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PRODUCTION OF ARTILLERY SYSTEMS

By

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13. ABSTRACT

Manufacture of tube artillery weapons is discussed. Emphasis is placed on manufacture of weapon tubes, beginning with a forging and ending with a finished tube, ready for installation and deployment. Some discussion is present on other parts of the weapon. Specific types of machines used for performance of specific processes are detailed. Much discussion is devoted to quality control procedures, including margins left on stocks before and during machining, tolerances on critical surfaces and checking of the finished product.

TECHNICAL TRANSLATION

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ENGLISH TITLE: PRODUCTION OF ARTILLERY SYSTEMS
(Machining Weapon Barrels)

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INTRODUCTION

Production of artillery weaponry has been developed as the result of constant changes and perfection of this form of combat technology, as well as the increased scale of its use among the forces. History of the development of artillery production testifies to the fact that our fatherland's industry has always occupied one of the first places in the world in the area of artillery weaponry, providing the army and navy with weapon models of original construction which not only kept abreast of foreign models in battlefield capabilities, but often surpassed them.

The results of scientific work on creation of artillery weapons and the perfection of technical methods in its production in domestic industry and in the armed forces have often received widespread acclaim and priority, and have been used in Western Europe.

"Russian artillery" -- these words have always reminded the enemies of our homeland of the might of her armed forces.

According to the Golitsyn Chronicles, firearms (hand cannons) were first used in Russia in 1389, under Grand Prince Dmitriy Donskoy. Artillery production was significantly perfected and expanded during the reign of Ivan Vasilyevich the Terrible. There were already outstanding artillery craftsmen at this time, among which Audrey Chokhov was widely known. Among many other weapons, he cast, in 1586, the "czar-cannon", which had a bore of 89 centimeters and a weight of 2400 poods (close to 40 tons). The czar-cannon was the largest weapon of its time, with a cannon ball weighing 800 kg. This cannon has been preserved to the present time in the Kremlin as a symbol of the power of Russian artillery and a momento of the past. In 1577, Audrey Chokhov produced a harquebus with a bore of 216 mm, barrel length of 5330 mm, and a weight of 7436 kg. The Pskov cannon maker Semyon Dubinin produced a cannon with a bore of 180 mm, barrel length of of 5940 mm, and weight of 4750 kg in 1590. These cannons took part in wars, and various models of them are kept at the present time in the Leningrad artillery museum.

The industrial production of artillery weapons and ammunition and hand guns began in Russia under Peter I during the period 1700-1721. During this time, the Sestroretsk and Tula weapons plants, the Petersburg arsenal, the Sestroretsk and Okhtensk powder plants and a number of plants in the Urals were built.

In 1743 at the Tula plant, 42 mm and 48 mm light field cannons were first built with steel barrels having eight spiral grooves in the bore. Many similar historical references can be introduced, and they all testify to the fact that in the given period, the level of development of artillery technology in Russia was high.

Until the middle of the 19th Century, artillery and hand guns were smoothe-bored and muzzle loaded. During the Crimean War (1854-1855), weapon models with rifled bores and breech loading, as well as rifled hand firearms, were first used. The advantages of rifled weapons over smoothe-bored ones were confirmed in the experience of the war.

It is proper to place production of the first rifled weapons in Russia in the year 1855. There were separate batteries in the forces with rifled weapons in 1862. It is necessary to note that rifled weapons with wedge blocks were developed in Russia, significantly earlier than in Western Europe. This is confirmed by documents and models of such weapons which are preserved in the artillery museum in Leningrad. With the development of industry in Russia (1860), especially metallurgy and machine building, the serial manufacture of steel weapons with wedge blocks and rifled bores. The first individual models of steel weapons were already being manufactured at the Ural plants at the beginning of the 19th Century. During the period 1820-1850 in Zlatoust, Pavel Petrovich Anosov first scientifically based the possibility of production of high quality steels, particularly damask steel, and got these steels in production. He first used a microscope for investigation of steel structure, leading Western Europe by many years in this respect.

From the same Zlatoust came the well known Russian metallurgist Pavel Matveyevich Obukhov, who played a prominent role in the development of the Russian artillery industry. A cannon barrel of Obukhov's steel, cast in 1860 at the Prince Mikhaylovskiy factory, sustained over 4000 shots. This cannon received a high award at the 1862 world exposition in London. With his move to Petersburg, Obukhov built the Obukhov steel cannon plant. The first steel gun barrels often exploded during firing, however, because the preparation processes for high-strength, tough steel were not sufficiently well known.

In 1866, Obukhov invited Dmitriy Konstantinovich Chernov to the plant for permanent employment. Having completed work at a technical institute, Chernov had already spent five years as an instructor. Working at the Obukhov plant on metals research, he first discovered that the metal which broke up during the firing of a gun had a large-grained structure, while that in barrels which sustained many shots had a small-grained structure. Experimental testing of this observation led to the conclusion, extremely important for practice, that steel quality depends not only on the formula for its preparation, which is to say the type of steel, but also on its consequent heat treatment (annealing, hardening and tempering). In experiments and in his theoretical research, Chernov also first showed that under heating to determined temperatures, steel undergoes special transformations, in which its structure and mechanical properties are changed. Later, in metallography courses, those temperature points for steel transformation were named Chernov's critical points. D. K. Chernov created a scientific basis for the production and heat treatment of steel, and in so doing rendered great aid to the metallurgical plants of Russia and Europe. A number of his works, such as: "Materials for the Study of Steel and Steel Weapons" (Materialy dlya izucheniya stali i stalnykh orudiy) of 1868, "Research on Cast Steel Pigs" (Issledovanie litykh stalnykh bolvanok) of 1878, "On Manufacture of Steel Armor-Piercing Projectiles" (O prigotovlenii stalnykh broneprobivayushchikh snaryadov) of 1885, and "On Burning Out Steel Weapon Bores" (O vygoranii kanalov stalnykh orudiy), of 1912 remain factual up to the present time.

The work of the Russian scientist D. K. Chernov received widespread acclaim during his lifetime, both in Russia and in Western Europe, and was noted at the 1900 world industrial exposition in Paris. From 1889 on, D. K. Chernov was a professor at the Artillery Academy, while still working at the plant. D. K. Chernov died January 2, 1921 at Yalta, and remained a great patriot of his country to the end of his life.

During the period 1860-1890, A. V. Gadolin, a professor at the Artillery Academy, worked out the bases for theories of artillery design: "Resistance of Weapon Walls to Gunpowder Gas Pressure" (Soprotivleniye sten orudiy porokhovykh gazov), "Theory of Strengthen Weapons" (Teoriya skreplyonnykh orudiy), and a number of other works on the theory of resilience. A large scientific contribution in the area of exterior and interior ballistics was made by M. V. Mayevskiy (1850-1892), a professor at the Artillery Academy, and by his student, N. A. Zabudskiy, (1880-1917). These works were widely known in Russia and in Europe, and greatly furthered the development and production of artillery equipment.

Successes and achievements in the development of artillery science and production of artillery weapons allowed, in the second half of the 19th Century, creation of a number of artillery systems which were very modern for their time, for example the 1877 model 107 mm and 152.4 mm light and heavy cannons.

At the end of the 19th Century, production of smokeless pyroxylin powder was mastered. At that time, artillery projectiles began to be loaded with highly explosive substances: first pyroxylin, later melinite, and finally trotyl. From 1884 until 1887 the first Maxim machine gun was successfully tested in European countries and in Russia. Machine gun production in Russia, however, was held up for a long time by the bureaucratic apparatuses of the tsarist government, and production of the first batch of this weapon did not begin until 1900.

In 1891, the 7.62 mm (three-groove) five shot rifle designed by S. N. Mosin was accepted into the arsenal and put into serial production at the Tula weapons plant. This rifle has not lost its combat capability even to the present time.

In 1872, the task of designing a rapid fire field cannon on an elastic carriage, with barrel recoil during firing, was assigned to the outstanding Russian artillerist V. S. Baranovskiy, who worked at the Obukhov plant. Baranovskiy's premature death during testing of battlefield projectiles delayed realization of this project and production of cannons on elastic carriages. The 1897 model 75 mm cannon in France, the 1902 model 76.2 mm cannon in Russia, the 1905 model 18 pound (84 mm) cannon in England and the 1896 model 77 mm cannon in Germany were cannons of this type. In 1909-1911, the 107 mm, 122 mm, and 152.4 mm cannons and howitzers on elastic carriages, with barrel recoil during firing, had been created and put into serial production.

The scale of artillery production in the industry of old Russia can be judged from the following information. At the beginning of the First World War, there were 6500 light and heavy artillery pieces of ten different types in the weaponry of the Russian army, while at the end of the war, there were 21,000 weapons of all types. Over the entire war period, industry, with great effort, manufactured 13,500 field pieces, and introduced into production only one new 76.2 mm anti-aircraft cannon, model 1915.

After the establishment of Soviet power in Russia, serious attention was paid to the development of the metallurgical, machine construction and defense industries. Following the orders of V. I. Lenin, the Soviet government and the Communist Party did much for education of scientific, engineering and technical personnel in industry. The development of old artillery plants and construction of new ones, as well as training of personnel for them progressed, using the experience of the First World War and developments of science and technology during the post-war years.

At that time (1925-1940), scientific work which was important for the development of artillery was carried out and various types of artillery weapons were created in the USSR. Among the work, the scientific labors of Artillery Academy professor N. F. Drozdov, hero of socialist labor professor I. I. Ivanov and others earned widespread acclaim. The successful creative work of young Soviet specialists allowed creation and introduction into production of new, more perfect models of field, anti-aircraft, tank and rocket artillery.

During the 1941-1945 Second World War, our fatherland's artillery was better than that of Germany, England, or the USA in combat capability. After the reconstruction of plants and factories for war production and their removal to the East in 1941, the fatherland's industry, regardless of its reduced capability, could, by the middle of 1942, fully satisfy the army's demands for artillery equipment. From this time on, our industry annually produced up to 120,000 various artillery pieces, 30,000 tanks, 100,000 mortars, up to 450,000 light and mounted machine guns, and many other types of war equipment. Tactical and technical data on some field, tank and self-propelled cannons of the Second World War period appears in Table 1.

It should be noted, along with this, that during the Second World War, it was necessary to modernize almost all of the models of artillery equipment present in the armament, as well as create new, more powerful ones. All this equipment had to be quickly put into production and immediately sent to the army. Our fatherland's industry also successfully handled this difficult task.

Tanks and self-propelled artillery were especially greatly developed during the Second World War. Tactical and technical data on some of the tanks of that time appear in Table 2.

Production of various types of artillery equipment involves complicated and labor-consuming technological processes, the successful accomplishment of which is possible only through the powerful development of various branches of machine construction, and also through a sufficient number of scientific, engineering and technical personnel.

TABLE 1.

TACTICAL AND TECHNICAL DATA ON FIELD, TANK AND SELF-PROPELLED GUNS OF THE SECOND WORLD WAR (1941-1945)

№ по пор.	a. Наименование орудий	b. Вес снаряда q кг	c. Вес заряда ω кг	d. Объем каморы W дм³	e. Начальная скорость снаряда v_0 м/сек	f. Наибольшее давление пороховых газов p_{max} кг/см²	g. Дульная энергия снаряда E_0 тм	h. Толщина пробиваемой брони при угле встречи 90° в мм: i. на дистанции 100 м	h. Толщина пробиваемой брони при угле встречи 90° в мм: j. на дистанции 1000 м	k. Длина трубы ствола в мм
1	45-мм противотанковая пушка обр. 1942 г. (СССР)	1,43 0,85	0,390 0,365	0,52	873 1070	2500 2730	55,5 49,6	72 90	52 —	2994
2	50-мм противотанковая пушка обр. 1941 г. (Германия)	2,1	0,91	1,21	860	2350	77,6	82	52	3325
3	57-мм противотанковая пушка обр. 1943 г. (СССР)	3,14 1,76	1,5 1,7	1,96	990 1270	3100	156,8 144,5	115 175	96 95	3944

1. 45 mm anti-tank cannon, model 1942 (USSR)
2. 50 mm anti-tank cannon, model 1941 (Germany)
3. 57 mm anti-tank cannon, model 1943 (USSR)
4. 75 mm tank and anti-tank cannon, model 1941 (Germany)
5. 75 mm tank cannon, model 1942 (Germany)
6. 76 mm tank cannon (model 1940) and field cannon (model 1942) USSR

a. Weapon model
b. Projectile weight q, kg
c. Projectile weight, w, kg
d. Chamber size W, dm^3
e. Initial projectile velocity V_0, m/sec
f. Maximum powder gas pressure P_{max}, kg/cm^2
g. Projectile muzzle energy E_0, tm
h. Thickness of armor pierced with a 90° angle of incidence, mm
i. At a distance of 100 m
j. At a distance of 1000 m
k. Length of barrel tube, mm

TABLE 1 (cont.)

4	75-*мм* танковая и противотанковая пушки обр. 1941 г. (Германия)	6,8 4,1	2,75 2,67	3,17	740 990	2850	206	100 149	80	3375
5	75-*мм* танковая пушка обр. 1942 г. (Германия)	6,5 4,5	4,0	5,1	930 1050	2850	306 248	160 180	120	5043
6	76-*мм* танковая (обр. 1940 г.) и полевая пушки (обр. 1942 г.) СССР	6,5 3,0	1,08 1,3	1,65	680 950	2320 2400	135 139	75 130	60	2985
7	85-*мм* самоходная и танковая пушки обр. 1943 г. (СССР)	9,2 5,0	2,48 2,8	3,8	792 1030	2550	298 265	120 175	103	4146
8	88-*мм* танковая и самоходная пушки обр. 1943 г. (Германия)	10,2 7,3	6,9 6,7	9,0	1000 1130	3000	518 475	186 230	140	6030
9	122-*мм* танковая пушка обр. 1943 г. (СССР)	25	6,85	9,89	783	2750	773	160	130	5240

7. 85 mm self-propelled and tank cannon, model 1943 (USSR)
8. 88 mm tank and self-propelled cannon, model 1943 (Germany)
9. 122 mm tank cannon, model 1943 (USSR)

NOTE: The upper lines in the table are for projectiles of normal weight. The lower lines are for subcaliber projectiles.

TABLE 2.

TACTICAL AND TECHNICAL DATA ON TANKS USED DURING THE SECOND WORLD WAR (1941-1945)

№ по пор.	Наименование танка и год его выпуска a	Боевой вес т b	Мощность двигателя л. с. c	Длина корпуса м d	Ширина корпуса м e	Высота корпуса м f	Лобовая броня мм g	Бортовая броня мм h	Калибр орудия мм i	Вес снаряда в кг j	Начальная скорость м/сек k	Боекомплект на пушку шт. l
1	Легкий Т-26 обр. 1934 г. (СССР)	10,5	90	4,7	2,5	2,3	16	16	45	1,43	760	165
2	Средний Т-34 обр. 1940 г. (СССР)	30,5	500	6,1	3,0	2,4	45	45	76	6,5	680	100
3	Средний Т-34 обр. 1943 г. (СССР)	32	500	6,1	3,0	2,7	90	45	85	9,2	792	56
4	Тяжелый ИС-2 обр. 1943 г. (СССР)	45,5	520	6,85	3,1	2,7	100	90	122	25	783	28
5	Средний T-IV обр. 1942 г. (Германия)	24	320	5,8	2,9	2,6	50	30	75	6,8	740	80
6	Средний T-V обр. 1943 г. (Германия)	45	600	6,9	3,4	2,9	70	40	75	6,5	930	75
7	Тяжелый T-IV обр. 1943 г. (Германия)	56	650	6,25	3,6	2,9	100	60	88	10,2	1000	86
8	Тяжелый „Черчиль" обр. 1941 г. (Англия)	40	350	7,4	3,2	2,5	80	50	57	2,9	820	80
9	Тяжелый „Центурион" обр. 1950 г. (Англия)	48	640	7,5	3,4	3,0	150	76	83,8	9,0	1020	65
10	Средний М4-А2 обр. 1942 г. (США)	31,5	375	5,9	2,7	2,9	60	37	75	6,5	630	95
11	Средний М-48 обр. 1951 г. (США)	44	810	6,4	3,5	2,7	102	76	90	10,8	940	70

1. Light T-26, 1934 (USSR)
2. Medium T-34, 1940 (USSR)
3. Medium T-34, 1943 (USSR)
4. Heavy IS-26, 1943 (USSR)
5. Medium T-IV, 1942 (Germany)
6. Medium T-V, 1943, (Germany)
7. Heavy T-IV, 1943 (Germany)
8. Heavy "Churchill", 1944 (England)
9. Heavy "Centurion", 1950 (England)
10. Medium M4-A2, 1942 (USA)
11. Medium M48, 1951 (USA)

a. Tank designation and year off output
b. Combat weight, T
c. Engine power, hp
d. Hull length, m
e. Hull width, m
f. Hull height, m
g. Front armor, mm
h. Side armor, mm
i. Gun calibre, mm
j. Projectile weight, kg
k. Initial velocity, m/sec
l. Gun ammunition reserve, ea

CHAPTER I

General Information on Construction and Basic Technical Characteristics of Artillery Systems.

Artillery systems are divided according to their use into field cannons and howitzers, tank cannons, self-propelled, anti-tank, anti-aircraft and others.

Differences in the intended use of artillery systems stipulate their differences in construction.

Regardless of construction differences, the major portion of cannon parts and mechanisms have similar forms of construction and common technological qualities. This eases and speeds the development of production technical processes for various artillery systems.

For a better understanding in the future of artillery production technological peculiarities, we will briefly become acquainted with the construction and basic technical characteristics of artillery systems.

Figure 1 shows a 76.2 mm field cannon, model 1942, whose construction consists of the following basic parts: Barrel 1, muzzle brake 2, block 3, cradle 4, recoil brake 5, recoil return 6, sight 7, upper stand 8, aiming mechanism 9, lower stand 10 (trails), trail spades 11, wheeled carriage 12, and protective covering.

Other types of artillery systems: self-propelled and tank cannons, are shown in Figures 2 and 3.

The self-propelled artillery mounting has the following basic parts: barrel 1, forward moveable armor 2, moveable armored turret 3, stationary armored turret 4, fuel tanks 5 and 6, drive wheel 7, bogies 8, track 9, idler 10, and armored hull 11 (see Fig. 2).

Besides the weapon barrel and block, the self-propelled and tank cannons have many elements of construction in common with the field cannon, namely: muzzle brake, recoil return, cradle, aiming mechanism, and others.

The barrel of any cannon is the main part of an artillery system, and is intended to throw a projectile in a forward direction with a set initial velocity. It consists of a steel tube which is assembled from several parts.

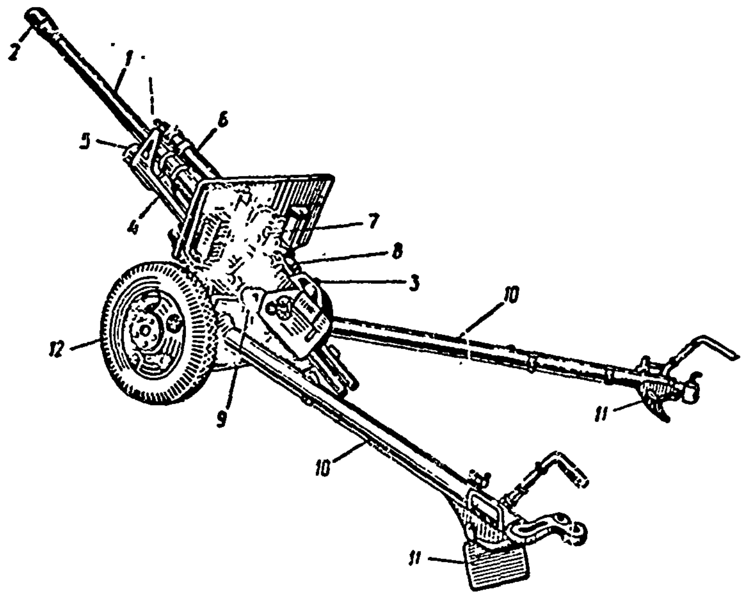


Fig. 1. 76.2 mm cannon, model 1942

1 - barrel, 2 - muzzle brake, 3 - block, 4 - cradle, 5 - recoil brake, 6 - recoil return, 7 - sight, 8 - upper stand, 9 - aiming mechanism, 10 - lower stand trails, 11 - trail spades, 12 - wheeled carriage.

The bore of this tube has a grooved cylindrical part and a charge chamber, in which the powder charge burns during firing. The breech part of the bore is closed with a block.

At the initial moment of firing, gas pressure in the barrel bore reaches 3000-3500 kg/cm^2, and from then to the moment that the projectile leaves, drops to 1000-1500 kg/cm^2.

Pressure of the powder gases, acting on the walls of the barrel, the block (Bottom of the bore) and the bottom of the projectile, moves the projectile along the bore. The entire firing process, ending with the flight of the projectile from the bore, takes place in the very short time period of 0.005 to 0.02 second.

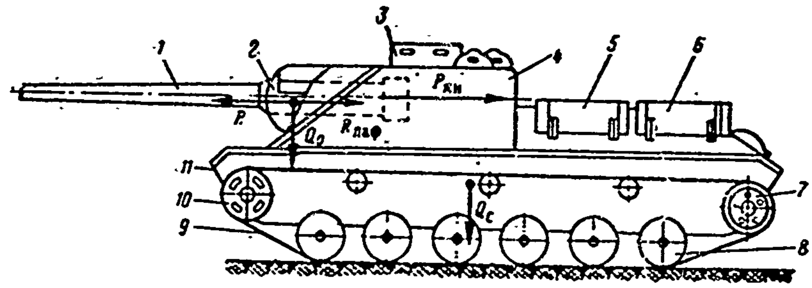


Fig. 2 Self-propelled Artillery Mounting

1 - barrel, 2 - forward moveable armor, 3 - armored command turret, 4 - stationary armored turret, 5 and 6 - fuel tanks, 7 - drive wheel, 8 - bogies, 9 - track, 10 - idler, 11 - armored hull.

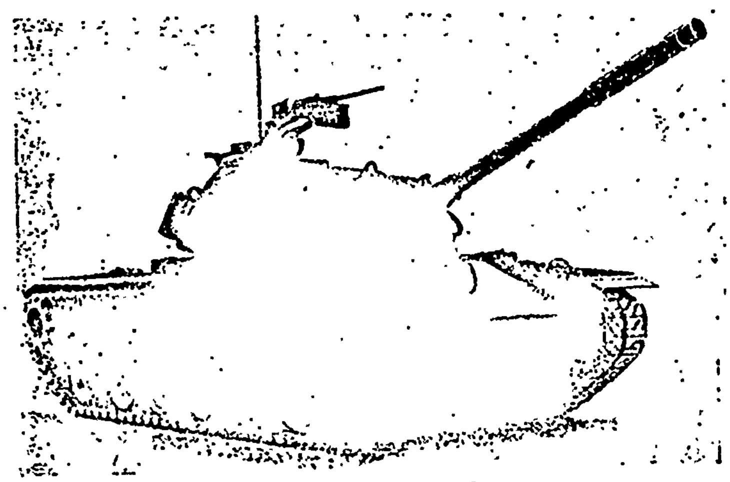


Fig. 3 Overall View of a Medium Tank

The basic technical characteristic of a gun is the muzzle energy of the projectile, whose numerical meaning is equal to the active force of the projectile's progressive movement at the moment it leaves the bore, and is determined by the formula

$$E_0 = \frac{qv_0^2}{2g},$$

where E_0 — muzzle energy of the projectile in kg m
q — weight of the projectile in kg
v — initial velocity of the projectile in m/sec
g — acceleration of gravitational force (g=9.81 m/sec^2)

During the Second World War (1939-1945), improvements in combat capabilities of artillery weapons took place, for the most part, due to increases in projectile initial velocity, rapidity of fire, and accuracy of fire. Increases in projectile initial velocity (up to 900-1100 m/sec for normal weight projectiles and 1100-1300 for subcaliber projectiles) were reached as the result of increased powder gas pressure and increased gun barrel length, as is evident from the data in Table 1. In order to increase gas pressure, however, it was necessary to increase the weight of the powder charge and, consequently increase its load ratio, which is determined from the following relationship:

$$E_{\omega} = \frac{\omega}{q}, \tag{2}$$

where E_{ω} — load ratio of the powder charge
ω — weight of the powder charge in kg.
q — weight of the projectile in kg.

The load ratio of weapon powder charges during the Second World War increased from 0.2-0.35 to 0.4-0.65 for projectiles of normal weight and up to 0.95 for subcaliber projectiles. This can be seen from the data (q and w) in Table 1.

During firing, the projectile moves forward along the barrel's bore under pressure of the gases, and the barrel moves in the opposite direction (gun recoil).

Gas pressure $P_{сн}$, acting on the bottom of the projectile and giving it its initial velocity and the moment of exit from the bore, is determined by the formula

$$P_{сн} = pF, \tag{3}$$

where p — gas pressure in the barrel bore, which is taken along the pressure curve in kg/cm^3;
F — area of bore section, taking into account the grooves, in cm^2 (F is usually 0.82d^2, where d is the bore diameter in cm.)

The force $P_{кн}$, acting on the bottom (breechblock) of the bore during firing and directed opposite to the movement of the projectile (see Fig. 2), is equal to the gas pressure force and the reaction of the projectile ring. It can be determined by the expression

$$P_{кн} = pF - \Pi. \tag{4}$$

Here, Π — projectile carrying ring reaction force, acting on the barrel during projectile movement through its bore (usually $\Pi \approx 0{,}02pF$).

Due to action of the force $P_{кн}$, the gun barrel recoils backward during firing, during which all the recoiling parts of the gun acquire the kinetic energy of the recoil, which is determined by the formula

$$E_{от} = \frac{Q_0 v_т^2}{2g}, \tag{5}$$

where Q_0 — weight of the recoiling parts of the gun (see Fig. 2) in kg;
v_T — velocity of the braked recoil in m/sec;
g — acceleration of gravitational force.

The kinetic energy acquired by the recoiling parts of the gun in the process of recoil is absorbed by the work of the resistant force created by the counterrecoil mechanism over the barrel's entire path of movement, and therefore can be written

$$\frac{Q_0 v_T^2}{2g} = R\lambda k, \tag{6}$$

where R — equally acting force of resistance to recoil (see Fig. 2) in kg;
λ — length of the recoil path in m;
k — coefficient calculating peculiarities in counterrecoil mechanism construction and conditions of the recoil process. It is smaller than one in size (usually $k \approx 0{,}85$—$0{,}9$).

If, in equation (6), we replace recoil velocity v_T with its corresponding expression, which is known in internal ballistics from solution of the problem on free recoil, and solve for the relative force , we get an expression of the following form:

$$R = \frac{(q + \beta\omega)^2}{2gQ_0\lambda k} v_0^2, \tag{7}$$

Here, β — coefficient taking into account the consequences of powder gases ($\beta = 1.57$ is usually used for calculations);
ω — weight of the powder charge in kg;
q — weight of the projectile in kg.
v_0 — initial velocity of the projectile in m/sec.

The path of recoil λ for many field cannons does not exceed 800-1100 mm, and for tank and anti-aircraft guns 350-500 mm. For the majority of weapons, maximum velocity of recoil v_T = 10-12 m/sec, and the elapsed time for the recoil process is approximately 7-9 times greater than the time of the projectile's movement in the barrel bore during firing. Taking into account data on time of recoil process and the condition of equality of impulses of the forces P_{KH} and R, we see that the magnitude of the equally acting force of resistance to recoil will comprise $1/8$—$1/12$ of the force P_{KH}, e. g. $R \approx 0{,}1 P_{KH}$.

If the barrel of the gun were securely fastened to the carriage or to the turret of a tank, the force P_{KH} would act directly on the gun carriage (or tank hull) and the gun (tank) would not have sufficient stability during firing.

Stability of the weapon during firing is provided by the fact that the gun barrel, installed in the cradle, is fastened to it with a flexible connection -- the counterrecoil mechanism, which allows the barrel to recoil backward during firing to the length of recoil. Due to this mechanism, the force R_{car} (see Fig. 2), equal in magnitude to the force resisting recoil, but opposite to it in direction, acts on the carriage of the cannon or on the hull of the tank during firing, and being concentrated at the center of gravity of the recoiling parts, this force is immediately transferred to the trunnions and to the elevating mechanism of the cannon.

Therefore, with the barrel and cradle flexibly connected to the gun carriage (or to the tank hull), the force R_{car}, significantly smaller in magnitude than force $P_{\text{кн}}$ ($R_{car}=R\approx 0{,}1P_{\text{кн}}$) acts during firing, and the gun has sufficient stability.

Modern powerful weapons, for increased stability during firing, have, in addition to counterrecoil mechanisms, a muzzle brake, which decreases the kinetic energy of the gun's recoiling parts by 20-50 percent, and consequently decreases the recoil resistant force R.

The use of muzzle brakes allows a decrease in the dimensions of counterrecoil mechanisms, particularly in the length of recoil λ, which can be seen from formula (6).

CHAPTER II

Basic Organization And Planning Of The Technological Process

1. General Information on Organization of Artillery Production

The production technology of machines and any other products which is realized in a concrete plant situation, depends on the type of equipment and the technical level of development of the plant-performer, the construction of the product produced, and the scale of its production. One or several machines which differ in complexity of construction may be in production simultaneously. Simple machine parts may be manufactured in one of the plant shops, while treatment of more complex parts may go on in several shops. Separate procurements, assemblies, or parts of the object under production are sometimes manufactured at specialized plants on the principle of cooperation, and arrive at the base plant according to an established plan.

Coordination of various production processes between plant shops, the base plant's exterior contacts with cooperating plants, and production planning are the task of the production organization.

Any machine or object of production which has independent usage is commonly called a "product". In construction, the product may be complicated (a tractor, artillery system, etc.) or simple. The degree of complexity of a product is determined by the number of parts and separate mechanisms which go into it, the physical properties of materials used, the geometric form of the product, and the requirements for exactness in treatment of its parts.

The complexity of construction, weight and dimensions of a product have essential influence on the production organization and technical processes of its manufacture.

Artillery systems are complex products, consisting of many mechanisms and a large number of parts which are different in size, geometric form, and mechanical properties of the materials from which they are manufactured.

Field artillery systems have from 750 to 3500 separate parts and from 8 to 15 separate groups or independent assemblies, which are separate mechanisms. Among these, over half of all artillery system parts are specialized, which is to say that they are parts which are applicable only to a certain (one or two) concrete system. Standardized (common to machine construction) and normalized parts, or parts which are used in many artillery systems (bolts, nuts, screws, knobs, pressure gauges, pumps, etc.), usually comprise about 30 percent of all parts. These parts do not play a large role in the development of production technology and determination of the product's cost price.

The weight and dimensions of artillery systems, as well as the number of parts going into them, depend on the purpose and construction of the system. Light, rapid-fire cannons, for example, weigh from 1000 to 1600 kg, and have a barrel length of 3000 to 4000 mm, while combat ready heavy field cannons and howitzers weigh from 3000 to 15000 kg, with a cannon barrel length of 5000 to 8000 mm, and that of howitzers from 3500 to 6000 mm. Recoilless weapons have a weight no greater than 300-400 kg, and a relatively small number of parts.

Self-propelled artillery pieces are more complicated in production, because they include both the gun and the moveable platform (armored hull, engine, transmission, running gear, etc.).

Artillery production, by its organizational forms and technological singularities, as well as by the weight, dimensions and quantity of artillery systems manufactured, can be broken down into unit (individual), serial, and mass production.

Unit production is used for manufacture of a small number of non-repeated groups of experimental or useable heavy, large-dimensioned artillery systems.

This type of production is characterized by:

advantageous use of universal metal-cutting equipment;

limited use of special adaptations and tools;

a small number of interchangeable parts and wide useage of various adjusting hand labor in assembly;

incomplete technological process development. Finalizing is usually done only on separate parts, and a large portion of the parts are manufactures according to simplified draft technical documentation;

highly qualified workers;

insignificant mechanization of technological processes and;

low productivity of labor.

Serial production is used for production of various artillery systems which are used in the armaments, and is similar to serial production in machine construction.

This type of production is characterized by the following singularities:

manufacture of artillery systems is repeated in lots over the course of a long time period, with no essential construction changes in the object of construction;

manufactured parts are interchangeable, and hand fitting in parts assembly is done only in certain instances;

technological processes are mechanized in large part, and a few of them are automated;

a large portion of the equipment consists of universal metal cutting machine tools, but special machine tools are also used;

universal and special attachments and tools are widely used;

centrallized preliminary adjusting of equipment is used in production;

technological processes are worked out for all parts, and include their route of treatment;

distribution of equipment among the shops corresponds to the technological flow of mechanical parts treatment and their assembly;

productivity of labor is high.

Depending on the size of the series (lot), serial production can be small-series or large-series, with the latter approaching mass production in essence.

Mass production is organized for manufacture of light and medium (by dimensions) artillery systems in large numbers. It is conducted over an extended time period.

With this type of production:

artillery system construction does not change, and parts and assemblies are full interchangeable, so that only on separate parts is a method of choosing allowed in their assembly;

technological processes are mechanized and automated. Automatic lines may be organized for several parts;

high-production, specialized and special metal-cutting machine tools, fitted with adaptations and multiple cutting head appliances, are widely used in production. Automatic and semiautomatic machines are used in large quantities;

universal machine tools which are equipped with adaptations are used in smaller quantities than in serial production;

technological processes are worked out in detail, and gain high stability in manufacture of supplies, schedule of treatment and movement routing of parts;

technical control is organized on the basis of use of mechanized means and automatic instruments;

various transport shop operations connected with movement of supplies and parts are largely mechanized;

productivity of labor is higher than in serial production.

In large-series or mass production, the technological processes are more highly perfected than in serial of small-series production. Consequently, they are also more productive and economically profitable.

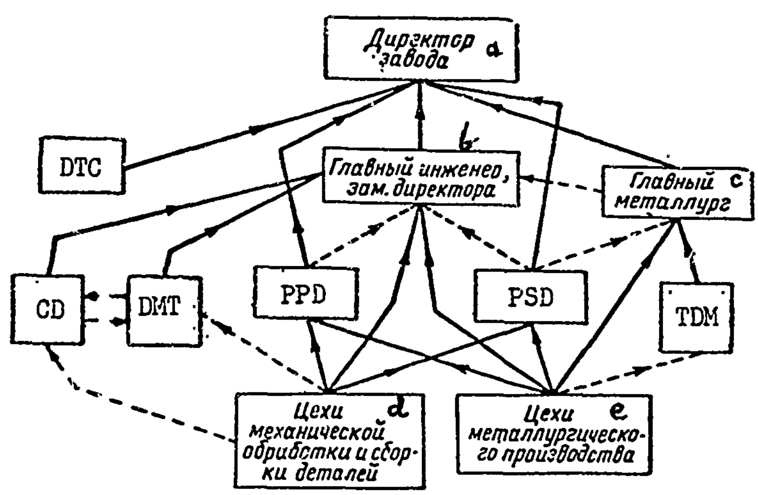


Fig. 4 Organization Chart of Basic Shops and Departments of the Plant.

a. Plant Director
b. Chief Engineer, Asst. Director
c. Chief Metallurgist
d. Mechanical Treatment and Parts Assembly Shops
e. Metallurgical Production Shops

——→ direct responsibility
- - - → functional one-way contact
⇄ mutual functional contact

Some plants in medium and heavy machine construction have a closed production cycle, in which all stages of production of whatever product, beginning with acquisition of open hearth ingots and rollings, production of supplies, mechanical treatment of parts, and assembly of the machines from them is accomplished at one and the same plant. With this type of organization for production, the bas artillery plant depends less on cooperating plants, which supply standardized parts and some final products (wheels, rubber items, optical and electrical instruments).

Figure 4 shows the part of the plant's principle organization chart which relates to production. According to this chart:

The Plant Director accomplishes guidance of production through his assistants (Chief Engineer and Chief Metallurgist) and indirectly through the management departments: production and planning (PPD), production and shipping (PSD), and technical control (DTC).

The Chief Engineer of the plant is the first assistant of the Director, organizes production and directs the production shops; the construction department (CD), which develops construction and working drawings for the production object, and the department of major technology (DMT), which works out the technological processes of production, plans the equipment around the shops and directs the scientific and research work of the engineering and technical staff of the plant.

The plant's Chief Metallurgist organizes metallurgical processes of production and directs the special metallurgical shops. He is indirectly responsible to the Plant Director, and in special problems in production, to the Chief Engineer. In large plants, the technological department of metallurgical production (TDM), which works out the technological processes of this production, is responsible to the Chief Metallurgist.

The department of technical control (DTC) affects technical control on quality of products manufactured by the plant, and has a group of controlling foremen and engineers in each shop.

Experience in some domestic and foreign plants points to the necessity for concentration of technical control in only the basic leading operations of the technological processes, in some parts assembly sections , and on completion of the product. In this case, the DTC apparatus might by significantly cut back, and ; together with this, quality control activity on the product produced by the plant increased.

The plant shops, according to their purpose and type of equipment, are divided into the three following groups:

1) metallurgical production shop group, to which the open hearth, foundry and form rolling, steel and non-ferrous foundry, forging and pressing, heat treatment, and spring shops and the metals test laboratory belong,

2) the mechanical treatment and parts assembly shop group,

3) the support shop group, to which the transport, chief mechanic's,

tool, and other shops belong.

Each shop has:

a technical bureau, consisting of a group of technicians, which effects management of the existing technological processes and introduction of new processes. In technical relationships, the bureau is subordinate to the plant's Chief Technician;

planning and distribution bureau, which is occupied with planning the shop's work, giving out work orders to different performers, and with the accounting for the shop's work,

production foreman,

mechanic.

The various shops for mechanical treatment and assembly of product parts are usually organized on the basis of technological processes of treatment and assembly, and the route and movement of parts.

In artillery production, the mechanical treatment shop group usually has:

1) a shop for preliminary mechanical treatment of large parts;

2) a barrel shop for treatment of tubes and assembly of barrels from them;

3) a shop for mechanical treatment of cradles and anti-recoil device parts;

4) a shop for production of breech blocks and type parts for elevating and traversing aiming mechanisms;

5) a shop for mechanical treatment of parts which are large or complex in form, with the exception of barrels, for example: breech rings, sleeves, toothed sectors, upper and lower mounts, and the like;

6) a shop for mechanical treatment of normalized parts which are used in many mechanisms;

7) a shop for stamped and pressed parts;

8) a shop for general assembly and trials.

The mechanical shop for preliminary treatment, which performs the rough turning, boring and cutting on tubes before their heat treatment, makes up one complex with the forging and pressing and the heat treatment shops. All the other shops must be spread out according to the technological route of parts movement flow and assembly in the general assembly shop.

With rational placement of mechanical shops, less time is wasted in inter-shop parts movements. In choice of mechanical shop equipment, it is necessary to consider the specialization of the given plant, construction and dimensions of the product manufactured by it, and its organizational form of production (serial or mass).

In artillery production plants, machine shop equipment can be divided into the following groups:

1) Universal general-purpose machine tools for performance of several operations in manufacture of many types of parts. Universal and speciat attachments can be used on these machines, allowing them to be effectively used in small-series, serial, and large-series production. Screw lathes, turning lathes, turret lathes, semiautomatic and automatic general purpose lathes, mortising machines, universal milling machines, horizontal and vertical milling machines, drill presses, cress planers and circular grinders all go into the universal machine tool category.

2) Specialized machine tools for treatment of one type of parts in strictly limited-quantity operation. These machine tools are fitted with manifold cutting heads which allow them to work on several surfaces of the part simultaneously, and provide a high productivity of labor.

3) Special general purpose machine tools for treatment of strictly determined parts. Among these are: backing machines, reamers, copiers, centering machines, cutter milling machines, tooth finishers, and special semiautomatic and automatic machines. Special general purpose machines are used the same in artillery manufacture as in any medium machine construction.

4) Special machine tools for artillery production, for performing special operations in treatment of parts. Machines in this category include: machine tools for drilling and turning deep cylindrical openings, for turning deep conical openings, and for treatment of exterior conical surfaces of gun barrels; machine tools for grooving gun barrel bores and for polishing and honing deep cylindrical and conical openings; ma hine tools for treatment of cradle trunnions, turning lathes for turning exterior surfaces of gun barrels and cutting bores; and machine tools for treatment of various cylinders, rods, and spindles of anti-recoil mechanisms, These are large machines, and require a large working area.

Organizational forms and technological processes are closely tied together and have considerable influence on the entire pace of production. The practice of more modern technological processes with the use of wise adaptations in them, and inculcation of more modern methods of parts treatment and various automatic processes will increase productivity of labor, simplify, and in turn, influence the organization and planning of production.

2. Technological Processes of Production

The productive activity of a plant is included in the accomplishment of a large number of different processes which convert materials or ready made parts into a finished product. These processes include: preparation of production for manufacture of the ordered product and supply with materials, manufacture of stock items and their machining on various machine tools, assembly of components from the parts, and then of the whole product, technical control of technological processes and the quality of their performance, interplant transportation and storage of parts, materials and finished production in warehouses, power and housekeeping service for equipment and work areas, etc. This entire complex of processes is called the production process, as the result of which a finished product is acquired.

Technological processes are separate parts of the production process. Each technological process includes all activity of a person and the equipment he uses, resulting in a change in the form of parts, changes in the physical and chemical properties of metals and other materials from which parts are manufactured, combination of parts into separate assemblies, and assembly of the product. The following types of technological processes differ in machine construction:

1) technological processes of metallurgical production, through which the physical properties of the metal are changed, and parts stock is gotten. These include: foundry production, forging, heat treatment, aging and other processes;

2) technological machining processes, which change the form of the parts stock;

3) technological assembly processes, in which separate parts are combined into components, assemblies, and finally into the finished product.

The production process, therefore, encompasses all activity and processes which take place in the shops, as well as external contact with other performer plants which provide for manufacture of the product, while the technological process is only that activity connected with changing the form and physical and mechanical properties of stock and parts. This is the basic difference in concept between production and technological processes.

The technological machining process occupies the central place in production. The problem of manufacture of a part is solved by a technician, who, considering the modern level of development of the machines, assigns the type of machine tool for treatment of the part, as well as attachments, the tool, sequence of operations and schedule of treatment. Examination of the parts machining processes, technical control and product assembly are also parts of this task.

Composite Parts of the Technological Process

Included in the technological process are not only activities which directly change the form of the treated part, but also activities which do not produce changes in the part's form, but are organically tied to the treatment process. Examples are installation and removal of parts from the machine tool or attachment, checking part dimensions after machining, and others.

The technological process of parts machining is made up of the following parts:

The technological operation is a part of the technological process, and consists of a number of actions, performed during treatment of a single part or composite part (assembly), by a single worker or several workers simultaneously, unbroken in time, and at one working place (machine tool). The operation is characterized by the fact that neither the object of treatment, the working place (equipment), nor the performers are changed during its entire course. Under these conditions, it is possible to draw up a primary technological document, an operational technological chart, for each operation. This chart shows the sequence of treatment, the necessary equipment, cutting and measuring tools, schedule and time of work, and the number and qualifications of the workers.

Complicated operations, besides this, are illustrated with drawings which show the sequential changes in the part's form and installation of the tool. This eases the worker's mastering of the whole document.

The technological operation is the basic unit of technological and production planning. It allows determination of the needed equipment and its load, cutting and measuring tools, auxiliary materials and work force.

Steps and passes are parts of the technological operation. A step is a part of the operation which is performed on any one part of the item's surface by one tool or several simultaneously working tools.

The character of work in changing the form of the treated part is preserved in a step. In a step, the situation of the part on the machine does not change, which is to say that installation and tightening of the part does not change, but work on the one surface of the part can be accomplished with several passes of the tool. The pass is the elementary part of the technological operation adn consists of one move of the tool in relation to the treated surface of the part in the direction of its feed. In a step, the worker might perform related activity, such as removing and applying the cutting tool, stopping and starting the machine, or turning on the automatic feed, but in a pass, only one working action takes place -- movement of the tool in relation to the treated surface in the direction of the part's feed.

The pass, a technological element of the step, is not considered separately on the technological chart.

Installation is a part of the technological operation accomplished with fastening one part or a number of parts to be simultaneously treated on the machine in one single position.

Position is the name for each of the situations of the part relative to the machine which are required for treatment. On milling machines, planers, and other machines, universal and special attachments are used to help in installing and fastening the treated part on the machine in the required position. An attachment allows the position of the part to be changed relative to the working tool and the machine.

The following component parts of the technological operation appear on the operational technological chart: installation of the part on the machine, including one or more positions, removal of the part from the machine, and several steps, consisting of one or more passes. All remaining movements and activities connected with treatment of the part are not reflected on the operational technological chart, but are calculated in total as auxiliary time of the operation. The technological process of machining complicated parts consists of several operations. Thus, for instance, the technological process of machining a cannon breech consists of 20-35 operations, depending on the complexity of its construction. The machining of a shaft, whose drawing appears in Figure 5, might serve as an example of a technological process which is simple in the amount of work it takes.

Shaft stock is a roller ∅ 55 X 415 mm, made of number 30 construction steel.

The technological process of machining the shaft consists of the following operations:

centering, to locate the centers of both butts of the stock;

lathe work, including turning the exterior surface of the stock to the required dimensions and trimming both its ends;

milling the keyways, and;

work to clean off burrs and sharp edges.

Each of these operations includes several installations, steps, and passes.

