rectilinear profile. In the process of teeth cutting the double-helical gear revolves in one direction cyclically (with stops), and the two racks, accomplishing fast reciprocating motions along the cavities of the slanted teeth, move on a tangent to the initial circumference, thus producing rolling. The front planes of racks A-A always remain

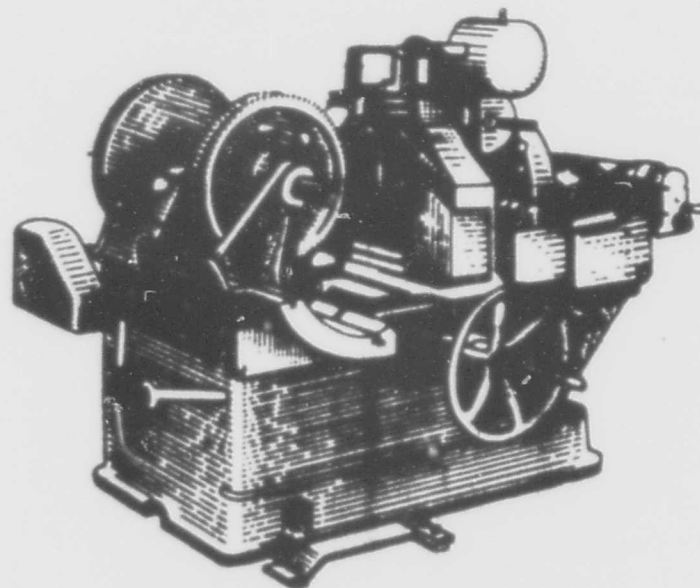
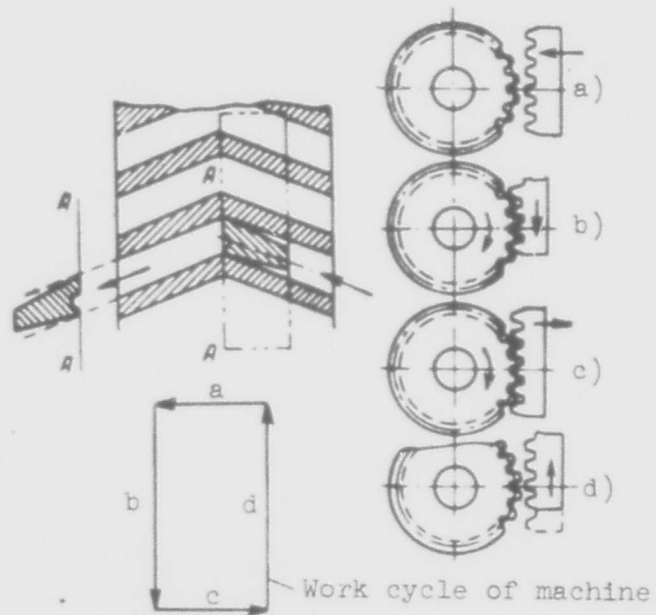


Fig. 5.9. Machine for herringbone tooth planing and diagram of motions of cutting racks in one cycle.

parallel to the end of the gear. Reconnection occurs after the rack teeth, reaching the lower point, complete the cutting of one, two, or three teeth. The processed gear then stops, and the racks return to the initial upper position; the rolling cycle is then repeated. The component is placed on the mandrel through the hole with support on the working end. Inasmuch as herringbone teeth cannot be ground, and the only method of finishing them after heat treatment (carburization with hardening or nitration) is lapping, cutting should be carried out with high accuracy (6th degree). This is ensured by exact fitting of the gear on the mandrel, using a set of several mandrels with different setting diameters or hydraulic mandrels which allow the fitting to be made without a clearance.

For increasing the accuracy of treatment of teeth, cutting is produced in several passes. For instance, a gear with modulus 6 mm is cut in three passes. In conditions of batch production the last pass is usually divided into a separate operation and it is executed on a higher-precision machine. The machining tolerance in this case should not exceed 0.8-1 mm on the thickness of a tooth. Purity of machining is of the 5th-6th class.

Gear Milling

External straight, and also slanted gear teeth are milled on "Komsomolets" gear-milling machines, machines of the Kolomensk Plant, Pfauter, Reinecker, Gould-Eberhardt, and others. The cutting tools are single-setting hobs, GOST 9324-60, multi-setting, and special hobs. On the various "Komsomolets" machines it is possible to cut straight spur gears with modulus up to 15 mm and external diameter up to 1500 mm. Larger gears with modulus up to 30 mm and diameter up to 5000 mm are cut on machines of the Kolomensk Plant. Helical gears are cut by the same hobs with the help of a differential device that

creates additional gear rotation on the machine for the formation of a slanted tooth. These machines cut the teeth of standard and hypoid worm gears. Gear milling can be carried out only when there is the possibility of inlet and outlet of the milling cutter without any interference that may be encountered during motion of the milling cutter in the direction of the feed in the form of projections or a row positioned flanges and crowns. Therefore, block gears with closely located crowns cannot be cut by this method. In spite of the fact that the teeth of spur gear of aircraft engines are usually ground, milling of them by grinding must be executed with a precision of the 7th degree (GOST 1643-56), ensuring a uniform grinding tolerance.

In the cutting of teeth the components is placed on a hole with a clearance of not more than 0.02 to 0.03 mm. The mandrel is preliminarily (during setup of the operation) aligned on the machine by an indicator with a precision of 0.01 to 0.015 mm.

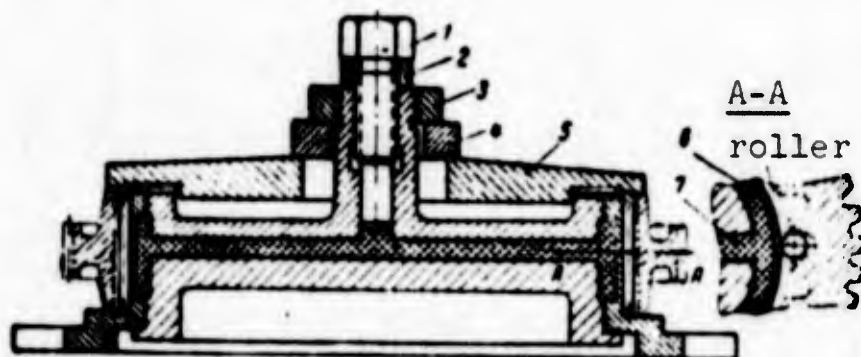


Fig. 5.10. Installation of gear with internal teeth on hydraulic mandrel along rollers.

For increasing the accuracy of installation (without a clearance) hydraulic mandrels are employed. An example of the application of a hydraulic mandrel is shown in Fig. 5.10, where the external teeth are cut in a gear that has internal teeth. In order to attain the exact

location of the external teeth with respect to the internal, installation is recommended along the lateral faces of the internal teeth on rollers. Before the gear is secured by disk 5 with the help of nut 3 (through split washer 4), by screwing in screw 1 a small pressure is created on hydraulic layer 7 which, being incompressible, increases the diameter of a thin bushing 6 and presses the rollers to the lateral sides of the internal gear teeth. The amount of pressure of rod 1 on hydraulic layer 5 is limited by calibrated washer 2 which does not permit large pressures and excessive deformation of the thin-walled bushing. Such mandrels are especially convenient and are reliable for the installation of gears along smooth cylindrical internal and external surfaces.

Flat gears (without projecting hubs) are best placed on the mandrel in several pieces (a stack); this increases the efficiency of gear cutting.

The number of passes in gear milling varies depending upon tooth modulus. Thus, gears with modulus up to 2.5 mm are cut in one pass, those with modulus up to 6 mm in two passes, and gears with modulus from 6 to 10 mm are cut in three passes.

In the practice of milling spur gears we find the use of one and two-setting hobs. The application of two-setting hobs increases the peripheral velocity of the gear and, thereby, increases cutting efficiency.

However, in cutting with a two-setting hob, due to the decrease in the number of cuts made on one tooth, the accuracy and purity of machining is lowered. Therefore, these hobs are employed for rough cutting.

The number of cuts (faces), which form the lateral tooth profile,

are determined in gear milling by the formula

$$K_0 = \frac{z_{\phi} \cdot \epsilon}{i}$$

where ϵ is the engagement factor of rack with processed gear;

z_{ϕ} is the number of teeth of the milling cutter (6-12) on a

i is the number of settings of the hob.

The magnitude of the engagement factor ϵ depends on the addendum of the rack or gear f'_K . For the rack, when $f'_K = 1.25 - \epsilon = 1.238$, $f'_K = 1 - \epsilon = 0.991$, and $f'_K = 0.8 - \epsilon = 0.7925$. Factors ϵ for spur gears are determined by the formula $\epsilon = k \cdot z_K$, and coefficient k , when $z_K = 14 - 80$ teeth, is found from the graph of Fig. 5.11.

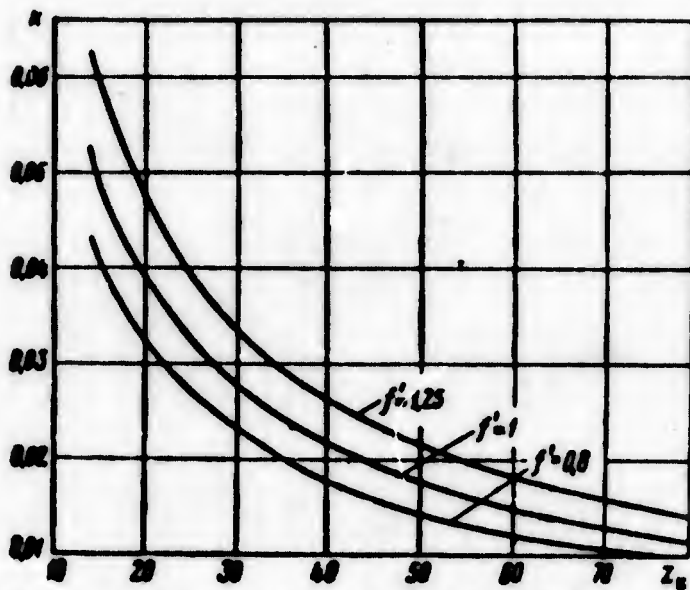


Fig. 5.11. Graph for determining the value of k .

The lateral surface of the tooth profile, which is cut by a hob on a gear-milling machine, is obtained with a face formed with 15-18 cuts, not depending on the magnitude of modulus. Thus, for instance, for milling a standard gear with $z_K = 30$, $f'_K = 1$, and $\alpha_{D.K} = 20^\circ$ with a hob with $z_{\phi} = 9$, addendum factor $f'_K = 1.25$, and num-

ber of settings $i = 1$, the number of cuts is

$$K_0 = \frac{(0.827 + 1.238) \cdot 9}{1} = 18.6 \approx 19.$$

For increasing the surface purity of teeth of spur and worm gears cut by hobs, and especially by the multi-setting type, it is recommended to introduce additional profiling with worm shavers without spiral grooves and with a large number of small teeth (Fig. 5.12). When making the shaving tolerance with these shavers, as shown in Table V.2, a surface purity of the 8th-9th class is attained.

Application of worm shavers is not required if the teeth of the worm

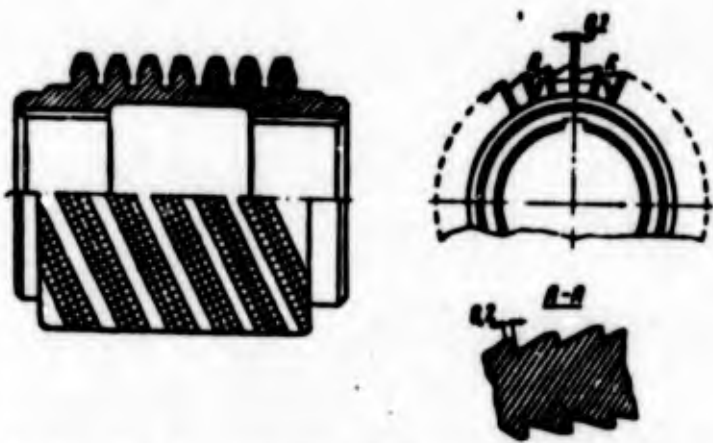


Fig. 5.12. Worm shaver for treatment of spur gear teeth.

gear have been milled by a single-setting or multi-setting milling cutter with axial feed.

In the cutting of gears with a small number of teeth by a tool of the rack type the tooth root is undercut. In a combination of certain conditions, gears with a large number of teeth can also be

undercut. Teeth are particularly undercut when they are cut with modified racks having a profile angle less than 20° . Therefore, in the selection of the cutting tool it is very important to know the conditions in which the teeth roots will be undercut.

For the solution of this problem in general form, a formula is given which makes it possible to calculate the z_{\min} of an external straight spur gear in which the tooth root will not be undercut:

$$z_{\min} = \frac{2 [f_K'' - f_r (1 - \sin \alpha_n)]}{1 - \cos \alpha_{d.k} \cos \alpha_n}$$

where $f_K'' = h_K''/m$ is the gear dedendum factor;

$h_K'' = r_{d.k} - R_{iK}$ is the gear dedendum;

$r_{d.k}$ and R_{iK} are the pitch and internal radii of the gear;

$f_r = r_1/m$ is the rounding-off factor of the tooth point of the cutting tool;

r_1 is the rounding-off radius of the tooth point of the rack tool;

$\alpha_{d.k}$ is the profile angle of the gear on the pitch circle;

α_n is the profile angle of the tooth of a rack-type cutting tool.

With this formula it is obtained that when $\alpha_{d.k} = 15^\circ$, $\alpha_n = 0^\circ$,

$f''_K = 1.4$, and $f_r = 0$, the root of even an 82-tooth gear will be undercut, and when $\alpha_{D.K} = 20^\circ$ and $f''_K = 1.25$; $\alpha_M = 20^\circ$ and $f_r = 0.3$; $z_{min} = 18$.

z_{min} for helical spur gears is determined by this formula with the substitution in it of all parameters along the face section.

In the cutting of slanted teeth the hob is placed in such a manner so that the direction of worm turns coincides with the direction of the cavities between the teeth of the component.

Cutting the teeth of worm gears has its own inherent peculiarities.

The first peculiarity consists in that there is no longitudinal feed along the tooth axis and it is replaced by radial feed of the blank to the hob (Fig. 5.13a) or axial feed of the hob (see Fig. 5.13b). The other peculiarity consists in the selection of the hob. The form, dimensions, and number of settings of the hob should completely correspond to the working worm with which the worm gear is engaged, with the exception of the external diameter which should be larger than the diameter of the working worm by two radial clearances, i.e., by (0.4 to 0.5) m.

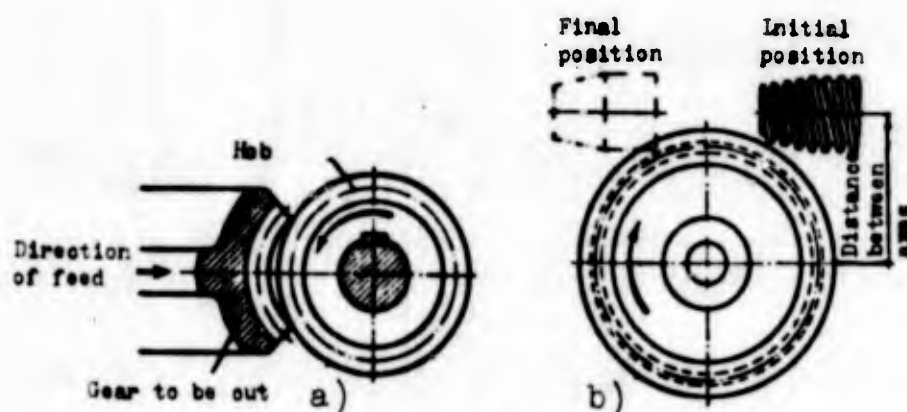


Fig. 5.13. Cutting a worm gear. a) radial feed; b) axial feed.

Spur gears can also be cut by a hob and on horizontal gear-milling machines, for instance model 534. These machines are resorted to for

the machining of teeth of components with long shanks. It is convenient to process the external splines of shafts on them.

On large scales of production we find the use of multi-spindle gear-milling machines with two, four, six, and more spindles. Each spindle of such a machine has its own drive. Multi-spindle machines are considerably more efficient than single-spindle machines and occupy a smaller area.

Gear Shaping

Gear shaping is produced on "Komsomolets" vertical gear shapers, models 512, 5A12, 5V12, 5M14, 516, Fellou, Lorenz, and others, and also on horizontal gear shapers of the "Farrel" firm. Machines of models 512, 5A12, and 5V12 have sufficiently high speeds; they have four stages of double movements of the pinion-type cutter from 250 to 600 per minute and are rather widely used in industry. However, for cutting teeth or splines with a pinion-type cutter on long shafts with flanges, when gear milling is impossible, horizontal machines of the Farrel-type are more convenient.

Gear shaping can be used to cut straight and slanted teeth of external and internal gears (Fig. 5.14).

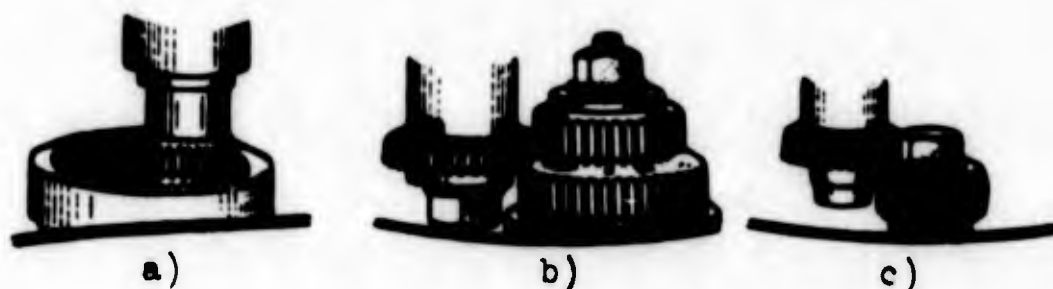


Fig. 5.14. Gear shaping on gear shapers. a-c) internal teeth; b) compound; c) external helical.

In the cutting of slanted teeth a spindle with a pinion-type

cutter attached to it accomplishes helical reversible motions in the direction of the tooth. For this purpose, the spindle head of the machine is fitted with a special master form with a helical groove. This groove, moving along a fixed block, controls the helical motion of the spindle with the pinion-type cutter. The cutter should also be slanted in this case. Simultaneously, the spindle obtains additional slow rotation at the rate of feed.

For gear shaping we find the application of pinion-type cutters of different form and with various numbers of teeth, as provided for in GOST 9323-60, and also special cutters. However, it is necessary to know how to correctly select the cutter, so that the tooth roots are not undercut, nor are the face points cut off, especially when shaping internal spur gears. It is necessary to indicate that an undercut tooth root or a cut-off face cannot always be revealed in a check.

In external spur gear shaping with pinion-type cutters with number of teeth z_H , there exists a minimum number of gear teeth $z_{K \min}$, when the tooth root will not be undercut. There also exists a maximum number of gear teeth $z_{K \max}$, when the tooth face will not be cut off.

These limitations on $z_{K \min}$ and $z_{K \max}$ are applied at determined gear addendum factors f'_K , dedendum factors f''_K , and ram addendum factors f'_H . It is considered here that all addenda and dedenda are computed from the pitch circle.

The numerical values of $z_{K \min}$ and $z_{K \max}$ can be determined with the help of a generalized graph (Fig. 5.15) on the basis of specified z_H , f'_H and f''_K when $f'_K + f''_K = 2.25$ and $\alpha_{d.k} = \alpha_H = 20^\circ$.

From this graph it is clear that with the increase of z_H there is an increase of $z_{K \min}$ and $z_{K \max}$. However, this growth is limited, and in real conditions of production the tooth root will be undercut

only when $z_K < 20$ and the tooth point will be cutoff when $z_K > 20$.

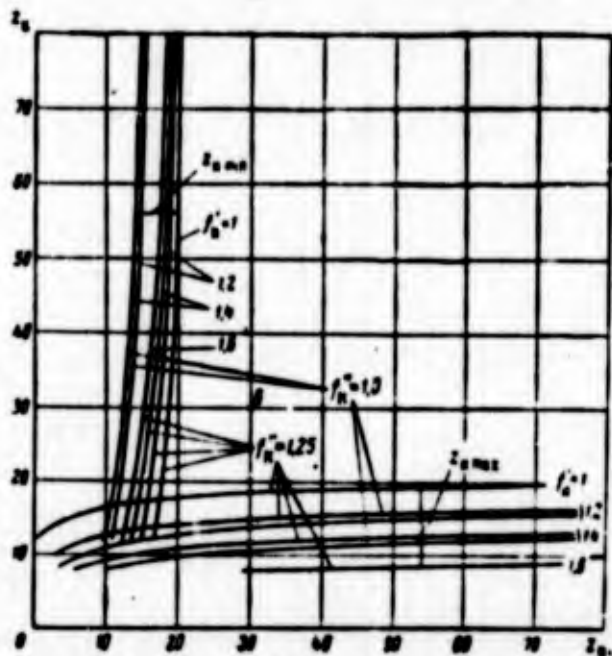


Fig. 5.15. Graph for determining $z_K \min$ and $z_K \max$.

If when cutting a gear with $z_K = 30$, $f''_K = 1.25$, and $\alpha_{Д.К} = 20^\circ$ a pinion-type cutter is selected with $z_M = 30$, $f'_M = 1.4$, and $\alpha_M = 20^\circ$, then the point of intersection of their coordinates B lies beyond the line of limitation and, therefore, the cutter will not undercut the root and cut off the face.

An example of poor selection is a cutter with $z_M = 14$, $f'_M = 1.2$, and $\alpha_M = 20^\circ$ which, when $f''_K = 1.25$ and $\alpha_{Д.К} = 20^\circ$, will undercut the tooth roots of all standard gears with $z_K < 16$ and will cut off the tooth points with $z_K > 17$. Thus, this cutter cannot be used for cutting without causing a defect to one standard gear.

The minimum number of teeth $z_K \min$ of any internal gear, including a corrected one, with dedendum factors f''_K and addendum factors f'_K , cut by a pinion-typecutter with number of teeth z_M and addendum factor f'_M when $\alpha_M = \alpha_{Д.К}$ without cutting off the tooth point by the tooth root of the cutter, is determined by the formula

$$z_{K \min} = \frac{z_M^2 \sin^2 \alpha_{Д.К} + 4z_M (f'_M - f'_K) + 4(f'_M - f'_K)^2 - 4f''_K^2}{2z_M \sin^2 \alpha_{Д.К} - 4(f'_M + f'_K - f'_K)}$$

Here

$$f'_M = \frac{R_{eM} - r_{DM}}{m}; \quad f'_K = \frac{r_{eK} - R_{DK}}{m};$$

$$f''_K = \frac{R_{eK} - r_{DK}}{m},$$

where R_{eM} and r_{DM} are the radii of the addendum circle and pitch circle in the cutter;

R_{eK} , r_{DK} , and R_{iK} are the radii of the addendum circle, pitch circle, and dedendum circle in the gear.

Cutting off of the tooth points of an internal gear by the tooth face of a pinion-type cutter is extraordinarily difficult to determine theoretically. Therefore, until recently the cutter was selected by the trail-and-error method.*

Teeth of gears of the 6th degree of accuracy with modulus from 2 to 6 mm are cut in two passes, and those with larger moduli are cut in three passes. The last final pass is desirably executed in a separate operation with a cutter of the corresponding accuracy.

Gears of the 7th and 8th degrees of accuracy, up to modulus 2.5 mm, are cut in one pass, and those with modulus higher than 2.5 mm are cut in two passes.

The number of double movements or cuts which form the lateral tooth profile of a gear K_D , characterizing the purity of this surface, is determined by the formula

$$K_D = \frac{\varepsilon \cdot t_D}{S_{окр}}$$

where ε is the engagement factor of the gear and cutter;

t_D is the pitch on the pitch circle of the gear ($t_D = m\pi$);

$S_{окр}$ is the circular feed through the pitch circle in one double movement of the cutter.

The circular feed ($S_{окр}$) is taken within the limits of 0.15 to 0.3 mm in one double movement of the cutter. The purity of treatment in this instance will correspond to the 6th-7th class, if the number of double movements for enveloping one tooth with modulus $m = 1$ is more than 30. For teeth of other moduli K_D increases or decreases in proportion to the modulus.

*V. A. Gavrilenko. Involute spur gearing, Mashgiz, 1956, p. 192.

In particular, for shaping an external spur gear $z_K = 30$, $m = 3$, $f'_K = 1$, and $\alpha_{Д.К} = 20^\circ$ with cutter $z_M = 23$, $f'_M = 1.25$, and $\alpha_M = 20^\circ$ with circular feed $S_{окр} = 0.25$ mm double movement, number of cuts $K_D = \frac{1.788 \cdot 9.425}{0.25} = 6.74$. If a gear had modulus 1, then the number of cuts

would be $K_D = \frac{67.4}{3} \approx 22$; and $z_{K \min}$ and $z_{K \max}$ for external and internal helical gears are determined by the same formulas with substitution of all parameters of the gear and cutter from the face section.

Examples of the installation of gears on gear shapers are shown in Fig. 5.16.

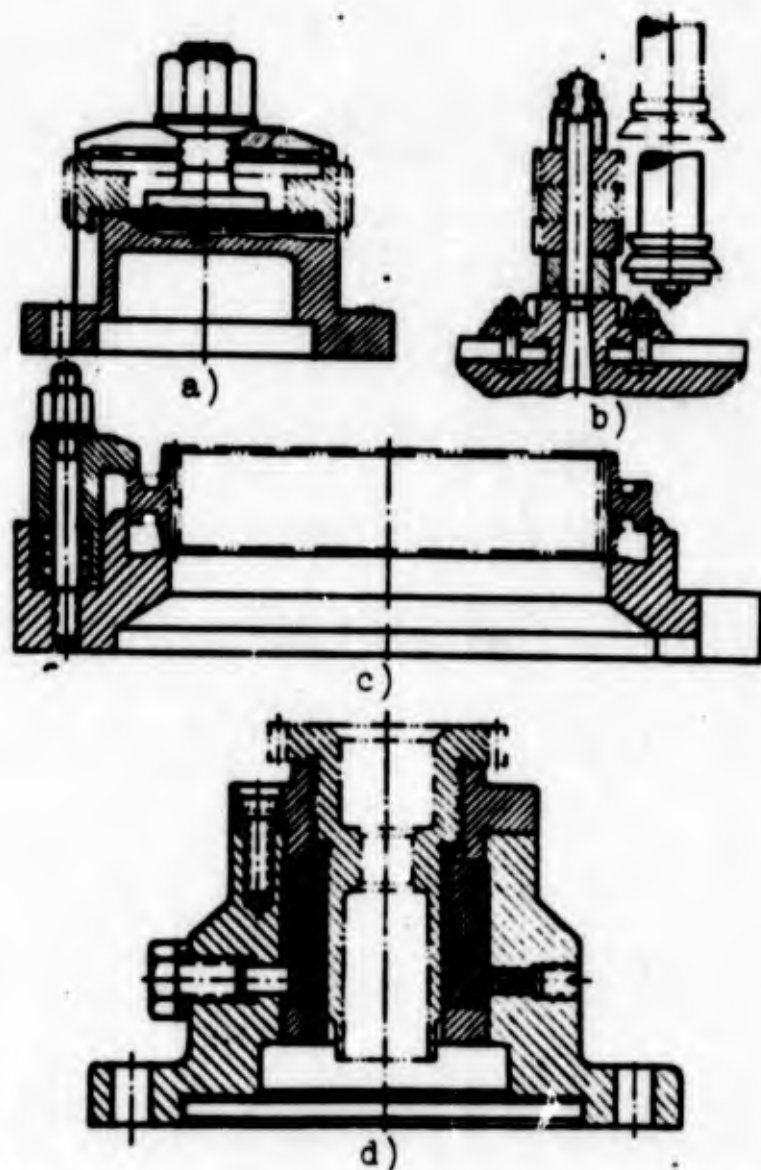


Fig. 5.16. Examples of installation of gears on gear shapers. a, b, c) on rigid cylindrical setting elements; d) in hydraulic bushing.

It is frequently possible to cut gear teeth both on gear-milling machines, and also on gear shapers. In these cases the most advantageous version is selected.

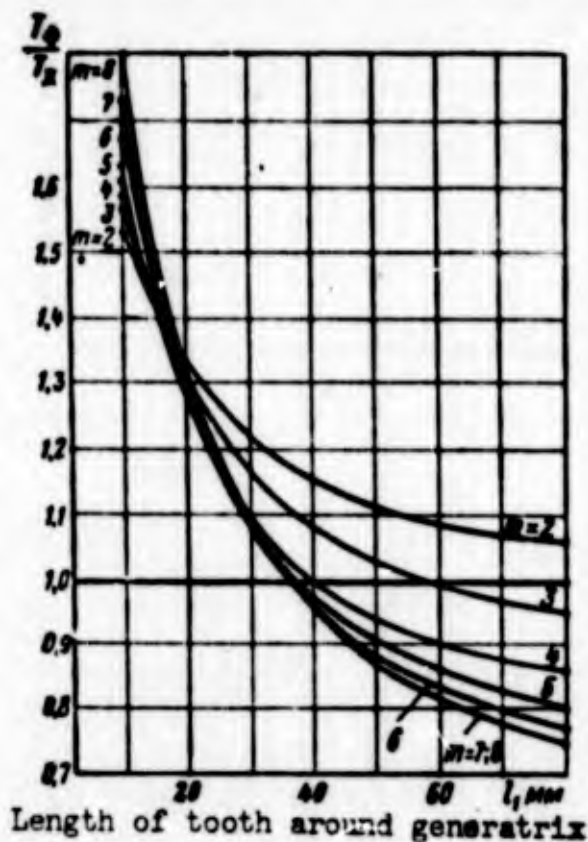


Fig. 5.17. Graph of comparative productivity in gear milling and gear shaping.
 T_{ϕ} - machine time for milling;
 T_{Δ} - machine time for shaping.
 a hob, since $T_{\phi} / T_{\Delta} < 1$.

Selection of a more productive method of gear cutting can be carried out with the help of a graph, e.g.,

Fig. 5.17, where along axis x the length of a tooth around the generatrix is plotted, and along axis y the ratio T_{ϕ} / T_{Δ} is plotted.

Curves are constructed for gears of different moduli. On this graph it is clear that teeth of small moduli are better shaped with a pinion-type cutter, since $T_{\phi} / T_{\Delta} > 1$, and teeth of large moduli with large length are milled better with

Cutting of Teeth on Machines of High Productivity

At present there are gear shapers that work as pinion-type cutters notched teeth by the generating method and with multi-cutter heads that work according to the forming method.

Pinion-type cutters with notched teeth can be used for cutting also on conventional machines, if the standard dimension of the cutter around its external diameter is maintained. On a cutter with one notch, half of the teeth are for roughing, and half are for finishing. The notched part of the cutter permits removal of the treated gear and positioning of the blank without withdrawing the cutter from it.

The constant distance between centers of the cutter and blank, and the presence of roughing and finishing teeth on the cutter, ensures entry to a specified depth and complete treatment of a component in one revolution of the cutter. When there are two notches in the cutter and the roughing and finishing teeth are symmetrically located, the simultaneous treatment of two gears is ensured in half a revolution of the cutter.

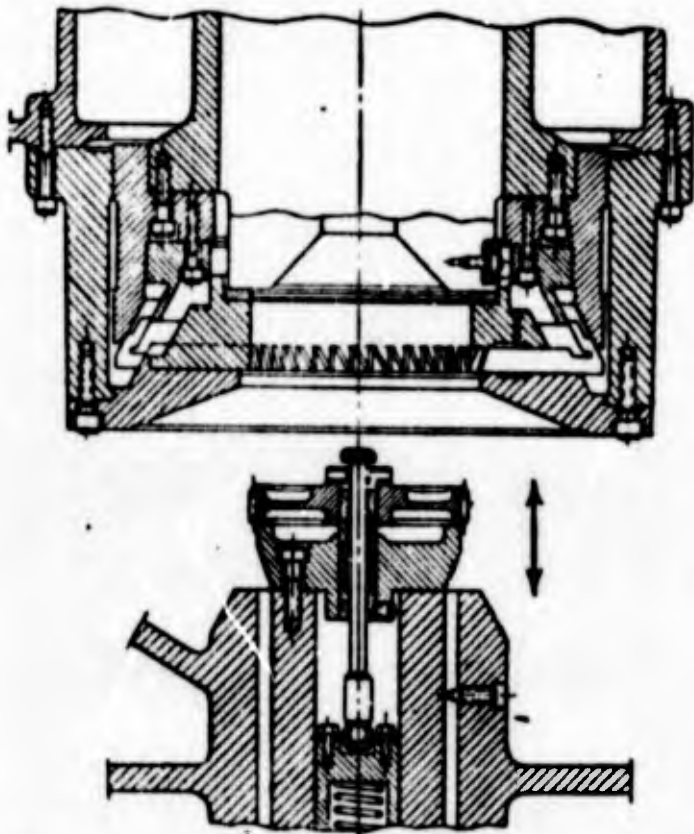


Fig. 5.18. Cutting teeth with a multi-cutter head.

Multi-cutter heads will cut straight teeth of spur gears on model 5110 machines without generating (Fig. 5.18). In the cutting process the head is motionless and the blank accomplishes reciprocating motions, passing inside the head with cutters. The cutters have a gear cavity profile. In one double vertical movement of the blank all cutters in the head automatically move in a radial direction depending on the amount of feed. With every reverse movement

of the blank the cutters are removed, owing to which their flanks are protected from abrasion. The process is distinguished by high productivity, but it has deficiencies which include the low accuracy of treatment of teeth (9th degree), the necessity of manufacture of a special head for every gear, and the complexity of sharpening the cutters.

The process of gear sharpening, developed in 1952 by VNII, is carried out on machines of the gear-milling type with high speeds of

GEOMETRIC NOT REPRODUCIBLE

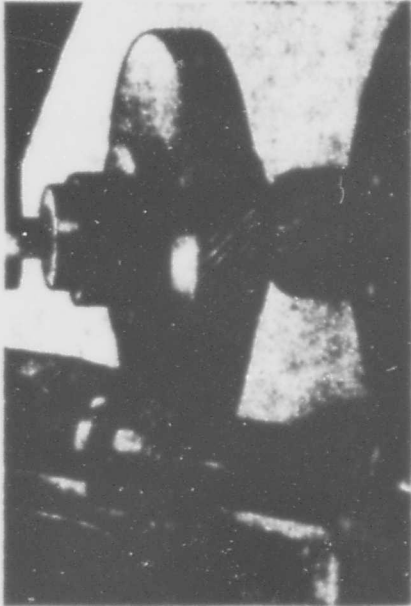


Fig. 5.19. Cutting teeth with a pinion-type cutter by method of gear sharpening.

rotation of the milling cutter spindle and the processed component (Fig. 5.19). Instead of a hob, the spindle is fitted with a circular pinion-type gear cutter that is in continuous engagement with the processed gear. Straight and helical spur gears with angle of inclination of teeth less than 45° are cut with helical cutters, and helical gears with angle of inclination up to 45° are cut with straight cutters.

The angles between the axes of the gear and cutter are selected in such a manner so that conditions for sliding

the cutter blade along the tooth profile of the gear are created. This slipping and shifting of the cutter along the axis is somewhat like shaving. However, in this process the cutting of teeth occurs in one or several passes of the cutter along the gear axis in one direction.

The process of gear sharpening is more productive than gear milling with a single-setting milling cutter, but yields to it with respect to accuracy.

Cutting the Teeth of Bevel Gears

The teeth of bevel gears are cut on gear shapers and gear-milling machines. Straight-tooth bevel gears with moduli from 2 to 8 mm are cut usually in two operations. In the first (rough) operation, cavities are cut into the whole depth and an allowance is left for the second operation, i.e., 0.5-1.0 mm on the thickness of a tooth. In the second operation the tooth profile is cut by the final generating

method. For increasing the accuracy of teeth, bevel gears are generated twice, leaving an allowance for the second generation from 0.4 to 0.3 mm on the thickness of a tooth.

On small scales of production, rough cutting of teeth is produced by gear cutters on horizontal milling machines with the help of universal dividing heads on gear-shapers, but without generating. On large scales of production, rough cutting is produced simultaneously by several gear cutters on multi-position dividing heads. The YeZ-1 "Komsomolets" and the automatic high-speed YeZ-11 machines operate on this method.

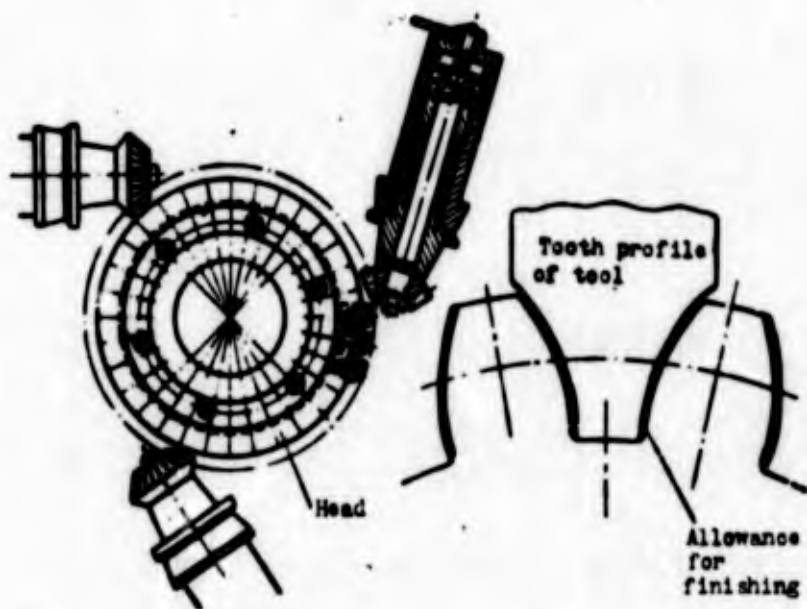


Fig. 5.20. Rough cutting of cavities of bevel gears on a semiautomatic machine with a cutter head.

For rough cutting we also find the use of semiautomatic Gleason machines with a large cutter head which simultaneously cuts three or four gears (Fig. 5.20).

Finish cutting of straight teeth of bevel gears usually is produced by the generating method on "Komsomolets" gear-shapers, model 526, Gleason and Harbeck.

Cutting of teeth on the 526, 5A26, and the Gleason is produced by two cutters that move back and forth along the teeth. Cutters are

selected according to modulus of gear to be cut. Usually they plane two sides of one tooth. Thickness of the cutter point should be less than the width of the base of the cavity for a small modulus. A diagram of the formation of a tooth profile is shown in Fig. 5.21.

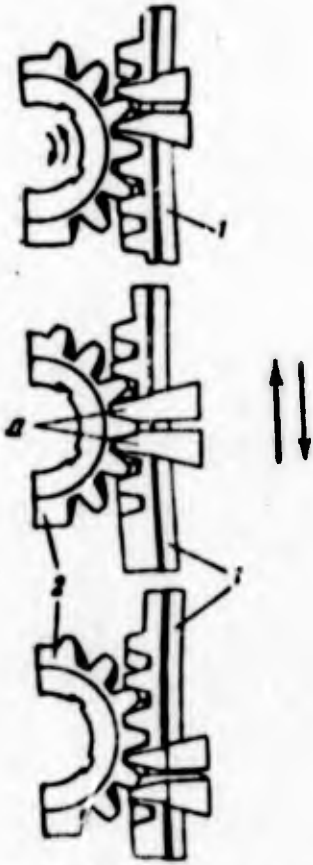


Fig. 5.21. Diagram of motion of cutters and level gear during cutting of teeth with generation.

Cutting edges of cutters are combined with two sides of the tooth profile of a imaginary flat gear 1 which is engaged with the component to be machined 2. Three positions of cutters with respect to gear tooth correspond to initial cutting moment, middle of cycle, and disengagement of cutters and tooth. In finish cutting, generating of every tooth is produced automatically twice: once with rotation of the cradle from top to bottom, and the second time with its rotation from bottom to top. In the second generation an allowance is made on the tooth thickness of approximately 0.2 mm. The process of planning on these machines is fully automated, but it is intermittent with time losses for the reverse idle motions of cutters and for

reconnection. This explains comparatively its low productivity.

The components are placed on a cylindrical surface (shaft or hole) and on the base face. Examples of installation and fastening of components are shown in Fig. 5.22. Sometimes the component is secured with the help of an industrial thread (Fig. 5.22c) which is cut off or ground off at the end of the entire machining of the component.

For increasing the productivity of cutting straight teeth of bevel gears the automobile industry is employing circular broaching.

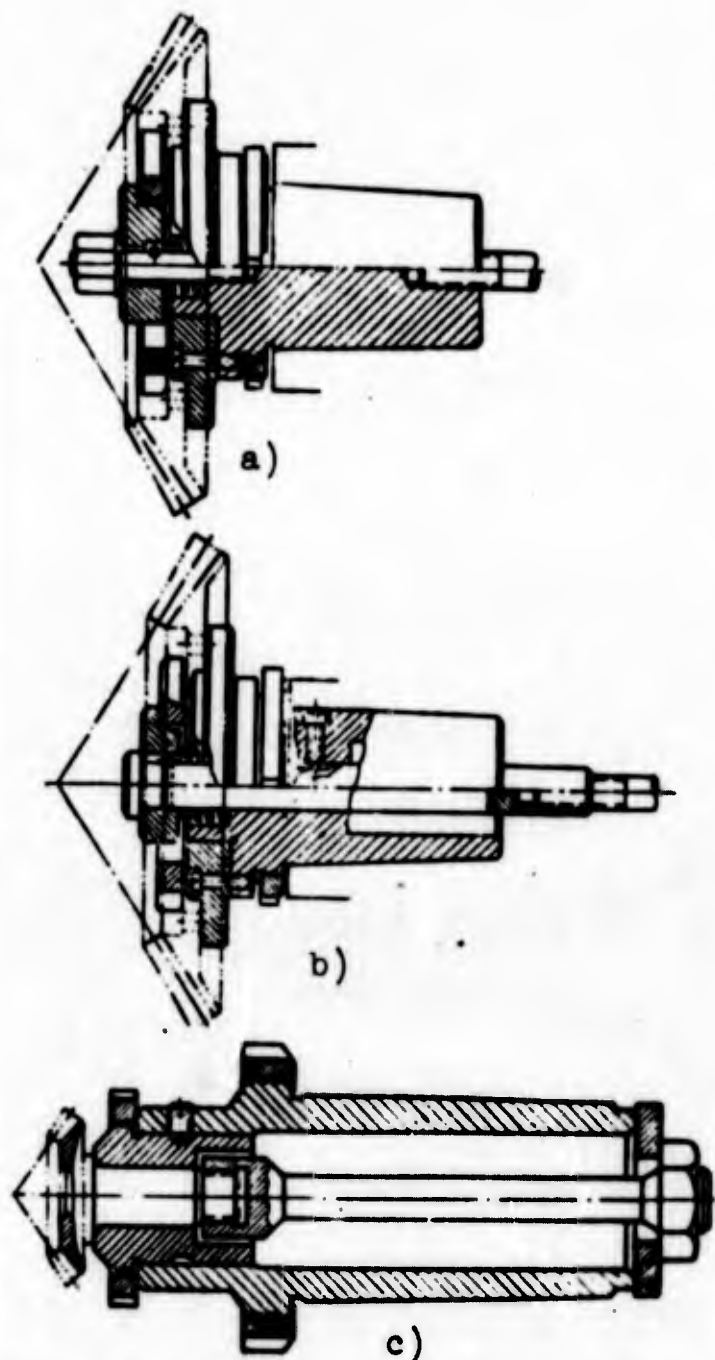


Fig. 5.22. Examples of installation of bevel gears for cutting of teeth. a) fastening in front by nut; b) fastening by bar (through spindle); c) fastening behind shank.

A diagram of broaching and the motion of the broach are shown in Fig. 5.23. Sections of the broach (usually 15-16 sections) are secured on a disk. As also in the conventional broach, the teeth are subsequently increased in this case around the radius. The teeth are backed off, which ensures constancy of profile during their regrinding. The tooth profile is constructed according to circle curves which are very similar to involute curves.

All teeth of the broach are divided into three groups: roughing, semifinishing and finishing. Roughing teeth cut a cavity almost to the whole depth; therefore, they should be larger than the others. Semifinishing teeth finish the coarse surface after roughing and prepare it for the finish operation. Finishing

teeth remove a small allowance on the profile and finally calibrate it.

The work cycle of the broach is the following. The processed gear is fixed during cavity cutting. A broach of large diameter (more than 500 mm) continuously revolves and slowly moves parallel to the base of the cavity from a small modulus to a larger one. During

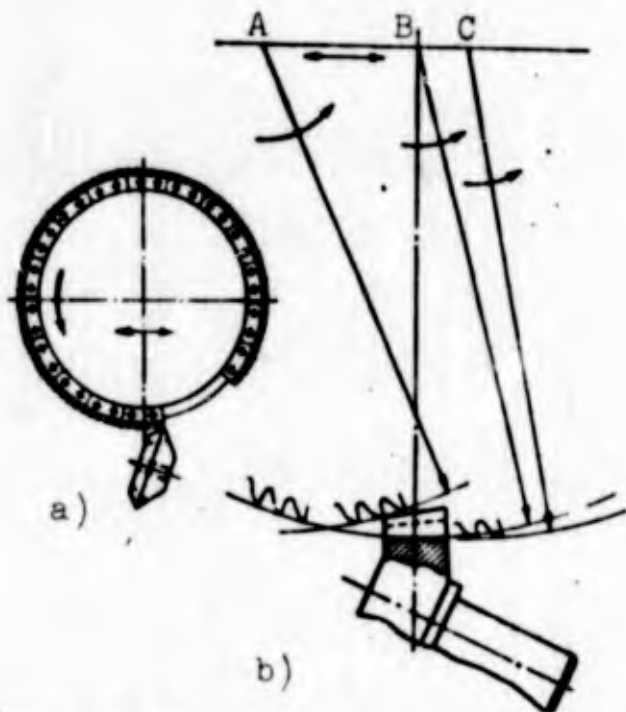


Fig. 5.23. Location of circular broach with respect to bevel gear a); and diagram of broach motion during treatment of one cavity b).

incision of the first rough tooth in the gear body the center of the broach is at point A. From point A the center of the broach moves to point C and stops at point B; after this, it returns to the initial position. During the time of movement of the broach from A to B, through the gear cavity there pass $3/5$ of all the rough teeth. When the center stops at point B the other $2/5$ of the rough teeth pass. Further, with accelerated movement of the broach from B to C there pass 6-8 semifinishing teeth. Then, when the first finishing tooth approaches the gear, the direction of the broach's motion changes and its center returns to point A. During that time interval the finishing teeth (≈ 20 of them) pass by, and in the space in the broach which is free from teeth there occurs division of the gear into the following cavity without its removal from the tool.

The disadvantages of circular broaching of teeth include:

1. the impossibility of engaging a gear that has been cut by broaching with a gear that has been cut by the generating method;
2. the need for a special machine for sharpening broaches;
3. lowered accuracy of broached teeth as opposed to those generated on a 526 machine.

The advantages of the process are the following:

1. high efficiency of machining;

2. execution of roughing and finishing in one operation;
3. long life of broach.

Curvilinear (arc) teeth on bevel gears are cut by various methods. The most wide-spread is the method of cutting with a circular cutter head (Fig. 5.24) on "Komsomolets" machines, models 527 and 528, Gleason machines.

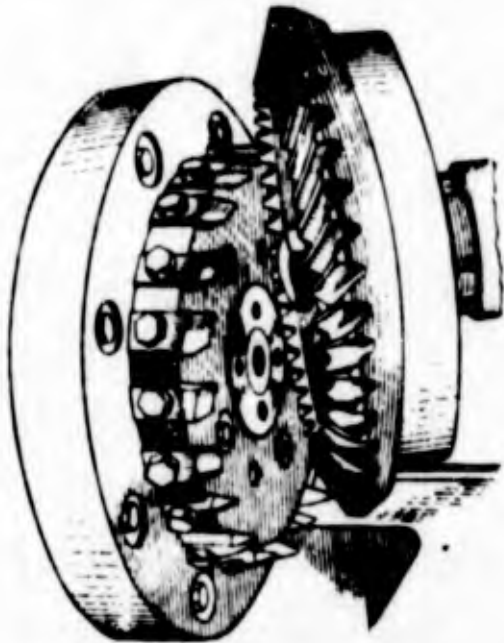


Fig. 5.24. Cutting of bevel gears with arc teeth.

Cutter heads are one-sided and two-sided. In one-sided heads the cutting edge of the cutters is located on one side, and in two-sided heads both sides of the cutters are cutting.

Teeth are cut in two operations, i.e., rough and finish. Rough cutting is produced by two-sided cutter heads on which there are almost twice as many cutters than on the rough type. Finish cutting is produced by three methods:

one-sided, simple two-sided, and double two-sided.

In the one-sided method every side of a tooth is cut by its own head in a separate operation. In the simple two-sided method the teeth of a large gear, which have smaller curvature of profile in cross section, are cut by two-sided heads, while the teeth of a small gear, which have large curvature, are cut by two one-sided heads. In the double two-sided method the teeth of two mated components are cut by two-sided heads.

The most exact mating of gears is obtained with the one-sided method, but efficiency in this case is lower than with the other methods. There is less exact mating with the third method, but then

its efficiency is the highest. This method is practical when the two mated gears have an identical or almost identical number of teeth. In certain cases the teeth of mated gears are even polished.

Teeth-Finishing Operations

Depending on the shape and hardness of the gear teeth, shaving, grinding, or lapping is employed for their finishing.

Shaving

Shaving (Fig. 5.25) serves for finishing of straight and slanted teeth of external and internal spur gears which have hardness HRC < 38.

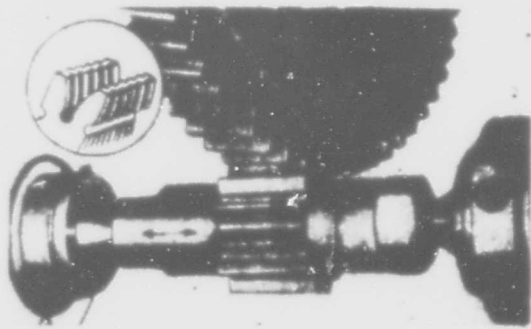


Fig. 5.25. Shaving the teeth of a spur gear with a circular shaver.

This method is being used with success for finishing of teeth that have no exit for the grinding wheel (compound gears). Efficiency with shaving, as compared to the other methods of finishing, is the highest.

Shaving of teeth is produced after they are cut. External teeth are shaved on 5712-type machines, and internal teeth are shaped on 5717-type machines. The tool used for circular shaving is the disk shaver. Around the profile of the shaver's teeth there are small grooves 0.9 mm wide and 1 mm deep, whose external edges are cutting. The process of cutting begins when the cutting edges of the shaver's teeth slide along the tooth surface of the gear. Circular shavers are made of steel R18 and are hardened to hardness HRC 62-65.

In the shaving of straight-tooth and slanted-tooth gears the axis of the shaver is set at an angle of 5, 10, and 15° to the axis of the processed component. Thus, for straight-tooth gears a shaver is employed with angle of inclination of teeth 5, 10, and 15°. Gears

with external teeth most frequently are set with their holes on a center mandrel with minimum clearance (0.01-0.015 mm). The mandrel together with the gear is placed in the centers on the machine table. Gears without holes are set on centers or on cylindrical surfaces that are connected with the processed teeth with the specified accuracy. The shaver, which in tight engagement with the gear, rotates with a speed of 100 to 300 rpm. Rotation of the shaver and the gear once each longitudinal movement of the table is reversed. The speed of longitudinal movement of the table on the average is 0.25 mm per revolution of the component.

Incision of the shaver is carried out by radial feed at a magnitude of 0.01-0.02 mm per revolution of the component. An allowance for shaving of 0.1-0.2 mm is taken in 10-12 working double movements of the table, then 4-8 more movements of the table are given without radial feed, mainly for increasing surface purity. The accuracy of shaving depends on the accuracy of the preliminarily cut teeth; shaving can increase the accuracy of the gear by approximately one degree. There are machines for shaving with a flat shaver that has the form of a rack. In an example with a flat shaver it is easier to comprehend the setup of the machining process, if we imagine that during longitudinal motion of the shaver the gear obtains only rotation and it will be motionless in axial direction. With such interaction of the tool and the component there will appear slipping along the lateral face of the tooth, at which the edges of the grooves render a scraping action. With shaving there can be obtained an elliptoid tooth shape. For this, the component is set into oscillatory motion with the help of a special attachment, due to which the shaver goes deeper into the tooth profile at the edges more than in the middle.

The magnitude of oscillation of the shaver should ensure the obtainment of a difference in thickness of 0.02-0.04 mm in the middle of the tooth and on its ends.

Besides the described method, diagonal shaving by a circular shaver is employed. This method differs from the conventional method by the fact that the reciprocating motion of the gear is not directed along the axis, but at an angle which reaches up to $30-35^{\circ}$. With this method the load on the teeth is more uniformly distributed, the length of gear play decreases, and efficiency is raised by 40-50%.

Grinding of Teeth

Teeth are ground by two methods: profiling and generating. The profiling method is mainly used for grinding straight teeth of external and internal spur gears. The most wide-spread machines, working according to the profiling method, are MSZ machines, models 586, 5860, and 5861, Orcutt, and Gear-Grinding. In this method of grinding the profile of the grinding wheel completely corresponds to the profile of the cavity of the processed gear. Dressing of the abrasive wheel on two sides in an involute profile is produced by two diamonds by means of master forms and a four-section mechanism, i.e., pantograph (Fig. 5.26). The forming wheel is dressed by a third diamond moving along the contour with curvature equal to the curvature of the base of the gear cavity.

Movement of tip 2 around master form 3 and oscillation of all sections of each pantograph around points c is produced with the help of the lever-spring mechanism for the hydraulic cylinder. Dimensions of the master forms increase usually in opposition to the dimension of the processed tooth in by 6 times (sometimes by 3 times).

During grinding according to the profiling method, the wheel revolves with a speed of 25 to 30 m/sec and it has reciprocating motion along the cavity of the processed tooth.

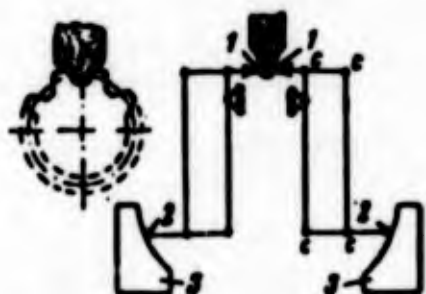


Fig. 5.26. Grinding of teeth by a profile wheel and diagram of a mechanism for dressing it. 1) diamonds; 2) cylindrical tips of gauges; 3) master forms.

Furthermore, the wheel also has vertical movement for incision, which is produced after each passage of all teeth. For increasing the accuracy of treatment, the incision before the last passage is very small, up to 0.010 mm on the thickness of a tooth. Sometimes the last passage is conducted without an incision (tending).

The grinding of internal teeth employs 586V and 5860V machines, and others which have a cantilever yoke, on whose end the abrasive wheel is placed. The yoke, together with the wheel, should pass into the gear hole. It is practically possible to grind the teeth of gears which have an internal diameter not less than 100 mm.

The accuracy of grinding teeth by the profiling method depends on many factors and does not always fit into the 5th degree. In particular, external spur gears with a large number of teeth and tooth length up to 30 mm can be ground with the 5th degree of accuracy, but with a small number of teeth this accuracy is difficult to obtain due to the large curvature of the profile. During grinding of internal teeth by a small wheel, on which the grain grade is especially noticeable, an accuracy higher than the 6th degree cannot be practically obtained. However, grinding by the profiling method, as compared to the generating method, is more productive. Surface purity during grinding is attained at the tooth root in the 9th class, and at the face, in the 7th-8th class.

The generating method can be employed to grind external and internal spur gears with straight and helical teeth, and also straight and helical bevel gears. However, for the most part, only external spur gears are ground. Internal gears until recently were not ground by the generating method and only lately did the MAAG firm begin manufacturing machines for grinding of internal teeth by one dish wheel.

There are quite a few different designs of gear grinders that work according to the generating method, but all of them can be divided into five groups that are distinguished from one another by their generating mechanisms (Fig. 5.27).

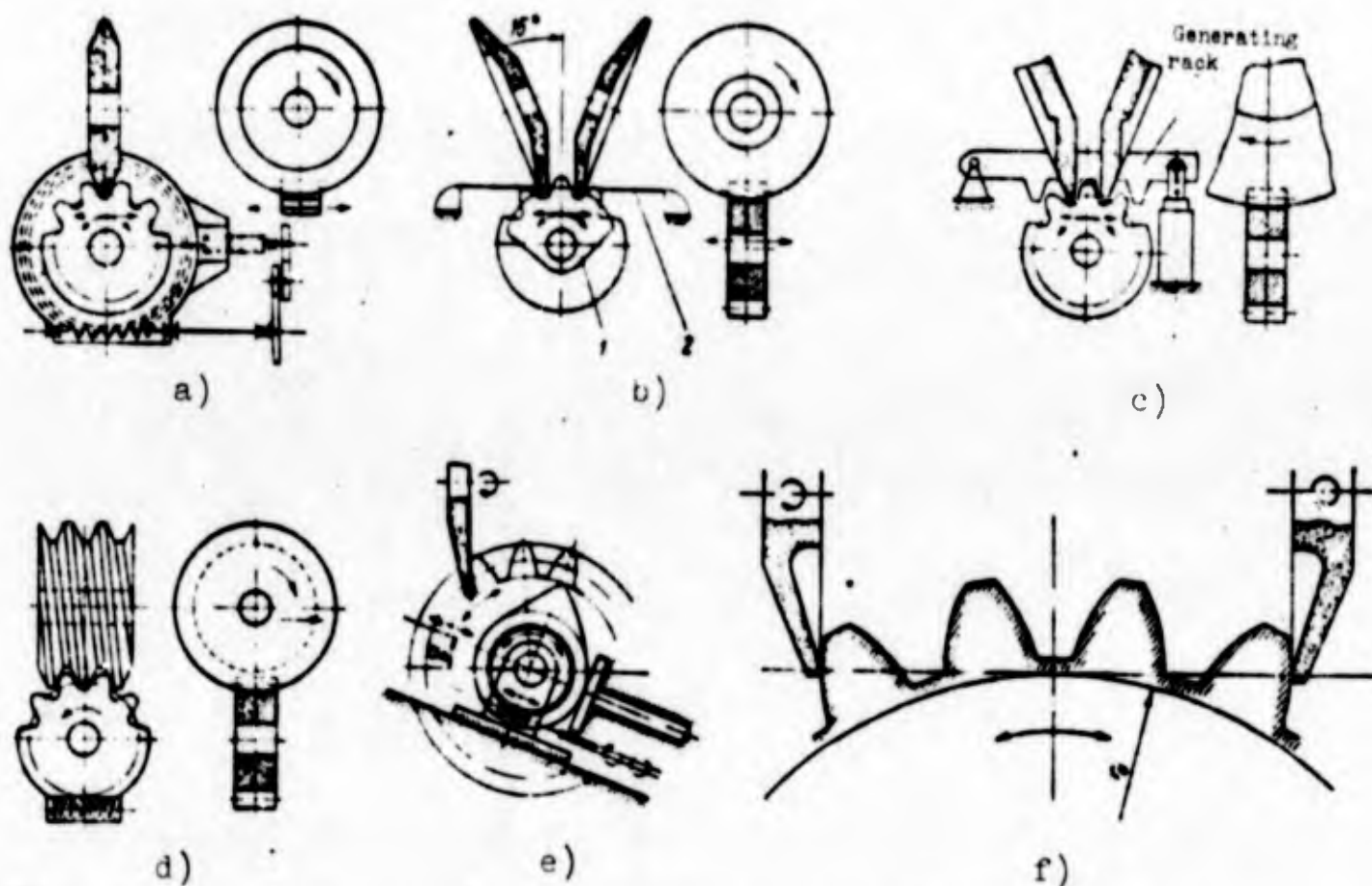


Fig. 5.27. Diagrams of gear grinding on machines working according to the generating method.

The first group (Fig. 5.27a) includes machines with a worm-screw generating mechanism in which the worm pair serves for rotation of

the gear (reversible), and the screw pair is for transverse motion.

In the second group of machines with a drum-band generating mechanism (Fig. 5.27b), rotation of the gear and its transverse motion are created with the help of steel tension bands 2 and generating drum (roller) 1. The bands shown in the figure of tape have one of their ends attached to the generating drum and other to the carriage.

In the third group of machines with a gear-and-rack generating mechanism (Fig. 5.27c) rotation and transverse motions of the gear are created by the motion of exact gears and the rack engaged with it (without clearance). The processed gear and the gear of the generating mechanism are on one axis.

The fourth group includes machines on which the machining is produced by an abrasive worm (Fig. 5.27d). The generating mechanism of the machine includes a worm pair just as in gear-milling machines.

Machines of the fifth group (Fig. 5.27e) have a worm-and-cam generating mechanism. The worm pair rotates the processed gear, and an involute cam creates its transverse motion.

"MAAG" machines of the second group have a device that compensates the wear of wheels in the machining process. This device (compensator) ensures the constant position of the wheel's cutting edge by its automatic feeding during wear.

The spindle angle of the grinding wheels on machines of older models is constant and equal to 15° . With external location of the cutting edges of wheels (see Fig. 5.27b), with certain limitations on z_k , it is possible to grind gears with any number of teeth and with profile angles more than 15° .

In the new "MAAG" machines with spindle angles 0° and internal location of cutting edges (see Fig. 5.27f) it was possible to grind gears with a small number of teeth without undercutting the involute.

The accuracy of treatment on "MAAG" machines is of the 5th degree or the 1-th class according to old aircraft standard 107MT.

The high requirements with respect to run-out of gear profiles command special attention in the selection of an attachment for their setting. None of the clearance fits of the 2nd class ensures setting accuracy of gears on grinding machines; therefore, the mandrels are selected in such a manner so that the fit is with minimum clearance. Most frequently gears are set without clearance on tapered (Fig. 5.28a, b) or expanding hydraulic mandrels (Fig. 5.28c).

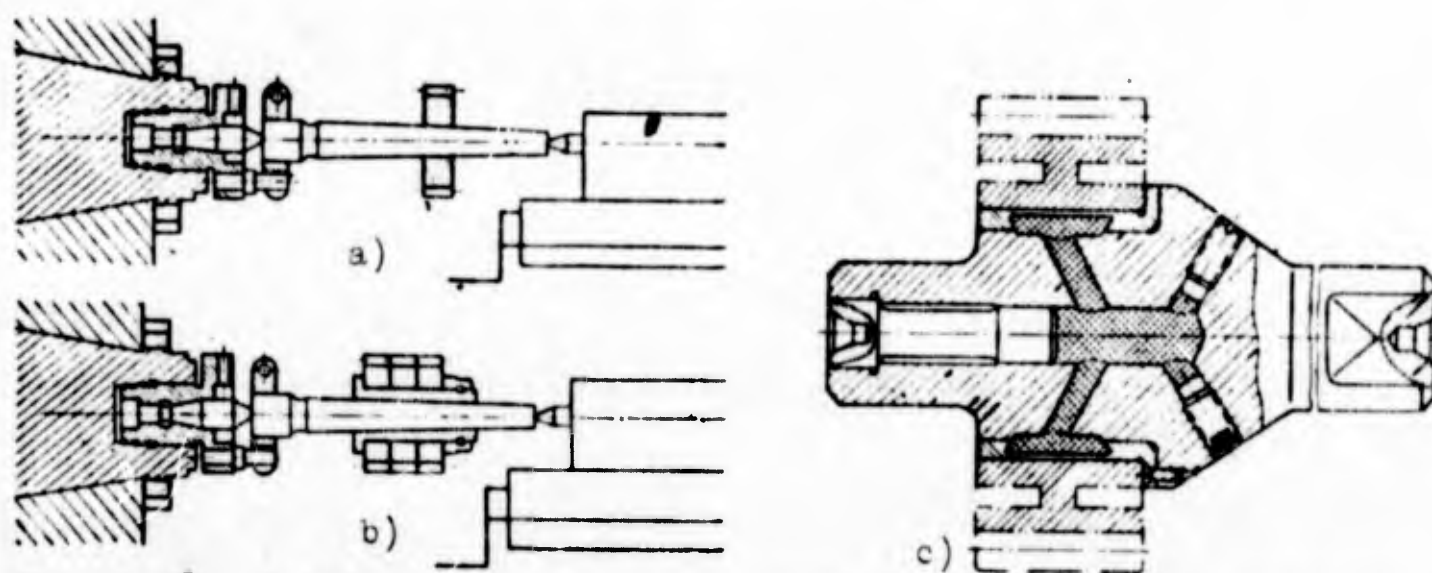


Fig. 5.28. Setting of gears on gear-grinding machine. a) directly on tapered mandrel; b) on tapered mandrel through bushing with clamp nut; c) on expanding hydraulic mandrel.

Flanked teeth (Fig. 5.28b) have their profiles ground first, and then the flank is removed in another operation. After the appropriate dressing of the wheels the flank can be ground in one operation with the profile.

The productivity of gear grinding of precision gears by the generating method is lower than gear grinding by the profiling method.

Grinding straight bevel gears has not yet obtained wide distribution because of the absence of machines. Only recently did there appear for this purpose the MAAG and Gleason machines. The universal

machines of the Reinecker firm, which are used in industry for planing and grinding of straight teeth by the generating method and made with rack segments, do not ensure accuracy, and therefore, they are not used in the aircraft industry.

On "MAAG" machines, models KS-42 (Fig. 5.29), bevel teeth are ground by two dish wheels with undercut. The generating motion is

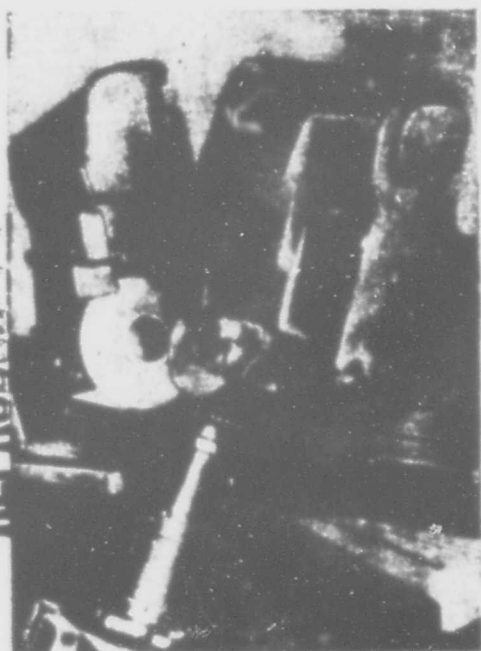


Fig. 5.29. MAAG gear-grinding machine for bevel gears.

reproduced by the double motion of the processed gear, which is typical for all MAAG machines. However, generating is produced here around the peak of the pitch cone. The quality of these machines and the accuracy of treatment on them in our industry still have not been verified.

Model 105 Gleason machines have appeared quite recently. Their kinematics are the same as and for the conventional gear planers of this firm, but, in exchange for planers, a grinding wheel with drive for its rotation is located on the slide rod.

If necessary, straight teeth of bevel gears can be ground on 526 gear planers, Gleason machines, and others, with certain conversion. Conversion of gear planers into gear grinders reduces to the replacement of cutters by a grinder.

For grinding of spiral teeth of bevel gears there are gear grinders, 5870 and 5872, and also Gleason machines No. 15, 17, and 27. The

abrasive wheels of these machines have a cup shape with a rack working profile (Fig. 5.30). The cup wheel, revolving with a speed of 25-30

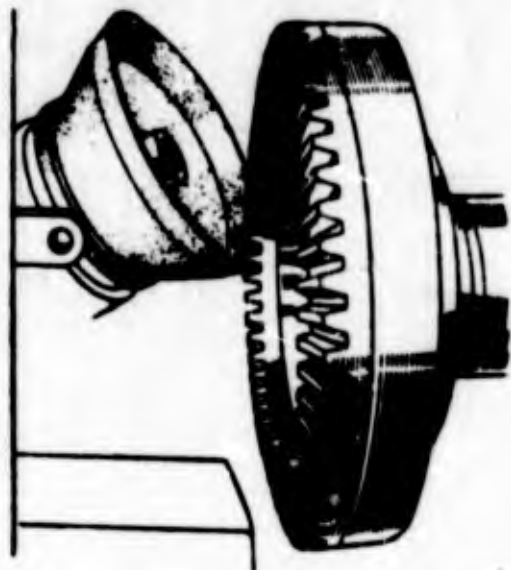


Fig. 5.30. Grinding of curved bevel gears.

m/sec, generates the working surface of the profile of the processed tooth. The generating motion is formed by the slow reversible rotation of the gear around its axis and the center of the grinding wheel around the same axis.

In practice, the teeth of bevel gears in most cases are not ground, but are lapped with the help of abrasive paste.

In connection with the increase of loads on a tooth, there recently has been given much attention to the quality of the surface layer and to the residual stresses that appear after grinding. Numerous investigations show that during grinding of the root fillet (bottom) -- the most stressed place in the teeth -- there appear considerable residual tensile stresses, and sometimes cracks. Due to this, the airplane industry began to employ gears with ground profile and unground root fillet.

Lapping of Teeth

The faces of teeth with hardness $HRC \geq 58$ are lapped. Usually this operation is conducted when it is required to increase the accuracy of gears, improve surface quality, and when it is impossible to apply gear grinding. It is possible to lap spur and bevel gears with straight and helical teeth, and also worm gears with worms. The process of lapping is (with the exception of worm lapping) a sufficiently productive method of final finishing of gears. Usually spur gears of medium dimensions are lapped for 2-4 minutes and attain

a profile purity of the 8th-9th class.

The accuracy of treatment of teeth in the process of lapping is increased if the accuracy of the lapping tool is higher than the accuracy of the processed gear and the machining allowance is not more than 0.01-0.02 mm on a side. In the presence of errors in pitch and involute profile more than 0.05 mm, lapping of precision gears is not effective, since an increase of the lapping allowance or lapping times leads to negative results.

Lapping of teeth of spur gears is carried out by three methods. The first method consists in that the external and internal teeth are processed by lapping tools, which also goes for spur gears made from soft gray cast iron. In the second method only gears with external teeth are lapped, and a cast-iron worm serves as the lapping tool. In the third method, components that are mated are lapped without an abrasive. This method is usually called running-in.

The pastes utilized in lapping consist of abrasive powder and oil. For example, mixtures of the following composition are employed: abrasive powder - 35% (grain size from 5 to 3), turbine oil - 50%, and grease - 15%.

The first method of lapping has the widest distribution and is carried out in two setups. In the first setup the axes of the component and the lapping tool are parallel, and in the second, they intersect one another. In accordance with these setups there are gear lapping machines, models 5736 and 573. In machines that operate in the first setup (Fig. 5.31) the gear is lapped by one lapping tool. The processed gear 1 is rotated by an electric motor and drives the lapping tool 2 behind it, which is braked by a mechanical or hydraulic arresting gear.

For aligning the layer of metal taken from the face of the teeth, and for increasing the productivity of lapping, additional motions

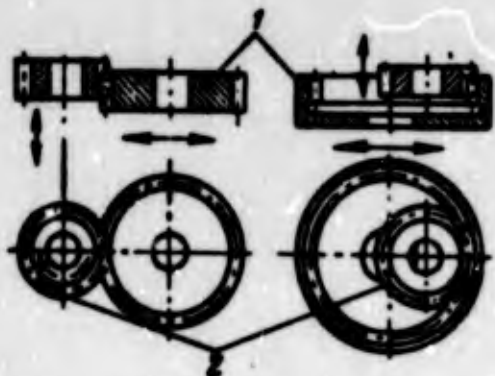


Fig. 5.31. Lapping of teeth by one lapping tool.

are provided. In particular, rotation of the gear and the lapping tool is reversed and furthermore, the gear has axial motions, while the lapping tool has transverse or radial oscillatory motions.

There also exist such machines where the lapping tool is the driver.

On gear lapping machines that work according to the second setup (Fig. 5.32), gears are lapped by three lapping tools. During lapping of a gear with straight teeth the lower lapping tools are made in

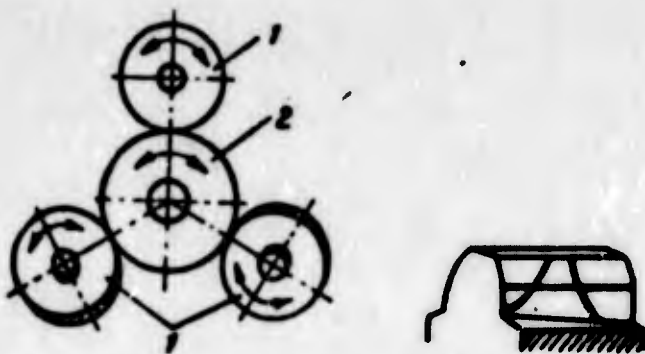


Fig. 5.32. Lapping of gear teeth by three lapping tools. 1) lapping tools; 2) gear being lapped.

helical form with tooth angle of teeth $5-10^\circ$; in one lapping tool the spiral is right, and in the other it is left. For uniform lapping of two sides of a tooth, the rotation of the gear in a specified interval of time, equal to half of the entire time of lapping, is automatically

reversed. For increasing the lapping

effect, the gear being lapped has oscillatory motions along its axis during rotation.