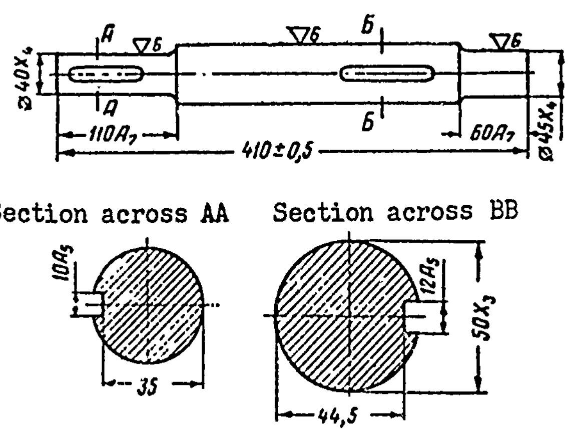


Fig. 5 Shaft (stock -- roller ∅ 55mm, KZO steel).

Lathe operations for treatment of the shaft, for example, will have five steps and three installations, which are accomplished in the following sequence, or by the following plan of treatment:

1) installation and fastening the stock on the machine -- installation;

2) trimming one end of the stock clean -- step;

3) turning the stock with two passes (coarse and fine) to the dimension $\phi\ 50X_3$ -- step;

4) turning the end of the stock in two passes (coarse and fine) at the 6C 1_7 length section to dimensions of $\phi\ 45X_4$ -- step;

5) removal of the stock from the machine for treatment of its other end, and re-installing it on the machine -- installation;

6) trimming the other end of the stock to a length of 410 ± 0.5 mm -- step;

7) turning the other end of the stock in two passes (coarse and fine) on the $110A_7$ length sector to a size of $\phi\ 40X_4$ -- step

8) removal of the part from the machine.

For clarification of differences in technological processes with regard to scale and composition of work, we will look at the machining of two parts, a recoil brake spindle of XM steel, and a regulating ring of construction steel, which are shown in Figure 6. The regulating ring B fits on the spindle and is fastened to a rod by threads in the piston. During firing, the ring, together with the rod, move, while the spindle remains stationary. Clearance of changing size is formed between the ring and the spindle, and the braking fluid flows through this clearance. The basic dimensions of the spindle A are given in Figure 6, and their numerical values appear in Table 3.

The spindle has a changing section over a length of 625 mm, and in this section it is machined to closer tolerances, approaching third class tolerance. After being machined, the spindle cannot have a curvature greater than 0.1 mm.

Machining of the spindle includes three operations:

lathe work , including cutting of threads, to bring all exterior surfaces to required dimensions;

grinding the external surface of the changing section;

work for treatment of wrench marks and removal of burrs.

The technological process of machining the regulating ring consists of one lathe operation, accomplished on a threading and turning lathe. Stock for the ring is a roller ϕ 80 mm, the length of two rings. The plan for lathe operations on the ring include the following installations and steps:

1) mounting and fastening the stock on the machine;

2) trimming the end to a smoothness of ∇5

3) turning the external surface to ϕ 75X4 on the 54 mm long section;

4) turning the external surface to ϕ $72_{-0.2}$mm on the 25mm long section for threads 3M72 X 2f;

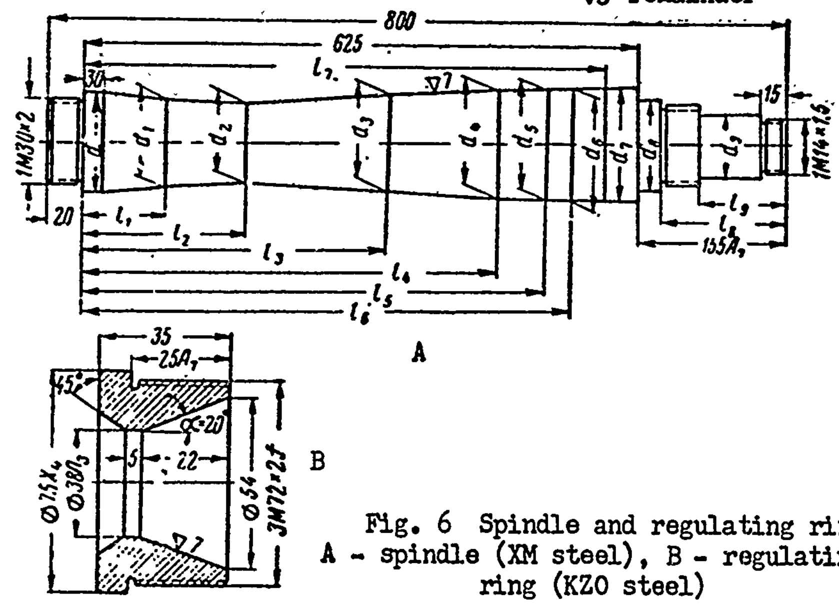


Fig. 6 Spindle and regulating ring. A - spindle (XM steel), B - regulating ring (KZO steel)

5) turning grooves 4mm in width and 69mm in diameter for the threads;

6) boring a passageway ϕ 35mm;

7) reaming the opening to a cone at the 22mm long section (cone angle α=20° largest diameter ϕ 54 mm);

8) reaming the opening from a size of ϕ 35 mm to one of ϕ $38A_3$;

9) cutting the threads 3M72 X 2f;

10) polishing the internal surface of the cone to ∇7 and cleaning the burrs;

11) removing the stock from the machine for treatment of its other face and fastening it on the machine in the new position;

12) trimming the face to size, keeping overall stock length to 76 mm;

13-16) repeat of steps 4, 5, 7, and 9;

17) cutting the stock into two rings, with a cut width of 5 mm;

18) trimming the face of the mounted ring to a size of 35 mm;

19) reaming the opening ∅ 38A_3 into a cone with an angle of 45°, keeping the ∅ 38A_3 size for a length of 5 mm;

20) polishing the interior surface of the cone and cleaning off burrs;

21) removing the ring from the machine, and mounting and fastening on the second (cut off) ring;

22-24) repeat steps 18, 19, and 20;

25) removing the second ring from the machine.

Most of the steps described have several passes, which are not reflected in the plan of operation

TABLE 3

DIMENSIONS AND TOLERANCES FOR THE SPINDLE WHOSE DRAWING APPEARS IN FIG. 6

Размеры диаметров по сечению a			Длины участков b		
условные обозначения размеров на чертеже c	величина размера, мм d	допуск на размер, мм e	условные обозначения размеров на чертеже f	величина размера, мм g	допуск на размер, мм h
d	36,4	±0,1	—	30	—
d_1	33	±0,05	l_1	96	±0,5
d_2	32	±0,05	l_2	190	±0,5
d_3	33,7	±0,05	l_3	358	±0,5
d_4	35,3	±0,05	l_4	480	±0,5
d_5	35,9	±0,05	l_5	540	±0,5
d_6	36,7	±0,05	l_6	570	±0,5
d_7	38	−0,15 −0,20	l_7	595	±0,5
d_8	24	X_3	l_8	140	A_7
d_9	16	X_4	l_9	118	A_7

a. Diameters by station
b. Section length
c. Size station on drawing
d. Size, mm
e. Size tolerance, mm
f. Size station on drawing
g. Size, mm
h. Size tolerance, mm

In the technological processes of parts machining, the following types of operations differ in amount of work done in them and number of various steps: large or concentrated, and simple or differential, which consists of two or three steps.

In large operations, the working places (machines, tools, and work process) are complicated, and therefore higher qualifications are required for the workers. In this case, however, some types of work can be automated, especially if they can be done on automatic machines. It is also common to work on a part with several tools simultaneously. As a result of the use of similar measures, concentrated operations become more economically profitable than simple ones. With concentrated operations, production planning is simplified and the number of planning and accounting documents is decreased. It is more advisable to use concentrated operations for treatment of large heavy parts, because their treatment is shortened with this cycle.

Differential operations are profitable only for treatment of a large lot of parts which are small in dimensions and simple in form.

Sequence of Operations in the Technological Process

The necessity for strict observance of operational sequence in the machining of many parts is often brought about by production conditions in which manufacturing exactness and consideration of economic expediencies are required. Under production conditions, for example, of such large artillery system parts as tubes, sleeves, breeches, cylinders, rods and wedges, whose stocks are forgings and must be heat treated, it is necessary prior to heat treatment to shape a closer form, remove the layer of metal with scale and uneveness from their surfaces, and for barrels, to additionally bore the passages.

This entire preliminary work is called coarse, and in it, a large amount of metal is taken off. In coarse machining, primary significance is attached to high rates of cutting, the use of manifold cutting heads, or simultaneous treatment of several parts (breeches, wedges), in which the work will correspond to 7th class precision. It is expedient to conduct all coarse treatment in a separate shop, located near the forging and pressing and the heat treatment shops, and equipped with powerful machines, to allow treatment to be done at high rates. Coarse treatment demands great cutting efforts and brings about much elastic deformation in the treated parts, the machines and tools.

The basic factor in fine machining is attainment of the required precision and smoootheness of the treated surface, and the treatment rates must be economically profitable, that is they must be as intensive as possible. Machines and attachments for fine machining are more exact than similar equipment for coarse treatment of parts.

In production, therefore, it is necessary to conduct machining of parts on the various machines, observing a determined sequence of operations, namely coarse operations at first, then fine, and finishing (polishing and grinding).

For a number of parts, however, which are not large in dimensions and are comparatively simple in form, it is advisable to conduct both coarse and fine treatment on the same machine, if such combination of work in the same place does not hinder attainment of the required precision. Treatment of the parts appearing in Figures 5 and 6 can serve as examples of combination of coarse and fine treatment operations on the same machine. Lathe work of the shaft's external surface (see Fig. 5) is accomplished, as is pointed out, in two passes: coarse and fine. Cutting depth in coarse turning will be significantly greater than in fine turning, while cutting speeds for both passes may be identical and the highest possible. Full mechanization of shaft treatment provides the required precision and will be economically more profitable than its coarse and fine treatment on separate machines.

3. General Proposition on Planning of Technological Processes

In a technical sense, artillery production has the following peculiarities:

the basic gun parts, manufactured from high quality alloyed steel, have high strength and resulting toughness;

some parts, for example, tubes, having a weight of 500 to 15,000 kg and length of 2500 to 15,000 mm, are manufactured from one large forging;

in manufacture of a number of parts, such labor consuming and technological operations as deep boring, cylindrical and conical reaming of long tubes, lathe work, polishing, honing, bore grooving, milling of grooves with a changing section over great length, and others are used.

Such technological operations require special equipment, large forges, presses, and horizontal and vertical ovens, special machine tools for mechanical treatment, and lifting and transporting means.

The greatest number of parts in artillery systems, however, are similar to parts of machines (metal cutting machine tools and tractors) in medium and heavy machine construction in their consturction and technology of production.

The development (planning) of technological processes is accomplished by the department of major technology (DMT) of the plant. In plants with large-scale metallurgical production, it is advisable to have two technical departments: one to head the machining and assembly processes, and the other for the processes of metallurgical production (see Fig. 4). The following tasks belong in the functions of the DMT for machining and assembly:

1) classification and sorting of all product parts into homogeneous groups according to technological and construction qualities of the parts;

2) development of the technological processes of machining all parts, with the widest use of mechanized and automated equipment;

3) selection of type of required equipment, considering use of machines present at the plant, and modernization of some machines. The department of

the chief mechanic is the basic performer in machine modernization;

4) composition of the technological route for parts and separate assemblies, in which parts movement through the plant shops and production cycles of their treatment are shown;

5) planning of equipment, showing its location in the plant shops;

6) development of working drawings for attachments and instructions for their manufacture and installation;

7) planning of special cutting tools, as well as testing them on the job and introducing them into production;

8) planning special control tools and instruments;

9) development of technological processes for artillery system assembly and a number of technical instructions for assembly of its separate components (assembly of antirecoil mechanisms, checking interchangeability, etc.);

10) development of machine cutting rates and norms for expenditure of primary and auxiliary materials;

11) operational guidance of the technological process in the plant shops and solution of various problems which arise in the process of production;

12) development of measures for raising qualifications of engineering and technical personnel of the plant, for providing all departments of the plant with technical information on achievements in the field of machines and production technology for exchange of work experience with other related plants and to take advantage of experience of plants of foreign firms.

This short list of the technical department's basic tasks shows that it must contain a large number of engineering and technical workers with various specialties. In production practice, the entire technical department engineering staff is divided into separate groups according to the following specialties: technician group for development of technological processes of machining and assembly, construction group for designing attachments and tools, a group to work out technological norms, and operational technological groups in the shops (shop technical bureaus), which are subordinated to the chief technician in a technical relationship, and to the shop foreman in an administrative one. In some instances, it is expedient that groups of engineers specialize according to separate artillery system assemblies, for example, barrels, breechblocks, antirecoil mechanisms, etc.

For every artillery system in production, it is necessary to pick out the leading technician, who must coordinate all technological problems in the shops with metallurgical production technicians and with the system designers.

The initial documents for technological process planning are working drawings and technical conditions for manufacture of the product (gun), which are worked out by the construction department (CD), headed by the plant's chief designer (see Fig. 4).

Artillery system design, as a whole or by its separate parts, has to be technical. An achievement in construction technicality is a complex task, which can be fulfilled with constant contact between the technician and the designer.

The basic measures which further increases in construction technicality of any artillery system are included in the following:

1) widest usage in construction of standardized and universal parts of existing artillery systems. These parts are usually common to several systems and are well proven in operation. It is proper to use this system design principle not only for secondary parts which are small in size and simple in form, but also for many complicated parts and assemblies (elevating mechanism boxes, cradles, recoil brake cylinders, breechblock wedges, etc.).

Use of standardized and uniform parts in system design allows use in production of standard tools, and significantly decreases the numbers of special tool and attachment types, as well as types of parts. All this eases production conditions for the system

2) limited use of expensive, high-alloy steels and non-ferrous metals (bronze and brass) for parts;

3) widest use of cast parts, and use of rollings, steel and centrifugal castings, hot and cold stampings for stock;

4) designing parts so that they can be used in construction without treatment of all their coarse surfaces, would have the lowest possible number of complicated steps from one surface to another, and would have convenient technological bases. All this simplifies planning of attachments, mounting of parts on machines, and assembly of the system as a whole;

5) sound determination of degrees of machining accuracy and surface smootheness. Unwarranted higher classes of accuracy, placement of surface smootheness complicate parts manufacturing processes and increase system production expenses. It is necessary, in planning the system, to conduct an analysis of tolerances by calculations, so as to eliminate mistakes in the determined degree of accuracy in treatment and sizes. Dimensions and tolerances on drawings must provide wide usage of maximum sizes and standards;

6) provisions for interchangeability of parts, considering operating conditions and repair of the system in the armed forces.

All the measures enumerated can be successfully realized if design development of an experimental system model and manufacture of its first lots are conducted with close contact between the designer, the metallurgical technicians , and the technicians for machining and assembly.

Experience in serial production of certain artillery systems during the Second World War confirmed that adoption of the measures described can produce highly effective results in decreasing labor consumption and cost of production.

The first design variant, for example, of the 76.2 mm division cannon, model 1942, had 1306 parts, and after design review of its parts and separate assemblies, it had a total of only 720 parts. The number of alloyed steel parts in this cannon decreased from 270 to 163 after design review, and the non-ferrous metal parts decreased in number from 134 to 92. The cannon's cradle body was first built from several riveted and worked parts, whose stock was made up of sheet steel stampings. After technical review, its stock was made up of a thin-walled steel casting.

All this simplified technology of the cannon's machining and assembly, and the total time for production fo the system was markedly reduced.

With a transfer from normal turning and thread-turning lathes to turret lathes and semiautomatic and automatic machines, machining time for a number of parts decreases by 40-65 percent. It should be noted, however, that a transfer to automatic machines is justified only with machining of large lots of parts.

In the process of production of an artillery system's first serial lot, the design of some parts and assemblies is made more precise, and in necessary cases, changed, during which the total number of parts may be decreased and the type of material and form for stock may be changed for many parts. In this instance, it is advisable to develop technological processes only for some major parts which cannot be essentially changed, while all other parts are limited to preliminary work, meaning rough draft development of the technological processes and adjustment of any special high-production attachments used for development.

After production of the first lot of the system is mastered and working, corresponding changes are made in the working drawings of parts and assembly, the latter becoming the primary technical documents for development of the technological processes for the artillery system serial production.

Classification of Parts

The first stage in planning of technological processes is classification of parts and their separation into groups according to their commonalities in construction form and uniformity in technological qualities. This measure makes it possible to concentrate manufacture of a group of parts which are technically the same in one shop or one section, and to develop a single technological process for them, choose equipment and tools which are more suitable for productivity, improve planning of machines and organize production flow of parts. Technical commonalities of such parts are determined with the following qualities:

construction form;

dimension sizes;
precision of machining and quality of machined surface;
type of material and its mechanical properties;
form of stock and means of its formation.

According to these technological qualities, all parts can be divided into the following groups:

A. Parts which are bodies of rotation

These parts include:

1) shafts and tubes of large dimensions, including gun barrel tubes;
2) hollow cylinders of medium dimensions, having a length of 10-15 diameters. These are cylinders and rods of antirecoil mechanisms, ylinders of counterweight mechanisms, and axles of some field guns;

3) shafts, axles, pins, pawls, stops, and other items having an uninterrupted section, relatively small dimensions (by length and diameter), and characterized by precision machining, turning and grinding of external surfaces. These are shafts of elevating and traversing mechanisms (Fig. 7), parts of the counterweight and stopping mechanisms and parts of the breechblock (Fig. 8, nos 1, 6, and 7).

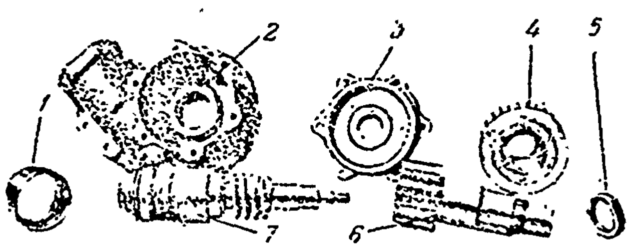


Fig. 7 El ing Mechanism Parts
1 - retaining .ing, 2 - case, 3 - case cover, 4 - worm gear, 5 - nut, 6 - gear shaft, 7 - assembled worm shaft.

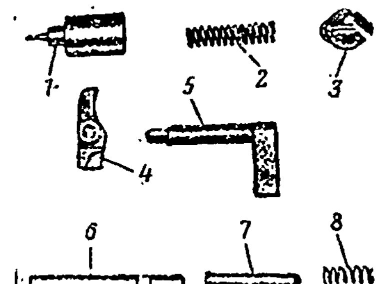


Fig. 8 Firing Mechanism Parts
1 - striker, 2 - striker spring, 3 - cap, 4 - hammer, 5 - hammer shaft, 6 - stop, 7 - stop pin, 8 - stop spring.

4) bushings, rings, bases, inserts, special pins and other parts which are simple in form, small in dimensions and have openings through them with concentric external and internal surfaces (see Fig. 7).

5) screw, worm, cylindrical, and conical gears for various purposes.

B. Parts having large flat surfaces

These parts include breeches, breechblock wedges and barrel sleeves.

Some of these parts (breeches) have circular internal openings with concentric surfaces, but the external surfaces are planes. These parts most often have a complex form and large dimensions, and stock for them is manufactured out of special alloyed steel and machined on certain surfaces with high accuracy.

C. Polyaxial Parts of Complex Forms

These are the cases for elevating and traversing mechanisms and the covers for them (see Fig. 7), brackets, upper and lower mounts, racks, cradle collars and caps, and trail spades. Stock for these parts are usually steel castings, on which certain surfaces remain coarse, and are not machined.

The practice of classification and separation of parts into groups by technological qualities is an example, and does not exhaust all the possible modes of classification. It is advisable, for example, to divide certain groups of parts into smaller sub-groups according to dimensions and less technological qualities. Some of the parts undergo machining on several (two or three) machines. Breeches, mechanism cases and various gears, for example, are machined on universal screw cutting lathes, and them on special tooth-forming machines. It is necessary to consider these peculiarities of technology when developing the technological process and routes of parts movement through the shops.

Classification of parts by design and technological qualities is a complex task, whose fulfillment calls for qualified engineers with production work experience.

The wise choice of parts into groups by general quality type allows fulfillment of technological processes on a higher technical level.

4. Development of Technological Processes for Parts Machining

For development of machining technological processes, the technician must have working drawings of the finished parts and their stocks, classification of the parts by technological and design qualities, and must know the number of machined parts, which is to say the number of parts in a lot put out in production, and the required number of parts per month and per year. Besides this, the technician receives instructions relative to the use of existing equipment in the shops, and of the possibility of acquiring newer, more modern equipment.

All these materials and information are primary for development of the following basic documents of the technological process:

The Routing Chart, made up for most parts other than standard fastening parts. Stock types and routing of their movement through the shops, number of simultaneously machined parts, lot size, equipment, and machine and total time are indicated on this chart. The routing chart makes it possible to correctly plan production and technological processes, determine shop employment, and follow accomplishment of these processes.

The Technological Chart, made up for each part and including enumeration of all machining operations for the given part, with indications for the type of machine, attachments, and cutting and control tools for each of them, as well as treatment rate, and machine, auxiliary, additional, and piece (total) time norms.

Heat treatment of the part and special operations for its technical control which are accomplished in the intervals between separate machining treatments, appear on the technological chart only by designation, with an indication of the shop in which it will be produced and treated separately. Steps of operations are indicated on the technological chart in the form of abbreviated orders, for example, "ream opening to ∅ 105 mm and depth of 75 mm", "trim butt ends", etc.

All steps of each operation are numbered in the order of their fulfillment sequence, and the treated surface is designated with the step number on operational sketches. The technological chart takes the place of working drawings, and is more convenient to use.

The Operational Chart is a full description of the given operation and includes all information about it according to the routing and technological charts. The operational chart has, besides this, mid-operation and operational sketches, the first of which depicts the stock (partly finished product), and the second shows the finished view of the part after the given operation. In a complicated (concentrated) operation, several views of the part stock should be worked up for three or four steps of the given operation. In some instances, brief indications should be set forth on machine adjustment, the attachment, and the tool. Besides this, sketches of installation of the part on the machine or on the attachment should be worked up for some complicated operations.

Operational Sketches, which must show the sequence of changes in form of the manufactured part, from stock to its finished appearance, adjusting surfaces, position of the part on the machine, and position of the cutting tool relative to the part. Sketches are worked up for each operation, and one sketch might include two or three steps, or in some instances, one step. We will look at the composition of operational sketches on an example of the manufacture of a mortar breech, whose sketch appears in Figure 9.

Technological treatment of the breech consists of the following operations: centering, turret lathe, milling to mill the ball pivot planes, drilling for treatment of the ball pivot opening, and working.

The turret lathe operation is basic, because almost all external and internal surfaces of the breech are machined during its fulfillment. Figure 10 shows the first four sketches of the turret lathe operation.

The first one (a) shows installation of the stock in the machine chuck and on the rear center. In this position, the stock is machined with the aid of the front and rear supports in the following manner: the external surface is turned to a size of $\emptyset\ 122_{-0.4}$ on a 140 mm length with tool 1, the external

Attachments and tools are worked out at the same time as development of the technological process. The technician working out the technological process must therefore have information on construction of special attachments and tool design, and the designer, planning attachments and tools, must know the form of the part, the type of machine, and the machining rate of the given part on it. All these conditions require constant contact with the technical department, which is working out the various technological documents.

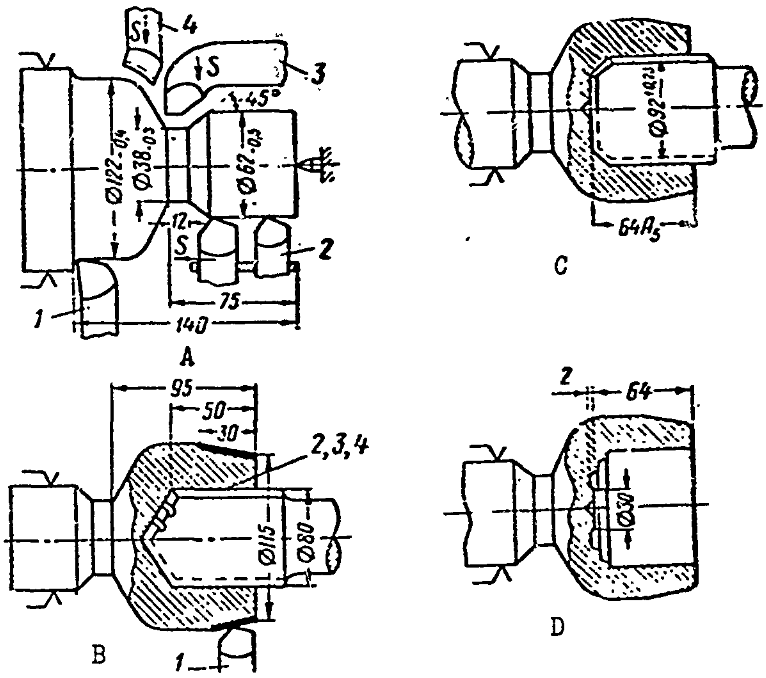


Fig. 10 Operational Sketches of Mortar Breech Machining

a - trimming butt end, machining cylindrical and formed exterior surfaces, b - trimming other butt end and machining exterior conic surface and drilling and reaming opening, c - turning opening d - machining circular ledges of the opening

Development of the technological process is completed with the development of the entire collection of technical documents which make it up. It is wrong to consider development of the technological process unchangeable, as certain of its operations may be changed in the course of production if necessary changes or additions enter the picture. The developed technological process is proven and refined in the process of manufacture of the first lot of products.

After this proving, all documents and drawings are finalized, and all attachments, stamps and special cutting tools are manufactured in the quantities needed for the entire production program.

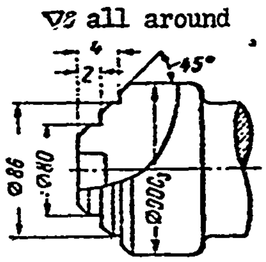


Fig. 11 Special cutter for machining circular ledges in a mortar breech opening.

CHAPTER III

Precision in Machining Major Parts of Gun Barrels

5. Technical Requirements and Tolerances for Major Parts and Assemblies

In planning the various parts and assemblies of artillery system mechanisms, the designer takes into consideration their normalized (calculated) dimensions, the mechanical properties of the materials used, and the required smootheness of machined surfaces. This information determines the strength, weight, and general form of the planned parts and mechanism assemblies. Manufactured parts and mechanism assemblies will differ from those planned in size, shape, mechanical properties of the metal, smootheness of surface, and weight.

The degree of difference (deviation) in these parameters between the manufactured parts and mechanism assemblies and the planned ones, which are shown on drawings, is the characteristic of accuracy for artillery system parts manufacture. This general description of the idea of parts manufacturing precision relates uniformly to any machine.

The technology of metallurgical production, machining and assembly cannot assure full accordance with plans in parts manufacture, but this is not required under the working conditions of any machine. After machining, parts will have imperfections, or various deviations from the sizes on the drawings or other parameters.

One of the designer's tasks consists of determining the amount of allowable deviation of actual sizes from their normalized values, and to show these deviations on working drawings or formulate them in technical conditions, or in other words, to determine tolerances for size in machined parts and fit for composite ones.

Class of precision according to tolerance, and character of fit are determined according to standards or special requirements which take into account the real working conditions for parts and mechanism assemblies, as well as conditions of technical capability and economic expediency in production technology

Tolerances for linear and angular dimensions of parts and for assembly dimensions are determined during workup of the drawings, and must be agreed upon by the designer and technicians in heat and machine treatment. Only under these conditions will the required parts manufactured accuracy correspond to the technical capabilities and economic expediency of production. Examples of tolerance assignments and development of technical requirements for some major artillery system parts are discussed below.

1. Gun Barrels

Gun barrels can be designed as momoblocs, built up, with a removeable tube, and lined. A monobloc barrel consists of a gun tube which is manufactured from one piece of stock, a breech, sleeve, and fastening parts. A built up barrel may consist of two, three or four gun tubes which are pulled one onto the other. In the remaining gun barrel designs, the tebes are assembled together freely, with some clearance between the assembled surfaces.

A drawing of a monobloc tube appears in Figure 12, and its basic dimensions and tolerances are given in table 4.

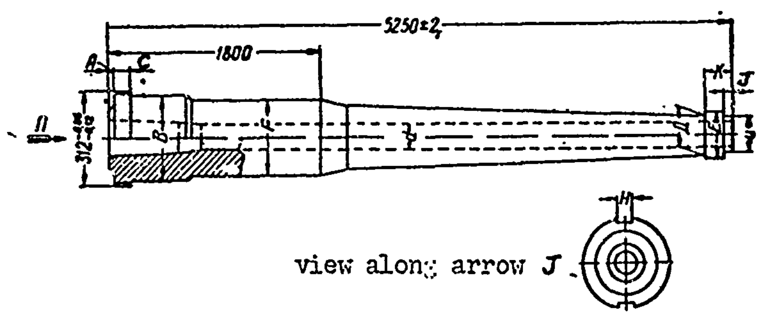


Figure 12. Monobloc tube

Tolerances for dimensions A, B, C, H, and the collar are determined by conditions of fit between the corresponding surfaces of the tube, breech, sleeve, and wedge breechblock. Tolerances for dimensions C and H correspond to 3rd class sliding fit, and for dimension B corresponds to 2nd class moving fit. The surface which fits against the surface of the aligning cradle has a tolerance on dimension F, and corresponds to 4th class moving fit, while the surface which provides alignment and centering of the muzzle brake relative to the tube has a tolerance according to dimensions E and G, which correspond to 3rd class moving fit. Tolerances on the remaining external dimensions of the tube correspond to 4th class accuracy. Smootheness of treatment of the external surfaces of the tube which are connected with the breech, or with the jacket or casing in other barrel constructions, is very important, and therefore belongs to the 6th class (∇ 6) group of semi-smoothe surfaces, while the free surfaces of the tube (not having contact) are in the 4th class (∇ 4) group of semi-smoothe surfaces. The external surface of the tube must be strictly concentric relative to the longtitudinal axis of the barrel bore.

Tolerances for barrel bore diameter dimensions along the lands (dimension d) and the grooves (dimension d_H) and tolerances on dimensions of the charge chamber diameters are set by conditions of loading and centering the projectile in the bore for its movement along the bore during firing. The sizes of these tolerances for weapons with rifled bores are accepted at limits of 0.1 to 0.2 mm in diameter, for which the smaller limit is for 45-85 mm weapons, and the larger limit is for weapons 203.2 to 210 mm. Smootheness of the internal barrel bore surface, which is finish-worked by honing or polishing, must correspond to the 8th or 9th class (∇8 or ∇9) surface smootheness group.

TABLE 4

Basic Dimensions and Tolerances for Monobloc Gun Tubes
(see Figure 12)

Dimension Designation	*A*	*C*	*B*	*F*	*D*	*E*
Dimensions and Tolerances, in mm	$8_{-0.15}$	$62_{-0.05}$	$285^{-0.05}_{-0.12}$	$262^{-0.2}_{-0.5}$	$168^{-0.15}_{-0.4}$	$180^{-0.06}_{-0.16}$

continuation

Dimension Designation	*G*	*K*	*J*	*H*	*d*
Dimensions and Tolerances, in mm	$170^{-0.06}_{-0.16}$	$190_{-0.2}$	$56^{+0.2}$	$28^{+0.05}$	$121,92^{+0.15}$

Figure 13 shows the jacket (casing), the free tube and the stock forging for the German 105 mm cannon tube. The jacket and tube are manufactured of weapon steel (σ = 60 kg/mm^2 for the jacket and σ = 70 kg/mm^2 for the tube). The maximum powder gas pressure of this tube p_{max} = 2800 kg/cm^2. As is shown on the drawing, the tube, over a length of 3109 mm, fits in the jacket along a conic surface, with a conic rate of 1 : 400. In assembly, a clearance of minimum size 0.06-0.08 mm and maximum size 0.16-0.18 mm is created between the tube and the jacket. Machined smootheness of these surfaces must correspond to the 7th class surface smootheness group. The collar prevents the tube from moving along its axis in the jacket, and two keys, 24 mm wide and 15 mm high, prevent its rotation. Construction, other dimensions, and tolerances of the jacket, tube, and tube stock are sufficiently clear in Figure 13.

In recent years, the use of composite inner tubes which are assembled lengthwise has become common in planning practice for monobloc, built up, and free tubes of weapon barrels. These barrels were used in some weapons of the World War II period (especially 1942-1945), as well as during the postwar years. Figure 14 shows a composite inner barrel tube for a German 88 mm cannon. Production of this cannon has the following peculiarities: stock for the tube is almost twice as short as usual, easing processes of their forging and machining, for which equipment of smaller dimensions and capabilities is required, but more time is spent in production of composite tubes.

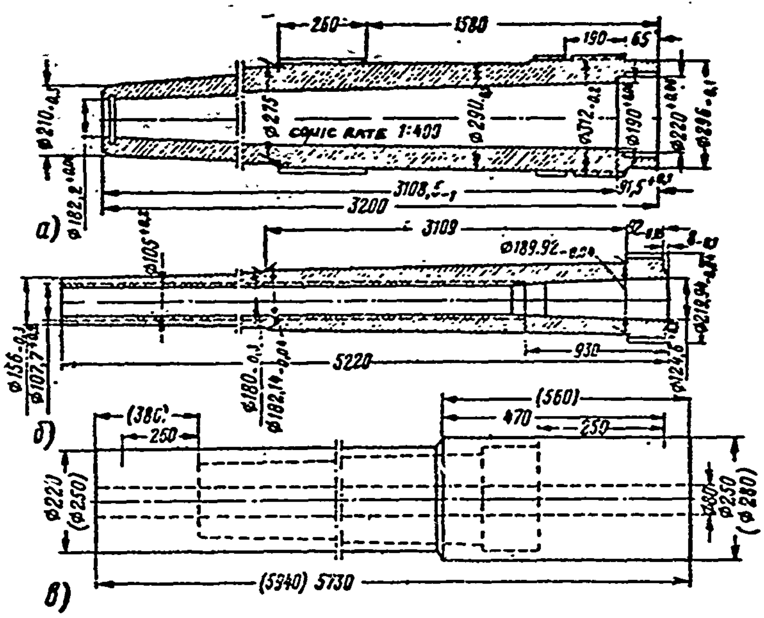


Figure 13. German 105 mm cannon
a - barrel jacket, b - barrel free tube, c - tube stock (stock dimensions in parentheses).

Composite tubes are no poorer than whole ones in operational qualities. The barrel of the German 88 mm cannon consists of the jacket 6, free inner tube, consisting of the rear 1 and forward 2 tubes, packing ring 3, connecting sleeve 4, and ring 5, which protects the threaded connection from dirt and moisture. The composite tube has an alignment section which is 560 mm in length and 158 mm in diameter, assuring alignment of the forward tube with the rear one. The given alignment is fixed with a continued key in section E. This alignment section of the tube is machined to great precision, with a rear tube diameter of $158^{+0.06}$ mm, and a forward one of $158_{-0.025}$ mm, which corresponds approximately to 2nd class sliding fit. The packing ring 3 is shown shown separately in Figure 14, B, and the ring turnings in the forward and rear tubes are shown in Figure 14, C.

Ring 3, manufactured from a special soft steel, is placed in the ring turning of the rear tube, seated during installation of the forward tube with a press, and finally fastened by the connecting sleeve 4. Sleeve 4 has two smoothe alignment surface sections, having dimensions of 184 and 198 mm. Tolerances for the tubes and connecting sleeve along these dimensions are assigned according to a sliding fit, and are between 3rd and 4th class precision in value.

The forward and rear tubes are connected with the aid of the supporting thread (see Fig. 16) and the alignment section of the sleeve, preventing their longtitudinal displacement and helping their centering. The forward tube has a small conic section, 20 mm in length, with a large diameter of 88.4 mm (see Fig. 14, C), which provides the best conditions for projectile movement in the barrel bore. Rifling such a bore is best accomplished after final tube assembly.

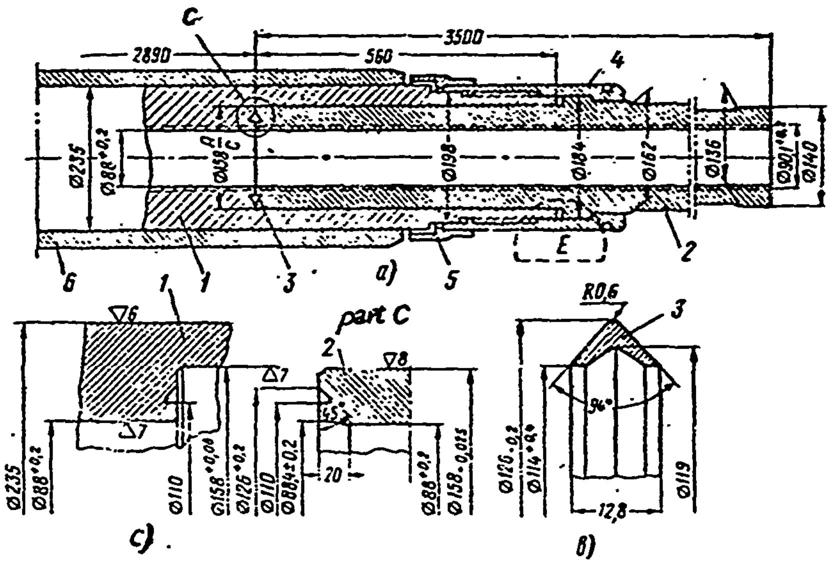


Figure 14. Composite (lengthwise) Inner Tube for an 88 mm Barrel.

1 - rear tube, 2 - forward tube, 3 - packing ring, 4 - connecting sleeve, 5 - protective ring, 6 - barrel jacket.

The other barrel construction (105 mm cannon with a free tube) appears in Figure 15. The barrel consists of the breech 1, free tube 2, jacket 3, connecting sleeve 4, lath stop 5, felt washer 6, and longtitudinal 7 and radial 8 keys. The free tube 2 is centered in the jacket 3 by two cylindrical sections, one of which extends from the breech and has a length of y = 205 mm, with a diameter of L = $215.5_{-0.1}$ mm, the other extending from the muzzle part with a length of 200 mm, tube diameter of $196.7_{-0.1}$ mm and jacket diameter of $196.75^{+0.1}$ mm. Between these sections, the jacket and tube are machined into a cone, and have a free clearance of 1.5 mm along dimension T. Overall length of the free tube is 5200 mm, and jacket length is 3000 mm. The collar, with diameter E and length C, prevents longtitudinal displacement of the tube, and the sleeve 4 prevents displacement of the jacket and the tube relative to the breech. Rotation of the tube in the jacket is prevented by key 7, and of the tube and jacket relative to the breech by key 8 (see Fig 15, view along bore). Key 8, with a width of 55 mm and thickness along the barrel axis of 45 mm, firmly fixes the position of the tube and jacket relative to the breech. It can move no more than ±0.05 mm relative to the barrel axis and the vertical diameter of the breech section. The tolerance for the 55 mm dimension of the key is given in Fig. 15 for slots in the breech, jacket, and tube.

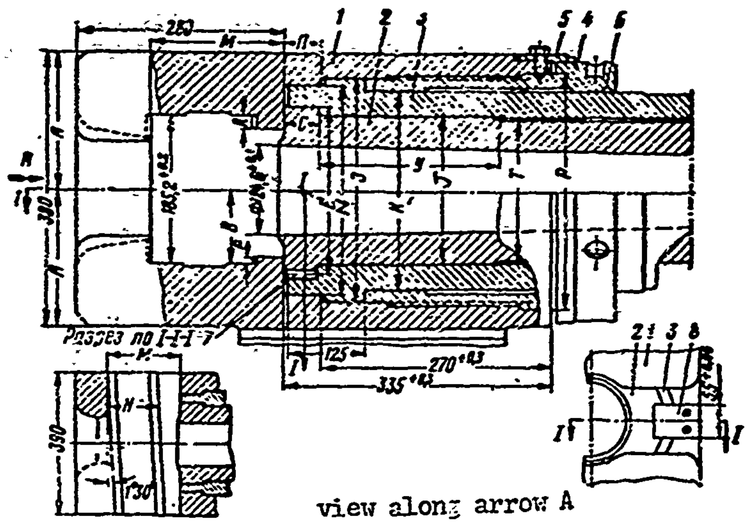


Figure 15. Installation Schematic for 105 mm Cannon Barrel With Free Tube
1-breech, 2-free inner tube, 3-jacket, 4-connecting sleeve, 5-lath stop, 6-felt ring washer.

For strong assembly of the breech, tube, and jacket in axial alignment and maintenance of the required clearance between the bottom of the bushing and the front face of the breechblock wedge when the block is closed, it is necessary that, after tube assembly, the butt surface of the collar is tightly contiguous with the cheeks of the breech and with the jacket along dimension C, so that clearance is always maintained between the butt surfaces of the jacket and breech along dimension P, as shown in Fig. 15.

Dimensions A and B of the breech also have essential importance, in that they determine the position of the breech opening for the breechblock wedge relative to the barrel axis, and consequently center the striker pin relative to the capsule plug of the bushing. These dimensions involve precise marking on the stock for machining of the breech opening on free equipment, or else special attachments are developed during planning for machining this opening for the breechblock wedge. The breechblock wedge moves into the breech along guiding surfaces, which are positioned at an angle of 1°30' to the barrel axis, and distance H apart from each other. Guiding surface deflection angle is usually kept within the limits of 1°30' to 2°10' with a tolerance of 0°5', which assures reliable locking of the bore and eliminates possibility of spontaneous breechblock wedge opening during firing. In weapon assembly, breechblock wedges are selected according to opening, or are adjusted by grinding the guiding surfaces. All dimensions and tolerances for the barrel appear in Table 5, whose information relates to the technical requirements for manufacture and assembly of the barrel parts.

Figure 16 shows the connecting sleeve of the 105 mm cannon, a simply formed part in whose machining it is necessary to keep machined surface concentric positioning within the limits of the assigned tolerances. Accuracy in cutting the stop threads and treatment of their faces are also very important in manufacture of the sleeves. These threads come under great load during firing and must not warp, a condition which is possible only if all the turns take the load simultaneously. The latter requires maintenance of the determined tolerance on thread step length (deviation in thread step over five turns must not exceed ±0.05 mm) and accurate formation of the thread face according to the dimensions given on the drawing. These requirements also apply to breech threads.

TABLE 5

Dimensions and Tolerances for Parts of a 105 mm Cannon Barrel with a Free Tube, in mm.

Условные обозначения размеров (a) по фиг. 15	Казенник (b)		Кожух (c)		Труба (d)		Соединительная муфта (e)	
	размер (f)	допуск (g)	размер (f)	до-пуск (g)	раз-мер (f)	до-пуск (g)	размер (f)	до-пуск (g)
A	190	±0,1	—	—	—	—	—	—
B	88,1	+0,1	—	—	—	—	—	—
F	6	−0,1	—	—	—	—	—	—
D	15	−0,1	—	—	—	—	—	—
З	320	+0,17 +0,05	320	−0,1	—	—	320	−0,1
Ж	300	+0,6 +0,3	300	−0,3	—	—	—	—
E	—	—	258,2	+0,3	258	−0,2	—	—
K	—	—	290	−0,1	—	—	290	+0,17 +0,05
J	—	—	215,55	+0,1	215,5	−0,1	—	—
M	179,5	+0,2	—	—	—	—	—	—
H	142,1	+0,1	—	—	—	—	—	—
P	340	+0,17 +0,05	—	—	—	—	340	−0,1
C	—	—	59,5	+0,3	60	−0,1	—	—
T	—	—	215	+0,5	213,5	−0,5	—	—

a. Dimension designation in Figure 15
b. Breech
c. Jacket
d. Tube
e. Connecting sleeve
f. Dimension
g. Tolerance

The design, dimensions, and tolerances of barrel parts shown in Figures 12-16 graphically show the technological peculiarities of their production. In the monobloc-tube gun barrel shown in Figure 17, all machined surfaces are surfaces of a rotating body and have the same axis, and only slots for keys and extractor claws are flat surfaces. Tubes and connecting sleeves for gun barrels are simple in design and convenient for machining. Breeches are more complicated parts, with a large number of slots, openings, and various faced surfaces, whose machining requires special marking, attachments, and tools.

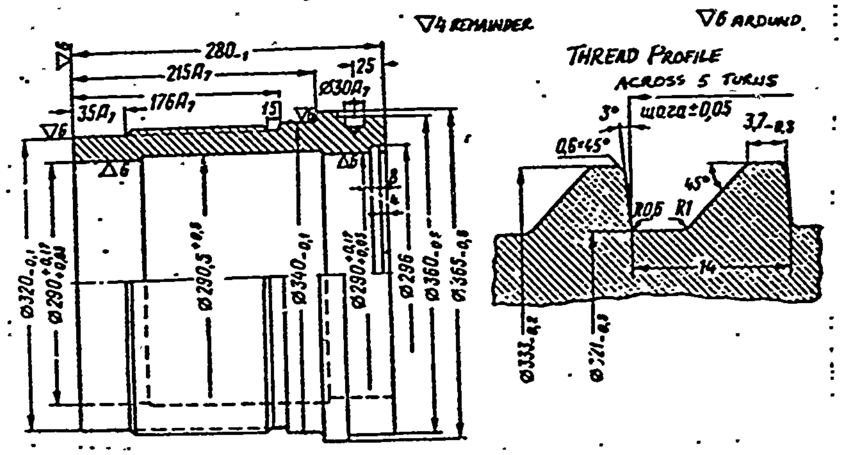


Figure 16. Connecting Sleeve (steel $\sigma_{0.2}$=55 kg/mm^2)

Exterior and interior tube surfaces must be concentric relative to the barrel bore axis, and for the bore, must be cylindrical and straight. In treatment of tubes, instances can arise in which, while keeping to assigned tolerances, such deviations in dimensions and openings and surface formation are gotten that the tube becomes unuseable.

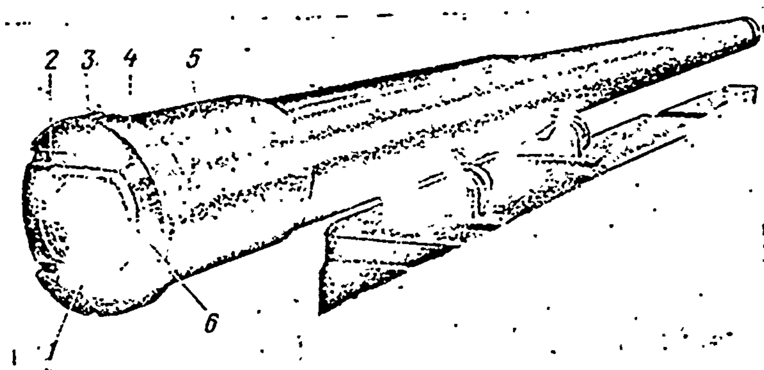


Figure 17. Monobloc Tube

1-extractor slot, 2-pressure vents, 3-keyway, 4-collar, 5-cylindrical shoulder, 6-butt step.

It is possible, for instance, to get waves on the interior surface of a tube during machining (Fig. 18, a). Such defects on barrel bore interior surfaces and various cylinders of artillery systems are not allowable. Indications of the appearance of the mentioned defects in technical conditions in tube manufacture can be gained by the fact that if for a bore diameter d, an overall tolernace of +0.15 mm is given on the drawing for the entire length of the tube, then difference in tube diameters on sections 100 mm apart, and overall conicness of the cylindrical bores cannot exceed half of that tolerance, cr +0.075 mm.

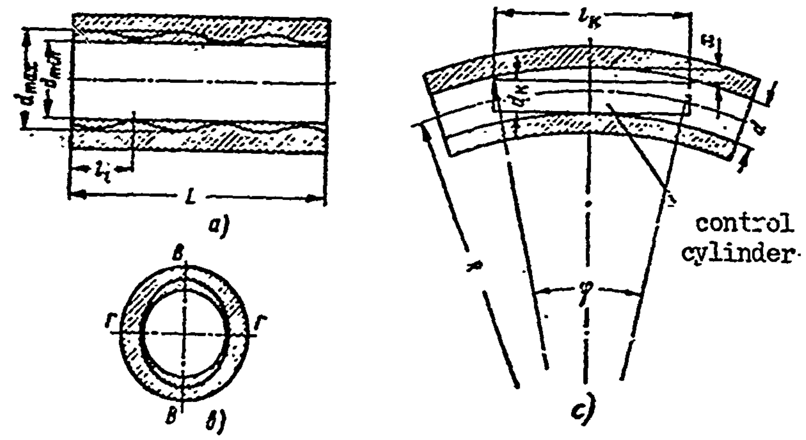


Figure 18. Possible Form Changes in Barrel Bores Within the Limits of Assigned Tolerances.

a-surface waviness, b-curvature, c-amount of ellipsoid shape and wall variation in a section.

In production practice during tube machining, defects are encountered in the form of curvatures (see Fig. 18, b) and variations in bore wall thickness. Causes of these defects are usually residual internal stresses in the tube material which arise after its heat treatment, or in some instances, straying of the tool during turning of the barrel bore. Research and technological checking of tube bores over 45 calibres in length shows that after machining, the axes of the majority of these tubes have curvatures which are determined by the angle $\varphi = 0^o 5'$, and in some cases up to 4 thousandths ($0^o 14.5'$). Bore curvature destroys the normal movement of the projectile along the bore, and it will deviate from the intended direction as it leaves the bore. Barrel bore curvature is easily determined with a smoothe cylinder of diameter d nad length l =5d (see Fig. 18, b). or with the use of optical instruments.

With a smoothe cylinder, bore curvature is determined accor ing to the formula

$$x=\frac{l_\kappa}{2}\operatorname{tg}\frac{\varphi}{4}, \qquad (8)$$

where l_κ — chord length acceptable for the arc length, according to the size of the angle

φ — central angle determining tube curvature

Weapon tube wall variations which are smaller than 1 mm do not significantly tell on tube strength and have no practical meaning. This is easily checked with a corresponding calculation. Wall variations increase, however, with increased bore curvature. Instances are known where barrel explosions have occurred with wall variation of up to 3-6 mm. Bore curvature exceeding 1.5 thousandths (0°5') and wall variations exceeding 1 mm are not usually allowed. Ovalness in the opening, determined by differences in horizontal and vertical diameters of any section of the tube, must not exceed half the tolernace on diameter, or 0.05-0.08 mm.

2. Barrel Bore, Shell Casing, and Projectile

A gun barrel bore is divided into three parts along its length: the rifled portion, charge chamber, and breechblock seat. The charge chamber may be designed for fixed charges (see Figures 19 and 20), cased separate charges, and separate loading (see Fig. 108, k). Charge chamber machining takes place after smoothe machining of the bore, but before cutting the rifling grooves.

Charge chamber construction is determined by its volume W, in which the powder charge is placed. The charge chamber for fixed charges consists of several connected cone sections (see Fig. 19). The first cone, of length l_1 is the base one, because over 90 percent of the entire powder charge is placed in it. It has a usual conic rate of k_1=1/70 to 1/90. With an increased angle of inclination α of the first cone, cartridge extraction is improved, but with this, it is necessary to increase the chamber diameter d_2 and the external diameter of the barrel, and both machining of the chamber and manufacture of the cartridge are made more complicated.

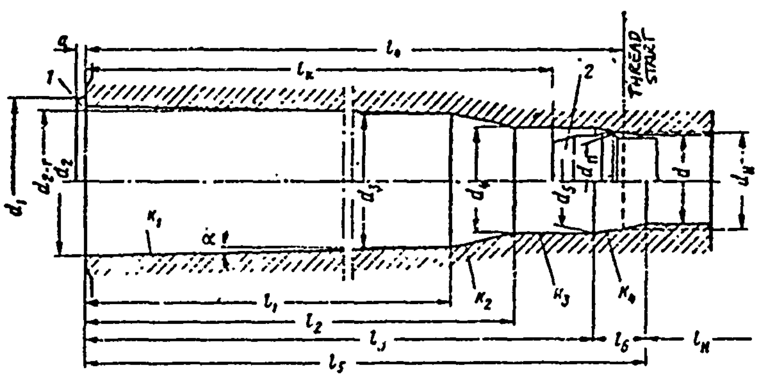


Figure 19. Profile of a Fixed Charge Chamber

1-cartridge base, 2-projectile, d_2-largest charge chamber internal diameter, $d_{2\text{-}r}$-largest cartridge base cone external diameter

It is necessary to assure a clearance between the cartridge casing and the chamber wall in the section of the first cone. Clearance size depends on the calibre of the weapon and the size of the cone. For example, for 50 mm and 76 mm guns, the clearance must be 0.2-0.5 mm on the diameter, and for 152 mm guns, it must be 0.5-1.0 mm. These clearances are determined by the sizes of tolerances on diameters of charge chambers and cartridge casings, whose values are shown in Figure 20 and 22, and appear in Table 6.

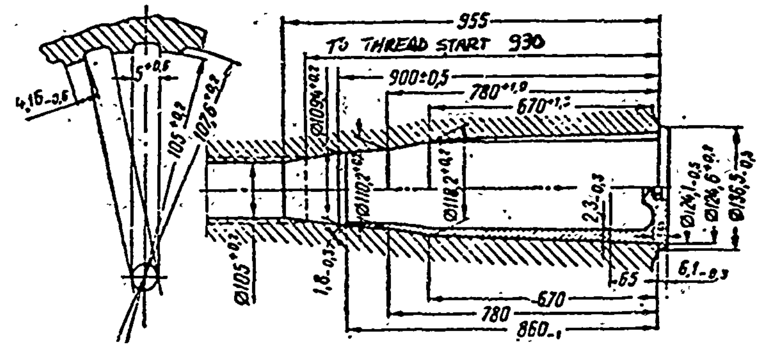


Figure 20. Profile of Charge Chamber, Cartridge Case and Rifling Grooves (36 Grooves, 4°30'-6° in steepness

The second chamber cone, connected with the first and with the cone for the cartridge neck, has a conic rate k_2=1/4 to 1/10 (see Fig. 19). Its dimensions are determined by diameters d_3 and d_4, because it is the connecting link between the base cone and the cartridge neck. For the majority of modern weapons, the second section conic rate is equal to 1/5.

The third section of the chamber, or its third cone, often called the "cylindrical" section, has a small conic rate k_3=1/80 to 1/120, allowing easier placement of the cartridge neck and the banded part of the projectile. In machining this section of the chamber, diameters shown on the drawing must be strictly adhered to, so that free seating of the cartridge is possible during loading, while at the same time the smallest possible clearance is attained between the exterior surface of the cartridge neck and the wall of the chamber. Length of the "cylindrical" section must not be more than one calibre, so that it is possible to seat cartridge necks with the projectile base and rear rotating bands in it. To assure free seating of the cartridge during loading, the difference between the chamber diameter d and the external diameter of the projectile rotating band d must be within the limits of 0.3-0.8 to 0.5-1.2 mm. For good powder gas obturation and functioning of the cartridge during firing, clearance B on the diameter between the chamber wall and the external surface of the cartridge neck (see Fig. 22) must not exceed 0.5-1.0 mm, and must not be smaller than 0.2-0.5 mm. The smaller limits of these clearances are used for 50 mm and 76 mm weapons, and the larger for 130 mm and 150 mm weapons.

The last cone, connecting the charge chamber with the rifled portion of the bore, must have a conic rate of k_4=1/10. The rifling shoulder (beginning of rifling grooves) and the forward rotating band of the projectile are located in this cone. It should be noted here that with a fixed charge, the forward rotating band of the projectile need not come into contact with the surface of this cone after loading in order to provide normal seating of the cartridge, tightness of the cartridge base against the breech of the tube, and normal closure of the breechblock wedge.

After loading, however, clearance A (see Fig. 22) must be as small as possible, approaching zero. All clearances cited above are determined on the basis of theoretical calculations and experience data from artillery system service. Tolerances for machining of base chambers and cartridges are assigned according to these clearances.

The basic dimensions for machining of charge chambers are the conic rate of their sections and the diameters of the chamber, which must be strictly kept within the limits of the assigned tolerances. It is proper to assign tolerances for charge chamber diameters with a plus sign, taking into account the calibre of the gun, namely:

for 50 mm and 76 mm guns . . . . +0.1 mm
for 85 mm and 120 mm guns . . . . +0.15 mm
for guns over 130 mm in calibre . . . . +0.2 mm

It is proper to assign external cartridge diameter dimensions taking into account attainment of minimum clearances. The nominal dimensions for external cartridge diameters must be at 0.2 mm smaller than the charge chamber diameters for small calibre weapons, and at 0.5 mm for large calibre weapons. It is proper to assign tolerances for external cartridge diameters with a minus sign, within the limits of 0.2 to 0.3 mm, which corresponds to 4th class sliding fit.

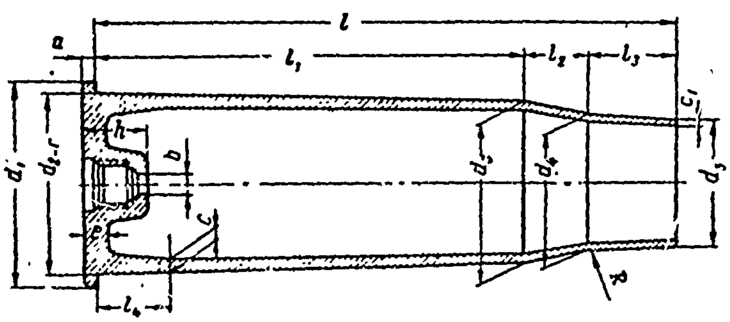


Figure 21. Fixed Charge Cartridge

d_1-external base diameter, d_{2-r}-greatest external diameter of the base cone, d_3-smallest external diameter of the base cone d_4 and d_5-external diameter of the cartridge neck, a-thickness of cartridge base, e-thickness of cartridge bottom, C and C_1-cartridge wall thickness, t-cartridge length

Tolerances for length dimensions of each separate charge chamber section are determined on the basis of the assigned tolerances for their diameters and

TABLE 6

Basic Dimensions and Tolerances for Barrel Bores, Cartridges, and Projectile Rotating Bands, in mm

Dimensions on Figs. 19 and 22	45 mm cannon, mod 1942	50 mm cannon, mod 1941	57 mm cannon mod 1943	75 mm German cannon 1942	76 mm German cannon 1942	85 mm cannon mod 1943	88 mm German cannon 1943
d_{2-r}	$53,0_{-0,2}$	$70,7_{-0,3}$	$83,7_{-0,23}$	$113_{-0,4}$	$83,7_{-0,23}$	$102_{-0,23}$	$131;5_{-0,4}$
d_2	$53,2^{+0,15}$	$71,0^{+0,1}$	$84,2^{+0,15}$	$113,9^{+0,2}$	$84,2^{+0,15}$	$102,4^{+0,15}$	$132,4^{+0,2}$
d_3	$50,2^{+0,15}$	$66,4^{+0,1}$	$78,5^{+0,15}$	$108,0^{+0,2}$	$79,6^{+0,15}$	$95,5^{+0,15}$	$123,9^{+0,2}$
d_4	$46,8^{+0,15}$	$52,9^{+0,1}$	$60,1^{+0,1}$	$79,0^{+0,2}$	$78,8^{+0,15}$	$87,3^{+0,15}$	$93,5^{+0,3}$
d_5	$46,8^{+0,15}$	$52,3^{+0,1}$	$59,4^{+0,1}$	$78,0^{+0,2}$	$78,3^{+0,15}$	$87,1^{+0,15}$	$92,5^{+0,2}$
d	$45^{+0,1}$	$50^{+0,1}$	$57^{+0,1}$	$75^{+0,2}$	$76,2^{+0,1}$	$85^{+0,15}$	$88^{+0,2}$
$d_н$	$46^{+0,1}$	$51,4^{+0,1}$	$58,8^{+0,1}$	$76,8^{+0,2}$	$77,72^{+0,1}$	$86,7^{+0,15}$	$90,4^{+0,2}$
$d_ц$	$45^{-0,1}_{-0,225}$	$49,85_{-0,15}$	$57^{-0,1}_{-0,225}$	$74,7_{-0,2}$	$76,2^{-0,1}_{-0,225}$	$85^{-0,1}_{-0,225}$	$87,9_{-0,2}$
$d_п$	$46,5_{-0,2}$	$51,8_{-0,2}$	$59,3_{-0,2}$	$77,2_{-0,1}$	$78,13_{-0,2}$	$87,1_{-0,23}$	$90,7_{-0,2}$
l_1	265	341	400	524	325	530	680
$l_к$	—	370	—	609	340	554	752
$l_з$	315	423	500	656	392	650	838
l_5	334	445	523	686	415	660	883
$l_н$	2660	2880	3421	4357	2587	3490	5150

TABLE 6 (cont.)

Dimensions on Figs. 19 and 22	88 mm German cannon 1944	105 mm German cannon 1944	122 mm cannon, mod. 1943
d_{2-r}	$176{,}0_{-0{,}5}$	$124{,}2_{-0{,}4}$	$134{,}6_{-0{,}26}$
d_2	$178{,}2^{+0{,}2}$	$124{,}6^{+0{,}2}$	$135^{+0{,}2}$
d_3	$162{,}2^{+0{,}2}$	$118{,}2^{+0{,}2}$	$126{,}5^{+0{,}2}$
d_4	$97{,}6^{+0{,}2}$	$109{,}5^{+0{,}2}$	$126{,}5^{+0{,}2}$
d_5	$96{,}0^{+0{,}2}$	$109{,}3^{+0{,}1}$	$123^{+0{,}1}$
d	$88^{+0{,}2}$	$105^{+0{,}2}$	$121{,}92^{+0{,}2}$
$d_к$	$90{,}4^{+0{,}2}$	$107{,}7^{+0{,}2}$	$123{,}95^{+0{,}2}$
$d_ц$	$87{,}9_{-0{,}2}$	$104{,}75_{-0{,}15}$	$121{,}92^{-0{,}1}_{-0{,}25}$
$d_п$	$90{,}7_{-0{,}2}$	$108{,}5_{-0{,}3}$	$124{,}7_{-0{,}26}$
l	877	630	780
$l_у$	1037	698	790
l_3	1070	800	894
l_5	1110	843	955
$l_к$	9797	5530	4285

53

TABLE 7

Dimensions and Tolerances for Cartridges

Dimensions on Figs 19 & 21	57 mm cannon, mod 1943	85 mm cannon, mod 1943	50 mm German cannon 1941
d_1	90	112	78,5
d_2	$83{,}7_{-0{,}23}$	$102_{-0{,}23}$	$70{,}7_{-0{,}3}$
d_3	78	95,24	66,2
d_5	57,5	85,8	51,6
c	2,2	2,7	1,85
c_1	$1{,}03_{-0{,}14}$	$1{,}28_{-0{,}14}$	$1{,}1_{-0{,}2}$
r	7	7,5	6,5
a	3,46	4	3,6
l_1	400	530	341
l	477	626	416

Dimensions on Figs 19 & 21	122 mm cannon mod 1943	75 mm German cannon 1943	105 mm German cannon 1944
d_1	143,6	123	136,4
d_2	$134{,}6_{-0{,}26}$	$113_{-0{,}4}$	$124{,}2_{-0{,}4}$
d_3	124	107,2	117,9
d_5	—	77	106,6
c	3,88	3,85	2,2
c_1	$1{,}6_{-0{,}2}$	$1{,}4_{-0{,}3}$	$1{,}65_{-0{,}3}$
r	14	10	9
a	5,04	5,1	6,1
l_1	—	523	630
l	780	635	763

conic rate, and are accepted within the limits of 1.0-1.5 mm. Nominal length dimensions of cartridges must be smaller than the corresponding charge chamber length by 1.0-1.5 mm, especially in the sections of length l_1 and l_2 (see Fig. 19). These data assure normal functioning of the cartridge during loading and for their extraction after firing.

Concentricity of the charge chamber sections relative to the axis of the barrel bore, especially in the section of the rifling groove shoulder and the "cylindrical" section for the cartridge neck, has just as much importance as their diameters and conic rate. Eccentricity or ovaloid formation of charge chamber sections will hamper loading and initial movement of the projectile in the bore in firing, and therefore, their size must not exceed half the tolerance on the calibre of the weapon.

The outline of the fixed charge cartridge must correspond to the profile of the chamber. The purpose of the cartridge is:

obturation of powder gases during firing;

placement of the powder charge and the primer cup; protection of them from the action of moisture and mechanical damage during storage and handling;

combination of all elements of an artillery roung into one body.

Cartridge construction is shown in Figure 21.

During loading, the cartridge must easily move into the charge chamber and provide the necessary tightness of barrel bore closure with the breechblock. After firing, the cartridge must be easily extracted from the chamber, and must not have ruptures, stretches, or other local damage. Besides this, the cartridge must allow multiple (up to 10-12 rounds) loading.

The most widely used cartridges are made of brass, composed of 68 to 72 percent copper, 28 to 32 percent zinc, up to 1 percent iron, uo to 0.05 percent lead, and other traces (phosphorus, arsenic, sulphur) totalling not more than 0.02 percent. Brass cartridges must have high strength and maintain their plasticity. Strength limit must be σ_b =35-50 kg/mm^2, stretch limit $\sigma_{0.2}$ = 25-35 kg/mm^2, and relative elongation δ =40-60 percent.

Cartridge wall thickness changes: it is smallest c_1 at the neck, and gradually increases toward the cartridge base to dimension c at the section of length l_4=0.5d.

Basic dimensions and tolerances for several domestic and foreign cartridge models appear in Table 7, and average values for some of their dimensions on the basis of generalized data from many models appear in Table 8.

Many cartridge models have dimension h, which is determined by the primer cup size, which are identical in value. Displacement of the primer cup fuze hole relative to the longtitudinal axis of the cartridge must not exceed 0.1 mm.

During the Second World War, composite iron cartridges were used, and were particularly widely used by the Germans. Iron cartridges proved unsatisfactory, however, because they did not provide good powder gas obturation during firing and could not be used for more than two or three shots. Dimensions and tolerances for projectile centering shoulders and rotating bands, and for projectile fit with the cartridge and barrel bores are given in Figures 22-24.

TABLE 8

Average Values for Some Basic Cartridge Dimensions

№	Калибры орудий мм (a)	Основные размеры (условные обозначения по фиг. 21) в мм (b)				
		c_1	c	l	a	h
1	45—76	1,0	2,0	7,0	3,5	14
2	85—105	1,6	3	12	5,0	15
3	122—152	1,8	4	14	6	15

a. Weapon Calibre, mm. b. Basic Dimensions (relative designations according to Figure 21), mm.

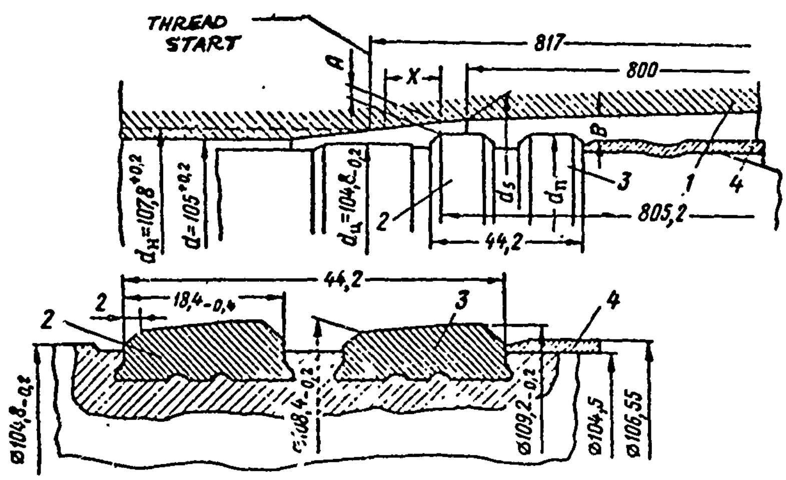


Fig. 22. Schematic of Projectile Rotating Band Position Relative to Charge Chamber in a Fixed Charge 1-chamber wall, 2-forward rotating band, 3-rear rotating band, 4-cartridge wall, A-clearance between rifling groove shoulder surface and forward rotating band, B-clearance between chamber surface and external cartridge neck surface after loading.

The projectile has two centering shoulders, forward and rear (near the rotating band), which provide alignment and centering of the projectile during its movement in the barrel bore. The projectile must move freely along the bore in a longtitudinal direction on its centering shoulders. If the projectile mass is unevenly distributed relative to its longtitudinal axis, even by a minute amount, and the clearance between its centering shoulders and the bore surface is larger than required, the projectile will oscillate in a radial direction during its movement in the barrel bore. With this oscillation, the lateral surfaces of the projectile will strike the rifling land surfaces, which will cut impressions up to a depth of 0.3 mm, and will themselves be seriously flattened out. Accuracy in machining the barrel bore and the centering shoulders of the projectile must be high in order to prevent radial

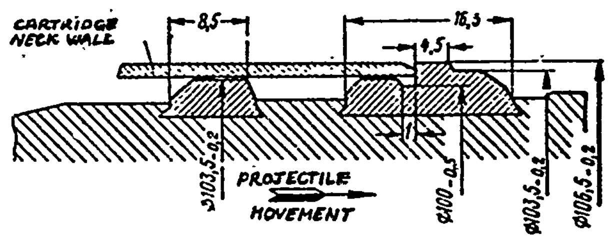


Fig. 23 Junction Schematic of the Cartridge Neck and the Projectile Rotating Band in Assembly of the Cartridge with the Projectile

oscillation of the projectile. Clearance on the diameter between the centering shoulder of the projectile and the surface of the bore along the lands, which is determined by the relationship (see Fig. 22)

$$\Delta = d - d_{u}, \quad (9)$$

must have a minimum size within the limits of 0.1-0.15 mm, and a maximum size of 0.35-0.5 mm, in which the smaller limit is for 50-85 mm weapons, and the larger is for 152 mm weapons.

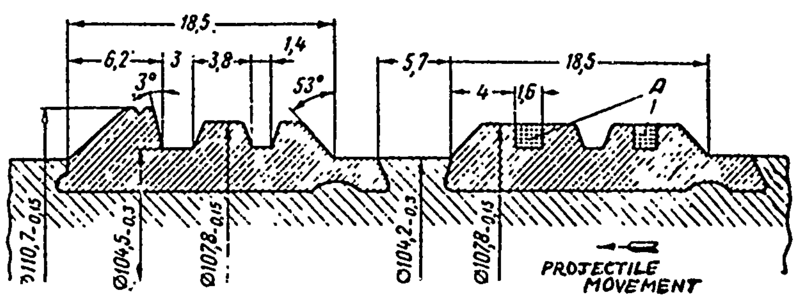


Fig. 24. Profile of One of the Projectile Rotating Band Variations. 105 mm cannon (weapon calibre $d=105^{+0.2}$ mm, diameter along the grooves $d_u=107.6^{+0.2}$ mm).

The difference between the rotating band diameter d_r and the diameter of the bore along the grooves $d_н$, called the amount of forcing, must be such, that powder gases do not breech through to the nose portion of the projectile, even if the barrel bore is worn. With an excessively large diameter difference d -d , however, bore wear increases, projectile movement along the bore is hampered, and the band may be cut and the rifling lands broken off. Normal amount of forcing is 0.1-0.4 mm, as can be seen from the data in Table 9, and only on the forward section of the band, on a length of 3-5 mm, can the amount of forcing be greater than the assigned limit, and its construction in this section resembles a circular comb (projection), as is shown in Figures 23 and 24.

TABLE 9

Clearances for Diameters Between the Cartridge and the Chamber Wall, Projectile and Gun Bore, and Amount of Forcing. Degree of Chamber Bottle Shape (Dimension Designations from Figures 19 and 22)

№	Наименование систем a	Зазоры в мм b. $d_2 - d_{2-г}$ max	Зазоры в мм b. $d_2 - d_{2-г}$ min	Зазоры в мм b. $d - d_a$ max	Зазоры в мм b. $d - d_a$ min	c. Величина форсирования в мм $d - d$ max	c. Величина форсирования в мм $d - d$ min	d Величина бутылочности $x = d_2/d$
1	45-мм пушка обр. 1942 г.	0,55	0,2	0,325	0,1	0,5	0,2	1,19
2	50-мм немецкая пушка 1941 г.	0,7	0,3	0,4	0,15	0,4	0,1	1,42
3	57-мм пушка обр. 1943 г.	0,88	0,5	0,325	0,1	0,5	0,2	1,49
4	75-мм немецкая пушка 1942 г.	1,5	0,9	0,7	0,3	0,4	0,1	1,52
5	76-мм пушка обр. 1942 г.	0,83	0,5	0,325	0,1	0,41	0,11	1,11
6	85-мм пушка обр. 1943 г.	0,78	0,4	0,375	0,1	0,4	0,02	1,21
7	88-мм немецкая пушка 1943 г.	1,5	0,9	0,5	0,1	0,3	0	1,54
8	88-мм немецкая пушка обр. 1944 г.	0,9	0,2	0,5	0,1	0,3	0	2,0
9	105-мм немецкая пушка 1944 г.	1,0	0,4	0,5	0,25	0,8	0,3	1,19
10	122-мм пушка обр. 1943 г.	0,86	0,4	0,55	0,1	0,75	0,29	1,11

a. System Designation
b. Clearance, mm.
c. Amount of Forcing, mm.
d. Degree of Bottle Shape
1. 45 mm cannon, mod. 1942
2. 50 mm German cannon, 1941
3. 57 mm cannon, mod. 1943
4. 75 mm German cannon, 1942
5. 76 mm cannon, mod. 1942
6. 85 mm cannon, mod. 1943
7. 88 mm German cannon, 1943
8. 88 mm German cannon, 1944
9. 105 mm German cannon, 1944
10. 122 mm cannon, mod. 1943

Tolerances for machining centering shoulders and rotating bands should be assigned with a minus sign, and their numerical values must lie within the following limits:

for centering shoulders . . . . 0.10 - 0.15 mm

for rotating bands . . . . 0.2 - 0.3 mm

Rotating bands for projectiles are usually manufactured of red copper, but during the Second World War, they were also manufactured of special plastics or ferro-ceramic materials, although these bands were not widely used. Rotating band profiles and dimensions are shown in Figures 22-24.

Figure 25 shows the distribution of clearances and the range of tolerances for projectile centering shoulder dimensions and barrel bore diameters along the lands. This chart graphically shows that machining of weapon bores and projectile centering shoulders in German systems is done with less precision than in domestic ones, and the degree of machining accuracy was significantly improved only for the model 1943 88 mm cannon. Due to this, accuracy and grouping of shots from this cannon were improved.

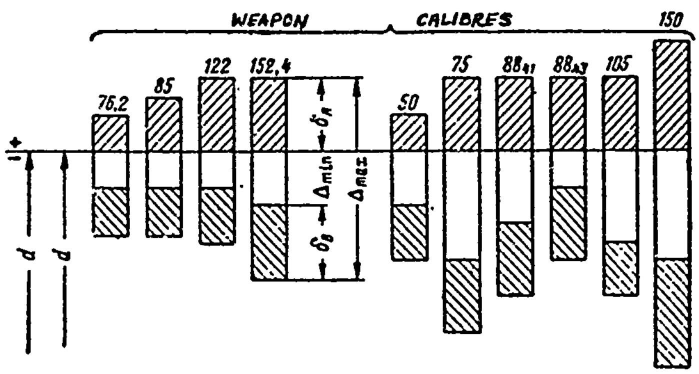


Figure 25. Distribution of Tolerance Ranges and Clearances on Dimensions.

d-barrel bore diameter along the lands, d_c-diameter of the projectile centering shoulder, δ_A-tolerance range on bore machining, δ_B -tolerance range on machining of projectile centering shoulder, Δ_{max} and Δ_{min}-clearances for some domestic and foreign weapons.

3. Breechblocks

A breechblock is a mechanism which provides strong and, together with the cartridge, tight blocking of the bore during firing, produces firing, and provides extraction of the cartridge after firing. These functions of the breechblock must be realized reliably and with sufficiently simple movements by the crew serving the system. Breechblocks must be interchangeable among barrels, both as assembled units and all of their separate parts, and this must be ascertained in production. Disassembly and assembly of the breechblock must be accomplished with a normal tool. Both of these basic requirements must be considered during manufacture of the breechblocks. Sliding wedge breechblocks are simpler assemblies than screw type breechblocks. The breechblock wedge shown in Figure 26 is a steel prism made of alloyed steel ($\sigma_{0.2}$=60-70 kg/mm^2). Wedge stocks, gotten from a forging for manufacture of two parts, or with smaller ones, from stampings, undergo heat treatment. Tolerances on dimensions of the basic worked surfaces of the wedge are assigned according to 3rd class accuracy of sliding and moving fit. Surfaces B and C must be strictly parallel with each other and have ∇7 smootheness. Worked surface A, which comes into contact with the bottom of the projectile and is called the mirror, is the base. The strengthening surface D which is opposed to it, and situated at an angle of 2°1' relative to the base, must fit closely with the surface of the breech, and this requirement is checked for each breechblock. Tolerance for the angle of inclination of surface D is determined from tolerances for linear dimensions (δ=0.08 mm), and is approximately equal to ±0°5'.

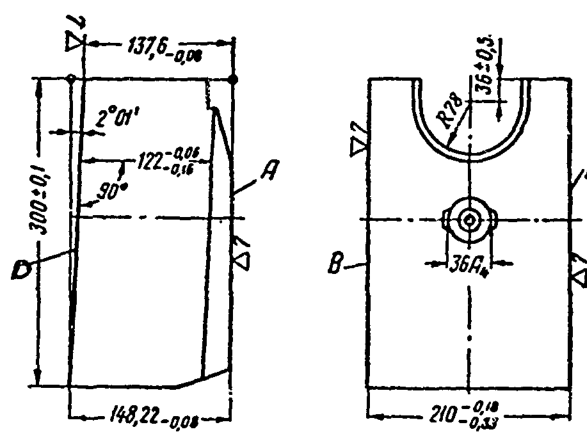


Figure 26. Breechblock Wedge

A-wedge mirror, D-inclined supporting surface which adjoins the breech, B and C-lateral surfaces (basic dimensions of the wedge).

4. Cradles and Antirecoil Mechanisms

The cradle serves as the base for assembly and installation on a carriage mount (or in a tank turret) of the tipping parts of a gun: the barrel, recoil brake, counterrecoil mechanism, block, and others.

Ring type (Fig 27) and box type cradles differ in construction. The ring type cradle consists of the front 1 and rear 2 rings, the front and rear lugs 3 for assembly of the recoil brake and counterrecoil mechanism, the front collar 4, bronze alignment guides 5, rear clamp 6, rear lug 7, toothed rack 8 of the elevating mechanism, and the alignment key 9 (see Figure 27). The front and rear rings, which form the body of the cradle, are joined together by welding. They are manufactured from steel castings, and must not have casting flaws, especially in the places where the trunnion reinforcing ribs are located. Sections of the ring with casting flaws must be removed and then refinished. During firing, the barrel moves along the bronze alignment guides 5, and therefore the surface of these guides must have $\nabla 6$ smootheness and must be strictly concentric with the longtitudinal axis of the cradle.

The alignment key 9, which fixes the position of the barrel in the cradle and prevents it from turning at the initial moment of recoil, must be sufficiently strong and have strictly determined dimensions. The recoil brake and counterrecoil mechanism are each fastened in the front lug 3 with a dry seal, and in the rear one with a clamp 6, the first being located in openings E, and the second in openings M of each lug.

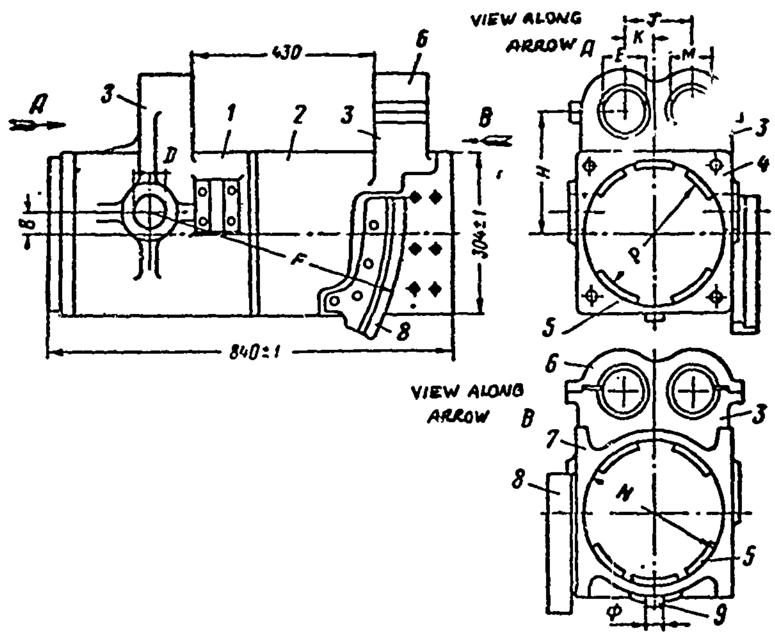


Figure 27. Ring Type Cradle

1-front ring, 2-rear ring, 3-lugs, 4-front collar, 5-bronze guides, 6-clamp, 7-rear lug, 8-toothed rack, 9-key, D-diameter of openings for trunnions.

The longtitudinal axes of the recoil brake and the counterrecoil mechanism must be parallel to the axis of the cradle, and their position in each (front and rear) lug 3 is determined by dimensions H, K, and J. Besides this, openings E and M must be concentric and precisely machined according to assigned tolerances.

The position of the centers of openings D are essential for assembly of the tipping parts of the gun. Vertical displacement of the centers of these openings relative to each other must not exceed 0.1 mm, and displacement relative to the cradle axis (dimension B) must not be greater than 0.15-0.3 mm.

The cradle dimensions presented in Figure 27 and in Table 10 are fundamental, in that they determine the accuracy of the cradle's machining.

TABLE 10

Basic Dimensions and Tolerances for Ring Type Cradles

Размеры и допуски мм a	Условные обозначения размеров по фиг. 27 d									
	B	F	D	E	K	J	M	H	P	N
Размеры b	35	513	98	145	70	150	135	220	260	275
Допуски c	±0,3	—	+0,04	+0,26	±0,25	±0,25	+0,26	±0,25	+0,3	+0,5

a. Dimensions and Tolerances
b. Dimensions
c. Tolerances
d. Dimension designations from Figure 27

Cradles of box construction are usually riveted or welded together from parts stamped out of steel sheet. In some cases, the stock for a box type cradle body is a steel casting.

5. Recoil Mechanisms

Recoil mechanisms consist of a recoil brake and a counterrecoil mechanism. The cylinders and rods of the recoil brake and counterrecoil mechanism come under great loads during firing. In a modern cannon, for instance, the force resisting recoil, and acting along the axes of the rods, comprises from 10 to 15 percent of the force of the powder gas pressure on the bottom of the barrel bore at the moment of firing, and the pressure of the working liquid in the brake reaches 500 kg/mm^2, and in the counterrecoil mechanism, it reaches 150 kg/mm^2. All these loads act for a very short time (recoil time is no more than 0.1 second, and counterrecoil time is no more than 0.5 second), are borne by the parts of the recoil brake and the counterrecoil mechanism, and are then transferred to the cradle trunnions.

Consequently, the parts of the recoil brake and the counterrecoil mechanism must above all else have the required strength and reliability under various working conditions according to the time of year and rate of fire. These demands are fulfilled by high mechanical properties of the materials used, and increased precision in machining the recoil brake and counterrecoil mechanism parts. In particular, the cylinders and rods of the counterrecoil mechanism are manufactured of high strength alloyed construction steel with a tensile strength of 50-60 kg/mm². Counterrecoil mechanisms usually have small-dimensioned cylinders and relatively thin walls. The interior working surfaces of the cylinders of these mechanisms cannot be oval shaped after machining, and the variation between diameter dimensions in the same section must not exceed 0.05-0.06 mm on these surfaces, or 0.1 mm on the section where the piston does not travel.

The interior surface of the cylinder, in the section of its contact (fit) with the brake piston skirt, is machined to third class precision (A_3), and must have ∇7 smootheness. The external surface of the bronze brake piston skirt is machined to third class moving fit precision. The resulting clearance between the piston skirt and the interior surface of the cylinder is a minimum of 0.05-0.10 mm, and a maximum of no more than 0.2-0.35 mm. The external and internal surfaces of the buffer piston rod are the same as the internal working surface of the cylinder, and must have ∇7 smootheness.

Besides this, the external surface of the rods must have an anticorrosion covering in the places where they fit into stuffing boxes. Curvature along the external surfaces of recoil buffer piston rod and spindle must not exceed 0.15-0.20 mm over its whole length. Curvature of the counterrecoil buffer rod itself may be slightly more, but no greater than 0.4 mm over its whole length.

An important factor in assembly of the recoil brake is the fit of the rod with the spindle moderator. In this assembly, the rod opening is machined according to third class precisions (A_3), and the external surface of the moderator is machined to third class moving fit accuracy (X_3). Clearance of the assembly is regulated by parts choice so as not to exceed 0.12-0.16 mm. Circular clearance between the variable section spindle and the regulating ring (see Fig. 6) is determined with a calculation according to the outflow of braking fluid. Requirements for machining of the counterrecoil working cylinder are the same as those for the recoil brake cylinder. Hydraulic braking of the recoiling parts of the gun is achieved with regulation of the flow of braking fluid over the entire length of recoil, and this is possible only with strict observance of the assigned dimensions and tolerances during machining of all parts of the brake and counterrecoil mechanism, and observance of counterrecoil mechanism assembly conditions.

#6. Analysis of Assembly Dimension Chains

On assembly drawings for products, the dimensions of parts which are tied to and dependent on each other, form an assembly dimension chain.

The simplest assembly dimension chain is one of dimensions which define assembly of a bushing with a shaft. This chain consists of three dimensions: the diameter of the bushing opening, the diameter of the shaft, and the clearance between the bushing and the shaft. The clearance is the final dimensional link in this dimensional chain, and characterizes the quality of assembly.

In complicated products, the assembly dimension chain consists of a large number of separate dimensions, each of which influences the quality of assembly and, consequently, the quality of the part as a whole. The dimension which determines the quality of the product's assembly is usually the final link in the assembly dimension chain.

Such a dimension might be, for instance, the total play (or free movement) in all moving joints of the parts of the elevating mechanism of a cannon, the vertical tilt of the barrel, etc.

The maximum value of each dimension of the dimension chain influences the size of its final link.

Analysis of the dimension chain allows checking of the correctness of tolerances and fit shown on the drawing, both of separate assemblies, and of the product as a whole.

Besides this, analysis of the assembly dimension chain also allows determination of the maximum dimension value of its final link, and brings in the necessary changes in tolerances and fit for separate intermediate dimensions. Dimensions of such closing links of the dimension chain, as total play or clearance, do not appear on the drawings, inasmuch as they are gotten facultatively as the result of the combination of the dimensions of other links of the chain which are designated on the drawing. These closing links, however, play an important role in the process of product assembly and, in the final accounting, determine its quality.

All calculations associated with analysis of dimension chains are directed toward the solution of geometrical problems which vary in complexity and to the determination of the size of the closing link of the chain.

Simple dimension chains are charts in which the dimensions of parts and assembly are interchangeable and are contiguous to each other, so that the final dimension closes the whole chain and is the value sought.

The dimensions in a dimension chain may all be located on the same surface (consecutive one after the other or parallel to each other), or may be partially on various surfaces.

In solution of complex dimension chains, it is sometimes necessary to make intermediate calculations for determination of an unknown value in order to build the dimension chain. Instances occur, where the total dimension chain is impossible to build, and its solution falls into a number of intermediate problems, one of which is solved through compilation of a number of simple dimension chains, another with a system of right angle coordinates, and the third with analytical means.

In determination of maximum and minimum values of the closing link of a dimension chain, it is necessary to conduct preliminary research on the moving joints of the product, the construction of parts and their relative location during movement or in stationary assembly. After accomplishment of such investigations, they go into the compilation of dimensions which comprises the dimension chain or the calculation formula. Finding the size and sequence of arrangement of all dimensions which determine any unknown clearance is the fundamental task for composition of the dimension chain, especially for comples products. The essence of composition of the dimension chain includes the fact that all dimensions which determine the unknown clearance must form the linking contour. Given below are some examples explaining the methodology in calculation of assembly dimensions and clearances with the help of dimension chains.

Determination of the Clearance Between the Breech Face of the Tube and the Breechblock Wedge Mirror in the Barrel Bore Locking Mechanism.

According to the schematic of the breechblock wedge barrel bore locking mechanism given in Figure 28, determination of the size of clearance Δ between the breech face of the tube and the wedge mirror is required.

The following parts fit together with the assembly: Tube, sleeve breech, and breechblock wedge.

From the working drawing of parts, we find the values of dimensions and tolerances influencing the size of the clearance Δ, and enter them into Table 11.

TABLE 11

Dimensions and Tolerances for Parts of the Barrel Bore Locking Mechanism with a Wedge Breechblock Which Determine Clearance Δ in mm. (see Figure 28)

PARTS DESIGNATION	INITIAL DIMENSIONS			LIMITING DIMENSIONS	
	DIMENSION DESIGNATION	DIMENSION	TOLERANCE	MAXIMUM DIMENSION	MINIMUM DIMENSION
TUBE	C	60	−0,05	60	59,95
SAME	B	8	−0,15	8,0	7,85
SLEEVE	A	60	+0,05	60,05	60
BREECH	F	164,46	+0,08	164,54	164,46
SAME	D	210	±0,1	210,1	209,9
"	N	152	+0,08	152,08	152
"	J	420	−1,55	420	418,45
BREECHBLOCK WEDGE	E	185	±0,1	185,1	184,9
SAME	H	139,34	−0,08	139,34	139,26
"	K	148,22	−0,08	148,22	148,14
"	M	300	−0,3	300	299,7
CALCULATED ASSEMBLY SIZE	h	—	—	+0,907	−0,977

According to these dimensions, we build the dimension chain, whole closing link is the unknown clearance (see Fig. 28). From the dimension chain we see that two complex dimensions go into it, namely

breech dimension $(D \pm h)\,\mathrm{tg}\,\alpha$;

wedge dimension $E\,\mathrm{tg}\,\alpha$.

Here, $\mathrm{tg}\,\alpha = \frac{K-H}{M} = \frac{F-N}{J}$.