Crossing of the axes of the two lower lapping tools with the axis of the gear ensures relative slip of tooth profiles along their generatrices and uniform removal of metal. As a result of such slip, on the surface of the tooth profile of the gear being lapped there remain curvilinear strokes that are characteristic for the given

process which are shown on the right in Fig. 5.32. The life of one set of lapping tools under normal conditions is approximately 15 to 17 work hours. The basic deficiency consists in the difficulty of manufacturing helical lapping tools higher than the fifth degree of accuracy.

In the second method lapping is produced by a cast-iron worm lapping tool on "Komsomolets" gear-milling machines (Fig. 5.33). The

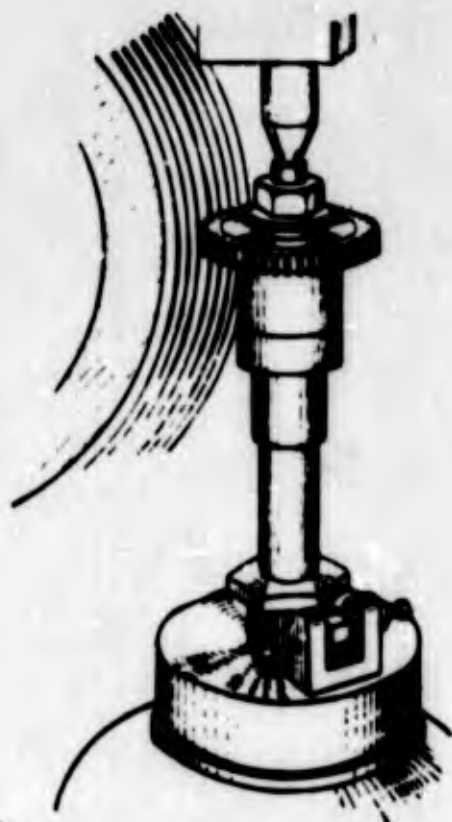


Fig. 5.33. Lapping of teeth by a worm lapping tool.

speed of rotation of the lapping tool reaches up to 10-12 m/min (diameter of lapping tool from 300 to 400 mm). An abrasive mixture of the earlier-indicated composition is usually fed to the lapping tool manually. This method of lapping is applied mainly for increasing the surface purity of grinding teeth of gears. The lapping of one gear $z = 42$ and $m = 4$ requires up to 40-50 minutes.

Bevel gears and worm pairs are lapped by lapping tools whose form and dimensions completely correspond to their paired gears or worms. Helical bevel gears and worm gears most frequently are lapped with the paired gears and worms which they will be combined with in the machine.

Due to the absence of additional motions (besides rotation), lapping of bevel gears is accompanied by nonuniform wear.

Polishing of Teeth

For the purpose of increasing the strength of teeth of the gears of aircraft engines we sometimes find the employment of polishing of

the tooth face and fillet in the root. Polishing is produced manually by soft wheels with a thin abrasive paste. With special regularity the accuracy of the profile during polishing can be preserved.

Recently there appeared the process of honing the teeth of spur gears of high hardness ($HRC \geq 55$). The essence of the process consists in generating the processed gear with a lapping wheel whose helical teeth are covered by an abrasive. In another version the lapping wheel is made from plastic and the teeth have a large quantity of abrasive grains.

Honing is carried out by generating the lapping tool with peripheral velocity at approximately 4 m/sec with reciprocating motion of the processed gear along its axis. A characteristic peculiarity of this process, which is like lapping, consists in that the lapping-hones have a large tooth angle. During honing of a helical gear the angle between the axes of the gear and the lapping tool reaches up to 90° .

Tooth Knurling and Pressing

Recently there has been an intense development of processes for knurling teeth on billets of spur and bevel gears, and also for pressing spur gears of simple form.

The essence of the process of knurling consists in pressing the teeth on the billet of a gear with the help of a toothed knurling tool during their joint rotation.

Knurling of teeth is carried out on a cold or hot billet. A more exact and simpler method is cold knurling (Fig. 5.34). Small modulus teeth of the 6th degree of accuracy can be obtained on aluminum, bronze, and brass billets.

On soft steel billets, made of steel 30KhGSA for example, the accuracy of teeth is sharply lowered.

Hot knurling is a very complicated process which allows us to obtain teeth of spur and bevel gears. Heating of steel billets to the

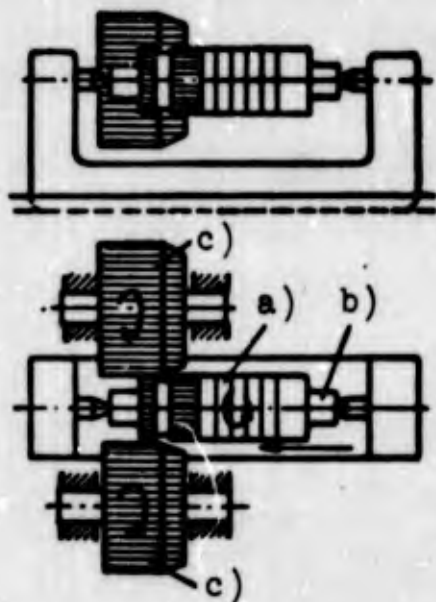


Fig. 5.34. Diagram of cold knurling of teeth. a) gear billets; b) mandrel; c) knurling tools.

required temperature is produced by a high-frequency current with the help of generator with a power of $\approx 100-120$ kilowatts and by means of female inductors. The time of heating varies from 0.5 to 1.5 minutes.

The accuracy of knurled teeth in most cases is low and on the level of rough gear cutting. However, in the knurling of billets by precision toothed knurling tools with $m \approx 2$ and their timely replacement when they are worn, the accuracy can be raised to the 8th degree.

In hot knurling, just as in cold, rotation of the billet and the knurling tools must be synchronized, which is attained either with the help of a profiling wheel fixed on one axis with the billet, or by means of a special mechanism.

Hot knurling is by the group and by the piece. In the group method the teeth of several billets fixed on one mandrel are knurled or several uncut billets are knurled directly on a rod. The last method sometimes is called the rod method. In the piece method the teeth are knurled on one billet whose form and dimensions do not permit them to be placed on the machine in more than one piece. Group or rod knurling of straight or helical spur gears is produced on a TsKBMM-22 knurling machine. It is possible to knurl gears with $m \leq 4$ and external diameters up to 220 mm on this machine by the method

of longitudinal feed of the billet or transverse feed of the knurling tools.

The productivity of knurling on this machine with longitudinal feed is high and depends on the magnitude of axial feed of the billet, which changes within the limits of $S = 0.36-0.5$ m/min in 30-45 rpms of the knurl. Knurling tools are usually made of steel 5KhNT with hardness HRC 50-55.

Piece knurling of spur gears is done on TsKBMM-13 and TsKBMM-58 machines on which gears with $m \leq 10$ mm and external diameters up to 600 mm are knurled.

Bevel gears with straight and curved teeth are knurled in hot state on TsKBMM-42 and NIITAvtoprom machines. On the TsKBMM-22 machine the axes of the knurling tools and the billets are located in the horizontal plane. Rotation of the billets and the knurling tools is synchronized by a machine mechanism. On the ends of the knurling tools there are flanges on two sides which keep the metal from spreading along the tooth generatrices. For removal and installation of a new billet, the knurling tools are withdrawn from the billet, thus ensuring free access to the locator of the machine.*

One of the essential deficiencies of the process of knurling the teeth of spur and bevel gears are the laps or shifts of the metal along the surface of a tooth. These laps appear on the rear side of the tooth in the course of rotation and they are arranged around the internal circumference. The dirt and scale which falls into the laps leads to the appearance of cracks with the use of knurled gears.

*For information concerning knurling, see:

N. I. Volodin, Knurling of spur gears, TsINTIMASH, 1962.

Progressive methods for the production of gear and their technological effectiveness, collection of articles, Mashgiz, 1962.

The pressing method is used to make spur gears of simple, disk, or rod form on conventional presses which use appropriate dies for this purpose.

Treatment of Teeth with Novikov-Type Engagement

External and internal spur gears with Novikov-type engagement can only have spiral teeth. These teeth, just as involute teeth, are processed by the forming method and the generating method. The faces of teeth in the end section are outlined by a circular arc (Fig. 5.35) and can be machined by methods known in the gear-cutting industry; namely; milling, gear-shaping, gear-grinding, gear-lapping, and broaching.

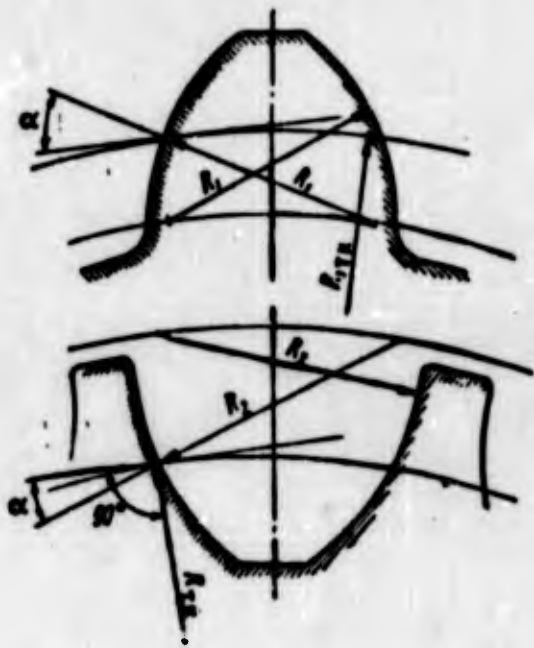


Fig. 5.35. Profiles of convex and concave teeth with Novikov-type engagement.

The transverse profile of teeth (flanks or roots) of a cutting tool that works according to the forming method completely corresponds to the profile of the processed gear in normal section. The profile of the tooth of a cutting tool that works according to the generating method is outlined by a compound curve which is usually calculated analytically or constructed by graphic methods which are described in special literature.*

Since the form and curvature of the profile of teeth of two engaged gears is different, i.e., on one gear it is concave with radius R_2 , and on the other it is convex with radius R_1 , then the cutting

*I. A. Frayfel'd, Tools that work by the generating method, Mashgiz, 1948.

Yu. V. Tsvis, Profiling a generating cutter, Mashgiz, 1961.

of these gears requires two paired cutting tools. These tools (milling cutters or pinion-type cutters), with certain errors that have no essential value, can be also used to cut gears with another (limited) number of teeth of identical modulus.

Cutting of external teeth according to the generating method is produced by hobs on gear-milling machines and by helical pinion-type cutters on gear shapers. Internal teeth, according to the generating method, are cut only by pinion-type cutters, and subsequently, with good utilization of engagement and on large scales of manufacture of components, broaches with helical teeth can be used.

Grinding of external and internal teeth, according to the forming method, is produced on machines 586, 5860, and 5861 with form-abrasive

wheels, and according to the generating method, on machines 5831 and 584 (Fig. 5.36). Truing of grinding wheels on the indicated machines is produced by diamonds from two sides on a master form with the help of a pantograph. A third diamond trues the wheel around the generatrix.

The teeth of Novikov gears can be lapped with an abrasive paste by means of a cast-iron lapping tool that completely corresponds to a paired gear. In spite of the fact that the Novikov engagement is a

point engagement, practically in the process of rotation with braking, the gear and the lapping tool will be in contact at a point travelling

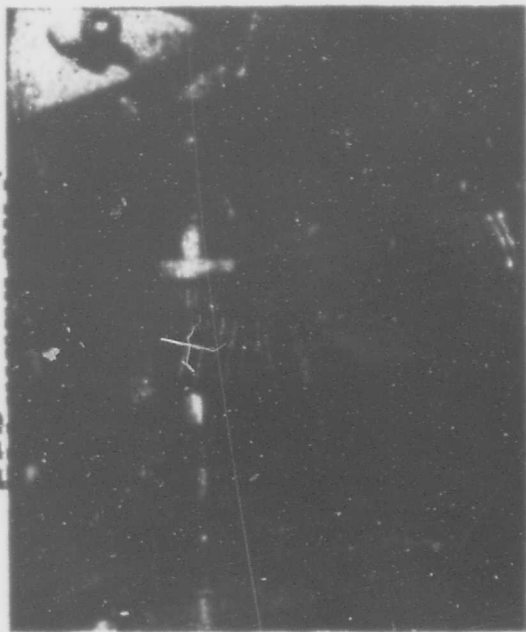


Fig. 5.36. Grinding teeth with Novikov-type engagement by generating on a model 584 machine.

around the profiles along the tooth.

The most important and exact parameter in these gears is the tooth helix angle which, with wide gear rims, should be maintained with a precision of $\pm 10-20''$. The accuracy of pitch and thickness of a tooth should be the same as for involute teeth. The smaller accuracy, as compared to involute teeth, allows curvature of profile.*

§ 4. CHECKING OF GEARS

The most productive and sufficiently reliable checking method in batch and mass production is the combined two-profile check (Fig. 5.37). These devices have two mandrels each, one of which is placed on a mobile carriage, and the second on a stationary carriage. The gear to be checked placed on the mobile mandrel, and a standard gear is placed on the other, where by both gears are in close engagement. Errors of engagement during rotation of gears will cause a shift of the mobile carriage, which is measured usually with the help of indicators. The magnitude of the shift will be influenced by the errors of profile, pitch, run-out through roots, deviation in thickness of teeth, and their misalignment; therefore, this method of checking is combinational.

In addition to the combined check, separate engagement parameters are also checked: base pitch, profile, tooth thickness, run-out, and misalignment of teeth with respect to the axis of the component.

Thickness of teeth is checked by a tooth tester, a limiting clamp, or a compound clamp (Fig. 5.38). The last method is employed for checking the thickness of teeth of external and internal spur gears. Measurement can be performed by vernier calipers, micrometer,

* There is a detailed discussion of the Novikov engagement in the following book: Investigation and mastery of gear transmissions with Novikov engagement, Publishing House of the Academy of Sciences USSR, 1960.

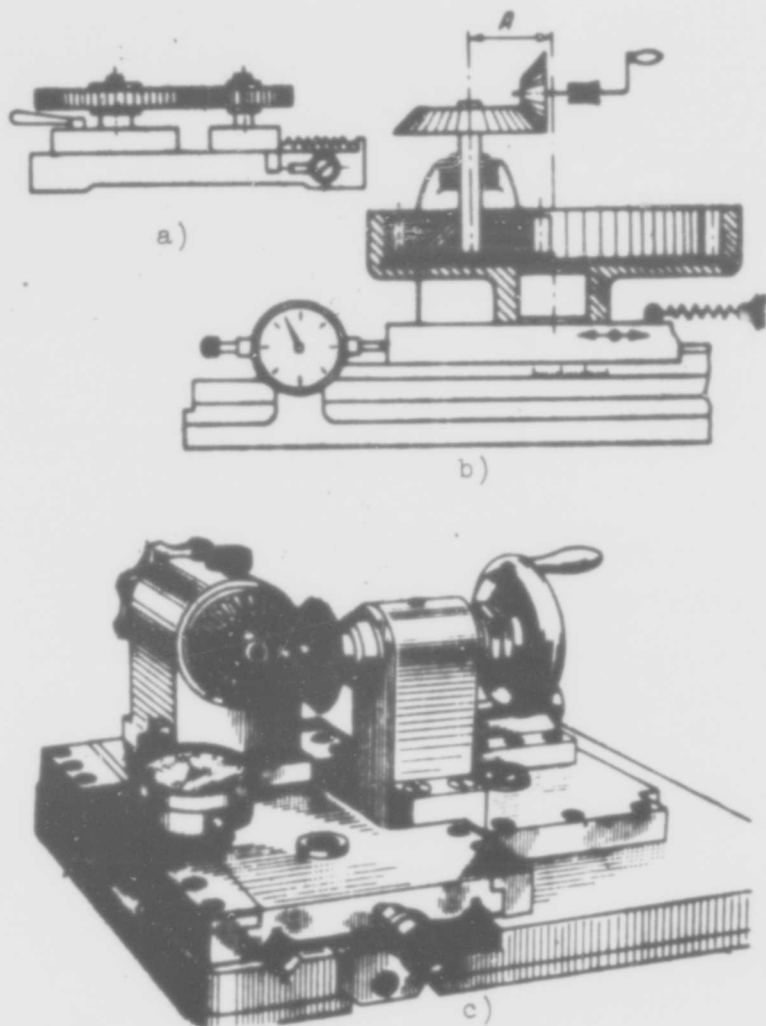


Fig. 5.37. Combined check of gears. a) external spur gears; b) internal spur gears; c) bevel gears.

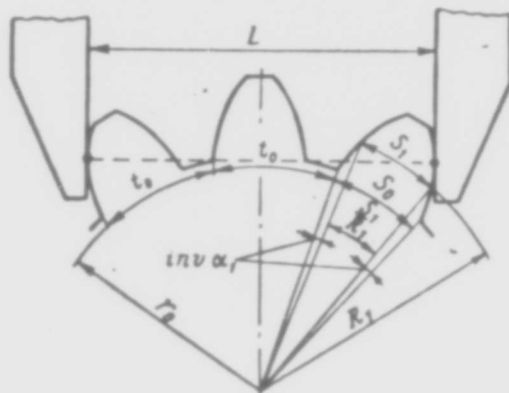


Fig. 5.38. Check of tooth thickness by a compound clamp.

end gage, and also by specially made limiting clamps or indicating instruments.

The size of compound clamp L , with the specified tooth thickness S_1 on radius R_1 , in general is determined by the formula

$$L = (n-1)t_0 + S_0.$$

If the drawing also specifies the displacement factor of the profile ξ , then

$$L = m \cos \alpha_m (\pi (n-0,5) + z \operatorname{inv} \alpha_m + 2\xi \operatorname{tg} \alpha_m).$$

In the presented formulas:

- n is the number of teeth enclosed by the clamp;
- t_0 is the base pitch ($t_0 = m \pi \cos \alpha_{\text{DK}}$);
- S_0 is the tooth thickness on the base circle

$$S_0 = 2r_0 \left(\frac{S_1}{2R_1} + \operatorname{inv} \alpha_1 \right);$$

- z is the number of gear teeth;
- r_0 is the radius of the base circle

$$\left(r_0 = \frac{mr}{2} \cos \alpha_m \right);$$

$\operatorname{inv} \alpha_1$ is the involute angle in radians

$$\left(\operatorname{inv} \alpha_1 = \operatorname{tg} \alpha_1 - \alpha_1; \cos \alpha_1 = \frac{r_0}{R_1} \right);$$

α_{DK} is the gear profile angle on the pitch circle.

The number of teeth n in general is determined by the formula

$$n = \frac{\alpha_x^2}{100} + 0,5 = \frac{\alpha_x \operatorname{tg} \alpha_x^2}{3,14} + 0,5.$$

Angle α_x is determined by the formula $\cos \alpha_x = r_0 / R_x$, where R_x is the radius on which there takes place contact of the compound clamp with the tooth profiles. It is recommended to take $R_x = R_e - f' \cdot m$, where R_e is the external radius, and f' is the addendum factor from

the pitch circle.

In a particular case, when

$$\alpha_s = \alpha_{sk} = 20^\circ$$

$$n = 0,111z + 0,5.$$

The calculated value of n is rounded off to the nearest integer.

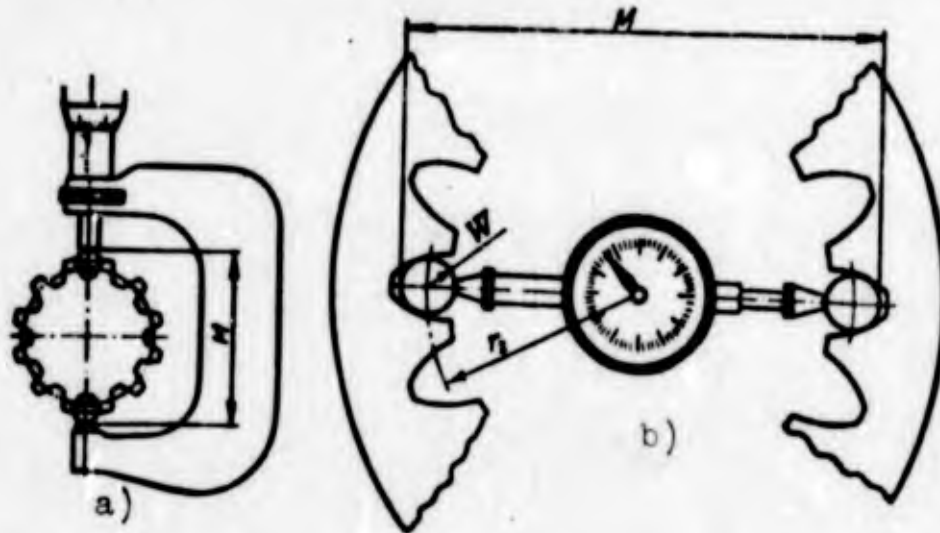


Fig. 5.39. Check of tooth thickness of gears by the position of rollers or balls in roots.

Tooth thickness can be measured (Fig. 5.39) indirectly by the distance between rollers placed in opposite roots of teeth. This distance will change depending upon thickness of teeth.

The dimension between rollers is calculated by the following formulas:

for spur gears with even number of external teeth

$$M_e = 2(r_2 + w);$$

the same for internal teeth

$$M_{in} = 2(r_2 - w).$$

Correspondingly for odd numbers of teeth

$$M_e = 2\left(r_2 \cos \frac{90}{z} + w\right)$$

and

$$M_{in} = 2\left(r_2 \cos \frac{90}{z} - w\right).$$

The radius of the roller w for uncorrected gears is taken as equal to $(0.8-0.85) m$. Under these conditions the roller will project around the top circle of external and internal gears.

Radius r_2 (to the center of the roller) is determined by the formula

$$r_2 = r_0' \cos \alpha_2.$$

Angle α_2 in radians for external gears is determined by the formula

$$\alpha_2 = \frac{\pi}{z} + \operatorname{tg} \alpha_1 - \frac{S_1}{2R_1} - \operatorname{inv} \alpha_1,$$

and for internal gears,

$$\alpha_2 = \operatorname{tg} \alpha_1 + \frac{S_1}{2R_1} - \frac{\pi}{z} - \operatorname{inv} \alpha_1.$$

Angle α_x is determined by $\cos \alpha_x = r_0 / R_x$, where R_x is the selected radius of contact of roller with involute profile.

S_1 is the specified tooth thickness on specified radius R_1 , and $\operatorname{inv} \alpha_1$ is the involute angle which is determined by $\cos \alpha_1 = r_0 / R_1$ with the help of a table of involutes.

According to the found angles α_2 and α_x we determine the theoretical radius of the roller $W = r_0 (\tan \alpha_2 - \tan \alpha_x)$, radius r_2 and dimension M .

If this dimension of the roller radius is rounded off or, in general, changed to the value of w , which is permissible, then the value of angle α_2 changes and it must be determined by $\operatorname{inv} \alpha_2$. For external gears,

$$\operatorname{inv} \alpha_2 = \frac{S_1}{2R_1} + \operatorname{inv} \alpha_1 + \frac{w}{r_0} - \frac{\pi}{z}$$

and for internal gears,

$$\operatorname{inv} \alpha_2 = \frac{\pi}{z} + \operatorname{inv} \alpha_1 - \frac{S_1}{2R_1} - \frac{w}{r_0}.$$

Example: Determine dimension M on rollers for an external gear with parameters $z = 40$, $m = 1$, $S_1 = 1.5708$, $R_1 = 20$, $\alpha_1 = 20^\circ$

($\text{inv } 20^\circ = 0.0149$, $\cos 20^\circ = 0.93969$), $r_0 = 18.7938$, and $2w = 2$.

First we determine

$$\text{inv } \alpha_2 = \frac{1.5708}{40} + 0.0149 + \frac{1}{18.7938} - \frac{3.1416}{40} = 0.02881$$

From the table of involutes, $\alpha_2 = 24^\circ 41.8'$, $\cos \alpha_2 = 0.90853$,
and

$$r_2 = \frac{18.7938}{0.90853} = 20.686$$

Then $M = 2 (20.686 + 1) = 43.372$.

In order to consider the allowance for tooth thickness, it is necessary to calculate the value of M twice, putting in formulas the values of thickness with upper and lower deviations.

Tooth thickness of a corrected (with respect to shift ξ) gear can be determined by the formula

$$S_1 = \frac{m \cdot \pi}{2} + 2m\xi \text{tg } \alpha_m = m(1.5708 + 0.728\xi)$$

Deviation of base pitch of external teeth is checked by pitch gages of the Kalibr Plant, MAAG, and others (Fig. 5.40). A pitch gage with ball ends can measure base pitch in internal gears. In this instrument the diameter of the large ball or roller is determined by earlier given formulas. The diameter of the small ball is taken as equal to $(0.2-0.3)$ m.

Run-out along roots of straight spur gears are checked (Fig. 5.41) with the help of rollers, while spiral and bevel gears are checked with the help of balls.

The profile of external teeth of spur gears is checked on involute gages of the MIZ Plant or MAAG type with replaceable disk A (Fig. 5.42) and on universal instruments with fixed disk or involute cam and lever mechanism.

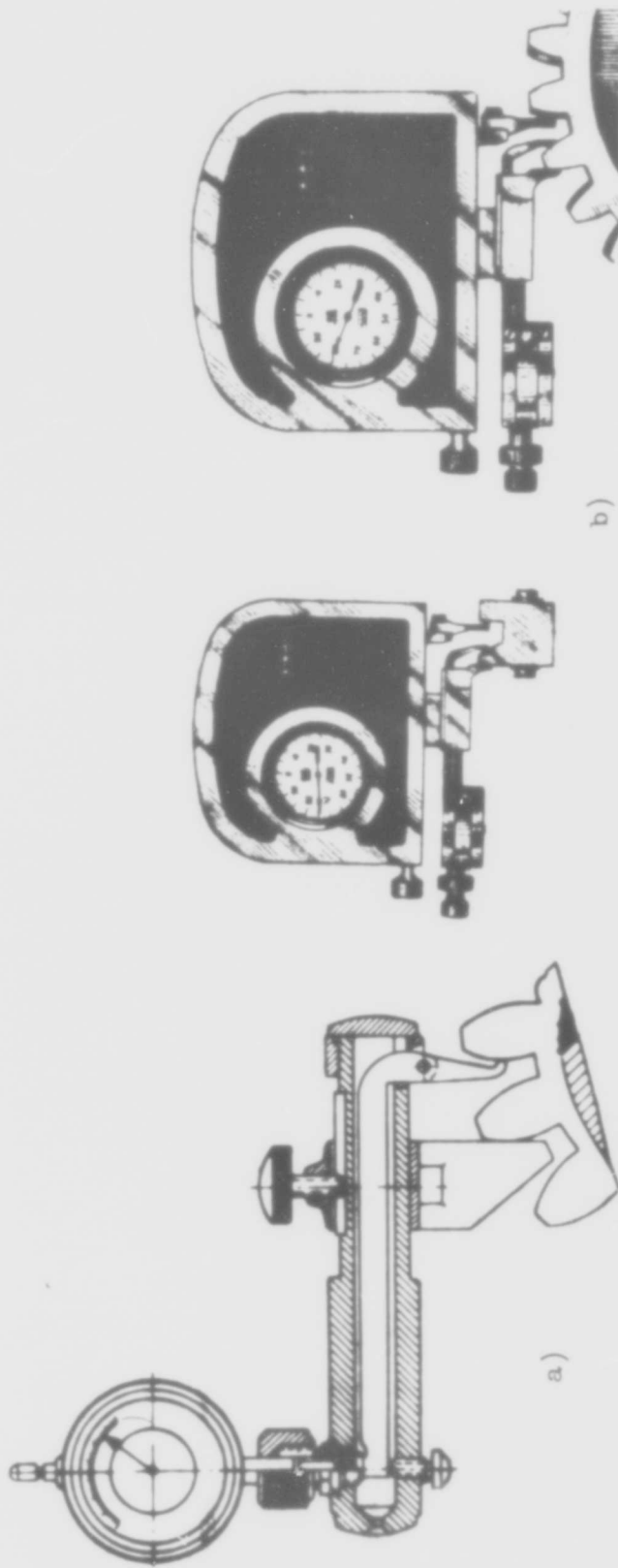


Fig. 5.40. Tuning pitch gages and checking base pitch with them. a) Kalibr Plant pitch gage; b) MAAG pitch gage.

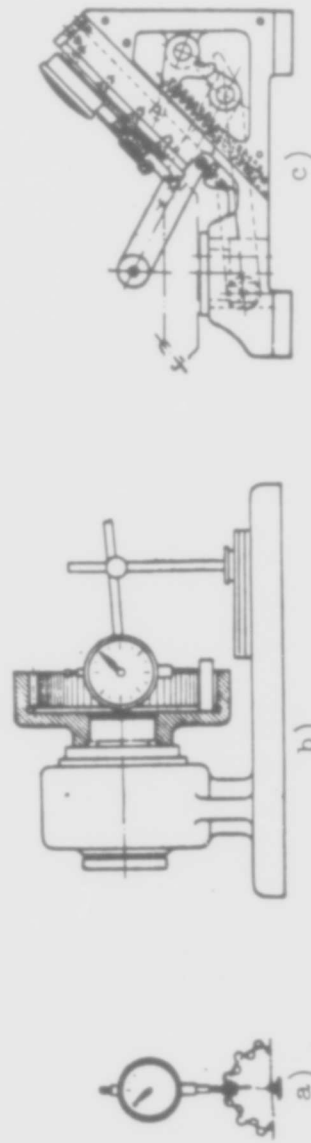


Fig. 5.41. Check of run-out through tooth roots. a) external spur gears; b) internal spur gears; c) bevel gears.

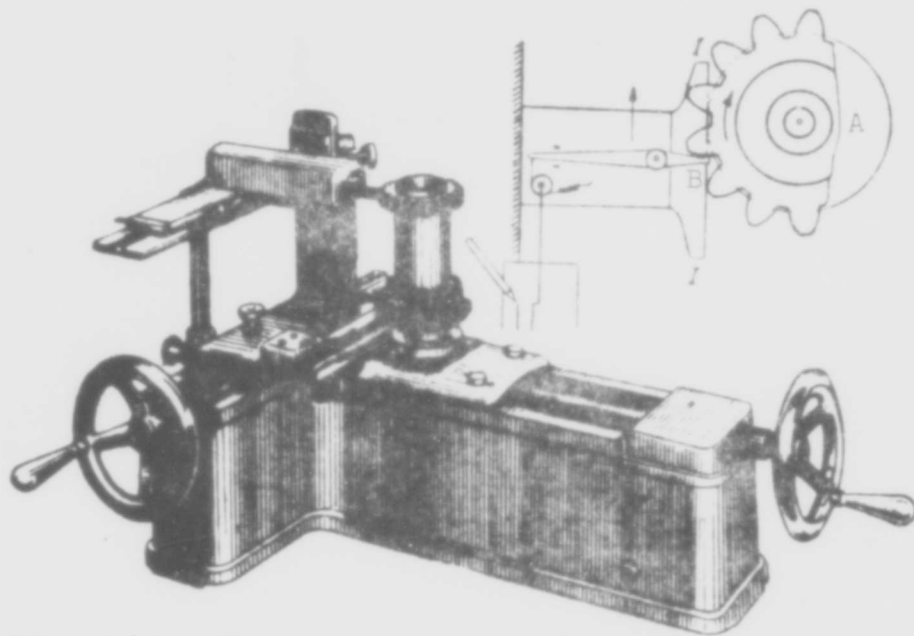


Fig. 5.42. Check of tooth profile on an involute gage.

The work of these instruments is based on the principle of involute scanning. They have a probe which is placed in contact with the tooth profile of the gear being checked. Through a system of levers the probe is connected with a recorder or an indicator which records the deviation of the involute from the theoretical value.

The principle of action of the instrument with replaceable disk (Fig. 5.42) reduces to the following. Rotation of the screw (behind the flywheel) gives rectilinear movement to the carriage with the probe mechanism and straightedge B. The probe then comes into contact with the tooth profile on line I-I and the straightedge is in contact with disk A, whose diameter is equal to the diameter of the base circle of the gear. If the tooth profile is made exactly involute, then, during longitudinal travel of the carriage and rotation of the gear, the lever of the probe will not deviate and the stylus of the recorder will trace straight line on the tape which is parallel

to the edge of the straightedge. If, however, there is distortion of profile, then the probe lever will deviate and the stylus will trace a slanted and broken line. On the paper tape there is a grid which is drawn taking into account the scale of the instrument.

The universal involute gage, with the help of fixed disk A and lever mechanism, can be tuned to different (in dimension) spur gears. This instrument also has an oscillating and moving probe, one end of which is in contact with a tooth of the gear being checked, and the second end is connected with a recorder that records the involute errors on tape.

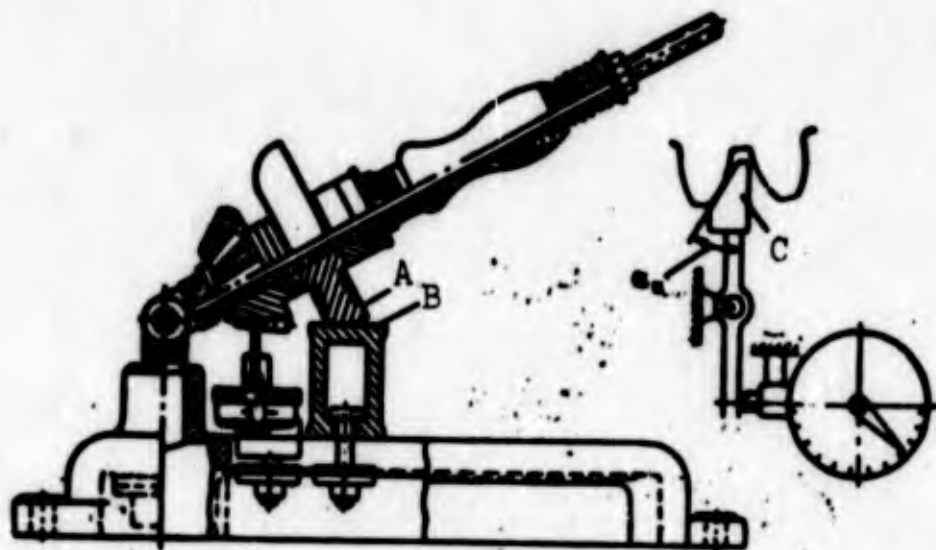


Fig. 5.43. Diagram for checking the tooth profile of a bevel gear.

The profile of a straight bevel gear can be checked with the help of an instrument whose diagram is shown in Fig. 5.43. On the shaft of the instrument there is placed a generating cone A and the component to be checked. The generating cone rolls without slipping along plane B with respect to its peak. The tooth profile of the gear during this time, which is rolling, is in contact with the flat end of lever C whose other end is connected with the recording mechanism.

Misalignments of teeth of external and internal spur gears are checked with the help of rods, as shown in Fig. 5.44. The difference

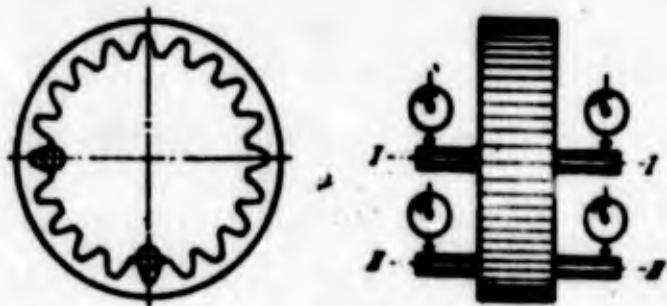


Fig. 5.44. Diagram for checking the direction of teeth.

of readings of the indicator on the ends of the rod I-I indicates misalignment of teeth, while the difference of readings on the ends of the rod II-II indicate their taper.

Check of separate elements of teeth of bevel gears is connected with large difficulties and can not always be qualitative. Instead of checking the elements in factories of batch production, a comparative checking method is used, i.e., the paint method. With this method a pair of gears is generated, one of which is standard, and the other is the one to be checked. Paint is put on the standard and during generation it is impressed on



Fig. 5.45. Location of paint spot on the tooth of a gear.

the teeth of the gear being checked. The form and position of the paint impression on the tooth is shown in Fig. 5.45. The dimensions of the imprints are regulated by GOST 1758-56; they depend on the accuracy of treatment of the gears and are given in percents of length B and height h_a . For the 5th degree of accuracy for instance, h and a are equal

to 75% of h and B ; for the 7th degree, 60%, and for the 9th degree, 40%. The same method (with paint) is sometimes employed to check the correctness of engagement of spur gears and worm pairs in assembled reduction gears.

The form of location and the dimensions of paint imprints for

spur gears are established by GOST 1643-56, and for worm gears, by GOST 3675-56.

CHAPTER VI

MANUFACTURE OF ANNULAR PARTS

A considerable number of parts of jet engines have the form of rings with different cross-section profiles (Fig. 6.1). Among such

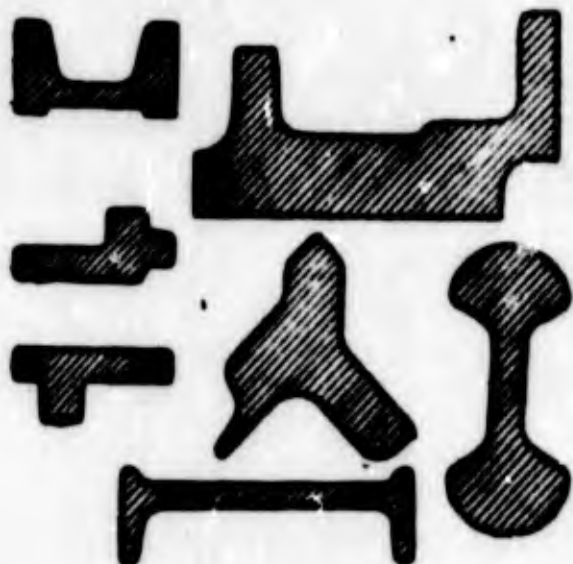


Fig. 6.1. Profiles of cross sections of annular parts.

parts are: turbine housing, flanges of jet pipe, external casing of guide, flanges of combustion chamber, rings of labyrinth seals, various rings of chambers of rocket engines.

Precision of annular parts differs, depending upon their function: for certain parts the different working surfaces are prepared with precision of 2nd to 3rd class and cleanliness up to 7th class.

Such precision is usually attained by machining. Non-working surfaces are executed by 5th to 7th accuracy class and can be obtained, when this is allowed by construction, in process of manufacture of blank (without machining).

Materials of annular parts are carbon steel 10 and 20, alloy steel EI69, 21-11-2.5 and 1Kh18N9T, heat-resisting alloys, for instance EI435, and also aluminum alloys.

§ 1. OBTAINING BLANKS

Obtaining blanks for annular parts is the basic stage of their manufacture. Blanks are obtained by casting, forging, rolling on machines, bending from profiled bars with subsequent welding of butt joints.

Casting of rings can be produced by two methods: casting in earthen forms and centrifugal casting in metal molds. By these methods there can be obtained a blank with a simple form of section.

In casting in sand there are obtained flows of metal in flow gates and air holes, which must be cut off before the blank proceeds to machining. The basic deficiency of blanks cast in sand is that they have insufficiently dense structure and, therefore, cannot be used for loaded rings.

During casting of blanks by centrifugal method melted metal is poured into a rotating cylindrical steel chill mold, painted on inside with heat-resisting paint. To eliminate sharp stresses at the time of filling, the chill mold is heated to 200-300°C. Poured liquid metal is subjected to action of centrifugal forces and, therefore, crystallization of poured blank is zonal. By centrifugal method blanks are cast in the form of a short pipe, which is then cut into separate rings. To cast blanks with a shaped profile in this way is inexpedient, since for this there will be required a split chill mold, dangerous for application in centrifugal casting. Sharp zonal distribution of crystallization in the blank and liquational porosity on internal contour of blank are a deficiency, which prevents use of these blanks for manufacture of loaded parts. For such parts this method can serve for production of initial blank, for instance, for subsequent rolling.

Forging is the sole method of manufacture of ring blanks, when in factory there are no other attachments for these purposes. When in the factory they have machines for rolling, forging serves as a preliminary operation. The initial blank for forging of rings can be castings (medium- and low-carbon steels) and cut lengths (heat-resisting alloys and high alloy steels).

Heating of cut blanks for forging is best done in continuous flame furnaces with gradual increase of temperature the length of furnace up to forging ($1100-1200^{\circ}\text{C}$). Blanks from low alloy steel can be rapidly heated to forging temperature ($900-1000^{\circ}\text{C}$). Blanks for annular parts can be obtained by flat-die forging and die forging under a hammer or press.

Attachment for rolling of rings by flat-die forging is shown in Fig. 6.2. It consists of a massive horn anvil, which is set and

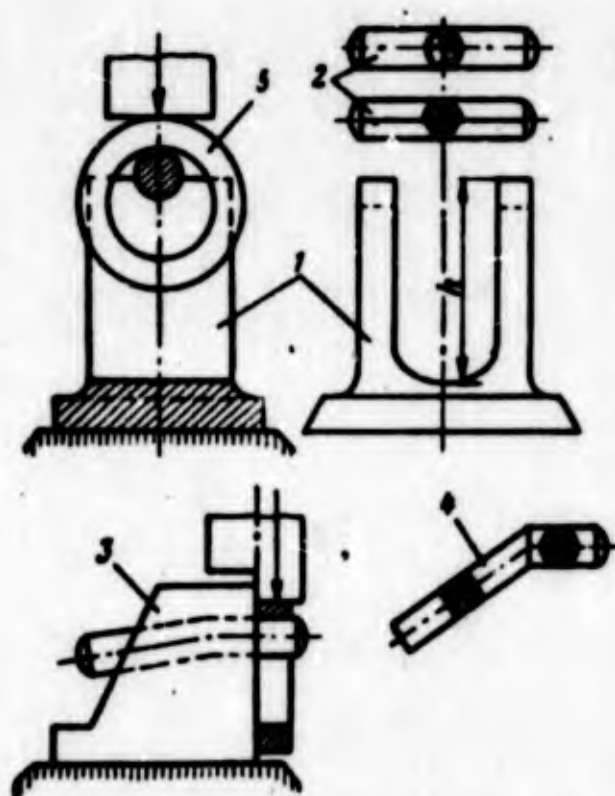


Fig. 6.2. Diagram of attachment for rolling rings by flat-die forging. 1) stirrup; 2) shift holders with various profile of section; 3) horn anvil; 4) shift cantilever horn; 5) blank to be rolled

fastened on anvil block of hammer. Initial blanks for rolling on attachment are obtained by flat-die with piercing of hole by an overhead die block.

Manufacture of rings by flat-die forging is produced with multiple heatings; therefore, given method of production is insufficiently productive.

Rings of small dimensions, according to experience of ball-bearings plants, are best forged on horizontal forges.

Casting or forging does not

permit obtaining of a blank with small allowances. Even with relatively simple form of section of rings, blanks forged under a power hammer or press are such that their weight is 4-5 times greater than weight of finished parts, and for rings with complex cross section form the ratio of weights of the blank and finished part is still greater. This means that the major part of the expensive metal is changed into shavings, and labor-consumption in machining is impermissibly great.

Problems of obtaining blanks with minimum allowances for machining have recently received considerable attention. There are already known achievements in this area.

Thus, as a result of large jobs in factories of aircraft engine construction there have now been introduced such methods of obtaining annular blanks as the method of rolling and bending of rings from profiled bars with subsequent butt welding.

Method of rolling first began to be used for manufacture of wheel rims of railroad cars; then it was improved in the bearing industry, and recently it was introduced in factories of aircraft engine construction.

Rolling is produced on a special machine, whose plan is shown in Fig. 6.3. The initial blank for rolling is a ring, which can be forged or cast centrifugally. Before rolling such a blank is usually roughed in order to remove the defective surface layer. Rolling is produced in hot state; the blank is heated to the forging temperature for the given material.

The hot blank is set on a profiled central roller 1, and in the process of rolling it is supported by lateral rollers 3. With increase of the dimension of the rolled blank lateral rollers released to the sides. Profiled stamping roller 2, revolving with a speed near

80 m/min presses down on blank with force of 12-15 T (\approx 120-150 kilonewton). As soon as the blank obtains required dimensions and touches external surface of roller 4, process of rolling automatically ceases. Roller 4 is connected with stop mechanism, which is turned on at the moment when roller, due to contact with blank, turns on its axis. Simultaneously with cessation of rolling rollers 2 and 3 move away from the blank, freeing it on the machine. Rolled blanks have small working allowance (2-4 mm) and dense structure of metal with high mechanical qualities. Productivity of the described method is higher than during forging in stamps, and at the same time costs in manufacturing forging equipment are small.

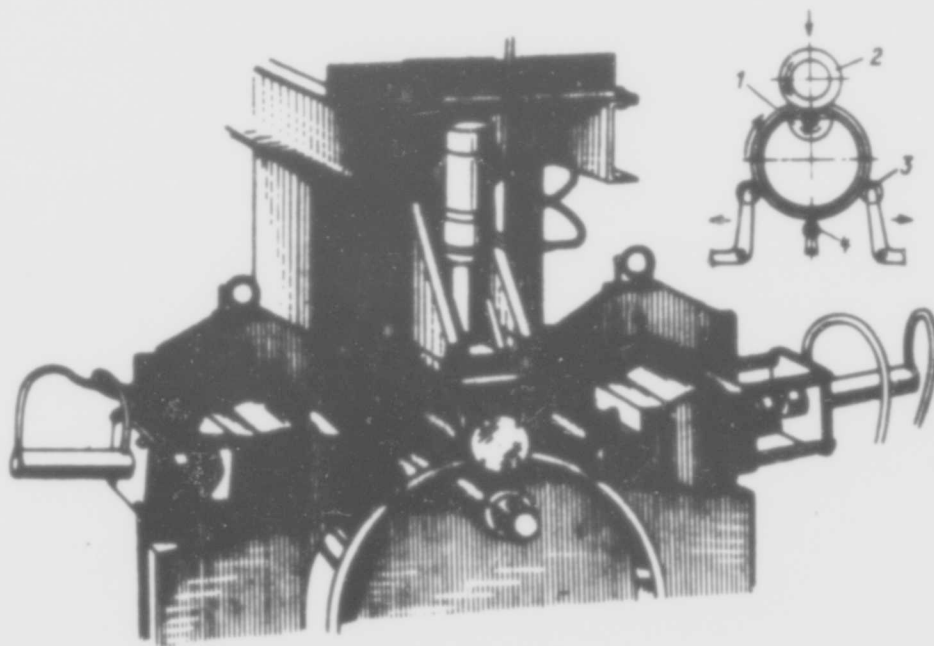


Fig. 6.3. Rolling of an annular blank.

But a still more promising method is bending of annular blanks (parts) from profiled bands with subsequent welding of the butt joints. The initial blank for bending is a profiled band, obtained by rolling or hot pressing.

A diagram of pressing of profiled blanks is shown in Fig. 6.4. Pressing is produced on horizontal press with a force, e.g., of 2,000 T (≈ 20 meganewtons). Material in the form of a cylindrical rod is packed in a container and is pressed through the hole of a die (drawing die). Rods can be cast (of steel 21-11-2.5) or forged (1Kh18N9T; steel 20; EI69; EI435). Diameter is selected so that degree of pressing is within limits of 14-40. Rods are packed in container freely with gap of 5-6 mm on a side. Before insertion rod is heated and then wrapped with glass fabric or coated with glass particles. Heating of rods, in order to avoid formation of cinder, is done in barium baths or in a medium of neutral gas. Time of heating is 12-15 sec per millimeter cross section.

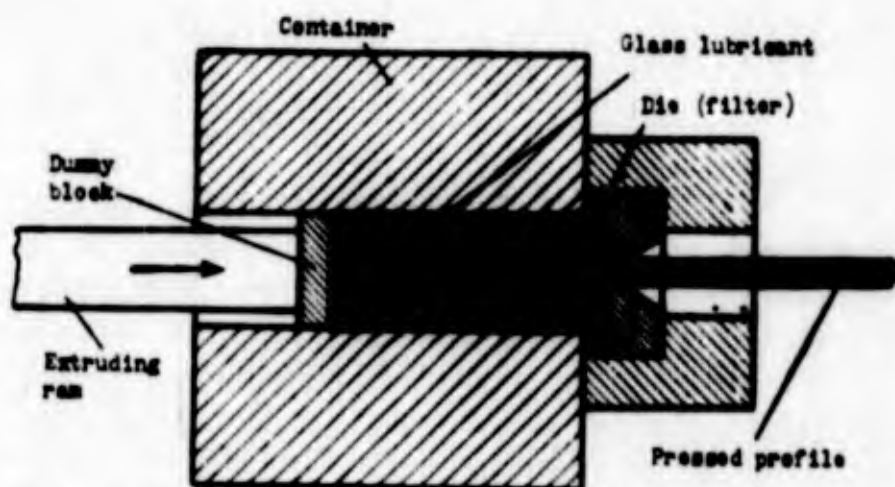


Fig. 6.4. Diagram of pressing of a profiled band.

Lubrication is of great importance for flow of procession of pressing as do conditions of pressing and material of dies. Lubricant is glass, which during pressing is melted, forming a film between the material and walls of the container and the die. By experience there have been fixed the following optimum conditions for pressing

steel; speed of pressing 45-60 m/min; pressure of press-plunger 0.12-0.16 T/mm² ($\approx 1200 \cdot 10^6$ to $1600 \cdot 10^6$ newton/m²). Best material for dies is still alloy ZhS6 with admixture of boron. Dies normally consist of two halves, which are cast and then ground. Inlet part of die is executed by a radius, thoroughly cleaned and polished. Output part has an incline. Dies may have cavity for cooling by water, which increases their life.

The pressed bar, emerging from die, enters receiver, made in the form of a pipe with a profiled hole. Transmission through the hole of receiver protects bar from twisting. However, the bar is nevertheless, somewhat warped; therefore, after pressing it is straightened on a drawing press. The obtained bars have fairly precise profile; deviation of its dimensions usually does not exceed 0.02-0.04 mm. Material has dense, fine-grained structure and high mechanical qualities. Precision of profile can be still higher, if after hot pressing the bar is subjected to calibration by cold dragging.

After cutting off its ends the bar is moved to operation of bending of annular blanks.

Annular blanks can consist of two parts - semirings or to be closed with one break.

Bending of blank is produced on profile-bending machine, for instance model PG4 (Fig. 6.5). Diagram of work of such machine is presented in Fig. 6.6.

Machine is equipped with four rollers. Upper roller 1 is the feed roller, lower middle on 3 is support, and lower lateral rollers 2 and 4 are bending rollers. Initially rollers are separated for installation between them of profiled bar. Then rollers come

together and press the bar (position A); then rotation of upper roller is switched on. In process of bending the bending roller, in the direction in which the bar shifts, should be lifted and moved close to axis of middle roller a defined distance, at which ring will obtain assigned diameter (position B).

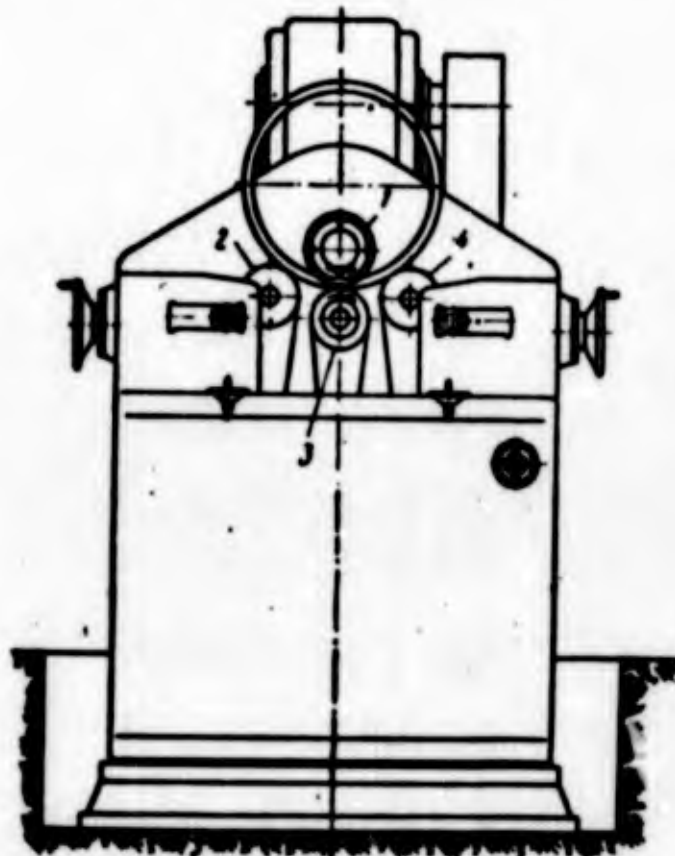


Fig. 6.5. Bending of a profiled annular blank on machine PG-4.

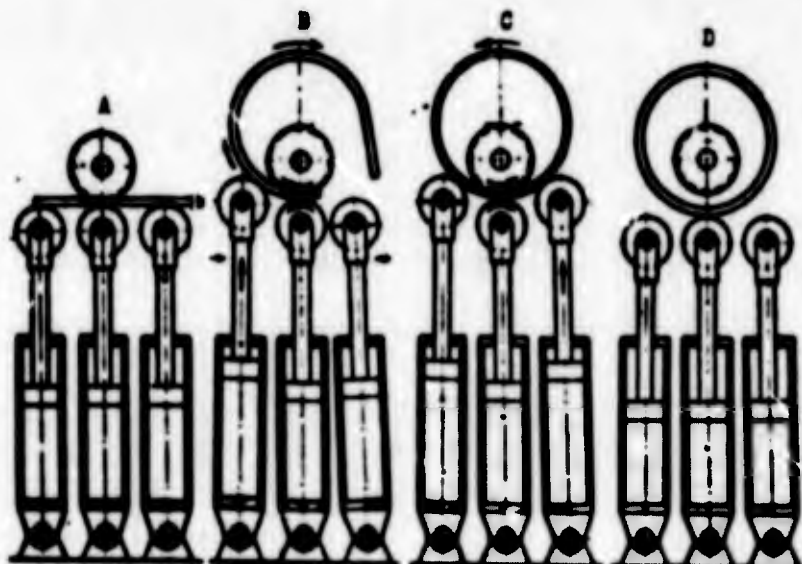


Fig. 6.6. Diagram of bending of ring on shape-bending machine.

If bending is produced with one direction of rotation of feed roller, the end of the bar remains unbent; therefore, at a defined moment direction of rotation of this roller changes (reverse) and second bending roller rises. During opposite direction of rotation of feed roller bending of ring will be completed (position C). To release ring the rollers must again be parted (position D).

Shifts of rollers are controlled by hydraulic cylinders. Speed of process of bending is selected according to section of ring and its material.

Profile of rollers corresponds to profile of bar. Material of rollers is tool steel KhVG. Hardness of rollers is Rockwell, C scale 54-60. After bending butt joints of ring are cleaned by abrasive wheel; then they are degreased and the blank proceeds to welding.

Welding may be manual, but more productive and more conducive to high quality of welded seam is flash welding on welding machines.

The ring blank (or half) is set on its external surface near seam in precision contact blocks, made from copper alloy. Part is clamped by overhead clamps on its face, and the gap is closed by rods of lateral power units. Installation on welding machine is shown in Fig. 6.7.

In process of fusion there is produced upset of butts up to 8-12 mm a side (depending upon area of cross section of ring); thus, blank should have such an allowance. Upset pressure and other parameters of butt welding are chosen depending upon material. In Table VI.1 there are given conditions of welding, which are taken from practice of aviation plants, works of NIAT and VIAM [All-Union Scientific Research Institute of Aviation Materials].

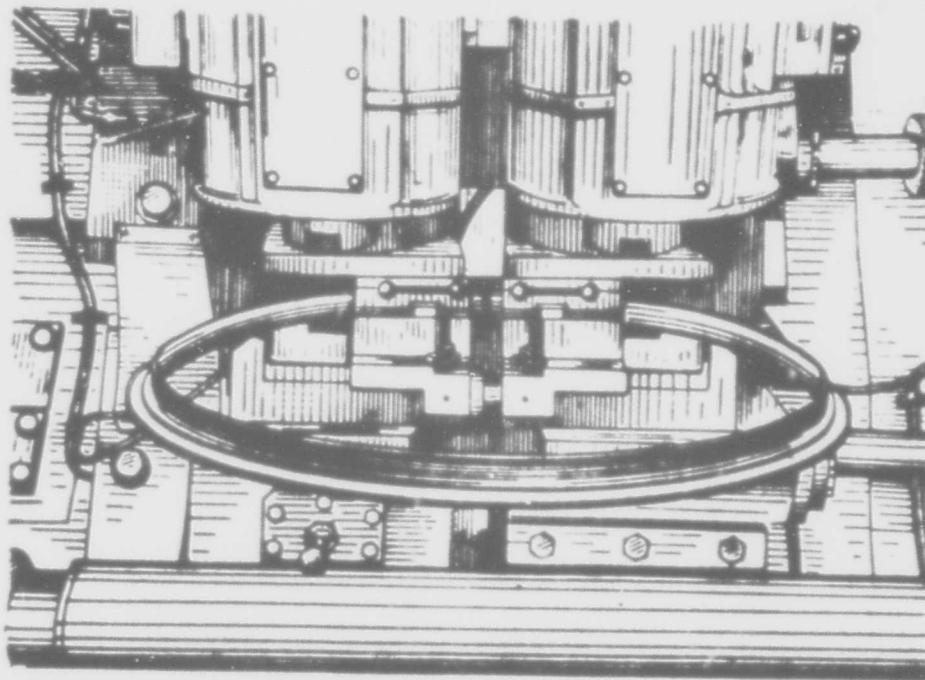


Fig. 6.7. Installation of annular blank for welding on machine MGSA-300.

Table VI.1.

Material	Upset pressure, kg/mm ² *	Current density, amp/mm ²	Specific power, kva/mm ²
Carbon steels	8-10	8-14	0.14-0.18
Stainless steels	20-25	6-12	0.8-0.12
Heat-resisting alloys	28-35	6-12	0.8-0.12

$$*1 \text{ kg/mm}^2 \approx 10^7 \text{ newton/m}^2.$$

Welding is produced in just a few seconds. Its quality is very high.

In Table VI.2 are given data of strength of welded joints, carried out by butt welding, taken from factory experience.

After welding the seam is cleaned, and they visually check its quality; then there follows operation of heat treatment, which is

conducted to remove internal stresses. During heat treatment the blank may be warped; therefore, before machining of it, it must be calibrated. Rings of great rigidity are sometimes calibrated in hot state. To reduce the cycle of treatment it is possible to transmit them to this operation directly after heat treatment, before they cool.

Table VI.2

Material	$\bar{\sigma}$ of basic material, kg/mm ²	$\bar{\sigma}$ of welded seam		Heat treatment
		kg/mm ²	% of basic material	
Steel 20	51	50.5	99	Hardening 900°
EI419	129	120	93	Hardening 1050°, tempering 670°
38KhA	90	89.5	99	Hardening 850°, tempering 560°
30KhGSA	110	108	98	Hardening 890°, tempering 530°
1Kh18N9T	58	54.5	94	Hardening 1100°
EI435	73	70	96	Hardening 1050°
22-11-2.5	—	—	97	—

Calibration is produced on hydraulic presses of force 300-500 T (~3,000-5,000 kilonewtons) in dies by drawing. In these stamps the blank is also corrected in plane of faces (is straightened).

Drawing by dies is the simplest method of calibration. Construction of dies such that when calibration of the blank of another part is necessary replacement of the whole die is not required. In this case it is possible to be limited only to replacement of certain parts, the shape and dimensions of which correspond to the other article.

Blanks obtained by bending from pressed profiled bars can have small allowance (0.5-1.5 mm) for machining, high mechanical qualities and sufficiently high precision, 0.3-0.4 mm in diameter.

Experiments have shown that strength of welded seam should not be in doubt, and the part should be practically considered uniformly

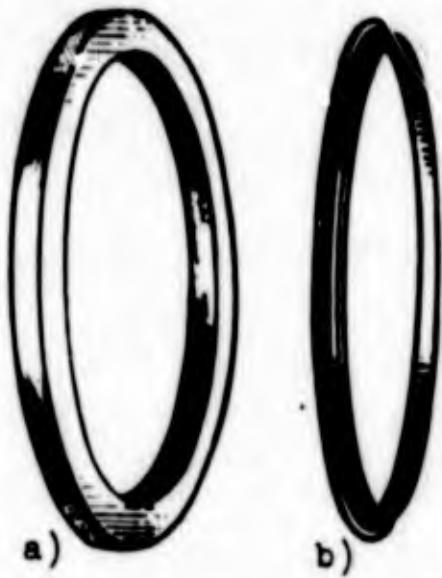


Fig. 6.8. Blanks. a) cast centrifugally; b) bent from profiled bar with butt welding.

strong. An idea of advantages of described method of obtaining blanks as compared to centrifugal casting of them is given by example in Fig. 6.8.

§ 2. MACHINING

Peculiarity of machining of annular parts is that their comparatively low rigidity determines conditions of sequence of working and methods of installation on machines. Shape of part makes for application basically of lathes, where parts of large diameters are best worked on vertical or facing lathes.

As for the sequence of working, for such parts it has already become a rule to first work the hole and face, and then on base of these surfaces to work the top. If the part has small holes, grooves or some deepening, the operations of working them are usually left to the last stage of machining.

During boring of hole the blank is set in a chuck on external diameter resting on a face. In this operation, besides the hole, they also work the exposed face. Working of these surfaces from one installation ensures their exact mutual location. By these surfaces the part is set during machining of top.

If internal diameter should be carried out with precision, it is reamed additionally after treatment of the top. To avoid deformations in positioning the part is fixed by recess of face plate and secure by cleats on its face.

When checking dimensions it is necessary also to consider low

rigidity of rings and to use inspection means whose application excludes possibility of deformation of parts. These conditions are met by indicator instruments.

CHAPTER VII

WORKING PARTS AND UNITS MADE FROM SHEET MATERIAL

§ 1. DESIGN, SPECIFICATIONS AND MATERIAL

In contemporary jet engines many important parts and units are made from sheet material. Among them are: combustion chamber, nozzles blades, chambers heads, various ducts, tanks, ejectors, jet nozzles, and so forth (Fig. 7.1).

Peculiarity of units in that they are nondetachable structures. Separate parts, obtained in most cases by stamping, are connected in units usually by means of welding (Fig. 7.1a and b) or soldering (Fig. 7.1c and d).

Specifications for manufacture of units from sheet material include requirements with respect to precision of shape and dimensions, airtightness, quality of surface and coatings, and also quality of seams.

Requirements with respect to airtightness are presented only when units work in conditions of high pressures or serve for storing of fluid. As a rule, such unit subject to hydraulic tests under pressure 50-100% higher than operating pressure.

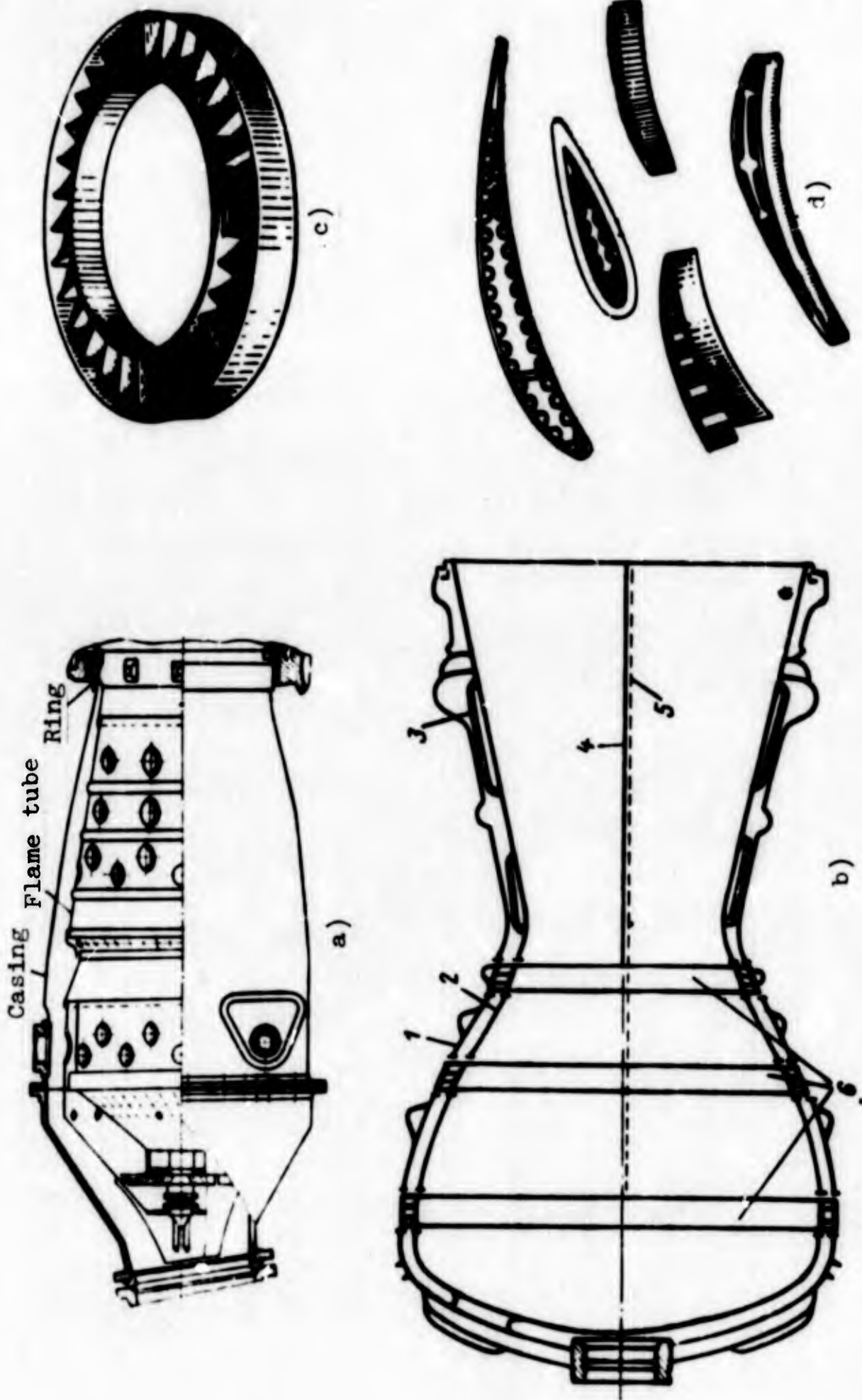


Fig. 7.1. Units made from sheet material. a) combustion chamber of gas-turbine engine (GTE); b) combustion chamber of liquid-fuel rocket engine (LFE); c) nozzle ring of GTE turbine; d) cooled blades (cross section). 1) outer shell; 2) inner shell; 3) liner; 4) joint seam of inner shell; 5) joint seam of outer shell; 6) ring.

High requirements are presented to quality of surface, especially in units which form the blading of the engine. On surfaces of parts of blading there should not be creases, folds or cracks, and cleanness of them should correspond to cleanness of rolled material. In certain cases a higher degree of cleanness is assigned. Thus, for instance, for blades of inlet manifold there is assigned cleanness of surface corresponding to 8th-9th class, which is attained by polishing

During selection of material they take into account temperature conditions in which the unit works, the function and period of service of the engine.

For aircraft engines, designed for prolonged work, thermally-stressed parts and units (parts of flame tubes, the nozzle, etc.,) are prepared from heat-resisting alloys, most frequently EI435, EI602, EI-696, 268L, 08Kh13, 20Kh3, steel 1Kh18N9T, and others. Parts of the same engines, working under conditions lower temperatures, are made from steels of brands 21-11-2.5, 08KP, 10SP (casing of combustion chamber of GTE), and others. They also apply aluminum and magnesium alloys, e.g., AD1, AD, AMts, AMg3, D16A-T, V95-T, AMgA-M (parts of intake manifolds), and others. For parts and units of engines of brief action, working in conditions of high temperatures, they use, e.g., steel 1Kh18N9T and more frequently cheaper steel of brands KhN-25, 08KP, 25KhGFA, EI643, 10G2A, 27KhGSNA, 23Kh2NVFA, and others. Tanks and bottles for fuel and oxidizers are usually made from steels 12G2A, 12KhMA, EI654, and from other special acid-resistant steels. Sometimes these parts are passivated. Recently, for manufacture of parts and units they have begun to use titanium alloys: VT1, VT5, VT4, OT4, and others.

To the producer plant sheet material proceeds with required thickness and dimensions in accordance with an All-Union Government Standard.

By special order there may be delivered sheets with dimensions larger than foreseen by the All-Union Government Standard. Material is supplied in annealed and mordanted state.

Applied materials should have high plasticity, resistivity to corrosion and good weldability, and also be easily worked on metal-cutting machines.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

Most complicated is the technological process of manufacturing units in the form of shells, among which are combustion chambers.

Sample Working Plan

1. Cutting of material.
2. Preparation of material for cutting or blanking flat blanks (lubrication of bars with oil).
3. Cutting or blanking flat blanks.
4. Preparation of flat blanks for drawing or bending.
5. Operations of shaping (drawing or bending).
6. Machining of parts before welding or soldering.
7. Treatment of holes, notches, etc.
8. Assembly of parts in units for welding and soldering.
9. Welding or soldering of units.
10. Treatment of units after welding or soldering.
11. Coating or painting of surfaces.

When there are special requirements in the technological process there can be introduced additional operations, for instance, beading, polishing, etc.

Relationship of dimensions and shapes of parts comprising a unit does not always permit one to be limited to a single operation of drawing or bending. Most frequently it is necessary to conduct such operations several times, completing their shaping (calibration). But after drawing or bending, just as after welding, it is necessary

to produce heat treatment, in order to remove internal stresses, formed during the preceding operations.

§ 3. EXECUTION OF BASIC OPERATIONS

Blanking

Laying out of sheets. Sheets of normal dimensions before cutting or blanking flat blanks are laid out and then cut into bars or squares. They are most frequently cut on guillotine shears, with sheet set on rests, adjusted in accordance with the required dimensions. Allowed deviations of bar width or of the side of the square (depending upon their dimensions) is 0.5 to 2 mm.

Sheets are sometimes laid out for several different parts of identical thickness. This permits us most profitably to use sheet area.

For laying out sheet it is necessary to determine shape and dimensions of flat blanks of parts. This can be carried out by one of the following methods:

1. Method of equality of areas.
2. Calculation of lengths with respect to a center line.
3. Method of equality of volumes or masses.
4. Graphoanalytical method.

Question of selection of one or another method is determined by the shape of the part. For instance, for determination of the shape and dimensions of a flat blank of a part consisting of simple elements most convenient is the method of equality of areas.

For determination of dimensions of flat blank of a part produced by bending with slight drawing (Fig. 7.2), most convenient is the method of calculating lengths with respect to a center line. For

this they take sections in the transverse and longitudinal directions (aa, bb, cc, etc.; AA, BB, CC, etc.,) and calculate length with respect to the center lines, considering allowance for machining. Thus, we determine coordinates of points, lying on edges of flat blank. Final shape of flat blank is determined by tracing, applying smooth linkages.



Fig. 7.2. Example of laying out with respect to center lines.

Method of equality of masses is convenient to apply when before composition of technology there was a part already manufactured. Flat blanks for parts of complex form usually are determined by method of equality of volumes or graphoanalytically.

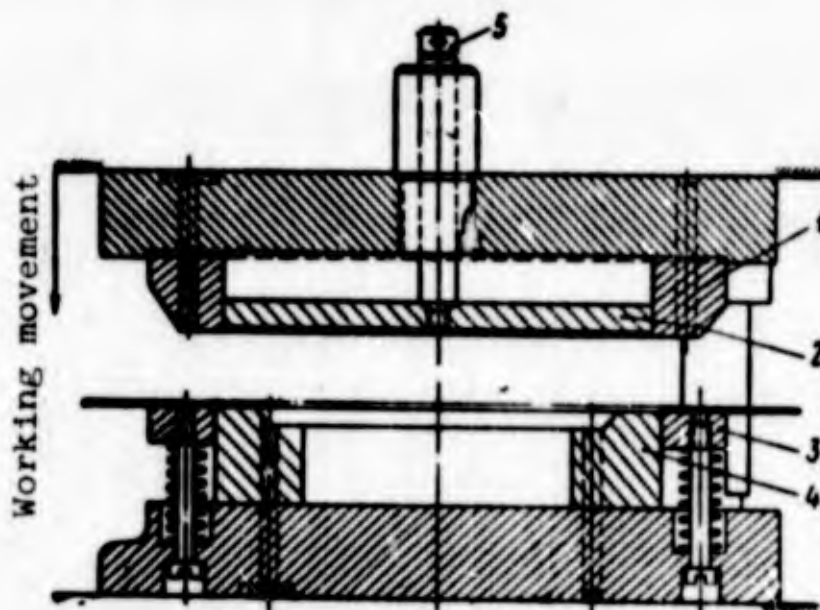


Fig. 7.3. Stamp for cutting flat blanks.