According to this chain, we write the equation of relationship for the dimension chain, which has the following appearance:

$$\Delta = F - (D \pm h)\frac{F-N}{J} - H - E\frac{K-H}{M} - B - C + A. \tag{10}$$

Expanding this equation relative to the limiting values of the dimensions going into it, we get the following expression for determination of maximum and minimum values for clearance Δ:

$$\Delta_{max} = F_{max} - (D_{min} + h_{max})\frac{F_{max} - N_{max}}{J_{min}} - H_{min} - E_{min}\frac{K_{min} - H_{min}}{M_{max}} - B_{min} + (A_{max} - C_{min}),$$

$$\Delta_{min} = F_{min} - (D_{max} - h_{min})\frac{F_{min} - N_{min}}{J_{max}} - H_{max} - E_{max}\frac{K_{max} - H_{max}}{M_{min}} - B_{max} + (A_{min} - C_{max}).$$

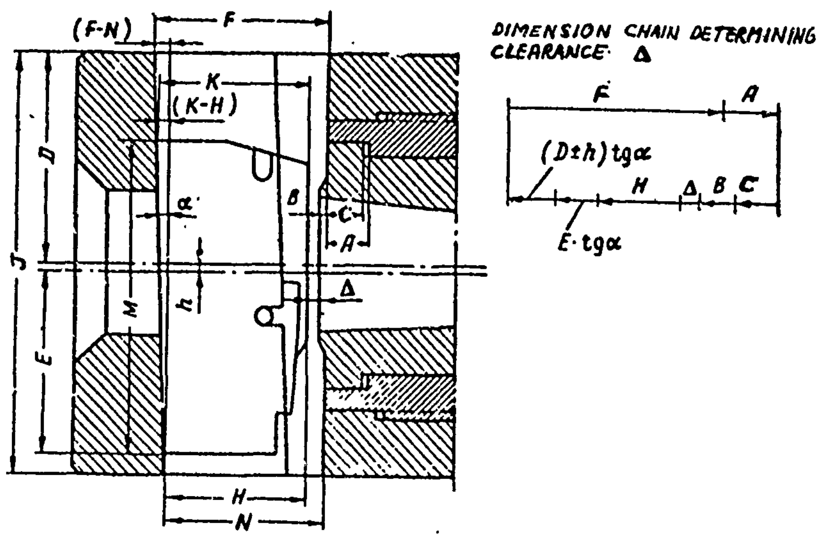


Figure 28. Schematic of Barrel Bore Locking with a Wedge Breechblock

In compilation of the dimension chain schematic and equation of its relationship, the correct determination of signs for the separate dimensions is very important. The signs of the intermediate dimensions on the dimension chain schematic coincide with the direction of the arrows on them. Solving the following two equations using the limiting values of the dimensions shown in Table 11, and rounding off tg α with an error of up to 0.0003, we get

$$\Delta_{max}=5,68 \text{ мм},$$

$$\Delta_{min}=5,30 \text{ мм}.$$

In loading after the cartridge is seated and locking the breechblock, the cartridge base will be located between the tube breech face and the wedge mirror. The resulting clearance will be decreased by the thickness of the cartridge base (see Fig. 28). It is necessary that clearance be maintained between the wedge mirror and the cartridge base, so as to provide free movement of the wedge during locking of the breechblock. With the maximum value of this clearance, it is also necessary to guarantee effective movement of the firing pin on the primer cap, which is achieved with corresponding dimensions of firing pin protrusion relative to the wedge mirror, and depth of the primer cap relative to the cartridge base. For determination of the clearance between the wedge mirror and the cartridge base, we use the following additional dimensions from the drawings:

thickness of the cartridge base, equal to 5.1 C . Its limiting values will be 5.1 and 4.94 mm;

depth of the primer cap relative to the base, which must not exceed 0.5 mm;

protrusion of the firing pin relative to the wedge mirror, which is equal to 2.0-2.38 mm.

We then determine the limiting values of the clearance between the wedge mirror and the cartridge base Δ from the following expressions:

$$\Delta'_{max}=\Delta_{max}-4,94=0,74 \text{ мм};$$

$$\Delta'_{min}=\Delta_{min}-5,1=0,2 \text{ мм}.$$

These clearances assure free locking of the breechblock wedge. Knowing the limiting values of clearance Δ', it is possible to determine the depth of the firing pin dent in the primer cap from the following relationships:

$$i_{min}=2,0-(\Delta'_{max}+0,5)=0,76 \text{ мм};$$

$$i_{max}=2,38-\Delta'_{min}=2,18 \text{ мм}.$$

The reliable striking of the primer cap by the breechblock firing pin is assured with these indentation depths.

The dimensions and tolerances shown on the parts drawings and entered into the dimension chain, therefore, assure free breechblock wedge locking after cartridge seating and reliable action of the firing mechanism.

Regardless of this, these conditions are checked practically during breechblock assembly with the loading of two cartridges having base widths of 5.1 mm and 4.94 mm, and by indentations on a cartridge primer cap of firing pins which protrude 2.0 and 2.38 mm relative to the wedge mirror.

Determination of the Clearance Between the Front Face of the Internal Cylinder and the Nipple Rim face of the Rear Bottom in the Recoil Mechanism

Figure 29 shows a schematic of the recoil mechanism arrangement. The exterior cylinder 1, front cover 2, and rear bottom 3 are welded together in assembly of the recoil mechanism, and the combination of these parts is inseparable. The internal cylinder 4 is threaded on one end to the front cover, and the other end fits on the nipple of the rear bottom, which also centers it relative to the axis of the recoil mechanism. During assembly of the internal cylinder, it is necessary to insure a hermetically sealed connection between it and the front cover, so that air and fluid cannot leak between the internal cylinder and the front cover. This is achieved by squeezing the packing ring 5 to 1 mm, which is possible if the clearance between the front face of the internal cylinder and the face of the rear bottom nipple rim is positive, or in other words, $\Delta > 0$. First of all, we determine the largest and smallest values of this clearance. Just as in the previous example, we take from the working drawing all dimensions which affect the compression of the packing ring 5, and consequently the value of the clearance Δ. We enter these dimensions into Table 12.

Then follows compilation of the dimension chain schematic (see Fig. 29) and the equation of the relationship of its dimensions, which will have the following appearance:

$$\Delta = M - B - F + D - E + N - C + T + J - K. \qquad (11)$$

Expanding this equation with the limiting values of the dimensions going into it, we get

$$\Delta_{max} = M_{min} - B_{max} - F_{max} + D_{min} - E_{max} + N_{min} - C_{max} + T_{min} + J_{min} - K_{max},$$

$$\Delta_{min} = M_{max} - B_{min} - F_{min} + D_{max} - E_{min} + N_{max} - C_{min} + T_{max} + J_{max} - K_{min}.$$

Substituting the limiting values of dimensions from Table 12 in the last equation, we get:

$$\Delta_{max} = 10{,}43 \text{ мм};$$

$$\Delta_{min} = 2{,}22 \text{ мм}.$$

Considering the necessity to compress the packing ring to 1 mm, a clearance within the limits of 1.22 to 9.43 mm will satisfy the technical requirements for assembly of the recoil mechanism.

Determination of Total Vertical Tilt of the Barrel and Slack in the Elevating Mechanism

In adjusting with the elevating mechanism, the required angle is given to the gun barrel in a vertical plane. The basic parts of the elevating mechanism are shown in Figure 30.

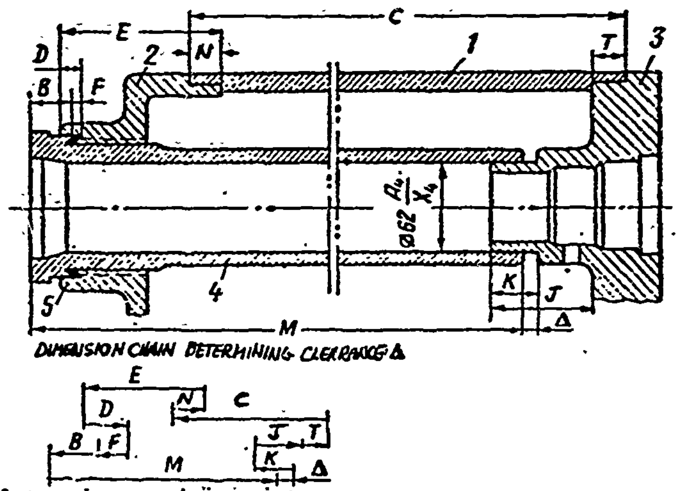


Fig. 29 Assembly Schematic of Recoil Mechanism Internal Cylinder

1-external cylinder, 2-front cover, 3- rear bottom 4-internal cylinder, 5-copper packing ring.

TABLE 12

Dimensions and Tolerances for Recoil Mechanism Parts, in mm (see Figure 29)

PART DESIGNATION	INITIAL DIMENSIONS			LIMITING DIMENSIONS	
	DIMENSION DESIGNATION	DIMENSION	TOLERANCE	MAXIMUM DIMENSION	MINIMUM DIMENSION
FRONT COVER	D	8	+0,36	8,36	8
SAME	E	90	−0,87	90	89,13
PACKING RING	F	3	−0,25	3	2,75
REAR BOTTOM	J	60	+0,74	60,74	60
SAME	K	18	+0,43	18,43	18
EXTERNAL CYLINDER	N	25	+0,52	25,52	25
SAME	C	750	±1	751	749
	T	20	+0,52	20,52	20
INTERNAL CYLINDER	M	765	±1	766	764
SAME	B	25	−0,52	25	24,48

When the handwheel on the worm shaft is turned, movement is immediately transferred to the worm shaft and worm gear, which is fastened to the cylindrical gear shaft with keys. The gear C turns, rolling against the toothed rack 8 of the cradle (see Fig. 27 and Fig. 30). As the result of turning the handwheel, the rack, together with the cradle and the barrel will be moved in a vertical plane. The cradle is mounted in strong bearings by its trunnions, and the barrel is situated in the cradle on bronze guiding inserts.

Due to clearance (play) in the assembled parts of the entire moving chain of the elevating mechanism, vertical play in the barrel and free movement in the elevating mechanism are created. The amount of barrel play and elevating mechanism slack depends on the machining tolerances used and the type of fit of parts going into the kinematic layout of the elevating mechanism. The term vertical barrel play should be understood to mean movement of the gun barrel in a vertical plane as the result of a selection of clearances in all links of the elevating mechanism kinematic chain without any movement of its handwheel. Free slack of the traversing mechanism is determined by rotation of the handwheel without changing the position of the barrel, said rotation being the result of clearance choice in all links of its kinematic chain.

It should be noted that with increased vertical barrel play and slack in the laying mechanisms, time for laying the gun increases and accuracy worsens. Upper limits to the amount of barrel play and laying mechanism slack are established, therfore, in the technical conditions of artillery system manufacture.

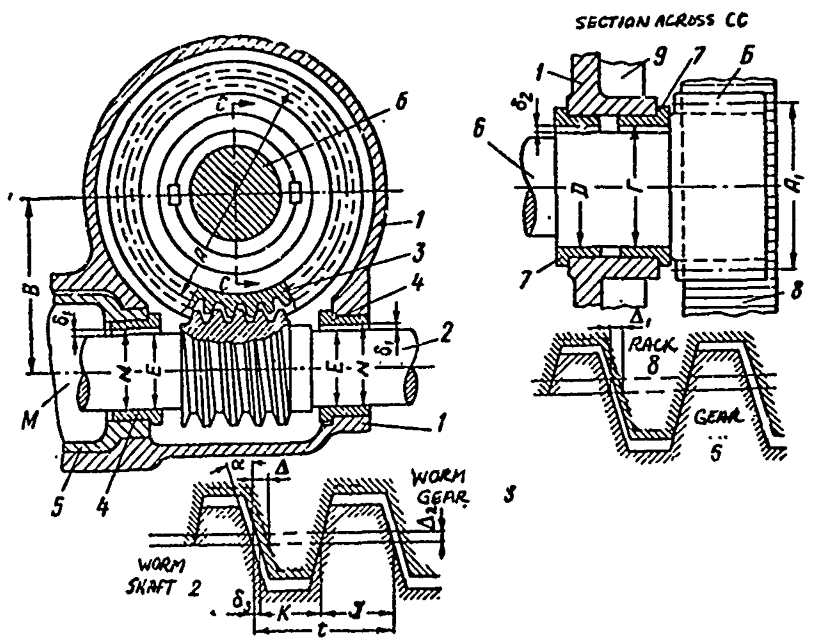


Figure 30. Elevating Mechanism Schematic

1-case body, 2-worm shaft, 3-worm gear, 4-bearing, 5- insert body, 6-shaft with cylindrical gear C, 7- bearing, 8-toothed cradle rack, mechanism bracket.

Determination of the total vertical barrel play and elevating mechanism slack is a complex problem, whose solution requires determination of the limiting values of clearances in all moving parts junctions. It is impossible to find these clearances through solution of a dimension chain, and therfore we use the analytical method.

For determination of the total barrel play, we use the elevating mechanism diagram shown in Fig. 30 and the dimensions and tolerances from the working drawing which are presented in Table 13.

We will determine the numerical values of the following clearances of the elevating mechanism:

1) clearance between the worm shaft 2 and the races of the bearings 4 from the relationship

$$\delta_{1max}=\frac{1}{2}(N_{max}-E_{min})=0{,}075\ мм,$$

$$\delta_{1min}=\frac{1}{2}(N_{min}-E_{max})=0{,}016\ мм;$$

2) clearance between shaft 6 and bushing 7 from the relationship

$$\delta_{2max}=\frac{1}{2}(F_{max}-D_{min})=0{,}09\ мм,$$

$$\delta_{2min}=\frac{1}{2}(F_{min}-D_{max})=0{,}02\ мм;$$

3) clearance between the teeth of the worm gear 3 and the worm shaft 2 from the relationship

$$\delta_{3max}=t-(K_{min}+J_{min})=0{,}255\ мм,$$

$$\delta_{3min}=t-(K_{max}+J_{max})=0{,}055\ мм;$$

4) clearance between the axes of the worm shaft and the worm gear from the relationship

$$\Delta_{2max}=\delta_{1max}+\delta_{2max}+\delta_{4max}+\delta_5=0{,}465\ мм,$$

$$\Delta_{2min}=\delta_{1min}+\delta_{2min}+\delta_{4min}+\delta_5=0{,}136\ мм.$$

Here, δ_4 — is the clearance on dimension B=9?.25 mm of the elevating mechanism body ($\delta_{4max}=0{,}2$ мм, $\delta_{4min}=0$),

δ_5 — total skew of shafts and other parts which changes the centers of tooth engagement (we take as constant and equal to 0.1 mm);

5) lateral clearance in engagement of the worm couple from the relationship

$$\Delta_{max}=2\Delta_{2max}\operatorname{tg}\alpha+\delta_{3max}=2\Delta_{2max}\operatorname{tg}15^\circ+\delta_{3max}=0{,}506\ мм,$$

$$\Delta_{min}=2\Delta_{min}\operatorname{tg}\alpha+\delta_{3min}=2\Delta_{2min}\operatorname{tg}15^\circ+\delta_{3min}=0{,}128\ мм.$$

Further, knowing clearance , we determine the vertical play of the barrel which is created due to clearances in the elevating mechanism by the following formulae:

$$\beta'_{max}=\frac{360\cdot 60\Delta_{max}}{\pi A}\,\frac{z_{ш}}{z_c}=\frac{360\cdot 60\cdot 0{,}506\cdot 13}{3{,}14\cdot 130{,}5\cdot 171}=2{,}03'; \quad (12)$$

$$\beta'_{min} = \frac{360 \cdot 60 \Delta_{min}}{\pi A} \frac{z_m}{z_c} = \frac{360 \cdot 60 \cdot 0,128 \cdot 13}{3,14 \cdot 130,5 \cdot 171} = 0,51'. \quad (13)$$

Vertical barrel play β'', which arises as the result of clearance Δ_1 in engagement of cylindrical gear C with the toothed rack, whose teeth number Z_c= 171, is determined by the fact that according to technical requirements, this clearance must be no greater than 0.3 mm.

The required amount of clearance Δ_1 is provided during assembly with adjustment of engagement with eccentric bushings.

TABLE 13

Dimensions and Tolerances for Elevating Mechanism Parts (see Figure 30)

PARTS DESIGNATION	INITIAL DIMENSION			LIMITING DIMENSION	
	DESIGNATION	DIMENSION	TOLERANCE	MAXIMUM DIMENSION	MINIMUM DIMENSION
BEARING	N	42	+0,05	42,05	42
WORM SHAFT (z_B=1)	E	42	{ −0,032 −0,100	41,968	41,9
WORM SHAFT (z_B=1)	t	14,13	—	14,13	14,13
WORM SHAFT (z_B=1)	J	7,045	−0,1	7,045	6,945
WORM SHAFT (z_B=1)	α	15°	—	15°	15°
SHAFT WITH CYLINDRICAL GEAR (z_m=13)	D	68	{ −0,04 −0,12	67,96	67,88
CASE BUSHING	F	68	+0,06	68,06	68
CASE	B	95,25	+0,2	95,45	95,25
WORM GEAR (z_4=29)	A	130,5	—	130,5	130,5
WORM GEAR (z_4=29)	K	7,03	−0,1	7,03	6,93
WORM GEAR (z_4=29)	t	14,13	—	14,13	14,13
WORM GEAR (z_4=29)	α	15°	—	15°	15°
TOOTHED RACK (z_c=171)		—	—	—	—

Considering that diameter A of the initial circumference of gear C is equal to 78 mm and Z_w=13 teeth, we see that

$$\beta'_{max} = \frac{360 \cdot 60 \Delta_{1max}}{\pi A_1} \frac{z_m}{z_c} = \frac{360 \cdot 60 \cdot 0,3 \cdot 13}{3,14 \cdot 78 \cdot 171} = 2,01'. \quad (14)$$

For determination of the vertical barrel play in the cradle, whose diagram of installation is given in Fig. 31, the dimensions and tolerances taken from the drawing are presented in Table 14.

TABLE 14

Dimensions and Tolerances for Cradle Parts in mm (see Fig. 31)

PART	INITIAL DIMENSIONS			LIMITING DIMENSIONS	
	DESIGNATION	DIMENSION	TOLERANCE	MAXIMUM DIMENSION	MINIMUM DIMENSION
BRONZE GUIDING INSERTS	Н	68	±1	69	67
SAME	П	34	±0,5	34,5	33,5
FRONT RING	Т	275	+1,35	276,35	275
SAME	α_1	90°	±2°	92°	88°
"	У	250,1	+0,34	260,44	260,1
"	Ю	10	±0,5	10,5	9,5
REAR RING	У	260,1	+0,34	260,44	260,1
SAME	Ю	10	±0,5	10,5	9,5
CRADLE	И	822	−2	822	820
GUN BARREL	Ц	260	−0,2 −0,5	259,8	259,5

On the basis of data from Table 14 and the diagram in Fig. 31, it is possible to determine the following amounts:

$$\sin\alpha_2=\frac{H_{\min}-\text{П}_{\max}}{\frac{1}{2}T_{\max}}=2\,\frac{H_{\min}-\text{П}_{\max}}{T_{\max}}=2\,\frac{67-34{,}5}{276{,}35}=0{,}2352,$$

$$\alpha_{2\min}=13°35';$$

$$X_{\max}=2\,\frac{\text{У}_{\max}}{2}\sin\frac{\alpha_{1\max}-2\alpha_{2\min}}{2}=260{,}44\sin\frac{92°-2\cdot13°35'}{2}=$$

$$=260{,}44\sin 32°25'=139{,}6\ \text{мм};$$

$$K=n_{\max}-l_{\min}=\left(\frac{\text{Ц}_{\min}}{2}-\sqrt{\frac{\text{Ц}^2_{\min}}{4}-\frac{X^2_{\max}}{4}}\right)-$$

$$-\frac{\text{У}_{\max}}{2}\left(1-\cos\frac{\alpha_{1\max}-2\alpha_{2\min}}{2}\right)=\left(\frac{259{,}5}{2}-\sqrt{\frac{259{,}5^2}{4}-\frac{139{,}6^2}{4}}\right)-$$

$$-\frac{260{,}44}{2}\left(1-\cos\frac{92-2\cdot13°35'}{2}\right)=0{,}1\ \text{мм};$$

$$\Delta_{3\max}=\text{У}_{\max}-\text{Ц}_{\min}+K=260{,}44-259{,}5+0{,}1=1{,}04\ \text{мм}.$$

Knowing the size Δ_{3max}, we determine the angular movement of the gun barrel in the cradle in a vertical plane β''_{max} from the relationship

$$tg\,\beta''_{max}=\frac{\Delta_{3max}}{H_{min}-2Ю_{max}}=\frac{1,04}{820-2\cdot 10,5}=\frac{1,04}{799}=0,0013,$$

and consequently, the angle $\beta''_{max}=0°4'$.

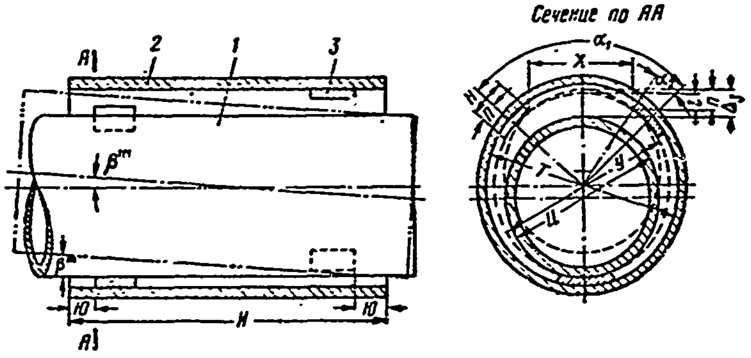


Fig. 31. Diagram of Barrel Installation in the Cradle

1-barrel, 2-cradle ring wall, 3- bronze aligning inserts

In reality, the vertical play of the gun barrel in the cradle in one direction will be half the value received, or two minutes.

It should be noted that play (clearance) of the barrel in the cradle which arises as the result of clearances between its exterior surface and the bronze guides of the cradle, is a constant amount which cannot be uncovered with sighting devices. This clearance is most often not included in the total barrel play. During firing of the gun from its place, it has no meaning, in that before the shot the barrel has no inclination, and during firing on the move this clearance has affects shot groupings.

Therefore, the largest total vertical barrel play β_{max} is the sum of elevating mechanism slack β', engagement of the cylindrical gear with the toothed rack β'', and in the cradle β''', or

$$\beta_{max}=\beta'_{max}+\beta''_{max}+\beta'''_{max}=2,03'+2,01'+2,0'=6,04', \quad (15)$$

which comprises 1.7 divisions of the goniometer, and consequently,

$$\beta_{max}=0-01,7,$$

which does not exceed norms of acceptance.

For determination of the largest amount of elevating mechanism handwheel slack which arises due to clearances in the connection of the handwheel hub with the worm shaft, and further, in the whole mechanism, we use the data presented in Tables 15 and 13.

TABLE 15

Dimensions and Tolerances of Parts Connected to the Elevating Mechanism Handwheel (see Figure 32)

PART	INITIAL DIMENSIONS			LIMITING DIMENSIONS	
	DIMENSION DESIGNATION	DIMENSION	TOLERANCE	MAXIMUM	MINIMUM
WORM SHAFT	H_1	16,43	−0,44	16,43	15,99
WORM SHAFT	P	6	+0,08	6,08	6
WORM SHAFT	$Д_1$	20	−0,07 −0,21	19,93	19,79
HUB	$Ф$	6	+0,025	6,025	6
KEY	$Ш$	6	+0,025	6,025	6
KEY	H_2	6	+0,08	6,08	6

Note: The number of turns on the worm gear shaft , the number of teeth on the worm gear , the number of teeth on the cylindrical gear , the number of teeth on the rack

Rotation of the handwheel in clearances of the keyed joint, shown in Fig. 32, is determined from the following expression:

$$\alpha_{3max} = \frac{P_{max} - Ш_{min}}{\pi Д_{1min}} \cdot 360° - \frac{(6,08-6)}{3,14 \cdot 19,79} \cdot 360 = 0,46°,$$

$$\alpha_{4max} = \frac{(Ф_{max} - Ш_{min}) \cdot 360}{\pi 2\left(H_{1min} + H_{2min} - \frac{Д_{1min}}{2}\right)} = \frac{(6,025-6) \cdot 360}{3,14 \cdot 2\left(15,99+6-\frac{19,79}{2}\right)} = 0,12°.$$

Knowing the angles of rotation of the handwheel α_{3max} and α_{4max}, we get the largest angle of handwheel rotation in the keyed joint

$$\beta_{1max} = \alpha_{3max} + \alpha_{4max} = 0,46° + 0,12° = 0,58° = 34,8'.$$

We find the gear ratio between the elevating mechanism handwheel and the barrel from the relationship $i = \frac{z_3}{z_4} \frac{z_ш}{z_c} = \frac{1 \cdot 13}{29 \cdot 171} = \frac{1}{381,5}$.

Information gained on the total vertical barrel play β_{max} and the largest angle of handwheel rotation β_{1max} allows determination of the largest amount of handwheel slack γ_{max} from the expression

$$\gamma_{max}=\beta_{max}i+\beta_{1max}=6{,}04'\cdot 381{,}5+34{,}8'=2338'\approx 39^\circ. \qquad (16)$$

This value for the largest amount of slack in the handwheel is less than 45°, or less than 1/8 of a full turn, which satisfies the technical requirements set forth for the barrel elevating mechanism.

Slack in the elevating and traversing mechanisms of artillery systems has essential meaning, especially in firing on moving targets or firing on the move, when the gun itself is moving. Experiential data from multitudinous shots show that improvements against norms of slack (clearances) in laying mechanisms and in the cradle result in improvements in time of gun laying, amplitude of weapon barrel deviation (in vertical and horizontal planes) and dynamic loads on the parts of the mechanism, resulting in turn in improved wear of parts. Slack is especially important in firing on the move (tank, self-propelled and antitank field cannons), because with an increase, for instance, in slack in the links of the kinematic chain of aiming the tipping parts of the gun from 2.5 to 7.5 thousandths, mistakes in aiming increase by 50 to 100 percent, lowering the percent of hits and decreasing effectiveness of fire by 1.5 to 3.5 times.

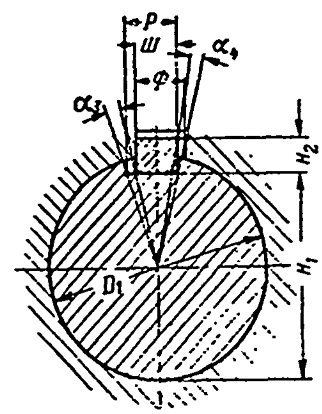


Fig. 32. Diagram of the keyed connection of the elevating mechanism shaft and handwheel.

This information makes necessary the improvement of precision in parts manufacture and creation of mechanism with slack eliminated. These mechanisms include links with cutaway gears, hydraulic drives, and others.

#7. Accuracy of Parts Machining and Economy of Production

Machining accuracy in machine construction depends on many factors, of which the following have the most importance:

shape and dimensions of the parts;

physical and mechanical properties of the materials for parts;

tolerances and technical requirements for manufacture of parts;

types of stock and their dimensions;

construction of the machining tool, attachment, and machines;

cutting schedule in machining and hardness of the parts, machines and tools in the system;

possible mistakes in measuring dimensions, and

qualifications of the workers and their working conditions.

The designer who establishes the dimensions of the parts must calculate the technical requirements for their manufacture. It is highly desirable that the construction and assembly bases, the axes of symmetry of the surfaces along which the dimensions are determined, are also the technological bases, by which the parts are mounted on the machine or on the attachment. The combination of construction and assembly bases with the technological ones eases planning of the technological process and attachments, eliminates the necessity for recalculation of dimensions and tolerances, and lowers expenses for manufacture of the parts with the assigned machining precision.

Tolerances and technical requirements determine the accuracy with which parts must be manufactured, or the deviation of their actual dimensions from their nominal values. In assignment of classes of accuracy or fit, the type of parts assembly should be considered, as well as the expenses of production or manufacture of these parts. It is well known that cost of parts production progressively grows with increased machining precision, and this is undesirable under conditions of economic production.

The weight, dimensions and type of parts stock directly determine labor consumption and possible errors in machining. Thus, for instance, the stock for a breechblock wedge might be a free forging or a hot stamping. Machining the stock from a stamping requires half the time of machining the one from a forging, and the parts in both cases are identical. In some cases, it is wise to leave a steel casting coarse and not machine it. Wise choice of the type of stock decreases production expenses without, in the process, decreasing the required accuracy of parts production.

The cutting schedule for metals (depth, feed, and speed of cutting) depends on the material, construction, geometry and stability of the cutter, the capacity of the machine, properties of the machined material, and a number of other factors. Speeding up the cutting schedule increases vibration in the system of machine, tool, and part, especially with insufficient hardness or with uneveness in its turning parts. Such phenomena are characteristic for large forgings in coarse and peeling operations. The cutting tool becomes worn out in the process of work, and machined cylindrical surfaces become conical, the smootheness of the surface is poorer with a faster cutting schedule, and precision of machining decreases, especially during machining of large parts. Together with this, machining time for the part also slows down.

The technician must consider all these factors and capably combine machining accuracy, time expenditure, and cost of tools.

Tolerances on the corresponding dimensions of the attachments, on which accuracy of mounting and machining of the parts depend, must be closer than the corresponding dimensions of the machined parts. Usually, in machining parts to 2nd or 3rd class precision, tolerances on the corresponding dimensions of the attachment must be respectively equal to $\frac{1}{2}$ or $\frac{1}{3}$ of the amount of tolerance on the part dimension. In deeper machining, for instance 4th or 5th class precision, tolerances on attachment dimensions must be respectively equal to $\frac{1}{4}$ or $\frac{1}{5}$ of the amount of tolerance on the dimensions of the machined part. Generally, the accuracy of manufacture of the attachments (in basic dimensions) must be one class higher than the accuracy of the parts treated on them. Only in machining parts to 2nd class precision can tolerances for attachments be accepted in mean value between 1st and 2nd class precision, and in certain cases closer to 2nd class precision. Rigidity of the attachment has essential significance in increasing machining accuracy. If the attachment is sufficiently stable, the accuracy of all lots of parts machined on it will be stable and correspond to the established requirements.

After machining, parts are checked by limiting calibres, or in certain cases by universal measuring instruments.

The technical composition of the control instrument and its correct usage in measuring dimensions determine, to a large degree, the accuracy of parts machining.

Transferred technological factors can be reasons for parts machining errors, and some of them will be systematic and be repeated regularly, while others will be incidental and without regularity.

Machining accuracy is closely tied to economy of production. Parts costs increase with increased machining accuracy to the point where the production process might become economically unprofitable.

Various indices of technological process evaluation are used in production practice which reflect their economic expedience. Such indices include:

labor consumption, determined by the dimensions, weight and construction of the parts;

coefficient of material use in parts manufacture, determined by the relation between the weight of the stock and the weight of the finished part. This coefficient gives a representation of the rationality of stock selection and establishment of margins between operations;

coefficient of equipment load, which in serial production oscillates between the limits 0.85-0.95;

time norm relationship, determined by the coefficient

$$\eta_0 = \frac{T_0}{T_{шт}}, \qquad (17)$$

where T_0—basic machine time;
$T_{шт}$—piece time, which includes all time spent in manufacture of the part;

percent of waste caused by deviations from assigned tolerances in machining or allowable norms.

The transferred indices only partially characterize production economy, because they do not express its direct tie with treatment accuracy.

Precision in machining accuracy is economically expedient when, in normal working conditions, the production process corresponds to the modern level of technological development, the machined parts fully meet data on drawings and the established technical requirements, and all time and material expenses do not exceed those planned.

CHAPTER IV

Stock for Tubes

#8. Materials Used in Weapon Production

A large number of artillery system parts are manufactured from various types of steel, and only a small part of them (piston skirts, spindle moderators, guiding inserts or runners, packing rings, and some bushings) are manufactured out of bronze or red copper.

All the steels used in artillery production divide into four groups:

1) gun barrel steel;

2) construction steel for various parts of artillery systems, mortars, and rifles;

3) steel for small arms barrels;

4) special steel for armor-piercing projectiles;

We will look at characteristic steels of the first two groups.

Gun barrel steel must have the following basic physical and mechanical properties:

high strength, in combination with high elasticity and toughness, so that there will be no deformations, splits or ruptures under powder gas pressure;

sufficient hardness and high resistance to shock load and mechanical friction;

uniform structure over the entire length of the stock and in all of its sections, without the presence of nonmetallic inclusions;

high resistance to the action of chemical products of powder decomposition and the action of the atmosphere.

The production of these steels must be based on domestic raw materials and must be economical.

Artillery and small arms barrels work in high rates of fire, and consequently, with high strain and in a wide temperature range of their surroundings (from - 45° to + 40° C.). Steel for barrels must therefore have sufficient toughness to prevent destruction of the barrels under loads (stresses) which do not exceed its tensile limits. Two types of steel failure are known; stretch and brittle. Stretch failure is preceded by plastic deformation of the steel, and brittle failure occurs without any sign of plastic deformation. Steel which does not have a sufficient margin of toughness in low temperatures, ranging from - 15° to - 40° C, may enter the critical interval of brittleness, and in temperatures below - 40° C, it is characterized by massive failure.

The composition of the required strength and toughness with good tempering and preservation of uniformity in structure is achieved in special alloyed steels.

Nickel is a good alloying element, and provides steel with high strength, the required margin of toughness and good tempering with thick tube walls.

Molybdenum also promotes improvement of steel's mechanical properties and improves its tempering. Steels alloyed with nickel and molybdenum, besides the properties pointed out above, also do not have a tendency toward initial brittleness, which has an especially important meaning for artillery steel.

Considering the scarcity of such additives as nickel and molybdenum, it is necessary in the development of artillery weapons production in large quantities, especially during wartime, to use less scarce types of steel and, where possible, to decrease the composition of nickel and molybdenum in artillery steels. To this end, alloyed steels are replaced with chromates and carbides in manufacture of gun barrel jackets and other less stressed parts, and also in manufacture of small arms barrels with lower rates of fire.

Construction steel is widely used for manufacture of various artillery system parts. these steels vary in their mechanical properties, and the majority of them are usual carbon steel types. Only such crucial parts as rods, spindles, antirecoil cylinders, shafts, gears and racks of the aiming mechanisms, trunnions, pintle centers and others are manufactured of nickel-chrome steel, with a decreased composition of nickel.

Steels are produced with the open hearth process and by electric smelting. The open hearth process is more productive than electric smelting, and is wideused in steel production. In character of smelting, the open hearth process can be oxygen, basic, or duplex process.

The oxygen process is accomplished with a clean charge which does not contain any harmful mixtures (phosphorus and sulphur). This is a low-production process, in that small volume furnaces, from 50 to 125 tons, are used in it, but it provides pigs of higher quality barrel and special construction steel.

The basic process is used to get pigs of construction steel for various purposes. It is more productive than the oxygen process, and more profitable economically, in that the volume of its furnaces can be increased to 150-200 tons. The major deficiency in the basic process is the increased composition in the steel of gases and ferrous oxides. Barrel steel which is smelted in basic open hearth furnaces has poorer characteristics of elasticity, toughness ., and is more sensitive to flaking.

Barrel steel smelting in basic furnaces is a complicated process, demanding selection of charge and exacting control. Such smelting is conducted with intensive boiling of the steel for maximum riddance of gases and burning out the carbon to the required level.

The duplex process is used for smelting special steels. Smelting in this process is first conducted in basic furnaces, and then liquid steel or steel stocks are loaded into an oxygen furnace.

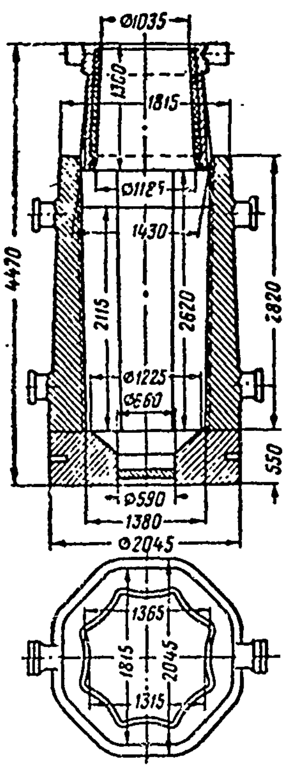


Fig. 33. Mold for steel ingot, 32,000-39,000 kg in wt.

Steel is poured from the open hearth furnace along a trough into a ladle, and from it into molds (Fig. 33). The trough and ladle must be carefully prepared for the steel pouring, for which they are well cleaned, equipped with a strong lining, and dried. The ladle, besides this, must be heated to red heat. These same measures are used in preparation of the mold, whose inner surfaces are covered with graphite, and then the mold is heated to 200° C.

The mold can be six sided or eight sided in form, and has some expansion toward the bottom. The upper part of the mold has a removeable heated extension which enables conclusion of a shrinkage cavity at the head part of the ingot. With large dimensions, the mold sub-floor is sectioned. The weight of the mold with its sub-floor is greater than the weight of the ingot without its head portion, usually by 60 to 130 percent with small ingots weighing 1000-3000 kg, and by 0 to 30 percent in large ingots weighing 20,000-50,000 kg. The weight of the head portion of the ingot does not exceed 14 to 24 percent of its total weight, and the larger the weight of the ingot, the smaller the relative weight of its head portion.

The steel poured into the ladle is retained in it for some time to decrease its boiling. The time the steel is kept in the ladle and the schedule of its pouring into the molds depend on the method of smelting and the type of steel. Quiet (non-boiling) steel in the process of hardening makes a shrinkage cavity above in the heated head extension of the mold. Boiling steel makes a significantly smaller shrinkage shell than quiet steel, and shrinking is distributed around the entire volume of the ingot in the form of bubbles and small shells. The steel is tested before it is poured off to check its bending and breaking, and to ascertain its structure and the chemical composition of the metal. Each ingot is controlled by external observation. The head of the ingot is partially separated on cutting machines, and the number of the casting is stamped on the face of the ingot.

#9. Methods of Stock Formation

Steel ingots, shaped and sheet rollings, and non-ferrous castings, from which parts are manufactured, are called materials. The stock from which a determined part is manufactured in the process of heat and mechanical treatment, is a semi-fabricate, or an only partially treated material.

In artillery production, as in any production of medium and heavy machine construction, parts stocks consist of forgings, stampings, special rollings, centrifugal steel castings, formed steel and non-ferrous castings, and welded semi-fabricates.

Stocks gotten by free forging have widespread usage in artillery production, because it is thought that heat treatment of metal with pressure (forging) best provides its required structure and mechanical properties. Stocks for the following parts are gotten from free forgings: Mortar breeches and barrels, jackets for all artillery systems, trail spades, cylinders, rods and spindles of antirecoil mechanisms, racks, shafts and some gears of the aiming mechanisms. Stocks for ring type cradle bodies, which are large, hollow, and relatively thin-walled parts, are also gotten from free forgings in some cases.

As the result of having such a wide selection of parts whose stocks are gotten from free forgings, the forging and pressing shops get overloaded and often hold up output of artillery systems. Significant changes in the methods of getting stocks took place during the Second World War and in the postwar era. Full capability for manufacturing the parts listed above from rollings, shaped steel or centrifugal castings has been installed into production. Mortar barrels of all calibres and antirecoil mechanism cylinders for some pieces are manufactured from steel seamless tubes. A number of parts (spades, cradles, and others) were changed over to steel formed castings or hot stampings. Barrel jackets and various cylinders can be made from centrifugal casting stock. In some instances, half-cylinders are stamped, and then welded together. In all these methods, material properties correspond to the technical requirements, and metal and time expenditures for making the stock are much smaller than for a free forging.

Table 16 shows comparative data, based on treatment of experiential production data, on the relative weight of metal in finished parts, for various methods of stock production.

TABLE 16

Metal Expenditure on Parts Manufacture for Various Methods of Stock Formation

№	a Способы получения заготовок	b Вес металла в % c готовые детали	d заготовки	e исходный материал
1	Поковки под молотом	100	376	560
2	Штамповки под молотом	100	230	280
3	Штамповки под прессом	100	310	365
4	Штамповки под прессом листового материала	100	110	120
5	Литье стальное	100	135	275
6	Прокат	100	220	320

a. method of stock formation
b. metal weight in percent
c. finished part
d. stock
e. initial material

1. hammer forging
2. hammer stamping
3. press stamping
4. sheet material press stamping
5. steel casting
6. rolling

In forging, the amount of smooth metal going into the finished part comprises 14 to 22 percent of the weight of the casting for gun barrels and 8 to 12 percent for thin-walled antirecoil mechanism cylinders. The weight of a built-up, two-layered gun barrel, consisting of four parts (without the breechblock), is 5030 kg, and the weight of the ingot from which it is manufactured is 31,200 kg (620 percent), with the weight of the forging at 16,400 kg (326 percent). The clean weight of a large gun barrel tube is 9105 kg, the weight of the ingot for it is 49,000 kg (538 percent), and the weight of the forging is 25,100 kg (275 percent).

Problems concerning the wise choice of stock type and amount of margin for all operations of its machining and heat treatment are still not solved to the present and are pressing for resolution. Their timely solution largely depends on the technical knowledge and experience of the technicians.

The forging, regardless of the deficiencies described, maintains its importance as a means of getting stocks from special steels. This importance stems from the following considerations. A cast steel ingot has a number of deficiencies which are posited by its cooling and hardening in the molds; namely, large localized crystals are formed in the ingot which are nonuniform in their structure and configuration, and empty spaces are formed as a result of shrinkage. These deficiencies are the reasons for nonuniformity in the mechanical properties of the steel across the section of an ingot. The forging, combining heat and mechanical processes, affords increased uniformity of the metal and deforms the crystals giving them a fibrous structure and increasing intercrystalline cohesive strength.

#10. Forged Stocks for Large Parts

In artillery production, forgings for large stocks have an exterior diameter of from 150 to 2500 mm, a length of from 1.5 to 25 meters, and a weight of from 0.5 to 50 tons. The weight of forgings for the majority of gun barrel tubes does not usually exceed 5.5 to 12.5 tons, with a length of from 5.5 to 10 meters. Only certain forgings for large gun barrel tubes and forgings for special shafts and cylinders for industrial purposes might have a length of up to 25 meters and a weight greater than 30 tons. Among these large industrial-purpose forgings are all-forged drums for high pressure boilers, shafts for turbines and ships, cylinders and columns for forging hammers and presses, etc. There are, therefore, quite a few large stocks which are formed by forging and are similar to gun tubes in form and size. The forgings can be either solid section or hollow. For manufacture of breeches, breechblock wedges, and similar parts, forgings are divided according to sizes into several parts of right angle or square section.

The process of forming a stock for large parts consists of heating steel ingot, its forging, and consequential cooling of the stock formed from the ingot.

Steel Ingot Heating

The rate of heating of the ingot and the process of its forging have an exclusively important meaning and depend on the type of steel, the size and weight of the ingot, and the forging formed from it. The ingot first undergoes preliminary heating to a temperature of 650° C, and during winter the ingot is kept in the temperature conditions of the shop for 12 hours before heating. Preliminary heating of the ingot is conducted in vertical or horizontal furnaces with staging temperatures of 250 to 400° C. The furnace is loaded with ingots of approximately the same size, and they are kept at the staging temperature for 1 to 3 hours so that the entire mass of the ingot metal is evenly heated and is at the staging temperature. After this, the ingots are heated to a temperature of 650 to 700° C over a period of 1.5 to 4 hours and kept at that temperature for 1 to 3.5 hours.

The final heating of the ingots to forging temperature is conducted in horizontal flaming furnaces with a sliding fettling. Ingots in these furnaces are distributed on special linings so that the heating of the entire mass of metal of the ingots is even. During heating of small-sized ingots it is necessary to periodically turn them. Heating of the ingots to forging temperature (1100 to 1150° C for alloyed steel and 1220° C for some carbon construction steels) takes place over a period of from 2.5 to 4.5 hours, and they are kept at this temperature for 1.5 to 4 hours. These time ranges of heating and holding are average for ingots corresponding to the molds shown in Fig. 33. It is very important that forging of the ingot takes place with its single heating. In forging large ingots, they must be additionally heated to forging temperature, and there must be no more than two of these additional heatings of the ingot, either in whole or in its separate parts. The number of heatings (passes) of the ingot is indicated on the technological chart for each model of stock and type of steel. Ingot heating should be done under conditions for the least possible formation of scale, with temperature being adjusted every 40 minutes.

Forging must be completed at a temperature which is close to--but somewhat higher than--the critical point A_{c3}. For the majority of special steel weapon forgings, forging begins with temperatures of 830 to 850° C.

Stock Forging. It is necessary to be guided by the forging drawing and the technological chart in forging the ingot. We will look at the forging process in an example of manufacture of a barrel forging for a 76 mm cannon (Fig. 34). The technological chart for the forging and pressing operations to get the forging is shown in Fig. 35. Initially the ingot must be lightly pressed along its entire length so that it becomes approximately cylindrical in form (knock down edges). Scale should be removed during pressing. A tail is then drawn from the head end of the ingot and extra metal of the head portion cut away. The size of the tail portion of the forging depends on the dimensions of the ingot, and is established at each plant according to its norms and determined by the convenience for grasping the forging with the chuck and sequential operations of its settling and drawing. Settling of forgings takes place after the ingot is initially pressed along its edges and receives its initial round form. During settling of the forging of round section, the stocks turn out with a right angle section, or in certain cases they may remain round. It is highly desirable that the forging is worked along its entire length after settling without additional heating. Settling is am important operation, and if it is improperly done, longitudinal cracks may appear in the forging.