Blanking of flat blanks. Blanking of flat blanks is done by a stamp on an eccentric or crank press. In Fig. 7.3 is given typical construction of blanking stamp with overhead location of die.

Upon motion of upper part of stamp downwards die 1, pressing through material to stripper 3, lowers it, thanks to which punch 4 is bared and cutting of blank is produced. With reverse movement tail remaining on punch is removed from it by stripper 3, and cut blank is ejected from die by ejector 2, actuated by pusher 5.

To ensure correct process of cutting between die and punch there is a gap, the magnitude of which depends on thickness and brand of material (Table VII.1).

Table VII.1. Bilateral Gaps Between Cutting Edges of Punches and Dies in mm

Thickness of material, mm	Steel 18h18N9T, alloy EI417			Alloy Mn70T		
	minimum	optimum	maximum	minimum	optimum	maximum
0,6	0,040	0,065	0,110	0,040	0,060	0,120
0,8	0,060	0,080	0,160	0,065	0,105	0,175
1,0	0,080	0,130	0,220	0,080	0,105	0,280
1,2	0,085	0,145	0,265	0,085	0,160	0,280
1,5	0,090	0,165	0,300	0,105	0,180	0,375
1,8	0,110	0,190	0,360	0,125	0,215	0,450
2,0	0,120	0,200	0,400	0,140	0,230	0,500
2,5	0,160	0,250	0,500	0,175	0,275	0,625
3,0	0,180	0,300	0,600	0,210	0,330	0,750

For selection of press we determine first of all necessary force of cutting, using formula

$$P = \tau u t,$$

where P – force of cutting in kg;

τ – resistance to cutting in kg/mm^2 ;

u – perimeter of flat blank in mm;

t – thickness of material in mm.

For different materials depending upon ultimate strength $\bar{\sigma}$ and other factors τ may be taken equal to:

for steel.....(0.75-0.90) $\bar{\sigma}$
 for aluminum.....(0.60-0.90) $\bar{\sigma}$
 for duralumin.....(0.60-0.90) $\bar{\sigma}$

Upper limiting values pertain to materials of thickness from 0.5 to 2 mm; lower, to materials 2 mm or thicker.

Besides steel stamps, for blanking flat blanks they also use stamps with a rubber die (Fig. 7.4). With the help of such stamps it is possible to blank flat blanks from aluminum sheets of thickness up to 1.5 mm, duralumin up to 1.3 mm, of steel not more than 1.0 mm thick.

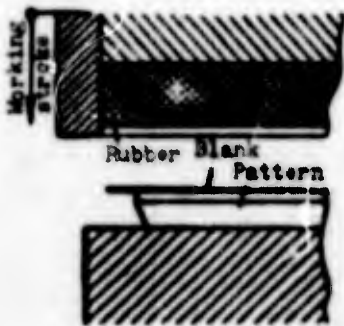


Fig. 7.4. Stamp with rubber die for blanking flat blanks.

Role of punch in such a stamp is carried out by a steel plate (pattern), and role of die is played by a rubber pad, having relative elongation of about 400% and compression under load of 100 kg/mm^2 ($\approx 100 \cdot 10^5 \text{ newton/m}^2$) within

range of 40-60%. Thickness of pattern is 6-12 mm; thickness of rubber is 30-60 mm.

Stamps with rubber die are cheaper than steel ones. They are usually set in friction presses.

Cutting of flat blanks. From the point of view of economy

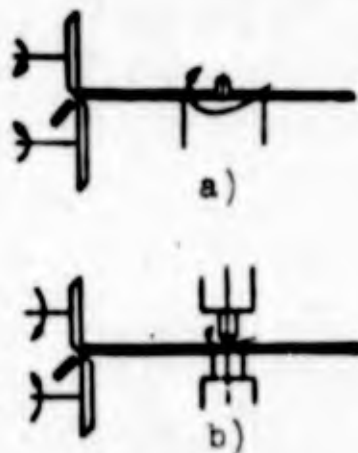


Fig. 7.5. Blanking of round blanks on roller [?] shears.

stamps justify themselves in considerable scales of production, when initial expenditures can be compensated. Therefore, for small scale production flat blanks usually are not blanked, but are cut on roller shears (for thin round blanks) or by a gas cutter (for thick-walled blanks with complex shape of contour).

Blanking of round blanks on roller shears is shown in Fig. 7.5. If in stamped part there

can be a hole, the sheet is previously positioned by a bored hole ($d = 10-12$ mm) by a pin (see Fig. 7.5a). If however, hole in bottom cannot be made, the sheet is held by its center (see Fig. 7.5b).

On shears it is possible also to cut flat blanks with contour of complex form; then, before cutting it is necessary to produce marking by a pattern.

For blanks, cut on roller shears, edges are rather even; therefore, allowance for machining in this case is taken the same as during blanking under a stamp.

Gas cutting is produced by marking. Edges in this case are uneven, and therefore, allowance for subsequent machining is increased. For instance, for blanks of halves of the nozzle of the combustion chamber of a liquid-fuel rocket engine, obtained by gas cutting, they provide allowance for machining of 18-20 mm a side.

Shaping Parts from Sheet Material

Preparation of flat blanks in stamping-drawing. Process of stamping-drawing is accompanied by considerable friction of part on surface of clamp of die and punch of the stamp. Dry friction frequently leads to formation of low points and creases on part and rapid wear of stamp. To avoid this, flat blanks, before drawing, are lubricated with pure oil, oil with graphite, etc. However, best results are obtained by coating the blank with a film of polyvinyl chloride varnish with subsequent lubrication of coated surfaced with oil. Layer of varnish is applied by sprayer and dried in a furnace or in the air. When the part is stamped in several operations, after each drawing they conduct heat treatment, in which layer of varnish burns. Therefore, operation of preparation should be conducted before every operation of stamping. If, however, the part

is stamped in heated state, the need for such preparation disappears.

Stamping of parts. Depending upon shape of part they apply processes of bending or drawing. Bending in dies is used for parts having simple form, e.g., half a nozzle. Bending is usually done in one operation. For parts having a wall of thickness of 6 mm or more, the blank is preheated (for instance, for steel 25KhGFA, to 1080°C).

Parts having a shell shape are prepared by drawing. In working out the technological process it is sometimes necessary to determine the number of operations of drawing. In such cases they see to it that on every operation, stresses in the material do not exceed its ultimate strength while fully using its plastic properties. Usually, the number of operations and their sequence is determined on the basis of experimentally fixed coefficients of drawing, consisting of the ratio of subsequent (after operation) diameter to the preceding. Thus, for instance, for first operation coefficient of drawing $m_0 = d_1/d_0$,

where d_1 - diameter of part after first drawing;

d_0 - diameter of flat blank.

For subsequent operations coefficients of drawing are ratios:

$$m_1 = d_2/d_1; m_2 = d_3/d_2; \dots m_{n-1} = d_n/d_{n-1}.$$

where $d_1; d_2; d_3; d_{n-1}$ - diameters of intermediate forms of procurements;

d_n - diameter of finished part.

In Table VII.2 are given mean values of coefficients of drawing for steel, depending upon relative thickness of material.

In factories they sometimes take higher coefficients $m_0 = (0.6-0.7)$, in order to avoid formation of cracks due to nonuniform thickness of material.

Table VII.2. Mean Values of Coefficient of Drawing

Coefficient of drawing	Relative thickness of material t/d in %					
	2.0-1.5	1.5-1.0	1.0-0.6	0.6-0.3	0.3-0.15	0.14-0.08
m_0	0.5	0.53	0.55	0.58	0.60	0.63
m_1	0.75	0.76	0.78	0.79	0.80	0.82
m_2	0.78	0.79	0.80	0.81	0.82	0.84
m_3	0.80	0.82	0.82	0.83	0.85	0.86
m_4	0.82	0.84	0.85	0.86	0.87	0.88

Heat treatment. To remove internal stresses between operations of drawing parts are heated to defined temperature with subsequent cooling in air or with furnace. Heating is produced in electrical furnaces, since in flame furnace due to direct contact of part with fire there may occur burning through of the thin wall of the part.

Temperature of heating differs for different materials. Thus, for instance, sections of flame tube from alloy EI435 are heated to 1050° , kept at this temperature 15-20 minutes and cooled in air. Sections of combustion chamber, prepared from steel 1Kh18N9T, are heated to 1150° , kept for 15-20 minutes and also cooled in air.

After heat treatment from surfaces of part it is necessary to remove cinder. This is attained by etching or sandblasting. Before each subsequent operation of drawing it is necessary to again conduct preparation - coat the part with varnish and oil.

Process of heat treatment is usually accompanied by warping of part; therefore, after last operation of drawing and heat treatment the parts must be formed (to calibrated), which is most frequently done in dies.

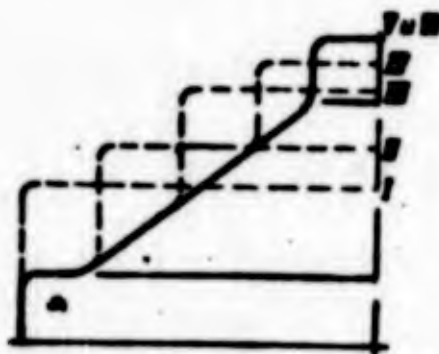


Fig. 7.6. Operations of stamping intake cone of flame tube of combustion chamber. I-V) drawing; VI) forming.



Fig. 7.7. Operations of stamping of casing of combustion chamber. I-V) drawing; VII) forming.



Fig. 7.8. Stamp with ejection of part by compressed air.

Stamps, in which for ejection of the part compressed air is applied, are more simple in construction, more convenient in operation, and permit one to use a press without pushers.

Stamps for forming differ little in construction from drawing stamps.

Worthy of attention is the method hydraulic forming of parts in a special stamp (Fig. 7.9). Stamp consists of two parts - upper and lower - connected with mobile and fixed parts, respectively, of hydraulic press. Before beginning of working movement, when upper part of stamp is lifted, punch-piston 2 under action of springs 3 is lifted to rest in plate 1. Cavity under punch-piston is filled with

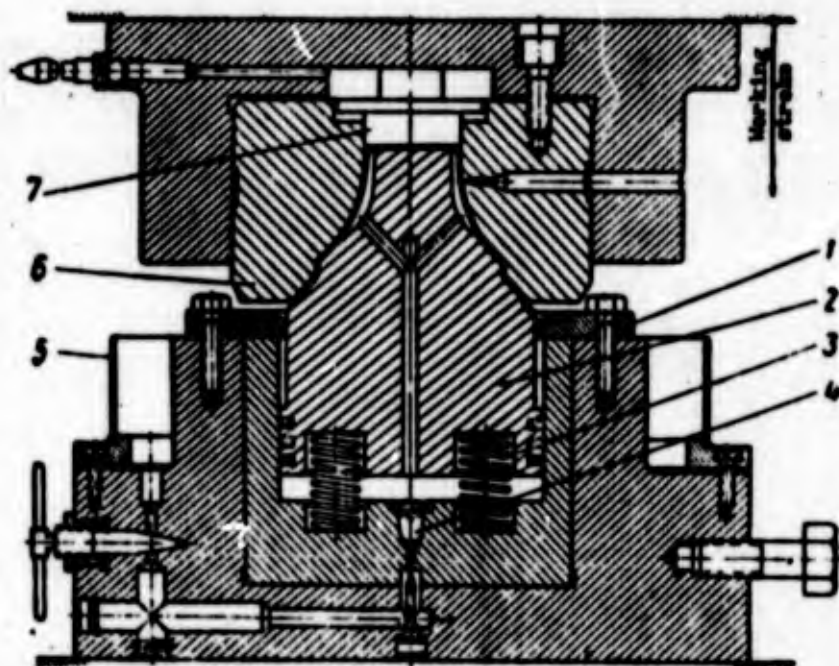


Fig. 7.9. Stamp for hydraulic stamping of intake cone of combustion chamber.

mechanical or by compressed air. Such a stamp is shown in Fig. 7.8. Air proceeds from plant line in hose through fitting 1 into cavity between die 2 and punch 3.

Stamps, in which for ejection

water, proceeding through check valve 4 from bath, formed by casing 5. During working movement of press formed part is first pressed (on lower part) between punch-piston and die 6, and then as upper part is lowered, and consequently also the punch, it is calibrated by form of die under

As an example, in Figs. 7.6 and 7.7 there are given diagrams for working the casing and intake cone of the flame tube of the combustion chamber of a GTE. As can be seen from the diagrams, the intake cone, e.g., is produced in five operations of drawing and one of forming. For seamless casing, there will already be six drawings and one forming.

During working movement of press, the blank is first pressed between upper and lower parts of die, and then during whole all working movement of the press it is extruded. When designing the die or selecting of the press, special attention should be paid to guaranteeing necessary clamping pressure of the flat blank. If pressure is insufficient, then during drawing, in the part there may form a break in the material. Both defects are incorrecible. Experience established that, for instance, for drawing of steel part with thickness of wall 1.5-2 mm clamp pressure should be near 25 kg/cm^2 ($\approx 25 \times 10^5 \text{ newtons/m}^2$).

It is also important to select correct gap between die and punch, for which probable burrs are least during stamping. Gap is established depending upon the material, the operation of drawing and is selected within limits $(1.1-1.5)t$ a side. Sometimes for initial operations of drawing, the gap is additionally increased by 0.05-0.1 mm (considering that material may be of nonuniform thickness).

Quality of drawing is influenced also by character of transition from the plane to the hole of the die. Usually this transition is made by radius, constituting 6-10 thickness of the stamped material. Transition should be smooth, for which it is polished.

In construction of stamps, they anticipate a device for removing of stamped part from the punch, or ejection of it, from the die -

pressure of water. Water emerges from cavity under punch-piston through central and slanted holes in cavity between the part and punch. During reverse movement of press springs lift punch-piston to initial position, and water will flow back into the cavity under the punch. The part is ejected from die with the help of compressed air by stripper 7.

Accuracy hydraulic forming is higher than forming in usual stamps, inasmuch as pressure on part is distributed evenly, forcing it to rest tightly against internal surface of die. During manufacture of such a stamp it is not necessary to force the form of the punch to match form of die, as this occurs during manufacture of stamps whose construction is similar to that shown in Fig. 7.8.

Stamping by rubber or liquid die. Of great interest is the method of stamp-drawing by rubber or liquid die.

For stamping-drawing by a rubber or liquid die it is possible to use both special units and also hydraulic presses. The plan of

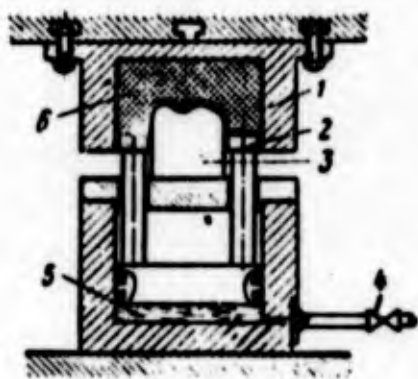


Fig. 7.10. Diagram of stamp for drawing a rubber or liquid die on hydraulic presses.

stamp is depicted in Fig. 7.10. Basic elements of the stamp are container 1 with rubber or liquid die 6 and punch 3. Hydraulic buffer 5 serves to support necessary pressure on the part of clamp 2. In process of stamping, pressures can be adjusted to required magnitude by valve 4.

The only replaceable parts are annular clamp and punch. They are replaced depending upon shape of stamped part. All remaining parts of stamp are constant.

Essence of process consists in pressing a billet located between

clamp and die, by a rigid punch, whose external contours correspond to internal contours of the stamped part.

For stamping-drawing by shown method they apply a soft rubber of high elasticity (relative elongation of at least 600-700% with Shore hardness not more than 20-30). If as the die there is used a liquid, the latter consists of elastic rubber shell with thickness of walls from 3 to 5 mm.

One of the advantages of the process is the obtaining of parts of high precision with walls of uniform thickness.

Described method gives the possibility of most fully using the molding ability of sheet material. However, its application is still limited to parts, having small relative thickness of walls (for instance, for t/d below 1%).

Rotary pressing.^{*} By this method it is possible to prepare complex parts of cylindrical and conical form with rectilinear or curvilinear forming, having constant, variable or stepped cross section of walls.

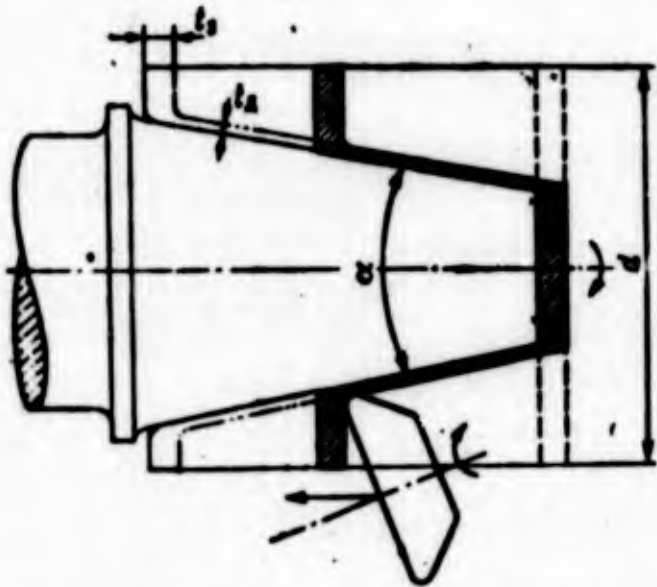


Fig. 7.11. Diagram of rotary pressing.

Diagram of method is shown in Fig. 7.11.

A part having the required form is produced by method of deformation by redistribution of metal.

For manufacture of parts by this method there have been produced special machines with one or two supports for rollers,

^{*}This method of forming is sometimes called drawing with ironing.

allowing one to obtain part with diameter and length up to 2 m. Press roller is established on support in roller holder. For manufacture of parts with a complex external curvilinear contour on carriage of machine there is established hydraulic servodevice. Mountings are usually prepared from tool steels; their surfaces are thoroughly polished, since the least roughness is completely reproduced on the part. Hardness of mountings are by Rockwell, C scale 56-60. Press rollers have shape of a frustum of a cone with radii of curvature. Rollers are prepared from high-speed cutting tool steels and are hardened to hardness Rockwell, C scale 68-70.

Manufacture of parts by method of rotary pressing is produced from flat blanks in the form of disk, cylindrical or conical vessels, obtained by preliminary drawing, ductile, or drop forging. As initial blanks it is possible to apply welded units and pipes.

During rotary pressing diameter of blank d is selected equal to diameter of flange of finished part. Thickness of material of blank is determined by relationship

$$t_1 = t_2 \sin \frac{\alpha}{2},$$

where α – internal angle of cone;

t_1 – thickness of wall of part;

t_2 – thickness of blank-disk.

In complicated cases thickness of blank is determined for equality of volumes of metal of blank and part.

By this method there can be worked both soft and highly durable metals. Most of them are processed at room temperature. However, this must not be for titanium and its alloys. Titanium, as it is known, has a hexagonal crystal lattice which hampers its working in a cold state. But with preheating to a temperature near 540°C it

submits to pressing more easily than soft steel.

Pressure on roller during pressing from 200 to 300 kg/mm² ($\approx 200 \cdot 10^7 - 300 \cdot 10^7$ newtons/m²). Most metals are worked at speed near 300 m/min with feed of roller 0.2-0.6 mm/rev. In one transition it is possible to prepare part on the condition that thinning of material does not exceed 83% for nonferrous metals and 75% for steel. During manufacture in several transitions it is sometimes necessary to perform intermediate heat treatment. During pressing heat is intensely liberated. For production of good quality parts and to avoid fast wear of rollers they apply liquid cooling (water emulsions), which is fed in the form of a stream under the roller.

By extrusion with ironing it is possible to prepare parts with precision of ± 0.05 mm. In a number of cases mechanical properties of metal after extrusion become higher than for metal in initial state.

Explosive forming of parts. This method has recently been developing rather rapidly thanks to its relative simplicity and large possibilities, allowing one to obtain part of the type of bottoms with diameter 3-3.5 m without presses and other complicated equipment.

By form of energy transmitter methods of explosive forming are divided into: powder forming and forming by gas mixtures.

By method of transmission of kinetic energy methods of forming are divided into methods in which gases, formed during combustion of explosives, act on blank directly; methods in which gases act through a piston. In Fig. 7.12 there are shown diagrams of methods, anticipating use of high explosives. The simplest of them are methods based on direct influence of gases on the blank and through an air transmission medium. For forming by these methods it is necessary to have only a die and a charge.

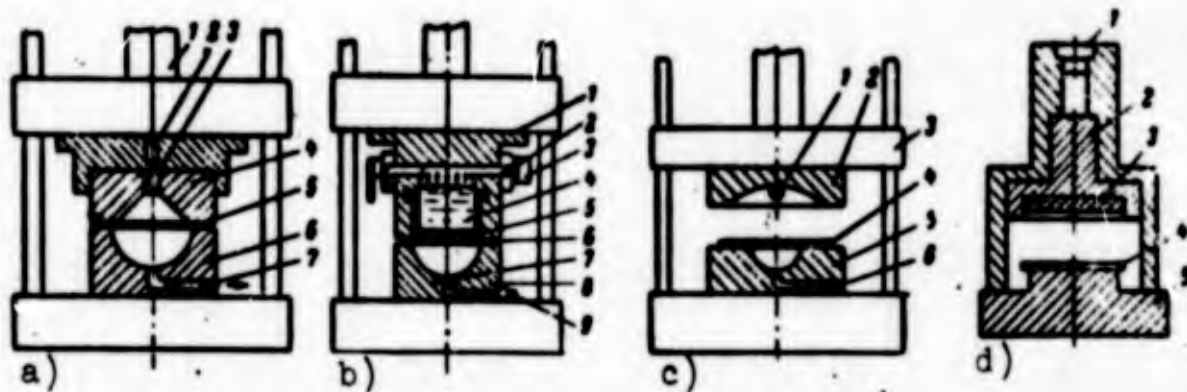


Fig. 7.12. Diagrams of forming of parts using energy of an explosion. a) stamping by pressure of gases; 1) lift rod of crossarm; 2) ignition mechanism; 3) explosive die; 4) locking die; 5) billet; 6) female die; 7) drain hole; b) stamping by blast wave; 1) charge; 2) reflector; 3) crossarm; 4) blank; 5) die; 6) drain hole; c) stamping by explosion with pressure propagation through liquid; 1) plate, locking the cavity; 2) charge; 3) ignition mechanism; 4) liquid; 5) rubber diaphragm; 6) blank; 7) porous metal; 8) die; 9) vacuum tube; d) stamping by explosion with pressure propagation through rubber; 1) charge; 2) piston; 3) rubber pad; 4) blank; 5) die.

However, of greatest interest are methods, anticipating use of a transmission medium. The explosion is produced in water or another medium a certain distance from the blank. The shock wave influences the blank through the medium. These methods ensure more equal distribution of pressure and to considerable degree decrease sound effect.

Installations for explosive forming are located in open places of the enterprise, strictly observing all safety measures in case of an accident. Explosives and detonators are kept in special safes, having fireproof walls.

Installation for forming are of basin and ground types. Reservoir of ground type is assembled from sections. Its height is determined by the height of water column necessary for stamping.

Installations of ground type are best used for forming bottoms of small dimensions both in unit production, and also in deadline preparation of production.

Installations of basin type are more versatile, although they are more complicated. Instead of creation of artificial basins it is

possible to use natural reservoirs.

During explosive forming only dies are required, monolithic or in the form of ring. In monolithic dies it is necessary to provide a system of holes for removal of air from working cavity. In small scale production dies can be prepared from wood and concrete with epoxy facing. Upper part of such dies should still be steel.

For explosive forming there can be applied different disruptives, for instance, ammonite, trotyl, hexagene, and others. When selecting explosives one should consider their power and sensitivity to impact. Here, of course, there is not ignored their cost.

Electromagnetic forming of parts. Essence of this method is that the initial metal blank, possessing proper electrical conductivity and placed in magnetic field, obtains assigned form under action of this field. Forming occurs due to pressures, attaining 3500 kg/cm^2 ($\approx 3500 \cdot 10^5 \text{ newtons/m}^2$) in the form of pulses lasting 10-20 μsec . For electromagnetic forming there are being created at present special machines on which it is possible to prepare part of rather complex form. Examples of electromagnetic forming are shown in Fig. 7.13. When it is necessary to form corrugation in pipe for fastening of it in another part (see Fig. 7.13a) electromagnetic coil 1 is placed inside the pipe (blank) 2. After carrying out the operation the pipe obtains shape 3. If it is necessary to form a unit consisting of pipe 3 with a rolled part (see Fig. 7.13b), magnetic coil 1 is placed on outer side of dies, encircling blank 2. During manufacture of corrugated plate 3 (see Fig. 7.13c) blank 2 is placed between coil 1 and a die.

Parts formed in a magnetic field are not inferior in accuracy to parts obtained by forming in stamps with application of usual equipment for pressing.

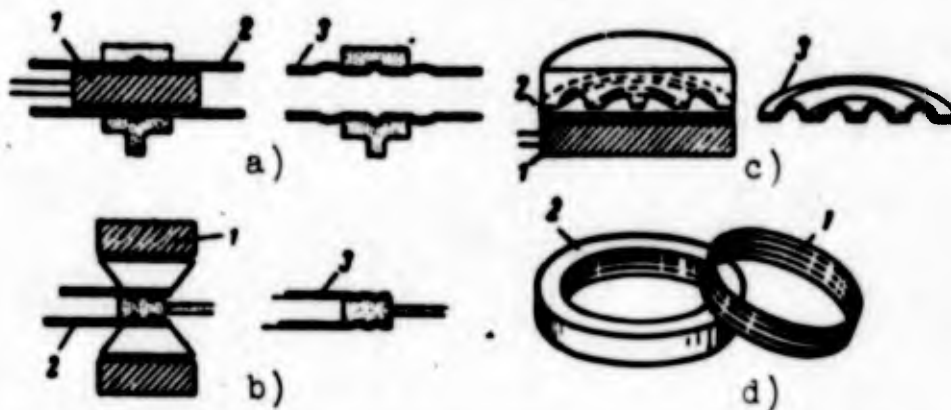


Fig. 7.13. Electromagnetic forming. a and b) molded corrugations for pipes; c) forming of corrugated plate; d) corrugated ring; 1) formed part; 2) die.

Forming on spinning lathes. This method has been known for a long time. Basic deficiency of it is the necessity of manufacturing, for each part, special arbors of corresponding shape. In complex cases arbors must be made demountable from a large number of parts taking into account possibility of removing from them formed parts. Working thus does not exclude obtaining parts with local thinning of walls. Recently, there have appeared machines with transcribers and programmed control for assigned shift of spinning roller.

Complex form of part on such machines can be obtained in 2-3 operations (Fig. 7.14). In first operation, gradually, transition by

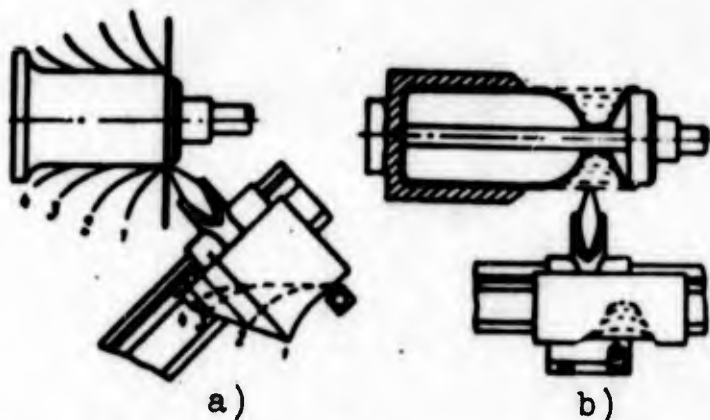


Fig. 7.14. Manufacture of chamber in two operations. a) spinning of cylinder; b) spinning of connector.

manufacture of complicated equipment.

transition (1, 2, 3, 4), they obtain a cylindrical form, and in the second they form the connector and inside part there is fed compressed air.

Such method of spinning ensures high accuracy, is very productive, and does not require

Stamping of corrugations. Corrugated parts are more frequently encountered in constructions of liquid-fuel rocket engines. They fulfill role of lining of shells or outer shells. Usually such parts are prepared from separate corrugated sections, the number of which depends on shape and dimensions. Sections are connected by welding.

Technology of manufacture of corrugated parts can be presented in the following way. First there are cut flat blanks of sections in cutting dies under a press or layout on vibration shears, depending upon scale of production. On edges of blank there is left allowance for welding (flank edges) of ~1 mm and for clipping 10-20 mm.

Then corrugations are stamped in a die, fixed on a hydraulic press, whose dies have 3-4 grooves in the form of corrugations. Shape of grooves varies; therefore, it is given in two sections. Accuracy of manufacture can be judged by tolerance and data in a table. Forming of corrugations is produced so that after every working movement the part shifts one groove; otherwise, there may form fissures, folds, and crumplings.

Formed sections are thoroughly cleaned on edges and then welded by argon arc welding with tungsten electrode without an addition. Welded sections are clamped near the seam to an attachment made from copper alloy for the best heat transformer. Sometimes in the attachment there are holes for supply with supplying from beneath seam argon to prevent oxidation. In spite of the fact that the seam is made overlapping, the sections do not have noticeable transitions (steps), in the seam there is obtained a small influx, which is usually cleaned by an abrasive wheel. Steps are not obtained due to clamping of the section in fixture by force, sufficient for formation of contact of article with positioning element in process of welding. After



Fig. 7.16. Parts, prepared by method of bending with stretching.

Operation of bending with rotation of die block can be presented in the following way. Let us assume that, for instance, it is neces-

sary to prepare connecting ring of combustion chamber, shown in Fig. 7.17.

For this purpose we preliminarily clamp rolled bar by one end on die block, and by other in a special high speed grip connected to rod of hydraulic cylinder.

Then the bar is stretched and in stretched state it is screwed into revolving die block (die). During whole process of bending force of extension is kept constant. Sometimes the part is pressed to revolving die block

by a bronze shoe, secured to rod of lateral hydraulic cylinder. Lateral

Fig. 7.17. Obtaining of formed ring on machine for rotary bending.

pressure ensures higher precision of part. To avoid depressions in part and die block the latter is lubricated with grease before beginning of bending. After bending the part, in the form of a ring, has one break, which in the following operation will be welded by butt welding.

In the same way they produce bending of parts of more complicated

welding the corrugated part (unit) obtains a conical form. Final forming, for instance, for nozzle profile, is carried out in special die-fixture or in a die of more simple design, but with installation of it on a press, having sufficient movement of slide. Machining (clipping) is produced with installation of part in fixture. If necessary, here there can be performed flanging or other similar operations.

Bending on machines. Frequently it is expedient to produce bending, not in press stamps, but on bending machines. Expenditures in these cases are incomparably lower. Bending of parts having cylindrical, conical, and also bucket-shaped form, can be done, on general-purpose bending-rolling machines.



Fig. 7.15. Diagram of rolling on three-roller sheet-bender.

Diagram of bending-rolling is shown in Fig. 7.15. A deficiency of this method is the inevitability under-rolling of the edge and low precision. Usually after bending-rolling parts must be straightened, in which quite a lot of time is expended.

During manufacture of parts of assemblies of aircraft engines over more widely used is method of bending with preliminary extension on special bending machines. This method permits obtaining of accuracy, corresponding approximately to 3rd class, and reduction of waste to a minimum. It is applicable for manufacture of parts of both little and also great thickness from different materials, including heat-resisting.

In Fig. 7.16 there are presented parts, which are prepared by bending with stretching. They distinguish two methods of bending with stretching: by means of rotation of die block (sometimes called rotary) and jacketing.

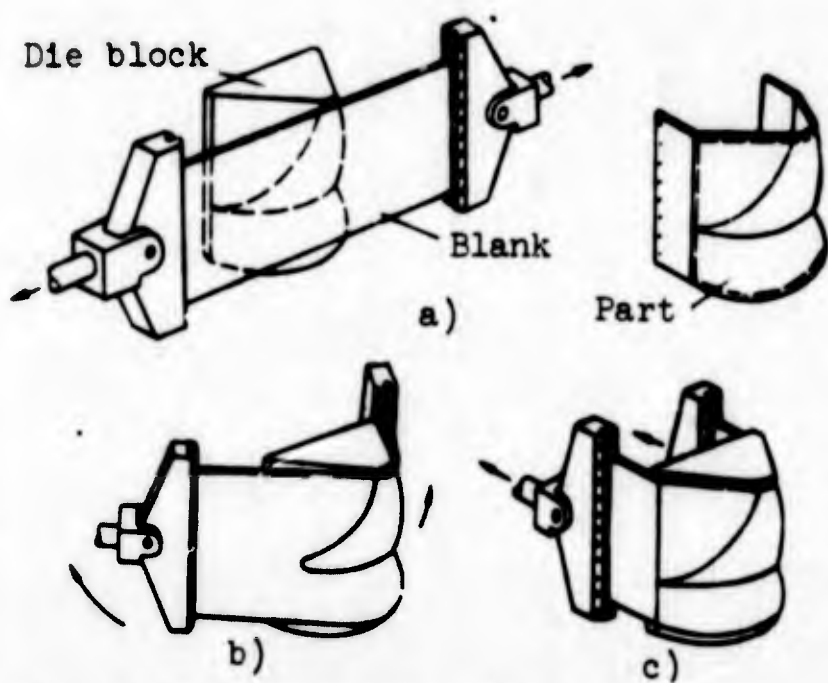


Fig. 7.18. Jacketing with preliminary stretching of flat blank. a) stretching of blank; b) step of jacketing.

form, e.g., parts of the nozzle, shells of chamber with diameter of more than two meters, etc.

Diagram of bending by means of jacketing is shown in Fig. 7.18. During bending by both methods in material there are created stresses, exceeding the yield point (but not exceeding tensile strength).

Proceeding from this, we determine the force of extension

$$P = \sigma_{0.2} \cdot F,$$

where P - necessary force of extension;

$\sigma_{0.2}$ - yield point;

F - area of cross section of blank.

As a rule, before operation of bending with stretching parts do not have to have holes or notches.

Machining After Forming

After drawing or all the more so after bending on roller machines edges of parts are uneven; therefore, before welding edges must be machined.

In certain cases parts have variable thickness of wall, for instance, at intake of cone of flame tube. Variable thickness is also obtained by machining.

Depending upon shape of part machining is conducted on a lathe,

a mill, or other machines.

As setting bases during machining they take external or internal surfaces of part, obtained during stamping.

For parts, welded end to end and having wall more than 3 mm thick, besides matchining of the end of edges, they also take chamfers for welding at an angle of 45° . For parts constituting solids of revolution, this operation is done on lathes. For parts of type of half a nozzle in small scale production they are chamfered by drill manually; for sizeable scales of production they are chamfered on milling machines by a master form.

Machining of holes, recesses, flanges, flanging, and beading.

In accordance with blueprint requirements it is often necessary to carry out a series of operations of machining holes, recesses or flanges, flanging, and beading.

Holes in parts of sheet material are drilled or punched by stamp. During designing of operation it is necessary to consider both profitability of application of one or another method of machining for the given scales of production, and also requirements on quality of parts. If, for instance, holes are located on stressed section of the part, they are usually bored to avoid additional internal stresses, which can appear during punching by stamp. Internal stresses can lead to formation of cracks and destruction of the part during its work. Holes are also bored in those cases where they are located close to one another or when the ratio of their diameters to thickness of material does not exceed 1.0-1.5. When $d_{OT}/t \leq 1$ breaks of punches of stamp are possible. Operations of boring of holes in parts made from sheet material do not differ at all from boring of other parts. Depending upon the scale of production and the shape of the part holes are

bored by layout or with the help of jigs. With a large number of holes, located close to one another, they often use jigs with dividers or unit-head machine tools.

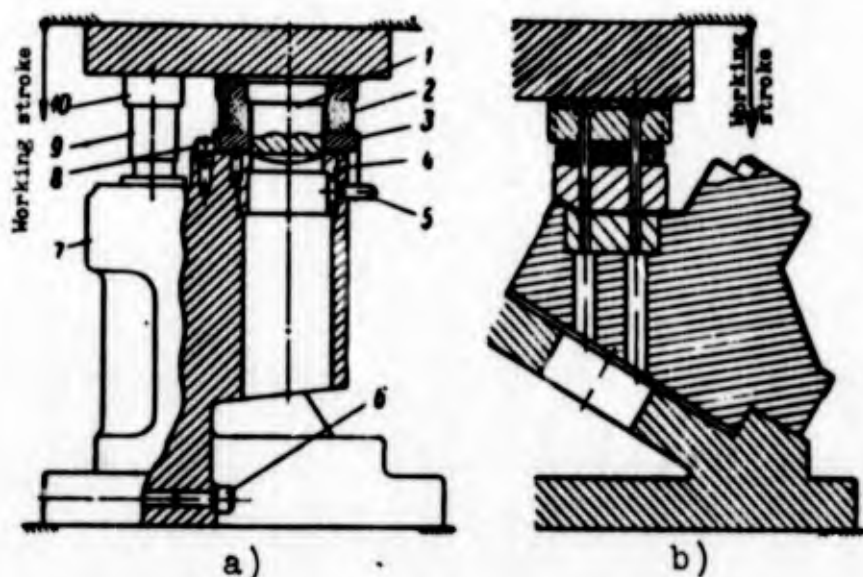


Fig. 7.19. Stamps for punching holes.

Punching of holes by stamp is produced, as a rule, on eccentric or crank presses.

In Fig. 7.19 are given typical constructions of stamps for punching holes in parts of cylindrical or conical

form (of such form are sections of the flame tube of a combustion chamber). Console stamp (Fig. 7.19a) has punch 1, die 4, and clamp 3, the shape of working surfaces of which corresponds to the part's shape. For production of required dimension from end to center of hole the part is set on rests 6 and 8. Angular spacing of holes is ensured by latching device, consisting of index pin 5 and index wheel, set before punching on the processed part. The part is pressed to the die (during the working stroke of the press) by elastic (rubber) buffer 2. For direction of punch with respect to die stamp there are heels 9, pressed in body 7. During movement of press heels slip in holes of cast-iron bushings 10. Such a stamp is designed to punch holes of one bar. For puncture of holes of other bar it is necessary to have other stamps of the same design or one more complicated construction with longitudinal adjustable rest.

If holes are closely spaced, they apply stamps with several punches (see Fig. 7.19b).

Recesses and flanges are usually obtained by stamping. However, this method is not always applicable.

By experimental means it has been established that qualitative stamping of recesses or flanges can be obtained with relation $h/d \leq 1.0$ for steel parts and $h/d \leq 1.3$ for parts of aluminum and other soft materials. Here h is depth of recess; d is diameter of recess.

Flanges or recesses can be stamped on eccentric, crank, and frictional presses (Fig. 7.20). Machining occurs as follows. Before

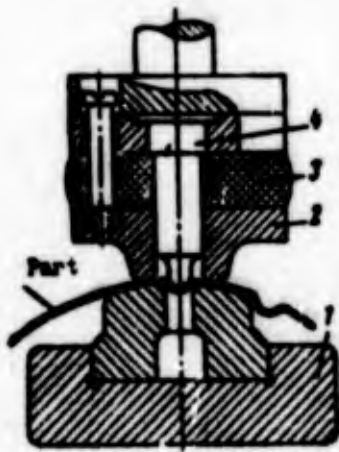


Fig. 7.20. Stamping of recesses.

the working movement of the press the machined part is set by rest on die 1; during working movement the part is first pressed to die by clamp 2 (under action of rubber buffer 3); then there occurs extrusion of recess by punch 4. During extrusion of following recesses the part is fixed on lateral face of die (or on recess in die). If shape of part, power of press and property of material, permit, they apply stamps with several punches, thereby reducing labor-consumption of machining, and dimensions between holes become more precise.

Sometimes it is more convenient to stamp recesses or flanges in stamps with location of punches in horizontal plane.

Flanging of small holes is produced in stamps, which in construction are similar to the stamp in Fig. 7.20.

Flanging of large holes is produced in stamps with replaceable punches counting on carrying out operation in several transitions. In Fig. 7.21 is given construction of stamp which can be used not only for cupping a part, but also for flanging of holes. Such a stamp can

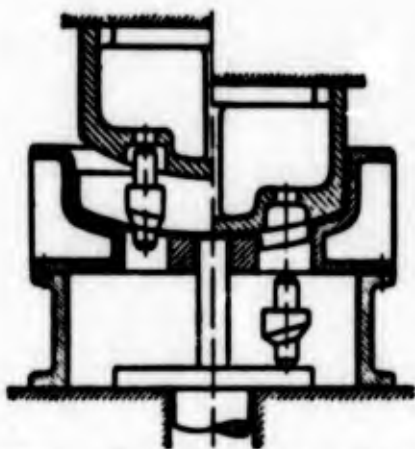


Fig. 7.21. Flanging of holes.

be used, for instance, for drawing and flanging holes for blocks of injectors at bottom of chamber head, shown in Fig. 7.1b.

Beading is executed on a beading machine, on whose spindles there are fixed and secured special rollers. Before positioning of work piece spindles are parted so that rollers do not prevent positioning. If it is necessary to

make in a part a series of annular ridges with definite spacing between them, they apply step rests.

Besides special machines for beading, they sometimes use lathes. In this case on spindle of machine they establish unclamping arbor with annular or (depending upon construction of part) spiral grooves. Ridges are pressed by a roller, freely resting on shaft of holder, secured in support of machine. To produce the constant force, with which the roller should be pressed to the part, screw of transverse shift of support is removed and upper part of support is loaded by a weight or spring.*

On lathes it is also possible to produce flanging of edges of a part, rolling and other similar operations.

Etching. During manufacture of parts and units from thick sheet materials it is sometimes required to obtain local flanges or cavities. Usually this is done by milling, where much time and money is spent on machining. Recently for this purpose they have begun to apply etching** (Fig. 7.22). Essence of this method consists of the following.

*Such a scheme is used during working from a master form.

**Etching is sometimes called chemical milling.



Fig. 7.22. Part, treated by etching.

The part or unit is first degreased, the unworked surface is protected by chemically stable materials and then dipped in a bath with etching agent for the time necessary for etching to the assigned depth. Depending upon dimensions of baths they simulataneously load various numbers of parts; therefore, productivity of etching department can be very high. Protective, chemically-stable materials (during local etching) are usually applied to unworked surface by a pattern by means of spraying. The thin film thus obtained can be left on part for protection of it from corrosion during use. It is also possible to apply other methods of protection: gluing of stable strips, imposition of patterns, galvanic coating, and others. Different etching agents are applied depending upon material of part. Thus, for instance, for aluminum alloys they apply strong alkalis with special additions, ensuring obtaining of smoother surface. For soft and medium-carbon steels they apply an etching agent, consisting of chrome and sulfuric acid. For chrome steels, for instance, they apply an etching agent composed of one part (by volume) HCl (20°) and one part HNO_3 (42°). After 10-15 minutes this etching agent removes a layer about 0.1 mm deep.

Treatment of etching has a number of advantages over machining.

1. Etching is $1/4$ to $1/5$ as cheap as machining.
2. Etching can be produced on two sides simultaneously.
3. Process easily submits to adjustment.
4. Physico-mechanical properties of etched material do not worsen.

5. Precision of treatment is approximately 0.05 mm.

Application of etching is limited by depth of removed layer.

Experience shows that during etching to a depth of more than 10-12 mm precision is lowered due to lateral etching of walls.

Joining Parts in Assemblies

Parts of sheet materials are joined in assemblies by welding or soldering and are assembled in special fixtures, ensuring required location of separate parts in the assembly. If, for carrying out of welding it is necessary to remove the assembly from the fixture, before doing this they connect parts among themselves by welded points (tack welds). Operations of assembly with the help of fixtures are usually conducted in the following order: first they set base part of assembly in such a way that it touches surface (setting bases) of corresponding parts of the fixture (setting elements) and occupies the prescribed position. In this position it is secured by a gripper. Then, relative to the secured base part they position the remaining parts of the assembly, using here the corresponding locators and grippers of the fixture.

After assembly, without removing unit from fixture, at separate points on the place of the future seam they produce tack welding by point, electric arc or gas welding.

Welding of Assemblies

In contemporary jet aircraft engine construction welding has found wide application in manufacture of the most important assemblies. There are applied various methods and means of welding.*

*V. N. Belikov and A. N. Nikitin. Assembly of aircraft engines, "Machine building," 1964.

When selecting methods of welding one should take into account the following consideration.

Weldability of steels to a considerable degree is determined by their carbon content. The more carbon contained in steels, the worse their weldability. Steel, containing carbon up to 0.25%, weld well by all methods. Limited in application is only welding in stream of argon or helium, since due to low content in these steels of deoxidizing agents with the shown methods of welding pores are obtained. To this class belong steels 08KP, 08SP, St 10, 15, 20, and others.

During welding of medium-carbon steels, containing 0.25-0.45% carbon, there appear difficulties, connected with possibility of appearance of crystallization and tempering cracks. To surmount these difficulties in most cases it suffices to decrease carbon in addition metal by application of low-carbon wires of brands Sv-08 and Sc-08GA. For medium-carbon steels there can be applied all methods of fusion welding. Selection of one or another method depends on requirements, presented to the assembly. In this group are steels 25, 30, 35, 40, 25G, 30G, 35G, and others.

Low-alloy steels 12G2A, 15GS, 15KhMA weld the same as low-carbon steels. Medium-alloy steels 20KhGSA, 30KhGSA, 30KhGSNA, 30KhNMFA, 12Kh5MA, VL1D, and others can be welded by manual welding by high-quality electrodes, automatic welding under a layer of flux, and also welding in a stream of protective gases.

Steels of austenitic class of type 1Kh18N9T weld well by all methods; however, during welding there may appear hot cracks. To avoid this one should limit content of sulfur in metal (below 0.02%), and apply wires ensuring in the fused metal a two-phase austenitic-ferrite structure.

During welding of steel EI395 it is recommended to apply wire Kh15N25M6. The steel can be welded in a stream of protective gases, under a flux (brand ANF6 and ANF5) and by electric-arc welding. For welding heat-resisting steels EI481 and EI835 there are recommended wires EP-88 and EI-395. Casting alloys VP7-20 and VL7-454 can be welded to steels EI395, EI481 and 1Kh18N9T, applying wire EI395, EP-88 and VZh-98.

Application of welding by electrode bundle in a vacuum considerably decreases inclination of heat-resisting steels to crystallization cracks.

During welding of austenitic steels with low-carbon steels it is recommended to apply wire Kh25N12T or Kh25N12TYu; with medium-carbon steels Sv-08Kh20N10G6 or Sv-08Kh20N9G7T.

During welding of refractory metals, such as molybdenum, niobium, zirconium, tantalum, tungsten, there is required good protection of the molten metal from influence of atmosphere, since they have large chemical activity with gases, especially to oxygen, as a result of which there is obtained strong embrittlement of the metal. Best results are obtained by welding these metals by an electron beam in a vacuum.

Refractory metals allow rather wide combinations with welding. Thus, for instance, molybdenum can be welded with tungsten, niobium, titanium, tantalum, and stainless steel. Tungsten is well welded with titanium, niobium, nickel, tantalum, stainless steel. Titanium can be welded with zirconium.

Welding of metals, not possessing mutual solubility in liquid state and forming fragile chemical compounds, can be carried out by application of intermediate inserts of other metals. Thus, for

instance, titanium can be joined to steel with the help of an insert of vanadium, a copper alloy with titanium, through tantalum.

Quality of welding to a considerable measure is determined by operations of assembly of parts to be welded and perfection of assembly-welding fixtures. For point and seam welding of engine parts there are applied fixtures of the following basic forms:

- a) patterns for correct installation of welded parts;
- b) fixtures for fastening parts before welding;
- c) assembly jigs, serving for correct installation of parts and simultaneously holding them during welding;
- d) welding fixtures, serving for current feed and pressure propagation.

Quantity, character, and complexity of applied fixtures depend on volume of production. In many cases simplicity of construction of welding attachment is attained by means of application of shaped electrodes of complex form and, conversely, more complex fixtures give the possibility to work with simple straight electrodes.

During manufacture of welded assemblies they basically apply nonmagnetic alloys (1Kh18N9T, 21-11-2.5, EI435, EI602, etc.); therefore, fixtures for assembly and tack welding are also prepared from nonmagnetic material - aluminum alloys or stainless steels - in order not to increase inductive reactance of the secondary circuit of the welding machines. Before welding parts of assemblies are often assembled by special fixtures.

In a number of cases for assembly and welding it is possible to use the same attachment, which permits reducing the time for carrying out the operation.

Simple, and at the same time reliable in operation, are fixtures

for assembly and welding of assemblies of the flame tube of a combustion chamber, shown in Fig. 7.23. Fixtures are positioned on lower bracket of welding machines.

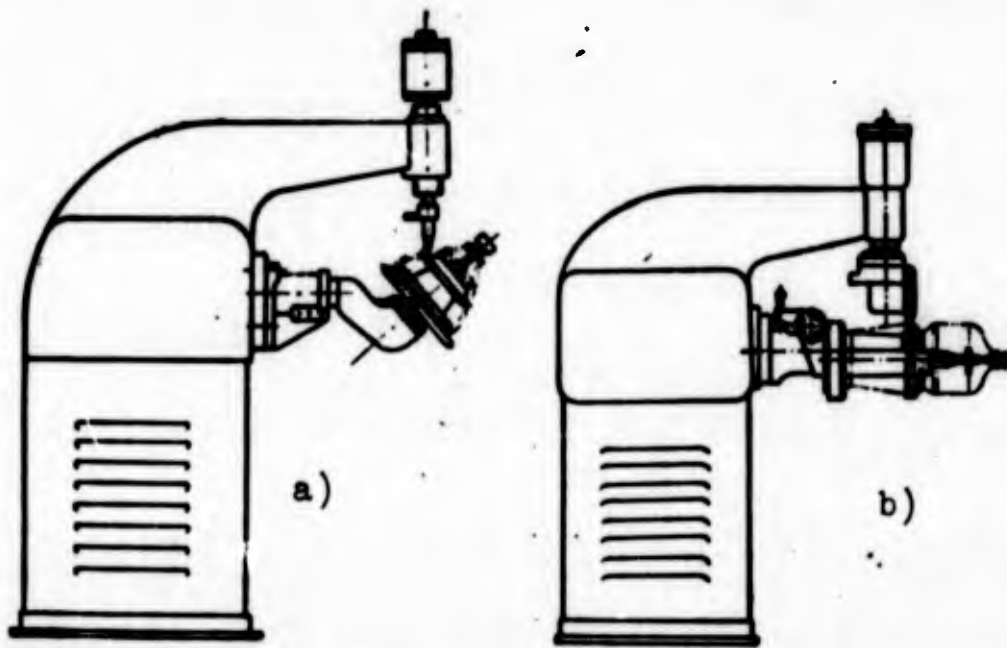


Fig. 7.23. Fixtures for welding assemblies of a flame tube. a) on machine for spot welding; b) on machine for seam welding.

For butt joints they most frequently use such forms of welding: hand argon arc, automatic argon arc and automatic submerged arc welding. Atomic-hydrogen welding finds comparatively small application due to certain inconveniences connected with necessity of manipulation of burner during welding, and in many cases has already been replaced by improved arc welding in a medium of argon or helium. Regarding gas welding, its share of jobs is comparatively small, and it is mainly used during welding of nonferrous and light metals or small parts of low-carbon steels.

Application of fusion welding and its replacement by point and seam welding in many cases is explained by the fact that in butt joints there are no places of concentration of stresses. As compared to lap joints they possess increased vibration strength

(from 2 to 8 times), which is one of the decisive factors in manufacture of assemblies and parts which work in specially rigid conditions - during alternating loads or at high temperature conditions. The good aerodynamic form of the butt joint, and also the absence of technological difficulties when checking the quality of welded seams also explains the rapid growth of introduction of these forms of welding in engine-building.

In many plants widely developed is manual arc welding (in medium of argon or helium of purity up to 99.2%) of assemblies with short butt seams or seams of complex configuration. By this method they successfully weld steels 1Kh18N9T, EI654, 21-2.5, and others. Steels or alloys with a large number of alloyed components, for instance, EI617, EI602, EI435, EI437, are best welded by protecting the reverse side of the seam by a stream of neutral gas or a flux of brand Zh-8.*

During welding of thin-walled parts they sometimes apply heating. Thus, for instance, during welding of the header to the hollow blade of a nozzle they apply a heating current of high frequency. Induction heating of the blade edge to 800° in process of welding eliminates formation of cracks and zones of thermal influence. Time of preheating is 25-30 sec.

Manual welding of small assemblies is most frequently produced without fixtures. In the same cases, when it is necessary to weld large and heavy assemblies, they apply special fixtures, allowing one to give different positions to welded assembly for access to places of welding. Such fixtures, besides base and clamp elements, also

*Flux Zh-8 is composed of: porcelain, marble, titanium dioxide, ferrosilicon, ferromanganese, and ferrotitanium.

have devices for turning and slanting (manipulators).

Assemblies with longitudinal and circular seams in more or less considerable scales of production are welded by automatic welding in a medium of protective gases or under a flux.

Automatic welding in a medium of protective gases (argon, helium) occurs in two forms: consumable electrode and nonconsumable tungsten electrode without addition material. In first case it is more expedient to weld steels of thickness of 2.0 mm or more, in second, steels from 0.5 to 2.0 mm.

For the purpose of economy of argon and helium at present non-essential joints are also welded by arc welding by a consumable electrode in a medium of carbon dioxide.

Automatic arc welding under a layer of flux, just as arc welding in a medium of protective gases, is a process which ensures high quality of welded joints: depth of penetration, homogeneity, and purity of metal of seam and even surface. Large density of welding current (4-5 times higher than in manual welding) ensures high productivity - up to 80 m/hr.

For welding low-carbon and low-alloy steels, and also for steel EI654, there widely apply flux of brand of AN-348A, and for stainless steels (for instance, 1Kh18N9T), flux FTsL-2. Composition of these fluxes (in %) is given in Table VII.3.

For automatic welding both in a medium of protective gases, so also under flux, they apply different automatic machines, automatic heads and stands. Most widely applied in the aviation industry are welding tractors of ADS-1000-2 and UT-1500, transferred from alternating to direct current, and also welding torches and automatic machines designed by NIAT.

Table VII.3. Chemical Composition of Fluxes

Brand of flux	SiO ₂	CaO	MnO	MgO	CaF ₂
М-340А	41—43,5	to 5,5	34,5—37,5	5,5—7,5	3,5—4,5
FTol-2	35,5—36,5	31,5—32,5	—	15,5—16,5	7,5—8,5

Brand of flux	Mn ₂ O ₃	Al ₂ O ₃ + Fe ₂ O ₃	S	P
М-340А	0,1—0,3	to 4,5	to 0,15	to 0,12
FTol-2	—	to 8,0	to 0,020	to 0,030

In fig. 7.24 there is given a diagram of automatic welding under flux of circular seams of combustion chambers from steel 08KP of thickness 3 mm. They weld chambers with a speed of 60 m/hr.

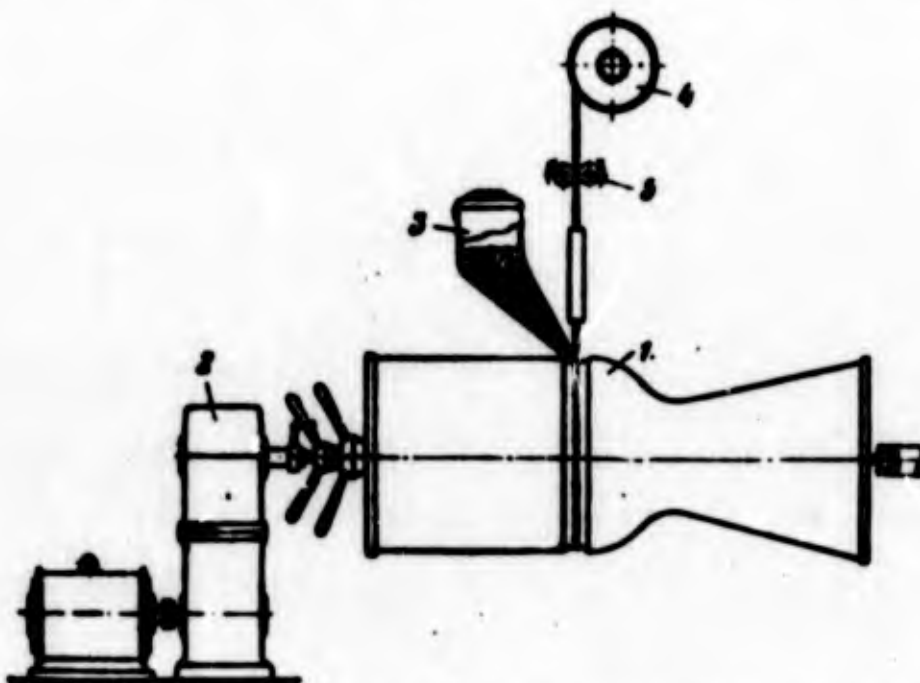


Fig. 7.24. Diagram of automatic welding of circular seams. 1) welded assembly; 2) reducing gears; 3) flux hopper; 4) electrode wire holder; 5) feed rollers.

In Fig. 7.25 there is shown a welding stand with tractor ADS-1000-2 and pneumatic clamp of edges. Stand is used for welding longitudinal seams of shells of vessels of a length up to 1.5 m and a wall thickness of 2.5 mm.

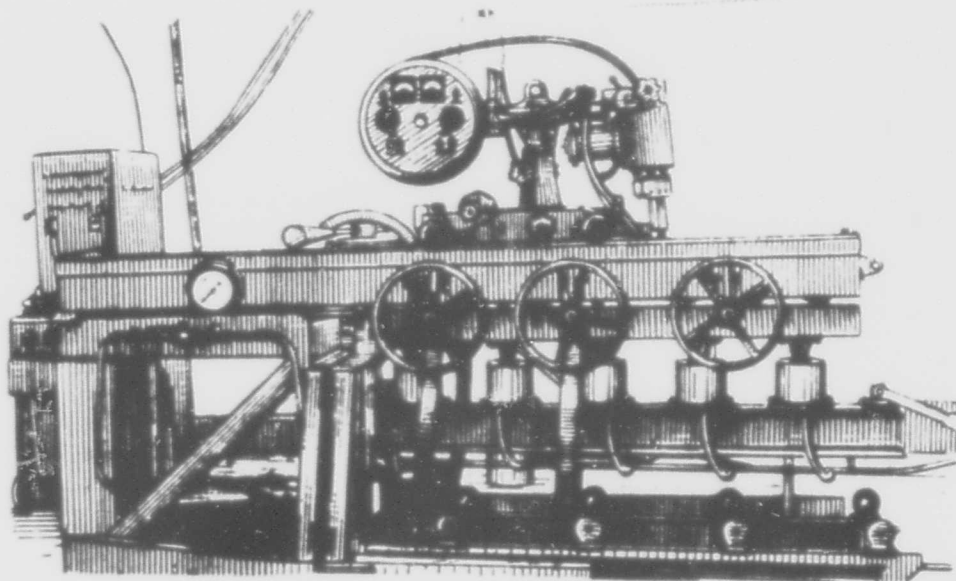


Fig. 7.25. Welding stand with tractor of ADS-1000-2.

In certain cases, for instance, for welding assemblies of chambers of steel 25KhGSA and 25KhGFA with walls thickness up to 10 mm

it is advisable to apply manual arc welding by electrodes, coated with special alloying; slag-protective coating UONI-13 or VIAM-101, composed of: marble, fluorspar, titanium dioxide, quartz, and different ferroalloys. Here they usually apply low-carbon wire of brand O8A or 18KhMA, seeking alloying of metal of seam by ferroalloys of the coating.

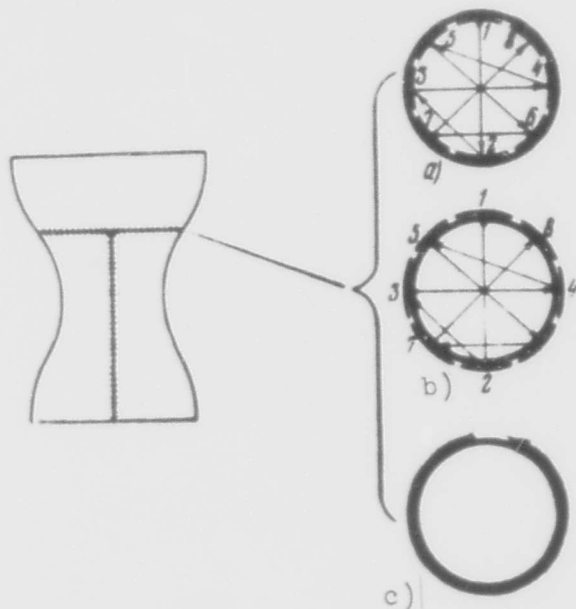


Fig. 7.26. Welding of middle ring with nozzle of combustion chamber.

On Fig. 7.26 is given sequence of fulfillment of operation of

manual arc welding of thick-walled chamber, ensuring minimum warping

of assembly, sufficient strength and good airtightness of seams. First, in separate sections the seam is welded from within in the order shown in Fig. 7.26a; then they weld in the same manner the seam from the outside (see Fig. 7.26b) and then on external seam they fuse a solid second layer (see Fig. 7.26c).

Soldering Assemblies

Soldering of metals,* just as welding, is widespread in machine building. By physical properties of applied solders soldering is divided into soft and hard. Soft soldering is conditionally such a process, in which the applied solder melts in the range 60-450°C. With a higher temperature of melting of solder (over 500°C) the process usually is called hard soldering.

For jet engine building of greatest technical and practical interest is hard soldering. If hard soldering is conducted properly, it gives good external form to the joint, permits preserving the exact form and dimensions of parts and in many cases can ensure strength of joints, equal or almost equal to strength of base metal, even at high temperatures.

During hard soldering as solders there serve alloys of silver, copper, zinc, cadmium, nickel, chromium, manganese, and other metals. They are divided into four groups: silver, copper-zinc, copper-phosphorous and so-called high-temperature solders.

During use of high-temperature soldering one should consider the following:

1. Speed of heating in range of melting points of the solder should be **maximum**.

*See footnote on p. 315.

2. Time during which part is sustained at the temperature should be minimum.

3. Gap in seam and quantity of deposited solder should be minimum.

So that process of soldering flows normally, surface of parts should be clean. In the presence on metal of foreign matters the solder does not moisten surface and soldering becomes impossible. Therefore, from surface of parts they remove dirt, grease, and scale by etching or by sandblast apparatus. However, thin film of oxides appears on surface of metal very rapidly; therefore, they remove it directly in process of soldering with the help of fluxes.

The most commonly used fluxes are different mixtures of borax and boric acid.

Machining Assemblies

Welded seams of important assemblies of an engine are thoroughly cleaned, and sometimes even polished. These operations are usually performed by a portable drill. They clean with coarse-grained wheels and polish with felt wheels, on the periphery of which there are glued abrasive grains.

After welding or soldering assemblies are sometimes machined: they cut face edges, bore holes, cut threading, etc. Welded or soldered assemblies can also be worked by etching. In principle, operations of machining do not differ from those conducted before assembly of parts.

Sometimes, in accordance with technical requirements, assemblies are coated with metal by galvanic means or means of metallizing. Before this it is necessary to conduct corresponding preparation of surfaces, namely: to clean burrs, rounds and any unevenness, and

also to degrease and wash.

Surfaces are most frequently cleaned by drill. Degreasing in baths within solution of caustic, trisodium phosphate, and soluble glass at 85-95°C. Compositions of baths for ferrous and nonferrous metals differ.

After welding and heat treatment assemblies are often considerably warped as a consequence of which there arises the necessity of their

straightening. Straightening is done by different methods: assemblies of simple form in small scale production are usually straightened manually on dummies; assemblies of complex form, especially with considerable scale of production, are calibrated in special dies or fixtures on presses. Thus, for instance, the nozzle of the chamber of a liquid-fuel rocket engine is straightened in a forming die, the construction of which is shown in Fig. 7.27. Die consists of two main parts - lower 1, secured to table of hydraulic press, and upper 2, secured to its mobile part. Before working movement, when upper part is raised, on

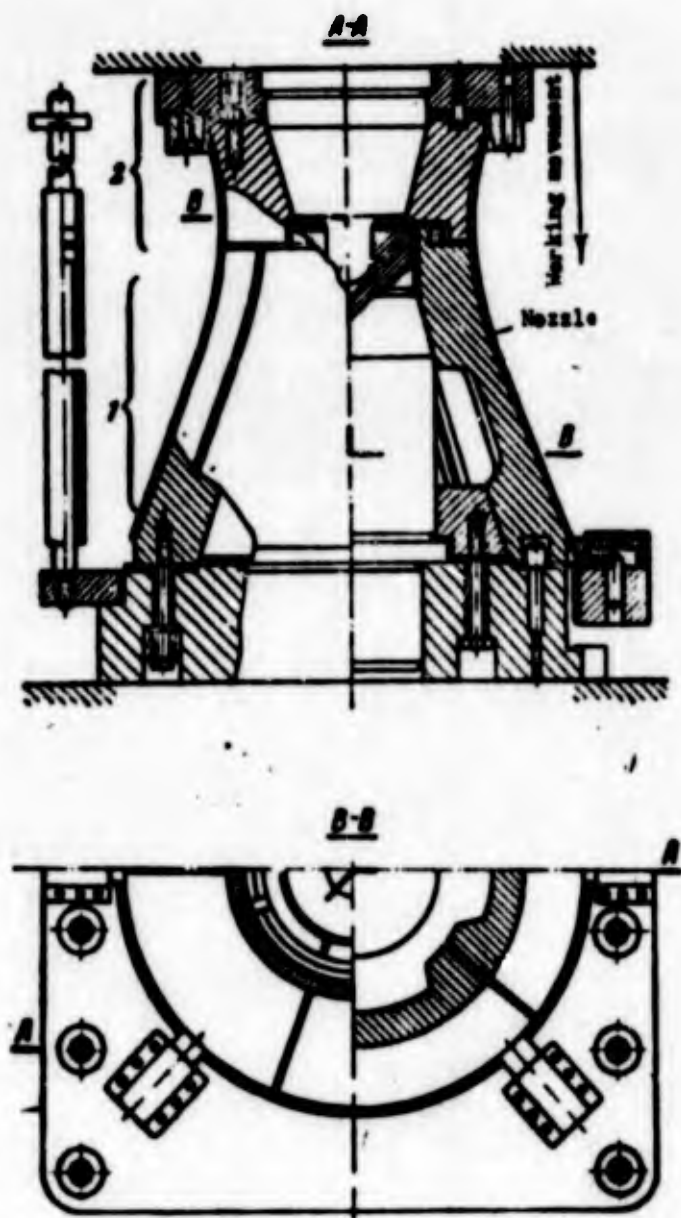


Fig. 7.27. Die for calibration of nozzle after welding.

lower part they set the nozzle.

During working movement upper part, being lowered, presses on

ends of sectors of lower part. Being connected with a cone sectors start to part, thanks to which there occurs calibration of nozzle.

Sometimes they apply special hydraulic fixtures for calibration.

§ 4. INSPECTION OF PARTS AND ASSEMBLIES FROM SHEET MATERIAL

Inspection of parts and assemblies from sheet material consists of external inspection, check of dimensions and shape of walls and of quality of seams. Methods of checking dimensions and shape are usual ones and almost do not differ from methods of checking machined parts.

However, thickness of wall of parts, especially large ones, cannot be checked by usual mechanical gauge. Therefore, recently they have begun to apply instruments for ultrasonic checking.



Fig. 7.28. Checking thickness of wall by instrument with cathode-ray tube.

More convenient, however, are instruments for which instead of pointer-indicator instruments there are used cathode-ray tubes (Fig. 7.27).

Principle of work of such an instrument is the following. Oscillator sets in oscillating motion the quartz plate of probe, which radiates ultrasonic waves of various frequency (for instance, from 500,000 to 1,500,000 oscillations per second). Change of frequency of oscillations occurs by sine-wave law thanks to rotation of rotor of capacitor C (from motor). At the time when frequency of oscillations of plate (oscillator) and frequency of natural oscillations of wall of part coincide (resonance), on screen of oscillograph there

will appear a splash. Splash for definite division of horizontal scale shows real dimension of wall. Division value can be 0.01 mm.

For connection of quartz plate with wall of checked part the latter is preliminarily lubricated by a film of oil.

During manufacture of welded or soldered assemblies from sheet material special attention is paid to checking of the quality of the seam.*

Flaws of welding or soldering in articles are the consequence of incorrect conducting of the process, nonobservance of conditions foreseen by corresponding instructions and technology, or unsatisfactory quality of base metal and other applied materials, tools, or equipment.

*See footnote on p. 315.

CHAPTER VIII

PRODUCTION OF HOUSING PARTS AND ASSEMBLIES

§ 1. DESIGN, SPECIFICATIONS AND MATERIALS

Housing parts of jet engines in design-specifications can be divided into the following groups:

1. Large dimension hollow thin-walled housing parts of cylindrical form with flanges and reinforcing ribs: housings of axial-flow compressors and nozzles, inner and inner shell of combustion chambers, jet nozzles, mouthpieces, etc.

2. Large dimension load-carrying parts of complex form: housing of supports.

3. Housing parts with shaped surfaces of air (and liquid) ducts: blading section of front housing of compressor, diffusers, housings of turbopump units.

4. Medium-dimension housing parts of box-like type: housings of reducing gear units and oil pumps, boxes of unit drives, covers, flanges, adapters, etc.

5. Small housing parts of units of adjustment and control.

Most thin-walled housing parts of jet engines of the first group are complex assemblies of cylindrical form with considerable dimensions in diameter and length. In design they are whole and split,

welded, cast and combined. Most frequently they consist of separate sections which are connected among themselves in split housings by bolts, and in nondetachable housings, by welding. Depending upon design features, applied material and form of blank, and also according to method and complexity of manufacture, it is possible to divide them into three basic subgroups (Fig. 8.1):

1. Low-responsibility, unloaded shells (Fig. 8.1a), prepared from light-gage sheet (steel 20, 08KP, 1Kh18N9T, etc.,) by drawing bending, pressing and welding. After stamping, bending and welding surfaces of linkage are usually machined. Manufacture of such parts is considered in Chapter VII.

2. Thin-walled housing parts, castings from aluminum and magnesium alloys (AL4, AL5, MA5, ML5, and others) of annular type, one-piece (see Fig. 8.1b) or combined from two halves (housings of axial-flow compressors), outstanding in their rigid specification on manufacture and high precision of linked and base surfaces. Precision of working of basic cylindrical surfaces of parts of this type are within classes 1-2. Mutual play of precision surfaces is allowed within limits 0.03-0.05 mm; nonparallelness of faces is tolerated to 0.03-0.08 mm, nonperpendicularity of faces to axis is tolerated to 0.05 mm. Machining of these parts is distinct in complexity and labor-consumption. Characteristic operations of machining are lathe cutting, boring, drilling and, into a small degree, milling.

3. Housing parts from stainless, creep-resistant and heat-resisting alloys (1Kh18N9T, 30KhGSA, EI696, EI702, and others), prepared from annular forgings or from sheet materials with welded machined flanges, shells, bosses, reinforcing ribs, etc., (see Fig. 8.1c).

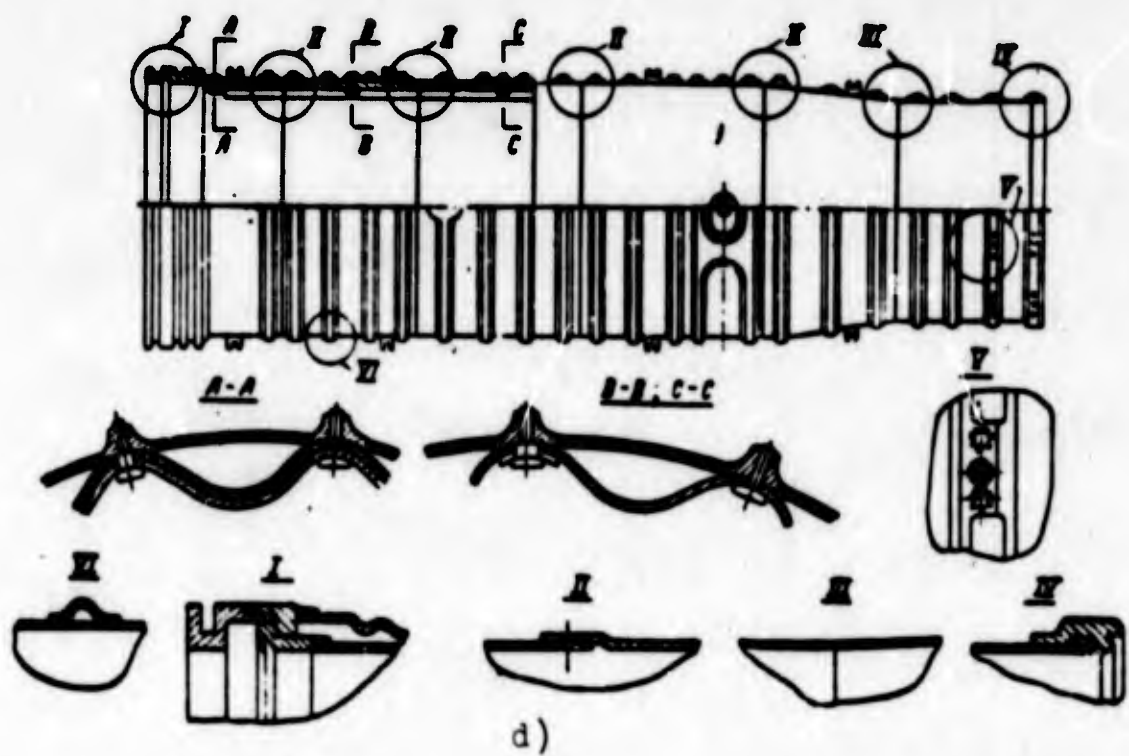
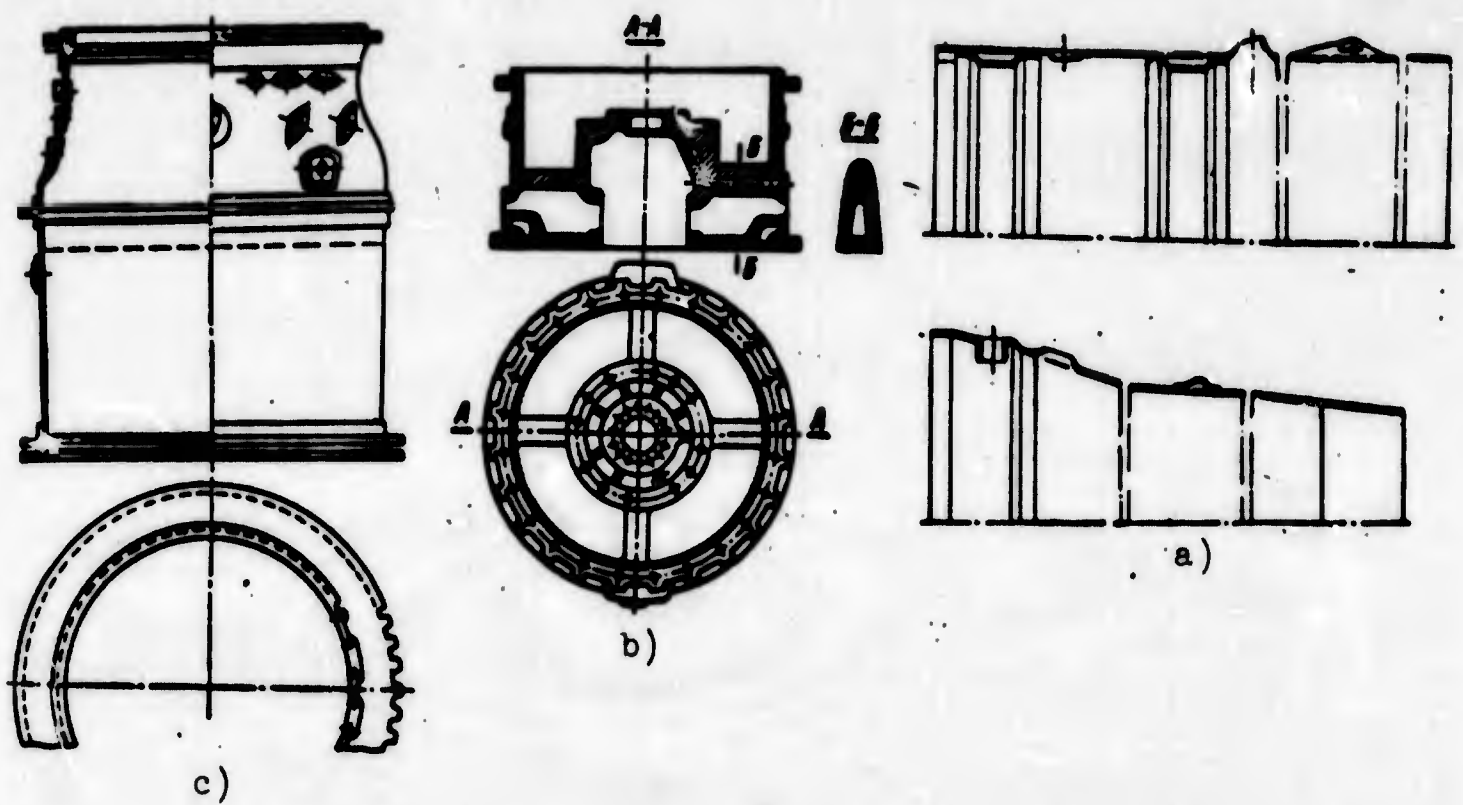


Fig. 8.1. Large dimension housing parts. a) from sheet materials; b) from castings of magnesium and aluminum alloys; c) from forgings and welded parts of rust-resistant, creep-resistant and heat-resisting alloys; d) from forgings and welded parts with reinforcements and ribs.

Welded housings from sheet materials in contemporary constructions of jet engines compose an overwhelming majority. As compared to cast housings they, as a rule, are cheaper and lighter. Certain surfaces of parts, in an assembly, are worked preparatory to assembly and welding so that their finishing is produced assembled. Such order of working permits obtaining high precision of dimensions of fitting shoulders and their mutual location. Accuracy of working of fitting shoulders is frequently set at 2nd class, and permissible play relative to one another and to the axis is 0.03-0.05 mm. Permissible ovalness of flanges in free state is not more than 1.5-2 mm. Tolerances on exact linear dimensions are set at 3rd class, less precise at 5th to 7th (All-Union Government Standard 2689-54). Displacement of fastening holes in flanges from nominal position is tolerated within 0.1-0.2 mm; tolerances of distances between axes of holes varies from 0.02 to 0.15 mm.

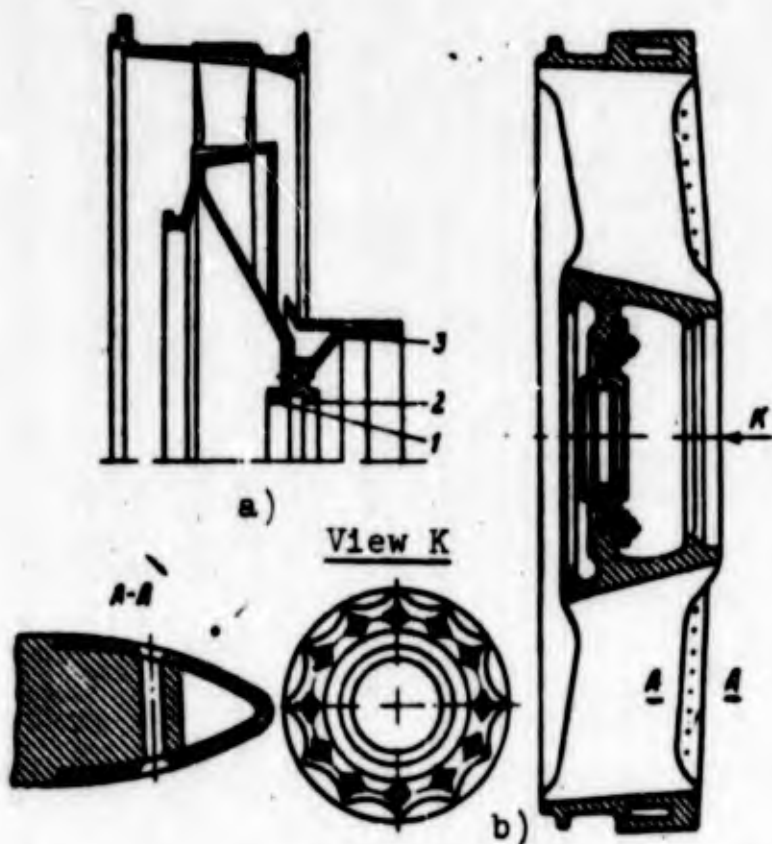


Fig. 8.2. Housings of supports. a) welded; b) cast.

Housing parts of the second group, housings of supports, in different engine designs are executed in the form of cast housings, machined from stamped blanks, or complex welded assemblies, where along with machined parts there are parts from sheet materials, combined by welding (Fig. 8.2). Precision of machining bearing holes 1 and 2 and fitting shoulders 3 is 1st or 2nd

class; their relative play does not exceed 0.05 mm. Clean boring of

holes for bearings in supports in most cases is done in assembled state.

Housing parts of the third group are characterized by presence in them of shaped surfaces of aerodynamic profile (Fig. 8.3). Typical representatives of such parts are diffusers. In most engine designs they are carried out in the form of welded assemblies (see Fig. 8.3a). Accuracy of working of fitting shoulders is 2nd class; tolerable relative play of them is 0.05 mm; play of faces of linked surfaces is not more than 0.03 mm per 100 mm length. Tolerable errors of profiled part of diffuser do not exceed 1 mm.



Fig. 8.3. Housing parts with shaped surfaces.
a) welded diffuser; b) cast diffuser.

More complicated in manufacture is the construction of a vaned diffuser (see Fig. 8.3b), constituting of an annular body with profiled grooves, located uniformly on one side of the end. Housings of a vaned diffuser are prepared usually from aluminum alloy AK4-1. There are allowed nonparallelness of face surfaces of not more 0.05 mm, warping of no more than 0.3 mm, ovalness in free state on internal diameter of not more than 0.2 mm, play of external diameter relative to internal 0.1 mm, deviation of profile of channels from nominal position in any direction of not more than 0.2 mm. Cleanness of working of profiled

channels (blading) is 7th of remaining surfaces, 5th class.

Housings of turbopump units have channels of closed and half-open form. They are made detachable, cast and nondetachable – by welded construction. Detachable constructions usually consist of the housing of the turbine, housing of fuel supply pump (Fig. 8.4). In turn,

each of these housings consists of two parts: the housing and a cover. Such breakdown of the construction creates possibility of separate assembly and testing of each separate unit; however, here there is required increased precision of manufacture of the linked surfaces, high airtightness of joints, which complicates the technology of manufacture.

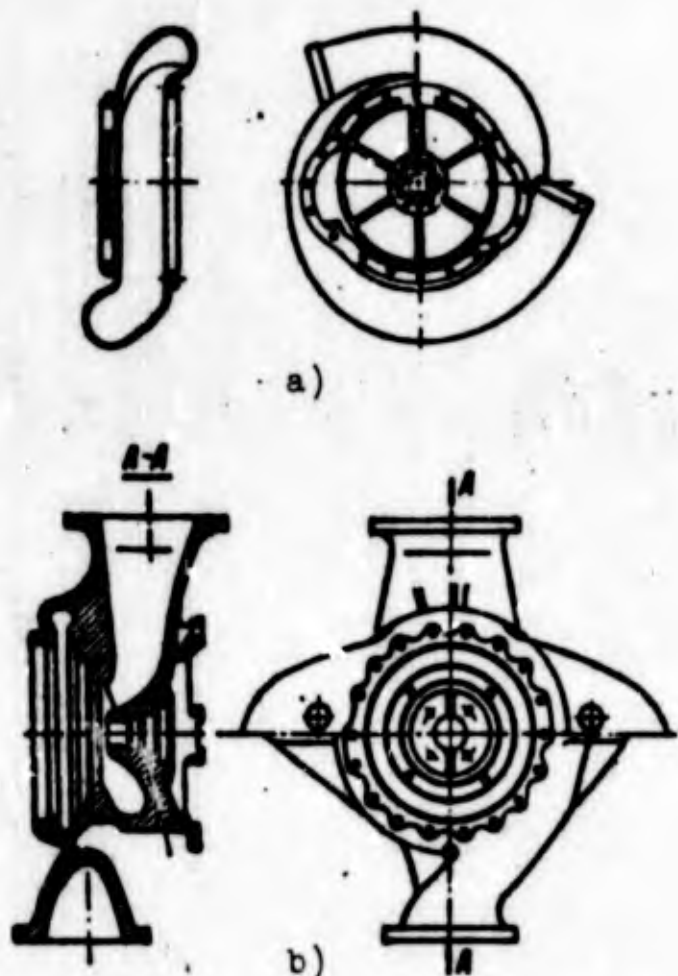


Fig. 8.4. Housings of turbopump units. a) housing pump; b) turbine housing.

In welded construction of turbopump units the housing is a complicated assembly, consisting of separate parts, prepared from forgings and sheet material

and combined by welding. Specifications for housing parts of turbopump units anticipate high accuracy of manufacture of linked surfaces (1st or 2nd class) and hydraulic testing for airtightness. Applied brands of material for manufacture of housings are determined by conditions of work of the turbopump unit (temperature, pressure, composition of working substance), and also technological properties

of the material (stampability, weldability, machinability). Housings of pumps are prepared mainly from aluminum alloys AL4. The housing of a turbine for low temperature of the working substance is prepared from alloy AL4; for raised temperatures they apply heat-resistant stainless steels (1Kh18N9T, and others). For manufacture of welded bodies they apply alloys EI-602; EI654, EI961; steel 1Kh18N9T, and others.

For manufacture of parts of pumps intended for pumping aggressive media, they have begun to widely apply titanium alloys, possessing high corrosion resistance.

Housing parts of the fourth group are very different in structural shapes and dimensions. These include housings of pumps, oil pumps, box of drives and other housings of box-like form. Along with a series of precision holes (mounts of rotating parts), in housing there are a large number of channels and threaded fastening holes. Housings of box-like type most frequently are made detachable, consisting of a housing and a cover (Fig. 8.5). Most of them are cast from aluminum alloys AL4, AL5, AL9, AL19 and magnesium alloys MA5, AMg3, etc., and technical requirements on their manufacture are characterized by the following basic specifications: precision of fitting diameters of 2nd class; cleanness of linked cylindrical surfaces and planes of 7th class; permissible mutual play of basic cylindrical surfaces, not more than 0.02 mm; noncoaxialness of holes for shafts, gear stems, and so forth, within limits 0.01-0.02 mm; nonparallelness of face planes of not more than 0.03 mm; nonperpendicularity of faces with respect to holes of not more than 0.02 mm on an arm of 50 mm. Planes linked with covers are checked by die; required adjoining is at least 80%. Nonperpendicularity of bottom faces of fastening holes to the

axis of threading, not more than 0.05 mm. Permissible deviations of free dimensions in casting is 5th to 7th classes as per AN1026, after machining 22AT-52. Parts of this group, working with internal pressure of liquid or gases, are subjected to hydraulic or pneumatic tests usually under a pressure of one and a half times the working pressure.

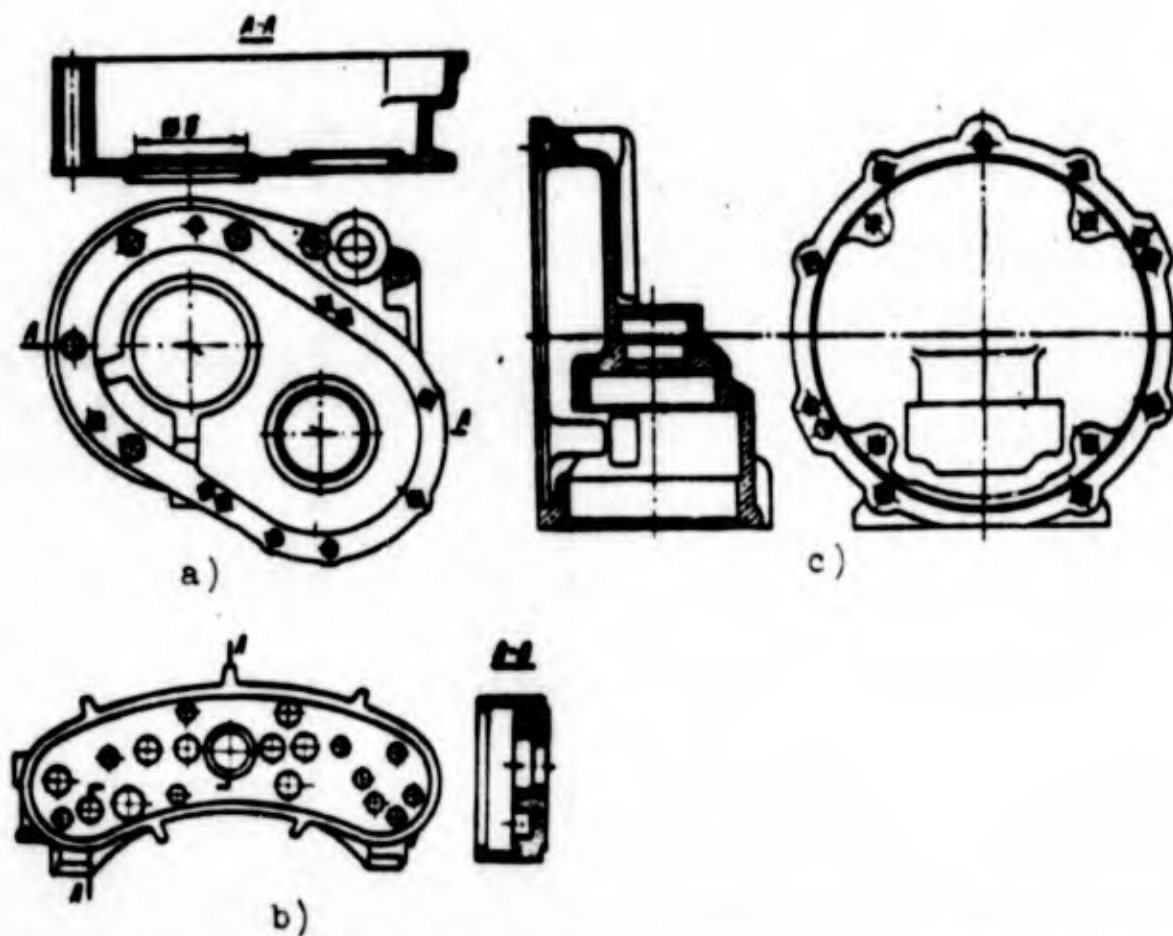


Fig. 8.5. Housing of box-like form. a) housing of two-speed transmission; b) drive box; c) transmission housing.

The fifth group includes small housing parts of different units of adjustment and control (valves for fuel flow control, pressure reducers, starting mechanisms, and others). Many surfaces of housing parts of this group are subjected to machining. Basic technical requirements are the following; play of working surfaces of holes, hollow chamfers and fitting faces (conical surfaces) relative to corresponding fastening threading should be not more than 0.03 mm;

noncoaxialness of oppositely located holes and fastening threading should not exceed 0.03 mm; permissible nonperpendicularity of surfaces of intersecting holes is 0.1-0.2 mm; and permissible misalignment of axes of parallel holes is from 0.01 to 0.05 mm per 100 mm length. Required cleanness of working surfaces should correspond to 4th or 5th class. Housing parts of this group are usually prepared from aluminum alloys AK4, AV, steels 45 and 20.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

General Principles

At the basis of construction of a rational technological process of production of housing parts there should be assumed the idea of standardization, opening possibilities of mechanization and automation of production.

Construction of the technological process of manufacture of housing parts is determined by the character of those operations which ensure specified accuracy and cleanness of treatment of the basic and the most important surfaces (fitting bosses, holes and planes, linked surfaces, working profiles). Selection of bases, methods of working, sequence of fulfillment of separate operations should be subordinated to solution of this main problem of the technological process. Simultaneously, it is necessary to ensure high productivity and economy of working both in mass and small-lot production. During working of housing parts it is especially expedient to apply multiposition and multitool fixtures, multi-spindle drilling heads, assemblies and special machines. It is also expedient to use a group method of working.

As a rule, when working housing parts it is necessary to deal not with one surface, but with a group of interconnected surfaces, where

required accuracy of mutual location of surfaces in a single group is considerably higher than required accuracy of mutual location of these groups. In connection with this it is necessary to seek such construction of the technological process in which the surfaces of each group would be worked in one stop of the part. If, however, surfaces cannot be worked at one position, then one should anticipate use of such bases, in which error connected with transposition would be the least. In connection with difficulties of obtaining exact geometric forms and dimensions during working of thin-walled housing parts, due to their deformation in the process of working, there should be foreseen special technological measures, ensuring necessary rigidity during working of them on machines.

Very significant factors, determining the technological process of working housing parts, are dimensions and shape of the part, the form and material of the blank, the volume of production and the level of technical equipment of the enterprise with contemporary highly productive equipment. Dimensions and shape of a housing part determine selection of equipment for working the basic surfaces of the part. Thus, for instance, in big housings of box-like form (housing of reduction gear, box of transmissions drive) it is preferable to work basic holes and adjacent planes on a machines of bore type, where base surface will be the splitting plane; consequently, this plane should be treated before the other surfaces; this circumstance also conditions the basic line of construction of the technological process for working such a part. An absolutely different principle of construction of the technological process will exist in working of housings which are solids of revolution, for instance, housings of the compressor or nozzle. Here more advisable is working on machines

of lathe type (centering, facing, turret). During working of parts of the first type the most reliable positioning base, worked first and most frequently used in subsequent operations, will be the flat surface, and during working of parts of the second type such a base will be a hole or external fitting shoulder. In the technological process for parts of the first type there will predominate milling and boring operations, whereas in the process of working parts of the second type, the main ones will be lathe operations.

Working of small and medium-size housing parts in most cases is best conducted on lathes and turret lathes (working of planes and holes). Thanks to small dimensions and small mass of parts transposition of them is usually not connected with great difficulties. During working of such housings it is easier to combine positioning and designing bases than during working of big parts.

Rational construction of the technological process of working housing parts in many respect depends on correctness of selection of primary setting bases. The form of the initial blank and the method of obtaining it is of decisive importance here. As primary bases one should try to use surfaces which remain unworked in the finished part. In this case one can achieve more exact mutual location of worked and nonworked surfaces. In experimental and small-lot production housing parts are worked on general-purpose equipment; operations consist of a large number of transitions. In large-lot production they use special and specialized machines; with increase of volume of production their use increases. Considering the large labor-consumption of machining housing parts, with a large production program and stability of the object of production it is expedient to use transfer lines. In the aviation industry for working monotypic parts especially

effective are multiple range readjustable transfer machines, arranged on the base of standardized units.

Plans of Working

Cast housings

As an example of construction of technological processes there can serve the manufacture of the middle housing of an axial-flow compressor, consisting of two sections with longitudinal split.

A blank of semicylindrical form is a casting in sand from alloy AL5

(Fig. 8.6). After cutting off risers and hydroabrasive cleaning, they pass casting through hardening at 400-420°C in a

silico furnace for 8 hours. Primary base for working and layout are extreme bosses on jointing plane of the casting

Tolerances on free dimensions of casting are 7th class (AN1026). Allowance

for machining is from 3 to 6 mm. Technological process consists of three basic

stages: working of separate sections,

assembly of unit and treatment assembled.

Sample Working Plans

Front section.

1. Milling of jointing planes of both halves.
2. Drilling of holes in jointing planes.
3. Milling of bosses.
4. Clipping of faces from both sides.
5. Assembly of two halves.
6. Boring of internal recesses for blades.
7. Drilling of holes in flange.
8. Milling of grooves on rear flange.
9. Milling of bosses on rear flange.

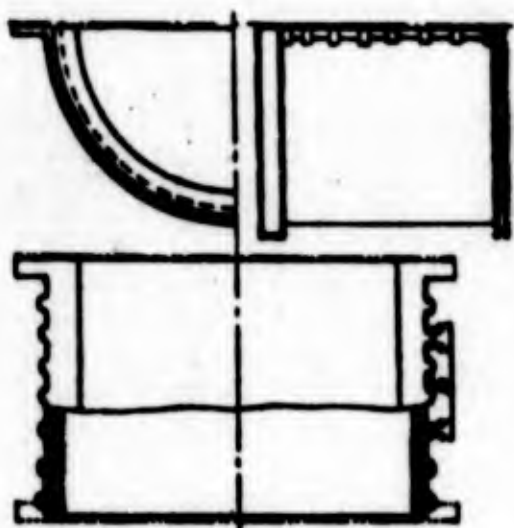


Fig. 8.6. Casting of front section of middle compressor housing.

10. Milling of straight sections of external lateral surface.
 11. Milling of recesses between holes for blades.
 12. Milling of crown on flange.
 13. Drilling of holes for blades in 4 strips.
 14. Final boring of places for blades.
 15. Inspection.
- Plan for working rear section is analogous to front.

Assembly of housing

1. Assembly of front and rear sections.
2. Working of fitting bosses and clipping of flanges.
3. Boring of semirings (labyrinth).
4. Drilling of holes in flange on side of rear housing.
5. Milling of places for nuts in bosses.
6. Drilling of places for cleats.
7. Bench stripping of burrs and installing of cleats.
8. Disassembling of housing into halves.
9. Inspection.

Housings from heat-resisting, creep-resistant and stainless alloys

A representative of this type of part can be the housing of a GTE (gas-turbine engine) nozzle. In small-lot production annular blank of such a housing is obtained by method of rolling rings or bending profiled bands with subsequent butt welding.* Basic requirements for welded blank are the following: oval shape in range of tolerance on internal diameter, warping of faces is allowed up to 1 mm, welded seam should be cleaned flush with basic material, displacement in the joint is allowed up to 1 mm, remaining requirements are by TU. Machining of housing is characterized by considerable labor-consumption in lathe and boring operations.

For working of the hole the main base is the external shoulder and face of the flange. During working of external surface the housing is set on the worked hole.

Sample Working Plan

1. Preliminary boring of hole and groove on top on one side.
2. Preliminary boring of hole and groove on top on the other side.
3. Final turning on top and clipping of flange on one side.
4. Final boring of hole and clipping of flange on the other side.

*Presented in detail in Chapter VI.

5. Drilling and reaming of locating hole in the flange.
6. Milling of crown.
7. Bench stripping of burrs.
8. Drilling of radial holes in two strips, reaming and counter boring of platform sites.
9. Bench cleaning, counterboring of faces and cutting of threading.
10. Drilling of nine holes and cutting of threading on three platform sites.
11. Inspection.

Housing of welded construction

Machining of such bodies is associated with a number of difficulties, caused by deformations of parts, which appear both before machining (during welding) and also in the actual process of machining. In spite of the variety of designs of welded bodies, the technological process of their manufacture is constructed basically on one principle. Examples of this can be technological processes of manufacture of the middle housing of a compressor (welded construction), the housing of a combustion chamber, nozzle, jet pipe, and others. The technology of working normally only includes operations of assembly of parts and working of the housing assembled. As for parts in the assembly, in small-lot production they are manufactured by independent technological processes, worked out for each part separately.

Sample Working Plan (housing of compressor, housing of combustion chamber)

1. Preconditioning of flanges and intermediate rings.
2. Laying out sheet material, bending and welding of shells.
3. Cutting of sheet into strips, profiling and bending of reinforcing rings.
4. Assembly of parts in dock and tack welding.
5. Welding of assembly, welding of bosses and lateral flanges.
6. Heat treatment.
7. Finishing of seating bosses and face surfaces of flanges.
8. Drilling of holes and cutting of threading in bosses and flanges.
9. Bench cleaning, straightening.
10. Setting of pins, bushings, lock flaps and other fittings.
11. Inspection.
12. Anticorrosive and heat-resistant coatings and paints.

Housings of pillow blocks

The most important operations of the technological process of manufacture of housings of blocks are boring of places for bearings, working of labyrinth seals (grooves) and drilling of deep slanting holes for cooling and lubrication of bearings. General construction of the technological process of production of blocks depends on peculiarities of construction. Blocks of welded construction pass through three production stages: manufacture of parts entering into the assembly, assembly and welding of the assembly. Final machining is done in the assembly. Cast constructions pass through two stages: preconditioning of parts and finishing of the most important surfaces in the assembled unit. Below there are given sample plans for working in assembled form the housing of the middle pillow block of a welded construction (see Fig. 8.2a) and the case front block of a demountable construction (see Fig. 8.2b).

Sample Working Plans

Welded housing

1. Assembly of units (installation of labyrinth of pillow block).
2. Tacking of labyrinth to internal ring.
3. Welding.
4. Final working in assembled form on the front flange.
5. Final working, assembled, on the rear flange.
6. Drilling of holes in front flange.
7. Talcing of surfaces 1, 2 and 3.
8. Boring of labyrinths in talc.

Cast housing

1. Setting of labyrinth and pressing of pillow block.
2. Grinding of hole for bearing race.
3. Finishing labyrinth grooves.
4. Boring holes and cutting threads in plugs.
5. Screwing in of three fittings and installation of setting plugs.
6. Installing of bearing cap.
7. Injection of annular duct (oil ducts) and check of airtightness.

Housing parts with shaped surfaces for air (liquid) ducts

Diffusers. Basic operations of the process of manufacture of a diffuser (see Fig. 8.3a) are similar to operations of working thin-walled housings of welded construction. A peculiarity of the technology of manufacture of a diffuser is working of the profiled surface when assembled.

Housing of vaned diffuser (see Fig. 8.3b) is prepared from a stamping (alloy AK4-1). After heat treatment and aging, the stamping passes 100% ultrasonic inspection.* Allowance on machining is 4-6 mm a side. Construction of technological process of working the housing of a vaned diffuser in many respects is like the plan of working of semi-shrouded impellers.** Working of a diffuser is divided into two stages: preliminary milling of contour of blades and final milling of contour of blades, 12 hours after stabilization of part at 180°C, and then polishing.

Sample Plan for Working Housing

1. Preconditioning of external, internal and face surfaces of part.
2. Drilling of base hole.
3. Preliminary milling of blades on a line and on contour of radius R_1 and R_2 .
4. Stabilizing tempering.
5. Working of base surfaces.
6. Final milling of blades on a line and on contour of radii R_1 and R_2 .
7. Drilling of holes and benchwork stripping.
8. Polishing of profile of blades.
9. Inspection.
10. Anodization.

Housings of turbopump units

The housing of a pump and turbine of split construction in

*Presented in detail in Chapter II.

**See Chapter IV.

small-lot production is made from castings, poured in shell forms or in a chill mold with sand rods. Material of castings is alloy AL4. Worked surfaces of housing are cast with allowance of 3-4 mm to a side; internal ducts are cast with final dimensions and only require stripping. Tolerances on free dimensions of casting are by AN1026. Primary base for layout and machining both of pump housing, and of turbine housing are bosses of the crosspiece. Technological process of manufacture of the pump housing is divided into two stages: preconditioning before hydraulic test and finishing of precise fitting surfaces after hydraulic testing, and is identical in principle to process of working of a turbine housing. During designing of technological process of manufacture of welded bodies of turbopump units, one should follow recommendations presented in Chapter VII.

Sample Working Plan

1. Milling of risers and filing of bosses.
2. Benchwork stripping of internal cavity.
3. Hydroabrasive cleaning of castings.
4. Layout.
5. Boring of central hole and internal recess on one side.
6. Chamfering of bosses of crosspiece and preliminary boring of holes and centering shoulders on the other side.
7. Milling of groove in four bosses of crosspiece.
8. Milling of facets of flanges (or the end of pipe at turbine housing).
9. Boring of throat.
10. Drilling and countersinking of holes in flanges.
11. Cutting of threads in flanges, benchwork stripping and insertion of pins.
12. Hydraulic and pneumatic testing.
13. Finishing of fitting points on one side.
14. Finishing of central hole and fitting bosses on the part of the crosspiece.
15. Inspection.
16. Anodization.

Average-dimensional housings of box-like shape

Different construction of technological processes of manufacturing housing parts of this group is caused both by the very variety of

structural forms and dimensions of housings, and also the necessity of applying different methods of working depending upon the volume and technical level of production. Here, of essential value for selection of bases and the sequence of operations is the number and accuracy of mutual location of central holes in the housing. In practice we most frequently meet housings of box-like form with parallel and crossing axes of center holes. The principle of construction of a technological process for producing such housing will be sufficiently intelligible from consideration of the technology of manufacture of three basic types, shown in Fig. 8.5a, b and c.

Their blanks are most frequently a chill casting from alloy ML5.

The base for layout and working is the external nonworked and surface and the contour of bosses.

Basic operations of manufacture of these housings include precision working of central holes, in accordance with specifications of their mutual location. In order to ensure airtightness of connections of housings with covers, coaxialness of holes in them and mutual perpendicularity of planes of faces and adjoining central holes, working of these surfaces is conducted with one setting on a lathe or boring machine. In separate cases, when joint plane has significant dimensions and is eccentrically located relative to the central hole, it should be milled before working the hole.

Sample Working Plan.

1. Clipping of end and preliminary boring of hole on lathe.
2. Clipping of second end and turning of the boss.
3. Preliminary boring of hole.
4. Drilling of holes in joint plane.
5. Milling of shelf (on lateral surface).
6. Milling of bosses for nuts.
7. Hydraulic testing.
8. Drilling of ducts.
9. Drilling, counterboring and reaming of hole in lateral boss.

10. Benchwork stripping, cutting of threading.
11. Final turning of two holes simultaneous.
12. Hydraulic testing.
13. Inspection.
14. Oxidizing.

Small housings parts of control and adjustment units

Housing parts of this group usually are prepared from forgings, less often from rods and pipes. In small-lot production for manufacture of small-size housings from nonferrous alloys, at present there is widely applied pressure casting. Housing parts cast under pressure do not require large expenditures on machining, have good mechanical properties, do not have porosity, cavities, and other internal flaws, peculiar to forgings and castings. Characteristic for the technological process of working of housing parts of this group are turret, drilling and thread-cutting operations. The primary base during working of cast and forged housings is the external cylindrical surface most convenient for fastening in self-centering grippers (tong, wedge-shaped, plunger, 2- and 3-jaw chucks, and others).

§ 3. FULFILLMENT OF BASIC OPERATIONS FOR WORKING HOUSINGS

Large-Dimension and Thin-Walled Housings

Middle housing of axial-flow compressor (cast, jointed)

Joint Planes of both halves of the middle housing of a compressor are worked on a vertical mill in one passage by facing cutter by method of high-speed milling. The blank is positioned by bosses on adjustable supports.

This operation is executed also on horizontal mills. Both planes are milled simultaneously by two cylindrical milling cutters with

slanted teeth.

Holes, located in large quantity on different surfaces of the compressor housing, are drilled, counterbored, reamed and cut in case of a small volume of production on radial-drilling machines by a positioner. In small-lot production for working fastening holes there

are applied multi-spindle drilling heads with fold away plate jigs and special multi-spindle machines (Fig. 8.7). For working holes, located on circumference and on lateral flanges of the compressor housing, widely applied are unit-head machine tools, arranged from standardized units. Thus, for instance, holes for blades in the middle housing are processed on a unit-head bore with a turning table, working on an automatic cycle, and simultaneous drilling, surfacing and cutting of threads in lateral flanges

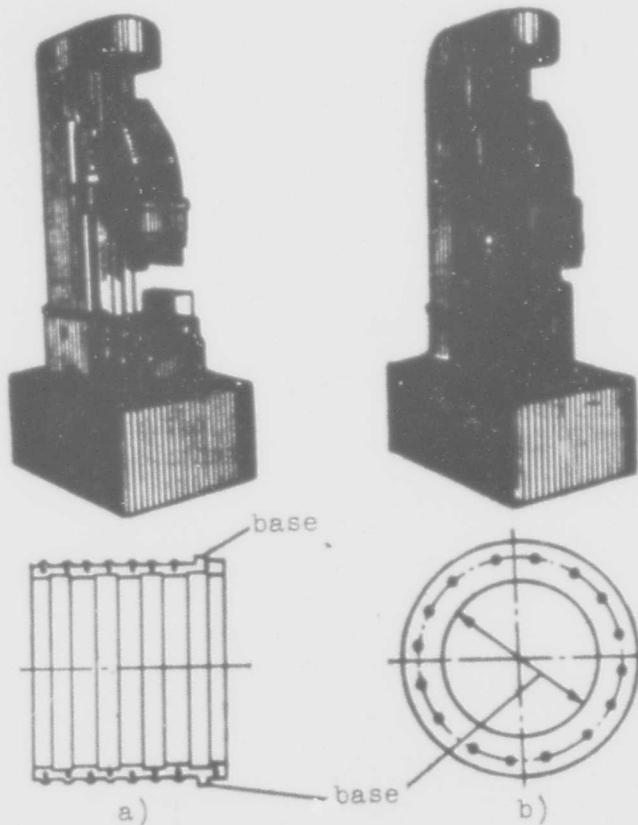


Fig. 8.7. Drilling of holes on multi-spindle drilling machines in front section of compressor housing. a) in bosses in joint plane; b) in flanges.

and bosses of housings is produced on unit-head drilling and milling machines (Fig. 8.8).

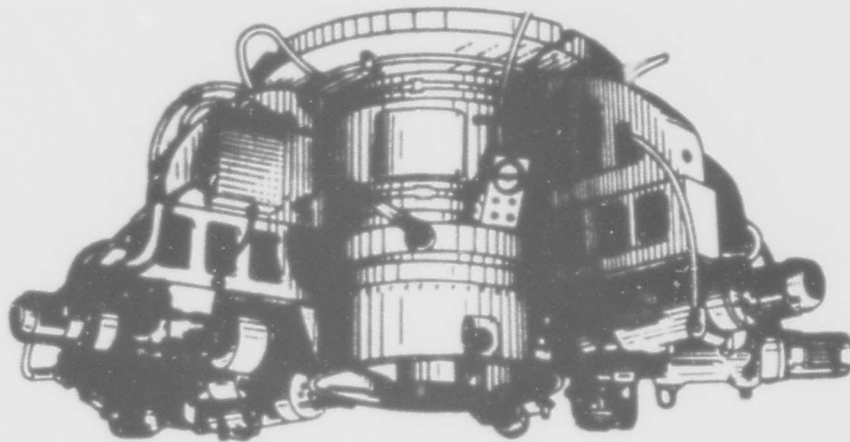


Fig. 8.8. Drilling, surfacing and cutting of threads in lateral flanges and bosses of housing of a compressor on unit-head machine tool.

Internal surfaces, fitting bosses and flanges are processed in three stages:

joint roughing of both halves before assembly;

semifinished and finished boring of internal recesses for blades in sections of housing after assembly of both halves;

finished boring of fitting bosses, labyrinths and facets of flanges in assembly after final assembly of middle housing.

Roughing of end surfaces is executed on turret lathes, and halves of the housing are fastened by tie bolts.

Boring of internal blades grooves is the most labor-consuming operation. Usually it is executed on lathes of increased rigidity with great height of centers. Recesses in front and rear sections are preconditioned before assembly of halves. Concentricity of recesses during working when assembled is attained by high accuracy of working of base surfaces and of installation of the part on a jig of face plate type, with fitting in a precision shoulder (Fig. 8.9). Boring is conducted by a boring bar with boring cutters or plates. Massive

boring bars prevent pressing of tool from processed surface in course of working, and for quenching vibration on the part they place rings of soft rubber. Working of fitting bosses and boring of the labyrinth are the most important and complicated operations in connection with high requirements for accuracy (nonparallelness of end surfaces of opposite flanges of not more than 0.05 mm for diameter of 600 mm, mutual play of fitting bosses 0.03-0.05 mm, play of internal surfaces of semirings with respect to fitting bosses, not more than 0.05 mm). During working it is seen that a layer of talc on inner surface of semirings is at least 0.2 mm. Working of fitting shoulders with abutting face surfaces of flanges and boring of inner surfaces of semirings in the housing are done in two operations on high-precision lathes with a special jig.

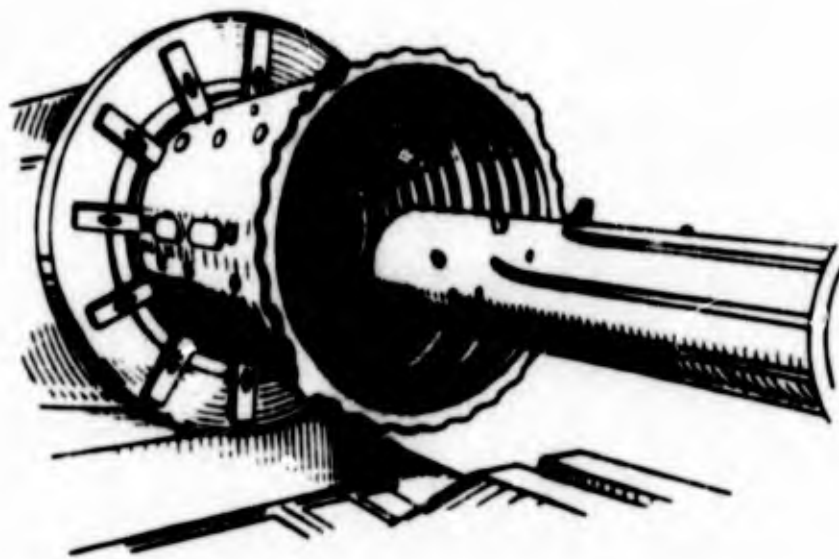


Fig. 8.9. Boring of internal blade grooves in housing of an axial-flow compressor.

Requirement of high accuracy of dimensions of fitting surfaces of the middle housing when assembled and of their relative location makes necessary each time before beginning working of a lot of parts, thorough alignment of installation of jig on the machine and check

of dimensions of fitting collar. On collar there are located removable plates, which upon wear are replaced.

End grooves in front section are milled on vertically-milling machine with dividing fixture.

The part is set on a turning table, centered on internal fitting boss, and is secured by hydraulic clamps. Drive of feed of milling head of machine is hydraulic, with automatic cycle of work from electrical control rests. Turn of table is interlocked with motion of milling head and is carried out automatically after cutting by milling cutter of each groove. Accuracy of division of table is 0.03-0.05 mm. High productivity of machine permits applying it under conditions of large-lot production.

Nozzle housing (forging from stainless steel 1Kh18N9T)

Roughing of external surfaces and boring of the hole is produced on turret lathe in a three- or four-jaw chuck.

Final boring of hole and machining on top is produced on powerful lathes of increased rigidity in a fixture of face plate type with centering on external shoulder and clamping on the flange face.

Radial holes for fastening blades are usually worked on a radial drill in a dividing jig with a fold-back positioner (Fig. 8.10) in one installation. The base is the external fitting boss and face: the housing is fixed on dividing face plate by a positioning hole in the flange. More productive is working of holes and platforms on unit-head machine tools (Fig. 8.11).

Shaped recesses in flanges of a compressor housing end of a nozzle housing (crown) do not require accuracy of execution. In small-lot production they usually are milled on vertical mills by end milling cutters of corresponding diameter by method of incision (to a rest)

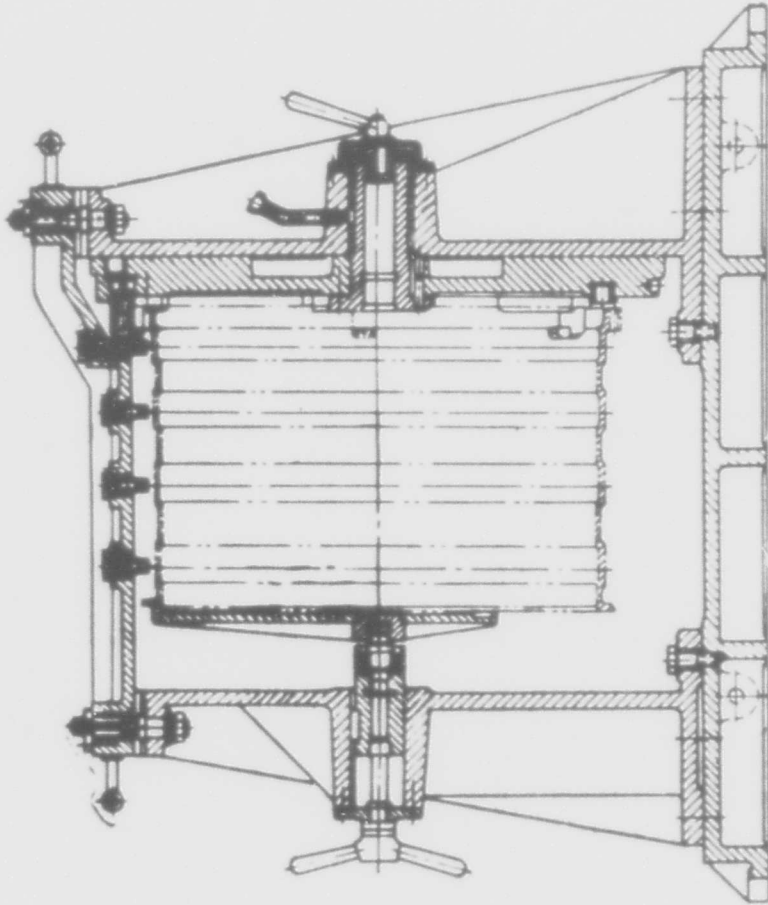


Fig. 8.10. Drilling of radial holes in sections of a compressor housing and in a nozzle housing on a radial drill in a dividing jig with a fold-back positioner.

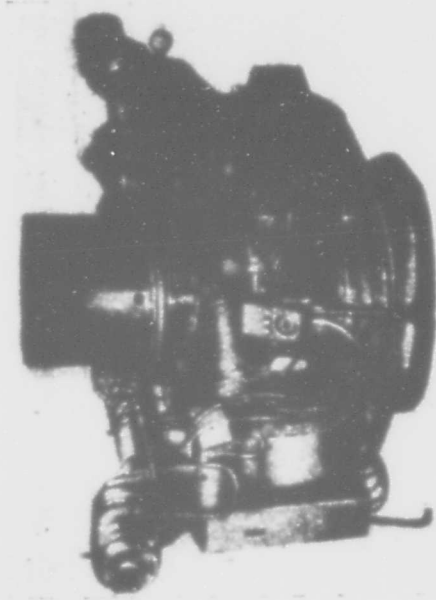


Fig. 8.11. Working of radial holes and platforms in a nozzle housing on a unit-head machine tool.

on a dividing jig. It is more productive, however, to work the corona on a unit-head machine tool.

Welded housings (compressor housing, combustion chamber housing, afterburner housing, and others)

Flanges and spacers are basic elements, constituting the frame of a housing. They form surfaces for connection of parts from sheet materials and for attachment with other units. They are prepared chiefly from annular blanks, obtained by rolling of rings or bending of profiled bars with subsequent welding of joints. Rings are basically machined on lathes.*

Shells, cylindrical and conical, entering into assembly of a welded housing, are prepared from a sheet by bending with subsequent longitudinal welding of the seam. Bending is produced on three-roller machines, and preliminary bending of the side of the billet is done in a stamp. An improved method of manufacture of cylindrical and conical shells with a straight-line generatrix is carried out on special bending machine, model GLS-2K. On this machine forming of shells is produced by method of bending-rolling from precision development of the surface without preliminary bending of ends of the billet, which considerably reduces labor-consumption and increases quality of manufacture of shells. Process of bending a sheet on machine GLS-2K is carried out with help of four shafts — two driving ones in the vertical and two bending ones in the horizontal plane (Fig. 8.12). Whole process of forming of a shell of the machine is executed in two passages (one forward and the other reverse).

*Considered in detail in Chapter VI.

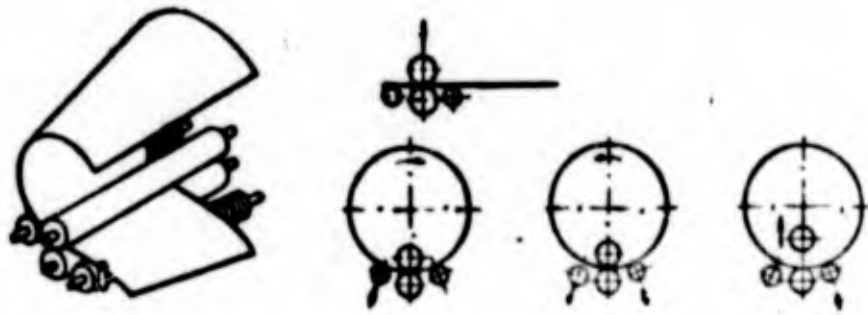


Fig. 8.12. Diagram of bending of shells on machine GLS-2K.

After bending and automatic welding of longitudinal seam there is produced flanging, stripping of edges and other operations preparatory to assembly and welding of parts in a unit.

Assembly and welding of the housing consists of a series of operations of successive connection of separate sections, welding them and welding on of fittings. Sections are completed units, joined end to end. Assembly and tacking of combined sections and parts is produced in a dock [?].

Surfaces of butt ends are thoroughly fitted and cleaned to metallic brightness. To guarantee correctness of assembly separate units are preliminarily fitted and on joined surfaces there are inflicted a marking line, by which there is determined mutual location of parts for final assembly. In Fig. 8.13 there is shown the diagram of annular joint by overlapping. Figures designate the order of point tack welding, in which it is possible to avoid large warping of parts of the unit.

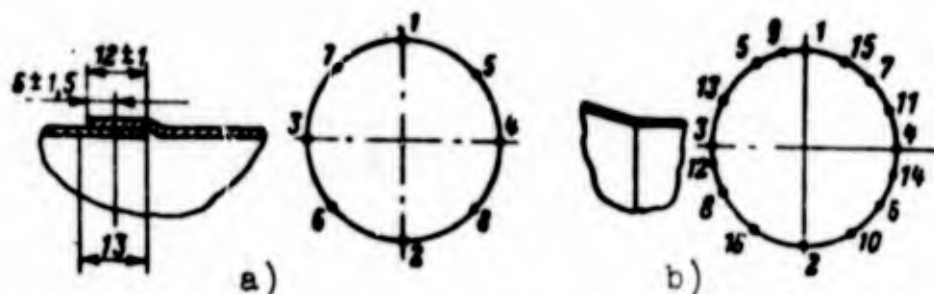


Fig. 8.13. Diagram of location of tacked seams during assembly of separate sections of a welded housing.

After assembly and tacking there is produced seam welding of the unit on a welding machine of type MShPR-300. Conditions of welding are selected depending upon brand and thickness of the material.

With butt joint of sections tack welding is produced by argon arc welding with a tungsten electrode of diameter 1.5-2 mm. First 16 tacked points are located according to diagram of Fig. 8.13; the remaining ones are located evenly on circumference with spacing of 30-50 mm.

Operation of welding annular joints of separate housing sections (by fusion or resistance welding) is executed on a special stand. In process of welding the article revolves, and welding head remains motionless. Welding head is set on a cantilever, which shifts in a guide column from one welded joint to the next. The cantilever together with head can also turn about the axis of the guide column, which permits one to establish it in the required position with respect to the surface of revolution of the welded article.

For welding of fittings with annular seams there are applied welding installations, including: a) welding torch, revolving about axis of welded part; b) cantilever with column; c) manipulator or other device, intended for setting welded article in required position. On this installation the article is motionless during, and welding torch revolves around axis of welded part. Welding of fittings with curvilinear seams in different planes in most cases is executed by semiautomatic or manual welding.

Certain difficulty is presented by welding of fittings of the type of flanges of different configuration to thin-walled shells of the housing of a combustion chamber, afterburner, and other bodies of welded construction, prepared from stainless steels 1Kh18N9T,

EI435, and others, due to hot cracks, cracks in the seam and in basic material of flanges in the zone of heating. Step-roller welding on

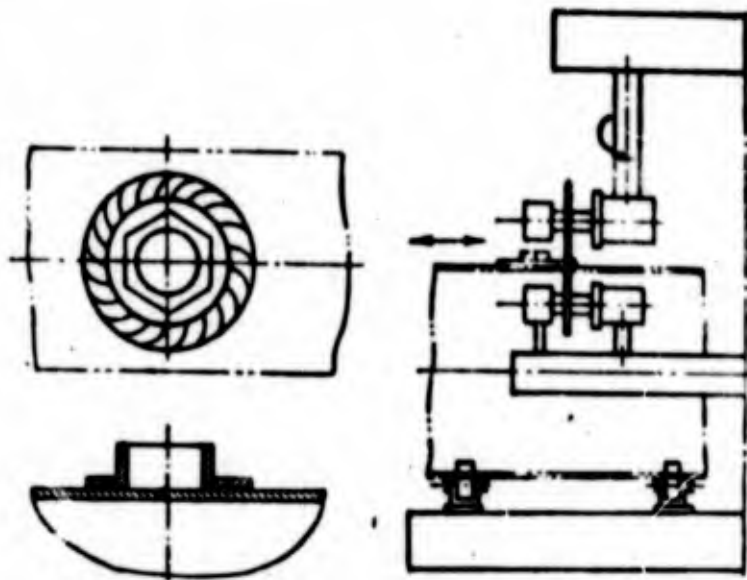


Fig. 8.14. Step-roller welding of fittings to shells.

welding machine of type MShP-150, equipped with special roller head of system "roller-roller" and mechanism of step feed of rollers during welding, permits one to eliminate possibility of appearance of cracks (8.14).

Machining of a welded

housing after welding and heat treatment, conducted for the purpose of removal of residual

stresses in the zone of welded seams, consists of operations of drilling of holes, thread cutting in bosses and lateral flanges, working of centering shoulders in flanges, working of sleeves in bosses.

Working of centering shoulders and drilling holes in the housing of a welded construction hardly differs at all from fulfillment of similar operations in an assembled split body, the description of which was given above.

Certain peculiarity is presented by working of radial holes in a compressor housing after setting of sleeves. To guarantee concentricity drilling and reaming of holes in housing is produced through a hole in the sleeve, which serves to guide the tool.

Talcing, application of aluminum-talc mixture on surface of labyrinth seal of the housing, is produced in the following way: on a thoroughly degreased surface by brush there is applied a uniform

film of enamel Al-701, consisting of varnish 701 (85%) and aluminum powder (15%), serving priming. After drying in air for one hour on primed surface by spatula there is applied a uniform layer of aluminum-talc mixture of thickness 0.5-0.6 mm. First the part is kept at room temperature 30 minutes and then is placed in a drying cabinet, in which the temperature is gradually increased to 190-220°C, and it is kept there 2-3 hours. After cooling the part in air the surface of the layer is cleaned by sandpaper, rubbed with a cloth moistened in alcohol, and then there are applied 5-7 more layers of the aluminum-talc mixture.

The profiled surface of the diffuser of welded construction, presented on Fig. 8.3a is polished by felt wheels on polishing mandrels. Operation of polishing does not require skill; in process of polishing exact dimensions not are maintained, and operation ends upon achievement on whole profiled surface of the diffuser the required finish.

Polishing of the profiled surface of a vaned diffuser, presented in Fig. 8.3b, is a more complicated and labor-consuming operation, since in process of polishing geometric form of blades should be preserved. Polishing is produced manually by a polishing machine (drill) with coarse felt wheels and application of abrasive powder and paste of the following composition:

corundum M28.....	60%
paraffin with stearin.....	35%
remainder.....	wax, olein acid and technical grease

More productive is electric polishing with preheating of electrolyte to 35-40°C. Anode current density is 15-30 amp/dts²[?]. Duration of working is 5-7 minutes. Preparation of part for electric polishing

consists of thorough degreasing in vapors of trichlorethylene or in this solution:

caustic soda.....	20 g/liter
trisodium phosphate.....	50 g/liter
liquid glass.....	30 g/liter
temperature.....	50-60°C

Housings of the Pump and Turbine of Turbopump Units

Stripping of internal surface of closed ducts of cast housings of turbopump units is a very labor-consuming operation. After trimming and filling of risers and ribs housings from aluminum and magnesium alloys are subjected to sand-blast finishing. Final stripping of channels from ribs and unevenness is produced by cutters with the help of drills.

The center hole and fitting bosses in housings of turbopump units are worked in two stages. During roughing there is removed the main part of the allowance; in the second stage there is attained high precision of fitting dimensions and required cleanness of working. Large dimension bodies of pumps and the turbine of a turbopump unit are worked on general-purpose single-column turret lathes (model 1510 of the Sedin plant).

Small-size housings are worked on turret lathes. Primary positioning base of the pump and turbine housing of turbopump units, given in Fig. 8.4, is the surface of bosses of the crosspiece. The worked housing is set in special jig with fixation on internal surface of crosspiece bosses resting on the face of these bosses. First they preliminarily turn fitting bosses and cut the face of the pump housing on the side of the entrance channel of the collection chamber, but then holes and fitting bosses on the side of crosspiece bosses. Here, for the base there is taken the worked external shoulder and

face of the housing. The same sequence of operations is sustained during finishing. Boring of the hole and fitting bosses is produced on turret lathe, model 1510 by a set of cutters set up to dimension, located on turret head of vertical support with automatic turn of turret head. Face surface will be cut by a cutter from a horizontal (lateral) support. Operations of working the central hole and fitting bosses in housings of turbopump units consist of a large quantity of labor-consuming transitions, and require high skill. In large lot production fulfillment of these operations is best produced on an 8-spindle semiautomatic turret lathe of consecutive action of type 1283C of "Red proletarian," plant. On this machine the part can be completely worked from two sides. Machine has 8 positions, one of which is loading.

Finishing of the central hole and fitting bosses in the pump housing is produced after testing cavity of pump for airtightness.

Sequence of operations of working of holes and cutting threads in housings depends on character of holes and their location in the housing. Usually holes are drilled and counterbored on radial drilling machines through positioners. Cutting of threading is produced by machine taps on drilling machines with reversible movement or with application of special reversible chucks.

Hydraulic and pneumatic testing of turbopump unit housings are produced on a special stand after preconditioning. To test airtightness the central hole is stopped, the housing is established in a special jig and is secured through a rubber washer. Through a hose from a pump the housing cavity is filled with water under pressure, exceeding working pressure by 1.5 to 2 times, and is kept there 5-7 minutes. In pneumatic testing the housing and jig is lowered into water bath;

to cavity there is fed air at pressure 5-6 atm ($\approx 5 \cdot 10^5$ to $6 \cdot 10^5$ newton/m²) and kept for 5 minutes (Fig. 8.15a and b).

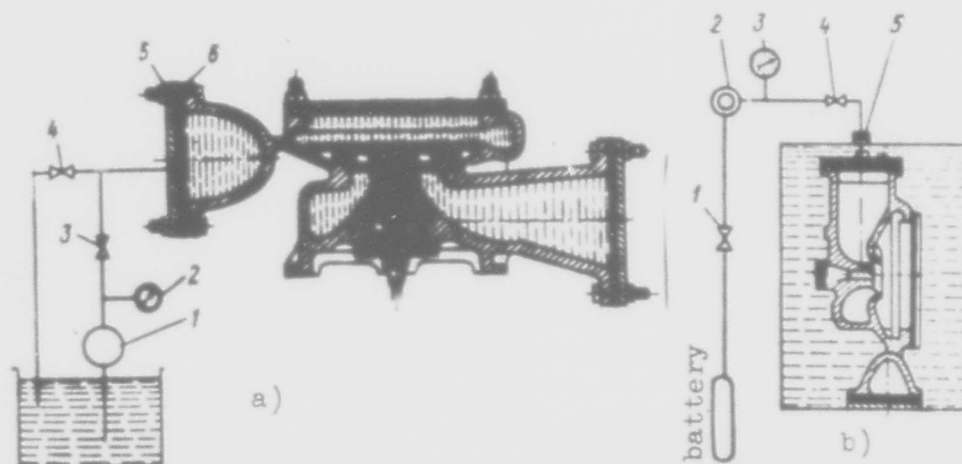


Fig. 8.15. Diagrams of test on airtightness of turbopump unit housings. a) hydraulic test; 1) pump; 2) manometer; 3-4) cocks; 5) cover; 6) rubber lining; b) pneumatic test; 1) cock; 2) reduction valve; 3) manometer; 4) valve; 5) hose.

Medium-Dimension Housings of Box-Like Form

Purpose of preliminary lathe working of housings with parallel and crossing axes of central holes (Fig. 8.5) in the first operations is creation of positioning base for finishing. Primary base for working of a housing (see Fig. 8.5a) is the external diameter of the boss and the unworked end of the housing. Clipping of end and preliminary working of a hole in diameter B in one installation ensures play of not more than 0.02 mm. These surfaces subsequently serve as basic bases for drilling of ducts and fastening holes, and also for finishing central holes.

For working the housing (see Fig. 8.5b) the primary base is the external contour of the part. The housing is clamped in a chuck with special jaws. In first lathe operation the face of the large

flange is cut, and the fitting boss is reamed. Then they bore holes in the large flange. One of these holes is for fixing during installation of part for working of surfaces on small flange, located in another plane. This hole is counterbored and reamed by 1st accuracy class and serves for fixation of part in attachment during working in two mutually perpendicular planes. Surfaces on the small flange are preworked on a lathe or turret lathe in a special fixture of square type on the base of the face of the large flange with centering by shoulder of flange and fixation by hole. Noncoaxialness and nonparallelness of holes and nonperpendicularity of face surfaces of small and large flanges depend mainly on accuracy of installation of part in fixture, and also on accuracy of manufacture of the actual fixture and installation of it on machine. Therefore, in conditions of small-lot production it is expedient to perform this operation a specially set-up machine, not allowing frequent resetttings of the machine, involving removal of the fixture.

Holes in flanges and joint planes in housings of box-like shape are drilled depending upon their number, dimensions and character of

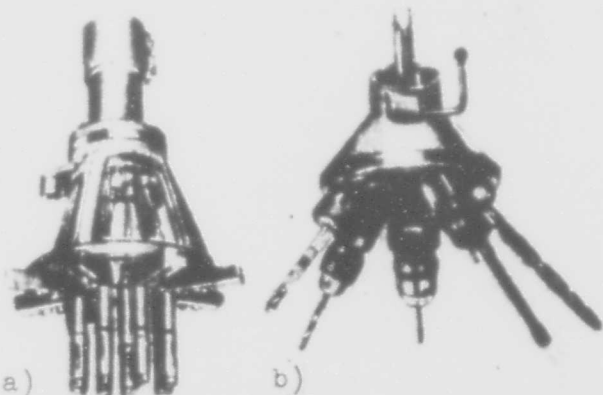


Fig. 8.16. Multi-spindle drilling heads. a) with Cardan transmission, adjustable; b) revolving, automatic.

location in the housing on vertical boring or radial drilling machines on a positioner. To increase productivity of working during drilling of a large number of holes, there are widely applied model adjustable multi-spindle drill and thread-cutting heads

(Fig. 8.16). For working holes in medium-dimensional housings of box-like type there are applied the

following types of adjustable multi-spindle drilling heads: with spindles located on line with worm transmission; with spindles located on circumference with gear transmission; drilling heads with Cardan transmission for working of holes located at an angle.

Central holes in housings with parallel or perpendicular axes in small-lot production are finally reamed most often on precision boring machines. Necessity of guaranteeing high accuracy of dimensions, coaxialness, parallelness and other rigid specifications for manufacture required the development of special high-speed and precision machines for fine boring. In Fig. 8.17 there is shown a precision semiautomatic two-way horizontal boring machine for fine boring of holes in housing parts with parallel axes of holes. The machine is high-speed; rotation of drill bar with tool is up to 5,000 rpm; minimum feed is 0.002 mm rev. For boring holes there are applied diamond or hard-alloy cutters; cleanness of working here is ensured to 8th class; precision of working is 1st class.

**GRAPHIC NOT
REPRODUCIBLE**

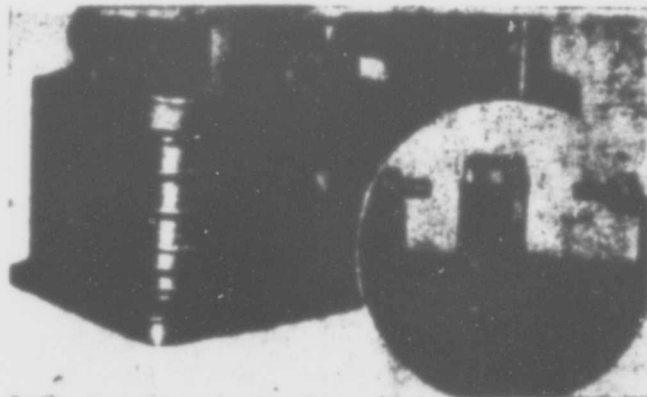
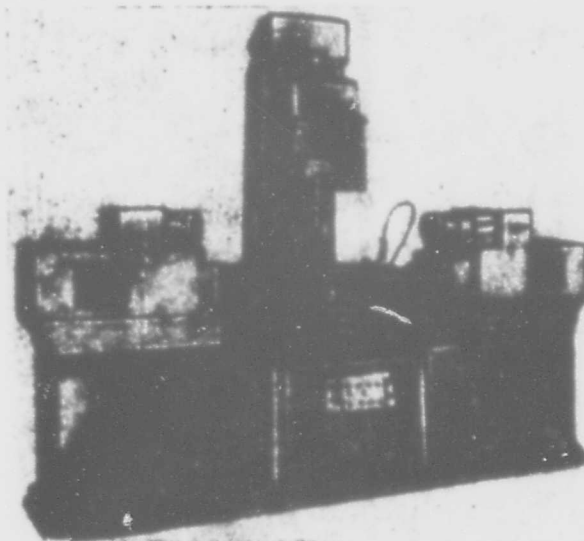


Fig. 8.17. Fine boring of holes in housing parts with parallel axes of holes.

In Fig. 8.18 there is shown the operation of boring of mutually perpendicular holes in housing parts on a special three-way semiautomatic bore. Working on this machine ensures high accuracy of mutually perpendicular holes and high productivity.



**GRAPHIC NOT
REPRODUCIBLE**

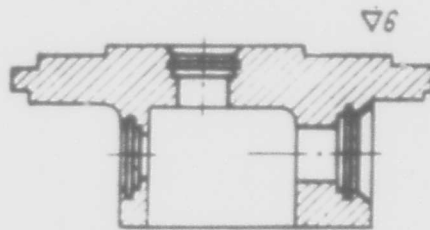


Fig. 8.18. Boring of mutually perpendicular holes in housing parts on special three-way semiautomatic boring machine.

Small Housing Parts

Working on turret machines of housing parts of valve housing type is expedient in all cases when it is necessary to work several different surfaces, and the operation consists of many transitions requiring a large number of different tools. Working on turret machines is produced by rests with application of efficient setups,

allowing simultaneous working of several surfaces as, for instance, turning of the top and boring, clipping of end and shaping, and so forth. Here, there is attained high precision of mutual location of worked surfaces. At the same time turret working is much more productive. For working small housing parts there are applied turret machines (Fig. 8.19) with horizontal axis of turret head, model 1336, and with vertical axis, model 1338. The blank is secured in wedge-shaped chuck. The female thread will be cut on turret machine by machine taps, the male thread by thread-cutting, self-opening heads.

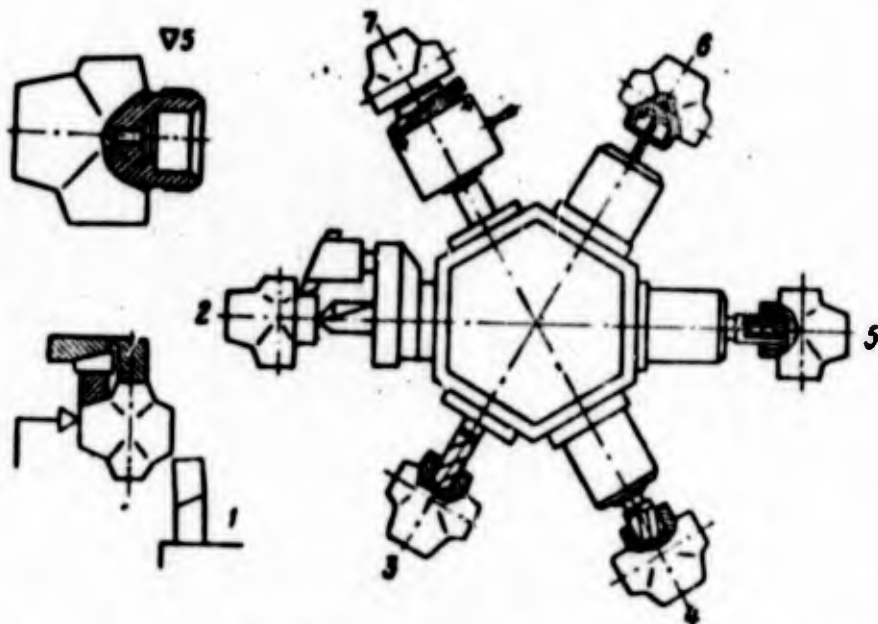


Fig. 8.19. Working of high-pressure valve housing on machine of model 1338.

Recently for working of parts with multistep internal and external cylindrical surfaces the machine-tool industry of the USSR has begun to produce turret lathes with digital programmed control (model of machine 1336 PR). Surfaces of parts on these machines are worked by preassigned program on a punch card. Relay-contact system of digital programmed control with feedback allows one to carry out very exact shifts of the carriage and turret head, which ensures high accuracy of working (in diameter 0.05 mm, in length 0.1 mm). The part is

clamped on machine in a rodless pneumatic chuck, controlled by pneumatic distributor of solenoid type. Pneumatic chuck is rapidly readjustable and permits clamping with change of the base, which is especially important when working parts of this type.

Automation of Working of Housing Parts

One of the basic directions in improving the technological processes of manufacture of housing parts is automation of their working. Transfer machines, one of highest forms of automation of production, best answer problems of sharp increase of labor productivity and quality of articles. However, transfer machines for working housing parts in the practice of aviation production both here, and abroad, have not enjoyed wide use. This is explained by the fact that in aviation industry there occurs frequent replacement of objects of production and they are produced in small lots, for which capital expenditures on development and manufacture of transfer machines cannot always be compensated by the economy from their introduction. Therefore, under conditions of aviation production automation of working of housing parts is carried out along the line of introduction of specialized and unit-head machine tools from standardized units, produced by the machine-tool industry. Such machines are assembled by the plants themselves by arrangements developed by the plants. Specialized machines, arranged from standardized units, have all the advantages of special machines (high productivity, semiautomatic work cycle, etc.,) and at the same time are free of their deficiencies (high costs, prolonged periods of development and introduction, impossibility of use in case of replacement of the object of production). Recently in domestic plants there have been created and

introduced a large number of high-speed highly productive unit-head machine tools - semiautomatic machines arranged from standardized units for working housing parts (assembly-drilling, assembly-milling, combined, boring and multiposition semiautomatic machines). Combination of such separate machines permits us in a number of cases to create a flow line. An example can be flow line for working two housing parts, arranged from unit-head machine tools, shown in Fig. 8.20. For servicing of the line one worker suffices. Productivity of working of housing parts with introduction of such a line into production is increased by factor of 2 to 3.

**GRAPHIC NOT
REPRODUCIBLE**

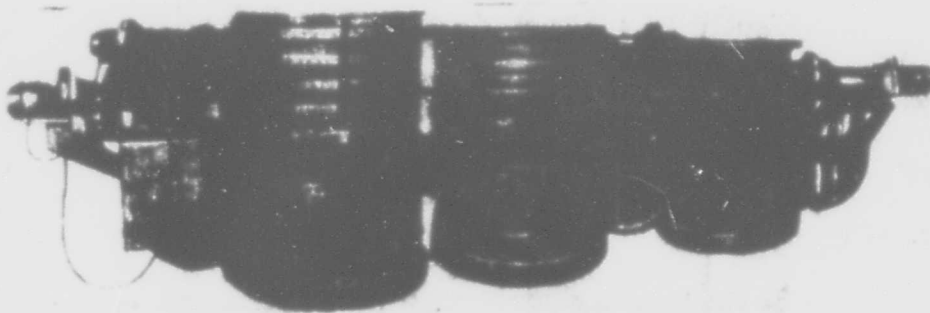


Fig. 8.20. Technological line of unit-head machine tools for working housing parts.

§ 4. INSPECTION OF HOUSING PARTS

Quality control of manufacture of housings is produced both during manufacture and also after final working. After every operation of machining basic dimensions and cleanness of working are checked. During inspection of thin-walled, large-dimension housings certain difficulty is presented by measurement of exact fitting diameters of large dimensions. With insufficient rigidity of construction of these parts in process of working and transportation there inevitably appear different forms of deformations, causing considerable errors of form and dimensions, as a consequence of which diametrical dimensions

must be checked in several mutually perpendicular planes. For measuring precision fitting dimensions we use special instruments and tools. Indicator instrument, consisting of a combination of a depth gage with an indicator, permits measurement of external and internal diameters of large-dimension housing with an accuracy of 0.01 mm. During measurement of large diameters during working one should also consider influence of temperature on change of dimensions, rendered especially noticeably during working of housing parts from aluminum alloys. To decrease measuring error the best solution in this case would be application of measuring tools with temperature compensators; however, such tools are too expensive and complicated in manufacture and use. A simpler means is application of standard parts for setting-up measuring instruments, cooling of parts by compressed air, heat insulation and maintaining a constant temperature in the inspection area.