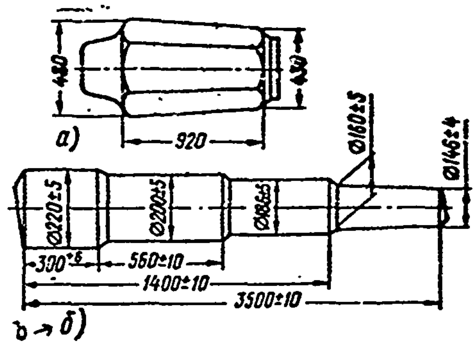


Fig. 34. Forging for 76.2 mm cannon barrel

Key: a. ingot for two forgings
b. forging

During drawing the forging is lengthened at the expense of decreases in its diameters. Drawing is used more often as a method in forging operations. Deep stretches of the forging in one pass, forming sharp steps with large decreases in section and deformation of section, should not be allowed during drawing. An example of consecutive drawing of a forging of comparatively small dimensions is shown in Fig. 35.

Forging must be completed at a temperature 20 to 30° higher than the critical point A_{c_3}, which is strictly determined for each forging and the type of its steel.

Production of a forging when the stock is cold or with uneven ingot heating is forbidden. The heat rates for forging each large stock (gun tube) are registered in a special journal.

The head portion of an ingot for large hollow stocks is cut off and the opening is drilled through its entire length before forging operations. The heart of the ingot, which has more casting defects than the external layer, is removed with a circular cutting head. The size of the diameter of the opening drilled through the ingot is determined in dependence on the size of the ingot and the size of the mandrel with which forging of the hollow forging is done. To get a representation of the changes in dimensions during forging, Figures 36 through 40 present sizes of forgings, stocks for heat treatment, and the various artillery systems received from them. Fig. 36, in particular, shows the stock for a tube which prepared for heat treatment and obtained as the result of a peeling operation and drilling of the forging depicted in Fig. 34. In Figures 36 through 40 it is also possible to get a representation of sizes of the margins which should be considered in planning of forging operations.

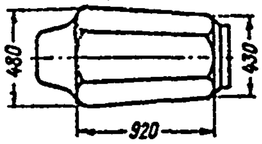
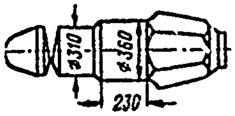
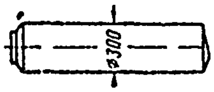
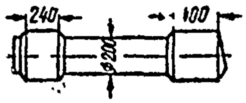
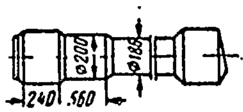
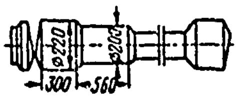
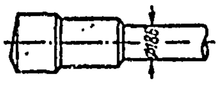
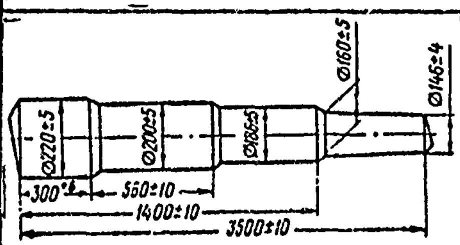
No.	Operational Sketch	Composition of Work	Equipment
1		Heat ingot from 670 to 1160° C	Horizontal furnace
2		Press the ingot from one side along dimensions ∅360 and ∅310 mm. Cut off excess side.	Forging press
3		Press other side of ingot a-long dimension ∅360 mm and then press entire stock to dimension ∅300 mm	Same
4		Press middle part of stock to dimension ∅200 mm, keeping dimensions 240 and 400 mm	"
5		Draw middle portion of the stock to dimension ∅186 mm, keeping diameter 200 mm on length of 560 mm	"
6		Press breech portion of stock to dimension ∅220 mm. Cut off excess, keeping dimension 300 mm.	"
7		Press muzzle portion of stock on all its length to a dimen-sion of ∅186 mm	"
8		Draw muzzle portion of stock to a cone with dimension ∅160 to size ∅146 mm, keeping dimension 1400 mm. Cut off excess, keep-ing dimension 3500 mm. Forge ends with a temperature of 830° C	"

Fig. 35. Technological chart of forging and pressing operations for a 76.2 mm cannon barrel forging (See Fig. 34)

Cooling the Stocks After Their Forging

After forging, all forgings of special steel must cool slowly and evenly to a temperature of 150° C. If these conditions in the metal of an especially large forging are not observed, large inner stresses will arise causing cracks, distortion of the forging, and other flaws. To prevent these defects, all forgings are cooled under a layer of heated earth in special boxes which are heated with covers and hot plates. Cooling rate of forgings does not usually exceed 15 to 20° per hour. Forgings of nickel chrome steels are sometimes cooled in furnaces. The majority of forgings of carbon steels and small forgings of special steels are cooled in the temperature conditions of the shop by stacking them in piles in places which are not subject to drafts. The forgings must not be allowed to cool under the press or hammer longer than 15 minutes during which time the temperature must not be less than 650° C.

It should be additionally noted that the operations of the heating, forging, and cooling processes of large forgings have essential importance; for instance, maintenance of the ingot in forging temperature has the aim of equalizing temperatures throughout the mass of its metal, increasing the elasticity of the metal, and eliminating hydrogen from it which was formed during production of the ingot.

In large-stock forging requiring extended time periods, in that part of the stock which is forged first and with high temperatures significantly exceeding the temperature of the critical point A_{c3} of the metal, a large-grained structure will be formed in which the grain of the metal in it will grow until the stock temperature reaches the temperature of the critical point of the metal.

In the part of the stock which will be forged second, with a temperature close to the critical point of the metal, small-grained structure will be formed.

Forging of a stock under temperatures somewhat less than those required for the operation may produce a striped structure in the metal; and with temperatures lower than the critical point A_{c3}, cold hardening will result. Uneven cooling of the forging leads, not only to large inner stresses but also, to partial hardening of separate surfaces of the stock.

To even the structure of the metal (steel), to relieve inner stresses in the metal which were formed during its cooling in the process of forging, and to eliminate hydrogen from it, the forging is subjected to the annealing operation.

Gas saturation of the ingot metal during forging leads to the formation of flakes in it, the most dangerous defects of gun barrels. Flakes are microcracks which are formed as the result of compressing the hydrogen inclusions (bubbles) in the steel during forging and as the result of the steel's cooling.

The time length of annealing of the stock in the furnace is determined by the dimensions of the stock and the type of its steel. The structure of the steel changes during annealing, and it can be made sorbitic and hydrogen saturation of the steel is eliminated.

Stocks obtained by forging must undergo annealing, and, with this, are prepared for the sequential heat treatments, hardening, and tempering.

#11. Heat Treatment of Large Stocks

The following operations are understood by the term heat treatment in the broad sense: Annealing, normalization, hardening, tempering, and cementation. In this section, only the operations of hardening and tempering thick-walled tubes, specifically for artillery production, are reviewed.

Stocks which are obtained from forgings undergo coarse machining before heat treatment so that they have a more convenient form for heat treatment.

For solid forgings, the exterior surface is turned, the faces are trimmed, and the bore is drilled (See Fig. 36). In these operations the uneven exterior layer of metal formed during forging is cut away from the forging, the fringe and unevennesses-of-forging marks are cut off the faces, and the core is removed. During this the defects formed during production of the ingot and its forging are removed, and a margin, necessary for later machining and removal of discs for metal testing, remains on the inner and outer surfaces. The described coarse machining of the forging has an important meaning for the stock obtained from it in that during the machining the thickness of the wall and the length of the tube (stock) are decreased, providing more even tempering. The sharpest transitions in contour line are rounded off, the coarse-forging unevennesses on the surface are smoothed, and, finally, the sharp changes in the section area of the forging are reduced which decreases the remaining internal stresses during annealing and consequently eliminates the possibility of formation of cracks.

During preparation of large stocks for heat treatment the fact should be considered that special alloyed steel allows good tempering and attainment during annealing of uniform structure to a depth of 65 mm, and, therefore, it is desirable that wall thickness in large tube stocks does not exceed 110 to 130 mm.

Figures 37, 38, and 39 show models of large forgings for a liner, an inner tube, and a jacket. Each figure gives the data on the basic dimensions of the solid forging, the stock for heat treatment with margins for machining and removal of discs for metal testing, and the finished parts. It can be seen from a comparison of the dimensions of the forging and the stock for heat treatment that during coarse machining of the forging, a layer of metal 12 to 18 mm on a side is removed from its external surface, a forging fringe 120 to 170 mm in length is removed from each side, and a layer of metal 11 to 15 mm thick remains on the interior surface which is a margin with a diameter of 22 to 33 mm.

The stock for a relatively thin-walled tube is shown in Fig. 40.

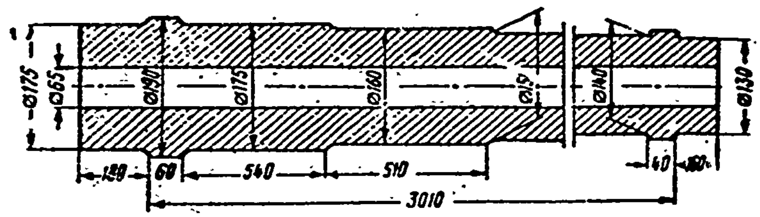


Fig. 36. Stock for 76.2 mm cannon monobloc tube, prepared for heat treatment

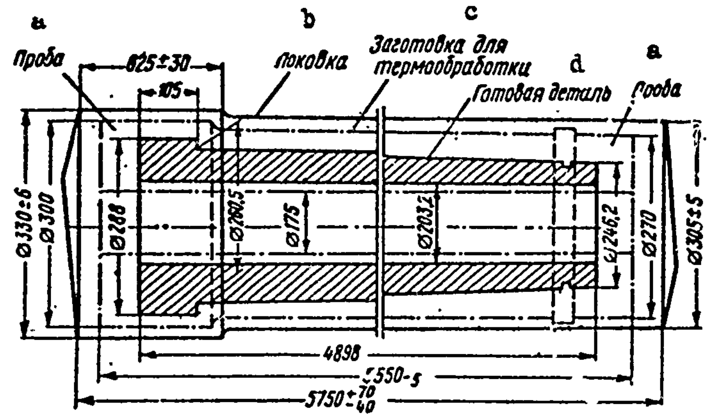


Fig. 37. Forging and stock for heat treatment and finished tube (liner)

Key:
a. test
b. forging
c. stock for heat treatment
d. finished part

Heat operations of annealing and tempering of stock have as their aim the attainment of the necessary structure (for the majority of large stocks this is sorbitic structure) and high mechanical qualities of the steel.

The following factors have essential meaning during annealing and tempering of large stocks: The construction of the furnace for heating the stocks, rate of heating and cooling for each stock, and the cooling means and methods of technical control for the operation.

Vertical furnaces are used for heating and tempering tubes. Stocks of large diameter and length over 6000 mm are most often heated in the furnace

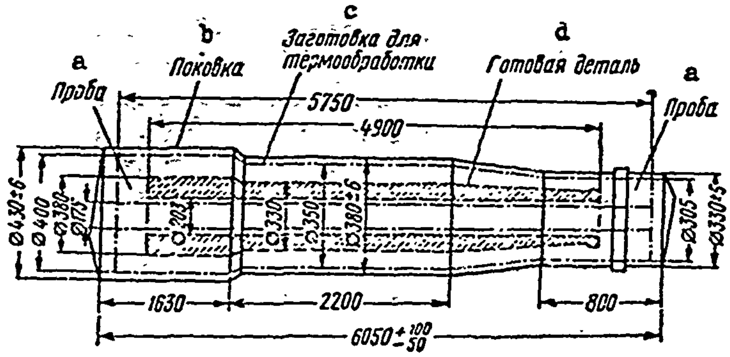


Fig. 38. Forging and stock for heat treatment and finished inner tube of built-up barrel

Key: a. test
b. forging
c. stock for heat treatment
d. finished part

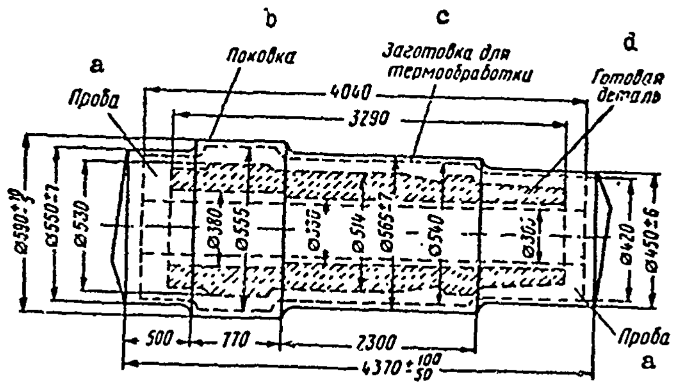


Fig. 39. Forging and stock for heat treatment and finished built-up barrel jacket

Key: a. test
b. forging
c. stock for heat treatment
d. finished part

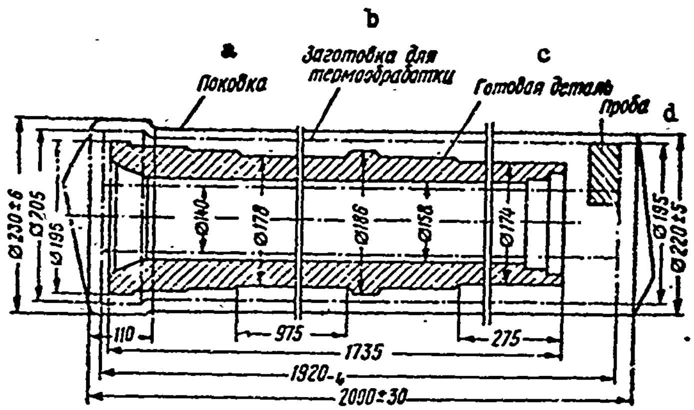


Fig. 40. Forging and stock for heat treatment and finished recoil mechanism cylinder

Key: a. forging
b. stock for heat treatment
c. finished part
d. test

singly while medium-sized stocks are loaded into the furnace in lots of three to five. Seven to nine stocks of diameter not greater than 250 mm and length up to 4500 mm are loaded into the furnace simultaneously. The stocks are fastened into a special star and hung in the furnace in a strictly vertical position at a distance from each other not less than 0.6 times the largest exterior diameter of the stock and at a distance of 400 to 600 mm from the interior walls of the furnace. Even heating of the surfaces of all stocks is provided under these conditions, and localized overheating is prevented. The furnace can be loaded only with stocks of identical dimensions and one type of steel at the same time.

Fuel is conducted into the furnace through special nozzles in the form of a stream directed tangentially to its interior surfaces. The furnace temperature is controlled with thermocouples or other special instruments located in its various sections.

During insertion of the stocks the furnace must have a temperature close to 500° C, and the stocks must have a temperature of not less than 15° C (air temperature in the shop). The annealing temperature of the stocks, which must be higher than the temperature of the critical point A_{c_3} by 30 to 45° C, is determined by the type of steel. For several alloyed steels, for instance, it is in the limits of 840 to 860° C. The speed of heating the stock largely depends on its dimensions and the overall mass of metal in it. For a stock of medium dimensions, ∅330 x 6000 mm, heating speed does not exceed 80 degrees per hour, and for stocks of smaller dimensions it increases to 100 degrees per hour.

In the process of heating, even heating should be provided through temperature regulation for all surfaces of the stock and the entire mass of its metal. After the stock is heated to annealing temperature, it is held at this temperature for 1.5 to 10 hours. The holding time, dependent on the dimensions of the stock and the type of steel, allows even heating of the entire mass of the metal of the stock (along its length and in section) and provides its normal annealing. Nonannealed parts of the stock decrease the reserve of elastic qualities of the steel.

After heating and holding the stock in annealing temperature comes the annealing process itself, the cooling. After the application of heat to the stocks is ceased, the stocks, together with the furnace, cool somewhat so that their temperature drops but remains above the critical point A_{c3} by 20 to 30° C.

The stocks are then removed from the furnace and cooled in a corresponding medium; for instance, the majority of stocks made of alloyed steel are cooled in oil and stocks of chrome molybdenum steel, in water. The selection of the cooling medium and the method of cooling the stocks depend on the dimensions of the stocks and the type of their steel. The cooling medium is very important for the annealing of the stocks. In practice, the stocks are tempered only in oil or in water, or at first in water and then in oil, dipping them in a cooling medium, bathing in it, and using various other methods of cooling.

When the tempered stocks are dipped in it, the cooling liquid must have a temperature of 30 to 40° C. During tempering the cooling liquid must be intensively circulated around the stocks to prevent the formation of a gas skirt around them.

The breech portion of the stock is usually more massive than the other parts, and therefore the time of its holding in the cooling medium must be somewhat longer.

After completion of the annealing operation, the stock undergoes the tempering operation. This operation is also realized through heating the stocks, usually in horizontal furnaces, except for long stocks.

Loading of the stocks in the furnace for tempering takes place with a furnace temperature of 300° C. The stock is held at this temperature for 1.5 to 4 hours and then heated to the tempering temperature of 590 to 620° C, which must be lower than the critical point A_{c3} by 120 to 140° C. In practice the stock is heated to the temperature of tempering at a rate of 60 to 80° per hour. After the furnace is heated to the maximum tempering temperature, the evening of the stock temperature takes place. For this the stock is kept at the established temperature for a period of 3 to 8 hours, depending on its dimensions, type of steel, and purpose of the part.

The cooling of the stock, the tempering operation itself, takes place in various media. At first, for a short time, in air, then for 10 to 15 minutes in oil, and then again in air under the temperature conditions of the shop. In some instances cooling of the stock may take place at first in water for a period of 4 minutes, and then in air. Sometimes slow cooling of the stocks in the furnace is used for tempering. It should be noted that in annealing and tempering, the most effective means for combating possible defects in the stocks, i.e., warping, internal stresses, and cracking, is the correct selection of the rates for their heating and cooling. Observation of these conditions is especially important with alloyed steels. For these compositions the speed of heating and cooling in tempering must be slower than for annealing. Annealing and tempering also have great influence on the mechanical properties of the steel, its structure, and on the amount of internal stresses remaining in it.

Hollow and solid stocks of relatively large length most often warp and bend in heat treatment as the result of formation of inner stresses in the metal. These defects should be eliminated by correction of the stock, while hot, under a press. The press for correction is most expediently established on the technological route of movement for the large stocks between the shop for coarse turning of the exterior surface and bore drilling, and the heat shop. For correction the stock must be heated to no higher than 500 to 530° C, which is 70 to 80° lower than the tempering temperature. The time for heating the stock to this temperature averages no greater than 2.5 to 4.5 hours, and then the stock is held at that temperature for 1.5 to 2.5 hours to even its temperature and partially eliminate interior stresses in the metal. Correction of the stock should take place with gradual increases in pressure of the press on various surfaces so that the stock is corrected evenly and gradually and the correction operation must be completed with a stock temperature no less than 400° C. After correction the stock should be slowly (over 2 to 2.5 hours) heated to a temperature of 470 to 490° C and held at that temperature for 1.5 to 2 hours, and then slowly cooled in air under the temperature conditions of the shop in a dry place without drafts.

The characteristics of the rates of heating and cooling for large stocks in the process of their heat treatment cited above are average in their values. In practice these characteristics should be determined in accordance with the actual working conditions of the shop, the dimensions of the stock, and the type of its steel.

There are examples known of attainment of good results with heating and cooling of large stocks in the process of their heat treatment at faster rates than are cited above. In this instance, however, the demands for stricter control on fulfilment of the established technology and more careful fulfilment of the operation are ever increasing. It is always necessary to consider that the high qualities of strength, elasticity, and tensility, and the required structure of alloyed steel are basically assured by their correct heat treatment. If the first heat treatment of a stock does not give satisfactory results in mechanical qualities and structure in testing, then it is possible to allow a second heat treatment. In practice, examples are known of threefold stock annealing and tempering operations; however, such a situation cannot be considered normal and should not be allowed.

#12. Mechanical Testing of Stock Metal

Criteria determining the mechanical properties of stock metal are the following:

1) the limits of elasticity (relative) σ_c -- stress in kg/mm^2 with which the test sample is permanently lengthened by 0.002 percent of its initial length;

2) the limit of proportionality (relative) σ_p -- stress in kg/mm^2 with which the deviation from linear dependence, according to Hooke's law, between the stresses and deformation reaches a size such that the tangent of the angle formed by bend deformation and the axis of stress σ_p is increased by 50 percent of its initial value;

3) the limit of a field (physical) σ_s -- the least stress in kg/mm^2 with which the test sample is deformed without noticeable increase in load applied to it;

4) limit of yield (relative) $\sigma_{0.2}$ in kg/mm^2 corresponds to the stress with which the test section is permanently lengthened 0.2 percent of its initial design length;

5) limit of tensile strength (temporary resistance to breakage) σ_b -- tension in kg/mm^2 corresponding to the maximum load preceding breakage of the test sample;

6) relative lengthening δ in percents -- relation of the increased length of the test sample (after breakage) to its initial length;

7) relative narrowing ψ in percents, which is the relationship between the area of the cross section of the test sample after breakage with its initial cross section area;

8) shock strength α_k in kg m/cm^2 -- work expended on breaking the test sample related to the area of its section in the place of breaking. This is the mechanical characteristic of toughness of the metal.

In testing the stock metal in production practice, all the described characteristics are determined except the limits of elasticity. The basic characteristics of mechanical qualities of stock metal for thick-walled tubes made of alloyed steel are: The limit of proportionality σ_p, the relative narrowing ψ and the shock strength α_k, and the remaining characteristics are facultative and necessary only for general evaluation of the quality of the metal.

Construction steel is basically characterized by the limit of yield (relative) $\sigma_{0.2}$, the relative lengthening δ, the relative narrowing ψ, and the shock strength α_k, and construction steel used for nonstressed parts is evaluated only by Brinnell hardness.

The limit of proportionality is determined with accuracy to 0.5 kg/mm² according to the formula

$$\sigma_p = \frac{P_p}{F_0}, \qquad (3.?)$$

where P_p = effort (load corresponding to the limits of proportionality in k· and F_0 = initial area of the cross section of the test sample in mm².

The limit of yield $\sigma_{0.2}$ is calculated according to a similar formula, out load $P_{0.2}$ is used. This load corresponds to the stress. Fig. 41 shows th diagram of load (P) and the lengthening ($\Delta\ell$) under stress which is built the basis of results of testing and serves for determination of the characteristic σ_p and $\sigma_{0.2}$ of the stock metal.

Mechanical properties and microstructure of the metal stock are checked after their heat treatment. The number of these tests (of a batch of stocks or of each separate stock) is established with consideration for the type of steel and the purpose and dimensions of the part. All stocks of thick-walled tubes of medium and large dimensions undergo individual control, and the test samples for testing are extracted from discs which are cut off the muzzle and breech parts.

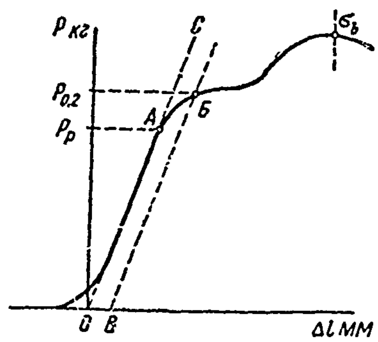


Fig. 41. Diagram for determination of the limit of proportionality σ_p and the limit of fluctuation (relative) $\sigma_{0.2}$

The schematic for cutting discs (test sections) from the tube stocks and the extraction of samples from them for mechanical testing is shown in Fig. 42. The first disc, 40 mm (0.25d) thick, is thrown away, and the second disc is tested. Cutting of samples from the discs takes place as shown in the schematic of Fig. 42 so that the sample cut from the disc must be located as close as possible to the tube exterior surface, which undergoes fine machining.

Of each test section, any two oppositely positioned samples are tested for breakage, and the other two are tested for shock strength. The dimensions of samples must correspond to the requirements of All Union State Standard 1497-42 and All Union State Standard 1524-42, or be shown in the technical conditions for the product. Samples are cut from only the cold (unheated) stock.

Fig. 43 shows the schematic for cutting discs and samples from the breech for mechanical testing. For the majority of breeches, breechblock wedges and pistons, the test sample for mechanical testing is taken from one stock out of which several parts are manufactured.

For small diameter tubes, pintles, and similar parts when it is impossible to cut samples from the stock discs which touch the circumference, samples are taken in the direction of the linear axis.

Mechanical characteristics of the stock material are given with calculation of the type of steel, construction and purpose of the part manufactured from it, and they are shown on drawings and in the technical conditions for manufacture of the part. Special alloyed steel from which stocks for thick-walled tubes are manufactured, for instance, may have the following mechanical characteristics: Limit of proportionality σ_p from 50 to 100 kg/mm^2, limit of fluctuation $\sigma_{0.2}$ from 60 to 115 kg/mm^2, relative narrowing ψ from 25 to 30 percent, and shock strength α_k from 3 to 4 kg/m/cm^2.

Monobloc gun barrels, liners, and inner tubes of built-up barrels which are subjected to a maximum gas powder pressure of 3000 to 4000 kg/cm^2, must have a limit of proportionality σ_p no less than 80 to 90 kg/mm^2 and a shock strength no less than 3.5 to 4 kg m/cm^2.

For gun barrel tubes which are subjected to a maximum powder gas pressure of 2400 to 2900 kg/cm^2, the limit of proportionality σ_p must not be less than 50 to 70 kg/mm^2 and the shock flexibility α_k within the limits of 3 to 4 kg m/cm^2.

The allowable size of difference between the characteristics σ_p of two samples of the same disc in testing for breakage depends on the type of steel and the dimensions and purpose of the gun tube. For the gun tubes shown in Figures 12, 13, 14, and 45, and having a limit of proportionality $\sigma_p = 65 - 75$ kg/mm^2, for instance, the variance in characteristics of two samples from the same disc must not exceed 3 to 4.5 kg/mm^2.

Characteristics σ_p of samples cut from different discs of the same tube, for instance, from the muzzle part and the breech, which is for the gun tubes shown in the previous example, may vary by 5 to 8 kg/mm^2. Under all circumstances of deviation from the described values (norms) of the characteristics σ_p, they are allowed only on the large side and under conditions so that the characteristics of flexibility of the metal (relative narrowing ψ and shock flexibility α_k) will not be lowered. Variance of the characteristic σ_p from the norm on the small side is allowed for only one of the tested samples and with a size less than one kg/mm^2. The norms for characteristics of

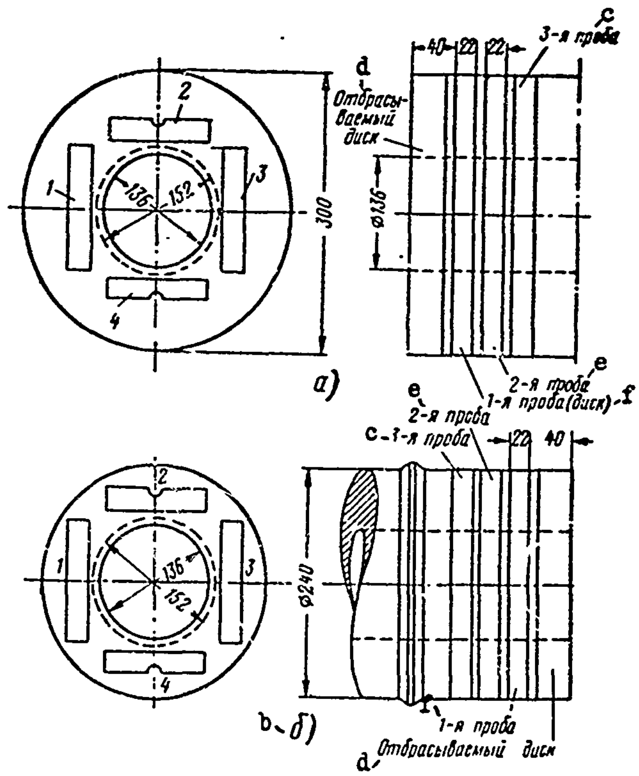


Fig. 42. Schematic of extraction of samples from tube stock for mechanical metal testing

Key:
a. breech
b. muzzle part
c. 3rd test
d. discarded disc
e. 2nd test
f. 1st test (disc)
1 & 3. samples for breakage testing
2 & 4. samples for shock strength testing

flexibility of the metal are established for each of two tested samples separately and for their sums. Deviation from the norm of the characteristics of flexibility of both samples in this will not be less than the norm established for it. Deviations of the characteristics of flexibility from the established norms to the large side are not restricted. Testing of the metal under low temperatures (-45° C) is essential for the characteristics of flexibility, and therefore such testing should be recommended.

If the stocks undergo a second heat treatment (annealing and tempering), then all mechanical testing of its metal should be repeated in full or in the same scale as in the first testing. Such a possibility is foreseen in the amount of margin for removal of the discs (See Fig. 42--1st, 2nd, and 3rd samples or discs).

It has already been stated above that the characteristics of flexibility of steel, especially that used for manufacture of gun tubes, working under pressures $p_{max} > 3000$ kg/cm^2, has a highly important meaning. The characteristics of the metal which are obtained by mechanical testing of the samples on breakage and for shock flexibility do not allow sufficiently full evaluation of the quality of the metal for the stock under dynamic loads which correspond to the working conditions of the barrel. At some domestic and foreign plants, for fuller evaluation of the properties of the stock metal material, and in addition to the regular mechanical testing, they undergo special breakage testing for which samples in the form of hollow cylinders ⌀30 x 15 mm, 65 mm in length, and machined to a smoothness of ∇6 are manufactured.

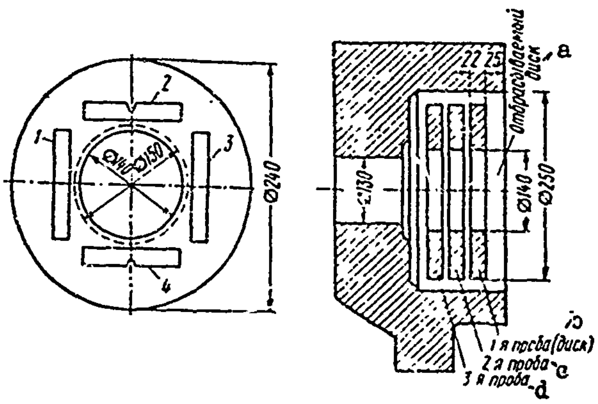


Fig. 43. Schematic of removal of samples from the breech for techanical metal testing

Key:
- a. discarded disc
- b. 1st test (disc)
- c. 2nd test
- d. 3rd test
- 1 & 3. samples for breakage testing
- 2 & 4. samples for shock strength testing

The interior of such a sample is packed with a TNT cartridge 2 to 5 g in weight. The weight of the charge of such a cartridge can be regulated in increments of 0.5 g and depends on the dimensions of the tested sample and the type of its steel. Breakage testing usually takes place in three samples, but in some instances up to six samples are required for each testing. The flexibility of the steel is judged according to the characteristics of the explosion of the sample during the tests (explosion into separate splinters, localized deep holes and cracks, or only residual deformations and cracks which are insignificant in dimension and do not reach the face of the sample. The explosion method of metal testing is not widely used, however, because it is still insufficiently mastered.

#13. Margins for Stock Dimensions

In the process of machining parts, a stock may sequentially be treated on various machine tools so that the same stock surface often undergoes several operations (coarse, fine, and finishing). The thickness of the layer of metal removed furing all these operations makes up the overall margin of the stock. For each separate machining operation a layer of metal remains on the stock corresponding to the thickness which is to be removed in the process of performing that operation. As a result of this, between-operation dimensions and tolerances with which help the size of the required margin is calculated, appear on the technological charts. Between-operation dimensions and tolerances are the technological requirements for the operation, and they are assigned by the technicians during workup of the technological process.

The thickness of the layer of metal removed from the stock in the process of manufacture of the part is called the margin. Thickness of the margin provides receipt of the part which corresponds to the drawings for the stock.

Margins are assigned on those dimensions of the stock (diameters, lengths, and wall thicknesses) which are changed in the process of its machining. For determination of the total amount of margin, the dimensions of possible defects in the stock which are eliminated in the process of its machining and the minimum thickness of the layer of metal removed during each planned operation should be calculated.

Defects in the stock may be various changes in its form which arise as the result of action of inner stresses remaining in the metal after the stock's heat treatment.

These defects include: Distortions of the stock along its exterior surface or interior bore; variances in wall thickness and ovality in section in hollow, round stocks; unevenness and steps in the surfaces which are formed after forging and casting; a layer of scale; and others.

Besides this, the dimensions of the layer of metal removed during removal of the discs and extraction of the samples for mechanical testing of the metal, as well as all types of machining to obtain the required precision and surface smoothness, should be considered during determination of the total margin. The margin assigned for each operation must be of such size so that the operation can be successfully completed and defects of previous operations can be eliminated. After each machining operation, the dimensions of the stock will have some variance from the between-operation dimensions. The tolerances on dimensions for each operation must therefore be considered in assignment of the margins. As a result, the overall total amount of the margins for a shaft, for example, is determined as shown in the schematic in Fig. 44, with the following data:

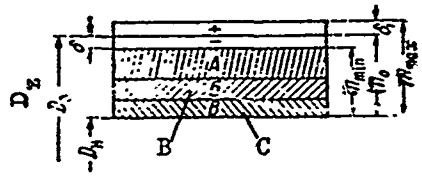


Fig. 44. Schematic of location of margins and tolerances of the stock

Key: D_H. nominal dimension of the part
D_z. nominal dimension of the stock
M_{max} and M_{min}. limiting values of the margin
M_o. nominal dimension of the margin
δ and δ_1. margins for the stock

Nominal size of the finished part D_H; nominal size of the stock D_z; operational margin on coarse, fine, and finishing operations A, B, and C; nominal amount of overall margin M_o; smallest and largest amounts of overall margin M_{min} and M_{max}; tolerances for the stock δ_1 and δ.

With this in mind, the overall amount of margin is the least thickness of the layer of metal in which are totalled the layers of metal removed in all machining operations, between-operational tolerances, and tolerances on stock dimensions (minus sign for the shaft and plus sign for the opening).

The choice for total and operational margins is closely tied to the requirements for production, economy, and precision of parts machining. In determining the amount of margins the technician must strive to obtain the least possible number of machining operations and the highest productivity in equipment and machining rates. An excess amount of margin makes production more expensive because changing the extra layer of metal into shavings requires additional expenses in time and irrationally increases capacity of the equipment, the wear of the tool, and the expense in auxiliary materials.

With assignment of irrationally small amounts of margins, accuracy of machining increases, and this in some cases is the reason for appearance of rejects.

The correct determination of operational margins has an important meaning in the machining of gun tube stocks and stocks for similar parts' tubes. As already asserted, the peeling operations on the exterior surface and the drilling tube bore have the aim of removing extra layers of metal from the stock and giving the stock a more correct form prior to its heat treatment. A sufficiently large margin must remain after these operations for the

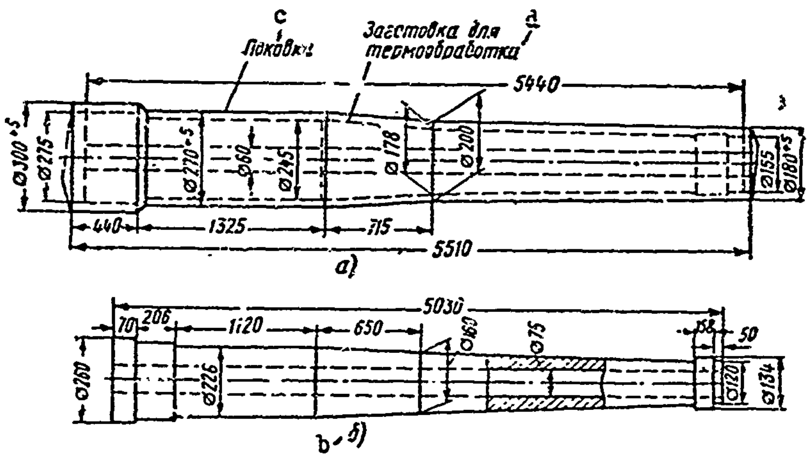


Fig. 45. Monobloc tube of 75 mm German cannon barrel, model 1942

Key:
a. forging and stock for heat treatment
b. finished tube
c. forging
d. stock for heat treatment

sequential treatment of the exterior surface of the stock, for coarse and fine turning, and for the finishing operations of its bore. The amounts of these margins for certain types of stocks are represented in Figures 13 and 36 through 40. In addition to these examples, Fig. 45 shows the forging and stock for heat treatment and the finished monobloc tube of a 75 mm German cannon barrel, Model 1942.

In the last example a layer of metal 10 to 15 mm in thickness is removed from each side and the forging is shortened on each end by 40 to 35 mm before heat treatment of the stock. During solid drilling of the stock it receives a bore, 50 mm in diameter. For the final machining of the stock after annealing and tempering, the following margins remain:

> For coarse and fine operations on the exterior surface, 8 to 10 mm--and on the interior surface, 7.5 mm on a side; on the length, for removal of discs for mechanical metal testing and trimming of the surface faces, 205 mm on each end.

The operational margins on dimensions and margins for removal of the discs for metal testing for the stocks shown in Figures 38 and 45 are excessive. Superfluous increases in margins are harmful but are often caused by the special conditions of stock production. The stock and monobloc tube obtained from it, shown in Figures 46 and 12 respectively, may serve as a more rational assignment of margins. Comparing the dimensions shown in Figures 12 and 46, it can be seen that the margin for machining the exterior surface does not

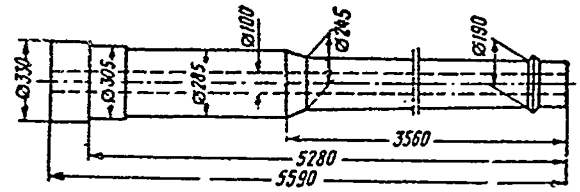


Fig. 46. Monobloc tube stock for heat treatment
(See Fig. 12)

exceed 7 to 10 mm and that of the interior surface does not exceed 11 mm on a side. On length of the stock, with calculation for removal of discs for metal testing, the margin is 170 mm on each end. Margins may be assigned on a side or on the diameter, but they should always be clarified, making corresponding explanations on the drawings.

During workup of the technological processes the size of operational and overall margins should be assigned with consideration for production experience and recommended norms for various stocks. In some cases for determination of margins it is possible to make use of empirical formulae, which are usually worked out on the basis of production experience. Such formulae, however, do not, as a rule, consider changes in production processes, and in practice they may be used only for approximate calculations.

Summarizing the data on margins for large solid forgings of great length in which dimensions and form correspond to the stocks reviewed, it is possible to obtain average values for the margins and tolerances on the diameter. The values of these margins and tolerances are shown in Table 17.

TABLE 17

Average Values of Margins and Tolerances on Diameters of Large Forgings in mm

Длина заготовки мм a	Диаметр заготовки (трубы) в мм b					
	120—180		260—360		360—500	
	припуск c.	допуск d.	припуск c.	допуск d.	припуск c.	допуск d.
1000—1500	14	±2	16	±3	20	±4
2000—3000	18	±3	20	±4	26	±5
4000—5000	20	±4	26	±4	30	±5
6000—8000	24	±5	30	±5	34	±5

Key: See the following page

Key:
a. length of stock, mm
b. diameter of stock (tube), mm
c. margin
d. tolerance

The margins shown in Table 17 are somewhat smaller in size than the margins presented in Figures 13, 36 through 40, and 45 through 46, but they are sufficient for manufacture of tubes with consideration for the peculiarities of artillery production. These margins and tolerances are larger than those recommended for general machine construction, but they take into account the large length of the stock and the peculiarities of machining these special tubes.

For tubes subjected to heat treatment the following margins on each side can be recommended:

> On exterior surfaces, 8 to 12 mm; on interior surfaces, 6 to 12 mm--with the least amount for tubes 75 to 100 mm in diameter and the largest amount for tubes with an inner tube diameter of 200 to 240 mm.

During manufacture of tubes, for dimension and form corresponding to those reviewed, the amount of smooth metal in the finished product in relation to the weight of the forging comprises 26 to 36 percent, and in relation to the weight of the ingot, 15 to 24 percent. The weight of the large forgings relative to the weight of the ingot usually comprises 52 to 65 percent, and the weight of smooth metal in the finished product relative to the weight of the stock manufactured for heat treatment comprises 50 to 70 percent.

From all the considerations presented in this chapter, it can be seen that the choice of the type of stock, the method of its treatment, and the amount of margins on the dimensions have essential meaning for the planning of the technological processes and the economy of production.

CHAPTER V

Bases of the Technology of Production of Gun Tubes

#14. Plan of Operation for Machining Gun Tubes

Dimensions. The weight of gun tube stocks and the required precision for manufacture of tubes are factors which should be considered in planning machining operations. Residual inner stresses remain in the stock material after its heat treatment under which action it is deformed (bent and warped) during removal of shavings from the stock. As the result of this, after machining, the tube may have a curvature, with consequent variations in wall thickness. Such defects may be reasons for rejection of all tubes. For elimination of curvature and variations in wall thickness of the tube, it is necessary to monitor the determined sequence of performance of lathe operations in machining the exterior surface and turning the bore of the tube.

The residual inner stresses in the stock metal are most effectively manifested during removal of the layer of metal from the exterior surface of the tube because the exterior layer of metal, due to sharper deviations in temperature during heating and cooling of the stock during heat treatment, retains larger residual stresses.

Besides this, with identical thickness the mass of metal cut from the exterior surface of the tube is 1.5 to 2 times larger than the mass of metal included in the interior layer of the tube as the result of differences in the sizes of their dimensions.

If a layer of metal is cut from the exterior of one tube, therefore, and a layer of metal of identical thickness is removed from the inner surface of another tube, the first of these will be more deformed or have greater bending and warping due to action of large inner stresses and removal of larger masses of metal.

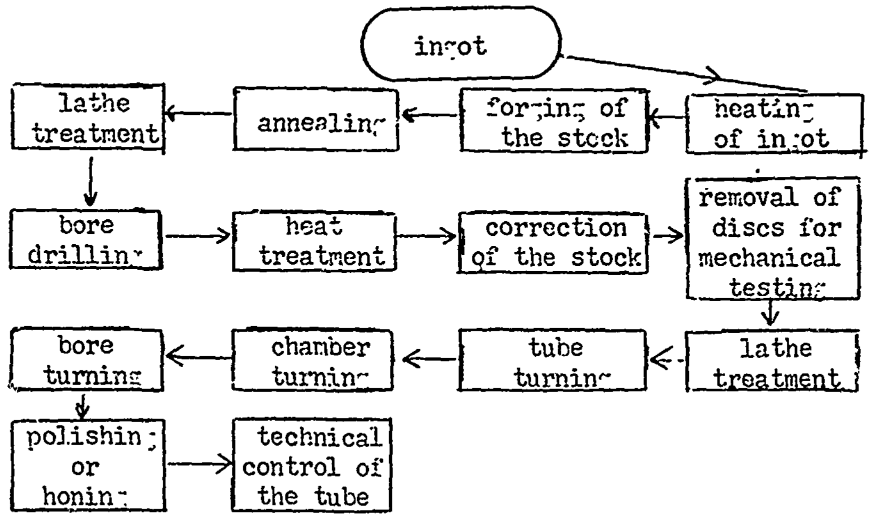


Fig. 47. Flow chart of the technological operation in gun tube operation

These elementary physical phenomena are sufficiently proven by production experience and must be considered basic in planning machining operations of the exterior and interior surfaces of tubes.

After turning of the exterior surface, the tube usually has a small curvature and, at the same time, its walls will be less stressed. During final turning of the tube's bore and removal of the layer of metal from its interior surface, residual stresses will not have essential influence and the form of the tube will not be significantly changed. Consequently, the bore, after turning, will maintain straightness, or will have insignificant curvature which can be eliminated in the next semismooth turning operation.

Taking these considerations into account, it is expedient that the coarse operations of reaming the stock precede the coarse operations of lathing work on its exterior surface. In this case the fine lathing treatment of the exterior surface of the tube must be the last completing operation for which the interior surface of the straight, finally-treated bore of the barrel will serve as the technological reference base. In the process of treatment the gun tube stock undergoes several different operations, and parts of these operations are basic (fundamental); which is to say they are determined by the technological routing of the stock and the qualitative composition of the technological process.

Fig. 47 shows the chart of such major operations during manufacture of gun barrel tubes. The chart visually depicts the route of movement of the stock through the various shops and the composition of work through the various technological operations.

In the examples reviewed, coarse and fine machining operations on the exterior and interior surfaces of the tube stocks will compose the following types of work which are performed in the sequence below:

-- Trimming of the stock faces
-- Lathe treatment (peeling) of the exterior surface and turning of the base cheeks of the stock
-- Solid or ring drilling of the bore
-- Heat treatment (annealing and tempering) of the stock
-- Correction of the tube while hot
-- Trimming the faces and removal of the discs for checking the quality of the metal from the muzzle and breech parts of the stock
-- Testing of the samples to determine the mechanical properties and structure of the metal
-- Coarse lathe turning of the exterior surface and turning of the base cheeks of the stock
-- Coarse turning of the bore
-- Semilathe turning of the exterior surface and turning of the base cheeks for mounting of the stock on the machine for final turning of its bore
-- Semifine turning of the bore
-- Fine turning of the bore. This operation may be conducted on the same machine and with the same mounting of the stock on the machine as semifine turning, but with different turning tool and with a different turning rate
-- Turning of the charge chamber
-- Smooth-lathe turning of the exterior surface of the tube and trimming of its faces to size
-- Technical checking and measuring of the tube on its exterior surfaces and bore
-- Polishing or honing the bore
-- Polishing the charge chamber
-- Technical checking and measuring of the bore of the tube
-- Cutting of the bore grooves
-- Polishing of the bore after rifling
-- Technical checking and measuring of the bore
-- Treatment of the face surfaces, milling of the keyways and ways for the extractor claws, and other metal working operations.