Check of mutual play of surfaces (diametrical and face) is usually produced directly on machines during working. Adjoining of linked surfaces of flanges is checked by paint. More complicated is inspection of welded housings. Check of quality of welded joints is produced directly after welding operation, after which there follows welding of revealed defects. The most frequently encountered defects of welded joints are: nonfusion, burns, cracks, porosity and contamination of welded seam by harmful impurities and slag inclusions. Manifestation of different defects of welded joint, besides external inspection, often requires application of labor-consuming inspection methods: metallographic, X-ray, magnetic, luminescent, thermoelectric, ultrasonic, chemical and others.* Separate welded units of housings

*Presented in Chapter VII.

are checked for airtightness.

Inspection of accuracy of manufacture of medium-dimension housings of box-like form and small-size bodies of control units anticipates check of basic dimensions, noncoaxialness of holes, radial and end play and deviation of distances between axes of holes.

In small-lot production dimensions of housing parts are checked by standardized instruments, caliper gages and plug gages. Mutual play of two coaxial holes is checked by installation of self-centering spindle with indicator. Upon turn of indicator relative to motionless spindle of 360° (its tip touches second hole) there is determined magnitude of play. Face play in box-like housings is most frequently

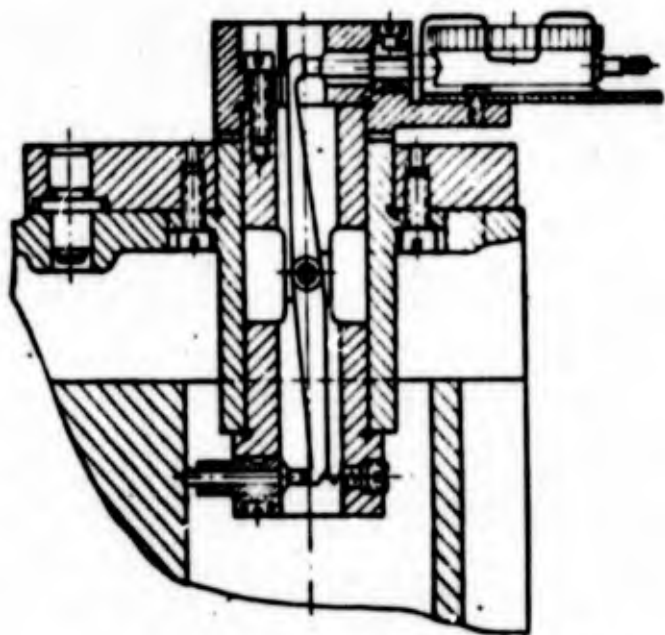


Fig. 8.21. Measuring device for checking coaxialness of holes.

checked relative to the central hole; in housings control units end play is checked with respect to the axis of the external or internal threading. To check face play with respect to hole there are applied indicator jigs, in which the part is fixed motionlessly on an unclasping base mounting, and measuring tip of indicator gauge, fixed an assigned distance from axis of the corres-

ponding base, turns 360° . The same method of shift of the measuring tip of an instrument along a circumference of assigned radius is applied for inspection of face play relative to the internal and external threading. In Fig. 8.21 there is shown a diagram of a throw-back measuring instrument for inspecting coaxialness of holes.

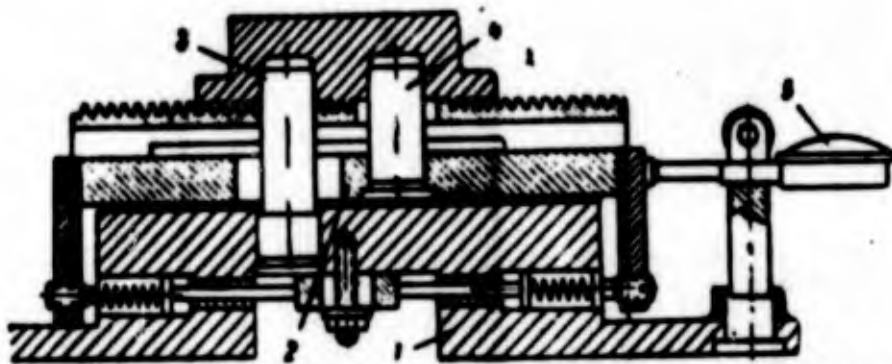


Fig. 8.22. Instrument for measuring distances between axes of holes in housings. 1) housing; 2) carriage; 3) motionless spindle; 4) mobile spindle; 5) indicator.

In Fig. 8.22 is shown the construction of an instrument for measuring distances between holes. Shift of mobile spindle 4 through carriage

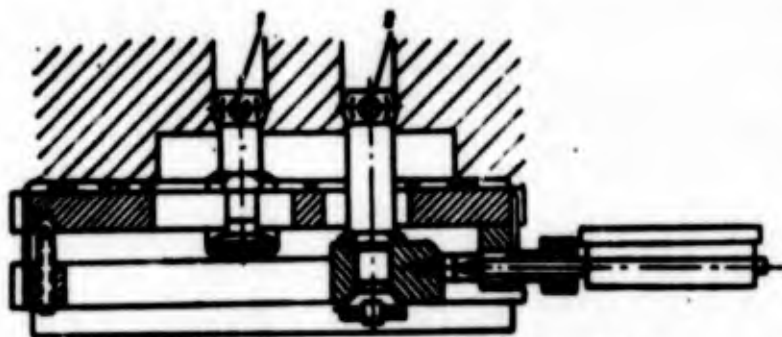


Fig. 8.23. Instrument with self-centering spindles for measurement of distance between axes of holes in housings.

2 is transmitted to indicator

5. Setting of the instrument is produced from a standard.

In process of measurement mobile spindle is shifted

from one side of the hole to the other by springs of carriage

2. On indicator they make

two readings (in two extreme positions of mobile spindle); half the difference of these readings determines amount of deviation of real distance from distance between axes of holes of the standard. Improved

instrument for measuring center-to-center distance is an instrument with self-centering spindles (Fig. 8.23). Determination of distance between axes on this instrument does not require additional calculations. Spindles 1 and 2 establish themselves in holes, they select radial gap and permit determining of distance between axes of holes independently of deviations of their diameters.

CHAPTER IX

PRODUCTION OF HEADS OF COMBUSTION CHAMBERS OF LIQUID-FUEL ENGINES

§ 1. DESIGN, SPECIFICATIONS AND MATERIALS

Heads for combustion chambers of liquid-fuel rocket engines are assemblies which ensure introduction of fuel and oxidizer, their mixing and proper distribution of the mixture in the combustion chamber. For introduction of components of mixture there are separate cavities or collectors, with which there are connected injectors (or slots), located in the flame stabilization dome.

Depending upon the shape of the flame stabilization dome we distinguish heads: spherical, hipped and flat (Fig. 9.1).

Spherical form of head is the most rational from the point of view of rigidity; however manufacture of domes with high degree of concentricity of the sphere and setting in them through injectors causes a number of technological difficulties. Probably, for this reason, at present, they are rarely applied.

Heads of hipped type (see Fig. 9.1b) most frequently are met in low thrust motors (Fig. 9.2). Technologically they are somewhat simpler than spherical ones; however, for production of satisfactory carburetion it is necessary to apply a complex set of injectors.

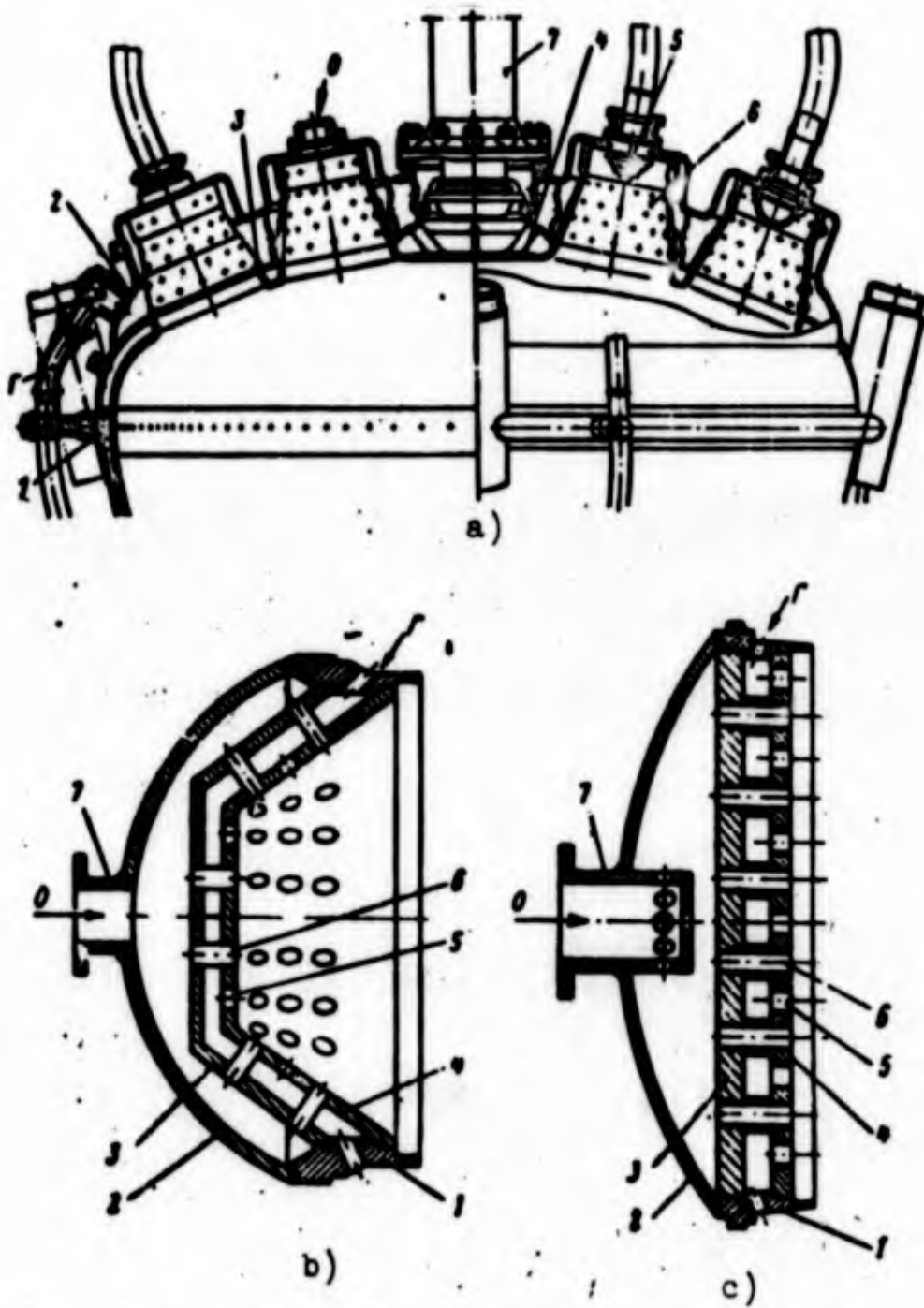


Fig. 9.1. Types of combustion chamber heads. a) spherical; b) hipped; c) flat. 1) thrust ring or head casing; 2) outer dome; 3) middle dome; 4) flame stabilization dome; 5, 6) injectors; 7) pipe; Γ) entrance to fuel cavity; 0) entrance to oxidizer cavity.

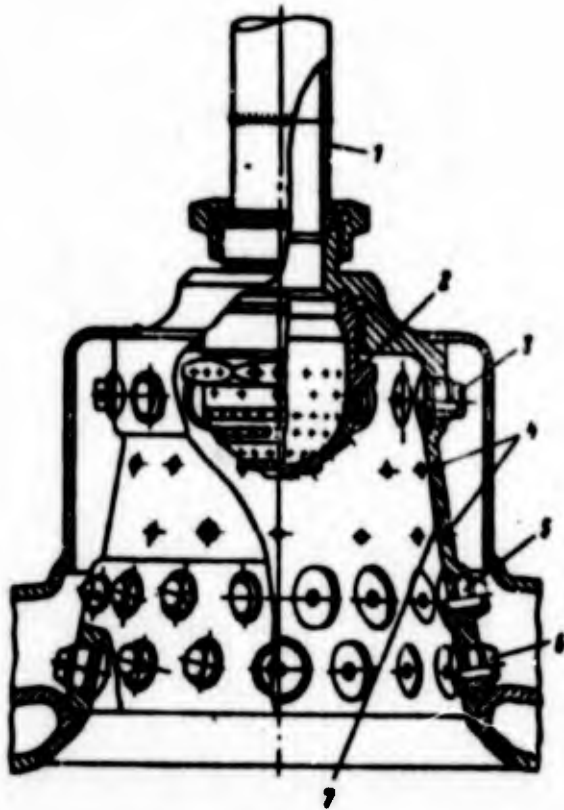


Fig. 9.2. Hipped mixing chamber of rocket motor A-4. 1) oxidizer feed tube; 2) central oxidizer jet; 3) upper row of swirlers; 4) lateral jets; 5,6) combined jets and swirlers; 7) inner shell of mixing chamber.

The overwhelming majority of chambers, working on spontaneously combustible components, have heads with flat flame stabilization domes (see Fig. 9.1c). This is explained by the fact that, while ensuring good carburation, technologically they are simpler; during their manufacture it is possible to maintain high requirements of airtightness. Increase of rigidity of such heads is attained by welding of gusset plates to the outer and middle domes. Basic parts of head (the set of domes, injector head casing) in period of starting and running of motor are washed by

aggressive or low-boiling liquids and are loaded with forces of pressure of the components and hot gases from the engine chamber. The least failure of airtightness of cavities of the head can lead to leakage or inadvertent ignition of components.

Proceeding from assignment and conditions of work, combustion chamber heads present the following basic requirements;

1. Complete airtightness of welded and soldered connections (at pressures 1.7 times working).
2. The set of injectors should ensure assigned flow of components within 2-4%.
3. Distribution of injectors in flame stabilization dome should ensure assigned mixture ratio by section (error in location of

injectors $\pm 0.1-0.2$ mm, misalignment of axes $10'-15'$).

4. Deviations from the assigned geometric form of the flame stabilization dome should not disturb process of carburetion (error of shape is normally 0.2-0.3% of diameter of the dome).

5. During manufacture of head and its assembly with the chamber it is necessary to ensure coincidence of the axis of the mixture flame with the combustion chamber axis.

6. In cavities and ducts of the head there should not remain shavings, welding burr, flux, oil, dust or other contaminations.

Materials for manufacture of heads should weld and machine well, possess plasticity and corrosion resistance. The flame stabilization dome, furthermore, should be highly-heat-resisting and heat-conducting for good heat removal.

At present for manufacture of heads there are used stainless steels 1Kh18N9, 1Kh18N9T, alloys EI654 and EI712, and also low-carbon steel 08KP and Steel 10, which are used for motors of single action working on unaggressive fuels. For the flame stabilization bottom along with the shown materials they apply alloys on a copper base, for instance brand BRKh-08, etc.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

Fulfillment of above-indicated requirements is possible only with high level of production technique and equipment of technological process with the latest equipment.

All operations, starting from making the blank and finishing by welding and soldering, are usually accompanied by thorough control. Edges for welding are cleaned to metallic brightness and thoroughly degreased. Tack welding of parts is carried out in jigs, ensuring correctness of their mutual location. Sequence and conditions of

tack welding are necessarily regulated. For adding seams, as a rule, they use argon arc welding. After stripping the seam is subjected to preliminary inspection for penetration of active liquid. Finally, quality of seams is checked by a hydraulic test under pressure, exceeding working pressure by a factor of 1.6-1.7.

Preparation for soldering consists of thorough (sometimes double) washing of parts and solder in gasoline B-70, and then in pure alcohol or its substitute. After preparation of assembly for soldering there is must not elapse more than 2-3 hours, before soldering, since on solder and parts there can form an oxidized film. Soldering is produced in special vacuum containers or in a protective medium of neutral gas. Conditions of welding and soldering for small-lot production are worked out preliminarily on samples, then there is prepared a setting batch of heads (5-6 pieces), which after carrying out of all tests proceed to investigation of micro- and macrostructure and mechanical properties of seams and joints. Thus worked out conditions are fixed on flow charts.

After welding and soldering, heads pass to hydraulic testing and check of flow rate of components, which is conducted by means of flowing them through on a special stand, allowing one to determine total flow of components and flow of each component separately.

Efficiency of combustion chamber is considerably influenced by coincidence of axes of the flame and the chamber. This is attained by a special jig for assembly of head with chamber with strict regulation of misalignment of welded faces of head and combustion chamber.

Process of manufacture of a combustion chamber head usually includes machining, welding, soldering, testing and other forms of treatment. Order of these operations as far as possible should be

such that shaving, welding burr or solder cannot contaminate cavities and holes of the head and injectors. When the shown order of operations is not carried out, it is necessary to insert plugs, protecting internal cavities of head from contamination. Between-operation storage and transportation of assemblies should be in special packing.

A fuller idea about carrying out of operations and their sequence can be obtained in examining the technological processes of working basic parts and assemblies of a head.

§ 3. BASIC OPERATIONS OF WORKING COMBUSTION CHAMBER HEADS

Basic parts of a combustion chamber head are: set of domes, thrust ring or casing of head and set of injectors. Inasmuch as manufacture of injectors is given in a separate chapter, below we shall describe basic operation of manufacture of domes, head casing, and also welding and soldering of the assembly as a whole.

Manufacture of Domes

For production of billets sheets of standard dimensions by guillotine shears are cut into squares, from which round blanks are cut in a stamp or on roller shears.

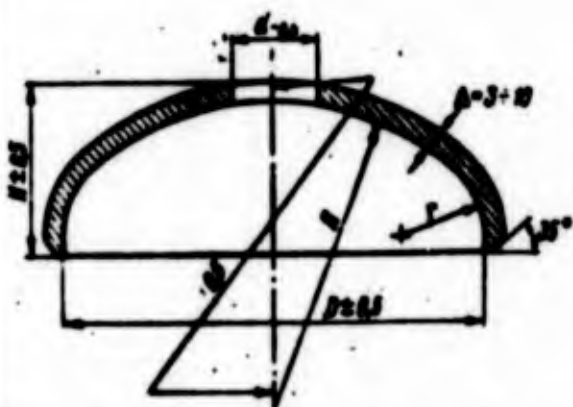


Fig. 9.3. Outer dome of combustion chamber head.

Outer domes have, as a rule, spherical (Fig. 9.3) or elliptic shape. They obtain the shape on a hydraulic press in a combination die, allowing simultaneously with forming cutting of the center hole.*

*Example is shown in Chapter VII.

Before stamping the blank is heat-treated, etched and coated with varnish KhVL-21. After stamping on a lathe they cut the face and chamfer for welding with installation of part by central hole on a special mounting with rest on the inner spherical surface.

Sometimes outer dome, besides a central hole, has one or two holes for connector pipes and radial slots for welding on reinforcing. Holes for connector pipes are usually drilled in a jig with a dividing device. If diameter of these holes is sufficiently great (>35-40 mm), they should be cut by hollow crown-shaped counterbores. With a sufficiently great program these holes can be cut in a stamp on an eccentric press.

Radial slots for reinforcing ribs are usually milled by disk milling cutters on a horizontal mill using a dividing fixture.

After machining to the dome there are welded the central pipe and connector pipes. Tacking is done by argon arc welding in a jig, ensuring assigned mutual location of the welded parts.

After welding the seam is cleaned and checked in a flow of kerosene.

Flame stabilization and middle domes (Fig. 9.4), as a rule, have identical flat form and are interconnected by through injectors.

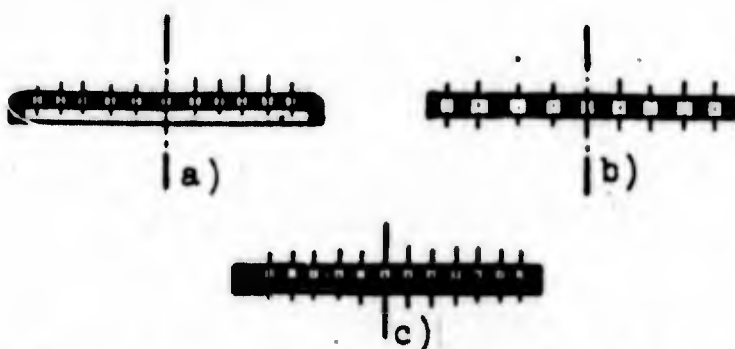


Fig. 9.4. Flat domes. a) dome with flanging; b) flat dome; c) dome with thickened rim.

Therefore, technological processes of machining these domes have much in common, and part of operations in their working is executed jointly.

Flat domes are processed as follows. Stamped blanks in the form of a flat circle

go to machining. In first operation domes with flanging (Fig. 9.4a) have their end cut on a lathe. Domes without flanging (Fig. 9.4b) are turned on external diameter. Domes are positioned on the lathe by their central hole, obtained during stamping or drilled before lathe work. Inasmuch as external diameter of domes is turned to 2nd or 3rd accuracy class, it is desirable before lathe operation to ream the base hole. Fastening of domes is produced by a revolving clamp, fixed in pinol of tailstock. Domes, not having flangings, are turned in pairs, where if the flame and middle domes have the same diameter and materials are close in technological properties, already on this operation they are worked jointly.

For domes of type "c," and sometimes of type "b" (see Fig. 9.4) after machining of external diameter they turn face planes, maintaining dimensions with precision of 4th class. In connection with this certain plants repeat operation of turning face planes after drilling holes for injectors.

Deviations from flatness are checked by role and probe. Maximum permissible deviation should not exceed 0.5 mm. For hipped and spherical domes, as a rule, after stamping they only cut the face. Turning of surfaces of hipped and spherical heads encounters a series of difficulties, for which to achieve assigned accuracy of thickness of domes stamping of blanks is done from calibrated sheet.

After lathe work the domes are washed, after which they drill holes for injectors. Diagrams of location of holes are shown in Fig. 9.5. During machining of holes it is necessary to consider that during application of single-fuel injectors approximately half, and during use of two-fuel injectors, all holes of the flame and middle domes should be coaxial. Noncoaxialness of holes will hamper setting of injectors, passing through the flame and middle domes. Holes are

worked with precision of 3rd or, more rarely, 2nd class. Tolerance on mutual location of any two holes (with observance of coaxialness) should not exceed 0.02-0.04 mm. Error of angular location lies within limits $\pm 10'$ - $20'$.

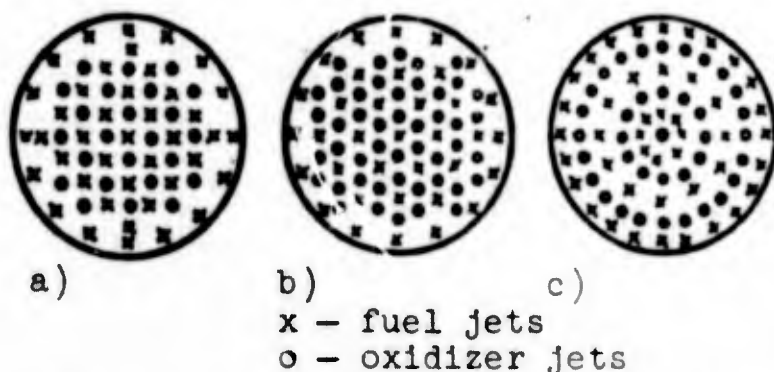


Fig. 9.5. Diagrams of location of injectors. a) checkerboard; b) honeycomb; c) concentric.

Coaxialness of holes in flame and middle domes can be obtained by:

1. Joint working of the two domes in one jig.
2. Separate working of domes by the same plate jig.

First method is applied when the flame and middle domes are made from materials, close in workability. Disks are installed by external diameter with gap of up to 0.1 mm. After drilling of all holes the plate jig for drilling is replaced by jigs for counterboring and reaming, which are installed with the help of calibrated plugs in two diametrically opposite holes. To decrease deformation during drilling the first dome rests on its whole face surface on an underlaid disk. If the second (paired) dome has flanging or a thickened rim, to prevent deformation it is set on a spacing disk, the thickness of which is greater than the height of the collar.

In the second method the flame and middle domes are worked separately on the same plate jig. To increase productivity in this

case they simultaneously work several domes.

Operation of machining holes for injectors is usually executed on a radial drilling machine; however, with a sufficiently great program it is possible to use a set of multi-spindle heads of electro-erosional punching. Holes for through injectors in spherical domes are cut by the first method, but here the thickness of the processing lining should be equal to the distance between domes in the assembled head. Operation is executed with the help of a jig, allowing one to revolve domes about two axes (Fig. 9.6). Flame dome

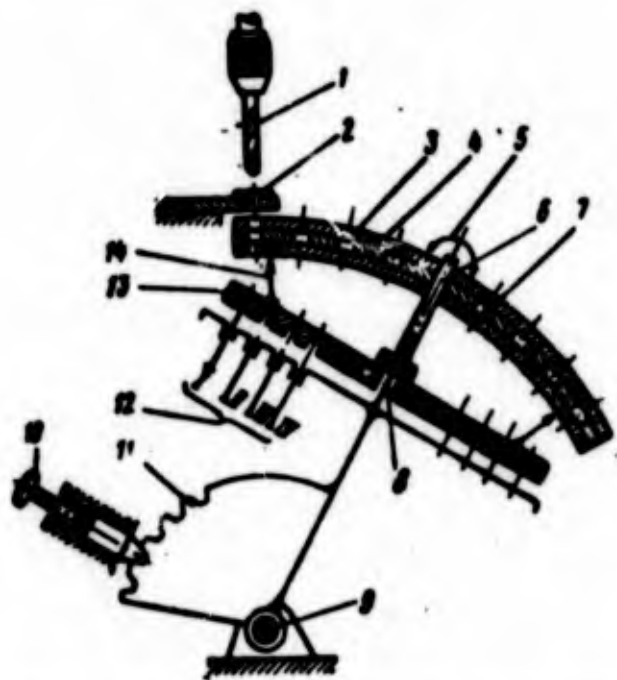


Fig. 9.6. Diagram of jig for drilling holes in spherical domes. 1) drill; 2) jig bushing; 3) middle dome; 4) insert; 5) clamp of parts; 6) centering pin; 7) flame dome; 8) axis of rotation of dividing disk; 9) axis of rotation of sector; 10) index pin of dividing sector; 11) dividing sector; 12) pins; 13) index disk; 14) support ring.

7 is set in jig with help of centering pin 6 and support ring 14. On flame dome there is put insert 4, angular location which fixed by one of the holes in it. The middle dome is placed on the lining and is centered by pin 6. The three parts thus fixed are secured by a common nut. Turning index disk 13 about axis 8, they drill the first strip of holes. To drill the second strip the jig is turned a definite angle about axis 9, using sector 11 and index pin 10. Drilling of second and subsequent strips of holes is conducted by corresponding

index pins.

With a sufficiently great program, holes for injectors in spherical domes can be drilled on unit-head machine tools by

semiautomatic cycle. Recently for production of holes in spherical domes they have begun to use the electro-erosional method of working (Fig. 9.7). Cutting of holes in hipped heads, having single-fuel injectors on a conical surface and one injector on the flat part of the dome, does not present special difficulties and can be executed both on drilling machines with help of usual turning jig, and also when assembled.

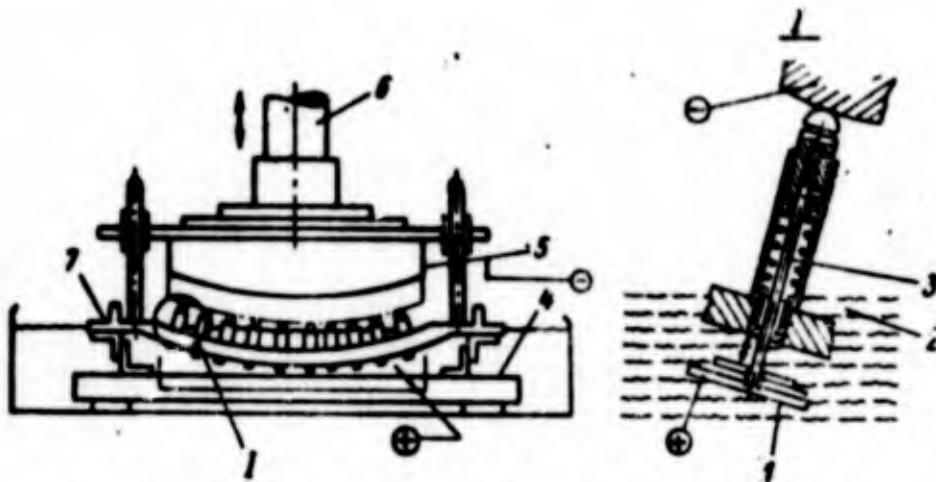


Fig. 9.7. Diagram of electro-erosional punching of holes. 1) workpiece; 2) electrolyte; 3) electrode; 4) jig; 5) punch; 6) rod of hydraulic cylinder; 7) clamp.

Drilling of hipped domes for through injectors is produced, as a rule, jointly.

After drilling, counterboring and reaming they deburr the dome with sandpaper, wash and inspect it. They check dimensions of holes and their location, deviation from geometric form, and also presence of surface defects. Necks, burrs, scratches and other defects are not permissible.

Manufacture of Casing

The head casing or thrust ring are among the basic parts of a combustion chamber head. This part in most cases is executed in the form of a ring, to which there are welded three domes and manifold.

In certain constructions, the head casing is made as a single unit with the middle dome. After assembly and test of head to the casing, they weld internal and external shell of the combustion chamber.

The blank for the head casing with the middle dome is usually a stamping. Blanks for casings without the middle dome can be obtained by stamping or rolling. Possible also is use of bending of the profile with subsequent butt welding. Blanks, obtained by stamping, have an allowance of 3-4 mm to a side. Machining of the head casing is to 4th accuracy class. Mutual play of fitting diameters is not more than 0.1 mm; nonperpendicularity and play of welding faces with shell of chamber is not more than 0.02-0.04 mm. Ends for butt welding should have sharp edges without burrs.

Roughing of the casing is produced on lathes with positioning of part by external diameter in a three-jawed chuck. After boring of internal diameter and cutting of end, they machine the external diameter and the second face. As a result of roughing the casing blank obtains configuration of the part.

In clean lathe operations the part is centered by diameters and is secured, to avoid deformation of the ring, by its faces. In these operations possibly, too, is application of tong devices.

In finishing operations they finally turn fitting diameters, grooves for solder (if the dome is soldered) and for rolling out.

Holes are drilled and counterbored in rotating jigs. Sometimes, for the purpose of increasing the cross sections for components and decreasing the danger of obstruction, neighboring holes are connected in pairs, milling out the crosspiece between them on vertical mill by a milling cutter. The described operation can be successfully replaced by electro-erosional working.

A head casing, made as a single unit with the dome, is worked analogously, but to operations of working the ring there is added clipping of faces of the dome and drilling of holes in it for injectors.

Welding and Soldering of an Assembly

After machining parts are assembled in separate sub-assemblies of the head for welding and soldering with subsequent testing. Thus, for instance, to outer dome they weld central pipe, connector pipes and other parts. From middle and flame domes, injectors and casing, there is welded and soldered the block of injectors, which is then welded to the outer dome. Between operations of welding and soldering, if necessary, there can be performed machining or testing of assemblies.

For welding to the head casing the middle dome is established in the casing and by a cover disk (sometimes for this purpose they use flame dome) and three bolts

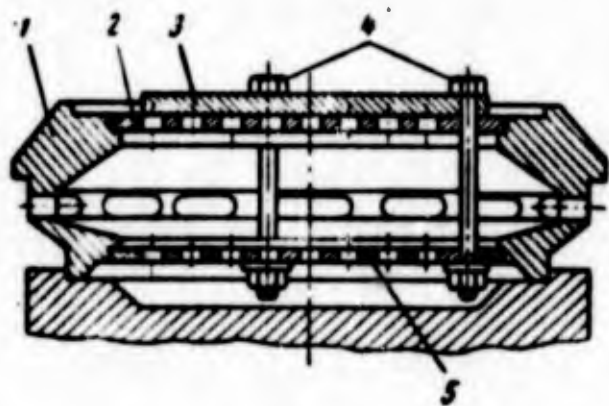


Fig. 9.8. Welding of middle dome with head casing. 1) head casing; 2) middle dome; 3) cover disk; 4) bolts; 5) flame dome.

evenly located on the circumference, passed through holes for injectors, is pressed to the head casing (Fig. 9.8).

Here, gap on diameter should be 0.02-0.03 mm; deformation is not allowed.

Welding is performed on argon arc welding machine with speed 2-2.5 m/min with an addition. After welding seams are cleaned (here there is allowed deepening in basic metal of not more than 0.01 mm) and are checked by kerosene. In case of improper seal of seam there is allowed welding with preliminary division in not more

than three places. After welding airtightness is again checked.

Then the casing with welded middle dome is assembled with injectors, is prepared for soldering and all parts, in the assembly are thoroughly degreased.

Soldering of the head is produced by hard solder PG-40, PSr-37.5, and others. The strip of solder, preliminarily rolled from wire of diameter about 2 mm, is rolled in rings which before setting in grooves of injectors are kept in exsiccator with alcohol. It is

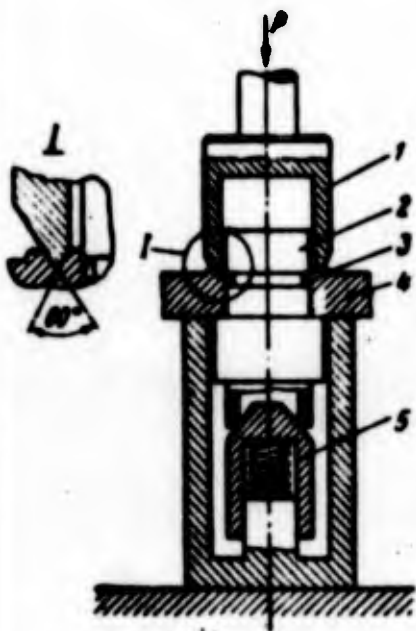


Fig. 9.9. Diagram of pressing of injector. 1) set die; 2) injector; 3) solder; 4) dome; 5) tightener cone.

necessary to pack solder in suede or nylon gloves. If solder is put on flat surfaces, then it is tacked on by electric-contact welding by a welding pistol. Thickness of solder strip should be less than depth of grooves by 0.02-0.03 mm. Then injectors are inserted in the dome and are pressed on a hydraulic press by strictly determined force, which is selected depending upon material of the dome and external diameter of the injector (Fig. 9.9). For instance, for domes of steel 1Kh18N9 force should be about 1500 kg (≈ 15 kilonewton). For a dome of copper alloy force is equal to

400-500 kg ($\approx 4-5$ kilonewton). Diameter of set die should be 1.5 mm larger than diameter of injector. Further, on injectors there are put thrust bushings, rings of solder and the flame dome, and injector is pressed from direction of flame dome. Then on lathe they roll out collar of flame dome (Fig. 9.10), and the block of injectors proceeds to soldering.

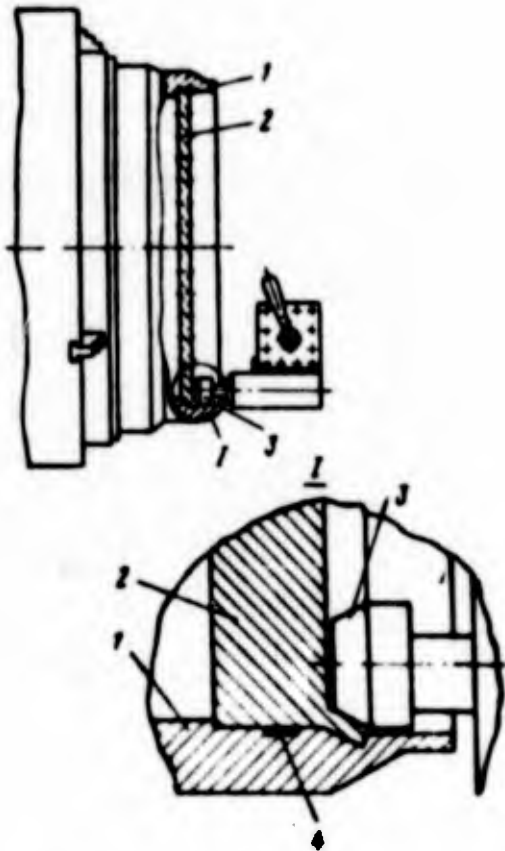


Fig. 9.10. Rolling out of flame dome. 1) head casing; 2) dome; 3) roller; 4) solder.

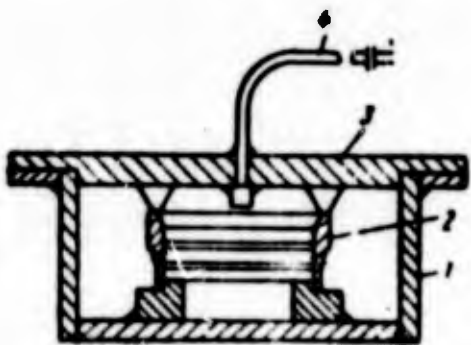


Fig. 9.11. Container for soldering of head in a vacuum. 1) container; 2) block of injectors (casing, dome, injectors); 3) cover of container; 4) tube for connection to vacuum-pump.

Soldering is produced in a special container (Fig. 9.11), which each time before placing a block of injectors in it (casing, two domes and injector) passes through sand-blasting and degreasing. After welding of cover the container is checked for airtightness by air under pressure of 1.2-2 atm ($\approx 1.2 \cdot 10^5 - 2 \cdot 10^5$ newton/m²); then it is kept in soapy water for 5 minutes. In case of poor sealing places of escape of air are welded, and repeatedly checked for airtightness. Soldering of injectors and domes at present is done in a vacuum or a protective medium. Soldering in a vacuum is produced with rarefaction of 10^{-2} mm Hg ($\approx 10^{-2} \cdot 136$ newton/m²). Container is loaded in furnace preliminarily heated to a definite temperature (during loading furnace will be turned off) and in it there is created required vacuum, simultaneously with rise of temperature in furnace. For soldering by

solder PSr-37.5 temperature of furnace should be $960 \pm 10^\circ\text{C}$, time of exposure should be 55-60 minutes from moment of arrival of furnace at assigned temperature, after which container is unloaded

from furnace, but the vacuum-pump (VN-4 or VN-6) is not disconnected until complete cooling of the container (approximately 2 hours).

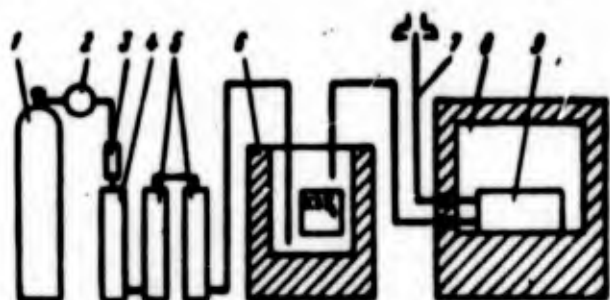


Fig. 9.12. Diagram of installation for soldering in protective atmosphere. 1) bottle of argon; 2) pressure reducer; 3) rotameter; 4) tank with silica gel; 5) tank with alumogel [?]; 6) furnace of thermal dissociator; 7) escape of gas from container; 8) furnace for soldering; 9) container with head.

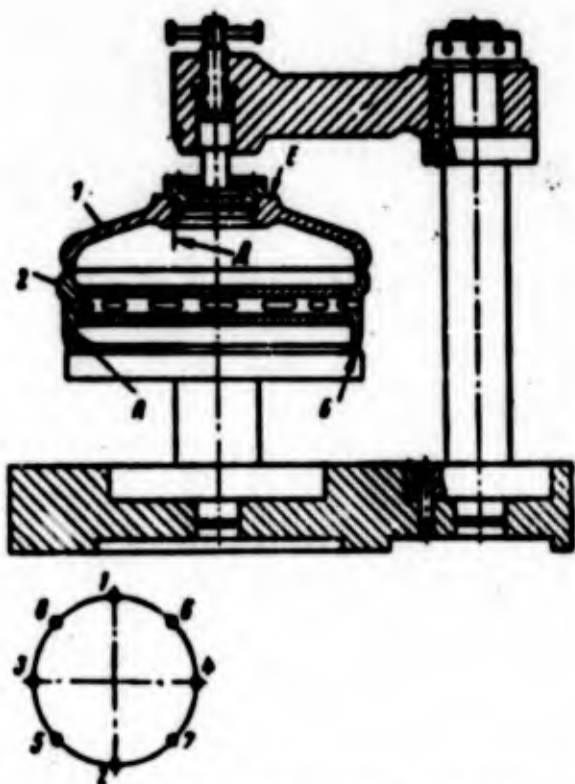


Fig. 9.13. Diagram of fixture for tack welding outer dome. 1) outer dome; 2) head casing.

After soldering they grind off welding seam on container and extract the head. When soldering is conducted in an argon medium, container has two tubes - one for feed and the other for removal of argon. On the way to the container argon passes through silica and alumogel for separation from it of moisture and thermal dissociation, where to argon there is mixed a slight quantity of BF_3 . Diagram of installation for soldering in protective medium is shown in Fig. 9.12. After soldering the assembly passes through pneumatic test and proceeds to subsequent working.

Outer dome with pipes and connector pipes welded to it is welded to head casing in last step (in certain cases after welding of head to chamber). For tack welding the head casing is set in a jig (Fig. 9.13) with surface A resting on face B. Outer dome is set on surface D and is slightly pressed in face E. For angular location of outer dome with respect to the

head casing they usually use pipes, welded to the dome and holes in the head casing. Tacking is produced at eight points in a cross pattern. After tacking, points are cleaned and are wiped with gasoline B-70. Basic seam applied by automatic argon arc welding.

§ 4. INSPECTION OF COMBUSTION CHAMBER HEADS

To check dimensions of parts, entering into the head assembly, along with general-purpose instruments, they also apply special measuring fixtures. However, the most specific control operations during manufacture of a head are checks of airtightness of welded and soldered joints and check of flow rate of components.

Airtightness of welded seams is preliminarily checked by kerosene immediately after welding and trimming of seam, and after cavitation they conduct pneumatic and hydraulic tests.

After welding and soldering of the flame and middle domes of injectors and head casing, they perform pneumatic test on block of injectors.

Head is set in a special fixture (Fig. 9.14). Through lateral holes in the head casing into the cavity between the flame and middle

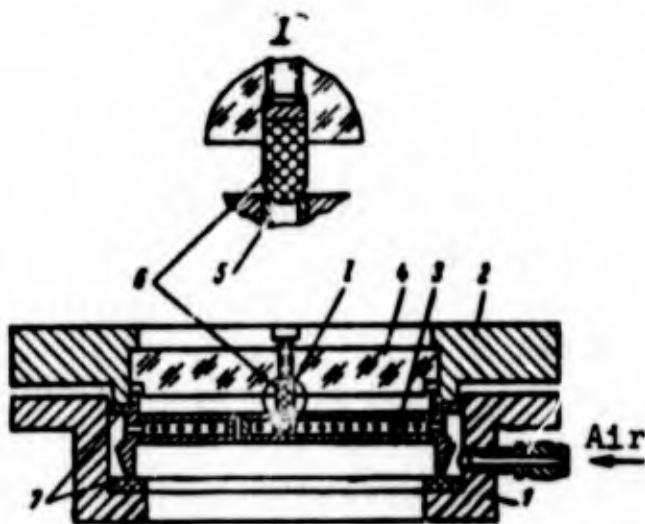


Fig. 9.14. Fixture for pneumatic tests of block of injectors. 1) casing; 2) cover; 3) block of injectors; 4) organic glass; 5) injector; 6) rubber plug; 7) rubber seal.

domes there is fed air under pressure of $5-10 \text{ kg/cm}^2$ ($\approx 5 \text{ to } 10 \cdot 10^5 \text{ newton/m}^2$). Escape of air through injectors is blocked by conical rubber plugs, and at ends by annular rubber seals. The fixture and head is dipped in water 5 minutes. In case of leaking there is allowed one repeated soldering or welding with repeated test. After

pneumatic test the part is dried and washed with gasoline. Drying is conducted in thermostat at 150-180°C for 30 minutes.

Flow rate of fuel and oxidizer is checked after welding on the outer dome. Head is established on stand (Fig. 9.15) and to it there are connected corresponding main lines. Flow of test liquid (water) is determined with help of differential manometers. Additional manometers measure pressure in oxidizer and fuel tanks, which permits us to determine pressure drop in main lines of fuel and oxidizer. The last parameter characterizes flow friction of fuel and oxidizer ducts and obtains especially great importance in those cases when head is tested after welding of it to combustion chamber.

Allowance on flow rate of test liquid fixed by recalculation is set at 2 to 4%.

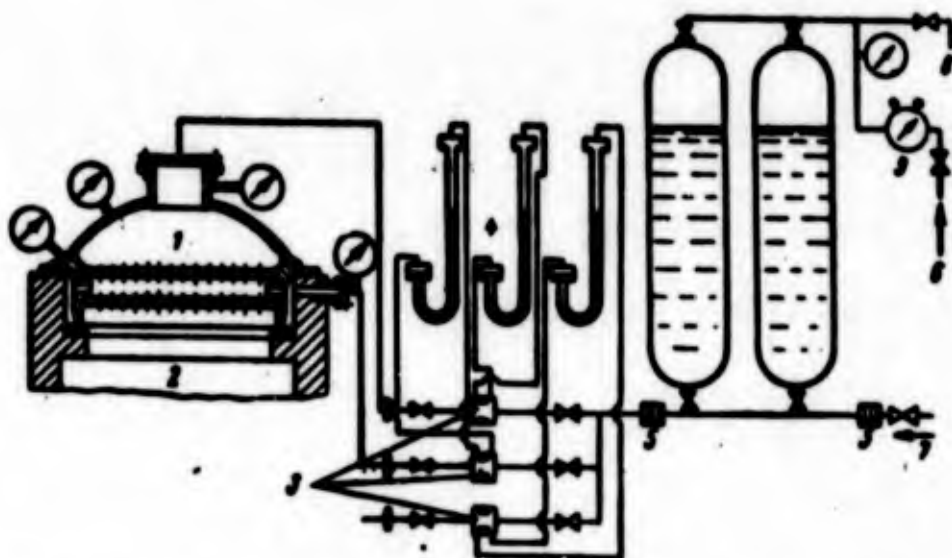


Fig. 9.15. Diagram of stand for checking flow of fuel and oxidizer. 1) chamber head; 2) overflow tank; 3) flow plates; 4) differential manometers; 5) filters; 6) compressed air; 7) filling of tanks; 8) drainage; 9) command reductor.

CHAPTER X

PRODUCTION OF FUEL INJECTORS

§ 1. DESIGN, SPECIFICATIONS AND MATERIALS

In contemporary aircraft engines there are applied many types of fuel injectors. For the purpose of standardization of the technological processes of working, assembly and testing of injectors there is adopted the following conditional design-technological classification:

- spray injectors (Fig. 10.1);
- swirlers with tangential holes (Fig. 10.2);
- screw swirlers (Fig. 10.3);
- combined injectors (Fig. 10.4).

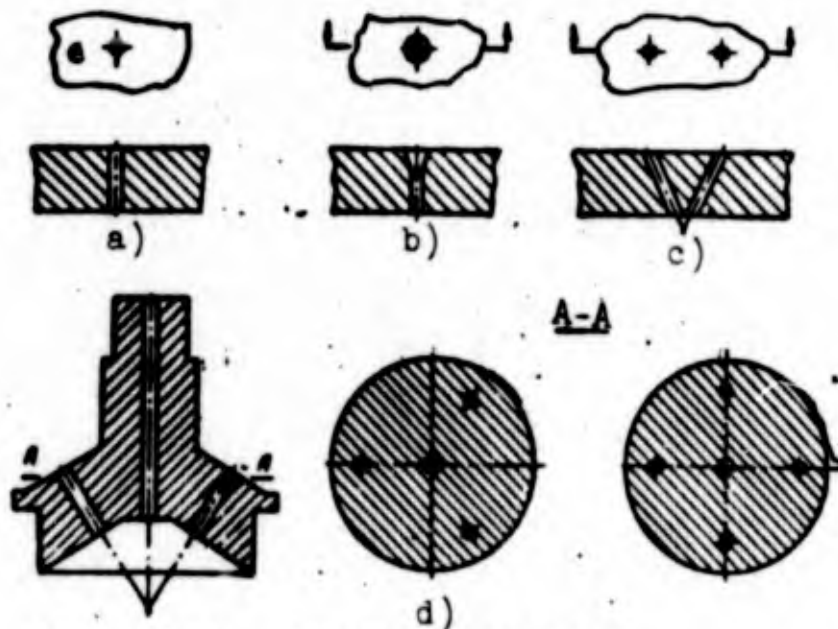


Fig. 10.1. Spray injectors.

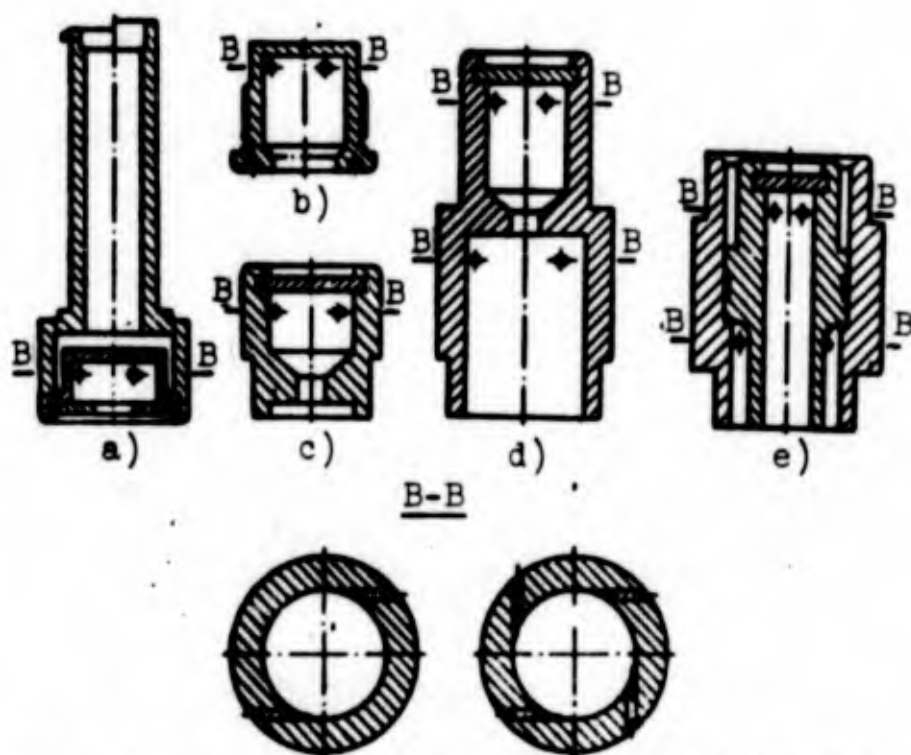


Fig. 10.2. Swirlers with tangential openings.

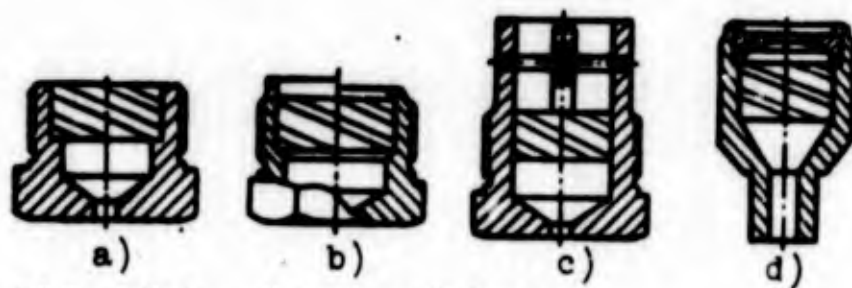


Fig. 10.3. Screw swirlers.

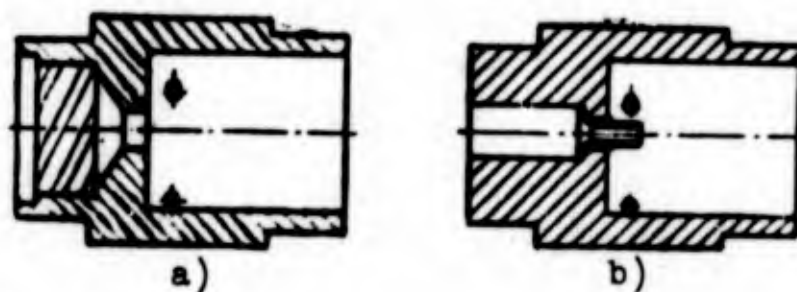


Fig. 10.4. Combined injectors.

Spray injectors are a part with exact holes, through which fuel is fed to the combustion chamber in the form of sprays. There exist the following varieties of spray injectors (see Fig. 10.1):

- a - with holes having sharp inlet edge;
- b - with holes, having inlet chamfer;
- c - with holes, carried out at an angle, for atomizing fuel components in the form of colliding spray.
- d - multi-spray, single fuel, and two-fuel.

Technological process of manufacture of spray injectors is determined by working of exact holes of small diameter. Diameter of hole is calculated depending upon form and specific flow rate of fuel for the given engine.

Swirlers are parts, in which a spray of liquid fuel moving under pressure is swirled in a swirl vane and is fed into the combustion chamber in the form of a thin conical film, of consisting from atomized particles of fuel. The most important part of swirlers is the swirl vane (Fig. 10.5). According to the kind of swirl vane applied and the method of obtaining twist of flow of liquid fuel swirlers are divided into tangential and screw. There are the

following typical constructions of tangential injectors (see Fig. 10.2).

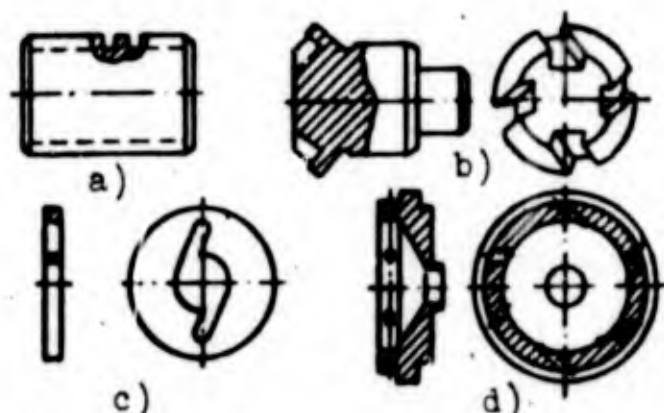


Fig. 10.5. Types of swirl vanes. a) cylindrical screw; b) conical screw; c) laminar; d) with tangential holes.

- a - single-fuel with swirl vane, rolled in the casing;
- b - single-fuel, one piece;
- c - single-fuel with insertable dome, rolled in the casing;
- d - two-fuel, one-piece;
- e - two-fuel, combined.

In each of the enumerated injectors they usually make two or four tangential entrance holes. Parts of combined injectors are connected by soldering or flaring. The process of manufacturing injectors of the given type consists mainly of automatic and turret lathe operations.

Screw swirlers are the most diverse in construction. Twirling of the flow of liquid fuel in them is created by a special swirl vane worm conveyer, having on its external surface screw channels. The simplest designs of this type of injectors consist of a casing, a worm conveyer and fastening parts (injector of liquid-fuel rocket engine). More complicated in construction are injectors of GTE (gas-turbine engines) consisting of a casing, a swirl vane, an atomizer, a protective cap and fastening parts. The casing in these injectors is an intermediate link, connecting the connector pipe of the pipeline with the atomizer. Fuel from the connector is fed to the swirl vane and atomizer through holes, drilled in the casing of the injector, or through special tubes, connected to injector by welding or soldering. There exist two types of screw swirl vanes - cylindrical and conical.

In Fig. 10.3 there are presented the following constructions of screw injectors:

- a - with a pressed worm conveyer;
- b - with finishing of worm conveyer by flaring edges of the injector casing;
- c - with pin bracing of worm conveyer;
- d - with finishing of worm conveyer by a rolled header, having a hole for entrance of the fuel component.

Manufacture of casings of these injectors hardly differs at all from manufacture of casings of tangential injectors. In most cases

they are also worked on automatic turret lathes of increased precision. A cylindrical worm conveyer is prepared by rolling; the conical one, by turning.

Combined injectors constitute a type of injector, in which atomized fuel is combined by principle of action of types of injectors given earlier. This type of injector basically unites two-component injectors of both internal and external carburation. Combined injectors are applied in the following two forms (see Fig. 10.4):

a - combining the principle of atomizing screw injectors and swirlers with tangential entrance;

b - combining principle of spraying of spray injectors and swirlers. This form of injector is applied mainly in engines for which one component is given in liquid, and the second is in gaseous state.

Features of manufacture of combined injectors are basically the same as for injectors, whose principle atomizing found application in this type.

Basic technical requirements presented to injectors of all types boil down to guaranteeing of fineness and homogeneity of atomizing of fuel, assigned shape and distance of atomizing flame and the required norm of fuel flow through the injector under a specific pressure.

In assembled form injectors should be mutually interchangeable. Fulfillment of these conditions depends on accuracy and quality of manufacture and assembly of injectors. Parts of injectors are prepared by 1st or 2nd accuracy class; cleanness of working of external surfaces of injector casings is 5th class; passage holes should not be below 7th class. Every injector is separately checked for carrying capacity and uniformity of distribution of fuel by

cross section of the cone, for angle and quality of fuel atomizing. Welded injector casings are tested for airtightness.

Parts of injectors are prepared chiefly from bars. Spray injectors are made from 1Kh18N9T and BrKh08. Two-component injectors are made from 1Kh18N9T. For manufacture of casings of working injectors of GTE's they apply steel 20 with subsequent coating with heat-resistant enamel, steel 38Kh and others; casings are cast from ZhS3. Separate parts of injectors, for instance, nozzle, atomizer, and others, are made from steel KhVG, 1Kh18N9T.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

Most injectors' parts, in form and dimensions, pertain to class of automatically-revolving parts. Below are plans of model technological processes for basic parts of injectors: casings, screw swirl vanes, tangential atomizers, and also the technology of mass production of spray injectors.

Technological process of working the casing of a two-component injector for a liquid-fuel rocket consists of the following basic operations:

1. Working of external and internal surfaces on automatic turret lathe.
2. Working of external and internal surfaces of injectors on the other side on a turret machine.
3. Drilling of intakes.
4. Deburring.
5. Washing.
6. Inspection and testing.

During manufacture of screw swirlers or combined injectors there is additionally produced forming of worm conveyer by pressing

or flaring, of edges of the injector casing.

The casing of a two-duct GTE injector (Fig. 10.6) is the intermediate link, connecting the connector pipe and atomizer. It

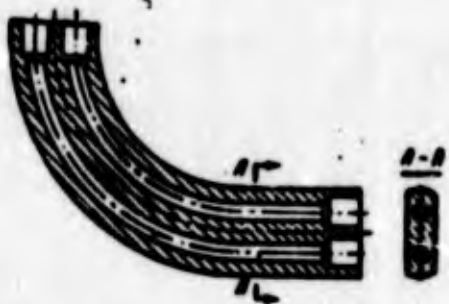


Fig. 10.6. Casing of two-duct welded injector.

has a bent profile with two ducts. With the connector pipe and atomizer casing it is connected by a special collar and

fastened by welding. The casing is made from bars (steel 20) and is coated by

heat-resisting enamel, protecting it from the corrosive influence of gases. Accuracy

of working is 3rd class; nonparallelness of

holes is 0.1 mm; nonperpendicularity of end surfaces ± 0.2 mm. Clean-ness of working of external and internal surfaces is 4th class.

Working of such a casing consists of the following operations:

1. Machining and cutting of dimensional blanks from a bar.
2. Centerless grinding of blanks.
3. Milling of base surfaces.
4. Drilling of holes of through ducts.
5. Bending.
6. Milling of face surfaces.
7. Counterboring of passage holes from two sides for bushings.
8. Milling of lateral surfaces.
9. Milling of chamfers.
10. Benchwork stripping.
11. Assembly.
12. Welding.
13. Inspection and testing.

The tangential atomizer is made from steel KhVG; the blank is a bar. Construction of technological process anticipates two stages

of working; preliminary up to heat treatment and final after heat treatment. Final working consists of operations of precision finishing of passage holes and face surfaces of the atomizer. These operations require accuracy of execution, are very labor-consuming and up to now have been little mechanized.

Working of atomizer may be done in this sequence:

1. Automatic working.
2. Turret lathe working on the other side.
3. Drilling of six tangential holes.
4. Heat treatment.
5. Finishing of holes (tangential).
6. Grinding of faces.
7. Grinding of external diameter.
8. Finishing of faces.
9. Polishing of sharp edges.
10. Oxidizing.

Cylindrical screw swirl vane (see Fig. 10.5a) is prepared from a bar of steel (1Kh18N9T). There are two variants of manufacture of the helical surface of the worm conveyer: cutting of screw grooves by a thread-cutting head by round chasers and rolling of them by knurls.

Technological process is constructed in accordance with applied method.

For first variant:

1. Working on top and cutting of screw grooves on automatic turret lathe.
2. Benchwork deburring.
3. Grinding of face surfaces.
4. Washing.

5. Inspection.

For second variant:

1. Cutting of bar into dimensional blanks.
2. Centerless grinding.
3. Knurling of screw grooves.
4. Cutting of knurled blanks into separate parts.
5. Grinding of face surfaces of parts.
6. Washing.
7. Inspection.

In large-lot and mass production the second variant of flow is the most expedient, since it is more productive and economical than the first.

§ 3. FULFILLMENT OF BASIC OPERATIONS OF
PRODUCTION OF INJECTORS

Casing of Two-Component Injector of a
Liquid-Fuel Rocket Engine

Working of external and internal surfaces of an injector casing from a bar is usually done in two operations. In first operation on automatic lathe they turn external surfaces, and central hole is drilled and counterbored. In the second operation they machine the hole and cut the face on the other side on turret lathes. For working of injectors parts there are applied, mainly, single-mandrel automatic turret lathe of type 1A124, 1A136 and high-speed turret lathes 1P326, 1340A, etc. High productivity and quality of working of parts depends on correctness of adjustment of automatic and turret machines. Sample diagrams of adjustment of machines for working injector casings are shown in Fig. 10.7.

Working of intake and tangential holes in injector requires especially careful fulfillment. During drilling of tangential holes

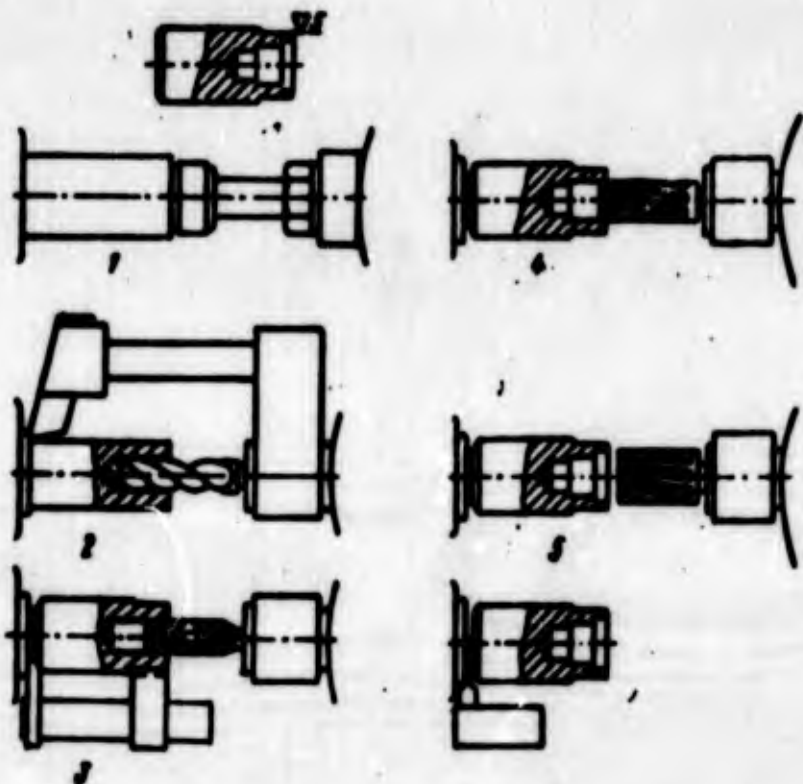


Fig. 10.7. Working the casing of a two-component injector on an automatic turret lathe.

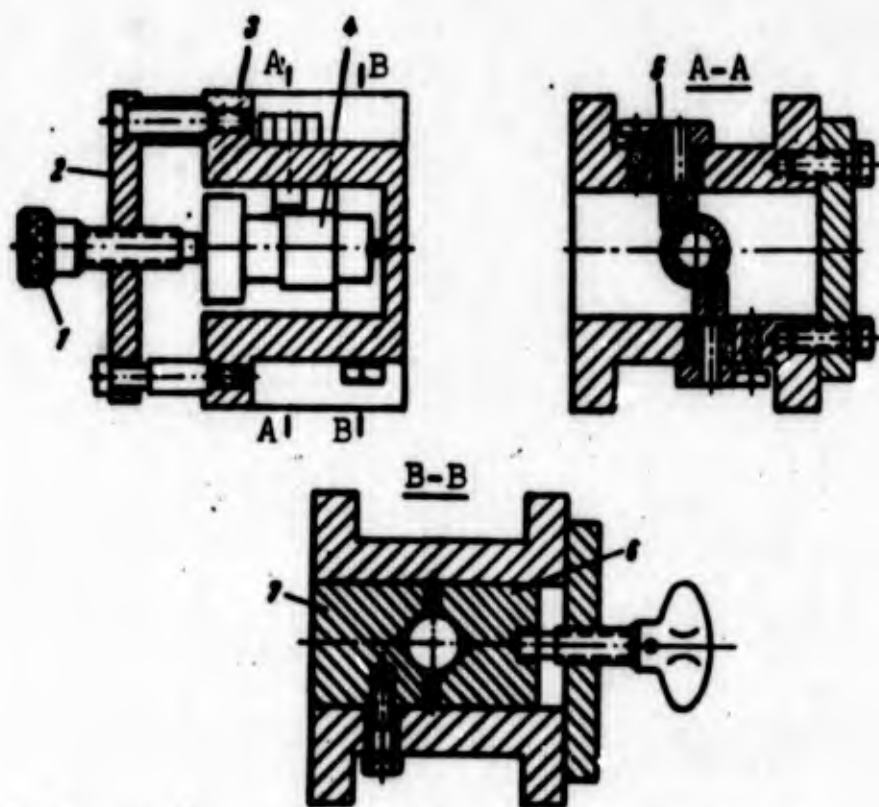


Fig. 10.8. Jig for drilling tangential holes in an injector. 1) clamp screw; 2) hold-down; 3) casing; 4) processed part; 5) jig bushing; 6) mobile prism; 7) fixed prism.

it is necessary that there is ensured emergence of these holes strictly on tangent to the generatrix of the surface of the central hole. This is achieved with the help of a jig, a model construction of which is shown in Fig. 10.8. The jig permits drilling of all tangential holes from one installation. Exact centering of the injector in the jig is achieved by prismatic adjusting elements. To avoid frequent breakings of drills during drilling of tangential holes the end surface of the jig bushing is carried out on a radius, embracing the external surface of the injector. Operation of drilling can be carried out, for

instance, on a high speed table drill of type NS-6 or on vertical boring high speed semiautomatic machine designed by NIAT [Scientific Research Institute of Technology and Organization of Production]. On this machine to increase stability of drilling there is provided a special device for imparting to the tool vibration oscillations in the direction of feed. Amplitude of vibrations (with smooth adjustment) is selected, depending upon the diameter of the drill and the magnitude of feed, in range 10-100 μ .

Casing of GTE Injector

Machining of the bar and cutting of it into dimensional blanks is produced on lathes or on multi-spindle automatic cutting lathes of type 1240-4, 1240-6. Machining on the top is produced with allowance for grinding of 0.2-0.3 mm on diameter. External surface is ground on a centerless-grinding machines, ensuring cleanness of surface of 6th or 7th class. In large-lot production for centerless grinding there are applied machines, equipped with sub-adjusters and hopper-type loading devices, automating the process of working. Automatic sub-adjustment is carried out periodically upon deviation of dimensions of parts from a norm.

Drilling of deep holes of small diameter in the casing of two-duct injector is the most labor-consuming operation and can be executed either in a jig on a table drill, or on a turret lathe in a special fixture. Working of holes by second variant ensures greater accuracy since in this method of working there does not occur large withdrawal of the drill and one comparatively easily attains required parallelness of holes. Besides these methods, holes can be worked by electro-erosion; however, when working steel 20, this method turned out to be less productive as compared to drill by an ordinary spiral drilled.

Bending of injector casing is produced on hydraulic or eccentric press in a die in a cold state. Plane of bending is in the same plane as the base surfaces, relative to which previously worked holes are oriented. Angle of bend is 90° , and face surfaces of both ends of the casing should be mutually perpendicular in the plane of bending.

End surface of the injector casing are milled after bending on horizontal mill in two transitions in a special fixture of vise type,

ensuring mutual perpendicularity of end surfaces. The same method of installation is applied during working of holes in ducts for centering sleeves (Fig. 10.9).

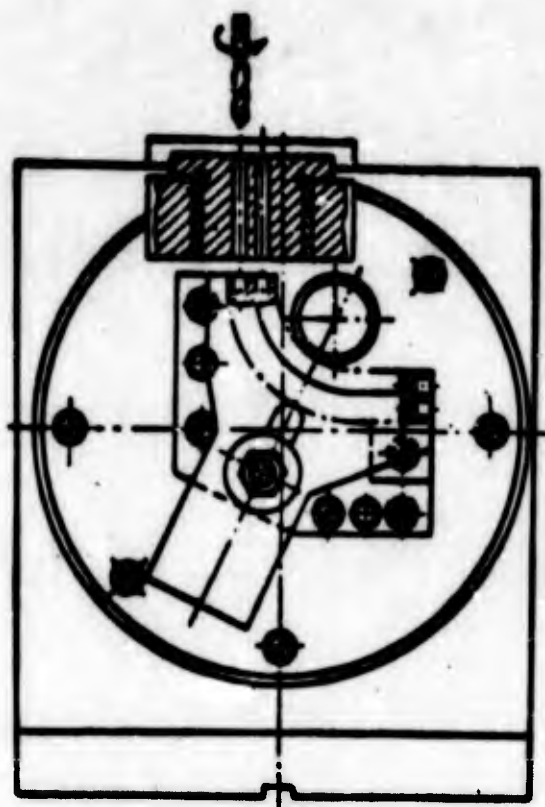


Fig. 10.9. Drilling and counterboring of four holes in the casing of a two-duct injector.

Lateral surfaces are milled on two sides simultaneously by two milling cutters on a horizontal mill with supply "on passage." The part is set on one of its end surfaces with fixation by a hole. Chamfers on end surfaces for welding are milled by angular milling cutters at an angle of 35° in the same fixture with two settings, with fixing of the casing

also by holes and with support on the end of the injector casing.

Assembly and welding of the injector casing (Fig. 10.10) is produced after benchwork deburring and coating with anti-corrosive covering in a special fixture. Installation of part is carried out by cylindrical surfaces. Position of parts during assembly is determined by clamps and an adjustable rest. Assembled parts are pressed together by a screw with the help of a hold-down. Two methods

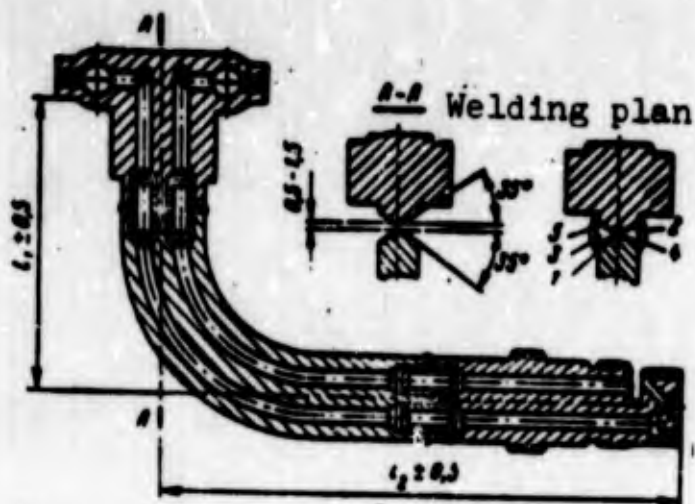


Fig. 10.10. Diagram of welding of the casing of a two-duct injector. 1-5) order of applying seams.

of welding are applied: atomic-hydrogen by a gas burner and argon arc electric welding by a nonconsumable electrode with addition material. Requirements on quality of welding are high. Cinders in the cavity of ducts, blisters, nonfusion, crack, and other surface flaws in welding seams are not allowed. Besides external inspection and check of quality of welding, suitability of assembly of the injector casing is controlled by a check of dimensions (see Fig. 10.10). In the checking operation there is anticipated a check of airtightness of the casing by circulation of kerosene, dye with paint "Sudan," through passage ducts of the casing.

Atomizer

External and internal surfaces of the atomizer, the nozzle ring, swirl vane and other small parts of GTE injectors, are worked on automatic precision turret lathes, giving with correct setup a high accuracy class.

Tangential holes are drilled in a jig on a high-speed vertical drill. The base is the external surface with rest on an end. After benchwork stripping the part is subjected to hardening.

Finishing of holes of the atomizer after heat treatment is produced manually with the help of hard uncharged laps with paste of GOI. The lap is rotated. For mechanization of operation there is anticipated application of semiautomatic multi-spindle machines, which at present are in the stage of development.

End planes of the atomizer are lapped on a cast-iron plate with

paste GOI. Parts are assembled in a holder and are first lapped on one, and then on the other side. For lapping there is applied a special lapping machine for one-sided lapping of ends. To increase productivity of working at present they are developing a special semiautomatic flat-lapping machine for lapping end planes of injectors parts simultaneously from both sides.

Swirl Vane

A cylindrical worm swirl vane by one of variants of technological process is worked on single-mandrel turret lathes automatic of type 1112, 1A124, and others. Screw grooves of worm conveyer will be cut by a thread-cutting head "2KA" or "2K" by round screw dies.

Of greatest interest is the second variant, one of the basic operations of which is knurling of screw grooves. Knurling of grooves is produced after external centerless grinding of blanks. Dimension of diameter of blank for knurling is determined by the formula

$$D = d_0 k,$$

where d_0 - average diameter of profile of screw grooves of the worm conveyer;

D - diameter of blank;

k - correction factor ($k = 0.95$).

Diameter of blank is maintained during grinding in 2nd accuracy class.

Screw grooves are knurled on general-purpose thread-cutters of type RN-10K by knurls with annular or screw thread of profiling grooves. The most effective method of knurling screw grooves of worm conveyers with blank length of 100 mm and more is knurling by knurls with annular threading of profiling grooves, since with this method diameter of knurls does not depend on diameter of the knurled blank and can be comparatively small; knurls with annular threading

are considerably narrower than knurls with screw thread, as a result of which the force required to form the screw groove is much less than during analogous work with wide knurls with screw thread. During work with knurls with annular threading axes of knurls are set relative to the blank at an angle, corresponding to the angle of ascent of the screw grooves. The blank is fed into the intake section of the knurls. Knurls rotate the blank, and it, tightening itself, is screwed in their annular turns. Calibrating turns of knurls give to profile of grooves their final geometric form. A diagram is given in Fig. 10.11. Cleanness of surface of profile of grooves after knurling corresponds to 7th class.

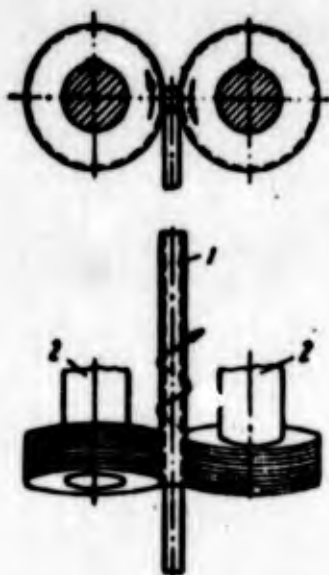


Fig. 10.11. Diagram of knurling of screw grooves of a screw swirl vane. 1) blank; 2) knurls.

Duration of operation is 1-1.5 minutes. The obtained blanks are cut into separate parts. End surfaces of worm conveyers are ground. Operation of grinding is executed on a surface grinding machine, where parts are placed on the plate of the magnetic table of the machine in a special frame.

Holes with parallel axes are drilled on semiautomatic high-speed table drills in a jig simultaneously in several parts.

On the same machine they drill slanting holes. The part is established in the jig by its external cylindrical surface resting on an end at an angle to the horizontal axis, equal to the angle of inclination of holes. The jig bushing by its chamfered end tightly approaches the end surface of the swirl vane and ensures during drilling of slanting holes the necessary direction, protecting tool from breaking.

Planes of swirl vane are finished after heat treatment

preliminarily on a flat-lapping machine with fine-grained abrasive paste and finally, after finishing of slanting holes, on the same machine with paste GOI.

§ 4. AUTOMATION OF PRODUCTION OF FUEL INJECTORS

Fuel injectors are among mass parts applied in engines in large quantity. Thus, for instance, in one liquid-fuel rocket engine there are placed several hundreds of spray injectors; in an air-breathing jet engine there are 100-200 screw and others types of injectors. Therefore, even with a small volume of production of aircraft engines automation of technological processes of manufacture of injectors is profitable. Especially broad prospects of automation of working of injectors are opened in connection with works conducted on unification of constructions of injectors and standardization of technological processes. Automation of working of injectors is conducted in two directions: partial automation of separate highly labor-consuming operations and overall automation, embracing into the whole technological process with application of transfer machines or machine-combines. The greatest possibilities for automation of working are presented by spray injectors. They are more numerous, simpler in construction and in character of working yield easily to standardization of the technological process, which is especially important for creation of transfer machines. Especially great prospects for automation of working of injectors are promised by introduction into production of rotor transfer machines. A peculiarity of rotor lines is combination of working of blanks with their transportation, as a consequence of which the flow of working on these lines is carried out continuously. A fundamental scheme of a rotor transfer machine is shown in

Fig. 10.12. It consists of a mechanism of automatic loading, feed rotor 2 and operation working rotors, control and transport rotors 4. Every rotor is an independent automatic rotor machine, consisting of drive 1 and blocks 3 with tools, moved by tracers. Depending upon the complexity of construction and accuracy of the injector the rotor transfer machine usually consists of 6-10 operation working rotors and approximately the same number of conveyor rotors. Besides rotor lines, for working of injectors they can successfully use transfer machines, arranged from special machines and automatic machines of general usage. Application of such machine as compared to operation manufacture of injectors gives considerable economy. As an example we can take the transfer machine for working spray injectors (Fig. 10.13). As the basis of the design there is a transfer machine for working the heel of a micrometer, developed by "Orgstankinprom" [State Design, Technology and Experimental Institute (Organization of Machine-Tool and Instrument Inductor)] and introduced at the Moscow plant "Kalipr."

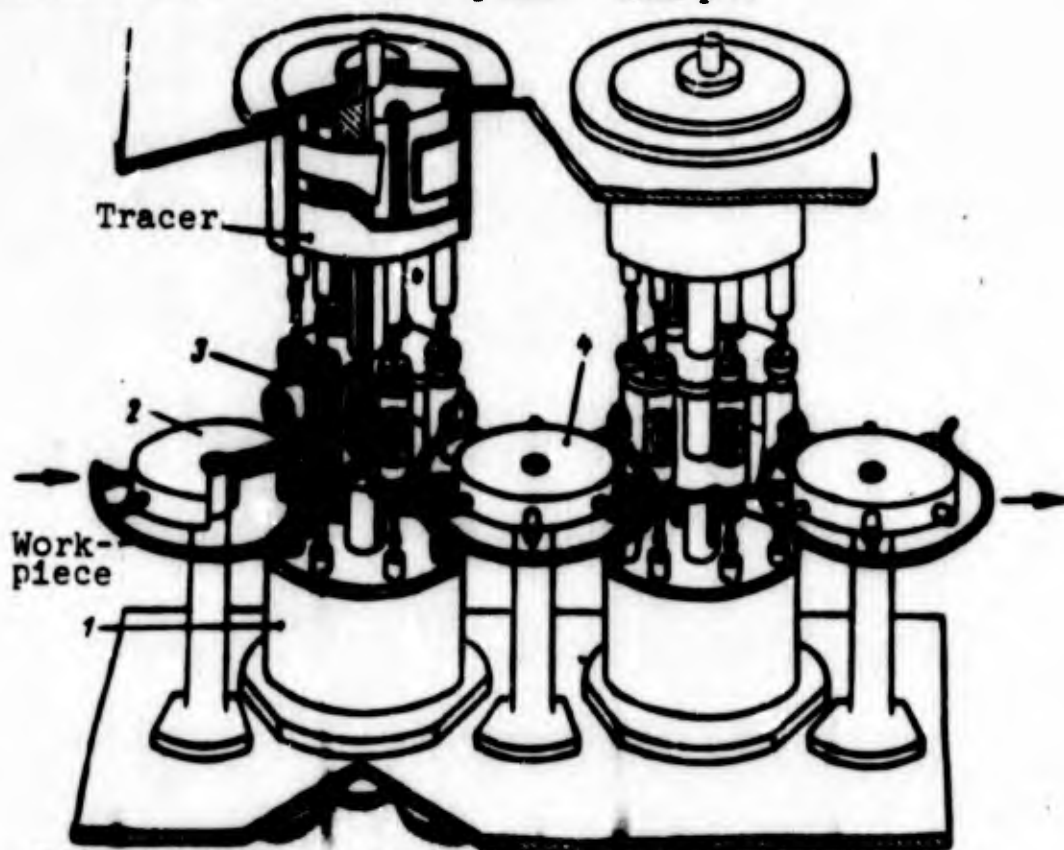


Fig. 10.12. Diagram of rotor transfer machine.

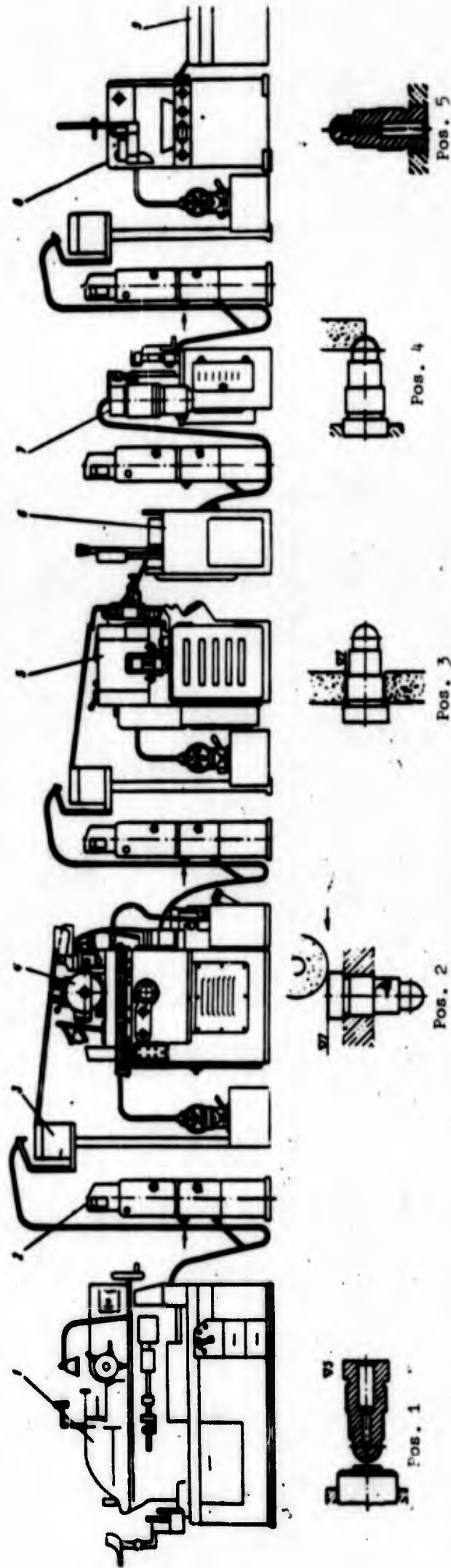


Fig. 10.13. Diagram of transfer machine for working spray injectors. 1) automatic turret lathe 11712; 2) pneumatic conveyor; 3) vibration hopper; 4) automatic end-grinder on SKB-3; 5) centerless grinding machine 3G132; 6) subsetter; 7) automatic sphere-grinder; 8) semiautomatic electric spark machine EP-5M for edging holes; 9) automatic checker.

On transfer machine there is provided execution of the following operations:

1. Working of central hole, machining on top and cutting. Time of working - 112 sec. In duration this operation limits productivity of transfer machine; therefore, arrangement of line provides the automatic machines working on this operation in parallel.

2. Grinding of end from the cutting side. Productivity up to 300 pieces an hour.

3. Centerless grinding of external surface.

4. Grinding of spherical end.

5. Piercing of spray holes.

Vibration hopper in centerless grinder of a capacity of 400-600 parts is mounted on a separate column and is activated by electro-magnet. Productivity of hopper is regulated by rheostat. Spiral tray of hopper has a section in the form of an arc of circumference, thanks to which blanks are arranged by axis of symmetry along the tray. Loading device is mounted on a support of the machine and is activated by a hydraulic cylinder. It is intended for automatic piece-by-piece supply of blanks to working zone and for direction of worked parts to the under setter for inspection.

Process of grinding of the spherical end includes preconditioning by grinding sandpaper with transverse shift of the part, finishing on the edge of a grinding belt without transverse shift and finishing by a felt wheel. During treatment the part is rotated around axis of symmetry and rocking about an axis, passing through the center of the sphere perpendicular to the axis of rotation. The length of the working cycle on the machine is 15-20 sec.

Broaching of atomizing holes of diameter 0.15 mm is produced on semiautomatic electric spark machine EP-5M in a special turning jig,

placed in a bath with kerosene. A steel jig sleeve with diameter of

working hole 0.15 mm is pressing in textolite intermediate sleeve which is insulation. The electrode brass wire of diameter 0.125 mm is automatically fed by rollers according to deepening in the hole. The moment termination of broaching each hole is fixed by a polarized relay, locked through and intermediate relay with the electrode feed and turning jig mechanisms, as a result of which after broaching of a hole the part can automatically turn an assigned angle for broaching of the following hole. Wire electrode from brass LS59-1 is fastened in a special head (Fig. 10.14).

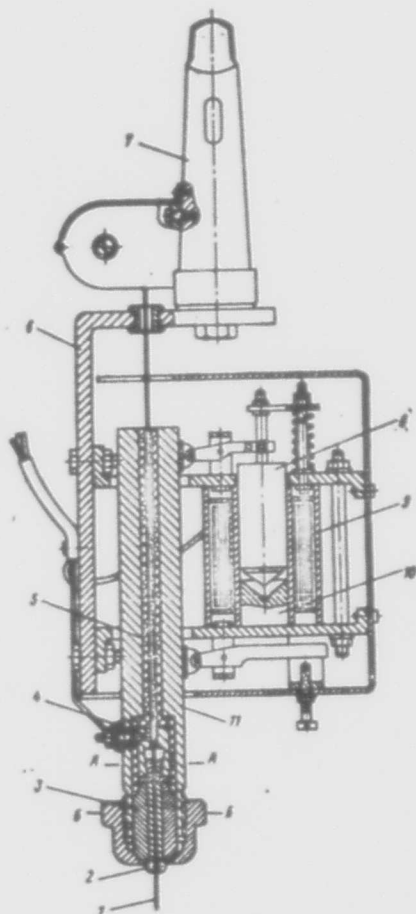


Fig. 10.14. Electric spark head for broaching holes of small diameter. 1) electrode wire; 2) rudy tip; 3) jig; 4) terminal; 5) insulation; 6) casing; 7) shank; 8) mobile core; 9) electro-magnet; 10) fixed core; 11) rod.

The end of the electrode has a conical form. Length of cone is approximately 0.2 the depth of the broached hole; conicity $K = 0.25 d/1$; cylindrical part of electrode is the calibrating part. During broaching the calibrating part of the electrode enters the nozzle chamber and ensures obtaining

of an exact cylindrical hole. The electric spark machine is equipped with a vibration hopper and automatic loading mechanism. Parts are fed into the working zone by a manipulator.

For conveying blanks from one working point to the next on a

transfer machine there is applied a pneumatic conveyor device. It consists of a pipeline, equipment for preparation and periodic supply of compressed air and command apparatus, controlling work of the equipment.

Pneumatic conveyor of the line permits carrying out autonomous connection of each pair of automatic machines. Pipeline between each pair of automatic machines consists of three sections: initial, where transported part moves under action of its own gravity; the main one, where the part is moved by compressed air; and a final one, within which there occurs deceleration of the transported parts. Pipeline begins with a receiver, carried out in the form of a conical funnel with fairly steep walls, smoothly passing into a cylinder. In order to decrease friction and prevent obstruction of tubes, initial and final sections of pipeline are made from steel rods, evenly located on a circumference, whose diameter is 1.5-2 mm larger than external diameter of a part. Basic sections of pipeline are made from segments of copper pipes (All-Union Government Standard 617-53). Compressed air is fed periodically only for the time of passage of parts through the pipeline, where several parts are immediately transported.

Accuracy of manufacture of injector is checked by a monitoring (flow-through) automatic machine, built into the transfer machine. Fitting diameters are checked by electric-contact heads (Fig. 10.15); accuracy of manufacture of holes with respect to eccentricity are checked by optical instrument with a photocell. Upon deflection of light beam from one of the holes, indicating incorrect position of axis of this hole, intensity of illumination of eyepiece of photocell is lowered and the latter gives the signal for rejects. Rejected injectors are rolled by tray into a box of

of rejected parts. Injectors, suitable as far as eccentricity of holes, proceed to flow-through.

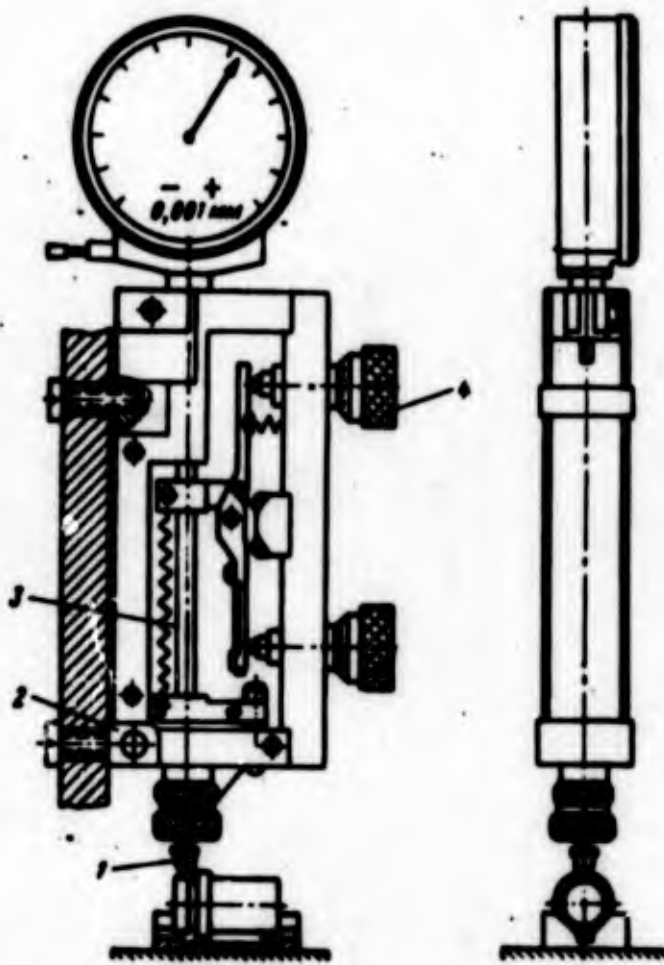


Fig. 10.15. Control of fitting diameters of injector with help of electric-contact measuring head. 1) measuring tip; 2) casing; 3) spindle; 4) tuning screw.

§ 5. INSPECTING INJECTORS

Accuracy of manufacture of the diameter of injector holes is checked by flow-through. To check remaining geometric dimensions of injector there is applied inspection by sampling. Flow-through is produced by water and by measurement of equivalent flow rate of water, passed through the injector per unit time, there occurs rejection of parts not meeting technical requirements on productivity.

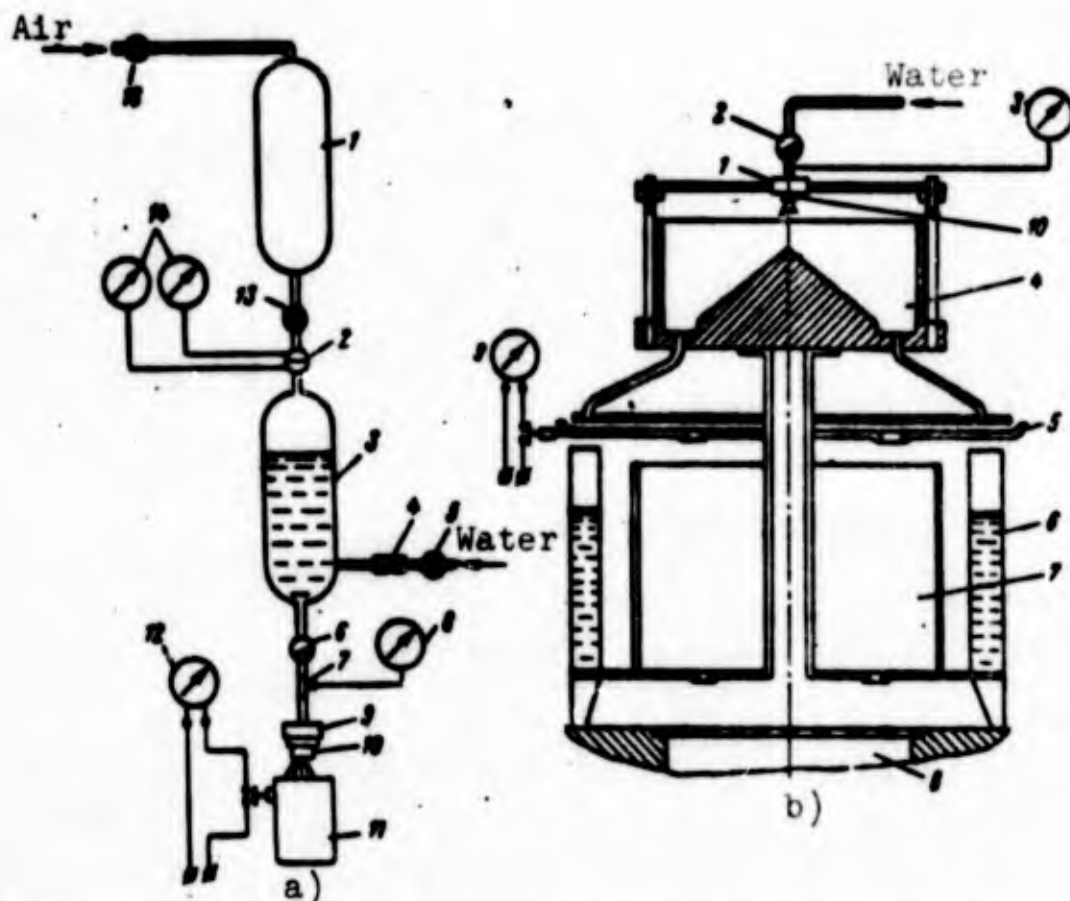


Fig. 10.16. Diagrams of flow-through stands for testing injectors. a) gravity stand; 1) air bottle; 2) filter; 3) water bottle; 4) valve; 5) throttle cock; 6) reductor; 7) tee; 8) manometer; 9) attachment of installation of injector; 10) block of injector; 11) tank; 12) stop watch; 13) valve; 14) manometers; b) stand for checking uniformity of uniformity of atomizing; 1) attachment for fastening of injector; 2) choke cock; 3) monometer; 4) intake with sector; 5) cut off; 6) measuring tank; 7) body of installation; 8) drain tank; 9) stop watch; 10) injector.

Check of productivity and quality of atomizing of two-duct injectors is produced on a special flow-through stand, whose scheme is shown in Fig. 10.16. Pump unit of stand ensures flow-through of all forms of injectors with flow rates up to 400 g/sec and with pressure 12-30 atm ($\approx 12 \cdot 10^5$ to $30 \cdot 10^5$ newton/m²). Two-duct injector passes through two check stages; first there is produced circulation of casing of injector by kerosene, then after washing of parts and assembly the injector is tested on a flow-through (gravity) stand. Tests consist of these operations:

1. Check of angle and quality of fuel spraying.
2. Check of irregularity of spraying of 1st cascade.
3. Check of productivity of 1st cascade.
4. Check of irregularity of spraying during simultaneous work of 1st and 2nd cascades.
5. Check of productivity during simultaneous work of 1st and 2nd cascades.

Testing of injectors if produced by kerosene T-1 with density $0.8-0.85 \text{ g/cm}^3$ at 20°C . Diagrams for checking the angle and uniformity of spraying are shown in Figures 10.17 and 10.18.

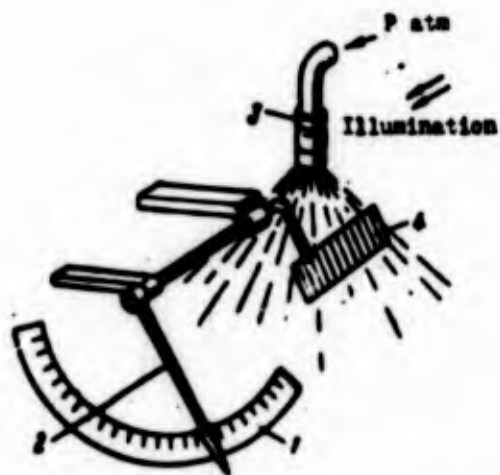


Fig. 10.17. Diagram of checking the spray angle of an injector. 1) dial; 2) indicator; 3) injector; 4) plate, established on generatrix of spray cone.



Fig. 10.18. Diagram of checking uniformity of spray of an injector. 1) drain tank; 2) injector; 3) separate sector; 4) measuring glasses.

CHAPTER XI

MANUFACTURE OF PIPELINES, FLEXIBLE HOSES, AND BELLOWS

§ 1. MANUFACTURE OF PIPELINES

The pipelines employed in engines, according to their purpose, are divided into pipelines of the fuel system, cooling, lubrication, the electrical system, and gas pipelines. With respect to form, dimensions, and methods of connection, pipelines are distinguished by their large variety. They are straight and bent, corrugated and smooth, long and short, thin-walled and thick-walled. According to methods of connection, pipelines are classified as: without fittings and seals, with grooved ends, with expanded ends and fittings, with welded nipple-nut fittings, with welded sleeves, flanges, and lugs. Figure 11.1 gives the classification of different forms of pipelines.

The technical requirements presented to pipelines are determined by the conditions of their work. Pipelines of hydraulic and fuel systems of aircraft engines work in the most difficult operating conditions. They are subjected to vibration loads and experience high variable stresses as a result of pulsations of liquid pressure, hydraulic shocks, with the change of the engine rating, and also under cavitation operating modes of pumps, and others. The basic technical requirements for pipelines of hydraulic and fuel systems reduce to the guarantee of airtightness and reliability of connections.

On the surface of pipes, especially in places of bending and in the zone where the fittings are attached, there should be no fissures, hairline cracks, deep scratches, and nicks noticeable to the naked eye. Welded seams must be tight, without cavities and poor penetrations. Testing for airtightness of hydraulic and fuel systems is produced at a pressure that exceeds the working pressure by 1.5 to 2 times. Technical specifications for pipes supplied by the USSR are regulated by GOST standards.

Group	Subgroup	Type		Without fittings and seals on ends	With grooved ends	With expanded ends of fittings	With welded fittings: nipple, nut	With welded sleeves, flanges, and lugs
		Character of manufacturing process						
Straight				Type 1 	2 	3 	4 	5
	$d \geq 16 \text{ mm}$, $R \geq 2.5 d$ with straight sections	On pipe-bending machines		6 	7 	8 	9 	10
Bent	$d = 10 \text{ mm}$ $R \geq 2.5 d$	Manually	Without filler without preheating	11 	12 	13 	14 	15
	$d = 16-25 \text{ mm}$ $R \geq 2.5 d$ without straight sections	Manually	With filler without preheating	16 	17 	18 	19 	20
	$d \geq 16 \text{ mm}$ $R = (1.5 \text{ to } 2.5) d$ $R \geq 2.5$ without straight sections	Manually	With filler and preheating	21 	22 	23 	24 	25

Fig. 11.1. Pipelines.

The initial blanks for the manufacture of pipelines are mainly seamless cold-drawn and cold-rolled pipes. General-purpose pipes are made of steel 20 (GOST 8734-58), special-purpose pipes from stainless steel 1Kh18N9T, duralumin of brands AMgM and AMg (GOST 1947-56), copper M2, M3 (GOST 617-59), brass L62, L68, L070-1 (GOST 494-52), and others.

It is necessary to distinguish the following basic varieties of processes for the manufacture of pipelines:

first, when the pipeline is made from seamless cold-drawn or cold-rolled pipe;

second, when components of the pipeline are made from sheet materials by the method of stamping and welding;

third - manufacture of metallic flexible corrugated pipelines (hoses and bellows).

Depending upon the methods of bending seamless pipes, the sequence of operations for the production of pipelines is produced in two variants. For bending of pipes with a liquid filler, the operations of expanding the ends and welding the fittings are performed first, and then the bending operations. In case of bending pipes on a mandrel, the bending operation usually precedes the operations of expansion and welding.

A typical technological process for the manufacture of pipelines of hydraulic and fuel systems of jet engines from seamless pipes consists of the following basic operations:

1. Sectioning and facing of pipes.
2. Expansion.
3. Welding or soldering of fittings.
4. Bending.
5. Testing for airtightness and strength.
6. Washing, blowing, and sealing of pipelines.

Cutting pipe blanks. This operation can be performed by one of the following methods: hack saw, circular saw, or abrasive wheel on pendulum cutting machines, on special pipe cutters with cutting tools or milling cutters, and also in dies on presses. In large-batch production the pipe blanks are cut most frequently on pipe cutters, for instance, model S-246A of the M. I. Kalinin Moscow Plant. This machine is intended for cutting pipes with diameters from 12 to 100 mm.

Lately, a number of plants have started using anode-mechanical pipe cutting which is based on the combined electrochemical, thermal, and mechanical influence on the anode, i.e., the pipe to be cut. The cutting tool - a revolving disk made from sheet steel up to 1.5 mm thick - is the cathode. The process of anode-mechanical cutting is

GRAPHIC NOT REPRODUCIBLE

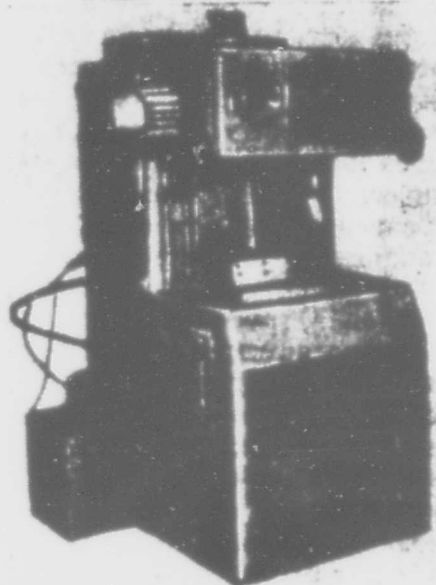


Fig. 11.2. Anode-mechanical machine for cutting pipes.

conducted in an electrolyte. The composition of the electrolyte is selected depending upon the brand of processed material. Anode-mechanical cutting employs special machines of the following types: AMO-31, AMO-32, and others (Fig. 11.2). The cutting mode for steel pipes:

direct current	
with voltage...	20-30 v
density.....	100-150 a/cm ²
working fluid..	solution of sodium silicate diluted to a density of 1.3-1.32 g/cm ³

Cutting of pipes in dies, as compared to the other methods, is a very productive method. It can be successfully employed for cutting pipes up to a diameter of 50 to 60 mm.

When sectioning pipes on pipe cutters and sectioning machines, the pipe clamps that are used must ensure perpendicularity of ends with respect to the longitudinal axis of the pipe. Perpendicularity of the plane of the end of a pipe to its axis is checked selectively by a pipe bend, 5 to 10% of a batch; the allowed deviation is not more than 0.2 mm.

Cleaning. Surfaces of pipelines are cleaned from corrosion and dirt usually before the bending operation. The most effective method is liquid abrasive cleaning which is produced on special injector-type devices or by forced feed of a semiliquid abrasive suspension by a pump. Figure 11.3 gives the diagram of an injector-type liquid-abrasive device. The abrasive suspension is pumped from mixing tank 1

through pipe 2 into jet mechanism 3 and goes to the processed surface of the pipe. The used suspension returns to the tank, ensuring a continuous work process. The suspension is fed by means of rarefaction of air in the jet mechanism from the plant's main line with a pressure of 4 to 5 atm ($\approx 4 \cdot 10^5 - 5 \cdot 10^5$ newton/m²).

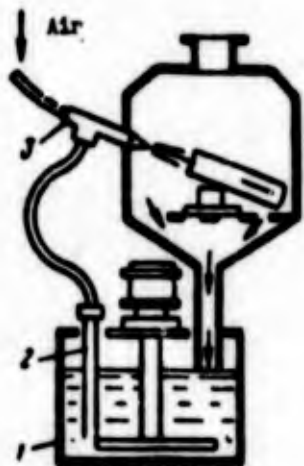


Fig. 11.3. Diagram of injector-type liquid-abrasive device.

After the liquid-abrasive treatment the steel pipelines are washed with a 2-percent solution of calcined soda. For washing pipes made from alloyed steel it is recommended to use a 0.2-percent bichromate solution or a 10-percent solution of sodium nitrite at 90-95°C.

Chemical purification of steel pipelines consists of operations of degreasing, washing, pickling, neutralization, and drying.

The solution for degreasing is 100 g caustic soda and 10 g sodium silicate solution in 1 liter of water; the temperature is 70 to 80°C; exposure is 8 to 10 minutes. Pickling is produced by a solution of 125 g HCl + 3 g pickling additive "KS" in 1 liter of water, at 40-50°C to complete removal of oxides, and neutralization is conducted with a solution of 50 g Na₂CO₃ in 1 liter of water for 5 minutes. Drying is done by compressed air at 40-50°C.

Lately, factories have been extensively employing ultrasonic purification of pipelines. The purification of pipe surfaces from scale and other contaminations employs special ultrasonic devices of the type UZA-2 (Fig. 11.4). The main parts of the device are: ultrasonic bath UZV-4 with four magnetostrictive converters PMS-8 built into its bottom; a mechanism for loading and unloading the

components and a pump unit for pumping the cleaning fluid. Purification is produced in conventional working fluids (water or kerosene). Ultrasonic oscillations are excited in the fluid with the help of the magnetostrictive converters which obtain their power from a UZG-10 generator. The converters excite elastic oscillations of high intensity and ensure the high quality of purification which is not attainable with the other methods. Steel pipes are preliminarily subjected to pickling for 2 hours.

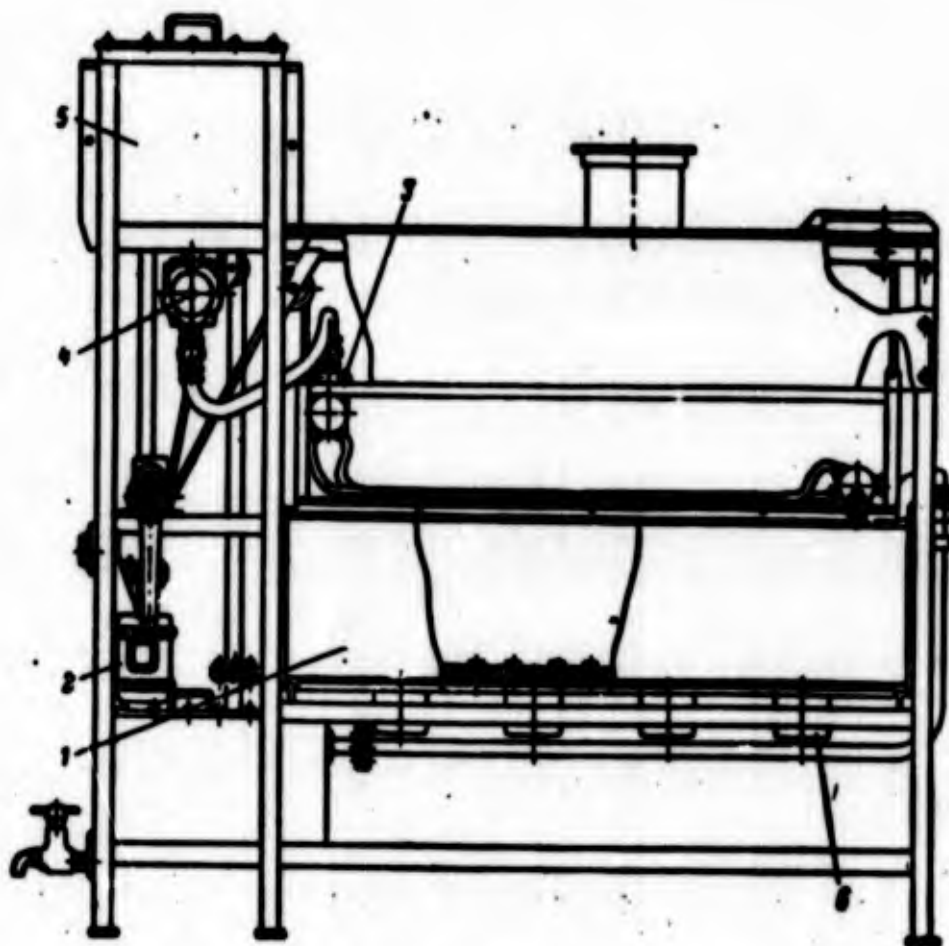


Fig. 11.4. Diagram of ultrasonic installation UZA-2 for cleaning pipes. 1) bath; 2) pump; 3) distributive collector; 4) regulating valve; 5) pressure tank; 6) PMS-8 converter.

Expansion of pipes. In fuel and hydraulic systems of flight vehicle engines for connection of pipelines, we most frequently find the use of fittings (GOST 551-569-41) in which sealing is attained by means of expansion of the pipes. On the quality of expansion in many

respects depends the operational reliability of hydraulic systems. In the zone of the expanded part there appear large residual stresses which, along with the working stresses (from vibration), may cause the formation of curved fatigue cracks which are a cause of destruction of pipelines during their use. In order to prevent the formation of these cracks, it is necessary during expansion to exactly retain the dimensions that ensure a tight connection of the pipe and nipple. A tightly fitted nipple will considerably increase the dynamic strength and vibration-stability of the pipelines. Batch production employs several methods of expansion, the most wide-spread ones being roller expansion on an expander, drill, or lathe, and punch expansion on a pneumatic or hydraulic press. For expansion of pipes on a drilling

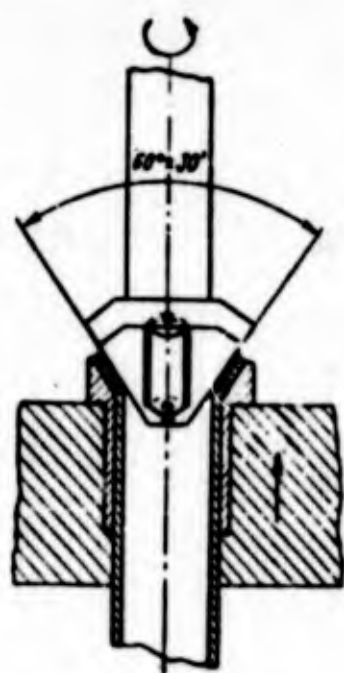


Fig. 11.5. Diagram of expansion and tool design.

machine, the roller tool (Fig. 11.5) is set into the machine arbor, and the pipe clamp is secured to the table. The pipe clamp is made with removeable clamp inserts and when it is placed on the machine the coincidence of the axis of the clamp insert hole is aligned with the line of centers of the machine.

Punch expansion is a more productive method. Punch expansion employs a special device with pneumatic drive. In this device the operation is executed in one setting because of the automatic replacement of flat and tapered punches.

Dimensions of expansion of pipes are taken according to standard 103 AT55. Thinning the pipe wall in the place of expansion is allowed up to 70% of the initial thickness.

Ridging. For connection of pipelines by means of durite hose, beads or ridges are made on the ends of the pipes on special ridging machines. The pipe is clamped in vises with removable inserts. A roller of the required profile is inserted inside the pipe eccentrically to its axis and is revolved.

Flanging of pipes. Figure 11.6 depicts the diagram of cold flanging of a pipe wall at a right angle in a die. The pipe is secured

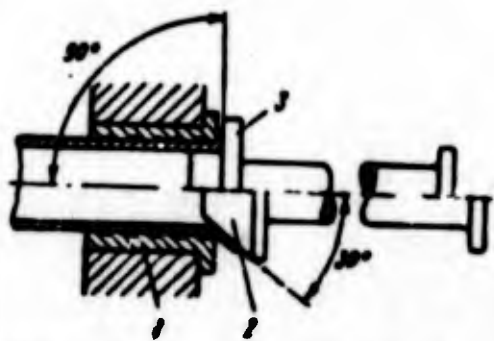


Fig. 11.6. Diagram of flanging the end of a pipe.

motionlessly in the gripper of the press with the help of two removable half-rings 1. For preventing slippage of the pipe in an axial direction under the action of considerable axial forces which appear during flanging, on the internal surfaces of the half-bushings a cut is made which cuts into its

external surface when the pipe is clamped. Flanging of the end of a pipe at an angle of 90° is produced in two transitions: in first transition the flanging is executed at an angle of 60° with punch 2, and in the second transition final flanging is done at an angle of 90° with punch 3.

Bending of pipes. Bending is one of the basic operations in the technological process for the manufacture of pipeline components. In the process of bending, the cross section of the pipe is severely deformed. In bending without a filler the cross section of the pipe is flattened and it takes on an oval form. In bending with a filler the cross section of the pipe remains circular, but has variable wall thickness. In thin-walled pipes, as a result of loss of stability, there occurs the formation of folds on the internal side of the pipe

elbow. In order to prevent loss of stability of pipes during bending (oval shape, corrugation formation), it is necessary to ensure such a stressed-state diagram in which the system of internal stresses in the pipe material, which appear during bending, would be balanced by the external pressure of the medium. Such a stressed-state diagram is ensured by feeding hydrostatic pressure inside the pipe or by the application of special bending filler-mandrels. Bending of pipes can be produced on pipe-bending machines or in dies (Fig. 11.7), and also manually on special bending devices. Selection of the bending method depends on size and technical level of production, on the material and the diameter of the pipes, and the bending radius. Depending upon dimensions, configuration, and technical requirements, bending of pipes can be carried out with a filler and without a filler. Pipes having diameter of $D < 16$ mm and with a bending radius of $R \geq 2.5D$ can be bent without a filler. With a pipe diameter of $D > 16$ mm and bending radius of $R \geq 2.5D$, it is necessary to employ a filler. For bending pipes made from aluminum alloys AMg, AMgM, and others, the filler most frequently used is river sand or paraffin. For steel pipes this sand is unsuitable, inasmuch as the forces acting on the pipe during bending are considerably larger than the resisting forces appearing in the pipe. For steel pipes, the filler employed is an emulsion which is fed inside the pipe and creates a hydrostatic pressure of approximately 200 atm ($\approx 200 \cdot 10^5$ newton/m²).

There are two possible methods of bending pipes with a liquid filling:

bending after preliminary filling by liquid under pressure and cutoff from the power source;

bending with filled liquid under pressure connected to a pump.

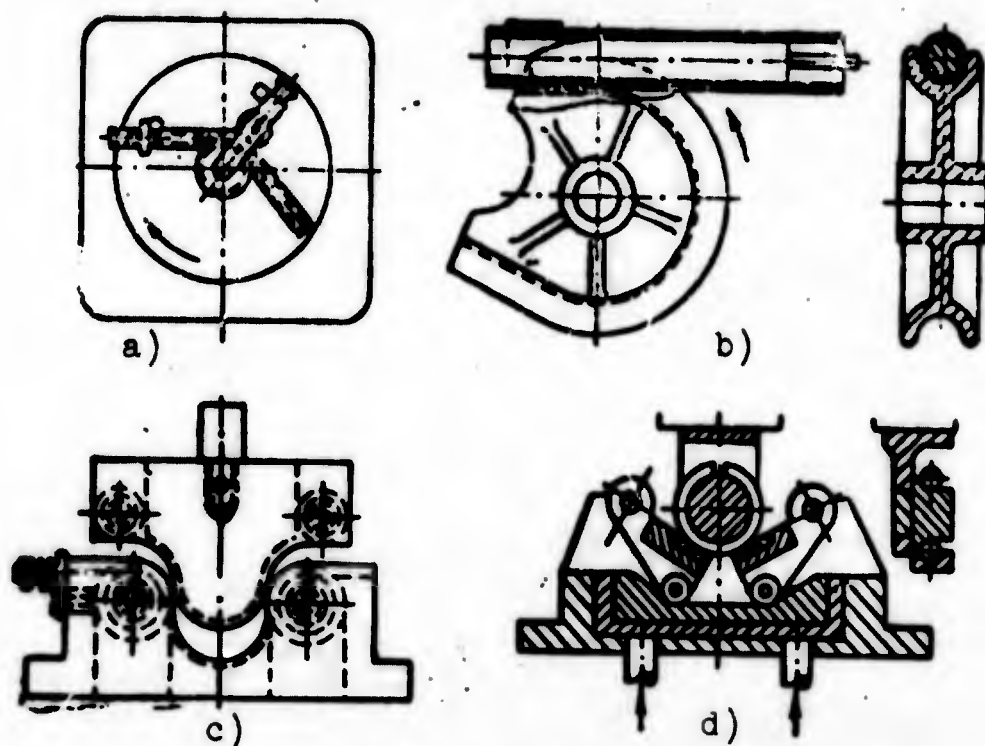


Fig. 11.7. Methods of pipe bending. a) on bending devices between two rollers; b) on pipe-bending machines with stationary mandrel; c, d) in dies.

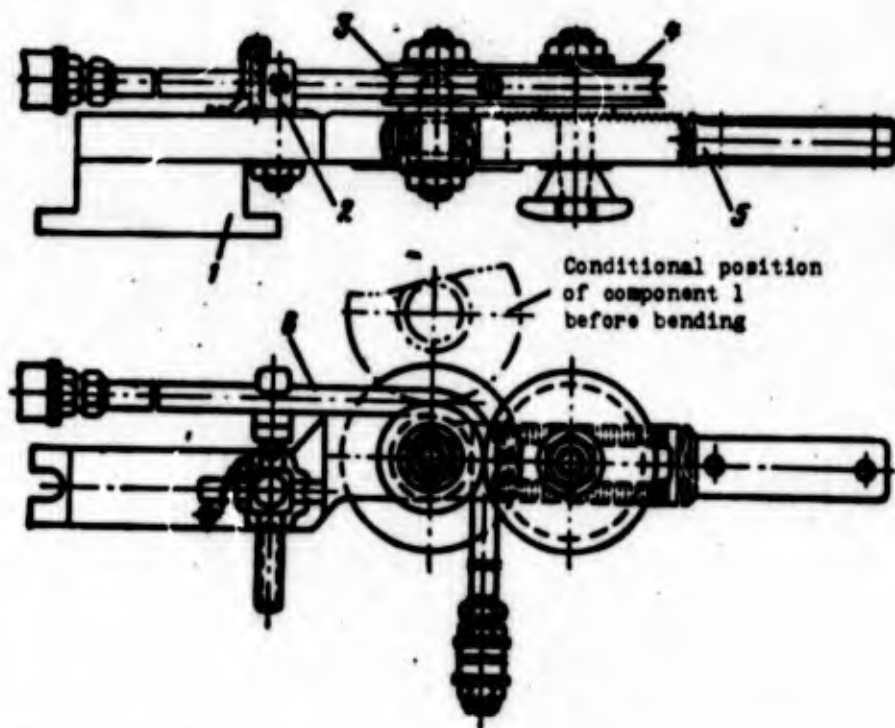


Fig. 11.8. Diagram of device for manual bending of pipes with liquid filling. 1) holder; 2) clamp; 3, 4) bending rollers; 5) handle; 6) pipe.

Figure 11.8 gives the diagram of a device for manual bending of thin-walled steel pipes of small diameter with a liquid filling. Before bending, the pipe is expanded and closed on one end by a check valve; the other end is connected to a hydraulic accumulator, and then the pipe is filled with liquid. The required pressure of the liquid is created by pressing on press. The hydraulic accumulators are preliminarily charged with air under a pressure of 200 atm ($\approx 200 \times 10^5$ newton/m²). Bending of pipes with a liquid filler complicates the technological process of manufacturing pipelines, since it requires a number of additional operations; for instance, flattening and welding of one end, expansion of the other, etc. Furthermore, at every work area where pipe bending is produced, a pump with a system for feeding the filler to the pipe is necessary. Therefore, in practice the bending of pipes on a mandrel in attachments or on pipe-bending machines is more wide-spread. In conditions of individual and small-batch production, the pipe profile is carried out on bending patterns that are made from 8-10 mm metal rods, or on pipe standards. The accuracy of pipe bending in this case depends on the qualification of the worker and the accuracy of manufacture of the patterns. Under conditions of large-batch production an improved method for bending pipes is employed. This method permits the obtainment of the required pipe profile on pipe-bending machines without the application of special wire or pipe standards.

Manual bending of pipes of small diameter in one plane with the application of a filler-mandrel can employ the device shown in Fig. 11.9. In this device the pipe to be bent is introduced into the slot between the passes of die 1 and is placed on the filler-mandrel to the stop; then, by means of turning eccentric 4, the pipe

is brought into contact with clamp 6 with such a calculation that between the pipe and the clamp there remains a clearance of 0.1 to 0.2 mm. After this, the pipe is pressed between die 1 and clamp 2 by means of eccentric 3. The pipe bend is produced by turning lever 5 clockwise. The end of the filler-mandrel is rounded around its radius

$$R = r_{BH} + S + d.$$

where r_{BH} is the internal radius of curvature of the bent pipe;

S is the wall thickness of the pipe;

d is the internal diameter of the pipe.

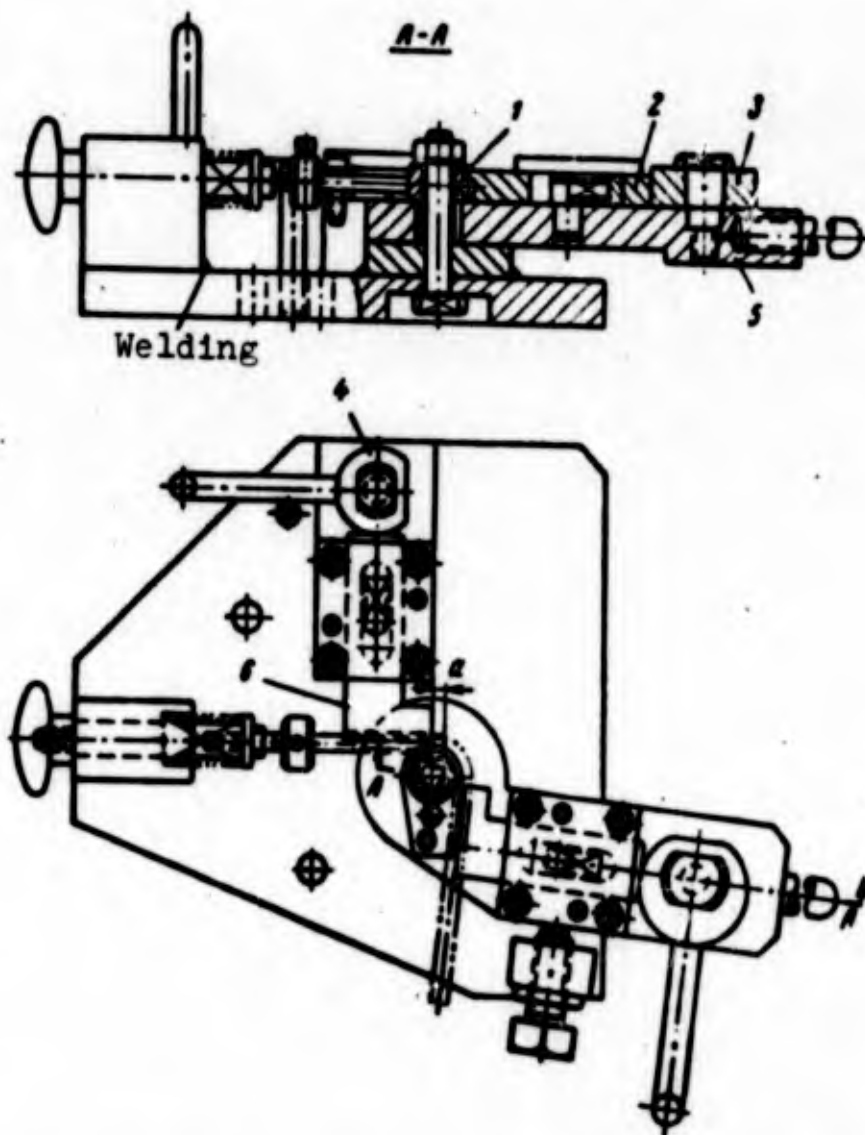


Fig. 11.9. Device for bending pipes in one plane. 1) bending die; 2) clamp; 3, 4) eccentrics; 5) turning lever; 6) clamp.

The rounded end of the mandrel (filler-mandrel) projects beyond the center of curvature of the die and is in the zone of deformation

of the tube (Fig. 11.10); as a result of this, during bending it is possible to avoid distortion of form of the cross section.



Fig. 11.10. Diagram of bending with the use of a mandrel.

For consecutive bending of pipes in different planes with diameters from 10 to 80 mm there has been

created and applied in factories of the aviation industry the automated universal pipe-bending machine TGS-2 which has hydraulic drive for the bending mandrel. It is possible to carry out pipe bending on it both in an automatic cycle, and also in transitions. Clamping and unclamping of the pipe and removal of the mandrel from the zone of bending are completely mechanized. Work of the machine within the limits of every bending cycle occurs in the following order: the pipe, pressed in a collet, is fed at a specified length and enters the groove of the bending roller. The collet is unclamped and the bending roller turns, bending the pipe at a specified angle. After bending one elbow, the carriage and bending roller return to the initial position, and the drum, on which the adjusting rests are placed, turns to one edge, and the following cycle starts. Upon completion of bending the pipe in the required directions, a milling cutter is introduced, which will cut the finished bent pipe.

For bending of steel pipes with large curvature, pipe-bending machines are applied with heating up by currents of high frequency (Fig. 11.11). The pipe is established in feeding rollers and is passed through an inductor. Upon inclusion of the high-frequency

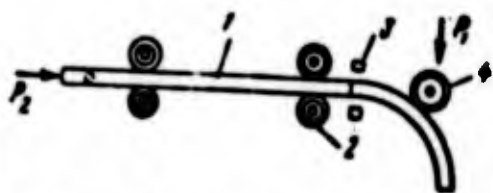


Fig. 11.11. Diagram of bending with induction heating up. 1) tube to be bent; 2) feeding rollers; 3) inductor; 4) bending roller.

generator in the zone of the inductor there occurs heating of the pipe band in the place of bending up to $900-1000^{\circ}\text{C}$. Bending of pipe occurs by means of rolling the end of the pipe by a bending roller. The bent section of the pipe is cooled by water after removal from the zone of heating. Bending of pipes with high-frequency current heating is conducted in a continuous cycle.

For obtaining qualitative pipelines one should avoid large bending curvature of pipes.

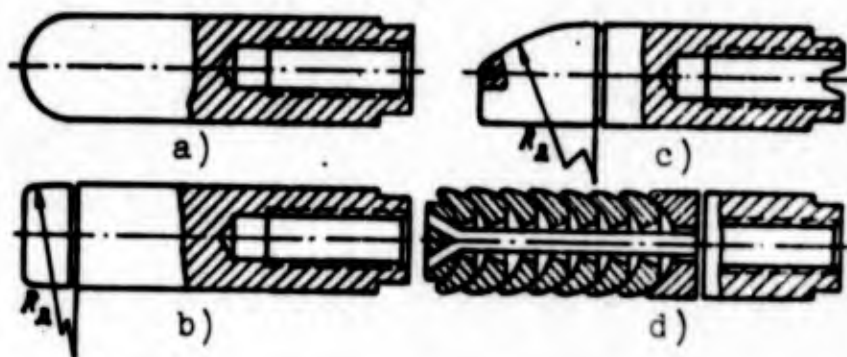


Fig. 11.12. Types of mandrels applied for cold bending of pipes. a) cylindrical; b) cylindrical, shortened; c) spoon-shaped; d) compound-hinged.

The types of mandrels are shown in Fig. 11.12a, b, c, d.

Control of bending quality. By external inspection they check for mechanical damage, scratches, dents, waviness, fissures, hairline cracks, and other visible defects, and also for ovality and thinning of the wall of the bent pipe. The diameter of a pipe after bending is measured around the small ovality axis. Thinning of the wall in the zone of bending is checked on cut samples from a batch of manufactured pipes. The quantity of pipes subjected to cutting is established by the technical specifications. Conformity of pipe

configuration is checked on a pattern or standard.

Welding and soldering of fittings with pipelines. The technology of welding pipes with fittings consists of preparatory operations, operations of welding, conditioning, and quality control of welded joints. Preparatory operations consist in division of joints and conditioning of surfaces for welding. It is necessary that the ends of the pipes be perpendicular to the axes of the pipes; sharp edges must be dulled and cleaned by sandpaper. The ends of pipes subjected to welding are polished around their external and internal diameters to a length of 8-10 mm.

The most wide-spread method for welding fittings with pipes is argon-arc electric welding which is produced in a special device by a

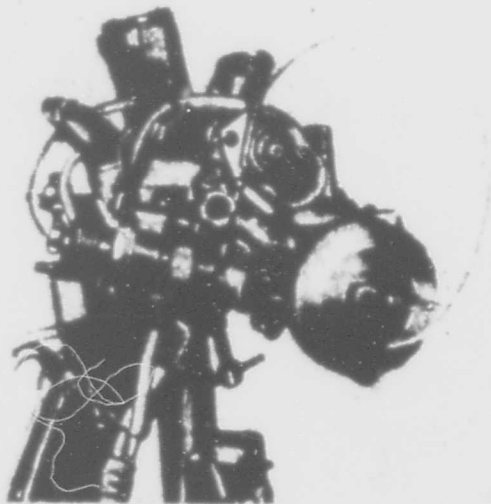


Fig. 11.13. Working zone of automatic machine for welding pipe joints.

welding burner with an infusible tungsten electrode. In the process of welding the pipeline assembled with fittings revolves, and the burner is secured motionlessly. Non-rotary pipe joints are welded by an ATV-15-40 automatic machine designed by NIAT. During welding, this automatic machine is placed on the pipe, around which the welding torch revolves during work (Fig. 11.13).

During automatic welding, the supply of additional material is produced

automatically, and the tungsten electrode moves as it evaporates.

Pipes with wall thickness more than 2 mm are made with nontapered edges. The total angle of division of edges is $45-50^{\circ}$; pipes with

wall thickness less than 2 mm are welded with fittings with nontapered edges. Before welding, the joint of the fittings with the pipe is secured in two diametrically opposed points by manual argon-arc welding with additional material. For welding of fittings with pipes made from stainless steel 1Kh18N9T filler rod made from the same steel is employed (GOST 2246-60) with a diameter of 1.2 to 1.6 mm. The diameter of the tungsten electrode is 2-2.5 mm.

Tentative Welding Modes for Steel Pipes

Welding speed.....	15-25 m/hr
Current intensity.....	120-160 amp
Voltage.....	10-12 v
Rate of wire feed.....	25-35 m/hr
Argon consumption.....	6-8 liters/min

For welding pipes made from stainless steel the protective gas employed is not pure argon, but a mixture of argon with 2 to 5% oxygen, whereupon the seams are of a higher quality. Fittings with pipes made of steel 20 are welded in a medium of protective gas which consists of 30% argon and 70% carbon dioxide. The filler rod is made from the same brand of steel. Welding of fittings of aluminum pipes insignificantly differs from welding of steel. Argon-arc welding of pipes made from alloys AMg and AMgM is produced with filler rod of brand AMg5V with a diameter of 2 mm or with tungsten electrodes with a diameter of 1.5 to 2 mm according to Tech. Spec. VT2-529-57. The protective gas employed is pure argon according to Tech. Spec. MKhP 4315-54. Preparation of the joint for welding consists in removing burrs from the face surfaces and chemical removal of oxide film (etching in a solution of acids and alkalies).

Tentative Welding Modes for Aluminum Pipes

Current intensity.....	60-90 amp
Voltage.....	10-12 v
Welding speed.....	13-20 m/hr
Wire feed.....	30-50 m/hr
Argon consumption.....	12-18 liters/min

For welding of fittings to thin-walled tubes of small dimensions, gas welding is employed along with argon-arc electric welding. Oxy-acetylene welding of pipes made from stainless steel 1Kh18N9T is produced with filler material of steel 1Kh18N9T with a flux consisting of fluorides of type ANF-5 (75% fluorspar, 25% sodium fluoride). The flux is applied to the welding wire. Welding is produced manually by a No. 0 gas torch. To avoid overheating and burns, welding is conducted quickly and without interruptions around the joint circumference.

After the operation of welding, the welded seams are cleaned from scale and slag by a metallic brush and sandpaper, and the pipelines are finally matched with patterns and standards. For removal of internal stresses caused by welding, the most critical pipelines made from steel of the austenite class are thermally processed after welding at 800 to 850°C for 10 hours.

Hydraulic tests. Airtightness of welded joints of pipelines is checked on a special installation with kerosene colored by "Sudan" for 5 to 7 minutes at a liquid pressure 1.5 times exceeding operating pressure. Recently, there started to be applied a new method for checking welded joints, founded on the ability of phenolphthalein to react to the presence of alkali solutions. The places to be checked are coated with a chalky solution of phenolphthalein and dried at room temperature for one hour. Then the pipes are given a 1-percent aqueous solution of monoethanolamine. After exposure of the pipeline under pressure for 5 to 7 minutes, in the places of leakage the

chalky coating is colored red.

Soldering. Fittings with pipes are heated during soldering in electric furnaces (arc, induction, contact) and with the help of a gas torch. In batch production, soldering of fittings most frequently employs high-frequency induction heating with the help of high-frequency generators for industrial electrothermics of the tempering type LGZ-30, LGZ-60, LGPZ-30, and LGPZ-60 with output power of approximately 10 to 60 kw and frequency of 70 to 200 kc. The working tool

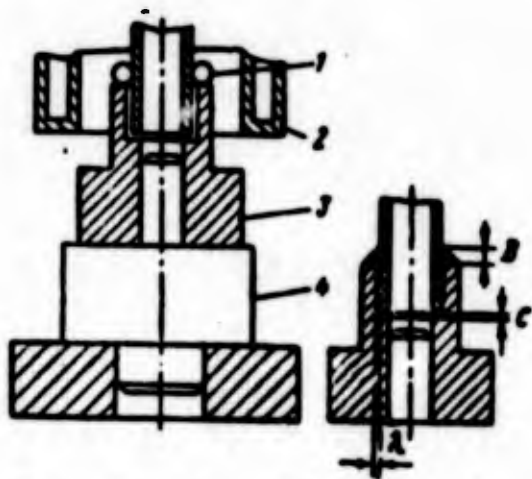


Fig. 11.14. Diagram of application of solder and form of hollow. 1) solder ring; 2) inductor; 3) nipple; 4) adjusting ring. λ - radial clearance (0.05-0.15 mm); B - height of hollow (2-4 mm); C - face clearance (2 mm).

is an inductor made in the form of a coil or a circular or rectangular copper tube with a cavity through which water is passed for cooling. The internal diameter of the inductor is selected in such a way so that the clearance between walls of the inductor and the component is 8-15 mm. The quality of high-frequency soldering depends on the correctness of assembly of fittings and the thoroughness of preparation of the surface of components for soldering. Surfaces of components having a length exceeding the zone of

soldering by 10-15 mm are thoroughly cleaned until the appearance of metallic brightness and are degreased. During assembly, special attention is given to the correctness of location of fittings with respect to the pipe. For guarantee of the necessary radial clearance between pipes and fittings from 0.05 to 0.15 mm, they are cleaned and pressed on presses. Solder and flux are introduced into the zone of soldering beforehand. The quantity of solder is selected experimentally, and subsequently during work it is maintained within the limits

of $\pm 15\%$. Flux is used either in the form of an aqueous solution of a not too thick consistency or in the form of a dry powder. In the first case the flux is applied to the surface of the pipe by a brush in hot form and dried. With the use of a flux in the form of powder, the pipe is heated first and the flux is applied; then the pipe is inserted into the nipple which is in the inductor, and soldering is produced. During soldering of assembled units the zone of soldering is heated to the specified temperature with exposure necessary for melting the solder and formation of a visible hollow of solder, thus forming a smooth transition from the tube to the fittings (Fig. 11.14).

Soldering of fittings of steel pipelines employs standard copper-zinc solders PMTs-52 and PMTs-54 (GOST 1034-62) and brass L62, L68 (GOST 1019-62), which possess higher mechanical strength and plasticity as compared to copper-zinc solders. For obtaining tighter connections, copper-zinc solders alloyed by tin and silicon, brass LOK 62-0.6-0.4 and LOK 59-1-0.3 are recommended. These solders possess high technological indices, have good spreadability, and ensure high mechanical properties of soldered joints. Borax is employed as the flux.

Soldering of collectors, branch pipes, and pipelines made from stainless steel and nickel alloys chiefly employs silver solders. The nomenclature of silver solders is very extensive. The most commonly used are standard solders PSr-25, PSr-40, PSr-45, and PSr-62 in accordance with GOST 8190-56.

Soft solders "Avio 1" and "Avio 2" ensure ultimate strength of joint to 10 kg/mm^2 ($\approx 10 \cdot 10^7 \text{ newton/m}^2$). Soldering with these solders employs rosin or stearin as the flux. However, these fluxes at low temperatures cannot destroy surface oxide film (Al_2O_3); therefore, it is necessary to preliminarily remove it by mechanical means.

Connections of fittings with pipelines made from aluminum alloys, soldered by soft solders, form a corrosionally unstable pair and poorly resist corrosional damage; therefore, the most reliable are refractory solders on an aluminum base, for instance, solders 35A and 34A. The removal of stable oxide film requires specially active fluxes, i.e., a mixture of chloride and fluoride salts of alkali metals. The melting point of the flux is about 450°C. Flux 34A possesses the ability not only to dissolve the aluminum oxide film, but also to cause strong corrosion of aluminum alloys; therefore, after soldering, the flux residue must be thoroughly removed. For this purpose pipelines are subjected to special treatment after soldering.

After washing, pipelines are dried in air and are finally dressed and are matched with a standard.

By rolling a ball of specified diameter we check the cross section of the pipeline, by external inspection we check for uniformity of seam, the presence of a hollow, and the smoothness of its transition to the pipe, and also the various visible defects of soldering. Hidden defects of soldering, such as incomplete filling of the seam by solder, porosity, and small cracks, are revealed by fluoroscopy. Airtightness of joints is checked by a pneumatic test under pressure in a bath with a 2-percent solution of potassium bichromate in water. Duration of tests is 15 to 20 minutes.

Hydraulic strength tests and pneumatic tests of pipelines are produced before the application of anticorrosive coatings.

§ 2. MANUFACTURED PIPELINES AND BRANCH PIPES FROM SHEET MATERIAL

Steel pipelines of large dimensions, branch pipes, adapters, and other components which have round, oval, box-like, and other forms of

cross section, are manufactured chiefly from sheet materials by stamping with subsequent welding of separate elements. The technological process of manufacturing pipelines from sheet materials essentially differs from the technology of pipelines manufactured from seamless pipe.

It usually consists of the following operations:

1. Opening of material.
2. Punching out flat billets.
3. Bending or drawing of separate elements.
4. Machining of surfaces for welding.
5. Assembly and welding of pipeline components.
6. Heat treatment.
7. Metal working.
8. Machining of unit.
9. Hydraulic testing.
10. X-ray check.

An example could be the technological process of manufacturing a manifold ring for liquid cooling of the inner shell of the chamber of a liquid-fuel rocket engine which consists of separate half-rings that are connected by welding (Fig. 11.15). The half-rings, which form the internal diameter, have a shaped profile of cross section. They are made from a shaped strip obtained by rolling or pressing. The operation of bending the shaped half-rings is executed on a shape-bending machine of the type PG4.* The generatrices of the external diameter of the ring are stamped in the form of separate segments with a cross section in the form of a circular arc of semiellipse and are connected by welding. Flat billets of the rings' components made from

*Considered in detail in Chapter VI.

sheet materials are punched out in a die or a cam or crank press.

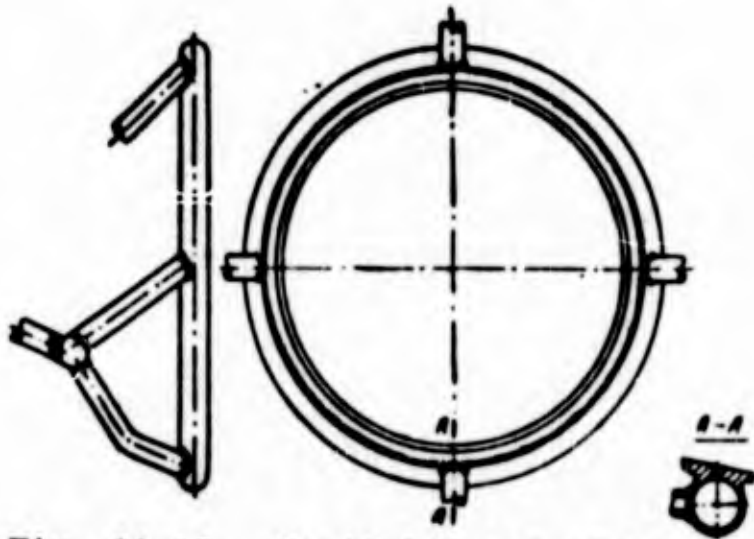


Fig. 11.15. Manifold ring of liquid-fuel rocket engine.

Bending of components of the ring is produced in one operation, after which the edges are faced, chamfering is done before welding, and the cross sections are drilled for feed of liquid coolant to the interjacket space of the chamber. Facing and chamfering are executed in one operation on a lathe in a special fixture; treatment of holes is produced through a plate jig. The ring units are assembled jointly with the assembly of the combustion chamber in a dock and are welded after preliminary clamping of the assembled unit.

The quality of welding is controlled by hydraulic testing at a pressure 1.5 times exceeding working, for 5 to 7 minutes. Seams are tapped by a mallet. Ten percent of the manufactured units are subjected to X-ray checking.

Connecting pipes manufactured from sheet materials are stamped in the form of two symmetric halves and are welded with longitudinal seam. For correctness of connection of both halves of the pipe, they are first assembled, secured by clamps, and held in two or three spots by welding. The allowed deviation in the cross section of the

configuration is checked on a pattern or standard.

Welding and soldering of fittings with pipelines. The technology of welding pipes with fittings consists of preparatory operations, operations of welding, conditioning, and quality control of welded joints. Preparatory operations consist in division of joints and conditioning of surfaces for welding. It is necessary that the ends of the pipes be perpendicular to the axes of the pipes; sharp edges must be dulled and cleaned by sandpaper. The ends of pipes subjected to welding are polished around their external and internal diameters to a length of 8-10 mm.

The most wide-spread method for welding fittings with pipes is argon-arc electric welding which is produced in a special device by a

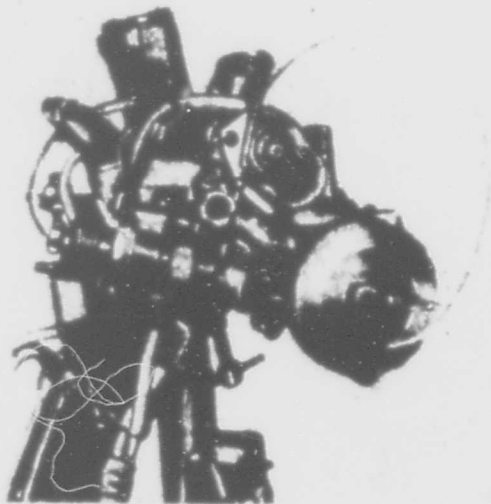


Fig. 11.13. Working zone of automatic machine for welding pipe joints.

welding burner with an infusible tungsten electrode. In the process of welding the pipeline assembled with fittings revolves, and the burner is secured motionlessly. Non-rotary pipe joints are welded by an ATV-15-40 automatic machine designed by NIAT. During welding, this automatic machine is placed on the pipe, around which the welding torch revolves during work (Fig. 11.13).

During automatic welding, the supply of additional material is produced

automatically, and the tungsten electrode moves as it evaporates.

Pipes with wall thickness more than 2 mm are made with nontapered edges. The total angle of division of edges is $45-50^{\circ}$; pipes with

On the outside, flexible hoses consist of a braid made from steel rust-resistant wire which protects them from mechanical damages and increases their strength.

The technological process of manufacturing flexible hoses of the first type consists of the following operations:

1. Cutting of measuring tape.
2. Shaping and spiraling of shaped strip.
3. Soldering or welding of corrugation.
4. Tests for airtightness and strength.
5. Wire braiding of corrugated hose.
6. Soldering or welding of fittings.
7. Tests for airtightness and strength.

The manufacture of corrugated hoses employs light-gage sheet of brands 1Kh18N9T, L80, and BROK4-3. The required strip width depends on the diameter of the hose, the height, and spacing of the corrugation.

The sheet material is cut into measured strips with guillotine or multiple-rotary shears with parallel axes. For obtaining clean edges without burrs, the clearance between the upper and lower blades is maintained at 0.1-0.2 from the thickness of the material.