The above sequence of machining operations of the exterior surface of the tube and the interior surface of its bore eliminate defects created during drilling of the bore, remove the stresses remaining after heat treatment of the stock, and assure attainment of a straight bore. The plan of completion for machining operations of built-up barrel tubes is somewhat different from that described because the semismooth and smooth treatment of the exterior surface of the jacket and the interior surface of the tube take place after assembly.

#15. Lathe Treatment of Large Stocks

Lathes are used in artillery production for various peeling and fine operations, cutting of registration and special grooves, and treatment of various formed surfaces.

Gun tubes and large stocks which are similar to them are treated on lathes which are different from the usual universal screw lathes in dimensions and in capacity.

Such machines for treatment of tubes and other stocks of 3000 to 14,000 mm in length, with a maximum exterior diameter of 500 to 2000 mm, have a length of 5 to 25 meters with a usual relation of machine length to length of treated stock of 1.4 to 1.8. The treatment of exterior surfaces of the tubes and shafts of great length by one moving cutter is highly impractical, and therefore the tools have two, and in some cases three, tool holders. On such machines two or three cutters can work simultaneously on the exterior surface at one or more diameters, which significantly increases the productivity of labor.

One end of the stock is installed in the chuck, faceplate, or special attachment of the spindle mandrel of the machine, and the other end is installed on the turning center of the rear mandrel. Long stocks, besides this, have a bearing in the center portion in the form of a nonmoving lunette on which they are positioned on a previously turned cheek.

In recent years production has been equipped with more modern lathes, and furthermore, the basic types of old lathes have been modernized. In the new, and especially in the modernized machines, the range of the number of revolutions of the spindles and the feed of the tool holders have been increased. Single-lever and push-button controls are being used in changing spindle speed and setting of feed, processes of parts installation, tool holder feed, and fec and fastening of the rear mandrel are being automated. Similar achievements are based on the use of various hydraulic mechanisms and drives.

Machine tools of large dimensions allow machining of large stocks to 4th and 3rd classes of precision, and in some cases to 2nd class precision with a surface smoothness corresponding to 6th to 8th classes of smoothness.

The technical characteristics of some types of large-dimension screw lathes are given in Table 18.

The heaviest lathes, weighing over 100 tons, allow machining of products having an exterior diameter of 4000 mm. Lathe models 1660, 1670, and 1680 have, besides the characteristics shown in Table 18, the characteristic of infinitely adjustable spindle speed, allowing the setting of any required speed of turning.

The following basic operations can be performed on lathes:

1) Turning of exterior cylindrical and conical surfaces of tubes and solid stocks;

TABLE 18

Technical Characteristics of Screw Lathes

a Основные технические характеристики	b Модели станков				
	1А64	1658	1660	1670	1680
c Наибольший наружный диаметр обрабатываемой заготовки в *мм*	450	650	860	1120	1520
d Расстояние между центрами при крайнем положении задней бабки в *мм*	2800	8000	6300	8300	10 000
e Количество устанавливаемых чисел оборотов шпинделя	24	24	3	3	3
f Диапазон чисел оборотов шпинделя в об/мин	7,1—750	5—500	3,1—200	2,5—160	2—128
g Количество устанавливаемых продольных подач	32	32	48	16	14
h Диапазон продольных подач в *мм/об* шпинделя	0,2—3,05	0,2—3,05	0,19—11,4	0,2—38	0,2—38
i Диапазон нарезаемых метрических резьб по шагу в *мм*	1—120	1—120	1—160	1—48	1—48
j Мощность главного электродвигателя в *квт*	28	28	60	100	100
k Габариты станка в *мм*:					
1 высота	1 660	1 760	2 060	2 600	2 750
2 ширина	2 000	2 000	2 340	4 020	4 060
3 длина	5 780	11 380	13 200	16 600	18 260
l Вес станка с электрооборудованием в *т*	11,7	21	44,87	126	136

Key:
- a. Basic technical characteristics
- b. Lathe model
- c. Maximum exterior diameter of machine stock in mm
- d. Distance between centers with the extreme position of the rear mandrel in mm
- e. Number of spindle revolution settings
- f. Range of spindle revolutions in revolutions/min
- g. Number of feed settings
- h. Range of feed in mm per spindle revolution
- i. Range of spacing of cut metric grooves in mm
- j. Power of the main electric motor in KW
- k. Dimensions of the machine in mm:
  1. height
  2. width
  3. length
- l. Weight of the machine with electrical equipment in tons

2) drilling and reaming of shallow openings;

3) turning of axles and shafts which have cylindrical and formed surfaces and steps;

4) cutting, in metric and inch measurements, of normal profile grooves, and also support and right angle special grooves which are widely spaced;

5) turning of thin rods and shafts of either constant or changing section which have little toughness and require high accuracy in machinings;

6) treatment of butt bearing surfaces, flat breech surfaces, and sleeves and other parts having large flat surfaces.

Boring lathes are used in some instances and can be employed for normal lathe machining and boring of deep openings in tubes. The construction of these lathes will be described in detail in Chapter IX.

A lathe peeling operation before heat treatment has the aim of removing unevennesses and defects in the forging and giving this stock a more correct and convenient form. During this operation a layer of metal from 5 to 15 mm thick is removed from each side, and this comprises up to 40 to 50% of the total margin.

After heat treatment, large stocks (tubes) undergo coarse, semifine, and fine lathing operations. During the coarse lathing operation, a layer of metal from 3 to 6 mm (50 to 60% of the remaining margin) is removed.

After the semifine lathing operation, during which the margin of from 1.5 to 3 mm is removed from each side, the form of the stock is not significantly changed, and it does not affect future cutting operations.

The fine turning operation has the aim of making the exterior surface of the tube strictly concentric relative to the final treated surface of the bore throughout its length and attaining the dimensions assigned on the working drawings. A margin of up to 1.5 mm on a side is removed during fine turning.

In some instances with a stock length less than 4000 mm, a semifine turning operation may not be done, and after coarse turning of the exterior surfaces, coarse reaming follows. Then, after checking the concentricity of the technological cheeks of the stock, semifine and fine turning of a bore are continued. The last machining operation must be a fine turning of the exterior surface of the tube during which concentricity of the exterior surface relative to the smooth treated surface of the bore is assured.

§16. Basics of Metal Cutting Theory in Tube Machining

Lathe machining of the exterior surface and drilling and reaming of the deep opening of the tube stock is accomplished with a rotary motion, which is the primary motion determining cutting speed, and the cutting tool accomplishes the progressive linear motion of the feed s (Fig. 48).

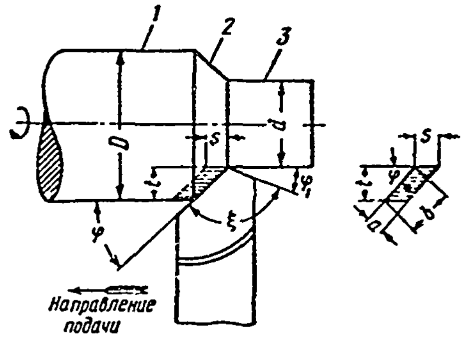


Fig. 48. Cutting elements for lathe machining

Key:
1. surface being machined
2. cutting surface
3. machined surface
t. depth of cut in mm
s. feed in mm/rev
a. thickness of shaving
b. width of shaving
c. direction of feed

Basic Characteristics of the Cutting Process

The following surfaces differ during cutting treatment: The surface being machined (1) of diameter D, the cutting surface (2) formed by the major cutting edge of the tool, and the machined surface (3) of diameter d which is attained after removal of the shavings (See Fig. 48).

The basic characteristics which determine the cutting speed in the process of machining are: Cutting speed v, cutting depth t, and feed s.

Cutting speed v is the path of movement in a unit of time of the stock surface being machined in the primary direction relative to the cutting edge of the tool. During the rotary primary movement, the cutting speed is the linear (circular) speed, and is determined according to the formula

$$v = \frac{\pi D n}{1000} \text{ [m/min]}, \qquad (19)$$

where D = the diameter of the surface being machined in mm, and n = the number of stock revolutions per min.

Feed s is the amount of travel the cutting edge of the cutting tool in one revolution of the stock in the direction paralleling its surface being machined.

In drilling, when the drill accomplishes the rotary and progressive movement, feed is the amount of linear movement of the drill in the axis of its direction in one revolution. The feed for one revolution of the stock s_0, measured in mm/rev, and the feed per min s_{min}, measured in mm/min, differ. These feeds are tied with the following dependence:

$$s_0 = \frac{s_{min}}{n} \text{ [mm/rev]}. \qquad (20)$$

Cutting depth t is the thickness of the metal layer removed and is seen as the distance between the surface being machined and the machined surface, measured perpendicular to the latter. During lathe machining, cutting depth is determined as half the difference between the stock diameters according to the following formula:

$$t = \frac{D - d}{2} \text{ [mm]}. \qquad (21)$$

The section area f of the shaving removed depends on the trimming depth and the amount of feed, and its form depends on these parameters and on the size of the measured angle of cutting ϕ. The parameters determining the section of the shaving will be: Thickness of shaving a, measured in the direction perpendicular to the main cutting edge of the cutter; and the width of the shaving b along the cutting edge of the cutter.

It can be seen from Fig. 48 that the thickness of the shaving (cut) has a formula

$$a = s_0 \sin \phi,$$

its width has the formula

$$b = t/\sin \phi,$$

and the cross section area of shaving removed has the formula

$$f = ts_0 = ab \text{ [mm}^2\text{]}.$$

With the same cutting depth t and feed s, the cross section of the shaving (layer cut away) has a varying form and depends on the form of the cutting edge (straight or formed) and the major cutting angle in the plane ϕ.

Elements and Angles of Cutting

In the process of cutting, the cutter wears out and its geometric parameters are changed. A worn cutter must be periodically resharpened. The longer time a cutter can work without resharpening, the greater its durability and productivity. Durability of the cutter depends on its construction, the geometry of its point, and the properties of the material from which it is manufactured, as well as the properties of the material of the part being machined and the cutting rate.

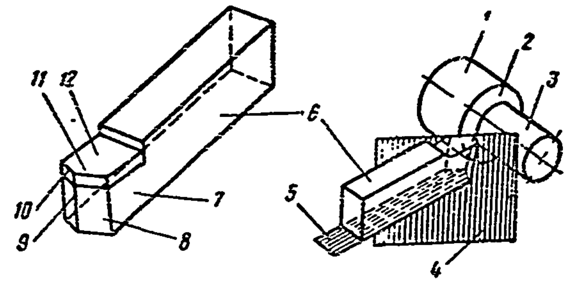


Fig. 49. Elements of cutting and basic planes

Key:
1. surface being machined
2. cutting surface
3. machined part surface
4. plane of cutting
5. base plane
6. cutter body
7. cutter head
8. rear cutting surface
9. auxiliary rear surface
10. auxiliary cutting edge
11. main cutting edge
12. forward surface

The cutter consists of the head, or working part, and the body which serves to fasten the cutter to the machine on the fastening device. The cutting head (7), which forms the point, has a front surface (12), along which the separated shavings fall away; a rear surface (8) which is in contact with the cutting surface (2); an auxiliary surface (9), a main cutting edge (blade) (11), which performs the cutting, an auxiliary cutting edge (10), and the cutter top, on which the main and auxiliary cutting edges are installed (Fig. 49).

The cutting angle is determined by the following coordinated planes: The cutting plane (4), which touches the cutting surface (2) and moves along the main cutting edge (11), and the base surface (5), parallel to the longitudinal and sectional feeds. The base surface in lathe cutting coincides with the bearing surface below it (see Fig. 49).

The main cutting angles are located in the main secant plane ff, perpendicular to the projection of the main cutting edge on the base plane, and the auxiliary cutting angles are located on the auxiliary secant plane bb, perpendicular to the projection of the auxiliary cutting head on the same plane (Fig. 50).

We will determine the angles of cutting on the example of moving lathe cutting shown in Figs. 49 and 50).

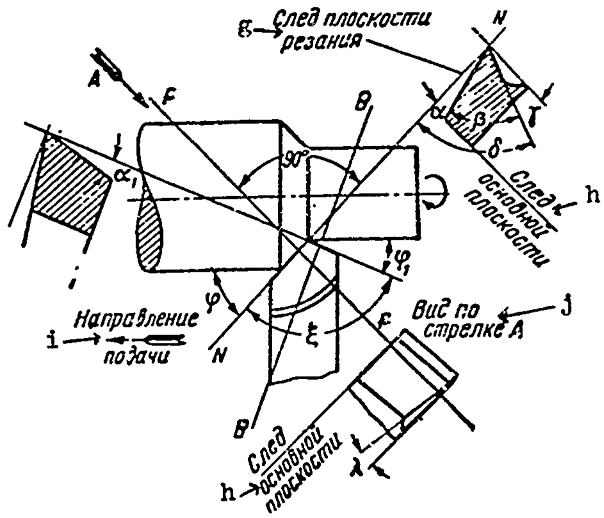


Fig. 50. Cutting angles

Key:
- NN. track of the cutting plane
- FF. base secant plane
- BB. auxiliary secant plane
- ϕ. main angle in the plan
- ϕ_1. auxiliary angle in the plan
- ξ. angle on the cutter top
- α. rear angle
- γ. front angle
- δ. cutting angle
- β. angle of point
- κ. angle of incidence of the main cutting edge
- α_1. auxiliary rear angle
- g. cutting plane path
- h. base plane path
- i. direction of feed
- j. view along arrow A

The main front angle γ is the angle between the front surface of cutting (12) and a plane perpendicular to the plane of cutting (4) and moving through the main cutting edge (11). If the first of the surfaces is located lower than the second, the main front angle is positive; and if it is higher, that angle is negative; and finally, it is equal to zero if both planes are the same height. The front angle has immediate influence on the process of shaving formation; namely, with an increase in the front angle, or with its positive value, the cutter can more easily cut into the metal, easing run off of the shavings along its front surface and decreasing both friction of the shavings along the front surface and plastic deformation of the shavings. As a result of decreasing cutting effort, the cutting process also goes along more favorably. With a large front angle, however, the angle of point β decreases and the cutting blade becomes insufficiently steady. Therefore, during machining hard and strong materials (special steels and gray pig iron), when the cutter experiences large cutting effort, and also during machining uneven forging surfaces, the angle γ should be decreased, and in some cases it should be given a negative value ($-\gamma$). During machining of soft materials, the front angle should be made as large as possible ($+\gamma$).

In practice the main front angle γ is maintained within the limits of -5 to $+25^{\circ}$, and for cutting with hard steel blades, due to their brittleness, it must be smaller than for cutting with fast-cutting steels.

The main rear angle α is the angle between the back cutting surface and the plane of cutting. With an increase in this angle, friction between the cutter and the cutting surface and along the machine surface decreases, and as a result of this, its wear decreases. With an excessively large increase in the rear angle, however, the angle of point β decreases, and this leads to weakening of the stability of the cutting blade. Besides this, the size of the rear angle depends on the amount of feed; namely, with an increase in feed, the rear angle decreases. In practice, the rear angle is maintained within the limits of 6 to 12°.

The auxiliary rear angle α_1 is the angle between the auxiliary rear surface (9) and the plane, passing through the auxiliary cutting edge (10), perpendicular to the base plane (5).

The auxiliary angle α_1 is usually equal in size to the main rear angle α, with the exception of special cutters; for instance, extracting cutters and cutters for grooving bores, for which angle $_1$ = 2 to 3°.

The point angle β is the angle between the front (12) and back (8) surfaces of the cutter. This angle is tied to the angles α and γ with the relationship $\beta + 90^{\circ} - (\alpha + \gamma)$.

The angle of cut δ is the angle between the front surface of a cutter (12) and the plane of cutting (4). This angle is tied with the main front angle by the relationship $\delta = 90^{\circ} - \gamma$.

The angle of incidence of the main cutting edge λ is the angle between the main cutting edge (11) and a plane passing through the cutter top, parallel to the base plane (5). This angle has influence on the form and direction of fall of the shavings, and besides this, the stability of the cutter top depends on it. Angle λ is considered positive if the cutter top is the lowest top of its main cutting edge (11) and negative if the cutter top is the highest point of the cutting edge. Cutters with a positive angle λ are more steady and strong than cutters having negative angles λ. In practice the size of angle λ is maintained within the limits from -5 to $+10^{\circ}$.

The main angle in the plan ϕ is the angle between the bisection of the main cutting edge (11) on the basic plane (5) and the direction of feed. With a decrease of angle ϕ, thickness of shavings α decreases, and width of them b increases so that the cutter top becomes more stable, and heat built up in the process of cutting is distributed on a large length of the cutting edge (See Fig. 48). All this improves heat dissipation and increases stability of the cutter. Together with this, with an unchanged cutting depth and feed and a decrease in angle ϕ, the radial composite cutting force increases, which presses the cutter away from the cutting surface, and with an insufficient system stability, the head, cutter, and machine begin to vibrate, which destroys the continuity of the cutting process. For elimination of such vibrations, it is recommended that angle ϕ be maintained within the limits of 55 to 75°, and with normal cutting conditions, the average value of this angle is equal to 40 to 50°.

The auxiliary angle in the plan ϕ_1 is the angle between the projection of the auxiliary cutting edge 10 on the basic plane 5 and the direction of feed. With an increase in this angle, the auxiliary cutting edge is brought closer to the machined surface, the cutter top is steadied, and a smoother machine surface is attained. The size of angle ϕ_1 depends on the type of machine; for instance, for moving coarse machining, the angle $\phi_1 = 12$ to 30° and for cutters used in fine machining, $\phi_1 = 4$ to 12°.

The angle along the cutter top ξ is the angle between the projections of the main 11 and auxiliary 10 cutting edges on the base plane 5. This angle is tied with the main and auxiliary angles in the plan by the relationship $\xi = 180^\circ - (\phi = \phi_1)$. The apex of this angle is rounded off to increase stability of the cutter and smoothness of the machined surface so that for moving cutting in coarse machining, the radius of rounding off r = 1.0 to 1.5 mm, and for fine machining cutters, r = 1.5 to 3.0 mm.

The described angles of moving lathe cutting may also be used for characteristics of other models of cutting tools, with angle size being determined by machining conditions.

The cutting tool is installed relative to the machined stock in such a way that the cutter top lies on the center line of the machine, or on the axis of rotation of the machined stock. If the cutter top is higher than the machine's centers, the main front cutting angle γ is increased, the main rear angle α is decreased, and conditions of cutting are worsened. With installation of the cutter top lower than the machine's centers, the front angle is conversely decreased, the rear angle is increased, and the cutting process is worsened even more significantly. It is acceptable to have the cutter top higher than the machine's centers by a distance of $h \leq 0.1d$ where d is the diameter of the machine surface.

Process of Shaving Formation

Metal cutting is a complex physical process, accompanied by deformation and shaving removal. Three types of deformation are observed in the process of metal cutting: Elastic, plastic, and destruction. The character and scope of deformation depend on the physical and mechanical properties of the treated material, the cutting rate, and the geometry of the cutting tool. Plastic deformation is the most widespread type of deformation in the process of cutting metals (steels).

The essence of plastic metal deformation is the fact that in the process of cutting-through action of the exterior load, its separate grains may change their geometric form, move relative to each other, and, finally, be partially destroyed. As a result of these phenomena the structure of the metal and its physical and mechanical properties are changed.

During cutting of metal, shavings are formed in the following manner. The cutter, under action of force P, cuts into the stock and separates a layer of metal from it (Fig. 51, b). During this action, first elastic and then plastic deformation occurs in the cut-away layer of metal. At the moment when stress in the metal created by the exterior force P exceeds the force of cohesion between the particles of the metal, destruction deformation occurs.

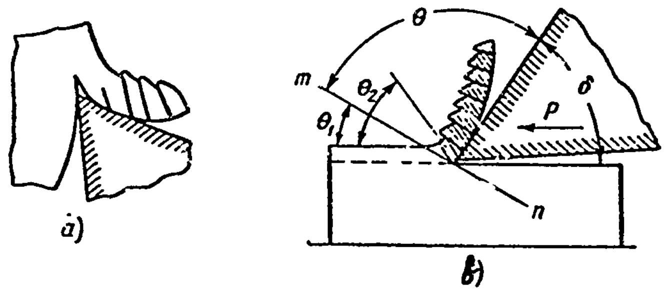


Fig. 51. Schematic of the process of shaving formation during metal cutting

Key: a. plastic deformation of the metal
b. separated metal layer mn--phase of splitting

This is the splitting-off of a separate element of a shaving in the plane mn. Further progress of the cutter leads to the splitting-off of another element, etc. Experience has established that the plane of splitting mn is located at the angle θ_1 relative to the direction of feed or the formed machine surface. The size of angle θ_1, the angle of splitting, depends on the type of material treated and size of the front cutter angle γ. For steels, the angle of splitting θ_1 = 25 to 40°. Plastic deformation of the shaving elements separated brings about displacement of the grains of metal relative to each other and extracts them into planes which are inclined at angle $\theta_2 \approx \theta_1 + 20^\circ$ to the direction of feed.

Plastic deformation during removal of shavings is also accompanied by the following physical phenomena:

-- Shrinkage of shavings
-- Appearance of cracks in front of the cutter and formation of growth on the top of the front surface of the cutter (see Fig. 51, a)
-- Appearance of binding, or strengthening of the cut-away layer of shavings and the surface layer of the machined surface

-- Friction between the shavings and the front surface of the cutter, and between the rear surface of the cutter and the stock

-- Heating of the cutting tool and decreasing of its stability.

In exterior appearance the separated shaving may be flow, shear, and fracture. Flow shavings are formed during cutting of soft and medium-hard metals, which maintain elasticity during various cutting speeds. Such a shaving resembles a smooth, unbroken tape or small separate curls. Shear shavings have a smooth surface on the side lying next to the cutter and a nonsmooth surface with sharply expressed shear elements on the side opposed to the cutter. Such shavings are formed during machining of medium and very hard steels with slow and medium cutting speeds.

Fracture shavings, consisting of separate nonconnected elements, are formed during cutting of metals with little elasticity (hard cast iron, hard bronze).

During turning of exterior surfaces, metal cutting is accomplished by the main cutting edge of the cutter, its point, and partially by its auxiliary cutting edge, which cleans off the flaws formed in the process of cutting. In this case, the conditions of cutting are more favorable and approach conditions of free cutting, which is accomplished with only one main cutting edge.

In drilling and reaming of openings, the process is complicated and takes place in less favorable conditions.

A drill is a more complicated tool than a cutter in that, together with the basic two cutting edges, a cross-section edge (crosspiece) and two band edges participate in cutting. The drill works in more difficult conditions than a cutter because during drilling, exhaust of shavings and application of a cooling and lubricating liquid to the drill to decrease friction between the separated shavings and the drill surface and between the drill and the cutting end, machined surfaces of the stock are made more difficult. Besides this, cutting speeds on the cutting edges of a drill vary, reaching their maximum values at the exterior edges and a value equal to zero at the center of the drill on its axis.

As a result, elements of shaving suffer varying plastic deformation, with the greatest deformation arising in the zone of least drilling speed, namely at the drill crosspiece and at the junction between its basic edge and the band edge. The drill cutting edges also have greater wear in these areas. The most important requirement for a drill is its maintenance of stability throughout the depth of drilling, especially during drilling of deep openings. In this instance, the shavings must have the appearance of separate length coils and be washed away by an intensive stream of the cooling liquid.

To get such small shaving elements, cutting depths are sometimes divided into two or three part by changing the construction of the cutting part of the tool, as shown in Fig. 52. In some instances both the cutting depth and the feed are divided. This is allowed by specially constructed cutting tools.

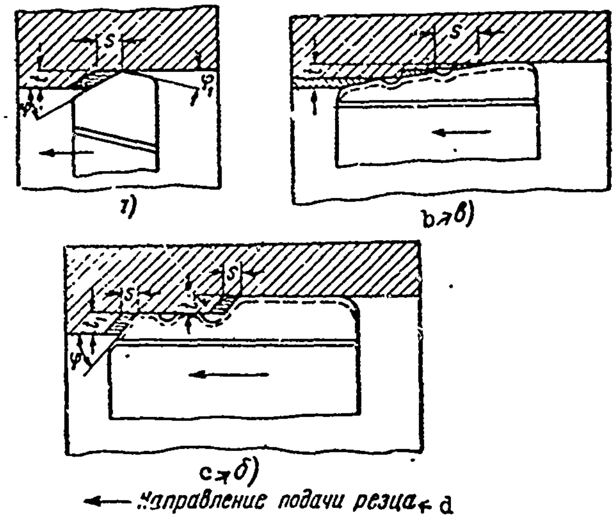


Fig. 52. Schematic of a cutting process during reaming of an opening with division of cutting depth t into several layers

Key:
a. cutting to constant depth
b. cutting with division of depth into three layers (smooth-blade reaming)
c. cutting with division of depth into two layers t_2 and t_3 [sic.]
d. direction of cutter feed.

The described peculiarities of the metal cutting process are characteristic not only for lathe machining and drilling of stock, but also for reaming of openings. The cutting process and geometry of the cutting tool will be reviewed in greater detail during drilling and reaming of deep openings in Chapters VI and VII.

Forces Arising in the Process of Cutting

The total equivalent force, acting on the cutter from the side of the machine's stock, is called the force of resistance to cutting. During length turning, the cutting resistance force may be divided into the following components: Cutting force P_z, directed tangentially to the cutting surface in the direction of measure movement; radial force P_y, directed along the radius; and axial force P_x, or force of feed, acting parallel to the axis of the machined part in a direction opposite to the direction of feed (Figs. 48 and 53).

The force of cutting resistance is determined according to the formula

$$P = \sqrt{P_z^2 + P_y^2 + P_x^2}\,. \qquad (22)$$

The composite forces of cutting are determined with the help of experimental formulae attained on the basis of many experiments, or experientially on the machine. The force of cutting P_z for exterior cutting can be approximately determined according to the following formula:

$$P_z = c_p t^{x_p} s^{y_p} k_p, \qquad (23)$$

where c_p = coefficient calculating the mechanical properties of the stock material;
t = depth of cutting in mm;
s = feed in mm/rev;
x_p, y_p = exponent (usually x_p = 0.95 - 1.0 and y_p = 0.7 - 0.8); and
k_p = correction factor calculating the conditions for cutting.

For steel (σ_b = 75 mg/mm^2), the coefficient calculating mechanical properties of the material, c_p = 215 to 225.

The values of the other coefficients and exponents going into formula (23) for various cutting conditions are taken as standards according to the cutting rates.

On the basis of experience, the amounts of cutting resistance forces can be approximately expressed for normal conditions of the cutting process by the following relationship:

$$P_z : P_y : P_x = 1.0 : 0.25 : 0.4.$$

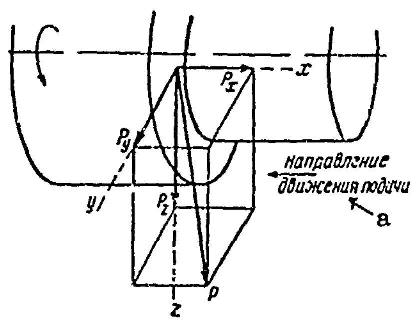


Fig. 53. Schematic of Forces Arising in the Cutting Process During Turning

Key: a. direction of feed

Cutting force P_z, the largest component cutting resistance force, has fundamental influence on the major movement mechanisms on the machine and determines the power N_{cut} which is required for cutting according to the formula

$$N_{cut} = \frac{P_z v}{60 \cdot 102} \text{ kW}, \qquad (24)$$

where v = cutting speed.

Knowing the amount of cutting force P_z, it is possible to also determine the required power of the electric motor for the machine N_M, using the formula

$$N_M = \frac{P_z v}{60 \cdot 102 \eta}, \qquad (25)$$

here η = coefficient of efficiency of the machine drive (usually η = 0.7 to 0.8).

Cutting Speed

Cutting speed during parts machining is one of the most characteristics of the cutting rate, and determines the productivity of the machining process. Selection of cutting speed depends on a number of factors of which the basic ones are the mechanical properties of the machined material and the material of the cutting part of the cutter, the durability of the cutting tool, the am amount of feed and depth of cut, the geometric form of the cutter, the conditions of cooling, and the type of machining (turning, drilling, milling, etc.).

For cutters made of fast-cutting steel, the allowable cutting speed for lengthing turning may be determined according to the following formula:

$$v = \frac{c_v}{T^m t^{x_v} s^{y_v}} k_v \text{ m/min}, \qquad (26)$$

where c = c efficient calculating the mechanical properties of the machined stock of material and conditions of machining;
T = endurance of the cutter in min;
t = depth of cut in mm;
s = feed in mm;
m, x_v, y_v = exponents;
k_v = overall correcting coefficient, determined by the expression $k_v = k_{M_v} k_{M_v} k_{\phi_v} k_{o_v}$.

Here k_{M_v} = coefficient calculating the changes in the mechanical properties of the machine stock material;
k_{M_v} = coefficient calculating the mechanical properties of the material of the cutting part of the tool;
$k_{\phi v}$ = coefficient calculating the major angle in the plan ϕ; and
k_{σ_v} = coefficient calculating the cooling intensity.

During machining of steels of fast-cooling intensity, m = 0.125, and with cutters of hard alloys, m = 0.18 to 0.25. From formula (26), it follows that, with an increase in cutting speed v, durability of the cutter T decreases.

Giving cutter durability a set value, for instance T = 60 min, and accepting the other factors as constant values, formula (26) may be simplified and written in the following form:

$$v = \frac{c}{t^{x_v} s^{y_v}} \text{ m/min.} \qquad (27)$$

The values of c_v, x_v, and y_v in the formula (27) during turning of exterior surfaces of stocks made of carbon construction steels (σ_b = 75 kg/mm^2) are shown in Table 19.

Cutting speed during machining of chrome-nickel and chrome-nickel-molybdenum steels should be decreased by the coefficient of machinability, equal to 0.85 to 0.8. During reaming and drilling of deep openings, the process will stretch into more difficult conditions and the correcting coefficient will be equal to 0.8. For machining of steels with cutters having hard alloy blades, cutting speeds should be increased, using data according to standards of cutting rates.

TABLE 19

Values for c_v, x_v, and y_v in Formula (27) During Turning of Carbon Steel Stocks (σ_b = 75 kg/mm^2)

b → Условия охлаждения	a → Величина подачи s мм/об	c_v	x_v	y_v
c → Без охлаждения	< 0,25	30,5	0,25	0,50
	> 0,25	24,5	0,25	0,66
d → С охлаждением	< 0,25	50	0,25	0,33
	> 0,25	32	0,25	0,66

Key:
- a. amount of feed s mm/rev
- b. cooling conditions
- c. without cooling
- d. with cooling

Cooling

In the cutting process, the a large amount of heat is generated, under whose action the cutting tool heats up and loses its hardness. Heat is generated as a result of plastic deformation of the layer cut away, friction of shavings and the front surface of the cutter, and friction between the rear surface of the cutter and the surface of the stock. With the correct choice of cutting rate, close to 73% of the generated heat leaves with the shavings, about 20% is absorbed by the cutter, approximately 5% goes to heating the machined part, and up to 2% is radiated into the surrounding medium.

Cooling liquids are used to assure the intensive exhaust of heat from the cutting edges of the cutter, to decrease friction between the shaving, the machined part, and the surface of the cutter, and therefore create normal condition for extension of the cutting process. The cooling liquid, forming a thin film on the surface of the metal, decreases friction between the front surface of the cutter and the falling shavings, as well as between the cutter and the machined part. At the same time, the liquid, penetrating into the micropores of the sheared layer, eases separation of the shaving elements in the cutting process. In this way, the lubricating and cooling liquid decreases metal cutting resistance, decreases cutter wear, increases its durability, assures attainment of a more smooth surface after machining, and makes possible an increase in cutting speed. Sulfofrezols and emulsions are the best cooling and lubricating liquids.

Materials Used for Manufacture of Cutting Tools

Cutting tools are manufactured from the following materials:

- Carbon tool steels;
- alloy tool steels;
- fast-cutting steels;
- hard alloys;
- mineral-ceramic materials.

These materials have the following characteristics:

Carbon tool steel contains carbon in the quantity of 0.7 to 1.4%. The types of this steel: U8, U9, U10, and U12 are of usual composition, and U8A, U9A, U10A, and U12A are of high quality with a composition of sulfur and phosphorus no greater than 0.03%. Carbon tool steels have little heat durability an in temperatures of 200 to 250° C partially lose their hardness. For this reason they can only be used for cutting tools which work at slow cutting speeds.

Types of alloy tool steels are: 9KhS, 9KhGS, KhV5, KhG, and KhVG. These steels have a higher resistance to wear and heat durability (300 to 400° C), which allows an increase in cutting rate with their use by comparison with rates for cutters of carbon steel. Types KhG and KhVG are used for cutting tools, during which heat treatment there might be deformations, decreasing the quality of the tool (stretches, elongations, etc.).

Fast-cutting steel has an increased composition of alloy elements (tungsten 9 to 18%, chromium 3 to 5%, vanadium up to 1.5 to 2.5%), due to which it maintains it cutting properties in temperatures up to 550 to 600° C. This makes possible a cutting speed two to three times larger than the cutting speed allowed for carbon steels. The basic types of fast-cutting steels, R-18 (RF1) and R-9 (EI-262), have a smaller composition of scarcer tungsten (8 to 10%).

Hard steels are widely used in cutters in the form of blades, formation of cutting edges, and working surfaces. They are obtained by means of sintering the powder, consisting of a carbide of tungsten and cobalt. To get such blades, the carbide of tungsten is first formed by mixing the tungsten powder with coal and roasting it in an electric oven at a temperature of 1500° C in an atmosphere of hydrogen. A tungsten carbide powder is then mixed with cobalt, and special blades are pressed out of the mixture in forms. The blades are later sintered in electric ovens at temperatures of 1100 to 1400° C. During sintering of the blades, the easily melted cobalt cements (bonds) the grain of the carbide into a strong alloy.

Modern hard alloys may be divided into two groups: The group of tungsten (VK), and a group of titano-tungsten (TK) alloys with a decreased composition of tungsten carbide. Both of these groups of alloys have a high resistance to wear and maintain their cutting properties at 850 to 1000° C. Besides this, the titano-tungsten alloys have a lesser tendency to fuse with the shavings and form holes on the front surface of the cutter. The basic types of these alloys are: VK3, VK6, VK8, VK10, with a cobalt composition of from 3 to 10%, T5K10, T15K6, and T30K4, with a composition of titanium carbide of from 5 to 30% and of cobalt from 10 to 4%. None of these alloys are sufficiently flexible and may chip off under high loads, especially those of changing size, for instance during coarse peeling operations while machining forgings and steel castings. Therefore, for strengthening the cutting blade made of hard alloys, the main front angle γ of the cutter must be equal to zero or must be negative. In some cases, the hard alloy blade is fastened in the holder in a way so that the main front angle of the cutter is negative.

Alloys VK8 and T5K10 are stronger and more flexible, and are used more often than any for cutters during coarse machining.

Mineral-ceramic materials are used for cutting tools in the form of blades, manufactured by pressing and special heat treatment out of clay (Al_2O_3) and thermo-corundum. These materials are available and inexpensive.

At the present time, mineral-ceramic blades are widely used for various cutting tools. These blades have a higher degree of hardness and heat durability ($\sim$ 1200° C), than blades of hard alloys, and are therefore used for machining metals (steels) with high cutting rates ($v \geq 500$ m/min). Mineral-ceramic blades, however, are not flexible. They are brittle and weak to bending and compression, which limits their use to only semifine and fine operations. In recent times, mineral-ceramic blades have been manufactured with increased flexibility and strength under bending, which affords the possibility of their use in coarse peeling operations also.

CHAPTER VI

Drilling of Deep Openings

Drilling is one of the most widely used technological processes to obtain cylindrical openings in solid stocks. This process is realized with two combined movements:

a) A rotating motion of the drill or stock (main motion), and

b) a continuous movement of the drill through the longitudinal axis of the stock (movement of feed).

If the depth of the hole drilled does not exceed five diameters of the drill ($L \leq 5d$), then normal spiral drills, corresponding to the standards in All-Union State Standard 2894-45, All-Union State Standard 885-41, and All-Union State Standard 888-41, are used to drill the openings.

Deep openings are considered those whose depth exceeds five diameters of the drill ($L > 5d$). In actual reproduction, depth of the hole drilled in the stock usually exceeds ten drill diameters and often reaches 60 to 80 diameters.

For drilling deep holes, special drills and attachments (shafts) on which they are fastened, are required. Depending on their construction and method of drilling, cutting tools for drilling deep holes can be divided into the following three groups:

Drills for solid drilling;
drills for expansion of holes; and
heads for ring drilling.

Drilling deep holes is a labor-consuming and lengthy technological operation. During the drilling of deep holes, a drill can deviate from its intended direction, or wander, when the axis of the drill opening is colocated relative to the axis of the stock. The amount of drill deviation α depends on the following factors: The diameter of the hole d, depth of the hole L, construction of the drill and the geometry of its cutting part, the mechanical properties of the machined stock material, the cutting rate, and the method of drilling (Fig. 54).

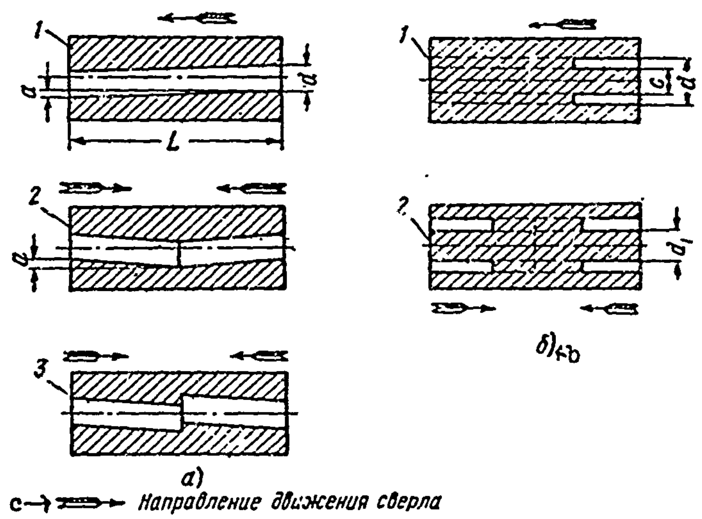


Fig. 54. Schematic of deep-hole drilling methods

Key:
- a. solid drilling
- b. ring drilling
- c. direction of drill movement
- 1. one-sided drilling
- 2 & 3. two-sided drilling

For elimination of defects caused by drill deviation, in the last operations after drilling, sufficient margin must remain on the wall thickness of the tube and on the length of the stock. The amount of labor and the time length of successive machining operations largely depend on the quality of performance of the deep hole drilling operation.

#17. Methods of Drilling

Depending on construction of the cutting tool, deep hole drilling may be conducted with one of the following methods:

1) Solid drilling with an exterior or interior shaving exhaust (see Fig. 54, a) and
2) ring drilling (see Fig. 54, b).

In solid drilling, all the metal filling the hole drilled in the stock is converted into shavings, and in ring drilling the heart of hole drilled in the stock remains whole and a solid core of diameter c is removed.

Solid drilling is used for holes of diameter from 5 to 80 mm, with holes of 60 to 80 mm being expediently drilled in two operations, first drilling to a diameter of 50 to 55 mm, and then expanding the hole to the required dimension.

Solid drilling may be one sided (see Fig. 54, a, position 1), when drilling takes place from only one face of the stock in one direction throughout its length, or two sided (see Fig. 54, b, positions 2 and 3), when drilling is simultaneously done from two faces of the stock. During two-sided drilling, one of the drills is turned off somewhat earlier than the other, at an approximate distance of 2 to 3 diameters from the plane of their possible collision.

Ring drilling, as a rule, is used for drilling openings of diameters greater than 100 mm and only in some instances for diameters 80 to 90 mm. With hole diameters 80 to 90 mm, however, great difficulties arise in the construction of the cutting tool head and in the exhaust of shavings from the hole, and the exterior diameter of the solid core received is rot greater than 40 mm. The hole and ring drilling at the beginning looks like a ring groove, which also served as the basis for the naming of the process. In drilling holes of diameter greater than 100 mm, the diameter of the solid core is equal to (0.5 to 0.75)d. Ring drilling also may be one sided or two sided (see Fig. 54, b, positions 1 and 2).

Solid drilling is more widely used in production than ring drilling, in that up to 65% of all stocks prepared for heat treatment have a hole diameter of up to 100 mm, or are tubes whose bores can initially be drilled only with solid drilling. The final dimension of the inner diameter of such tubes receives smooth reaming and does not exceed 115 mm.

When drilling deep holes of diameter greater than 100 mm, and especially of diameters greater than 150 mm, or for drilling holes in tubes of large dimensions, it is economically more profitable to use ring drilling because in this case it is possible to use a manifold cutting tool for elevation of productivity of labor; there will be less deviation of the instrument in the process of drilling, and consequently, the amount of margin and time on the consequent machining of the stock can be decreased; then the heart of the stock is not converted into shavings, but comes out a solid core.

In one-sided drilling, both solid and ring, deviation of the cutting tool α is greater in size than with two-sided drilling. In two-sided drilling, however, as a result of deviation of the drill or the cutting head of the cutting tool, steps are formed (see Fig. 54, a, position 3) in the metal which during heat treatment of the stock cause large inner stresses, and there may be cracking. For this reason, tubes with steps should be drilled or reamed out after drilling. Two-sided drilling is most often used for ring drilling; and the deviation of the cutting tool head is smaller in this case, and consequently, the steps are smaller.

The following types of stock and tool movement are possible during solid and ring drilling of deep openings:

1. The machine stock rotates in one direction, and the cutting tool accomplishes only the movement of feed, with the straight progressive movement in the direction of its axis. This type of drilling is the most widely used.

2. The stock and the cutting tool both rotate, but in opposite directions, and besides this, the tool, rotating, accomplishes a linear progressive movement in its axial direction. These types of movement of a stock and tool are used principally for drilling of cores of small diameters from 6 to 20 mm, with a stock length of up to 1500 mm, and in some instances for stocks of large dimensions.

3. The stock remains stationary, and the cutting tool accomplishes two movements: Rotation and linear progrogression in the axis of its direction. This type of drilling is used comparatively rarely for large stocks.

#18. Drill Shaft. Methods of Supplying Cooling Liquid to the Cutting Edges of the Drill and Exhausting Shavings from it

The drill shaft is an attachment for fastening the drill and directing it during drilling. It is a steel tube, on one end of which is fastened the drill. The other end of the tube is fastened to the driving support of the machine. The drill shaft must be sufficiently strong, straight, and not bend under the action of drilling effort. Its design must provide supply of a cooling liquid to the cutting edges of the drill and exhaust of shavings under the stream of pressure of this liquid during drilling of openings (Fig. 55). The shaft is manufactured of medium-hard steel and its exterior surface and the surfaces where the drill is fastened and centered in it to length ℓ are machined to high precision, as is seen in Fig. 55, position 6. The interior hole in the shaft, through which the cooling liquid is conducted to the cutting edges of the drill or shavings are exhausted from them by the pressure stream of this liquid, is machined to fifth class precision. A section of the shaft of length ℓ_1 serves to direct and center the drill. Fastening of the drill to the shaft is accomplished with a two- or three-course band thread which provides convenient and swift installation, fastening, and unscrewing of the drill. The length ℓ of the shaft section, in which the drill is centered and fastened, is usually equal to (1.4 to 1.8)d, where d is the diameter of the hole. The design of the end of the shaft, where it is fastened to the machine support, depends on the method of this fastening.

The shape of shaft section is determined by conditions of the supply of cooling liquid to the cutting edges of the drill and exhaust of shavings and liquid from them. For shaft sections forms 1, 2, and 3, the area of the opening, through which the cooling liquid is conducted, is approximately equal to 10 to 15% of the area of the hole drilled, and for the section form 4, it is close to 25 to 30% (see Fig. 55). The area of the opening which exhausts shavings and the cooling liquid for all shaft section shapes in Fig. 55 usually comprises 26 to 32% of the area of the drilled hole, and the live section of the shaft comprises 40 to 50% of this area. Exhaust of shavings through an inner canal in the drill and shaft is possible only with drilling of a hole whose diameter is greater than 30 mm (see Fig. 55, position 4).

For ring drilling, only hollow shafts of circular section are used, and shavings are exhausted along the exterior.