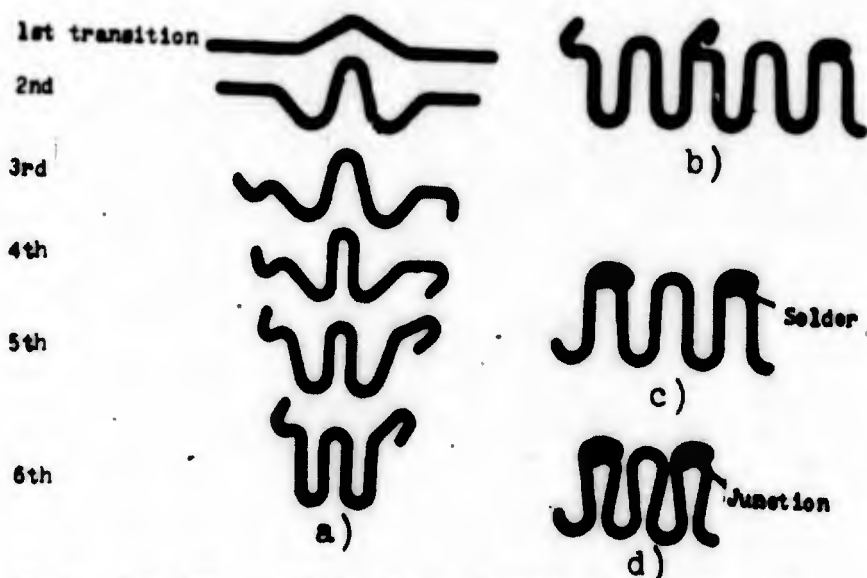


Fig. 11.17. Diagram of manufacture of metallic hoses with two-way corrugation. a) operation of strip shaping; b) diagram for obtaining a lock; c) shape of corrugation with normal location of turns; d) shape of corrugation with close turns.

Corrugating, spiraling, and formation of the lock is produced on a special multi-roller bending machine. If the hose is of soldered construction, then in the process of spiraling wire solder is simultaneously rolled into the corrugation lock. A diagram of the manufacture of corrugated hose with two-way spiral on a multi-roller bending machine in transitions is shown in Fig. 11.17.

Soldering of flexible hoses made of steel 1Kh18N9T is conducted with solder No. 40 (Ni, Cr, Mn) at 1188-1200°C in closed containers in an atmosphere of argon and gaseous flux with a preevacuated container. Braiding of corrugated hose is produced with wire made from stainless steel having a diameter of 0.3 to 0.5 mm on special braiding machines. Braiding can be single-layer, double-layer, and multiple-layer, depending upon the magnitude of internal pressure in the pipeline. The quality of braiding depends on its density and the braiding angle. The best braiding angle is 45°; density of braiding should be no less than 80-85%.

For connection of flexible metallic hoses to assemblies, fittings are soldered to their ends. Before soldering of the fittings, the ends of the hoses are faced and are degreased.

Soldering should ensure durable and hermetic connection of the corrugated part of the hose, braiding, and fittings. Soldering employs silver solder PSr-40 with melting point 650°C.

In the process of manufacture flexible metallic hoses are tested for airtightness and strength twice. The first time the test is conducted after soldering of corrugations. Hoses are assembled on a special fixture and connected to a bottle with compressed air through a reduction gear, and then together with the fixture they are lowered into a bath with water. Airtightness is checked under

a pressure of 10 atm ($\approx 10 \cdot 10^5$ newton/m²). The second time the hose test is conducted after braiding and soldering of fittings without a fixture. One end of the hose is choked, and the other is connected through the fitting end to the bottle with air. The hose is lowered into the bath with water and is given pressure to 15 atm ($\approx 15 \cdot 10^5$ newton/m²) for 3-4 minutes. After the pressure drops the testing process is repeated two or three more times. Suitable hoses are dried in a drying cabinet at 150-220°C for 1.5-2 hours. In addition to the test for airtightness, the hoses are tested for vibration strength and bending in accordance with a special program stipulated by the technical requirements.

Soldered hoses are used for pumping of unaggressive products. Work with aggressive products requires welded flexible hoses made from a strip or tubular billet. Welded hoses, just as soldered ones, are made from a shaped strip on a multi-roller bending machine and are connected in a spiral by roller welding. The shape of the corrugation by roller welding is circular around the overlap radius. For connection of fittings to welded hoses their corrugated end is expanded until a cylindrical surface is obtained, to which the fitting is welded by roller welding. The remaining operations for the manufacture of hoses of the welded type (braiding, testing, and others) are the same as in the manufacture of soldered hoses.

The technology of manufacture of flexible hoses of the bellows type in many respects is similar to the technology of manufacture of bellows. Certain peculiarities of obtaining long tubular billets and mechanical rolling of spiral corrugations for hoses will be specially noted when examining similar operations of the technology of manufacture of bellows.

§ 4. MANUFACTURE OF BELLOWS

Bellows (corrugated thin-walled vessels), employed as media separators and compensators, work in the same conditions as flexible hoses and are made from materials that possess high elastic properties: steel 1KH18N9T, EI702, titanium VT1, semitombac L80, and others. In their construction, bellows are subdivided into single-layer and multi-layer, with external and internal fitting diameters, only with external and only with internal fitting diameter, and the same for the fitting diameter and bottom (Fig. 11.18). The design dimensions of bellows are standardized. Semitombac bellows according to machine building standard MN 419-427-60 are intended for work as elastic sensor elements in instruments, flexible hermetic connections between components, and also in regulators, valves, and other mechanisms at temperatures from -60°C to $+100^{\circ}\text{C}$. The permissible media are air, oil, aviation gasoline, ligroin, kerosene, nitrogen, neutral gases, and oxygen. Contact of the bellows' surface with mercury, ammonia, and other aggressive substances is not allowed. Bellows are intended for compression work within the limits of elastic deformations. It is not recommended to employ bellows for extension work. For strong elastic connections, nonstuffing-box seals, and for accomplishing linear and angular transmissions of motion in aggressive media (concentrated nitric acid, hydrogen peroxide, ammonia, mercury, and halogens), and also for work in conditions of high temperatures, they use bellows made of steel 1Kh18N9T (GOST 4986-54). The design dimensions of bellows are in accordance with standard MN 428-60.

For internal pressures over 100 kg/cm^2 ($\approx 100 \cdot 10^5 \text{ newton/m}^2$) bellows are reinforced with external rings (Fig. 11.19).

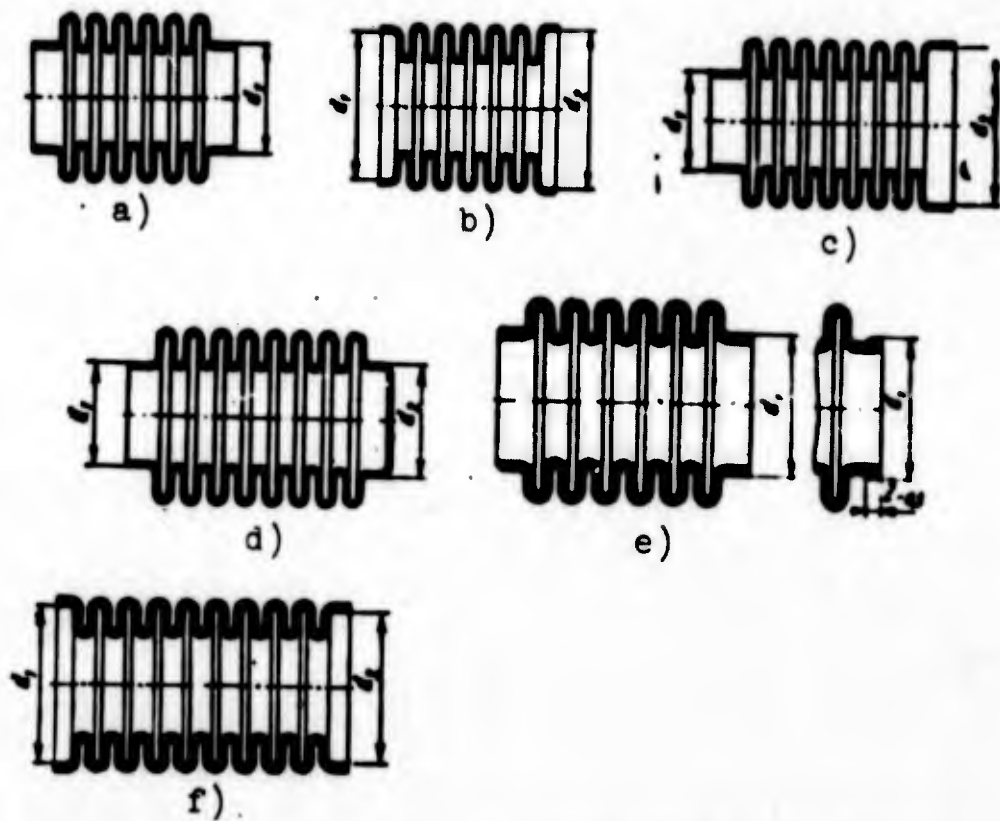


Fig. 11.18. Bellows. a) with external fitting diameter; b) with internal fitting diameter; c) with internal and external fitting diameters; d) with external fitting diameter and bottom; e) multi-layer with external fitting diameter; f) multi-layer with internal fitting diameter.

Manufactured bellows are checked for external form and dimensions, and are tested for airtightness and rigidity. The test for airtight-

ness is produced in a water bath at an excess air pressure of 1 kg/cm^2 ($\approx 10^5 \text{ newton/m}^2$) for semitombac bellows and 2 kg/cm^2 ($\approx 2 \cdot 10^5 \text{ newton/m}^2$) for steel bellows. The test for rigidity is produced on a special installation by means compressing the bellows to 1 mm of play under the action of an axial load. Norms

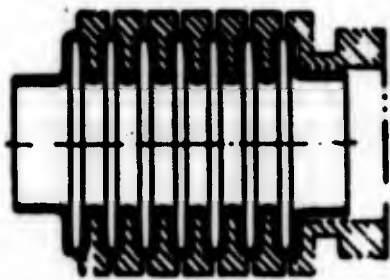


Fig. 11.19. Bellows reinforced with rings.

of rigidity, depending upon diameter and length of bellows, are given in standards MN 419-429-60.

The technological process of manufacturing bellows consists of operations for obtaining thin-walled tubular billets, shape-forming

of corrugations, flanging, and calibration of bellows with respect to height. The manufacture of semitombac bellows employs standard seamless thin-walled blank tubes (GOST 5685-51). They are divided into tubes without bottoms and tubes with bottoms; tubes are one-layer, two-layer, three-layer, and four-layer. External diameter of tubes is from 8 to 80 mm and thickness of walls is from 0.08 to 0.3 mm.

Measuring thin-walled tubular billets for the production of bellows made of steel 1Kh18N9T are obtained by deep drawing from a sheet, by rolling a tubular billet from a sheet, and by butt welding around the generatrix, by ball rolling of a standard pipe, and by the "Multi-Flo-Reform" method.

Drawing of a tubular billet from a cap obtained in a compound die from a flat billet is produced by a number of consecutive drawing operations with wall thinning in drawing dies on hydraulic or crank presses (Fig. 11.20).

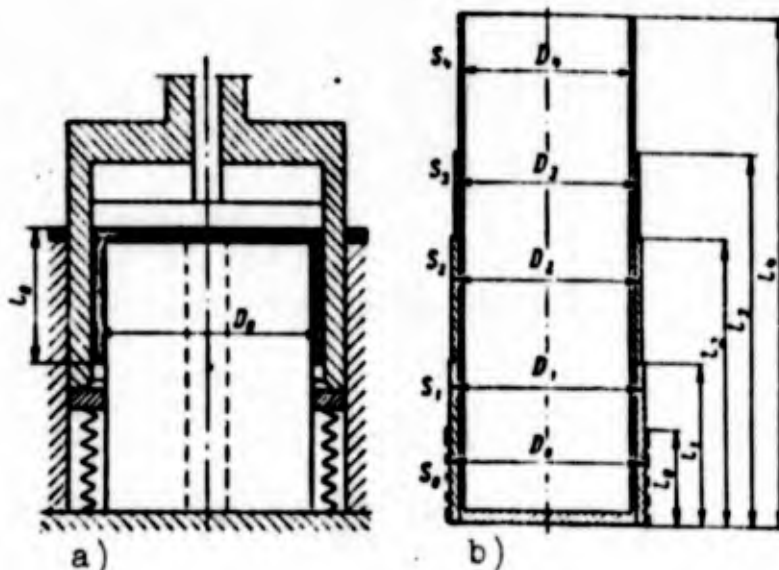


Fig. 11.20. Diagram for drawing a tubular billet. a) punching-drawing of cap; b) sequence of drawing tubular billet from cap.

This method for manufacturing tubular billets is the most labor-consuming and for obtaining a tubular billet with wall thickness of 0.1-0.2 mm from initial material 1Kh18N9T with a thickness of 1 mm it requires 12-18 transitions which are accompanied each time by coating the surface of the billet with varnish, subsequent multiple heat treatment, etching, etc. After the operations of drawing to the required dimension, the tubular billets are cut on a lathe on a special mandrel by a roller cutter that is fixed in the machine stock. Further, the tubular billets are subjected to annealing and etching, and the corrugations are formed.

A more productive method of obtaining a thin-walled tubular billet for bellows is the method of transverse ball rolling on a spinning lathe with the help of a special ball head (Fig. 11.21) or on a hydraulic press in a device consisting of ball head and spindle mounted in the body on bearings, and a drive pulley. The ball head consists of the body, two cone rings, and balls, assembled in a separator. The magnitude of pressing during rolling of the tubular billet is regulated by a ring with nut tension. For rotation of the ball head the press is equipped with an additional motor. The speed of rotation of the head is 1500 to 1600 rpm. The initial billet for transverse ball rolling can be a cap stretched on a compound die from a sheet without wall thinning, or a standard pipe with rolling in of a small thrust border-header. Transverse ball rolling considerably reduces the technological cycle of manufacture of the tubular billet as compared to deep drawing, and the operations of multiple heat treatment, varnishing, and other preparatory operations are dropped. The elastic properties and corrosional stability of the material are increased. This is especially important for bellows working in

aggressive media. In ball rolling the correct selection of the punch rate and the speed of the head ensures a high surface purity of the tubular billet (8th-9th class) and a wall thickness variation of no more than 10%.

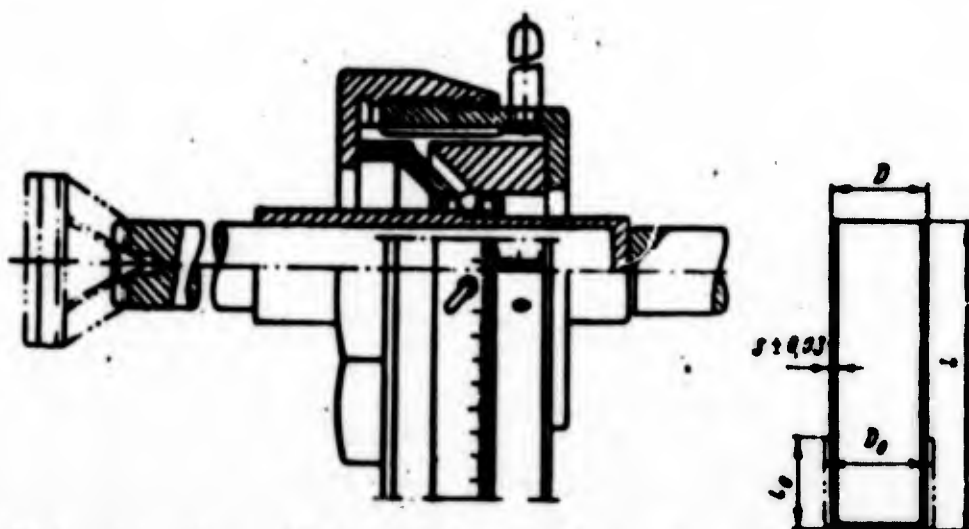


Fig. 11.21. Ball head and diagram of the process of rolling tubular billets.

Shape-forming of tubular billets by the "Multi-Flo-Reform" method, developed by engineers of the American firm Lodge and Shiply, consists of the following operations:

1. Punch-out of a flat billet of circular or square form.
2. Obtainment of an intermediate hollow billet in the form of the frustum of a cone from the flat billet by extrusion with ironing; its diameter at the apex is equal to the diameter of the finished component.
3. Shape-forming of a conical billet from a cylindrical one in one or several drawing operations.

The number of drawing operations depends on the magnitude of the maximum permissible deformation coefficient which is determined for each material experimentally (for instance, for steel 1Kh18N9T this coefficient is ≈ 2).

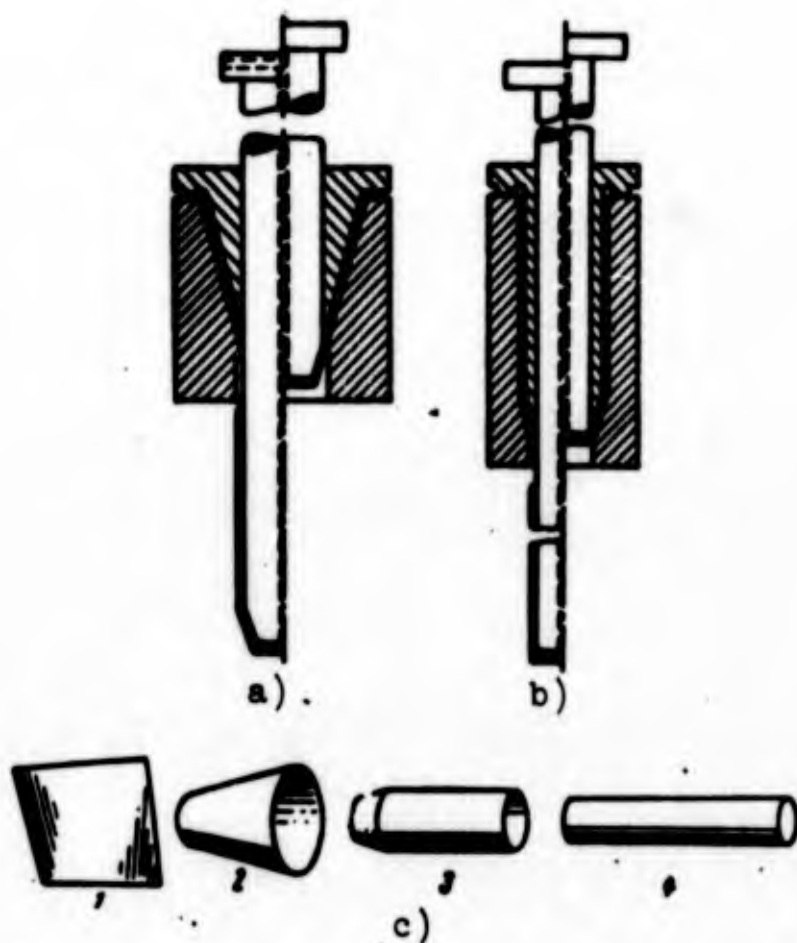


Fig. 11.22. Diagram of manufacture of a tubular billet by the "Multi-Flo-Reform" method. a) preliminary drawing; b) final drawing; c) manufacture.

Figure 11.22 shows the diagram of manufacture of a tubular billet by the "Multi-Flo-Reform" method. This method is considerably more productive than deep drawing and requires two less transitions in the manufacture of identical components.

Long tubular billets for the manufacture of bellows, flexible metallic sleeves, and pipelines are made by the welding method. The initial billet is measured tape of required thickness. The width of the tape is selected depending upon the diameter of the tubular billet to be welded. Roll-butt welding around the generatrix of the tubular billet is produced with a special automatic welder. The tape first enters shaped rolls where the joint edges are simultaneously trimmed. In the working rolls the tape is shaped into a pipe billet and the

drive rolls move it along its axis to the welding apparatus. Welding is produced by the electrode rings of the welding revolving trans-

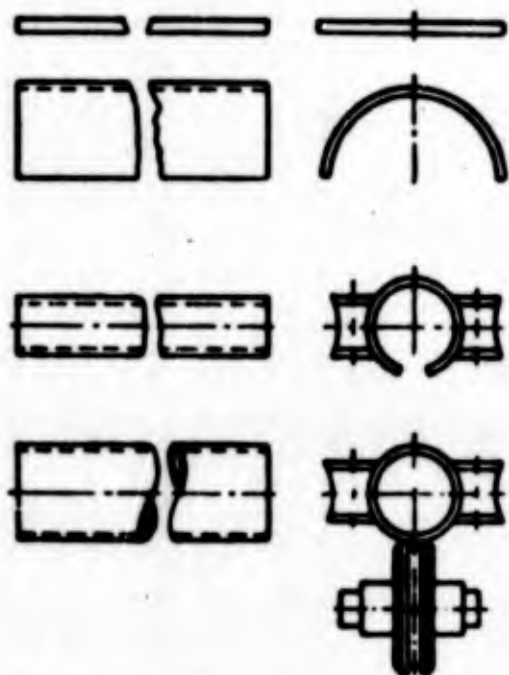


Fig. 11.23. Diagram of roll-butt welding of tubular billets.

former; the edges of the shaped tubular billet are resistance heated to the welding temperature, pressed by the back-up rolls and electrode rings, and welded. A diagram of roll-butt welding of pipe billets is shown in Fig. 11.23. In the process of welding, displacement of the edges of the pipe billet is not allowed. Flash from the external surface of the pipe is taken off in the process of welding in hot state by a cutter that is pointed at the radius of the pipe to be welded.

Molding of bellows. Shaping of the corrugations of bellows can be produced by mechanical rolling, hydraulic molding, and rubber molding.

Mechanical rolling is produced on a lathe. The tubular billet is placed on a mandrel that has grooves which correspond to the corrugation profile. The diameter of the mandrel is made 1.5 to 2 mm less than the internal diameter of the bellows. During rolling, the tubular billet revolves together with the mandrel which is secured by one end in the machine chuck; its other end is propped by the running center. Formation of the corrugation occurs by the gradual pressing in of the revolving roller partially due to local ironing of the wall of the tubular billet and partially due to reduction of its initial length. The spacing between grooves on the mandrel is determined by the development of corrugation of the bellows taking into account drawing of the material.

In the manufacture of flexible metallic sleeves and pipelines of the bellows-type, mechanical rolling of the corrugation is produced on a spiral with spacing equal to the corrugation spacing. The proximity of turns is made on a special device. A diagram of corrugation rolling is shown in Fig. 11.24.

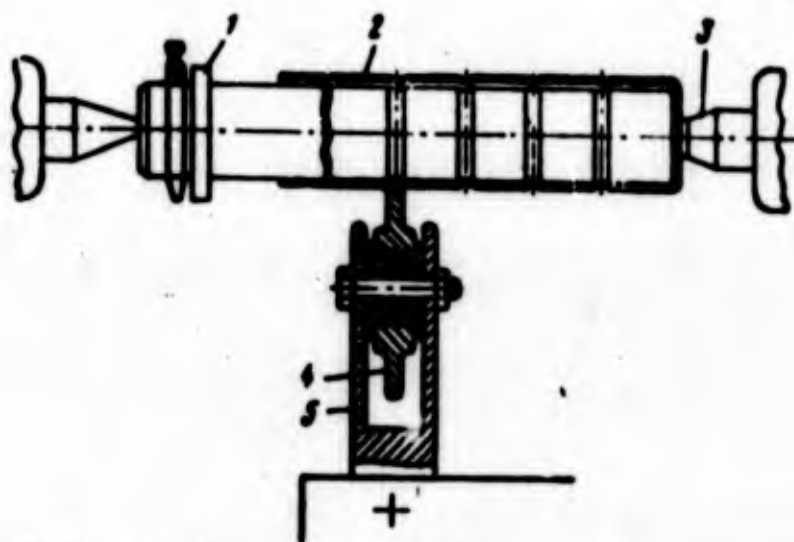


Fig. 11.24. Diagram for rolling corrugations. 1) mandrel; 2) tubular billet; 3) tail center; 4) roller; 5) holder.

Hydraulic molding of bellows is produced on a hydraulic molding machine of the type GUS or OU-30 in die plates (Fig. 11.25). Laminar dies are established at equal distances from one another and between them wedges are introduced which exactly fix the spacing of corrugation. In the dies there is placed a tubular billet which is hermetically pressed in the device. Inside the billet there is given a saponaceous emulsion under pressure, after which the adjusting wedges are removed from intervals between plates of the dies. Under the action of pressure from within a slight axial pressure, the bellows are formed. The magnitude of pressure necessary for molding bellows depends on the kind of material, the diameter and wall thickness of the tubular billet and is determined by the formula

$$P = \frac{\sigma}{D_0} h,$$

where P is the optimum pressure of hydraulic molding in kg/mm^2 ;

s is the nominal wall thickness in mm;

σ is the permissible stress in kg/mm^2 ;

D_B is the internal diameter of the tubular billet in mm;

k is a coefficient that depends on the mechanical properties of the material and is determined experimentally.

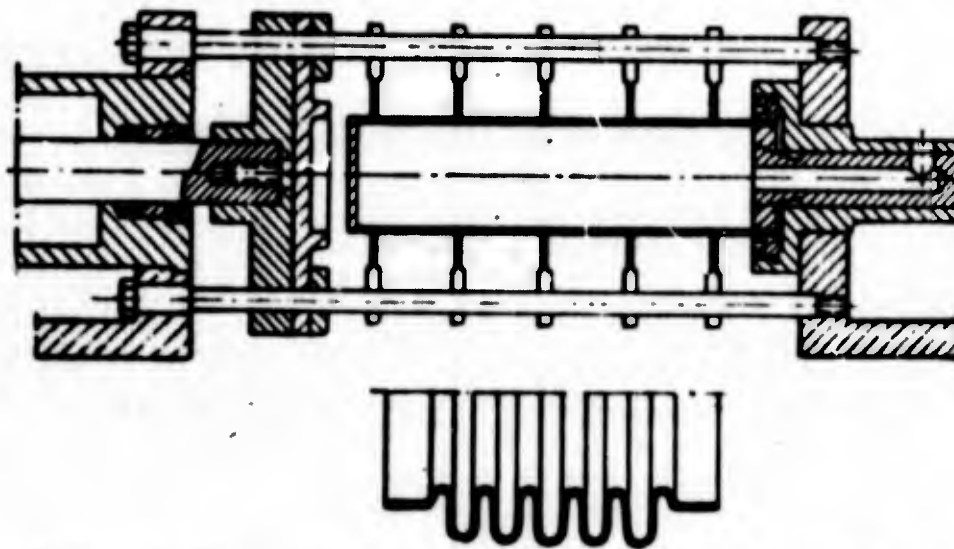


Fig. 11.25. Device for hydraulic molding of bellows.

Shape-forming of corrugations of bellows by rubber die molding occurs with slight ironing of walls, approximately 10-15% of the initial thickness of the tubular billet. Figure 11.26 shows the general form of a die with rubber top die and rigid counter die consisting of separate sections. The process of shape-forming of bellows by a rubber top die in a rigid counter die consists in the following: in the upper position of top die 3 the sectional die 7 is open; in this position a tubular billet is inserted into the counter die. With the movement of the top die downward to wedge 5, sections of the counter die shift to the center, moving along guide strips. The pressure caused by the slider of the press is transmitted to the rubber of the top die, whereupon the billet is plastically deformed, taking on

the shape of the counter die. With the movement of the slider of the press upwards, the top die and the die wedges also go upwards. Spring 6 opens the sections of the counter die, allowing removal of the bellows. During molding it is recommended to evenly apply industrial vaseline on the surface of the billet. The force of the press is selected depending upon the mechanical properties, the wall thickness, and the diameter of the tubular billet, with such a calculation so that the pressure of the rubber on the component is approximately $200\text{-}300 \text{ kg/cm}^2$ ($\approx 200 \cdot 10^5$ to $300 \cdot 10^5$ newton/m²). The method of shape-forming of corrugations of bellows by a rubber top die in a rigid counter die is simple, convenient, and productive.

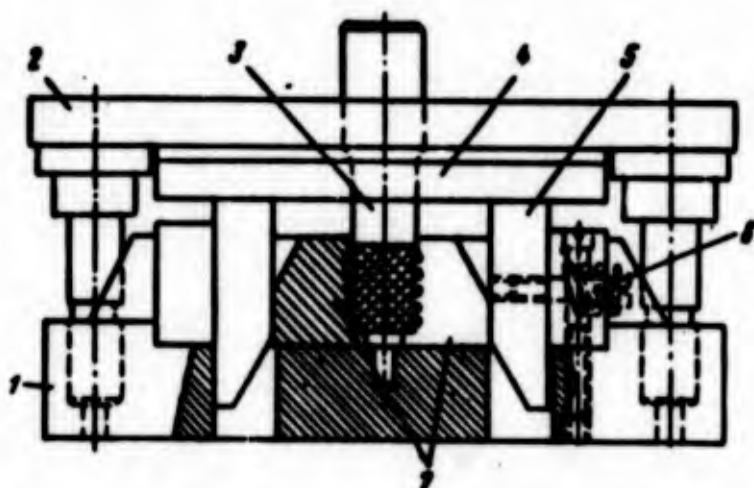


Fig. 11.26. Die with rubber top die for forming the corrugations of bellows. 1) lower plate; 2) upper plate; 3) top die; 4) top die holder; 5) wedge; 6) spring for returning sections of counter die to initial position; 7) sections of counter die.

After the operations of molding, washing, and processing of fitting borders, the bellows are calibrated in height and checked for rigidity and airtightness. Bellows that have flanged joints additionally undergo operations of welding or soldering and the preparatory operations accompanying them. Furthermore, bellows working in vibration conditions are subjected to vibration tests.

The fitting borders of bellows are turned in a special fixture on a lathe. Bellows are calibrated in height in accordance with the specified characteristic manually on a press. On special support the bellows are compressed until contact with the corrugations, and then the pressure is removed and the height of the bellows is measured. Calibration is produced by means of plastic deformations of the corrugated shell. After calibration, the corrugation spacing should be uniform and the bellows should not have misalignments with respect to the axis of symmetry. The presence of misalignment is checked by a square. After calibration, the bellows are subjected to heat treatment in a thermostat with electrical preheating for removal of internal stresses and stabilization.

Check of rigidity of bellows is produced on a special device. The bellows are first loaded by a small load which ensures preliminary compression of the bellows by 0.2 to 0.3 mm of the run, after which the needle of the indicator is established at zero. On a weight plate there is placed a load under whose weight the bellows deflect 1 mm according to the indicator. Rigidity is determined by the relation of the load to the magnitude of axial deflection of the bellows.

Bellows with fittings are connected by soldering or welding. Semitombac bellows are soldered by solders POS-40 and POS-61 (GOST 1499-54) with acid-free fluxes. Bellows of brand 1Kh18N9T steel are connected with fittings by roller short-pulse electric welding and argon-arc welding. Minimum wall thickness of fittings in the welding spot is 1.5 mm. Fittings in seam welding are installed with a forced fit; in soldering by solders, they are installed with a running fit. Fitting diameters of bellow flanges before welding and soldering are thoroughly cleaned until complete removal of oxide film in the places

of connection. Welding of bellows employs a roll-percussion welding machine of the MRK-2s type.

Airtightness of bellows is checked on a special installation. Bellows are choked on both ends by plugs, through one of which inside the bellows there is supplied compressed air through a pipeline. The bellows are dipped in a bath with water at a pressure exceeding operating pressure. Spot testing of bellows is produced at operating pressure.

CHAPTER XII

MANUFACTURE OF PARTS AND ASSEMBLIES FROM PLASTICS

§ 1. DESIGN, SPECIFICATIONS AND MATERIALS

Achievements of chemical science in the region of synthesis of various polymers and accelerated development of production of synthetic materials with different physical-mechanical properties creates favorable soil for expansion of the field of application of plastics in constructions of aircraft engines.

New forms developed during the last few years and mastered by chemical industry of plastics (polyamides, polyethylene, polyesters, polyepoxide copolymers, fiber glass reinforced plastics on the basis of polyesters and silicone compounds, and others), possessing high strength, lightness, thermal, chemical and electrical stability, can be widely used not only as substitutes for metals, but also as basic structural materials for manufacture of many important parts and assemblies of the aircraft engine.

In domestic and foreign aircraft engine construction plastic materials found application for manufacture of the following parts:

1. Housings of rocket engines, working on solid fuel.
2. Small-size housing parts of electrical equipment and different assemblies, covers, fuse caps, etc.
3. Blades of axial-flow compressors of rocket engines.

4. Tanks for chemically aggressive media (tanks for fuel, oxidizer, etc).
5. Pipelines, bellows (as separators of aggressive media).
6. Fittings.
7. Linings and packing (cups, rings, etc.).
8. Bearing backings, sleeves, various kinds of insert (for instance, graphite with silicone binders).
9. Gears.
10. Impellers, etc.

Furthermore, plastic materials are widely used for gluing articles, for anticorrosive and thermal insulating of metals, for hermetic sealing of fuel systems, etc. Plastic materials are also applied for plating the surface of metals for the purpose of adding thermal resistance, improvement of their antifriction properties, for production of new forms of materials on the basis of pressed metal-plastic powder compositions (for instance, bronze-teflon antifriction material for work in conditions of dry friction and in aggressive media).

Technical requirements, presented to parts prepared from plastic materials depend on their official function and practically do not

differ at all from requirements for parts from metal. Thus, e.g., the basic requirements for housings (Fig. 12.1) of solid-propellant rocket

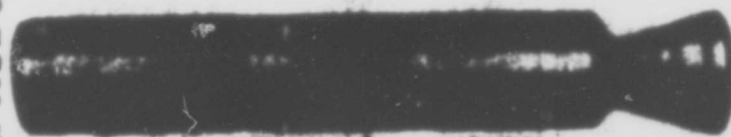


Fig. 12.1. Housing of a solid-propellant rocket engine from fiber glass reinforced plastics.

engines consist of guaranteeing high strength, airtightness and

thermalresistance. Such housings can be prepared from highly durable anisotropic fiber glass. For housings of electrical equipment and electric devices there are required plastic materials with high dielectric properties, and for housings of assemblies there is required resistance of plastics to aliphatic hydrocarbons. The same requirement pertains to plastic materials for manufacture of tanks for gasoline, diesel fuel and lubricating oils. Cleanness of surface of parts from plastic materials depends mainly on the quality of surface of the molding tool (press-forms, molding mouthpieces of extrusion heads, vacuum-chamber dies, etc.). For manufacture of parts from plastics, the working surfaces of the molding tool, as a rule, are polished to 10th or 11th class of cleanness, and in finished parts there is ensured cleanness of surface within limits of 7th to 9th class.

Cleanness of machined surfaces of plastic parts is determined by the method of working, and depending upon technical requirements for the part can also be obtained within limits of 7th to 9th class.

Accuracy of manufacture of parts from press-powders by pressing is in range of 5th to 7th class, and for parts from thermoplastic materials and fiber glass reinforced plastics it is within 4th or 5th class. With exact observance of all parameters of technological process and application of a precision molding tool there can be ensured obtaining of pressed parts of 3rd accuracy class.

Special technical requirements for housing parts prepared from plastics are in the following:

1. Externally articles should be evenly colored, smooth, brilliant, without spots, bubbles, impurities. On their surfaces there should not be traces of burring or places of splitting of the cast-mold, or cracks, chipping, scratches, traces of adhesion of

pressed material to the mold.

2. There is not allowed warping and swelling.

3. Threading should not have distortion of profile, dents, crumbling.

4. Molded fittings (sleeves, rings, pins, spindles, etc.) should not be deformed or displaced.

Gear transmissions from plastic materials work noiselessly and do not require lubricant; they are relatively insensitive to errors of assembly, are vibration resistant, are reliable and long-lasting in use, working at speeds of 900-1,500 m/min. From considerations of greatest wear-resistance of teeth, gears from plastics are usually coupled for work with steel gears.

In most cases plastic wheels are reinforced by steel hubs. On Fig. 12.2 there are shown various types of gears made from plastics.

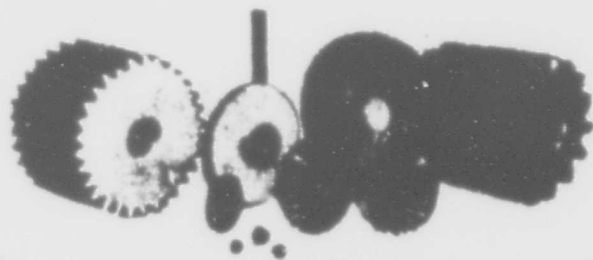


Fig. 12.2. Gears from plastics.

Specifications for manufacture of gears are determined in conformity with accuracy classes of gears according to GOST's.

Due to the fact that laminar plastics belong to structural materials with

strongly expressed anisotropy of mechanical characteristics, in specifications for manufacture of wheels there is specially indicated the location of teeth with respect to the direction of the highest mechanical properties. The magnitude of thermal expansion of plastics is 2-15 times greater magnitudes of expansion of metals. This causes danger of pinching of a tooth of plastic during work in a pair with steel; therefore, side play in the engagement is designated

taking into account the temperature of the medium.

Stator blades of a compressor, made of fiber glass reinforced plastics are finding application in engines in the first stages, where temperature does not exceed 150-250°C. The mass of blades from fiber glass reinforced plastics with the same strength comprises ~25% of the mass of steel blades. Structural elements of a blade made from glass plastics do not differ from steel or titanium stator blades. Blades from glass reinforced plastics are reinforced with a steel journal or are one-piece. Materials for manufacture of blades are glass fiber, impregnated with polyester resins, or fiber glass laminate on epoxy resins. Specifications on manufacture are: permissible deviation of profile of the blade from design is 0.3-0.5 mm, displacement of journals relative to nominal position ±0.1 mm, accuracy of diameter of journals is 3rd class, cleanness of surface of profile of blade and journal is 7th or 8th class.

Pipelines, bellows and fittings most frequently are prepared from vinyl plastic. Highly durable pipes are prepared from polypropylene, polyethylene, faolite and glass plastics on the basis of epoxy, polyester and furan binders. Basic technical requirements for parts of pipelines from plastics are guarantee of airtightness and strength under hydraulic blows and stability with respect to chemically aggressive liquids and gases, which is especially important for liquid-fuel rocket engines.

Bellows from plastics most frequently are applied as separators of aggressive media. They are prepared mostly from teflon. Bellows from plastics possess high operational qualities. Thus, for instance, bellows from teflon of diameter 62 mm and wall thickness 1 mm sustains a pressure of 10 atm ($\sim 10 \cdot 10^5$ newton/m²), and over 500 kilocycles of compression-extension. Basic technical requirements

on bellows from plastics are the following: minimum hysteresis, stability during transfer pressure, vibration strength and airtightness.

Bearings backings, bushings from plastics are applied in the most diverse mechanisms and vary in diameter in wide limits, from 2 to 1,000 mm or more. Model constructions of them are standardized.

As material for bearing backings there are applied phenol laminated plastics (laminated insulation, textolite) and polyamide. Polyamides have special advantage, as they contain graphite. Bearing backings prepared from this material can work in conditions of dry friction. Graphitized teflon FUG-3 is applied as an anti-friction material for work in aggressive media. For manufacture of specially loaded backings and sleeves there also are applied polyamides with powders of aluminum, lead, copper, graphite or molybdenum-sulfide with content of additions from 10 to 50%. Basic requirements for bearing backings from plastics are: high compression strength, high supporting power in a wide speed range, high antifriction properties and low coefficients of friction (0.002-0.005), wear-resistance. Accuracy of treatment is 1st or 2nd class; cleanness of surface is 8th class.

Packing parts (rings, collars, cups, etc.) depending upon conditions of work are divided into three categories: packers for fixed joints (ring-type packings); for joints with reciprocal motion of one of the joined parts (cups and collars) and for joints with rotation of one of the joined parts (various kinds of stuffing boxes).

Dimensions of packing parts are standardized, prepared in most cases from oil-resistant rubbers by TU 3544-55. Rubber collars and cups are made according to All-Union Government Standard 6678-53 and All-Union Government Standard 6969-54; stuffing boxes, by

All-Union Government Standard 8752-61.

Besides forming rubber of brands 3834 and VIAM-103, for manufacture of cups there is applied teflon. It is also used for filling stuffing boxes. With correct construction of cups from teflon they can be used at a temperature from 195 to 250°C and pressure 300-400 kg/cm² ($\approx 300 \cdot 10^5$ to $400 \cdot 10^5$ newton/m²). For manufacture of sealing rings, intended for work at high pressures, up to 450 kg/cm² ($\approx 450 \cdot 10^5$ newton/m²), they use caprone. Caprone rings have good elasticity, almost do not have plastic deformation and ensure reliable packing. Tolerances on manufacture of cups are 4th or 5th class. Working surface of cups should be smooth, without burrs, inclusions, cracks, bubbles and radial scratches.

Bottles, tanks from plastics for fuels and oxidizers applied in liquid propulsion systems differ in dimensions and shape. Most bottles work at high pressure and have cylindrical or spherical form. Such bottles are made from fiber glass on epoxy, polyester, furan, and other binders. As compared to welded bottles from aluminum alloy and steel bottles from fiber glass are lighter for the same volume and can work under pressure of up to 200 kg/cm² ($200 \cdot 10^5$ newton/m²). Besides this, they differ in their high stability with respect to acids and other chemically aggressive liquids. Basic requirements on finished articles from plastics, intended for storage and transportation of aggressive liquids, are guarantee of high airtightness and strength.

Fittings (drain cocks, connectors, and so forth) should be reliably fixed or prepared in one piece with the tank and well sealed.

Impellers from plastics are only made in small and average dimensions of semi-shrouded and shrouded type.

In central hole of plastic impellers there are pressed two

steel spline bushings with flanges. These bushing flanges are fastened to the nave of the impeller by through rivets. Blades and shelves between blades are not machined.

Materials for impellers are thermosetting plastics - fiber glass molding material AG-4, asbestos molding material K-6, and others. Normal use of impellers is limited mainly by temperature regimes. During heating of impellers above 100°C they sharply lose the strength properties. At present they are developing highly durable and heat-resistant plastics, able to work a prolonged time at high temperatures (near 300°C).

Precision of impellers remains identical to precision of metal impellers, described in Chapter IV.

Cleanness of lateral faces of blade and of shelves between them is 8th class, and of fitting surfaces is 6th or 7th class.

Quality of articles from plastics depends mainly on technology of manufacture. Selection of the correct technological process, in turn, depends on knowledge of the chemical nature and physical-mechanical properties of the initial materials. In Table XII.1 is a brief characterization of plastics applied in aircraft construction, and information on technology of working them.

Table III.1. Physical-Mechanical Properties of Basic Construction Plastics

Designation of material	Composition		Brand, TU or GOST	Methods of working	Density, g/cm ³	Thermal resistance by Martins, °C	Physical-mechanical properties Ultimate strengths in kg/cm ²			Area of application
	binder	filler					tensile	compressive	flexural	
Textolite (sheet)	Phenol-formaldehyde resins	Cotton-fabric	PT, PT-1 and PTK; GOST 5-52	Molding, machining	1.3-1.4	120-160	2300 1200	900-2000	1200-1600	Construction, building and anticorrosive material
Textolite crumbs	The same	Cuttings of fabric	A-B; TU M670-50	Molding	1.3-1.45	110-125	400-500	1400-2000	500-600	Construction and electrical articles
Asbestos-base textolite	The same	Asbestos fabric	A-B; TU MChP 2548-54	Molding, machining	1.6-1.8	160-250	650-1000	1200-2000	700-1400	Parts of coupling mechanisms, various linings
Hardened paper	The same	Paper	A, B, V, G, Vs, D, As, Bv, Rs, Dv, GOST 2718-54	Molding	1.3-1.4	150-160	700-2000	1500-2500	1000-1300	Parts of high-frequency installations
Indurated plywood	The same	Birch plywood	DSP (B, V, G) GOST 8697-58	Molding	1.3-1.4	150-170	1100-2600	1100-2600	1000-2800	Construction, electric insulating material
Fiber glass laminate	The same	Glass fabric	KAST; TU MChP 682-56 KAST-1; TU MChP 682-56 KAST-13; TU MChP 2182-54	Molding, machining	1.6-1.45	170-185	800-2800 1600-2800	800-3200	2200-2800	Construction, material in aircraft building, electrical and radio engineering
Fiber glass reinforced plastic	Polyester resin	Oriented fiber glass or fabric (SVAM an isotropic fiber glass)	—	Contact method, winding, hot molding, centrifugal and autoclave molding	1.6-1.85	170-185	2000-4000	2500-3000	2500-4500	Parts of increased strength, pressure tanks, rock-ets, housings

*kg/cm² = 10⁵ newtons/m². M. I. Yevstigneyev, et al.

Table XII.1. Physical-Mechanical Properties of Basic Construction Plastics (Continued)

Designation of material	Composition		Brand, TU or GOST	Methods of working	Density, g/cm ³	Thermal resistance by Martins, °C	Physical-mechanical properties			Area of application
	binder	filler					tensile	compressive	flexural	
Molding material from fiber glass	Phenol formaldehyde resins	Fiber glass	AG-4 (V and S) OMGU 431-57	Molding	1.7-1.8	280	V-800 S-to 2000	1300	V-1000 S-to 2000	Articles of construction and electric assignment of increased mechanical strength for work temperatures to 200°C
Faolite	Phenol formaldehyde resins	Asbestos and chrysotile	A, T, P; TU MOP 322-45	Rolling, extrusion, bonding, machining	1.5-1.67	100	120-200	600-900	500-600	Reactors, pumps, valves, pipes, fittings, various chemical equipment
Sheet vinyl plastic	Compositions on a base of polyvinyl chloride		TU 3823-53	Hot extrusion, welding, extrusion	1.95-1.4	65	400-600	800-1000	1000-1200	Anticorrosive material, construction
Polyfluoroethylene resins (tel-F, teflon, etc.)	Polymers of derivatives of ethylene		(3); VTU M-518-54 (4); TU M-162-54	Molding, injection molding, extrusion	2-2.4	-	300-350 140-250	500-400 -200	600-800 110-140	Packing diaphragms, insulation of wires, cups, valves, chemically stable bellows
Polyamides	Thermoplastic high-molecular polymer		P-68 (A, B); TU M-617-57 AK-7; TU M-90-57P-6	Injection molding	1.13-1.14	60 205 200 50	400-500 500-800 550-600 600-650	800-1000 700-900 750 700-800	800 1100 100 900	Construction antifriction material (gears, bearing backings, bushes)

Table XII.1. Physical-Mechanical Properties of Basic Construction Plastics (Continued)

Designation of material	Composition		Brand, TU or GOST	Methods of working	Density, g/cm ³	Thermal resistance by Martins, °C	Physical-mechanical properties			Area of application
	binder	filler					tensile	compressive	flexural	
Polyethylene	Thermoplastic polymer	—	Polycaprolactam PE-150, PE-300 PE-450, PE-500 VTU MKhP 4138-55	Injection molding, extrusion, inflation, molding, spraying	0.9-0.96	80	120-160	125	120-180	Construction material for corrosion-resistant fittings, pipes, parts, high-frequency installations
Polypropylene	Thermoplastic polymer	—	—	The same	—	—	220-450	300-400	200-380	The same
Polyurethane	—	—	PU-1	Injection molding, molding	1.17	50	300-360	600-700	9000-1200	For obtaining fiber, pipes, anticorrosive varnishes
Molding powders from phenolic plastics	Phenol-formaldehyde compositions with organic and mineral fillers	—	K-21-22 K-214-4 K-211, 3, 4 etc.	Molding	1.4-1.95	100-150	400-600	1500	500-700	Small-size housing parts, panels, parts of electric equipment

§ 2. SETTING UP THE TECHNOLOGICAL PROCESS

Selection of the proper method of manufacture of parts from plastics is determined by the type, dimensions, complexity of shape and specifications on their quality. In turn, the actual methods of manufacture of parts from plastics are directly dependent on properties of the binder and filler. For instance, the process of manufacture of parts from composition plastics (powder, cast) is based on the flowability of the molding material at high pressures and temperatures, and parts from glass reinforced plastics are prepared at relatively low pressures (except AG-4), since fiber glass fillers (glass felt, fiber, etc.) do not have flowability.

Molding of complicated articles with deep broaching with a filler of glass fiber, having low relative elongation (2-4%) and badly filling the mould is inadvisable; whereas materials with unoriented fillers permit us to obtain an article of any configuration.

Basic industrial methods of manufacturing articles from plastics are: molding in casting molds, injection molding, extrusion, winding by contact method, machining, welding and gluing. In Table XII.2 are given most commonly used methods of manufacture of parts from plastics.

The housing of a solid-propellant rocket engine. This assembly, consisting from machined steel parts and a multilayer cylindrical shell, prepared from glass reinforced plastics. Initial material for the shell is highly durable fiber glass with binding components, phenol-formaldehyde resins and silicone compounds. The most rational method of manufacture of the multilayer shell, ensuring obtaining of a highly durable part, is winding of fiber glass (glass filaments) in the form of variously-directed spirals on a special installation. Strength of the article here depends on the dimensions and strength

of the elementary fiber and the numerical ratio of the fiber glass and binder. Best results are shown by samples with content of fiber glass from 60 to 70% (volume), prepared from glass filaments 14-16 μ in diameter. In Figures 12.3 and 12.4 are shown the dependency of strength of a piece on percentage of fiber glass and of the strength of separate elementary fibers on their diameter.

Table XII.2. Methods of Manufacturing Parts from Plastics

Methods	Recommended classes of parts
Molding, transfer molding; injection molding	Small and medium size parts (reinforced, friction pairs, threaded, general assignment, loaded by weight up to 5-10 kg
Autoclave molding	The same, and also big parts weighing up to 20-30 kg
Vacuum-atmosphere and vacuum-pneumatic forming	Huge parts of general assignment and medium dimensions from sheet building plastics
Preliminary forming with subsequent molding; preliminary forming with subsequent impregnation	The same, with use of resins and chopped fiber
Forming	Parts of big and average dimensions from raw building plastics
Contact molding, fluidized-bed coating	Huge parts without limitation of dimensions, using resins, fabrics and chopped fiber
Styro method	Loaded parts of different dimensions with closed hollow contour
Winding of pipes and round hollow profiles of structural designation	Building material of average and large profiles of limited dimensions
Drawing	Building materials of small profiles without limitation of lengths
Method of extrusion	The same, and also films, plate, pipes
Machining, welding, bonding of plastics	Parts without limitation of dimensions
Flame coating, metal coating in a fluidized bed	Parts without limitation of dimensions

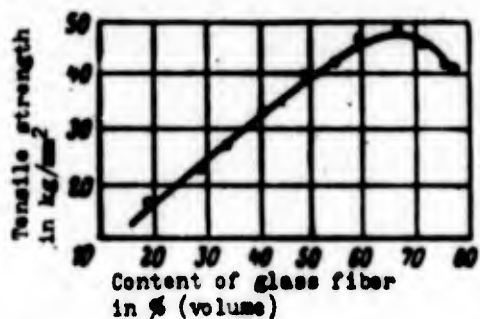


Fig. 12.3. Dependence of strength of fiber glass on content of glass

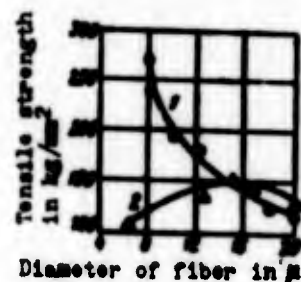


Fig. 12.4. Dependence of strength of fiber glass on diameter of elementary fibers. 1) strength of elementary fibers; 2) strength of fiber in composition with binder.

Technological process of manufacture of the housing of a solid-propellant rocket engine consists of the following basic stages:

1. Machining of base steel flange.
2. Assembling of attachment for winding (assembly of flange with mounting, application of protective coating on surface of mounting).
3. Winding of fiber glass.
4. Molding of housing.
5. Heat treatment.
6. Machining.
7. Assembly.
8. Inspection and testing.

Small-size housing parts, panels, covers, caps, etc. For manufacture of small housings, panels, covers, caps, etc., in conditions of small-lot production they apply molding, transfer molding and injection molding. In initial state, for working into parts, plastic arrives in the form of molding powders, rods, tubes, various

profiles, etc. Set up of the technological process of manufacture of plastic housing parts depends on physical nature of the plastics applied. Thus, for manufacture of parts from thermosetting plastics (powder-type - phenoplastics, monoliths, amino plastics, polyfluoroethylene resins; fibrous compositions - faolite, fiber and fiber glass molding materials; laminates - of the type of textolite and hardened paper) it is most advisable to apply hot molding in metal molds on hydraulic presses. Forming of the article from thermosetting materials occurs at a definite pressure and upon heating to a fluid state. Hardening of these materials occurs in the process of molding due to polymerization. Articles, prepared from thermosetting materials, cannot be softened and processed anew.

Thermoplastic materials, including most polymerized polyester plastics (polyethylene, polypropylene, polystyrene, polyesters, polyamides, fluorinepolymers [? Russian "ftoropolimed" unintelligible], polyformaldehydes, etc.), for forming require not only application of pressure and heating, but also cooling, necessary for preservation of the form given to the article, since thermosetting plastics do not solidify during heating, but remain viscous-fluid, plastic. A widely-spread method of manufacturing small parts from thermoplastic masses is injection molding. It especially well justifies itself during manufacture of thin-walled housing parts of complex configuration, and also parts, reinforced by thin metallic reinforcement or backs. Injection molding is outstanding in its high productivity (cycle of about 1 minute) and broad possibilities of automation.

Technological process of manufacture of small housing parts from plastics consists of the following stages:

1. Preparation of material (sifting of powder plastics or

crushing, and also cutting of rods or tubes).

2. Batching of material (volume or weight).
3. Performing.
4. Forming (pressing or casting).
5. Stripping of burr.
6. Machining (mainly, of complex housings).
7. Inspection.

Gear wheels. For manufacture of one-piece and combined gear wheels they most frequently apply laminar plastics (textolite, and others). In practice of machine building most widely applied are two basic variants of technology of manufacture of gears:

1. From building sheet laminated plastic (textolite) (Fig. 12.5).
2. From molding bakelized fabric (Fig. 12.6).

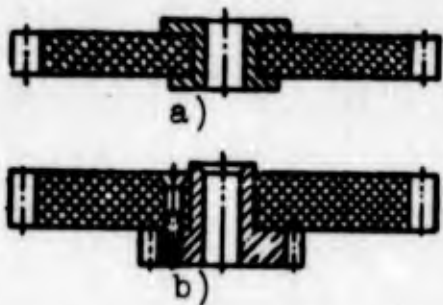


Fig. 12.5. Gears from sheet textolite. a) with expanded bushing; b) joint with steel gear by means of bushing and screws.

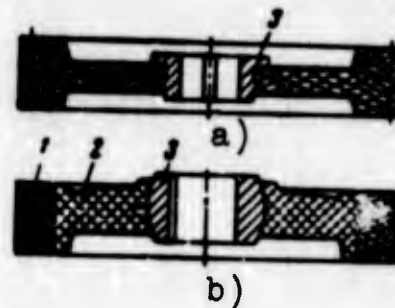


Fig. 12.6. Molded gear wheels. a) wheel with rim from round sheets of bakelized fabric; b) from segment strips of bakelized fabric.

Technological process for 1st variant is comparatively simple. A blank, cut from building plate textolite of brand 2 or 3, is turned on a lathe and then they cut teeth on gear-milling machine. Deficiency of such a technological process is high labor-consumption machining and great waste of material in shavings. Furthermore, strength of machined tooth is 25-30% lower than for wheels

manufactured from molded bakelized fabric.

Technology of manufacture of gears by the 2nd variant are somewhat more complicated, but less labor-consuming, and it ensures obtaining of wheels of higher quality.

Construction of the technological process of manufacture of wheels by the 1st variant is presented in the following form:

1. Cutting of blank from sheet of plate textolite.
2. Lathe work.
3. Pressing of metal bushing (with expansion or fastening by screws).
4. Cutting of teeth.
5. Benchwork stripping.
6. Inspection.

Construction of technological process by the 2nd variant:

1. Layout of bakelized fabric in segments for pressing of blank.
2. Stacking of segments in a pack by fixture for preliminary pressing of rim.
3. Heating of pack and pressing of rim of wheel in mold.
4. Second pressing with crumbs (chopped bakelized fabric) for formation of disk and nave of wheel blank.
5. Third final pressing of blank.
6. Finishing.
7. Cutting of teeth.
8. Benchwork stripping.
9. Inspection.

Stator blades of a compressor. Compressor blades are prepared from impregnated glass cloth or glass-plywood.

Technological process of manufacture consists of the following basic operations:

1. Layout of glass cloth into dimensional blanks.
2. Stacking of blanks in a pack.
3. Hot pressing in a mold at high pressure.
4. Heat treatment.
5. Machining.
6. Inspection.

Pipelines, bellows and fittings. The large variety of materials, applied for manufacture of pipelines of different assignment

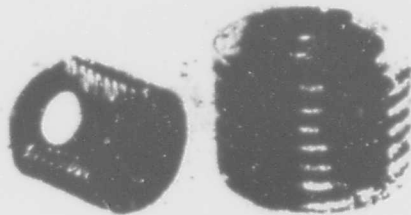


Fig. 12.7. Bellows, fitted with steel flanges.

and technical requirements for their quality, caused the development of different methods of manufacture. For aircraft engine construction of greatest interest are pipes and bellows (Fig. 12.7). The most productive methods of manufacture of pipelines are extrusion

(sinking) and injection molding.

The most advanced method of manufacture of fittings for pipelines (squares, tees, crosspieces, connectors, adapters, etc.) is the method of molding in closed molds. Construction of technological process of manufacture of fittings by molding is the same as during working by molding of small-size housing parts.

Technological process of manufacture of pipelines by extrusion consists of: a) preparation of the material (preliminary drying and preheating, mixing with additions, preliminary packing); b) process of extrusion; c) cutting; d) finishing the end fittings.

Bearing backings, bushings. Bearing backings and bushings from plastics in small-lot production are prepared by three basic methods:

1. Machining from tubular blank.
2. Molding from sheet plastic or crumbs.
3. Autoclave molding.

The simplest method is manufacture of backings from textolite tubes. Here, there is the possibility of using standard tubes with a wide range of dimensions. Machining of them is simple. It consists of machining the top, boring and cutting in two halves.

Molding is used for manufacture of backings of high-load bearings. Backings are prepared in molds by means of hot molding from cotton fabric or small cuttings of fabric impregnated by phenol-formaldehyde resin, and also graphitized polyfluoroethylene resin FUG-3 and combined polyamides with powders Al, Cu, and others.

Technological process of manufacture of molded backings consists of preparation of material, molding, stripping of burr and machining.

Sealing rings, cups. Basic operations of technological process of manufacture of sealing rings and cups (Fig. 12.8) from molding



Fig. 12.8. Parts of packing. a) fitted sealing ring; b) cup without fittings.

rubber 3834, VIAM-103, and others, are hot pressing in molds and vulcanization. Sealing parts of simple construction without

fittings are prepared in molds by compression method of molding. Complex articles and articles with fittings are prepared by hot transfer molding or injection molding.

Impellers. Procurements of semi-shrouded and shrouded impellers from plastic are poured in molds under pressure and molded with allowance for machining.

Allowances are left on seating surfaces, on external diameter,

on labyrinth strips and, in certain cases, on the ends. Allowances for machining should be small, ensuring minimum warping of part during its cooling after machining. Practically allowances on the impeller are within 0.5-1 mm a side.

In shrouded combined impellers and in their covers allowances are left also on surfaces of joining.

In constructions of casting molds and molds for molding on certain surfaces there are provided inclines to facilitate removal of blanks, and also special refrigerators for uniform cooling of the blank. All working surfaces of molds should be polished and chrome-plated to cleanness of 9th to 11th class.

During designing of casting and molding forms for manufacture of ribbed parts of the type of single-entry impellers it is necessary to consider that during nonuniform cooling warping appears.

Plan for working semi-shrouded impellers:

1. Turning of end of nave and boring of hole.
2. Stitching of end of nave on the side of the blade.
3. Pressing in hole from two sides of two steel bushings with flanges.
4. Drilling of through holes in flanges of bushings, setting of rivets and their riveting.
5. Boring of hole in bushing and clipping of faces with installation in impeller of blades.
6. Broaching of splines in hole of bushing.
7. Final turning of external diameter and labyrinth strips with installation of part by splines on mounting.
8. Benchwork stripping.
9. Final inspection.

§ 3. FULFILLMENT OF BASIC OPERATIONS

Screw winding of a cylindrical shell from anisotropic fiber glass is one of the most important operations of manufacture of the



Fig. 12.9. Diagram of winding of a rocket engine housing by fiber glass. 1) coil with fiber glass; 2) mounting; 3) support.

housing of a rocket engine. For execution of this operation there is applied a lathe or special winding machine specially equipped for this purpose. A hollow mounting having a steel flange, is rotated, and a carriage with bobbins, on which fiber glass is reeled, accomplishes reciprocating motion. Reeled from the bobbins, fiber glass is impregnated by a binder, then passes

through guiding device and is wound on the mounting. In process of winding the mounting is heated from within by heated vapor or liquid to $50-60^{\circ}\text{C}$. Rotation of mounting and motion of support with bobbins is synchronized in such a way that filaments are packed at a definite angle of spiral ($35-40^{\circ}$). The support has right and left motion; placing filaments on a spiral the length of the shell in one direction, it acquires motion along the generatrix in the opposite direction; as a result there is obtained a crossed layer-by-layer application of glass filaments (Fig. 12.9). During winding of the shell there sometimes is applied a combination of fiber glass materials: glass filament and cloth. In this case, application of glass cloth (in the form of tape) is alternated with winding of glass filaments. For packing, layers of cloth are rolled by clamp roller along the generatrix of the mounting. Impregnation of glass filaments with binder is produced directly before winding by transmission of them through a bath with the binding substance (on a base

of phenol-formaldehyde resins and silicone compounds).

Before winding to the mounting they preliminarily apply a protective coating, protecting the piece from adhesion and facilitating its removal from mountings.

Usually as coating there is applied a solution polyvinyl alcohol in a mixture of glycerine with water and ethyl alcohol; this solution will form on the surface of the form a thin film which, after drying, protects the article from adhesion. After winding the shell is subjected to molding and heat treatment.

Hot molding of small housing parts, fittings, bushings, backings, etc., from thermosetting plastics is produced in metal molds. Process of molding is realized under a pressure of 200 to 400 kg/cm² ($\approx 200 \cdot 10^5$ to $400 \cdot 10^5$ newton/m²) at 135-180°C depending upon physical properties of the molded material. The mold during molding is warmed by vapor or electric heater elements. Duration of molding depends on the thickness of the molded part; on the average for every millimeter of thickness of the wall of the part there is required 0.8-3 minutes. To accelerate the process of molding there is applied preheating of the thermoreactive mass to a temperature 10-15°C above the heated mold.

Molding is produced in molds (Fig. 12.10) of three types: open, closed and semi-closed. The open mold consists of two parts

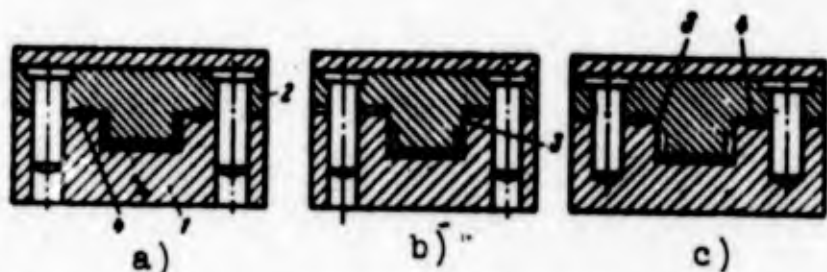


Fig. 12.10. Diagrams of molds. a) open type; b) closed type; c) semi-closed type. 1) die; 2) punch; 3) guide retainer; 4) ducts for removal of burr.

(see Fig. 12.10a):
a die 1 and a punch 2.
During molding a surplus of material is pressed into the gap and into a special cavity 4 between the
cavity 4 between the

punch and die, forming the so-called burr or flash. The open mold is the simplest and cheapest in manufacture, but during use of it it is necessary to anticipate allowance of material for the burr. A mold of closed type (see Fig. 12.10b) has in the die from above a retainer 1, which as a plunger (by exact fitting of motion) by the corresponding surface punch 2 enters. During molding the punch presses the material in the space closed by the plunger, and pressing of material outwards does not occur. Closed molds usually are used for molding housing parts of complex configuration. A failing of closed molds is the complexity of manufacture and necessity of exact batching of material. The mold of semi-closed type (see Fig. 12.10c) occupies an intermediate position between these two constructions of molds. It combines the advantages of both molds, is the most rational and commonly used. Dimensions of the working cavity of molds are made taking into account shrinkage of plastic. Phenoplastics, aminoplastics and other materials of hot molding have shrinkage of 0.2-1%. Here, plastics with larger content of filler have smaller percent of shrinkage. To ease unloading of molds parts from plastics should have draft of at least 1° and radii curvature of edges in corners of at least 1 mm.

In Fig. 12.11 there are shown varieties mold blocks for molding small parts. For manufacture of mold block parts block (die and punch) applied materials should possess high strength and wear-resistance. Furthermore, for forming certain thermoplastic masses, polyvinyl chloride copolymers, there is also required high corrosion resistance, especially to the action of hydrochloric acid. Most frequently mold block parts are prepared from alloyed steel Kh12, Kh12M, KhVG, less frequently from steels Y7A and Y10A. Well recommended are steel molds with chrome-plated working surfaces.

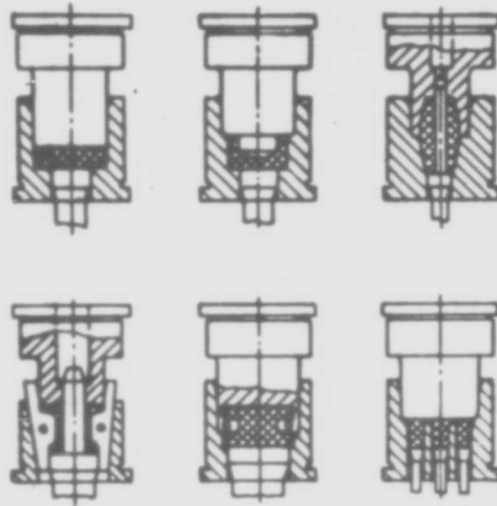


Fig. 12.11. Varieties of mold blocks for molding small parts.

Transfer molding of small housings, panels, fittings and other parts as compared to normal molding is a less productive

method. This method is applied mainly for forming thin-walled parts of complex configuration and parts with thin fittings.

Essence of transfer molding consists in the following: in mold 1 (Fig. 12.12) there is injected under pressure of from 500 to 1,500 kg/cm² a plastic mass, preheated to

visco-fluid state. The molding

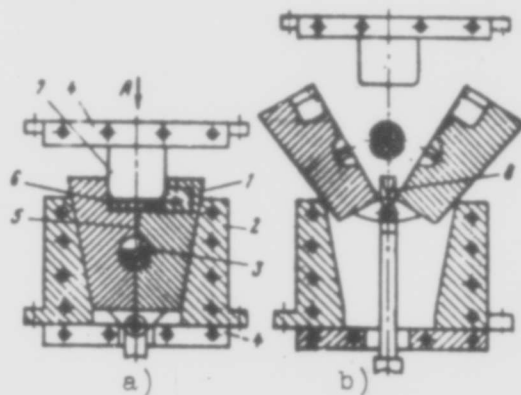


Fig. 12.12. Diagram of transfer molding. a) position of die in molding process; b) die in open position.

plastic is sprinkled into loading chamber (or hopper) 6, from which, upon heating from chase 2 and plates 4 under pressure of punch 7, is pushed through narrow nozzle (or casting channel) 5 into closed (molding) cavity of mold 3 and fills it.

Since plastic enters the mold in visco-fluid state, and not in solid or powder form, the mold is filled well, encompassing inserts, bushing or fittings and not displacing them from assigned position. Here, there are attained high accuracy of dimensions and cleanness of surface. Die 1 is made in split form and has the form of two wedges which is necessary for tight compression in the splitting plane during installation in chase 2. After holding and hardening of the material by motion of plunger upward, punch and upper plate 4 rise to the position shown in Fig. 12.12b. Simultaneously, the rod of the hydraulic press ejects the wedge-shaped die 1 from chase 2. The die in its upward motion opens arbitrarily or with the help of wedges 8, and the molded piece is freed.

Injection molding is most profitably applied in mass production of small housing parts and fittings of complex configuration, prepared from thermoplastic materials. The method of injection molding and the method of transfer molding coincide in the character of certain elements of the technological process. Both methods anticipate supplying

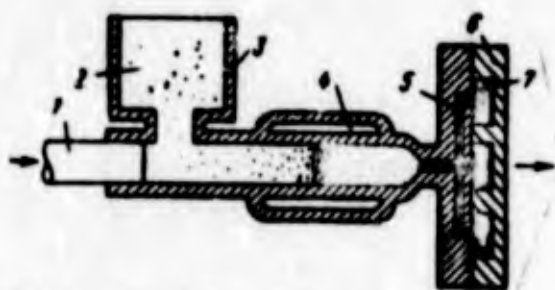


Fig. 12.13. Diagram of injection molding. 1) plunger; 2) molded mass in powder; 3) hopper; 4) heating chamber; 5) flow gates; 6) mold; 7) molded piece.

heated material to cavity of mold by a system of casting channels and heating of the material is carried on outside the forming cavity of the mold. The difference between injection molding and the process of transfer molding is that the first is designed for processing thermoplastic materials, the second mainly for thermosetting (can also be used in part

during processing thermoplastics). According to the properties of applied materials molds for injection molding are continuously cooled; molds for transfer molding, conversely, are only warmed. Injection

molding is carried out on special casting machines, for instance, brand LM-50. A diagram of injection molding of plastic parts is shown in Fig. 12.13. Process of casting consists of the following. The molded plastic is poured in powder form into the hopper of the casting machine and by plunger is moved to the heating head of the machine. Here, the mass is completely softened and through casting channels, rapidly and without considerable resistance, it fills the cavity of the casting mold. After filling the mold is cooled. The hot molded mass cools rapidly, and in the form of a finished piece without delays it is extracted from the mold. Operating pressure during casting is from 250 to 2500 kg/cm² ($\approx 250 \cdot 10^5$ to $2,500 \cdot 10^5$ newton/m²) of projection area of the molded part; temperature during casting of thermoplastics varies from 150 to 300°C depending upon their physical properties.

Injection molding is outstanding in its high productivity and ensures obtaining of parts of high quality.

Molding gears from bakelized fabric includes three treatments

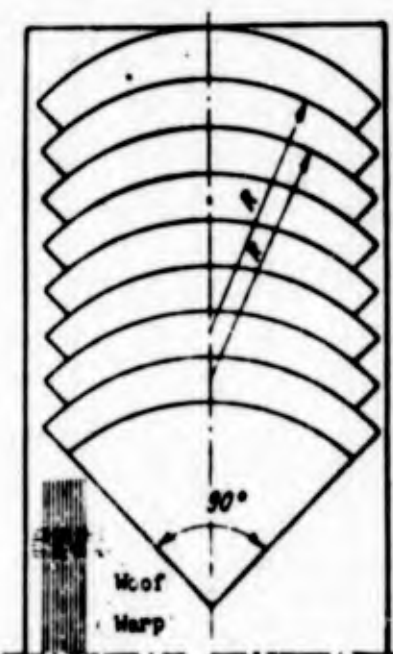


Fig. 12.14. Layout of bakelized fabric in segments for pressing of gear blank.

First, from 8-12 strips of bakelized fabric, assembled in a pack, there are cut on stamp segments (Fig. 12.14). Strips are cut in such a manner that longitudinal filaments of fabric (warp) are directed along the strip, and transverse filaments (woof) are directed across the strip. The center angle of the segment is selected for wheels of diameter up to 150 mm equal to 90°; for wheels of diameter greater than 150 mm it is 45-60°. Segments are packed in a special fixture one-by-one overlapping, forming the

the rim of the wheel. After stacking the required quantity of segments the collected rim is tightened securely by a bolt between two steel disks and is placed in an oven, where it is heated 10-12 to 60°C. Bakelized fabric here is softened and yields to compressing. The heated rim is preliminarily pressed in a mold; then it is cooled and freed from the disks. The rim obtains strength necessary for passing through the subsequent operations.

In second stage of treatment the pressed and cooled rim is placed in a second mold. Here, to it there is added chopped bakelized fabric heated to 60°C for formation of the disk and nave of the gear, and there is produced pressing. The second mold is arranged so that pressure of the punch spreads only to the textolite crumb, and not to the rim. The dummy thus obtained proceeds to 3rd stage of finishing.

In the third stage of working the dummy is placed in a third mold for hot pressing, where it obtains the final form of the blank. The process of pressing takes place with preheating to 160°C. Cooling is together with the detachable mold. The blank is removed from the mold only after cooling of it to temperature not higher than 50-60°C.

Specific pressure during preliminary pressing of rim is near 100 kg/cm² ($\approx 100 \cdot 10^5$ newton/m²), and during pressing of the dummy and the final pressing in a hot mold it is up to 400 kg/cm² ($\approx 400 \cdot 10^5$ newton/m²). Flow chart of manufacture of gear blanks from bakelized fabric by method of pressing is shown in Fig. 12.15. Wheel blanks of textolite are prepared with allowance for machining on external diameter of 2-2.5 mm, and in width of rim 1-1.5 mm. Cleanness of surface of pressed blank depends on cleanness of surface of the molds for final forming and is usually ensured within limits of 7th class.

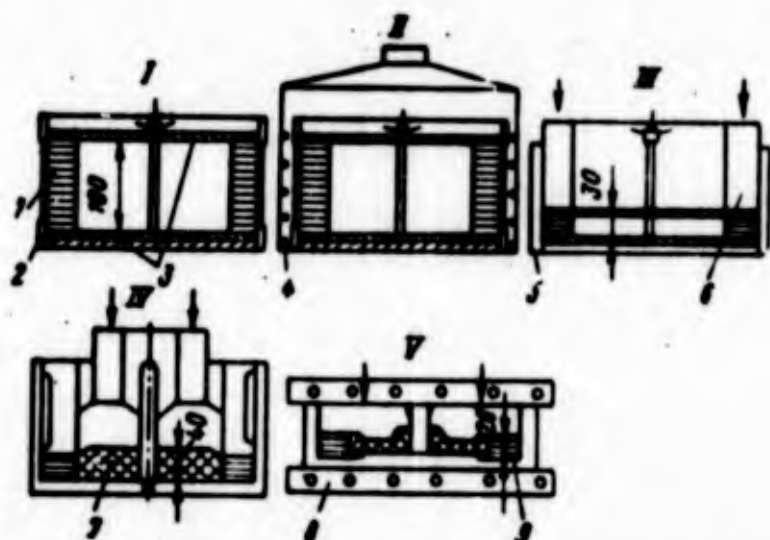


Fig. 12.15. Flow chart of manufacture of gear blank from segments of bakelized fabric by method of pressing. I) stacking of segments; II) heating; III) pressing of rim; IV) pressing of disk from textolite crumb; V) final pressing of blank. 1) segments of bakelized fabric; 2) chase; 3) steel disks; 4) oven; 5) mold; 6) punch; 7) textolite crumb; 8) heating plates; 9) textolite gear blank.

Machining consists of machining the rim and cutting teeth on usual gear-milling or gear-slotting machines. Cutting is produced without a cooling liquid. To avoid delamination of edges during cutting of teeth the blank for gears should be pressed between two disks of bronze or hard wood. Cleanness of surface of teeth of textolite gears during machining is attained in 5th or 6th class.

Pressing of stator blades of a compressor is produced in a metal mold. In the beginning from impregnated glass fabric (or glass ply) there are cut blanks taking into account allowance for shrinkage and machining, and they are gathered in a pack of necessary thickness for formation of the required size of the blade profile. Pack is placed in mold, where after preheating it is pressed under high pressure — of the order of 200 kg/cm^2 ($\approx 200 \cdot 10^5 \text{ newton/m}^2$). After operation of pressing, blades are subjected to heat treatment at $160\text{-}180^\circ\text{C}$. Machining of blades consists of deburring of nose and

trailing edges and finishing of the journal.

Extrusion of pipes from thermoplastic materials is carried out on worm molding machines of continuous action and high productivity.

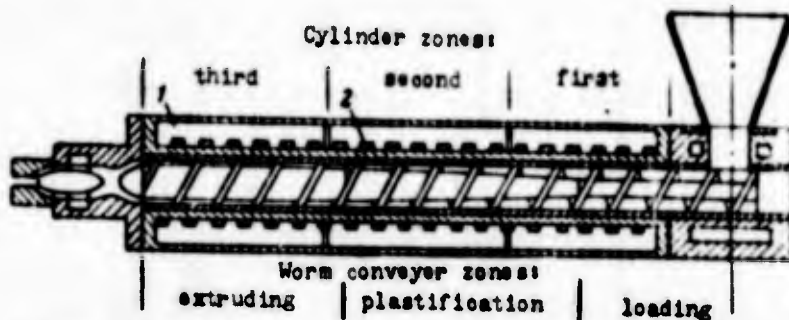


Fig. 12.16. Diagram of worm molding of plastics by extrusion. 1) heating chamber; 2) heating element.

Process of extrusion is the following: plastic in a cold state in the form of powder or granules is poured into the machine hopper and by a worm (or plunger) press, it is fed first into the heating chamber, and then after transition of mass into plastic state it is extruded through a die, having a hole of the required form and dimension. After emerging from the die the pipe is cooled and is cut into segments of required length. In Fig. 12.16 there is given a diagram of screw pressing. The installation includes a press with a control panel, a filling attachment, a heating device for heating the raw material, a pneumatic calibrating device, a cooling sprayer, a track mechanism and capacitor pickups for monitoring the diameter and thickness of pipe walls.

Molding of sealing rings and cups from molding rubber is produced in multiimpression molds (Fig. 12.17) on hydraulic presses.



Fig. 12.17. Diagram of molding of rubber cups in a multiimpression mold.

Specifications for molding depend on the composition of the rubber mixture, the construction of the piece and the mold. Optimum temperature of molding of molding rubber of brands VIAM-103, 3834 is $143 \pm 2^{\circ}\text{C}$. Specific pressure

of pressing is from 10 to 20 kg/cm² ($\approx 10 \cdot 10^5$ to $20 \cdot 10^5$ newton/m²). Duration of the process of vulcanization depends on the composition of the molding rubber, dimensions of the piece, pressure and temperature, and usually comprises 5-8 minutes. For best flow of the process of vulcanization to the rubber mixture there is added ground sulfur (0.06-1.5%) and accelerators "Koptiks,"* Altax, and others. To improve mechanical properties of packing parts (strength and wear) to rubber composition there is introduced as a filler carbon black.

For protection of molds from adhesion of the work piece in process of pressing its surface is sprinkled with talc. For molding, the molding rubber is cut in equal portions and is loaded in mold cavities. Process of pressing continues for 0.5-1 minutes; vulcanization of rubber goes for 6-8 minutes at 143°C.

Molding and vulcanization of reinforced cups is produced from rubber 3834 by method of transfer molding. The reinforcement is thoroughly degreased by gasoline, is inserted in the heated mold, after which in loading chamber there is placed a specific batch of molding rubber. The piece is pressed; the press is turned off; there starts the vulcanization process at 143°C for 6-8 minutes after which the finished part is removed from the mold.

Winding of bottles. Bottles of cylindrical and spherical form are prepared by method of winding of glass filaments, braids, ribbons or cloth on special winding machines. During winding there is created a definite filament tension, thanks to which there is attained tight packing of layers of wound material. For manufacture of bottles by this method there is chiefly applied a binder of contact type (polyester resins), solidification of which can occur both

*Most likely a misprint for Captax. [Tr. Ed. Note]

at room temperature and at raised temperature. The resin is applied in the process of winding of fiber glass by means of passage of filaments through a bath of resin, or manually (by brush). To guarantee airtightness of vessels layer-by-layer there are inserted sealing linings of elastic materials (rubber, thiocol, etc.). According to NIIKhIMMASH [All-Union Scientific Research and Design Institute of Chemical Machinery] good airtightness at high pressure was manifested by bottles prepared by a winding of fiber glass, where as intermediate layers by spraying from a pistol there was applied a polyethylene layer. Polyethylene powder links well with the raw surface of fiber glass or glass cloth and at corresponding temperature becomes gelatinous, tightly coheres to resin and forms a solid, thin, impenetrable film. Polyethylene, possessing high ability to be deformed, serves a compensator between the resin and fiber glass preventing formation of cracks in the vessel as a result of deformation from excess pressure inside the vessel; but remaining monolithic, it ensures airtightness of the vessel. Impregnation of fiber glass in this case is produced epoxy or furyl resin. Winding of fiber glass for production of cylindrical shells of vessels of open type is produced on winding drums of mountings, equipped with heating devices, necessary for solidifying the binder. Before winding of fiber glass on the surface of the winding drum from a pulverizer there is applied a solution of polyvinyl alcohol in a mixture of water and ethyl alcohol, which after drying will form a thin film of polyvinyl alcohol, preventing gluing of the workpiece to the surface of the winding drum and facilitating removal of the piece from the drum.

Machining of bottles and tanks consists of cutting off the allowance on the edges, general deburring of the external surface

and removing from fittings, accumulations of binder. Cutting of edges is produced by ordinary cutting tools or abrasive wheels, moistened with water. Deburring of the surface is produced by a variofles fiber wheel with glued emery paper No. 70-80.

Casting of semi-shrouded impellers is produced in molds under pressure.

Casting of shrouded impellers is complicated by form of the shrouded channels. If width of the channel from the periphery of the impeller to the center is constant, the cavity of the channels will be formed by sliding tapered metal rods. If, however, channel width increases (which more frequently occurs), the tapered rods are made demountable in three parts with fixation of them by signs. A demountable rod has a middle section with parallel sides and two lateral tapered sections, adjoining to it on the two sides.

To avoid durable adhesion of plastic to parts of the mold all working surface of the mold, and especially lateral wedges, are finished with great thoroughness to cleanness of 11th or 12th class.

Molding of semi-shrouded impellers is produced in molds on powerful hydraulic presses. Obtaining of uniform part thickness and required density is ensured by corresponding pressure and batching of molding powder. Construction of the mold for an impeller is very similar to a casting mold, and all its elements are rigid. A deficiency of molding of plastic in rigid molds is inconstancy of pressure on all surfaces of the molded part. Due to this, strength of the part in various places is unequal. To level out the specific pressure on all surfaces parts are pressed in vacuum molds, in pneumatic forms with the help of blowing of a rubber bag and in autoclaves. However, to apply these methods to molding of an impeller, and especially its blades, is extraordinarily difficult.

Assembly of housing and shroud of a shrouded impeller is produced by pins, rivets, gluing and welding.

Assembly by pins, entering holes of the cover, and by through rivets passing through the body of the blades, requires increase of blade thickness and is inferior in strength to gluing and welding.

Glued surfaces before assembly are turned on a lathe from a master form with precision in clearance of 0.1-0.15 mm. With clearance greater than 0.15 mm there is produced manual trimming. In small-lot production manual trimming can be replaced by molding of edges by a hot metal form.

The housing and shroud from plastic of brand AG-4 and K-6 are glued by glue BF-4.

With exact molding of blanks joint surfaces before gluing are not turned, but are cleaned by sandpaper to remove the gloss.

To weld the shroud with blades of the housing by a flame burner is impossible, since plastic, thus melted, loses its strength properties. Therefore, the shroud is welded to the impeller housing under a press with the help of hot flow-through air, directed by deflectors to the welded surfaces. Temperature of the air and magnitude of specific pressure during compression of parts will be selected by the composition of the plastic. On the average these temperatures are 100-150°C; pressure is 20-40 kg/cm² ($\approx 20 \cdot 10^5$ to $40 \cdot 10^5$ newton/m²).

It is possible to weld combined impellers by ultrasound. This method of welding is convenient in that it does not require preheating of the welded parts. However, there is still no industrial experience of ultrasonic welding of impellers. According to the plastics laboratory MEI [Moscow Power Engineering Institute], impellers from polyamide resin P-68 and from polypropylene ultrasound

had in seams identical strength with the basic material. Deformation and shrinkage of blades due to compression of them with the shroud in this welding was within 0.2-0.3 mm.

CHAPTER XIII

MANUFACTURE OF FUEL ELEMENTS OF NUCLEAR POWER PLANTS

Space power plants (SPP) being developed at present consist of two parts — power and accelerating.

In the power part are included source of thermal energy and arrangement for conversion of thermal energy into electrical. As source of thermal energy in overwhelming majority of installations there is used an atomic reactor, and as the converter — a machine generator.

Considering the complex of a machine power plant, it is possible to note that with the exception of the reactor, all remaining units have design prototypes, technological features of which are described in preceding chapters; manufacture of reactor and, in particular, fuel elements (FE) has its own peculiarities. These circumstances cause the necessity to discuss problems of manufacture of FE in this chapter.

§ 1. CONSTRUCTION, ENGINEERING FACTORS, AND MATERIALS

Fuel elements (Fig. 13.1) are devices containing nuclear fuel and providing when they are placed in a reactor core a fission chain reaction, generation of heat, and transmission of it by means of a

heat-transfer agent.*

Reactor core is assembled from separate fuel elements, from

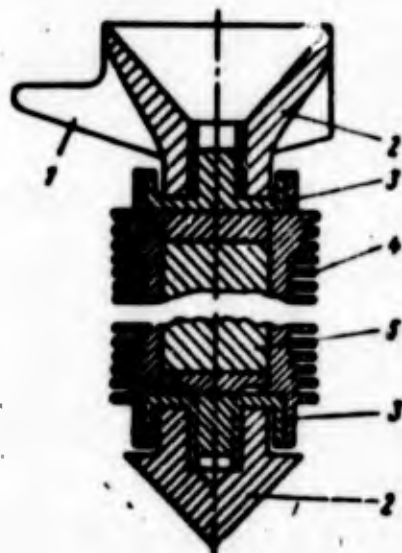


Fig. 13.1. Structural diagram of FE. 1) spacer part; 2) upper and lower centering cones; 3) upper and lower end parts; 4) finned shell; 5) active volume.

assemblies or units combining several elements in one common unit. Sometimes such a unit of several elements is called an "assembly." Design forms of FE are quite varied; however, the greatest attention is paid to rod, plate, strip, multitubular, and block multichannel FE (Fig. 13.2).

Active volume of FE usually has cylindrical, hexahedral, or flat shape and is protected from contact with heat-transfer agent by a shell, which should have a surface which ensures good heat removal and small flow friction for the heat-transfer

agent. In connection with this certain designs of shell have longitudinal or helical finning.** For decrease of temperature gradient between active volume and shell, the gap between them is filled with helium or sodium.

Conditions of operation of FE are characterized by presence of radiation damage, corrosion, and erosion processes, diffusion of elements of active volume into shell, periodic oscillations of temperature and possibility of allotropic transformations. For propulsion reactors it is necessary to consider also vibrations and

*At present there have been developed reactor-generators in which conversion of thermal energy into electrical is carried out by means of the thermionic effect.

**Helical finning with small angle of twist, simultaneously with improvement of heat withdrawal, fulfills the role of spacer components.

overloads appearing with change of velocity vector. At the same time, from fuel elements there is required absolute reliability. Therefore, to fuel elements there is presented an extensive complex of requirements, a considerable part of which have technological character.

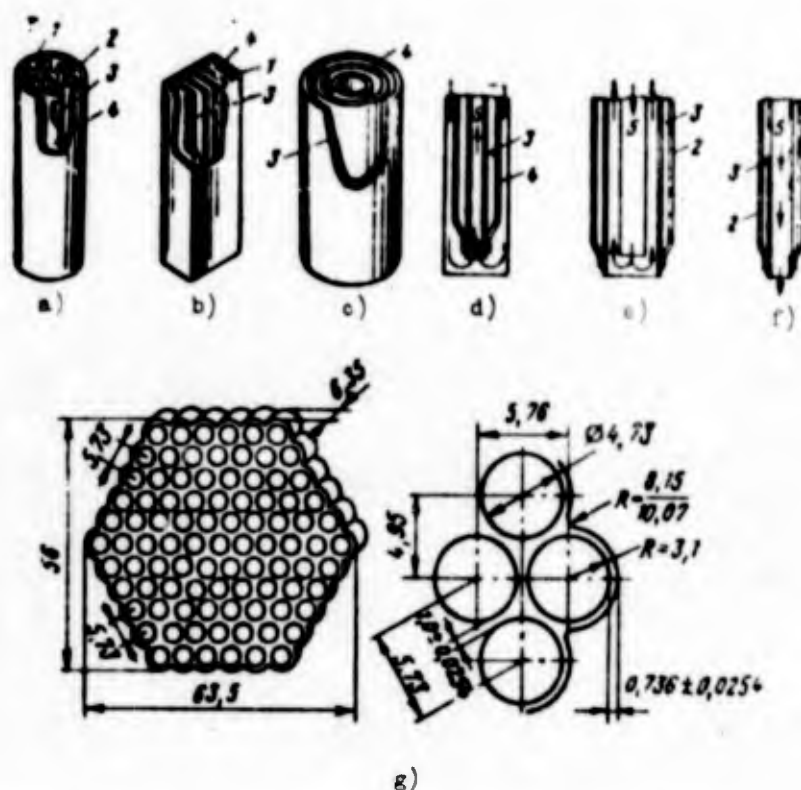


Fig. 13.2. Diagram of fuel elements, a) rod; b) plate; c) multitubular; d) field tube with bidirectional cooling; e) field tube with unidirectional cooling; f) single-tube; g) hexahedral multichannel. 1) case; 2) shell; 3) fuel; 4) FE; 5) heat-transfer agent.

Thus, for instance, for maintaining of design physical characteristics of reactor, deviation from given chemical composition for reactor materials must not exceed tenths, and sometimes hundredths of a per cent, and undesirable impurities are limited to thousandths of a per cent. These requirements extend also to composition of solders and filler materials used in welding. Quantity of fissionable material in fuel element is regulated with accuracy of 0.25-0.5%, and its concentration in volume of FE should be uniform

or change according to a given law. Internal part of element must not contain any contaminating chemical components. In connection with this, for decrease of adsorbing properties of surface of shells and blocks, they are subjected to electrochemical polishing. All joints of shell have to be strictly hermetic. Arbitrary change of dimensions and shape of element during operation of reactor can lead to local overheating and even melting of shell; therefore, processing of FE should ensure maximum lowering of residual stresses and also ensure the assigned accuracy of dimensions of active blocks or pellets, shells, or circulating tubes. Usually dimensions of cross sections of these components are made according to second accuracy class. Permissible bend of every element depends on construction of reactor and oscillates from 0.3 to 0.8 mm per 1 m length. In Fig. 13.3 there is given an example of design of FE with indication of requirements for manufacture.

Active volume of FE is filled with material containing in a definite amount of one of three radioactive isotopes: uranium-235, uranium-233, plutonium-239.

Depending upon type of nuclear fuel, there are distinguished fuel elements:

- 1) based on metallic nuclear fuel;
- 2) with ceramic nuclear fuel;
- 3) of dispersion type, in which ceramic nuclear fuel is distributed in a matrix of structural material.

Metallurgical uranium and plutonium in pure form have several allotropic transformations, which are accompanied by change of volume, and possess high chemical activity, which makes them not very suitable for use in fuel elements. Alloying of uranium with aluminum,

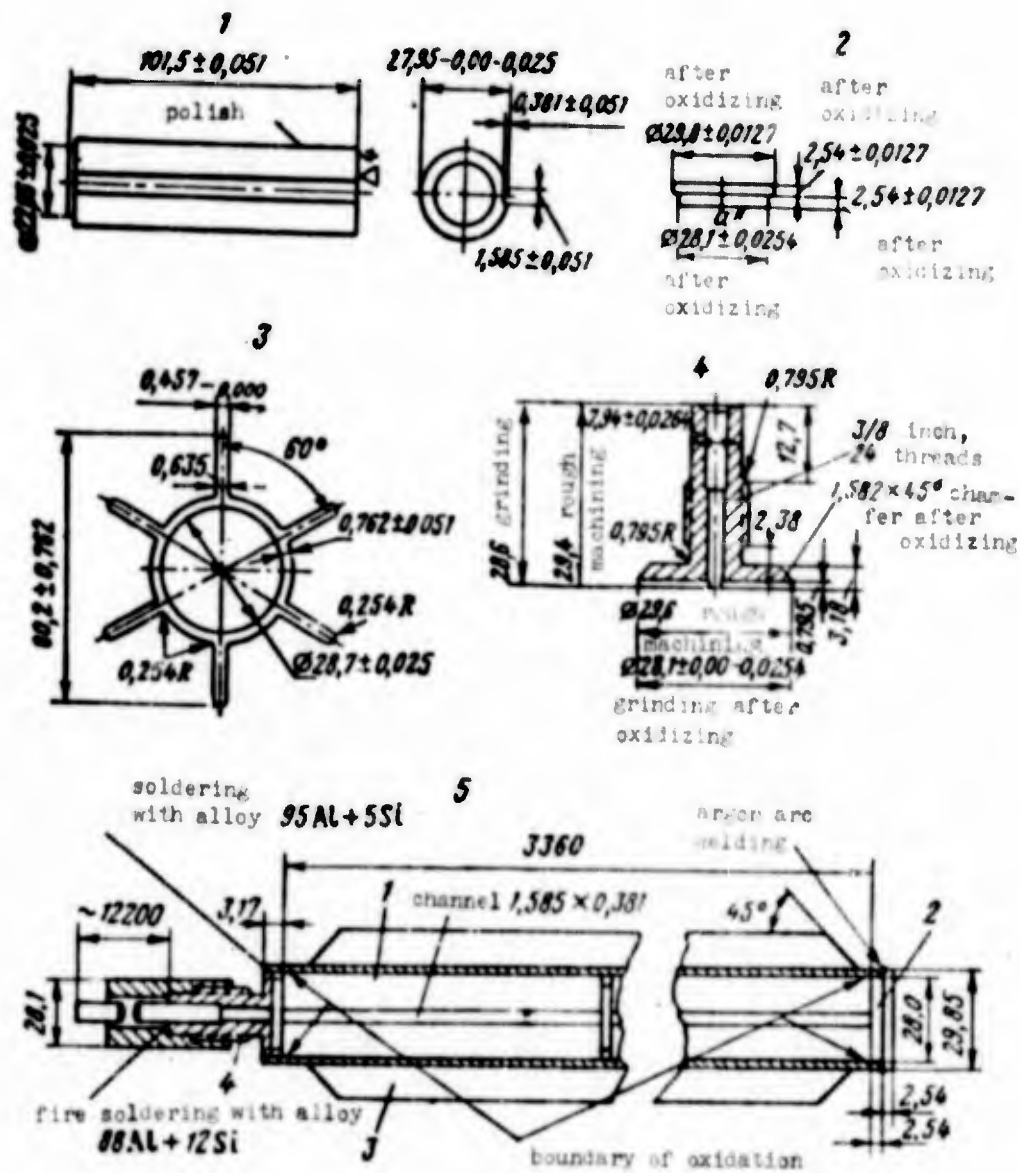


Fig. 13.3. Fuel element of Brookhaven National Laboratory. 1) uranium block; unparallelism of end surfaces not more than 0.025; projecting edges are not allowed; 2) upper cover; 3) shell with longitudinal fins; twist of fins is 3.28° ; curvature of axis is not more than 0.354 mm per 1 m; there are not allowed scratches, laps, abrasions, pits, cracks, blisters, or other defects; every pipe is placed into separate packing pipe with thickness of wall of 4.76 mm and packed in a wooden box; 4) lower cover; 5) overall view of FE.

chromium, molybdenum, zirconium, and niobium considerably improves its properties. Blocks made of uranium alloy with addition of chromium (0.1-0.4%), molybdenum (1.5-2.0%), or zirconium (2.0-6%) have α -phase and can be used for thermal-neutron reactors. Uranium alloy with 9-10% molybdenum or 10% niobium and 4% zirconium permits

obtaining γ -phase and can be used for fast-neutron reactors.

Alloys of uranium with lead and bismuth present interest for production of liquid-metal fuel.

Plutonium in alloys with metals of III group of periodic system of elements of Mendeleev retains plastic δ -phase. Thus, for instance, plutonium alloy with aluminum gives stability of δ -phase up to temperature higher than 600°C . Alloying of plutonium with elements of IV group: tantalum, zirconium, hafnium, considerably improves its properties and can be used for fuel elements of fast reactors. Iron, nickel, and cobalt form with plutonium low melting eutectics, which are suitable for use as liquid-metal fuel.

Compounds of uranium and plutonium find application for manufacture of ceramic pellets, multichannel blocks, and dispersion fuel elements. Besides high-temperature oxides, carbides, nitrides, and silicides, there are used different intermetallic compounds. In Table XIII.1 there are given brief characteristics of certain compounds of uranium and plutonium.

Of uranium compounds, the most widely used is uranium dioxide, which possesses inertness with respect to hydrogen, water, and carbon monoxide, and also retains good strength up to 1000°C . In connection with bad thermal conductivity of uranium dioxide, articles made from it have to have minimum thickness of walls. Carbides, nitrides, silicides, and other compounds of uranium and plutonium are used considerably less frequently.

Fuel-element jacket is a very important component. During operation of reactor it is subjected to intense irradiation, influence of non-steady temperature field with large gradients, and also to mechanical and chemical influence of the heat-transfer agent.

Table XIII.1. Brief Characteristics of Compounds of Uranium and Plutonium

Compound	Content of U or Pu		Melting point, °C	Theoretical density g/cm ³	Fission cross section, barns	Total absorption cross section, including fission cross section, barns
	mass %	g/cm ³				
UO ₂	88.2	9.68	2880	10.97	1.4	2.56
UC	95.2	13.00	2370	13.63	2.10	3.85
UC ₂	90.8	10.60	2470	11.68	1.39	2.54
UN	94.4	13.50	2650	14.32	2.10	4.79
USi	89.5	9.30	1600	10.40	2.10	3.91
U ₂ Si ₂	92.7	11.30	1665	12.20	2.52	4.65
UBe ₁₃	67.0	2.94	2000	4.37	0.32	0.59
PuO ₂	88.0	10.11	2210	11.46	240	339
PuC	95.0	12.91	1850	13.60	358	505
PuN	94.5	9.32	—	9.87	366	517
PuBe ₁₃	67.0	2.92	1700	4.36	51.5	72.5
Pu ₂ Si ₃	93.0	5.90	2200	12.70	233	407
PuAl ₂	81.5	6.60	1480	8.09	378	535

Of the materials of shell of FE there are made the following requirements:

1. Minimum parasitic neutron capture.
2. High thermal conductivity.
3. Mechanical reliability and constancy of geometric shapes.
4. Corrosion and erosion stability.
5. Compatibility with material of active volume of FE.

At present for shells of fuel elements there are applied: aluminum, magnesium, beryllium, nickel, zirconium, vanadium, niobium, molybdenum, tungsten, tantalum, alloys based on these metals and special steels.

For shells of fuel elements operating at temperatures of up to

700°C with superheated steam or liquid-metal heat-transfer agent (Pb, Bi, Sn, Na, Na-K, Zr) in fast reactors there are successfully applied chrome-nickel stainless steels of type OKh18N9 and OKh18N9T and also stainless steels of type Kh-13 (C - 0.15%, Cr - 12-14%) and Kh6M (C ≤ 0.15% Cr - 5-6.5%, Mo - 0.45-0.6%, V - 0.15-0.25%).

For fast-neutron reactors operating at temperatures of 700-900°C, there are used Nichromes (65-80% Ni; 10-20% Cr, 0.25% Fe) and alloys of type EI437 and EI617. Of the especially refractory metals (niobium, molybdenum, tungsten, and tantalum) there are now used niobium, which combines refractoriness with high plasticity, and molybdenum. Application of other refractory metals encounters a number of technological difficulties, on the surmounting of which at present time there are being conducted intensive works.

§ 2. CONSTRUCTION OF TECHNOLOGICAL PROCESS

Production of fuel elements, besides requirements of high precision of conditions of carrying out of all processes, wide application of vacuum and protective media, is characterized by the danger of internal and external irradiation, and also by the possibility of appearance of self-supported chain reaction. Especially large danger for the staff is presented by internal irradiation, which is connected with striking of human organism with α -active particles. Thus, for instance, maximum permissible quantity of plutonium in organism of person must not exceed 0.6 microgram.

In Table XIII.2 there are given norms of radiation contamination approved in USSR, and specific α -activity of atomic fuels.

Danger of internal irradiation is especially great during work with dry powders containing uranium or plutonium.

Table XIII.2. Maximum Permissible Concentrations of Radioactive Substances in Air and Water and Specific α -Activity (1g) of Atomic Fuel

Isotope	Permissible concentration in curies/liter		Specific α -activity (1 g)	
	in air of closed location	in water of open reservoirs	disintegrations/sec	micro curies
Pu-239	$2 \cdot 10^{-15}$	$5 \cdot 10^{-11}$	$\sim 2,3 \cdot 10^6$	~ 62000
U-233	$2 \cdot 10^{-14}$	$3 \cdot 10^{-11}$	$\sim 3,5 \cdot 10^6$	~ 9600
U-235	$2 \cdot 10^{-14}$	$3 \cdot 10^{-11}$	$\sim 6,4 \cdot 10^4$	$\sim 1,7$

*A curie is equal to $3.7 \cdot 10^{10}$ disintegrations per sec.

Protection from external α -irradiation does not present special difficulties due to the low penetrating ability of α -particles. External irradiation by γ -rays and β -particles can take place when there are certain impurities in the nuclear fuel (beryllium, hydrogen, and others), and also with accumulation of large quantity of fissionable material. Protection from γ -rays requires installation of special shields or remote control of the process; β -rays are easily absorbed by aluminum screen.

For preventing of fission chain reaction accompanied by powerful neutron radiation and liberation of heat, technological process should be designed in such a manner that there does not appear large accumulation of isotopes plutonium-239, uranium-233, and uranium-235. Magnitude of critical mass depends on type of nuclear fuel and reflectance of substances located around the fissionable material.

Special danger is presented by operations with aqueous solutions, during which critical mass is decreased by many times. Appearance of the indicated characteristics of processing of nuclear fuels depends on a number of factors whose influence is not subject to

strict regulation; therefore, development of technological processes of manufacture of fuel elements is usually conducted with participation of physicists.

Production cycle of manufacture of fuel elements can be divided into three processes:

1. Manufacture of active volume.
2. Manufacture of shells, end and spacer components.
3. Packing of active volume into shell of element.

This division has a conditional character, since in certain cases these processes are carried out jointly.

Methods applied during manufacture of elements (especially active volume) depend on type of nuclear fuel. Thus, for instance, elements with metallic nuclear fuels are prepared by methods of metal-working. Manufacture of elements from oxides, carbides, or other compounds of uranium or plutonium is based on ceramic technology. Methods of manufacture of elements of dispersed type depend on material of matrix in which ceramic fuel is distributed.

Main problem of first stage is obtaining of necessary quantity of fissionable material in the active volume. In case of assembly of active volume from metallic slugs, this is attained by strict regulation of dimensions of slugs; in case of use of powders there is introduced strict control of volumes or masses during preparation of mixture.

As the billet for metallic slugs of uranium there serves a rod obtained by rolling or by extrusion through a die. Rolling is conducted from cylindrical ingots, the mass of which depends on degree of enrichment of metal with fissionable isotope. Heating of ingot to 640° is carried out in salt mixtures ($\text{Li}_2\text{CO}_3 + \text{K}_2\text{CO}_3$ or $\text{BaCl}_2 + \text{KCl} + \text{NaCl}$) for 2-3 hours. Rolling of uranium is conducted

in α -phase on rolling mills by periodic or continuous rolling. Rolled rods with diameter of 35-38 mm are straightened, rough turned, and cut, and after hardening the slugs are usually finished on transfer machines.

Along with forging and rolling, uranium rods are obtained by extrusion in γ -phase with application of glass lubricants, which protect uranium from oxidation, and with heating of billet during extrusion by an inductor.

For production of uranium tubes or tubular slugs it is possible to use method of powder metallurgy; however, then there appear a number of difficulties in connection with high chemical activity of uranium powders.

Method of precision vacuum casting makes it possible to obtain satisfactory tubular blanks.

Thus, for instance, by precision casting there have been obtained blanks with external diameter of 19.1 mm, internal diameter of 6.55 mm, and length of 178 mm for fuel elements of the Dounreay fast-neutron reactor (attempt to cast uranium tubes with length of 535 mm was not successful, since minimum non-uniformity in pipe thickness reached 0.76 mm, and distortion of axis was more than 0.63 mm).

There was obtained satisfactory accuracy of internal diameter, and external diameter was machined. Tubes were cast from uranium enriched to 40%. Mass of melt did not exceed 3 kg.

Hollow metallic cores sometimes are prepared from a rod whose central hole is drilled on machines for deep drilling. This method gives high accuracy of dimensions with almost total absence of rejects. Deficiency of this method is low productivity, and also large quantity

of waste.

Plutonium metallic cores are processed by the same methods; however, during assignment of operating conditions it is necessary to consider tendency of this element toward allotropic transformations and formation of eutectic of plutonium with iron, melting point of which is below 500°C .

Active volumes of fuel elements of uranium dioxide and other compounds are obtained by methods of ceramic production or filling of powder into metallic shell with subsequent rotary forging or drawing for densification of powder.

Powders of the most widely used ceramic nuclear fuel — uranium dioxide — in most cases are obtained by following methods:

1. Decomposition of hexahydrate uranyl nitrate. This method consists of following operations:

a) Obtaining of UO_3 by means of decomposition of uranyl $\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ at 260°C .

b) Wet grinding of UO_3 powder.

c) Reduction of UO_3 to UO_2 by hydrogen or dissociated ammonia ($75\% \text{H}_2 + 25\% \text{N}_2$) at $680\text{--}800^{\circ}\text{C}$.

2. Precipitation of ammonium diuranate $(\text{NH}_4)_2\text{U}_2\text{O}_7$ from solution of uranyl nitrate with subsequent decomposition and reduction of filtered ammonium diuranate to UO_2 by hydrogen at 900°C .

3. Treatment of uranium hexafluoride, which consists of the following processes:

a) Sublimation of UF_6 by heating to 100°C .

b) Hydrolysis of UF_6 by solution of ammonia until obtaining of deposit of ammonium diuranate.

c) Separation of diuranate by filtration, washing with water,

and drying at 100-200°C.

d) Pyrohydrolysis of dry diuranate powder by steam 800-850°C until formation of U_3O_8 .

e) Reduction of U_3O_8 to UO_2 at 800°C by hydrogen or dissociated ammonia.

Quality of obtained powders is estimated by many parameters. The greatest effect on density of pressed and sintered articles is due to specific surface of powder and the ratio O/U. In Table XIII.3 there are given data on influence of specific surface and this ratio on density of pressed and sintered articles.

Table XIII.3. Density of Pressed and Sintered Articles from Powder of Uranium Dioxide [Pressure of Pressing 2.8 T/cm², (~280 meganewtons/m²), Sintering in Hydrogen at 1700°C for 30 min]

Initial uranium dioxide	Ratio O/U before sintering	Specific surface, m ² /g	Density of briquettes g/cm ³		% of theoretical density
			after pressing	after sintering	
Pyrolysis of uranyl nitrate to UO_3 , hydrogen reduction	2.048	1.38	6.62	8.65	78.75
Precipitation of ammonium diuranate from uranyl nitrate, decomposition and hydrogen reduction	2.112	3.83	5.72	9.96	90.0
Hydration of UO_3 by means of wet grinding in ball mill, hydrogen reduction	2.124	5.04	5.73	10.57	96.5

Process of manufacture of ceramic pellets or slugs consists of two stages: forming of article and its sintering. For forming there can be used methods of cold and hot pressing, extrusion and cross casting.

Of the enumerated methods the most widely used is cold pressing with subsequent sintering and grinding of article. Before pressing, into uranium dioxide powder there are introduced binder (1-2%) for increase of strength of pressed article and lubricant (0.2-1.4%) for facilitation of briquetting and decrease of wear of press-forms. As binder there are used polyethylene glycol, petroleum paraffin, and other organic compounds, derivatives of stearic acid, saturated hydrocarbons, and their alcohol derivatives. Press-forms are made from hard alloys or tool steels. Pressure of pressing is 2-3 T/cm²* ($\approx 200-300$ meganewtons/m²). For removal of volatile compounds binding and lubricating materials, articles after pressing are subjected to "drying" in atmosphere of CO₂ (800°C for 2 hours) or in dry hydrogen or dissociated ammonia (400°C for 1-4 hours).

The most important operation during manufacture of ceramic elements is sintering, which can be produced in atmosphere of hydrogen, inert gas, steam, or in a vacuum. The best results are given by sintering in hydrogen, which not only protects article from oxidation, but also reduces higher oxides to UO₂. In Fig. 13.4 there is shown dependence of density of article on temperature of sintering in hydrogen, from which it is clear that maximum density is attained at 1600-1700°C. Sintering in atmosphere of argon or steam permits lowering of temperature to 1300-1400°C; however, then there inevitably appears disturbed stoichiometry of the composition. For preventing of cracking of articles during sintering there is applied step heating with definite rate of change of temperature. Rate of sintering and density can be increased by introduction into uranium

*T = metric ton.

dioxide of the additions 0.1% TiO_2 or 0.4% NbO_5 . Introduction of

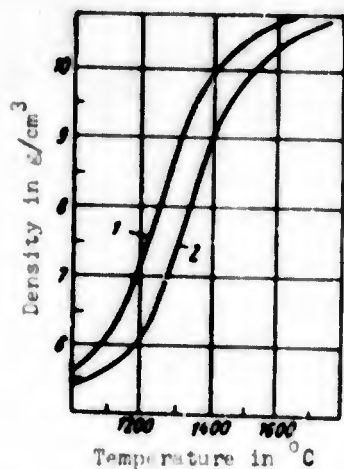


Fig. 13.4. Density of articles of uranium dioxide during sintering in hydrogen. 1) wet; 2) dry.

niobium oxide almost completely prevents change of shape of articles.

Second method of manufacture of fuel elements from ceramic fuel consists of filling of powder into metallic shell. Into the shell there usually is poured preliminarily sintered or arc melted powder with bumped down density from 3 to 7 g/cm³. For best bumping down it is recommended to pour in a mixture of powders consisting of the

following fractions:

- from 6 to 20 mesh. 60%
- from 35 to 100 mesh. 20%
- 325 mesh 20%

Bumping down of powder in tube is produced with help of vibration tables operating in spectrum of frequencies from 5 to 5000 cps with amplitude of 0.25-0.5 mm.

Subsequent rotary forging or drawing permit obtaining very high density (to 92% of theoretical) and good adjoining of shell to active volume. During reduction on rotary-forging machine, simultaneously with densification of powder there occurs lengthening and thinning of shell which makes it possible to obtain shell with very thin walls. In Fig. 13.5 there is shown change of density of powder, thinning, and lengthening of shell during reduction on rotary-forging machine. It is necessary to note that degree of compaction of powder depends on mechanical properties of material of shell. Fuel elements obtained by this method possess following deficiencies:

very low thermal conductivity of compacted, but not sintered powder and work hardening of shell remaining after reduction.

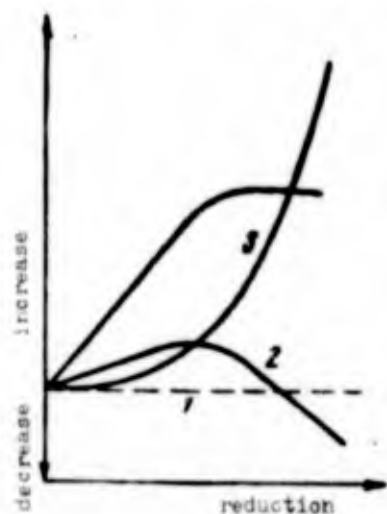


Fig. 13.5. Changes of density of uranium dioxide and geometric dimensions of shell during rotary forging. 1) initial conditions; 2) thickness of wall of shell; 3) length of element; 4) density of oxide.

Active volume of fuel elements of dispersed type is a heterogeneous mixture of ceramic atomic fuel with an inert diluent. Depending upon material of diluent, cores of such elements can be divided into two groups:

1. Ceramic fuel (PuO_2 , UO_2 , UC , and others) distributed in ceramic or graphite matrix (Al_2O_3 , MgO , SiO , ZrO_2 , BeO , graphite, and others).

2. Ceramic fuel distributed in metallic matrix (aluminum, nickel, steel, niobium, zirconium, alloy of type EI437, etc.).

First type of cores can be used for high-temperature reactors with gas heat-transfer agent. (Thus, for instance, in the American ship reactor MGCR, there is used mixture of UO_2 and BeO , which permits raising temperature of helium heat-transfer agent to 815.5°C).

Manufacture of cores of this type is based on methods of ceramic technology. Cores of second type possess a number of advantages, due to higher thermal conductivity and density of metallic matrix, which also makes application of soldering and welding for joining of active volume with shell possible.

Manufacture of cores with metallic matrix can be carried out by casting or the method of hot pressing of powders, which permits obtaining of optimum ratio of components and dimensions of their

particles, good distribution of fissionable material in matrix and is carried out at lower temperatures. The latter is especially important during manufacture of core from components which react with each other at high temperatures. Fuel elements of dispersion type have different structural shapes. In Fig. 13.6 there are shown

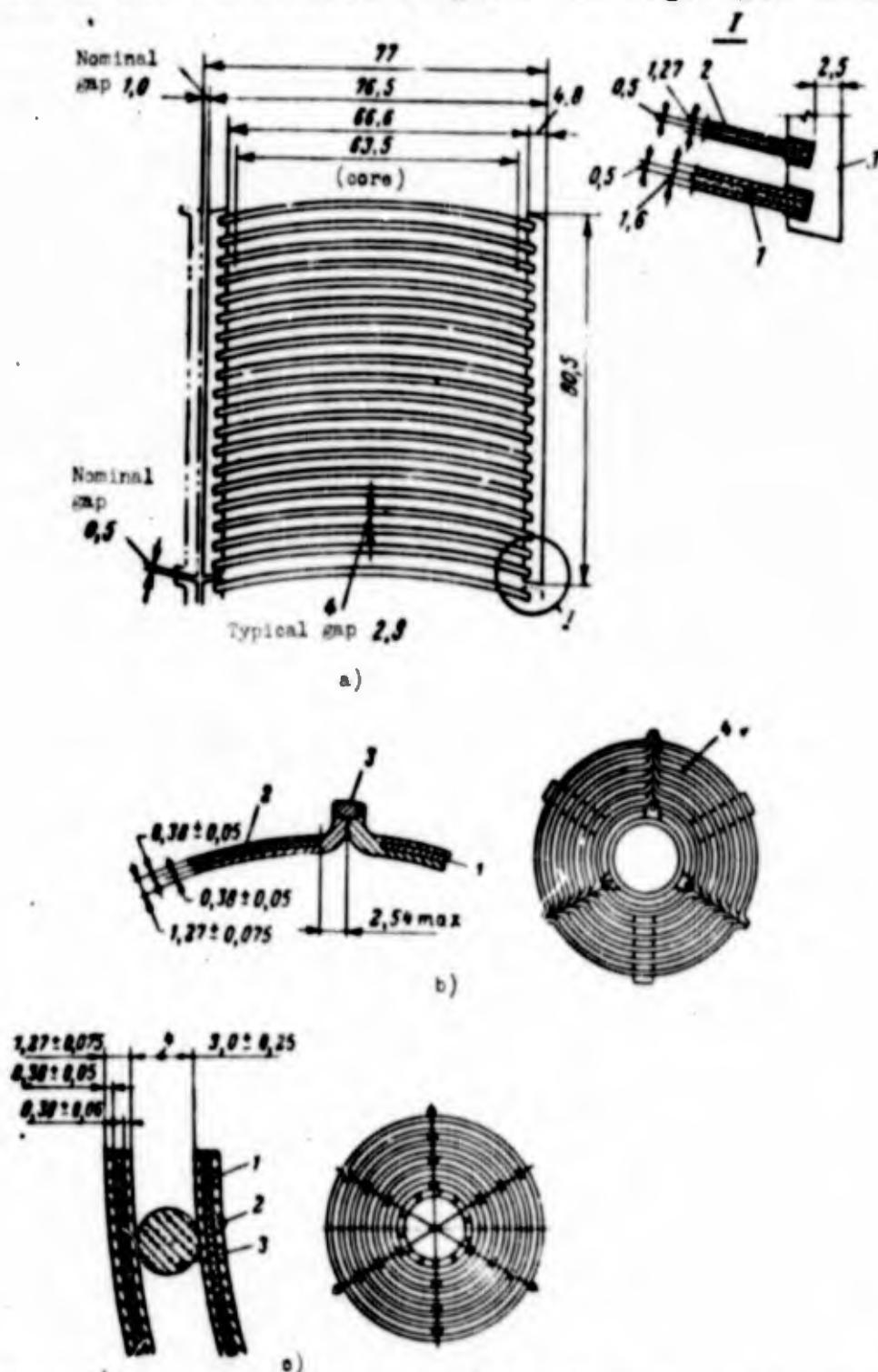


Fig. 13.6. Cross sections of fuel assemblies made up of elements prepared by "frame" technology. a) plate-type; b) annular-type made from three-seam tubes; c) annular seamless. 1) fuel; 2) shell; 3) spacer element; 4) gap for passage of heat-transfer agent.

cross sections of "assemblies" of fuel elements of dispersion type with metallic matrix. Technological process of manufacture of such elements ("frame" technology) includes mixing and pressing of powders or melting of components, which is carried out in graphite crucible with induction heating. Obtained blank is rolled into a strip whose thickness is approximately 3-4 times greater than thickness of finished core. Then from the strip there are cut plates, which are tightly inserted into a frame of structural metal. Frame with core is placed between two sheets of structural metal, heated and rolled with total reduction of up to 85%. In Fig. 13.7 there are shown components of fuel plate before rolling.

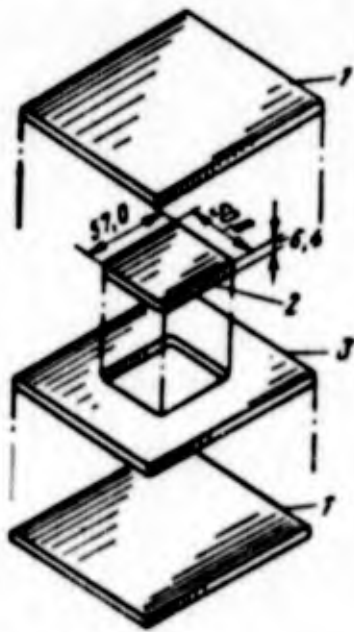


Fig. 13.7. Components of fuel plate before co-rolling. 1) outside plate; 2) active core; 3) frame.

welding or soldering into the so-called fuel "assembly."

Fuel elements in the form of seamless tubes are obtained by means of coextrusion of active volume with shell according to the diagram shown in Fig. 13.8.

Fuel elements of dispersion type can be also prepared by the

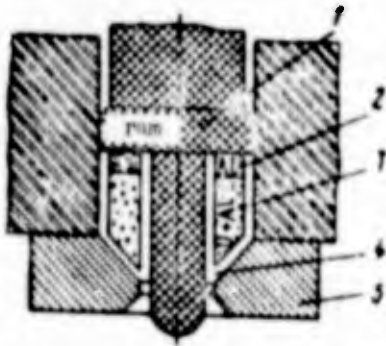


Fig. 13.8. Diagram of coextrusion of seamless annular element. 1) ram; 2) blank flange; 3) fuel; 4) shell; 5) die (inlet angle 90°).

above-described method of ceramic technology and filling of active mixture into a tubular shell with subsequent rotary forging or drawing. Bumping down of active mixture on vibration table should be carried out with small amplitudes to avoid segregation of powders.

From the considered technological processes of manufacture of active volume of element, it is clear that in certain

cases operations of manufacture of shell and packing of fuel into it are carried out jointly. At the same time there exist many designs of elements in which shell is made separately. The most widely used method of manufacture of shells is extrusion of them through a die with subsequent drawing or gaging broaching. This method permits obtaining of shells which are cylindrical, smooth, hexahedral, and finned in the longitudinal direction. In majority of fuel elements, longitudinal fins have small twist ($4-6^\circ$), which provides good spacing of elements in the reactor and increases surface of contact with heat-transfer agent.

In final operations, shells are polished, etched, tested for airtightness, washed, dried, degreased, and desiccated by heating in a vacuum to $150-200^\circ\text{C}$.

Spacer and end components, if they are not an integral part of the shell, are manufactured by machining. Wires applied for spacing of rod and tubular elements are obtained by drawing and welded to shell by resistance welding. End components are made on metal-cutting equipment. As a rule, all components are polished, etched,

and thoroughly washed.

Assembly of fuel elements of rod or tubular type is carried out in the following sequence:

1. Loading of active slugs into the shell.
2. Installation of end components.
3. Evacuation and check of airtightness.
4. Pressing of shell or filling of gap between shell and active volume with helium or sodium.

First operation starts with thorough inspection and, in case of necessity, chemical or mechanical cleaning of parts. To the shell is welded lower end component and slugs are carefully loaded into shell. During assembly of tubular elements, it is more convenient to put the annular slugs on the inner tube, and then to put on the outer shell; however, if inner tube is not welded with end component, (for instance, in the Dounreay reactor), slugs are loaded into outer shell, with subsequent installation of the inner tube.

After installation of slugs of active volume, the upper plug is set in place, the arrangement is evacuated and checked for airtightness, usually with help of helium leak detectors. If non-airtightness is detected, seams are welded or shell is replaced.

Operation of pressing can be carried out by hydrostatic or pneumatic schemes. Last method permits conducting of process at elevated temperatures. Pressure and temperature of pressing are chosen depending upon material of shell. Thus, for instance, for hydrostatic pressing of finned aluminum covering, there is applied pressure of 176 atm ($\approx 176 \cdot 10^5$ newtons/m²); pressing of magnesium shells of French reactor Cr-2 was conducted by two methods: in the beginning by water, then by air at pressure of 35 atm ($\approx 35 \cdot 10^5$ newtons/m²) and temperature of 400°C.

Fuel elements of type of multi-channel blocks (Fig. 13.9) are assembled from separate plates. Plates pressed from powders are



Fig. 13.9. Fuel element of type of multichannel block (into part of holes there are inserted tubes).

lubricated at the ends by mixture of uranium hydride with liquid paraffin oil and assembled with help of steel rods into blocks. After 30-minute exposure under press with total pressure of 4 T (≈ 40 k newtons) at $580-600^{\circ}\text{C}$, the block, for improvement of cohesion between plates, is subjected to heat treatment at 900°C for several hours. In channels of block there are inserted tubes, on which there are placed collector plates of stainless steel. For decrease of thermal stresses, argon arc welding is carried out in strict sequence according to a cross scheme. After welding of collector plates with outer shell, gaps between block and tubes are filled with liquid sodium.

§ 3. CARRYING OUT OF BASIC OPERATIONS OF MANUFACTURE OF FE

Casting of metallic cores from alloys of uranium is one of the basic operations.

Preparation of alloy is conducted in crucibles made of magnesium oxide or graphite of high purity. Charge is loaded in such a manner that after melting of uranium, more refractory, but less dense additions (zirconium, beryllium, titanium, and others) do not come to surface of melt, but remain in liquid uranium; this accelerates their dissolution. Melting is conducted in induction vacuum furnaces with vacuum of $10^{-3}-10^{-5}$ mm of mercury ($10^{-3}\cdot 136-10^{-5}\cdot 136$ newtons/m²).

For obtaining of homogeneity of alloy, after melting it is held

without increase of temperature; then alloy is cooled until hardening, and only after secondary melting is there produced casting of metal. Filling of casting mold can be produced by the lower or upper methods. For best separation of casting from casting mold, internal surfaces of it are covered with aqueous suspension of oxides (for instance, 18% ThO_2 and 2% ZrO_2) with subsequent drying until full removal of moisture. Evacuation of casting mold is carried out until pouring is begun. Volume of melt depends on degree of enrichment of alloy with fissionable isotopes.

Coextrusion of active volume with shell is produced on hydraulic presses. Preparation for extrusion and conditions of the process depend on materials, configuration, and dimensions of extruded articles. Cores filling the shell have to have uniform structure, otherwise the shell after pressing will have considerable nonuniformity in pipe thickness. For improvement of structure of uranium alloys, there is applied isothermal quenching from the γ -phase (790°C) with cooling in lead bath at 500°C . For facilitation of extrusion and protection of shell from oxidation during heating there is applied protective cladding of copper, low-carbon steel, or some other material which is inert with respect to the shell and sufficiently plastic for playing the role of lubricant during extrusion.

Before assembly of block for extrusion, parts are cleaned and etched in acid. For degasification of internal cavity, container is heated to $100\text{-}150^\circ\text{C}$ and evacuated to 10^{-5} mm of mercury ($10^{-5} \cdot 136$ newtons/m²). Then connecting tube is pinched and heating of container is produced (for uranium in zircalloy shell - 650°C). Extrusion is produced through a die made from tool steels or hard

alloy with a rate of 3-5 m/min. Angle of entrance into die in most cases is equal to 90° ; gaging collar has width of 0.5-1 mm. For subsequent cleaning and gaging of extruded rods, it is necessary to provide for an allowance of 0.05-0.2 mm. In Fig. 13.10 there is shown diagram of blank assembled for coextrusion.

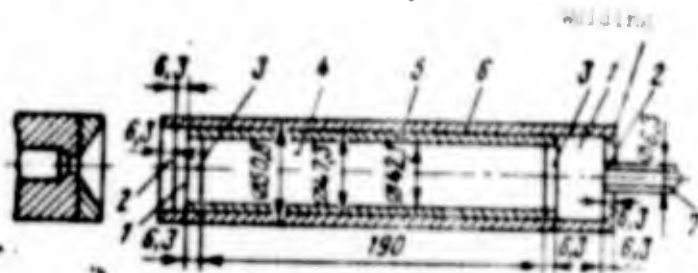


Fig. 13.10. Diagram of blank assembled for coextrusion. 1) plugs of copper-nickel alloy; 2) copper plugs; 3) end plugs of zircalloy-2; 4) core of uranium alloy with 2% zirconium; 5) shell of zircalloy-2; 6) copper protective shell; 7) copper tube for pumping out of air.

Pressing of plates for multichannel blocks is carried out in special press-forms (Fig. 13.11). Charge is prepared by prolonged (3-4 hour) mixing of finely divided pure powders. Stability of thickness of plates (+0.1 mm) is ensured by exact apportioning of powder poured into the press-form. Pressure of pressing is 5.6 T/cm^2 ($\sim 560 \text{ meganewtons/m}^2$). As a lubricant there is used camphor, which provides for normal flow of process of subsequent vacuum sintering, which lasts about 4 hours at a temperature of $5-10^\circ\text{C}$ below melting point of formed ceramic metal. Relative density of sintered plates reaches 98%.



Fig. 13.11. Press-form for pressing of plates of multichannel blocks. 1) housing of press-form; 2) tightening device; 3) upper ram; 4) forming rods; 5) lower ram; 6) pressed plate; 7) supporting plate; 8) base plate; 9) bearing disc for forming rods.

Welding of shells of rod-type or tubular fuel elements is carried out under protective medium of argon, helium, or a mixture of them. Special difficulty is presented by welding of shells from refractory metals, which should be carried out in a medium not containing traces of oxygen, nitrogen, or hydrogen. In Fig. 13.12 there is shown diagram of installation for welding of niobium components of fuel element of Dounreay reactor. Welding chamber is evacuated and purged with well-purified argon.

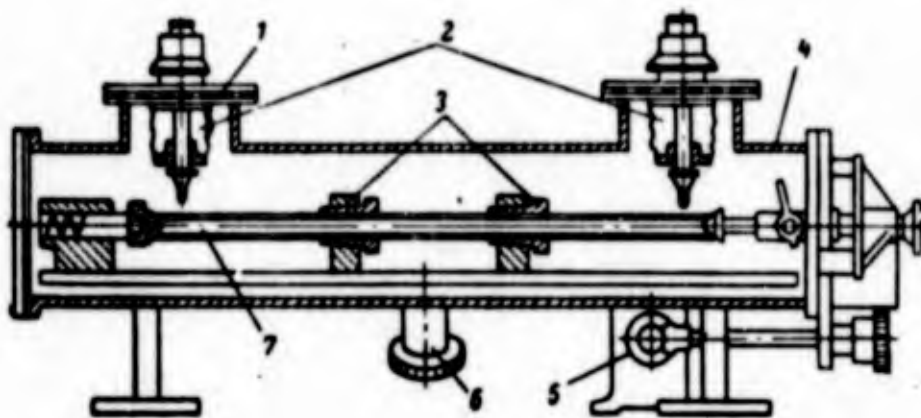


Fig. 13.12. Diagram of installation for welding of components of fuel elements in vacuum or argon. 1) insulation; 2) welding torches; 3) draw-in attachments; 4) housing; 5) drive for rotation of element; 6) feed to vacuum pump; 7) centered element.

Welding of spacer fins to shell is carried out on special automatic welding installation. Fins prepared from specially shaped wire are welded at an angle of 120° relative to each other with small angle of twist around shell of element. Three electrodes, simultaneously approaching each other, weld three fins by spot welding with step between points of 6-7 mm.

Filling of gap between shell and core with sodium is a very important operation. For good filling of gap, process is conducted at quite high temperature. High activity of sodium and danger of contamination of internal cavity of element with oxygen or nitrogen

requires carrying out of process in medium of pure argon.

§ 4. PROTECTIVE ARRANGEMENTS FOR WORK WITH RADIOACTIVE MATERIALS

For protection from irradiation of personnel working with radioactive materials, there are applied different types of safety devices and attachments. In certain cases, for very weak α - and β -activity, work can be conducted without safety devices only with observance of safety precautions, thereby preventing radioactive substances from getting into organism of a person. For work with materials possessing weak α - and β -activity, there are applied exhaust hoods, or tongs allowing the worker to execute simple operations while located at a safe distance from the active material.

For work with materials of average α - and β -activity and weak γ -radiation, there are used shields or chambers with open top. Observation of process in this case is conducted with help of mirrors or windows made from special material.

Work with materials having a high level of activity is conducted in completely closed chambers with help of remote control devices.

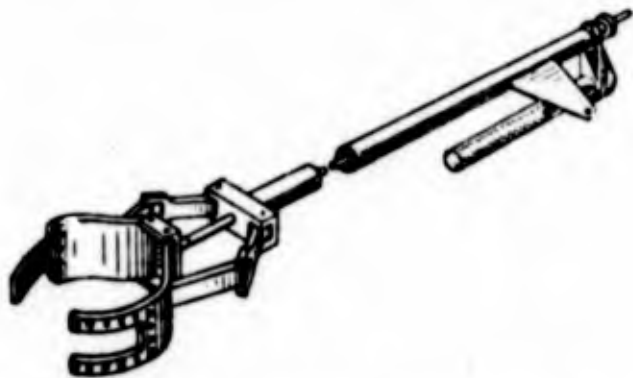


Fig. 13.13. Tongs for work with radioactive materials.

For simple manipulations with weakly active materials, in atomic plants there are used special tongs, shown in Fig. 13.13. Grip of tongs can be regulated depending upon dimensions of lifted objects.

There are made tongs from stainless steel, which permits carrying out repeated deactivation of them.

Work in closed chambers is carried out with help of universal or special remote-controlled devices.

In Fig. 13.14 there is shown a master-slave manipulator, which is a mechanical device reproducing motion of fingers and hand of operator. Controlling hand consists of three plates with rings for thumb, index, and middle fingers. The slave part repeats all motions of hand and fingers of operator. For convenience of work, usually there are installed two manipulators — for right and left hand of operator. Such manipulators possess great universality and give operator the possibility to feel the force with which the slave hand works. Deficiency of such devices is their small lifting capacity — 4-5 kg ($\approx 40-50$ newtons). For work in closed chambers with large and heavy objects there are widely used universal manipulators with electrical drive. In Fig. 13.15 there is shown universal manipulator with load capacity in any position of up to 35 kg (≈ 350 newtons) and along the vertical up to 350 kg (≈ 3500 newtons).

Deficiency of such manipulators is absence of "feedback"; this does not permit operator to feel force applied by tongs to object of work.

Along with universal devices, in practice there are widely used special purpose devices which are designed for carrying out definite operations. With help of such devices there are carried out extraction from reactor, transportation, and processing of fuel elements and several other operations.

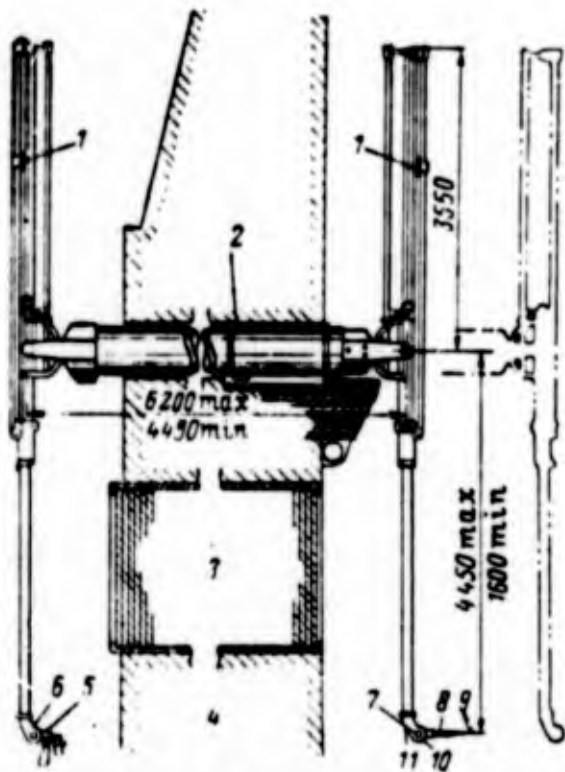


Fig. 13.14 Master-slave manipulator. 1) counterpoises; 2) pipes; 3) window; 4) shield; 5) controlling handle; 6) controlling "hand"; 7) rotation in vertical plane; 8) holding device; 9) twisting of holding device; 10) slave "hand"; 11) azimuthal rotation.

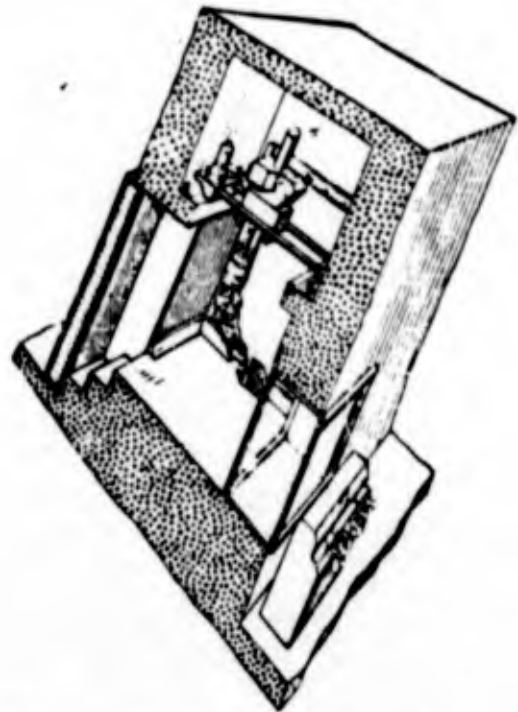


Fig. 13.15. Universal manipulator with electric drive.

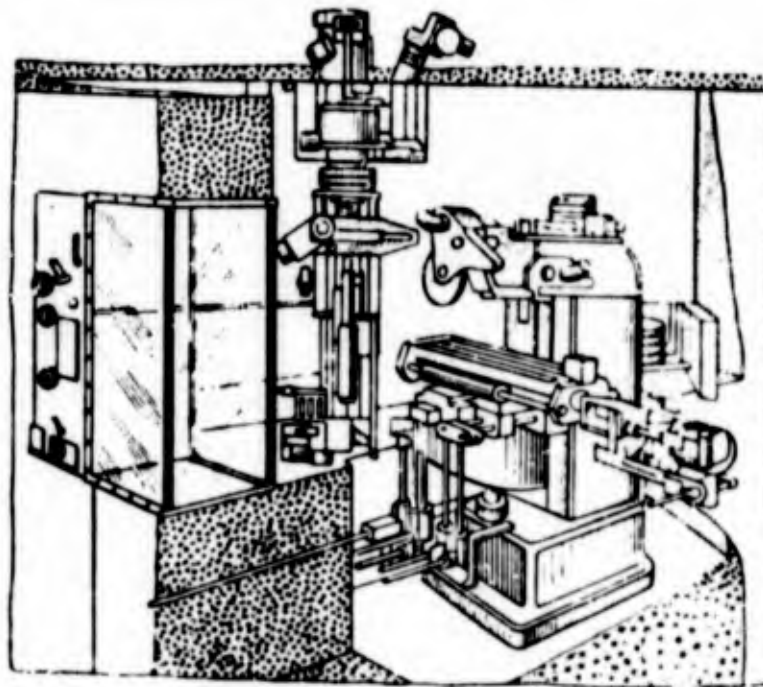


Fig. 13.16. Remote controlled workshop.

In Fig. 13.16 there is shown a remote controlled mechanical workshop for manufacture of metallographic samples from radioactive materials. Workshop includes lathe, milling and grinding machines, mechanical saw, and other equipment. Control of work of workshop is carried out by operator located behind a thick concrete shield. Observation is conducted through "liquid" window or with help of special optical devices.

§ 5. INSPECTION OF FE

The whole technological process of manufacture of fuel elements is accompanied by thorough inspection. Along with radiation monitoring, in the process there is widely used ultrasonic defectoscopy.

Dimensions of uranium slugs are controlled by automatic devices, built in to the machine-tool line.

With help of an ultrasonic beam with frequency of 5 Mc passing along a chord through moving and rotating slug, there is checked grain size in uranium rods. Rods with grain size of more than 350μ are rejected due to excessive coarsening of surface during their use in operation; grain size of less than 100μ may cause irregular growth of slugs during their irradiation in the reactor. With help of ultrasonic beam directed at an angle of 75° to surface of rod, there are revealed cracks, pits, grooves, and other defects to a depth of 0.5 mm.

For determination of quasiisotropism of core there is applied the resonance method, which consists of sending to the core oscillations, thereby forcing it to resonate in longitudinal and transverse directions. In view of sharp anisotropy of elastic moduli (tensile and shear), it is easy to distinguish quasiisotropic rods from even

slightly textured rods. Detection of internal defects of rods also can be carried out by γ -radioscopy with help of isotope Co^{60} .

Shells of fuel elements, besides visual detection for absence of scratches, are checked for non-uniformity in wall thickness. In cylindrical shells, this is checked before filling with help of a β -source moved along pipe and revolved about its axis. Thickness of shells during coextrusion of element is controlled with help of eddy currents. Quality of cohesion of shell with active volume is controlled by ultrasonics, or by high-frequency method.

In process of manufacture of fuel elements, considerable attention is allotted to airtightness of internal cavity of element. In spite of the fact that airtightness of pipes used for manufacture of shells is checked preliminarily by pneumatic testing, in process of assembly of element, for control of airtightness, there are widely used helium leak detectors. In Fig. 13.17 there is shown diagram of installation for checking of airtightness with help of helium. Operation is carried out in following sequence:

In vertically located pipe-container filled with helium there is placed fuel element whose internal cavity is connected with vacuum pumps. After achievement of high vacuum, to the system there is connected a mass spectrometer, with help of which there is revealed the smallest leakage of helium into internal cavity of element.

Porosity of shells of stainless steel is checked also, by placing element for 24 hours in a solution of nitric acid. After that the solution is concentrated and α -activities measured.

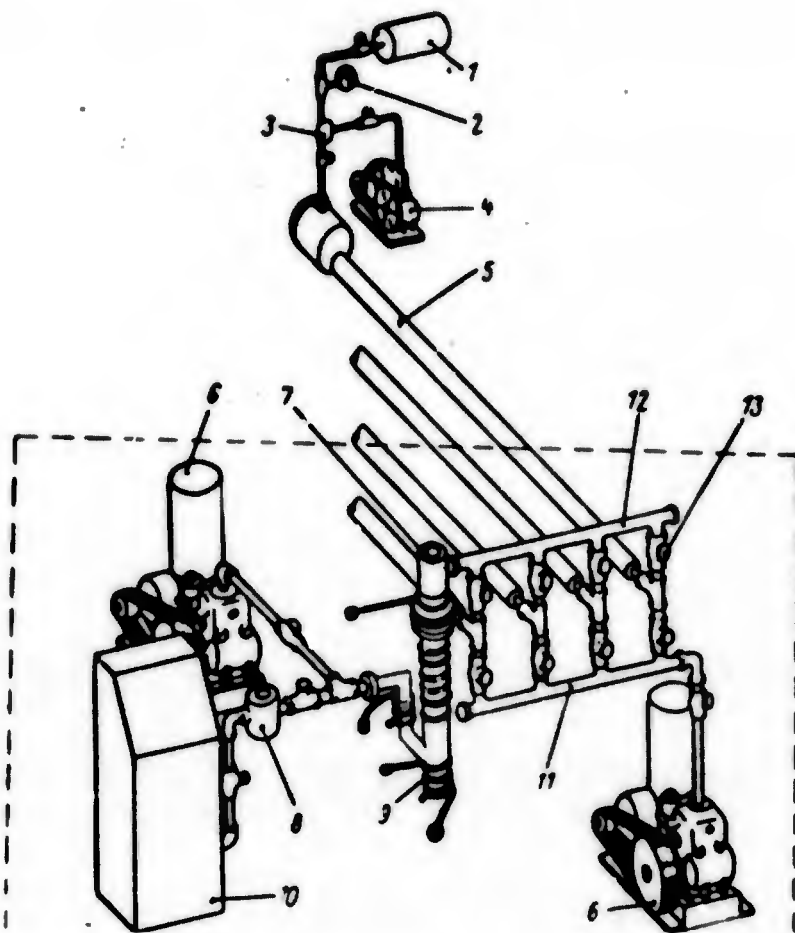


Fig. 13.17. Diagram of installation for checking of airtightness of shell of FE. 1) helium; 2) vacuum gage; 3) regulating unit; 4) vacuum pump; 5) pipe-container (4 each); 6) vacuum pump; 7) trap; 8) water separator; 9) diffusion pump; 10) mass spectrometer; 11) manifold No. 2; 12) manifold No. 1; 13) bellows valves.

LITERATURE

1. B. S. Balakshin. Fundamentals of technology of machine building, Mashgiz, 1959.
2. F. T. Blinov and V. P. Firago. Technology of machining of components of aircraft engines, Oborongiz, 1956.
3. V. N. Belikov and A. N. Nikitin. Assembly of aircraft engines, "Machine Building," 1964.
4. N. I. Volodin. Rolling of cylindrical cogwheels, TsINTIMASH, 1962.
5. V. A. Gavrilenko. Cylindrical evolvent gear drive, Mashgiz, 1956.
6. M. M. Gol'dberg and others. Nonmetallic materials and their application in aircraft construction, Oborongiz, 1958.

7. A. S. Zaymovskiy, V. V. Kalashnikov, and I. S. Golovnin. Fuel elements of atomic reactors, State Atomic Publishing House, 1962.
8. M. Ye. Zubtsov. Sheet press-working, Mashgiz, 1958.
9. M. F. Idzon. Machining of blades of gas-turbine engines, Oborongiz, 1963.
10. M. M. Il'in. Production of steel seamless rolled ring-blanks, Oborongiz, 1957.
11. Ye. I. Isachenkov. Stamping of parts made from stainless steel, Mashgiz, 1962.
12. B. A. Kiselev. Glass plastics, State Chemistry Press, 1961.
13. A. N. Malov. Technology of cold stamping, Oborongiz, 1963.
14. Metallurgy of nuclear power and effect of irradiation on materials, Metallurgy Publishing House, 1956.
15. L. A. Mordvintsev. Technology of welding and soldering, Oborongiz, 1957.
16. New materials in technology, Gostoptekhizdat, 1962.
17. A. V. Podzey, A. M. Sulima, V. P. Firago, and I. S. Tsukanov. Technology of aircraft engine construction, Oborongiz, 1957.
18. Progressive methods of production of cogwheels and their technological effectiveness, Mashgiz, 1962.
19. N. N. Rubtsov. Special forms of casting, Mashgiz, 1955.
20. G. N. Sinyarev and M. V. Dobrovol'skiy. Liquid-fuel rocket engines, Oborongiz, 1957.
21. G. S. Skubachevskiy. Aircraft gas-turbine engines, Oborongiz, 1955.
22. A. P. Sokolovskiy. Course of technology of machine building, Part I and II, Mashgiz, 1948 and 1949.
23. A. P. Fedotikov. Short reference book for the machine builder technologist, Oborongiz, 1958.
24. V. P. Firago. Design fundamentals of technological processes and apparatus, Methods of surface treatment, Oborongiz, 1963.
25. I. A. Frayfel'd. Tools operating by method of rolling, Mashgiz, 1948.
26. Yu. V. Tsvis. Profiling of cutting rolling tool, Mashgiz, 1961.

27. I. S. Tsukanov. Cutting of whole depth in outside cylindrical wheels cut by a tool of rack type, Transactions of MAI, No. 140, Oborongiz, 1961.
28. M. O. Yakobson. Technology of machining in automated production, Mashgiz, 1962.
29. "Welding Production," 1956-1962.
30. "Herald of Machine Building," 1957, No. 6; 1961, No. 8; 1962, No. 10.
31. Aircraft Engineering, 1961, No. 348.
32. Aircraft Production, 1954, No. 10; 1955, No. 7, 8; 1959, No. 1; 1960, No. 11; 1961, No. 2, 3, 7; 1962, No. 6.
33. American Machinist, 1954, No. 7; 1955, No. 10, 16.
34. Machinery (L), 1954, No. 2153, 2169; 1955, No. 2210, 2233; 1961, No. 2514, 2515.
35. Machinery (N.J.), 1961, No. 11.
36. Materials in Design Engineering, 1962, No. 4.
37. Metalworking Production, 1962, No. 14, 15, 27.
38. Metal Industry, 1961, No. 4.
39. Rockets and Missiles, 1960, No. 11.