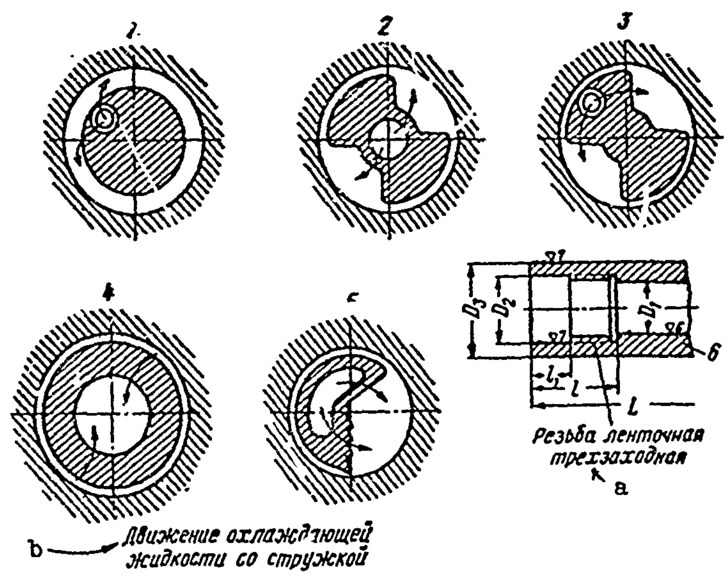


Fig. 55. Drill shaft section shapes

Key:
- a. three-course band thread
- b. movement of the cooling liquid with shavings
- 1, 2, 3, 4, and 5. shaft sections
- 6. shaft end, on which drill is fastened

#19. The Cutting Tool for Solid Drilling

The cutting process for deep hole drilling, by comparison with the cutting process for turning, has the following peculiarities:

The conditions of formation and exhaust of shavings from the front surface of the drill, as well as their future exhaust from the hole, is significantly more complex than with turning;

The supplying of cooling and lubricating liquid to the cutting edges of the drill is made more difficult. Besides its primary functions, the cooling and lubricating liquid is used to carry away (wash away) shavings from the hole; therefore its intensive supply to the cutting edges of the drill under pressure greater than that for turning is required;

Cutting speed on the cutting edges is varied and depends on their removal from the center of the drill. As a result of this, the character of plastic deformation of shavings is changed and the process of their formation is complicated;

Durability of the cutting edges of the drill must reliably provide drilling of the hole to an established depth in that any stoppage in the drilling process to exchange a new drill for a worn-out one is highly undesirable;

During cooling the drill must strictly maintain its assigned direction of movement.

Together with this, the drilling process also has several phenomena in common with the turning process. For instance, during cooling of plastic metals (steels), a flow of shavings is formed, just as in turning, and shaving shrinkage, binding and heat generation are observed.

These peculiarities of the deep-hole drilling process must be considered during planning of cutting tools and assignment of cutting rates. Standard type spiral drills, widely used in general machine construction, are not efficient for drilling deep holes (more than five diameters) because the shavings in them are not carried away and bind on the spiral grooves, which makes the cutting process more difficult. It is therefore necessary to extract the drill from the hole and clean the shavings from it after every 4 to 5 mm of depth.

The following types of cutting tools are used for deep-hole solid drilling:

1) Single and composite pointed drills;
2) one-sided cutting drills with interior or exterior shaving exhaust;
3) special drills with several cutting edges (two-sided cutting);
4) special spiral drills with interior shaving exhaust;
5) one-sided cutting drills for expansion of holes.

Drills are manufactured of carbon tool steels or fast-cutting steels. The drill edges are often blades made of hard alloys.

We will briefly review the design and areas of use of each of the types of cutting tools introduced.

The Pointed Drill

The pointed drill, introduced in Fig. 56, is made up of the front and tail sections, which are welded together. The front portion of the drill, the working cutting part of length ℓ_1, is manufactured of fast-cutting steel R9, and the tail part of length ℓ_2 is manufactured of carbon steel. The drill has two cutting edges K located at an angle 2ϕ to its axis and two auxiliary edges of length $\ell_4 = 0.4d$ to smooth the surface and direct the drill. Experience has established that the size of the angle 2ϕ must be within the limits of 90 to 140°, the lower limit for drilling soft materials and the upper limit for drilling hard and high-strength steels. The cutting edges K have grooves for crushing shavings and improving their exhaust. The auxiliary edges on length ℓ_4 are pointed so that their dimension on the diameter is equal to the diameter of the opening d. The working part of the drill has a back taper up to 0.15 to 0.25 mm on the diameter. The rear angle of cutting and auxiliary edges is usually equal to 8 to 10°, and the front angle is most often zero. The drill (1) is fastened to the shaft (2) by its tail. The shaft and drill have longitudinal canals through which the cooling liquid is conducted (the direction of liquid movement is shown by arrow A), and the drill, in addition, has two passages inclined at an angle of 40° to its axis for directing the fluid to the cutting edges. Pointed drills of this design are used for drilling holes 12 to 30 mm in diameter. In practice, drilling with pointed drills is used comparatively rarely because of its low productivity.

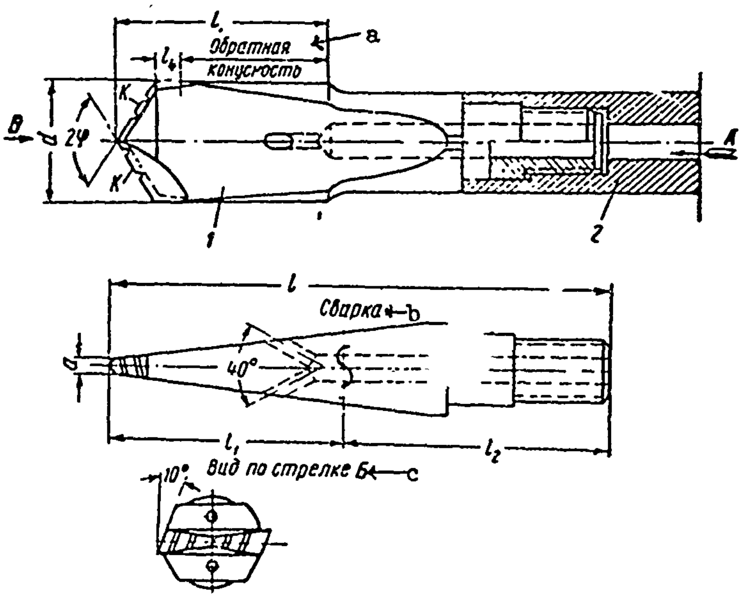


Fig. 56. Pointed drill

Key:
- a. rear taper
- b. welding
- c. view along arrow B
- 1. drill
- 2. shaft

The Plyusin Point Drill

The pointed Plyusin drill is an assembly and consists of the point (1), drill body (2), aligning keys (3), and fastening screw (4)(Fig. 57).

The drill point (1), manufactured of blades of R18 fast-cutting steel, has two cutting edges K located at an angle of 130° and two auxiliary blades, pointed along the dimension of the hole diameter d. The point is fitted in a slot in the body (2) and fastened in it by screw (4). The drill head body (2) has four aligning keys (3). The drill is connected to the shaft (5) by its tail on which there is a smooth portion for centering the drill in the shaft and three-course band thread for fastening it. The cooling liquid flows through the inner canal in the shaft and the drill body to its cutting edges, the blades, and is discharged together with shavings along the exterior grooves between the keys of the drill head body. The drill can successfully be used for drilling deep holes 25 to 80 mm in diameter, and maintains a sufficiently accurate direction during drilling.

During hole drilling in stock steels (σ_b = 65 to 76 kg/mm^2), a cutting speed of 16 to 20 m/min and a feed of 0.15 mm/rev are allowable.

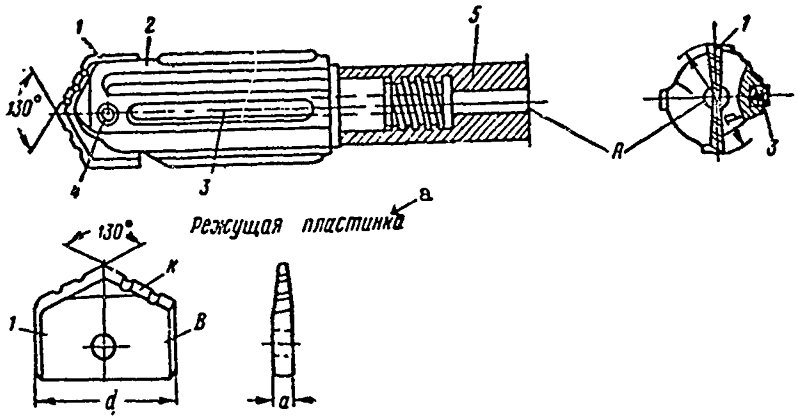


Fig. 57. Drill with Plyusin point

Key: a. cutting blade

Point with Extended Guide Blades

This point, a blade of R9 fast-cutting steel, has two main cutting edges K with a usual point and two auxiliary edges 1.5 times as long as the usual, or length ℓ = (1.4 to 1.5)d (Fig. 58). The tail section of the point is shaped like a fork, which eases its installation and fastening. The tail portion of the point is fastened to the head body or shaft with four screws. The cooling liquid is conducted to the cutting edges along two passages, and are exhausted with shavings through an internal canal in the shaft, as shown by arrows A in Fig. 58.

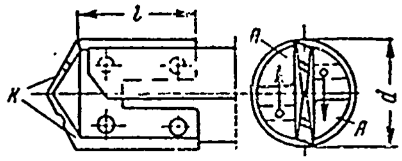


Fig. 58. Point with extended auxiliary guide blades

Key: K. major cutting edges

Points with extended guides allow drilling of holes in stock steels (σ_b = 75 kg/mm^2) with a cutting speed up to 14 m/min and a feed of 0.2 mm/rev. Such points have limited use in production.

The Geometry of Blade Points

Blades, although more rare than other types of drills, are used for drilling deep holes. They are advantageously manufactured of types R18 or R9 fast-cutting steels. The majority of blades have a length ℓ = (1.2 to 1.6)d and a thickness of a = (0.12 to 0.15)d (Fig. 59). For accurate fitting of the blades in the slots in the head body, they are ground so that the clearance between the blade and the slot walls is no greater than 0.05 mm. The blade has two cutting edges and two guiding calibrated edges (flats). The cutting edges of the blade are sharpened at an angle 120° to each other and must be strictly

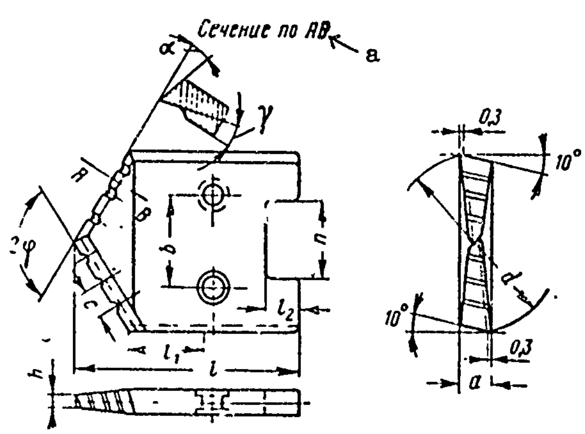


Fig. 59. Geometric parameters of the blades

Key: a. section across AB

symmetrical. The main front edge of the blade $\gamma = 10$ to 12^o, and its rear angle $a = 8$ to 10^o. During drilling of materials with high strength and hardness, angle 2ϕ, determined by the relationship of the main cutting edges, is usually equal to 130 to 135^o.

For breaking up shavings and providing the best conditions of their removal (cleaning out) from the hole, several gutters (shaving breakers) of width and depth 0.6 mm are milled from the cutting edges of the blades. The distance between the gutters c = 4 to 6 mm. The gutters are located nonsymmetrically on the edges. Flats (bands) of width 0.2 to 0.3 mm are formed on the auxiliary (guiding) edges of the blade. On length $\ell_1 = (0.3$ to $0.4)d$, the flat is sharpened to the dimension of the diameter of the hole d, and the remaining part of the blade has a reverse cone so that its diameter is 0.1 to 0.15 mm smaller than the diameter of the hole d. After annealing and tempering, the blade must have a hardness $R_c = 61$ to 64. The height of the fork step ℓ_2 and width n of the fork slot are the designed dimensions.

These geometric parameters of the blade were established in practice and are recommended for drill planning. In some special drills these data should be made more precise to be applicable to the actual conditions of their work.

The Spoon

The spoon as a tool for drilling holes has been used in production for a long time. In technical documentation relating to production of the nineteenth century, a description is encountered of a tool for drilling bores, which is reminiscent of a spoon. The naming of the spoon tool is apparently purely one of production, and apparently also appeared in the last century. This tool was widely used until 1940, and only recently has become rarely used.

The spoon consists of a shaft (4) with a beveled slot into which the cutter (2) is fastened with bolt (3) (Fig. 60). A cooling liquid is supplied to the cutter along pipe (5), which lies in a longitudinal slot on the exterior surface of the shaft, and is carried away along with the shavings along its external bevel. During drilling, the shavings often clump together, and they are then removed manually with a long metal hook. The keys (6) guide the spoon shaft and assure the steady position of the tool during the cutting process.

The cutter is a blade with one cutting edge p whose length is somewhat larger than the radius of the hole (see Fig. 60). The width of the cutter blade, c = 20 to 30 mm, must correspond to the dimension of the shaft passage, of width r = 5 to 8 mm and step b = 2 to 3 mm. The radius of curvature on the top r = 1.5 to 2.5 mm, and the hole length is a designed dimension. The spoon is used for drilling holes of diameter d = 40 to 100 mm with a cutting speed of 12 to 18 m/min and a feed of 0.1 to 0.25 mm/rev.

Fig. 61 shows a spoon of modified construction, known in production as the "GG drill." The cutter (8) of this drill is not fastened, as is the spoon,

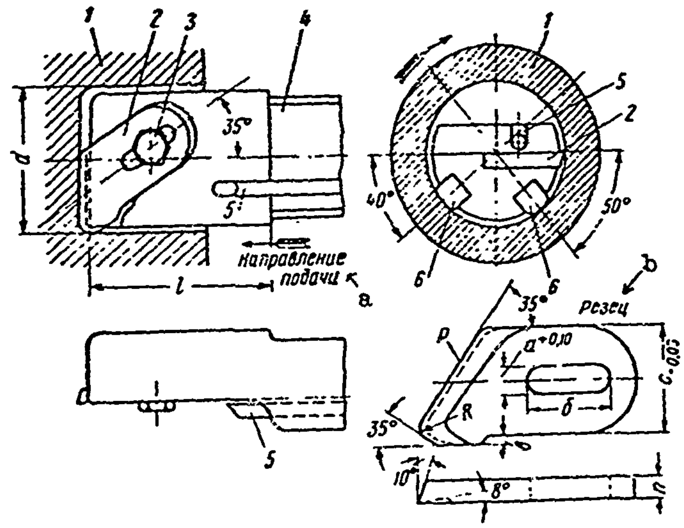


Fig. 60. One-sided drilling -- "spoon"

Key:
1. machined stock
2. cutting blade
3. blade fastening bolt
4. shaft
5. pipe for cooling feed
6. key
a. direction of feed
b. cutter
p. main cutting edge of the cutter

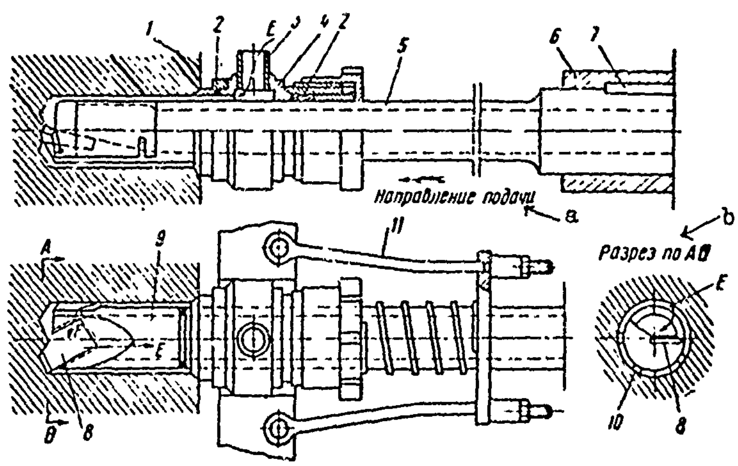


Fig. 61. Schematic of spoon drilling (GG small drill)

Key: See the following page

Key:
1. machined stock
2. gland
3. pipe for cooling liquid supply
4. cooling liquid supply sleeve
5. shaft
6 and 7. shaft fastening sleeve and key
8. cutter
9. shaft head (spoon)
10. drill guiding keys
11. sleeve tensioner
a. direction of feed
b. cutting across AB
E. arrows for direction of cooling liquid flow

and has an angle at its top. Besides this, it has two cutting edges and is set at an angle which composes its front angle. For more accurate cutter direction and stability during drilling, three metal guiding keys (10) are used. The drill shaft (5) is fastened to the machine support with a sleeve (6) and key (7).

The cooling liquid arrives at the cutting edges under pressure through pipe (3) and further along the circular clearance between the exterior surface of the shaft and the interior surface of the hole, and is carried away together with shavings along the internal canal of the shaft, as shown by arrows EF. To prevent leakage of the cooling liquid to the outside, a special attachment consisting of a sleeve (4) and tensioner (11) with connections, springs, and a gland, is mounted on the shaft. During drilling, the attachment slides along the exterior surface of the shaft while pressing against the face of the tube (1). The attachment is complicated in design and requires special installation for use. During drilling small holes, diameters less than 60 mm, the attachment does not always assure the exhaust of shavings. The spoon of new construction allows drilling of holes with a cutting speed of 14 to 18 m/min and feed of 0.16 to 0.20 mm/rev, but it has not received wide usage in production. In design and cutting process characteristics, the spoon and "GG drill" should be classified with the group of one-sided cutting tools with interior shaving exhaust.

One-Sided Cutting Drills with Interior Exhaust

One-sided cutting drills are those with a main cutting edge located on only one side of its axis. Such drills are used for deep hole drilling of diameters from 25 to 75 mm.

A one-sided cutting drill with internal shavings exhaust has a cutting part of length ℓ_2, a receiver part of length ℓ_3, and a fastening part of length ℓ_4 (Fig. 62). The cutting part of the drill, of diameter up to 40 mm, is manufactured of fast-cutting steel, and the receiver and fastening parts of the drill are manufactured of carbon tool steel, and both parts are welded

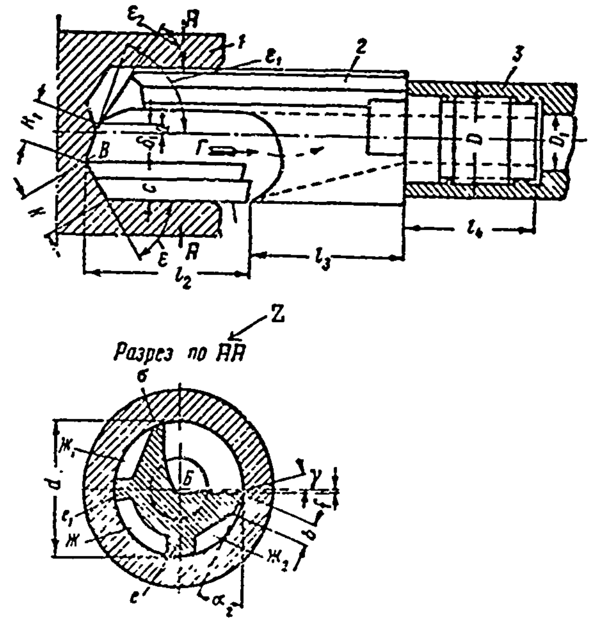


Fig. 62. One-sided cutting drill with internal shaving exhaust

Key: 1. machined stock
2. drill
3. drill shaft
K and K_1. main cutting edges
Z. cut across AA

together. In the cutting parts of drills whose diameter is greater than 35 mm, blades made of fast-cutting steels or hard alloys are most often used. The blade is fastened to the section of length ℓ_1 (see Fig. 64). If blades are used, the body of the drill is manufactured of carbon tool steel. After heat treatment, the blade or cutting part of the drill made of fast-cutting steel, must have a hardness of $R_c = 62$ to 64, and the receiver and fastening parts must have a hardness of $R_c = 35$ to 40.

During drilling, the drill metal deforms and removes a layer of metal, and overcomes the force of friction. The total composite forces of cutting during drilling are: Feed force P_s, directed parallel to the drill axis, vertical force P_z, composing the twisting moment, and radial force P_y (Fig. 63). These forces in the process of cutting arise simultaneously, both on the cutting edges K and K_1 of the drill and on the auxiliary cutting edge f. The radial component P_{y1} will be directed in the opposite direction to the component P_y, and therefore the resulting force in the radial direction will be $N = P_y - P_{y1}$.

The feed force P_s acts on the drill, shaft, and machine. The supporting guiding flat e is necessary to assure a stable drilling position with action of the twisting moment of force P_z.

The radial composite N affects the direction of the drill and makes necessary the guiding support flat e_1. The sizes of forces P_z and P_s may be determined by experience on the machine with the help of instruments.

Determination of the amount of radial composite N, which has great effect on the drilling process, is very difficult.

Formation of two cutting edges K and K_1 has the following purpose:

1) Dividing radial composite cutting forces into two forces P_y and P_{y1} and decreasing the amounts of their equally acting $N = P_y - P_{y1}$. As a result, drill deviation will decrease and the drill will work in more favorable conditions;

2) Decreasing the amount of total axial feed force P_s, which reaches a point where the cutting edge K_1 is continued behind the axial line by amount a and displaced below the center by amount v, and the drill top is displaced from the center to point B. Due to this, the crosspiece and zero cutting speed are absent in this drill;

3) Decreasing the radial and axial composite cutting forces as the result of drill top displacement by amount δ assures the best conditions for work of the drill (see Figs. 62 and 63). During this displacement of the drill top, the shavings formed during cutting are removed, drill deviation from intended direction is decreased, and shaving exhaust is eased.

The size of the angles of the drill's cutting parts should be assigned with consideration for the conditions and time length of the drill's work. According to production experience, the front angle γ for the cutting edges K and K_1 must be equal to zero, which simplifies sharpening of the drill and improves its stability. The rear angle a of the cutting edge K and the same angle a_1 of the cutting edge K_1 must vary in size. In assigning the sizes of these angles, it is necessary to consider that in the cutting process they will be decreased as the cutting edge approaches the drill center and with increases in feed s_o. During the cutting process, each point of the cutting edge of the drill will describe a spiral line whose angle of inclination ω is determined by the condition

$$\mathrm{tg}\,\omega = \frac{s_o}{\pi d_K},$$

where d_K is the diameter of the circumference described by any point of the drill cutting edges K and K_1 in mm; and s_o is the feed in mm/rev.

According to this formula, with $s_o = 0.2$ mm and $d_K = 30$ mm, the angle of inclination of the spiral line $\omega \approx 1^\circ 35'$, and with $d_K = 10$ mm at the same feed, $\omega \approx 4^\circ$. The decrease in rear angles a and a_1 in the cutting process will also correspond to these values of angle ω.

In practice, the rear angle a is in the limits of 7 to 9°, and the rear angle a_1 is within the limits of 12 to 15°. Besides this, the cutting edge K_1

should be lowered relative to the drill center by amount $y = 0.02d$. The rear angle of the auxiliary calibrating edge f is usually equal to 4 to 5°, and the angle a_2 along the surface b of this edge is 12 to 16°.

Angles on the drill top usually have the following values: $\varepsilon = 64°$; $\xi_1 = 72°$; and $\varepsilon_2 \approx 54°$. These angles afford the best supply of cooling liquid and increased ability of the drill during the cutting process (see Figs. 62 and 63).

The cutting edge K_1 must be of such a size that the overall width of the cutting part of the drill satisfies the condition $c + \delta_1 > \frac{d}{2}$. Usually, the size of $a = 0.04d$ and $c > \delta$ ($c \approx 0.28d$ and $\delta \approx 0.22d$) in the drill.

Displacement of the cutting edge of the drill relative to its center by sizes y and a makes possible formation of the zero spindle 4, which precludes zero cutting speed, decreases actual cutting force P_s, and maintains a more stable amount of rear angle a_1 of the cutting edge K_1. In summation, the work of the drill is improved and its deviation is decreased.

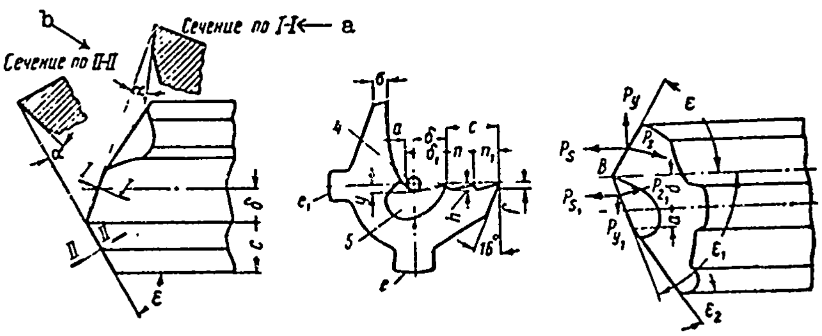


Fig. 63. Geometric parameters of the drill and schematic of forces acting during drilling with a one-sided cutting drill (see Fig. 62)

Key:
4. "zero" spindle
5. smooth section of the rear surface
a. section across I-I
b. section across II-II

The one-sided cutting drill has only one calibrated edge f of which 0.4 to 0.9 mm on the side of the cutting edge K, and a supporting guiding flat e_1 on the side opposite it. The calibrating edge f creates the necessary cleanness of surface and maintains a constant hole diameter throughout its depth. In cleaning the surface during drilling, it does not have to cut into the metal, and therefore does not move the drill away from its assigned direction. This is possible if the radial force satisfies the following conditions:

$$P_y > P_{y1},$$

and if force N, equal to the difference between these radial forces, acts on the support guiding flat e_1. For observation of the previous condition, it is necessary that the inequality

$$c > \delta_1, \ \delta < 0.25d \text{ and } \varepsilon_1 > \varepsilon$$

be fulfilled by the design.

In practice, one-sided cutting drills of diameter from 30 to 75 mm with interior shavings exhaust usually have the following geometric parameters (see Figs. 62 and 63):

width of calibrating edge f	0.4 to 0.9 mm
width of smooth section b	0.15d
angles on top ε and ε_1 respectively	64 to 72°
rear angle a of edge K	7 to 9°
rear angle a_1 of edge K_1	12 to 15°
rear angle a_2 of smooth section b	14 to 16°
width δ of edge K_1 along the radius	0.2d
diameter (position 2) at the zero spindle	(0.04 to 0.03)d
rear conic rate of the drill on sections ℓ_2 and ℓ_3 on the diameter	from 0.15 to 0.25 mm

It should be noted that the rear conic rate for standard spiral drills does not exceed 0.1 mm on the diameter. The significantly larger conic rate in special drills for deep boring decreases friction and heating of the drill, and adherence of the metal particles to the drill surface. All these factors are very important for extended work of the drill during deep hole drilling.

Shavings must be crushed to decrease their size and attain a form which is convenient for later extraction (cleaning) along the exterior canal of the drill and the shaft. The drill must have shaving breakers to crush the shavings. There are from two to four shaving breakers on the cutting edge, having a width n = 3 to 5 mm, depth h = 1 mm, and width of the shaving breakers on the calibrating edge must be somewhat larger than that of the remaining sections of the cutting edge, or $n_1 > n$ (see Fig. 63).

The direction of movement of the drill is assured by the guiding flat: e of width 8 to 12 mm; e_1 of width 6 to 8 mm; and σ of width 2 to 3 mm. The latter, besides this, provides direction for movement of the cooling liquid during its supply to the cutting edges and its exhaust together with shavings (see Figs. 62 and 64). The central angle ϕ of the main extractor of the drill should be kept within the limits of 110 to 115°, and the radius R equal to 0.7d. For drills of diameters 30 to 60 mm, the cooling liquid arrives under a pressure of close to 3 to 8 atm. Opposing streams, turbulent liquid, stagnant areas, and sharp changes in liquid stream areas should be avoided in that they hinder proper shaving exhaust.

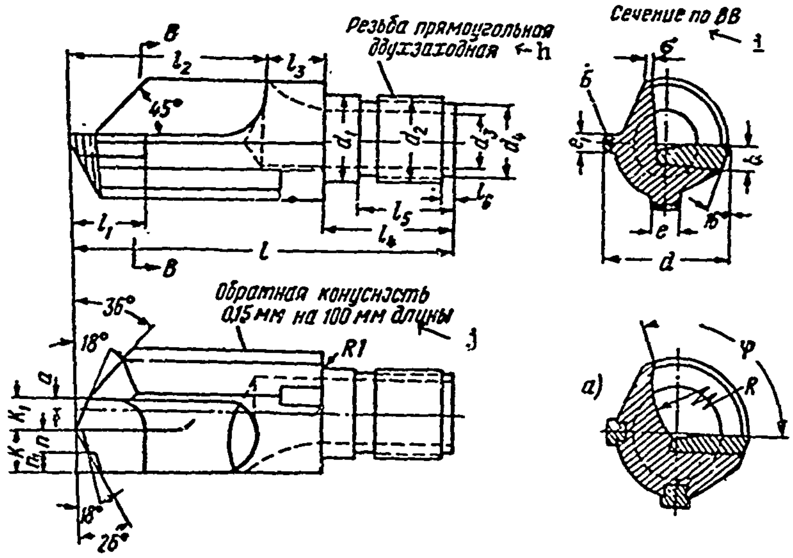


Fig. 64. One-sided cutting drill (scraping) with hard alloy blade

Key:
- a. section across BB (inserted guiding keys)
- h. right angle two-course thread
- i. section across BB
- j. rear conic rate 0.15 mm on 100 mm length

A reasonable liquid supply and proper shaving exhaust create favorable conditions for work of the drill, and therefore determination of the dimensions of the drill and shaft with consideration of these conditions is very important.

The exterior diameter of the shaft is determined from conditions assuring its necessary strength and circular clearance between the shaft and stock for supply of cooling liquid. In practice, the exterior diameter of the shaft is determined from the relationship

$$D = (0.76 \text{ to } 0.85)d,$$

and its internal diameter is determined with consideration for the conditions of normal exhaust of shavings by the relationship

$$D_1 = (0.42 \text{ to } 0.5)d.$$

The internal diameter of the fastening part of the drill d_3 must be 0.3 to 0.5 mm smaller than the internal diameter of the shaft D_1 (see Figs. 62 and 64).

The section area of the internal canals of the drill and shaft must each comprise 26 to 30% of the section area of the hole being drilled, and the live section of the shaft, which assures its required strength and stability, must be equal to 45% of the section area of the hole being drilled.

In the receiver section of the drill, which serves to direct the liquid with shavings during their outflow from the main extractor of the drill into the shaft canal, all surfaces must be smooth, and sharp edges must be rounded. The length of the receiver portion of the drill is

$$\ell_3 = (1.4 \text{ to } 1.0)d.$$

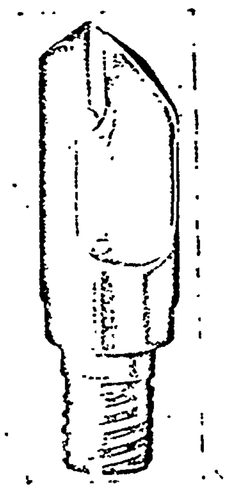


Fig. 65. One-sided cutting drill with interior shaving exhaust

There are two smooth sections of diameter d_1 and d_4 on the exterior surface of the fastening portion of the drill to center the drill relative to the shaft and a two- or three-course band thread to fasten the drill into the shaft. The length of the fastening portion of the drill is usually

$$\ell_4 = (1.3 \text{ to } 0.9)d,$$

and its overall length

$$\ell = (3.8 \text{ to } 2.5)d.$$

One-sided cutting drills with a cutting part (or blades) made of fast-cutting steel may successfully be used to drill steel ($\sigma_b = 75$ kg/mm^2) with a cutting speed of 20 to 30 m/min and feed of 0.14 to 0.20 mm/rev. The construction and overall view of the one-sided cutting drill with blades made of hard alloy is presented in Figs. 64 and 65.

One-Sided Cutting Drill with Exterior Shaving Exhaust

The one-sided cutting drill with exterior shaving exhaust consists of a working part (spike) of length ℓ and a shaft (Fig. 66). These drills are used for drilling holes 6 to 20 mm in diameter in weapon barrel stocks with a drilling depth of up to 1500 mm. Spike length depends on the diameter of the drill, for instance, for a drill ∅6 mm, it is equal to 60 mm, and for a drill ∅15 mm, it is approximately 85 mm. The spikes and shaft are hot stamped to get the required form of groove for shavings exhaust. The spike is manufactured out of fast-cutting tool steel and the shaft out of high quality carbon construction steel or alloy steel for gun barrels having high elasticity. A shaft and spikelet are butt-welded together.

Thickness of the drill wall, determined along its diameter d, is usually equal to 0.15d. The exterior diameter of the shaft d_1 must be 0.3 to 0.6 mm smaller than the diameter of the drill d, and its interior diameter d_2, like the interior diameter of the spike, must be equal to (0.65 to 0.7)d.

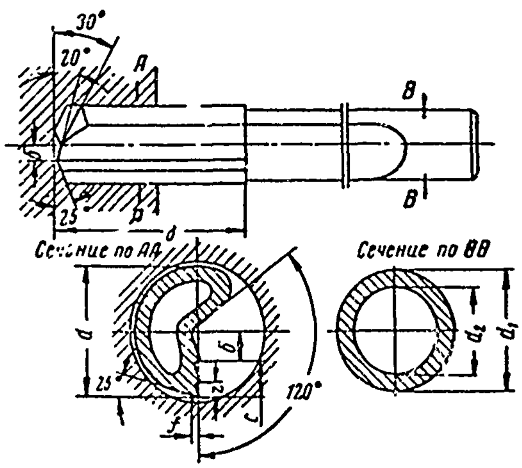


Fig. 66. One-sided cutting drill with exterior shaving exhaust

Key: a. section across AA
b. section across BB

The geometry of the drill point is shown in Fig. 66. The rear angle of the drill is maintained within the limits of 12 to 15°, and the rear conic rate of its spike is created by a decrease in diameter of the spike by 0.10 to 0.20 mm on its entire length. Width of the calibrating edge f is usually 0.4 to 0.5 mm. The drill top is displaced relative to its axis by an amount of $\alpha = 0.2d$

For the drill types under consideration (small diameter), dimensions and form of the shavings received during drilling are especially important. They depend on the diameter of the drill, the amount of feed, and the number of shaving breakers on the cutting edge. Such drills usually have two or three shaving breakers.

A nominal exterior diameter of drill d is determined by a calculation with consideration for the fact that, after drilling, gun barrels are additionally machined to contain a smooth and straight bore. This machining includes special reaming and roaching operations, which are fulfilled by special broaches.

Small diameter deep holes are drilled with a feed of 0.02 to 0.026 mm/rev or 40 to 60 mm/min. The possible drill deviation depends largely on the amount of feed s_o. The cooling liquid is supplied along the shaft canal in a quantity of 6 to 10 liters/min, and is exhausted together with shavings along the exterior groove in the shaft and drill.

Two-Sided Cutting Drills with Internal Shavings Exhaust

Two-sided cutting drills have two cutting edges which are located opposite each other (Fig. 67). Each cutting edge removes the thickness of shaving equal to half the feed of the drill for one of its revolutions. With such positioning

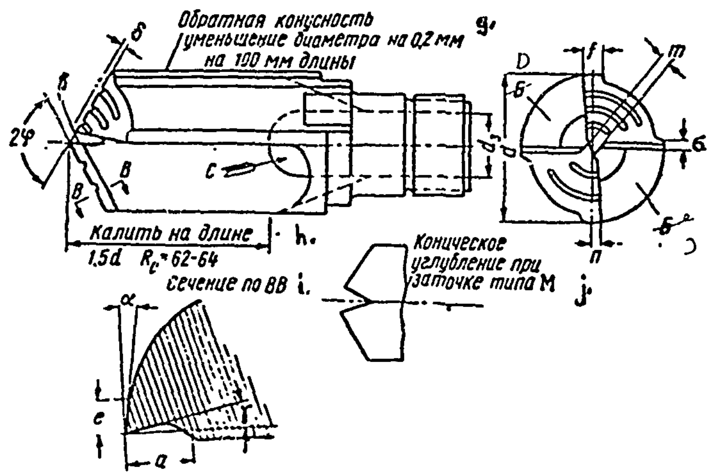


Fig. 67. Two-sided cutting drill with two cutting edges and internal shavings exhaust

Key:
- g. rear conicity diameter decrease by 0.2 mm on 100 mm length
- h. heat on length, 1.5d, R_C = 62 to 64
- i. section across BB
- j. conic deepening during sharpening of type M

of the cutting edges, the composite cutting forces are symmetrical relative to the axis of the drill, which significantly decreases the action of radial force and possible deviation of the drill. The intended direction of movement of the drill is maintained by the flats f and σ.

Backing of the drill is accomplished by sharpening its rear surface along a radius, equal to 0.5d, and sharpening its rear angle to 10°, with a control band of dimension e = 0.8 to 1.3 mm remaining on its rear surface.

To decrease the size of the drill crosspiece, a special slot b, of size so that the width of the crosspiece is m ≤ 1.6 to 2.5 mm, is removed. The cooling liquid arrives at the cutting edges along the exterior surface of the shaft and the exterior grooves of the drill, and shavings, attracted by the liquid stream, are first moved into the drill groove D, and then into the interior cavity in the grooved portion of the drill and shaft, as shown by arrow C in Fig. 67. The cutting part of the drill is manufactured of fast-cutting steel or, in the case of changeable blades, of hard alloy. The remainder of the construction of the drill is clear from Fig. 67 and does not require special explanation. Basic geometric parameters of the drill are presented in Table 20.

Fig. 68 shows a two-sided cutting drill with a cutting portion length shown greater than 2.5d. During wearing, this drill may be resharpened several

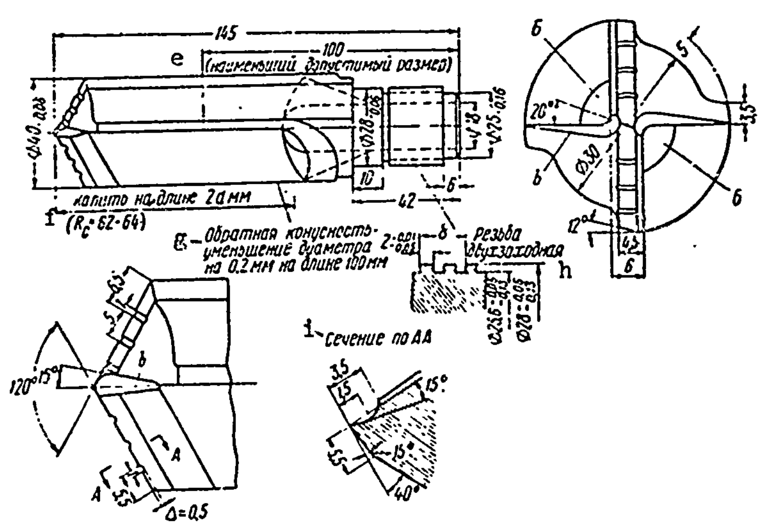


Fig. 68. Drill with two cutting edges and internal shavings exhaust

Key:
- e. least allowable dimension
- f. heat on length 2d mm
- g. rear conicity, diameter decrease by 0.2 mm on 100 mm length
- h. two-course thread
- i. section across AA

TABLE 20

Basic Geometric Parameters of the Two-sided Cutting Drill with Internal Shavings Exhaust

No.	Title of parameters and their dimensions in mm	Respective designation of parameters according to Fig. 67	Nominal dimension	Manufacturing tolerance	Allowable deviation
1	Crosspiece thickness	m	2.0	-0.2	0.5
2.	Angle at the top	2ϕ	120°	2°	4°
3.	Front angle	γ	8°	+2°	+3°
4.	Width of front groove	a	4	0.5	+2
5.	Distance from center to cutting edge	n	1.5	0.2	+1.0
6.	Difference in position of the cutting edges	δ	0	not over 0.02	0.4
7.	Flat width	f	4	0.3	+1.0
8.	Flat width	σ	3	0.3	0.5
9.	Rear angle	α	10°	1°	2°
10.	Control band width	e	1.4	0.2	0.2
11.	Non-parallelness of cutting edges		0	0.10	0.15
12.	Rear conicity -- diameter decrease		0.2	0.1	--

times if it is manufactured of fast-cutting or alloyed tool steel. The great length of the drill affords its best maintenance of assigned movement direction, but friction during drill turning increases, and therefore its fastening part must be stronger than that of a normal drill. Structure of the drill is sufficiently graphically shown in Fig. 68.

In solid deep hole drilling, the most difficult factor is attainment of a constant process, or stability of the drill throughout the depth of drilling. This is especially important in drilling bores greater than 5000 mm long. The two-sided cutting drill, whose cutting edge crosspiece dimension is kept to the possible minimum, or whose crosspiece is completely eliminated, is most productive with presence of back-pointing of amount type M. Back-pointing of the type M drill top consists of the fact that, in cutting edges up to 5 mm wide, the groove b is removed to such a dimension that the crosspiece completely disappears, and in the drill center a conic depression is formed, as shown in the sketch in Fig. 67.

With the same cutting speed, feed for a two-sided cutting drill may be increased to twice that of a one-sided cutting drill, in that each of the cutting edges removes a shaving of thickness equal to 0.5 of the feed.

For the above two-sided cutting, during drilling of holes in steels (σ_b = 75 to 90 kg/mm^2) of stocks, the following cutting rates are used: feed 0.3 to 0.4 mm/rev, and cutting speed 20 to 30 m/min.

Spiral Drills with Internal Shavings Exhaust

Spiral drills with internal shavings exhaust are more productive than points for drilling deep holes. The construction and geometric parameters of these drills are shown in Figs. 69 and 70.

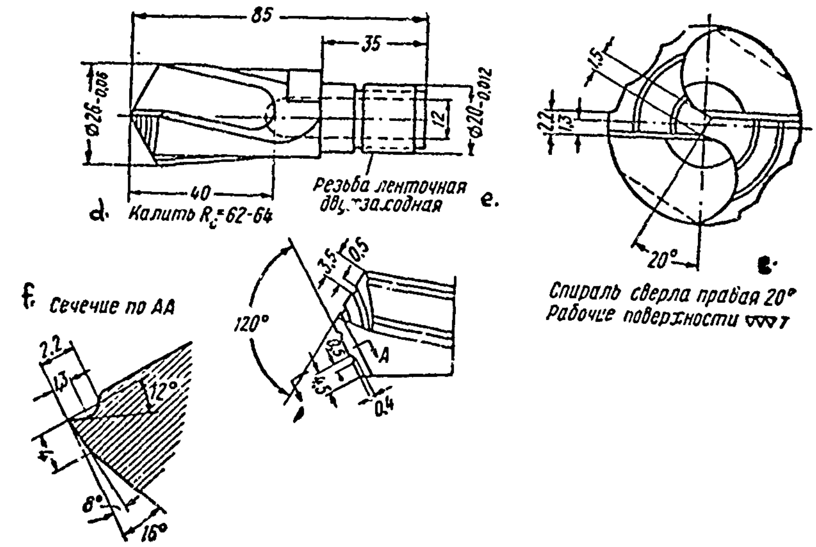


Fig. 69. Spiral drill with two cutting edges and internal shavings exhaust

Key: d. heat, R_C = 62 to 64
e. two-course band thread
f. section across AA
g. spiral drill right 20°
working surfaces ∇∇∇7

This type of spiral drill is used for drilling holes 25 to 75 mm in diameter, and the satisfactory exhaust of shavings is assured only with drilling holes over 35 mm in diameter. The essential deficiency in spiral drills is the presence of a sectional crosspiece between the cutting edges, which has a zero cutting speed. Attempts to eliminate crosspieces and thereby drilling a hole in the center of the drill to attain a zero core close to 2 mm have not given positive results.

Deep hole drilling with spiral drills results in somewhat greater drill deviation and a more coarse surface than with one-sided or two-sided cutting drills. Such drills are profitably used for coarse (preliminary) drilling of holes 35 to 60 mm in diameter, with their later expansion by a one-sided cutting drill to a diameter of 80 to 100 mm. The dimension norms of the fastening part of the drill are identical in spiral drills.

The cooling liquid is supplied to the cutting edges along exterior grooves in the drill, and exhaust together with shavings at first in the main groove, and then along the interior canal of the drill and shaft, as shown in Fig. 70. For supply of the cooling liquid to the drill, a special attachment, consisting of the fluid receiver (4), stuffing box structure (5), nipple (6), gland (7), moving lunette (8), and flexible bearings (9). The attachment is installed on lunette (8) and on the shaft (3) of the machine and is pressed against the butt surface of the machine stock (1) by the flexible bearings (9) to eliminate possible leakage of cooling liquid. The cooling liquid arrives under pressure through a special nozzle into nipple (6) and further into the circular clearance between the drill shaft (2) and the stock (1) to the cutting edges of the drill. The following cutting rates are recommended for spiral drills with internal shavings exhaust for drilling stock steels ($\sigma_b = 75$ kg/mm^2): Feed 0.16 to 0.30 mm/rev, cutting speed 18 to 25 mm/min, with the smaller feed limits for smaller diameter drills (25 to 35 mm).

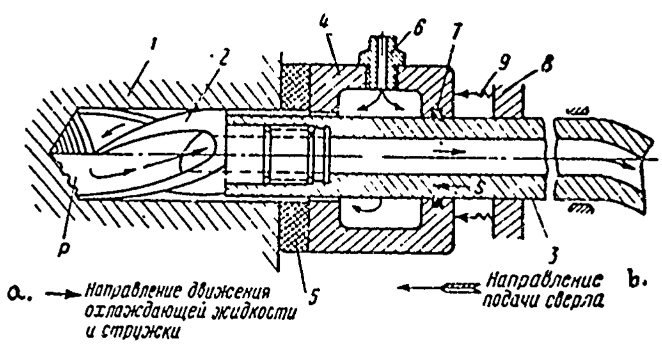


Fig. 70. Schematic of spiral drill drilling (see Fig. 69)

Key: 1. machined stock
2. drill shaft
3. machine shaft
4. fluid receiver
5. gland
6. nipple
7. seal
8. moving lunette
9. elastic bearing
a. movement direction of cooling liquid and shavings
b. direction of drill feed

Expansion of Deep Holes

In tube production practice the operation of expanding deep holes to the required tube dimension takes place before their heat treatment. The necessity of this operation is explained by the fact that the drilling of deep holes of 60 to 100 mm in diameter with a solid stock length greater than 4000 mm meets significant technological difficulties in that with the increase in drill diameter and stock length, defects arising during drilling increase, especially drill deviation from its assigned direction. In such stocks, it is more expedient to first drill deep holes of up to 60 mm in diameter, and then expand them to the required dimension (70 to 100 mm).

For expanding deep holes, a one-sided cutting drill with hard alloy blades, the scraping drill shown in Fig. 71, is used. The body (1) of such a drill is manufactured of carbon tool steel, and its guiding flats (keys)(2) are subjected to surface heat treatment. The cooling liquid, supplied from the canal of the fastening portion of the drill, moves along the lateral canals to the main channel of the drill and arrives then to its cutting and calibrating edges, spreading further along the exterior channels of the drill. The shavings are carried away by the cooling liquid through the previously-bored deep hole in the stock.

The main cutting edge of the blade (3), made of hard alloy, forms an angle of 70° at the drill top, and the edge opposite it on the drill body, not taking part in cutting, forms an angle significantly smaller in size (about 60°) so that between this edge and the stock cutting surface (4) a clearance E is attained. The cooling liquid is supplied to the back side of the cutting edge through this clearance so as to improve exhaust of shavings and eliminate friction between the face portion of the drill body and the cutting surface.

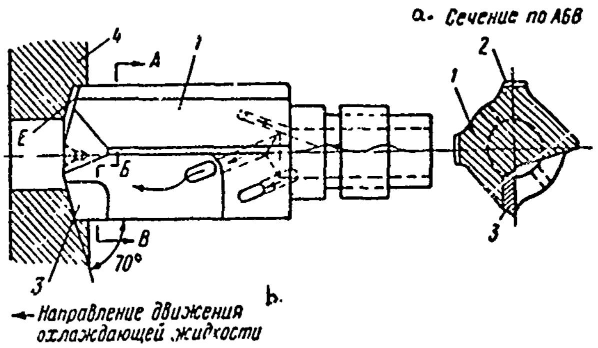


Fig. 71. One-sided cutting scraping drill with a hard alloy blade for expansion of deep holes

Key: a. section across AGB
b. direction of movement of the cooling liquid

The cutting process during expansion of holes takes place under more favorable conditions than during solid drilling because the drill top and surfaces close to it, having zero or low cutting speeds, do not participate in cutting; the drill more accurately maintains its assigned direction, and the shaving exhaust through its cleaning by the liquid stream in the direction of feed is eased. As a result, cutting rate can be significantly increased during expansion. In production practice for hole expansion, cutting speeds of 40 to 60 m/min and feed of 0.18 to 0.3 mm/rev are used, which are significantly greater than the cutting speeds and feed for solid stock drilling.

The use of hard alloy blades in deep drills is a more difficult problem than their use in normal cutters because of the peculiarities of the technological process of drill manufacture, the presence in them of crosspieces which work with zero cutting speed, and the necessity to have shaving breakers to crush shavings. Regardless of this, hard alloy blades are being more widely used in all drill constructions. Blades of hard alloys VK8 and T15K6 are most widely used in drills. The use of blades without shaving breakers creates difficulties in shavings exhaust because the shavings attain great widths. In their remaining structure and point geometry, drills with hard alloy blades are analogous to those with fast-cutting steel blades.

#20. Cutting Rates for Solid Drilling

As already noted in the previous paragraphs of this chapter, solid drilling of deep holes is a special operation in which the following requirements are produced:

1) Possibility for uninterrupted drilling throughout the assigned length of hole;

2) attainment of a straight hole or least possible drill deviation from its assigned movement direction;

3) normal shavings exhaust in the process of fulfillment of all drilling operations;

4) elimination of vibration of the cutting tool, which might arise during drilling as a result of insufficient stability;

5) capability of drilling stock made of materials with high mechanical properties (for instance, out of alloyed steels);

6) maintenance of satisfactory cutting tool stability throughout the entire operation.

All these requirements should be considered during determination of the optimal cutting rate, or the rate assuring fulfillment of the operation with the least machine time.

The requirement for uninterrupted drilling throughout the assigned length is conditioned by the fact that, with a stoppage of the machine and extraction of the shaft and cutting tool from the hole, the cutting edge can be broken, especially if hard alloy blades which are sensitive to breakage are used in the cutting tool. Besides this, exchange of a damaged tool causes machine stoppage and destroys the normal flow of shavings from the hole. With these considerations, continuity of drilling is one of the basic requirements in production practice.

With an increase in drilling feed, axial cutting effort sharply increases, especially with partial wear and blunting of the cutting edges of the drill so that the normal conditions for shavings exhaust are destroyed and drill deviation increases. Therefore, for selection of the amount of feed for each type of drilling and type of machine material, it is necessary to strive not only for minimum machine time in the drilling operation, but also for the least amount of drill deviation.

Conditions for shavings exhaust in drilling depend on their form and the pressure of the cooling liquid stream which attracts shavings behind it. For creation of normal shavings exhaust conditions, it is necessary that the shavings are light and in the form of flakes so that the cooling liquid circulates at the pressure of 4 to 10 atm (the small limit for large diameter drillings) and a volume of from 40 to 70 liters/min.

Cutting speed is determined by the mechanical properties of the stock material, the degree of stability of the cutting tool, the diameter of the drill, and the amount of drill feed. During drilling of alloyed steels which are strong and have a high flexibility, cutting speed must be slower than cutting speed for medium-hardness carbon steels. In this instance, the coefficient of machine's abilities should be taken equal to approximately 0.8. At the beginning of drilling, on a section two to three drill diameters in length, and at the end on a section up to 50 mm in length, the cutting rates should be decreased so as to assure a smooth entry and exit of the drill.

Average data on cutting rates for deep-hole solid drilling gathered on the basis of work experience are presented in Table 21.

Deep hole drilling is a coarse machining operation for which the basic labor productivity index is the volume of metal removed in a time unit. For a deep drilling operation, however, this index does not reflect the actual situation in that the basic requirements, constancy and drilling depth, are not considered in it. These requirements may be satisfied with assurance of necessary qualitative indicators, namely the greatest drilling depth in a time unit, and absence of drill deviation.

A more proper evaluation of labor productivity in deep drilling would be depth of drilling over the course of one hour. Comparative data on the productivity of labor according to volume of shavings removed and according to drilling depth over one hour are shown in Table 22.

TABLE 21

Average Data on Cutting Rates for Deep-hole Solid Drilling
(Drill of Fast-cutting Steel, 30 to 60 mm in Diameter)

No.	Drill type	Machine material strength limit $_b$ = 50 to 60 kg/mm^2		Machine material strength limit $_b$ = 70 to 80 kg/mm^2	
		Feed in mm/rev	Cutting speed in m/min	Feed in mm/rev	Cutting speed in m/min
1.	Plyusin point	0.15 - 0.20	16 - 20	0.12 - 0.15	16 - 18
2.	Point with elongated guides	0.18 - 0.25	15 - 20	0.12 - 0.18	14 - 16
3.	Spoon and GG drill	0.15 - 0.26	16 - 20	0.10 - 0.16	14 - 16
4.	One-sided cutting drill with internal exhaust	0.15 - 0.26	25 - 35	0.10 - 0.16	18 - 25
5.	One-sided cutting drill with external shavings exhaust and hard alloy blade	0.15 - 0.26	40 - 60	0.15 - 0.20	30 - 50
6.	Two-sided cutting drill	0.24 - 0.36	25 - 35	0.18 - 0.30	18 - 25
7.	Spiral drill	0.18 - 0.28	18 - 25	0.12 - 0.16	16 - 18

Note: Smallest feeds are for drills 30 mm in diameter.

It can be seen from the data of this table [Table 22], that with identical cutting rates, the 30 mm diameter drill has twice the drilling depth S_r and half the shavings volume W_r as the 16 mm diameter drill. Therefore, drilling depths in one hour is a more objective index of labor productivity in deep-hole drilling.

The amount of feed and cutting speed in deep-holing drill are very important, namely: With an increase in the amount of speed, shaving widths and hardness increase, and the shaving exhaust is made more difficult, especially during drilling small-diameter holes (under 35 mm). Cutting speed for a one-sided cutting drill should be maintained somewhat higher than for a two-sided cutting drill with a crosspiece. During determination of feed and cutting speeds for deep-hole drilling, the correction factor, equal to 0.65 to 0.70, should be introduced into the cutting rate recommended for normal spiral drills with a drilling depth no greater than 5d.

TABLE 22

Drilling Depth (S_r) and Volume of Shavings Removed W_r
in Solid Deep-hole Drilling Over One Hour

a Скорость резания в м/мин	b Глубина сверления S_r мм и объем снимаемой стружки W_r в $см^3$	c Сверло диаметром 30 мм		e Сверло диаметром 60 мм	
		d Подача сверла		f S_0 в мм/об	
		0,15	0,25	0,15	0,25
15	S_r	1425	2375	715	1190
	W_r	1005	1670	2010	3350
25	S_r	2400	3990	1200	2000
	W_r	1680	2785	3380	5660

Key:
- a. cutting speed in m/min
- b. cutting depth S_r mm and volume of shavings removed W_r in cm^3
- c. 30 mm diameter drill
- d. drill feed
- e. 60 mm diameter drill
- f. S_o in mm/rev

#21. Ring Drilling

Ring drilling is used to attain deep holes over 100 mm in diameter. The schematic of this drilling was shown in Fig. 54.

In ring drilling, the heart of the stock emerges as a solid core 0.5d in diameter, and only part of the metal is converted into shavings. As already stated (see #17), a manifold cutting tool, assuring high labor productivity, can be used in ring drilling.

It is advantageous in production to use a two-sided ring drill.

Heads for Ring Drilling

Figs. 72 and 73 show type constructions of heads for ring drilling of deep holes of various diameters. The head consists of a body (1), cutter (2), wedges (3) for fastening the cutters, and guiding keys (4). Heads of other construction may not have separate guiding surfaces, and instead may have guiding surfaces on the body itself (Figs. 73 and 74).

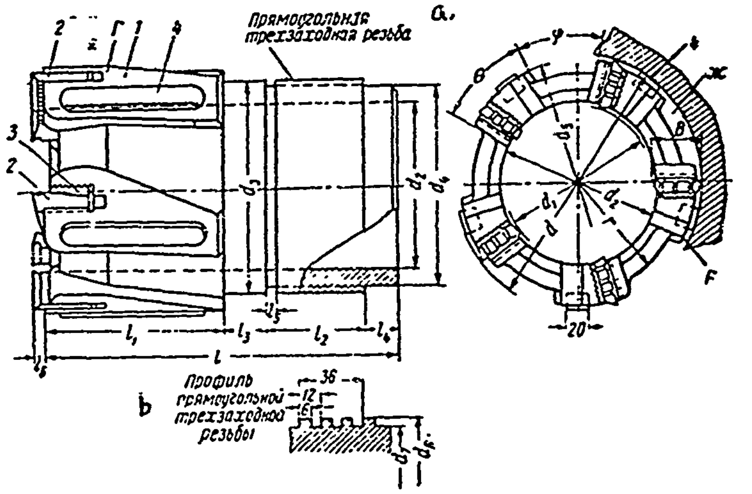


Fig. 72. Head for ring drilling with five cutters

Key:
1. head body
2. cutter
3. cutter wedges
4. guiding key
a. three-course right angle thread
b. profile of the three-course right angle thread

The head body is a hollow cylinder (inner diameter d_2), and the head has a front working part of length ℓ_1 on the formed cylinder and a tail (fastening) part connected to the machine shaft (see Figs. 72 and 73).

On the working part of the head there are channels H for exhaust of shavings which fall into the circular clearance between the machine shaft and the stock and are attracted by the cooling liquid stream. The head has several cutters on it. The cutters are fastened to the head by various means. One of the means of cutter fastening is with wedge (3) and corrugated surface having the appearance of a comb (tooth spacing 1.5 mm, depth to 0.8 mm, and profile angle 90°), shown in Fig. 72. This fastening is reliable, strong, convenient, and allows regulation of the cutter position in the head body after its repeated sharpening.

Another means of cutter fastening in the head is shown in Fig. 73. This method of fastening requires accurate fitting of the cutter in the head slot and fitting of the guiding rod E in the hole. In this instance, it is not possible to regulate the position of the cutters in the head after their repeated sharpening, and fitting of each cutter in the slot is individual.

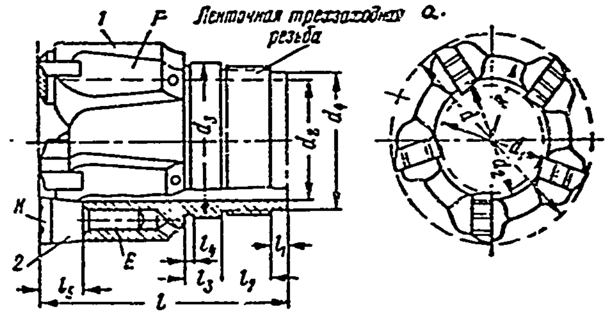


Fig. 73. Ring drilling head with five cutters

Key:
1. head body
2. cutter
F. guiding keys
K. cutting edge of the cutter
E. guiding rod of the cutter
a. three-course band thread

The head is guided in the hole by metallic keys (4), which are located immediately behind the cutters (see Fig. 72). In some instances, the keys may be manufactured of hard types of wood (lignum vitae, box tree, oak). Most often, built-up areas of harder metal than the head body are used instead of guiding keys. Sometimes the head guides F (see Fig. 72) of the head are thickened section (keys) formed during machining of the head body (see Figs. 72, 74, and 75). The exterior diameter of the metallic guides must be 0.3 to 0.6 mm smaller than the diameter of the drilled hole d to consider wear of the cutting edges. The diameter of the head guides may, if necessary, be increased to the required dimension by their building up and consequent grinding. The exterior diameter of the head body d_5 must be 5 to 8 mm smaller than the diameter of the drilled hole.

Fig. 74. Ring drilling head with six cutters

Channel H should be made as large as possible with consideration of maintenance of the necessary strength of the head body. The volume of the channel is determined by its radius r, diameter of the drilled hole, and number of cutters on the head.

Table 23 presents values of angles ϕ and θ for heads with varying numbers of cutters.

TABLE 23

Basic Parameters of Deep-Hole Ring Drilling Heads (see Fig. 72)

№ по пор.	a. Диаметр просверливаемого отверстия в мм	b. Количество резцов на головке	c. Угол θ°	d. Угол φ°
1	100—120	3	63	57
2	120—200	5	38	34
3	140—250	6	30	30
4	250—400	6	28	32
5	250—400	8	22	23

Key:
a. diameter of drilled hole in mm
b. number of cutters on the head
c. angle θ°
d. angle ϕ°

The radius of the channel r is tied with the diameter of the drilled hole and is determined by the relationship

$$r = (0.42 \text{ to } 0.45)d.$$

All the remaining dimensions of the head are designed dimensions, determined with calculation of the following considerations:

1) The smallest head wall thickness must satisfy the requirements for head strength, calculating the largest diameter d_2 and d_4;

2) circular clearance on the side between the exterior surface of the drilled-out core and the interior surface of the head, determined by the difference between the diameter d_1 and d_2, must be the least possible in size, but sufficient for cooling liquid supply and free movement of the core in the head and in the clear hollow of the shaft (see Fig. 72);

3) circular clearance on the side between the exterior surface of the drilled hole of diameter d, determined by the difference in diameters, must be

sufficient for free exhaust (cleaning) of shavings through it and 1.5 to 2 mm larger than clearance of the channel H along radius r;

4) a shaft must have sufficient rigidity and strength to drill holes at the maximum cutting rates;

5) cutter with B for width of the circular hole during drilling must be as small as possible, but sufficient for providing the necessary head wall thickness and clearances for cooling supply and shavings exhaust under pressure of the cooling liquid (see Fig. 72).

According to production experience, the average values of designed dimensions of the head may be determined according to the following relationships:

Exterior diameter of the drilled-out core

$$d_1 = (0.60 \text{ to } 0.73)d;$$

interior diameter of the head

$$d_2 = (0.66 \text{ to } 0.76)d;$$

exterior diameters of the guiding (centering) surfaces of the tail portion of the head

$$d_3 = (0.75 \text{ to } 0.84)d;$$

$$d_4 = (0.72 \text{ to } 0.80)d;$$

exterior diameter of the machine shaft

$$D = (0.84 \text{ to } 0.89)d;$$

its interior diameter

$$D_1 = (0.66 \text{ to } 0.75)d.$$

In these, the smallest dimensions are for heads 100 mm in diameter and the largest are for heads 300 mm in diameter;

cutter width

$$B = (0.2 \text{ to } 0.133)d;$$

length of the working part of the head ℓ_1 must be as small as possible, but sufficient for placement of the cutters and provision for the required length keys. Usually

$$\ell_1 = (0.80 \text{ to } 0.40)d;$$

length of the threaded portion of the tail part of the head

$$\ell_2 = (0.50 \text{ to } 0.32)d;$$

length of the guiding and centering portions of the head

$$\ell_3 = (0.20 \text{ to } 0.99)d;$$

$$\ell_4 = (0.10 \text{ to } 0.07)d;$$

the overall length of the head body

$$\ell = (1.6 \text{ to } 0.24)d.$$

Upon obtaining the basic dimensions of the head from the relationships enumerated, and then projecting its design, it is possible to determine all the remaining designed dimensions by using the dimensions if Figs. 72 and 73. The head body is manufactured of high strength alloyed steel, and after heat treatment must have a hardness of R_C = 50 to 54. All head surfaces must be smooth and sharp edges rounded off along a large radius. Basic dimensions of ring drilling heads of various diameters are presented in Table 24.

Figs. 74 and 75 show a six-cutter ring drilling heads for large and small diameter holes which are similar to the heads shown in Figs. 72 and 73 in construction.

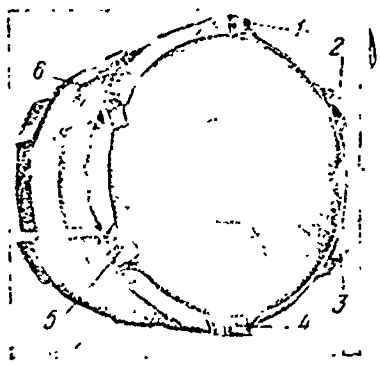


Fig. 75. Six-cutter head for ring drilling
large diameter holes

Key: 1-4. cutters
2 and 3. cutters
5 and 6. cutters with symmetrically located cutting edges

TABLE 24

Basic Dimensions of Ring Drilling Heads
(Figs. 72 and 55)

No.	Nomenclature of dimensions and their sizes in mm	Respective dimension designations according to Figs. 72 & 73	Diameter of the drilled in mm			
			100	140	200	300
1.	Exterior diameter of the drilled-out core	d_1	60	84	132	220
2.	Interior diameter of the head	d_2	66	92	141	230
3.	Exterior diameter of the guiding and centering surfaces	d_3	76	106	159	252
4.	Same	d_4	73	102	153	245
5.	Radius of channel H	r	43	60	88	135
6.	Exterior diameter of the machine shaft	D	85	118	172	268
7.	Internal diameter of the machine shaft	D_1	67	93	142	232
8.	Cutter width	B	20	28	34	40
9.	Length of head working part	ℓ_1	80	85	105	115
10.	Length of cutter on head	ℓ_2	50	65	80	90
11.	Length of guiding and centering portion of head	ℓ_3	18	20	25	25
12.	Overall length of head		160	185	230	250
13.	Clearance on a side between the head and drilled-out core	Δ	3	4	4.5	5
14.	Clearance on a side between drilled-out core and machine shaft	Δ_1	3.5	4.5	5	6
15.	Clearance on a side between the head and the hole in the stock along channel H	H	7	10	12	15
16.	Clearance on a side between the machine shaft and the internal surface of the stock hole	H_1	7.5	11	14	16
17.	Minimum head wall thickness on section d_4	c	3.5	5	6	7.5
18.	Minimum shaft wall thickness along diameters d_3 and D	c_1	4.5	6	6.5	8
19.	Maximum shaft wall thickness	c_2	9	12.5	15	18

Cutters for Ring Drilling Heads

Cutters for ring drilling heads are blades made of fast-cutting type R18 steel (Figs. 76 and 73). The width of the cutting edge of cutter B is very important during ring drilling. With an increase in cutter width, selection of the necessary head dimensions and clearances for exhaust shavings, shown in Table 25, are made more easy. With this, however, the exterior diameter of the drilled-out solid core is decreased, and consequently, the effectiveness of ring drilling decreases.

Shaving breakers are needed on the main cutting edge of the cutter. These must be located at a distance of one-half to three-quarters the size of clearance H from each other so that the width of the shavings can freely move through this clearance. The channel on the front surface of the cutter must be of such a form so as to provide shavings in small flakes. The front cutter angle γ should be maintained within the limits of 12 to 14^{o}, and the rear angle α within the limits of 7 to 9^{o}. The channel on the front surface of the cutter must have a width of 4 to 5 mm. Control flats f 0.2 to 0.3 mm in width should remain on the front and rear surfaces of the cutter to increase cutter stability and decrease its wear. The remaining dimensions appearing in Fig. 73 correspond to a cutter for drilling a hole d = 175 mm.

It is necessary to perform a final operation in cutter sharpening after their assembly and fastening into the head nests, during which all cutters must be uniformly positioned in the nests, determined by the dimension d and d_1, and their main cutting edges are located in the same face plane. Cutter position symmetry in the head nests assures favorable working conditions of the auxiliary edges in the section of length ℓ_5 (along the diameter d and d_1) and equal distribution of feed s_o between all cutters. As a result, the thickness of the shavings removed by each cutter may be determined from the relationship

$$s_n = \frac{s_o}{n} \qquad (28)$$

where s_n is the thickness of shavings removed by each cutter in mm; s_c is the head feed for one rotation of a stock in mm; and n is the number of head cutters.

The installation and placement of cutters in the head shown in Fig. 75 has the following peculiarities. In this head two cutters (we will conditionally label them a first and fourth cutter) are located symmetrically on the same diameter (inside and outside) and have a cutting edge width B, equal to the width of the circular opening during drilling; two adjacent cutters (5) and (6) having a cutting edge width B_1 = 0.6B and located from the side of the interior surface of the head; and finally, two adjacent cutters (2) and (3), also having a cutting edge width of B_1 and located from the side of the exterior surface of the head.

With described cutter position on the head, the shavings removed are divided into four equal parts according to thickness and amount of feed s_o and into two equal parts according to shaving thickness. This cutter position causes difficulties in their manufacture and sharpening. The head, however, works reliably, and shavings are divided into many parts according to thickness and width, which eases their exhaust from the drilled hole.

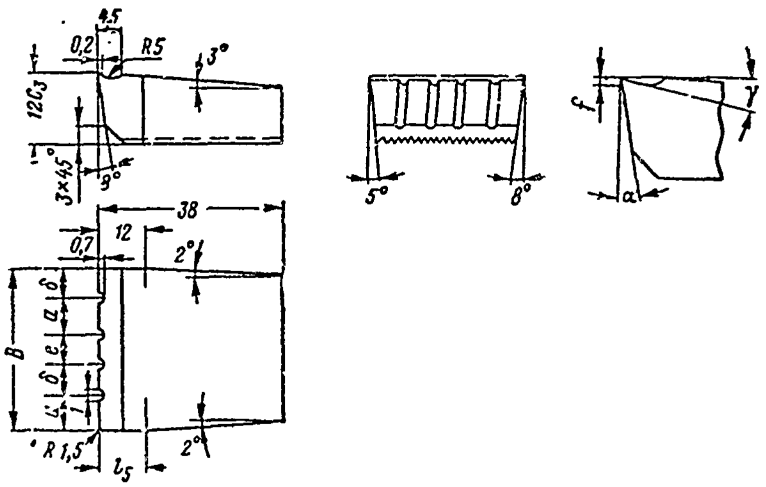


Fig. 76. Ring drilling head cutter (cutter material -- steel R9)

Shavings breaker dimensions in mm

Cutter No.	a	b	c
1 and 3	7	6	5
2 and 4	5.5	6.5	7
5	6.5	6	6

A simpler method of crushing shavings with cutters is shown in the schematic of Fig. 77. In this instance the installation of the head and cutters is normal, but the first and third cutters have a cutting edge width of A = 0.5B, and the other three cutters, a width of B, so that they are staggered relative to the first and third cutters at an amount equal to the feed s_0 (see Fig. 77, b).

When the head is turned on, the first and third cutters will remove shavings of width A during the first revolution (see Fig. 77, a), and then all the cutters will begin cutting (see Fig. 77, c). Cutter sharpening and installation with the described scheme of cutting is more complicated.

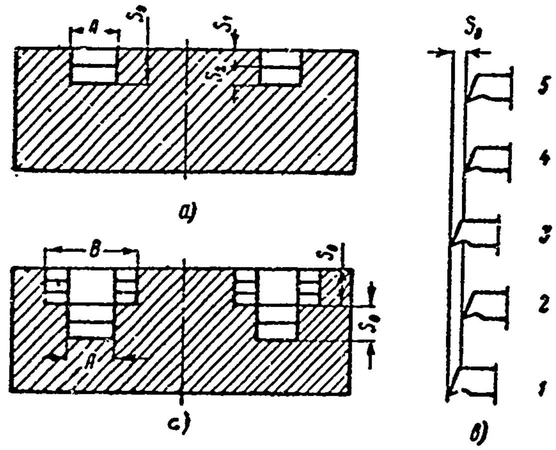


Fig. 77. Schematic of shaving divisions by depth and feed during deep-hole ring drilling by a five-cutter head

Key: a. shavings removed by first and third cutters
b. cutter position scheme
c. shavings removed by the remaining cutters

The simplest and most widely used method of crushing shavings is the symmetric positioning of the cutters in the head so that shaving width or feed is equally distributed among all the cutters, and division of shaving in width is achieved with shaving breakers (see Fig. 72).

Cutting Rates with Ring Drilling

Deep-hole ring drilling essentially differs from the processes of solid drilling and reaming. During ring drilling, the zero cutting is absent, a solid core is obtained which during the process of drilling rotates in the hollow shaft, shavings do not break away freely, and their exhaust through the circular clearance which has small dimensions is made difficult. All these factors compose the peculiarities of the ring drilling process.

Cutting rate for ring drilling is determined by the mechanical characteristics of the stock material, the diameter and depth of the drilled hole, construction and number of cutters in the head, the type of cutter material, and conditions of cooling and shavings exhaust.

With an increased strength and flexibility of the stock material, cutting speed and feed during ring drilling decreases. If one cutting rate per unit is used for drilling stock with a material strength of $\sigma_b = 60$ kg/mm^2, then for a stock whose material is characterized by the strength $\sigma_b = 90$ kg/mm^2, the cutting rate should be reduced, introducing the correction factor equal to 0.8, or the cutting rate should be reduced by 20%.

The diameter of the drill hole does not have significance influence on the speed of cutting. With increase ring drilling diameter, however, if cutting speed remains constant, feed may be increased in that it depends only on the mechanical properties of the machined material.

With a hole diameter change from 120 mm to 250 mm, for instance, it is necessary to introduce a correction factor, which is equal to 1.3 times the amount of feed, or increase the feed by 30%.

With an increased drill hole diameter, conditions of the process of cutting and shavings exhaust improve, and the possibility of increasing the number of cutters in the head appears. These factors allow thickness of shavings removed to be increased, or head feed to be increased.

With increased drilling depth, it is necessary to decrease cutting speed because of the worsened conditions of shavings exhaust, the decreased stability of the drilled-out core, and appearance of its vibration. During the drilling process with very long tubes, it is necessary to interrupt and cut off the drilled-out core in 3 to 5 meter lengths with a special head.

The cooling liquid drilling arrives at a pressure of 3 to 5 atm.

Cutting rates used in ring drilling for cutters made of fast-cutting steel are presented in Table 25.

It is evident from the table that with an increased number of cutters on the head, productivity of the drilling process significantly increases.

Using hard alloyed blades in the cutters, cutting speed may be increased to 50 m/min, and in some instances with drilling depth $\ell < 4000$ mm to 75 m/min. In this instance, feed for a head with three to five cutters must not exceed 0.5 mm/rev.

The cutting rates appearing in Table 25 are average and are used in many plants. In each separate instance when chosing a cutting rate, the latest production experience and laboratory experiments should be considered.

#22. Defects Encountered During Deep-Hole Drilling

The following defects are encountered during the solid and ring drilling of deep holes:

1) Drill deviation from its assigned direction;
2) curvature of the hole bore;

TABLE 25

Cutting Rate for Deep-hole Ring Drilling with Fast-cutting-steel Cutters

a Диаметр просверливаемого отверстия мм	b Материал заготовки, имеющий предел прочности σ_b=60 кг/мм²						Материал заготовки, имеющий предел прочности σ_b=90 кг/мм²					
	d Головка с тремя резцами			e Головка с пятью и шестью резцами			d Головка с тремя резцами			e Головка с пятью и шестью резцами		
	v м/мин	s_0 мм/об	s_r мм/час	v м/мин	s_0 мм/об	s_r мм/час	v м/мин	s_0 мм/об	s_r мм/час	v м/мин	s_0 мм/об	s_r мм/час
120	22	0,3	1044	24	0,38	1450	20	0,24	760	21	0,34	1128
150	22	0,33	924	24	0,48	1468	20	0,27	690	20	0,38	965
170	21	0,36	860	23	0,54	1393	20	0,30	675	20	0,42	944
200	21	0,39	780	23	0,60	1314	19	0,33	594	19	0,45	804
300	20	0,43	554	23	0,66	920	19	0,35	436	19	0,48	580

NOTE: v, cutting speed; s_0, feed/rev; s_r, feed/hr

Key:
- a. Diameter of drilled hole in mm
- b. Stock material having a strength limit c_b = 60 kg/mm^2
- c. Stock material having a strength limit c_b = 90 kg/mm^2
- d. Three-cutter head
- e. Five-cutter head

3) formation of steps on the interior surface of the hole bore during two-sided drilling;
4) ellipticity and ovality in the bore hole;
5) multi-edged interior bore surface.

With drill deviation, the drilled hole most often curves. Amount of drill deviation depends on the design of the cutting tool and its points, on the technical condition of the machine, cutting rate, quality of stock preparation for drilling, and type of its material, on the diameter of the drilled hole, and the depth of drilling.

With one-sided solid drilling, for instance, with proper preparation of its guiding surfaces, deviation would be less than with two-sided drilling. With proper installation of the machine, attachment, and drill points of one-sided solid drilling, deviation with a drilling depth to 4000 mm would not usually exceed 0.3 to 0.60 mm. Ring drilling makes deviation of the cutting instrument smaller than solid drilling. Cutting speed is not immediately tied with drill deviation, but considering its ties with feed and wear of drill cutting edges (cutters), it is possible to reach the conclusion that deviation would grow with increased speed. The guiding flats, keys, and slides, and the quality of the lubricating and cooling liquid used have great influence on the drilling process. Good lubricating qualities of the cooling liquid assure more favorable conditions for the drilling process because wear is decreased in the guiding surfaces and the cutting tool, along with its vibration and deviation. The mechanical properties of the stock material have an extremely important meaning for the drilling process. Nonuniformity and hardness or flexibility of the stock material throughout its length or section will create significant changes in the cutting effort in the process of drilling, affording increased drill deviation. Drill deviation is therefore caused by various factors whose effects it is not always possible to calculate. Using experiential data on drill deviation during two-sided drilling of holes 30 to 75 mm in diameter, it is possible to determine drill deviation according to the following empirical dependence:

$$y_0 = 0.65 \text{ to } 0.005d + 0.15\ell, \quad (29)$$

where y_0 is drill deviation in mm; d is drill diameter in mm; and ℓ is drilling depth in m.

According to this dependence, deviation of a drill 30 mm in diameter, with a drilling depth of 3 to 6 m, is equal to 0.95 to 1.4 mm, and for a drill 70 mm in diameter, it is equal to 0.75 to 1.2 mm. With a drill diameter of 70 mm and drilling depth of 10 m, drill deviation would comprise 1.8 mm.

These amounts of drill deviation are average and correspond to the correct installation of the machine and the normal conditions of the cutting process and shavings exhaust.

In production practice, drill deviation oscillates in limits which are significantly larger than average values, and mainly with a drill 50 to 60 mm in diameter. With a drilling depth 4000 to 6000 mm, deviation might comprise 0.5 to 5 mm. In practice, however, drill deviation larger than 3 mm is encountered comparatively rarely.

During drilling of small holes 7 to 14 mm in diameter and 800 to 1600 mm deep, drill deviation reaches 0.4 to 1 mm. In some instances, it may be increased to 2 mm, and in these instances it is impossible to correct this defect in a small diameter hole, and the stock is most often discarded.

Drill deviation usually involves bore distortion of arbitrary form, and in some sections the curvature arrow may reach 0.4 times the size of the drill deviation.

During simultaneous, two-sided solid and ring methods of drilling, drill deviation may be directed toward different sides, and in this instance a step will be formed on the interior surface of the bore at the section on which the two drills meet. With the presence of such a step in it during heat treatment of the stock, cracks may appear. As a rule, this defect is eliminated before heat treatment of the stock by reaming the bore if the height of the step exceeds 2 mm. Ellipticity and ovality of the hole are received as a result of improper centering of the cutting tool relative to the shaft and of the shaft and tool relative to the rotational axis of the stock. This causes great one-sided wear of the guiding and cutting tools for the elliptic or oval hole.

The multi-edged inner hole surface, a relatively rare defect, is most commonly encountered during ring drilling. With correct concentric grinding of the guiding surfaces of the head and lateral flats on the cutters, this defect is not usually observed. When solid drilling with a one-sided drill whose lateral control flat is sharpened to an improper height, a fluted hole may also occur. Multi-edged surfaces throughout the depth of a hole are usually observed in slanted spirals.

All the defects cited are results of unsatisfactory stock preparation (cheek turning, centering, preparation of the machined hole) or of sharpening and installation of the cutting tool.

Considering the defects encountered during drilling, in order to eliminate them it is necessary to increase margins on a stock and resort to additional coarse turning operations which naturally increase manufacturing time of the part. In production, therefore, results of technological drilling processes should be systematically learned in order to expediently use the necessary measures for full elimination or reduction of the encountered defects.

CHAPTER VII

Reaming Deep Cylindrical Holes

#23. Methods of Reaming

Reaming deep openings (tubes) is a machining operation during which a straight cylindrial hole with a smooth clean surface is obtained through the sequential removal of the metal margin.

During turning of the tube, defects of preceding operations are removed, or defects of the steel casting, if the tube was formed by centrifugal casting, or defects of heat treatment, correction, or drilling.

Tube turning is conducted together with the turning operations on the exterior surface, and as was shown in #14, Chapter V, the following operations differ according to the profile of the machined hole: Turning cylindrical and conic tubes and deep openings of more complex profile (for instance, charge chambers and cylindrical and conic tubes).

According to character of machining, or according to degree of accuracy of dimensions of the hole obtained and smoothness of its treated surface, turning is divided into coarse, semi-fine, and fine.

Coarse turning has the aim of removing the thickest layer of the margin remaining on the stock and removing the defects in the stock after its drilling, heat treatment, and correction (curvature and variations in wall thickness of the hole, unevenness and steps in the surface of the hole, and interior stresses in the metal). During coarse turning, 50 to 65% of the total margin is usually removed, leaving for heat treatment a layer of metal approximately 4 to 7 mm thick on a side. Coarse turning is conducted [illegible] the maximum cutting rates (by speed and feed) so as to remove the required amount of margin in the least time and make the tube bore straight. During coarse turning, however, as a result of cutting tool wear, the mentioned defects may not be totally eliminated.

As a result, after coarse turning, the tube bore will be conical, varied in wall thickness, and its curvature will be significantly decreased, but not fully eliminated. To decrease the remaining defects after coarse treatment of the bore, semi-fine turning of the exterior surface of the tube is usually conducted (with built-up barrels, the final turning of the internal tube).

Semi-fine turning is intended to eliminate defects remaining after coarse turning of the bore and semi-fine turning of the exterior surface of the tube. During semi-fine turning, variations in wall thickness of the tube and curvature in its bore must be totally eliminated, and the tube bore usually turns out straight or may have a curvature within allowable limits. Thickness of the layer of metal removed during semi-fine turning is uniform throughout the tube length and on the circumference of its bore, which assures the normal work of the turning head throughout the entire operation. During semi-fine turning, a margin of 2 to 4 mm on a side is usually removed. Semi-fine turning is a necessary operation, but in some instances the tube may be immediately subjected to fine turning after coarse turning. Elimination of the semi-fine turning operation is possible only under conditions where the technological processes of drilling and heat treatment of the tube stock are sufficiently well mastered and the mentioned defects are not encountered. Semi-fine turning is sometimes excluded on relatively short tubes, with a tube length not greater than 3 to 4 m and the bore diameter over 90 to 100 mm.

After semi-fine turning of the tube bore, the following defects may still remain:

Bore conicity up to 0.2 mm;

coarse-cutting marks on the machined surface with a surface smoothness no greater than ∇5;

curvature and variations in wall thickness within the limits allowable for norms of finished tubes, or somewhat larger than them.

Fine turning has the aim of getting the tube to the required assigned technical conditions in drawings, or the bore must be straight and cylindrical (must be perfectly circular in section), and its surface must have a smoothness no less than ∇6. For the majority of artillery system tubes, fine turning is the final machining operation of their bores, and only tubes whose surfaces are gun barrel bores, working cylinders of antirecoil mechanisms, and special purpose tubes, for which a surface smoothness no less than ∇8 or ∇9 are required, undergo the special operation of polishing or honing. A margin of 0.05 to 0.15 mm on a side remains for these operations.

For fine turning, two cutters (two cutting blades) are most often used, one of which, rigidly fastened into the turning head eliminates ovality, variations in wall thickness, and remaining bore curvature; and the other, free-floating (not rigidly fastened into the turning head), creates the cylindricality of the bore, bringing the bore diameter to the required dimension and providing the necessary smoothness of surface.

The margin for fine turning usually comprises from 0.5 to 1.5 mm on a side.

Fine turning is performed immediately after semi-fine turning of the tube bore, and then follows turning of the charge chamber, fine turning of the tube on its exterior surface, and other operations. All operations on turning of the tube are performed on special horizontal drilling and turning machines and require special attachments, tools, and installations. For each type of turning operation, it is necessary to consider the type of material and dimensions of the tube and use the most profitable machining rate.

For fine turning of small diameter tube bores (up to 100 mm) the drawing operation may be substituted for fine turning. This operation, however, requires special machines and a complex of broaches.

According to the character of work of the machining tool, turning may be performed by the compression method and by the tension method.

Turning by the method of compressing the machine tool is that operation in which the turning head (2) and shaft (1) of the machine are pushed through the tube bore (7), and the shaft and turning head experience compression, linear bending, and twisting (Fig. 78).

Turning by the method of putting tension on the machining tool consists of the fact that the cutting head (2) and shaft (1) of the machine in working configuration are drawn through the tube bore so that the shaft and the cutting head experience tension and twisting (Fig. 79).

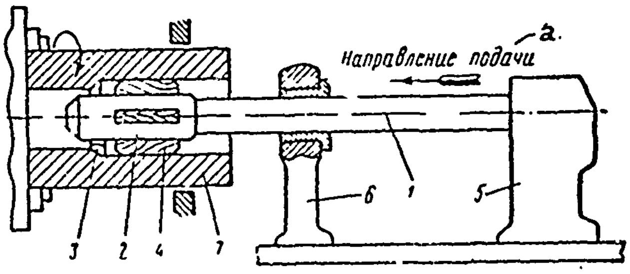


Fig. 78. Schematic of turning by the compression method

Key:
1. machine shaft
2. turning head
3. cutter
4. guiding keys
5. support
6. shaft bearing
7. tube
a. direction of feed

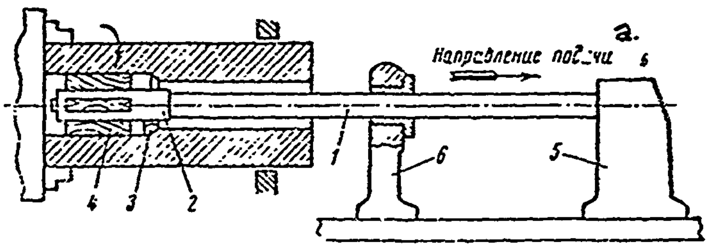


Fig. 79. Schematic of turning by the tension method

Key:
1. machine shaft
2. cutting head
3. cutter
4. guiding keys
5. support
6. shaft bearing
a. direction of feed

Both these methods of turning are widely used in production of tubes.

Turning in the compression method is used for deep holes of greater than 80 mm in diameter with sufficient stability of the machine shaft and the turning head. With this method, adjustment of the operation, setting of the cutting head, and checking on the course of the operation are more comfortable and accessible. Besides this, shavings do not fall on the head body and do not adhere to the exterior surface of the guiding keys (4) (see Fig. 78).

For deep holes smaller than 80 mm in diameter, stability of shaft and turning head in this method of turning would be insufficient, and vibration of the shaft would arise; the normal work of the head cutting tool would be destroyed and the quality of turning would be decreased.

During turning with the tension method, the machine shaft and turning head, even during turning of small diameter (30 to 45 mm) deep holes, work comparatively quietly with insignificant vibration. For this reason small diameter tubes (up to 80 mm) are usually turned with the tension method. However, setting up a cutting head before the beginning of the operation and observance of the course of the operation in this method of turning are made more difficult and inconvenient because it is necessary to conduct all these from the side of the chuck or special spindle face plate attachment. Shavings exhaust is also somewhat more difficult because the shavings carried away by the cooling liquid move through the longitudinal grooves of the exterior surface of the turning head body, move into the guiding keys, and with this, periodically destroy the work of the turning head and shavings exhaust. These reasons limit usage of the tension method of turning in production.

The types of movement of the machine tube and the tool have essential meaning during turning of deep holes. The most widely used method in production is that in which the machine tube performs a rotary movement, and the tool a linear feed.

Rotational movement of both feed tool and the machined product, with the tool also performing linear feed, is significantly more rarely used. These types of movement are sometimes used during drilling of small diameter deep holes.

Sequence of performance of turning operations.

After heat treatment and checking, the stock is a tube resembling the finished part in external appearance (Fig. 80, a).

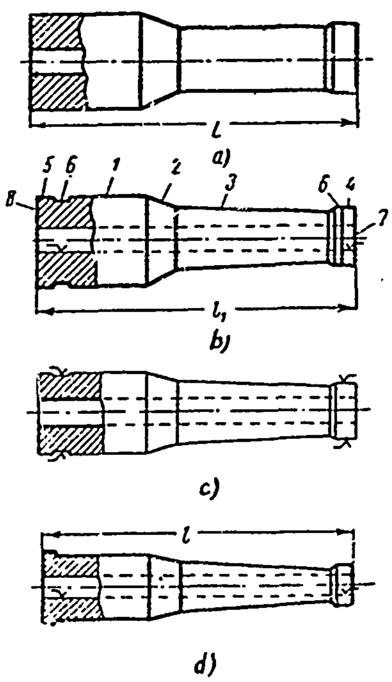


Fig. 80. Schematic of machining treatment of the exterior and interior surfaces of a tube

Key:
- a. stock after heat treatment
- b. turning of exterior surface
- c. coarse turning of bore
- d. semi-fine turning of exterior surface

TABLE 26

Tube Machining Operations

	Inner tube of built-up barrel ($d = 210^{+0.2}$ mm, = 8000 mm)	Free liner ($d = 203^{+0.2}$ mm)
	Stock -- solid forging	Stock -- solid forging
	Operations:	Operations:
1.	Removal of fringe and trimming of faces	Removal of fringe and trimming of faces
2.	Marking and centering faces	Marking and centering faces
3.	Peeling the exterior surface of the forging	Peeling the exterior surface of the forging
4.	Ring drilling of the bore to a diameter of 18? mm	Ring drilling of the bore to a diameter of 176 mm
5.	Checking of stock after heat treatment	Checking of stock after heat treatment
6.	Trimming of faces and removal of discs for stock metal mechanical testing	Trimming of faces and removal of discs for stock metal mechanical testing
7.	Coarse turning of the exterior surface and turning of the technological base cheeks	Coarse turning of the exterior surface and turning of the technological base checks
8.	Coarse turning of the bore to a diameter of 19? mm	Coarse turning of the bore to a diameter of 194 mm
9.	Semi-fine and fine turning of the exterior surface of the assembly section of the tube	Semi-fine turning of the exterior surface
10.	Assembly of tube and jacket	Semi-fine turning of the bore to a diameter of 201 mm
11.	Semi-fine turning of the bore to a diameter of 206 mm	Fine turning of the bore to a diameter of $203.1^{+0.15}$ mm
12.	Fine turning of the exterior surface of the jacket	Turning of the charge chamber
13.	Fine turning of the bore to a diameter of $209.9^{+0.15}$ mm	Technical control of tube
14.	Turning of the charge chamber	Polishing the bore to a dimension d
15.	Technical control of the tube	Rifling the bore
16.	Polishing the bore	Technical control of the tube
17.	Rifling the bore	Fine trimming of the exterior surface of the tube
18.	Technical control of the tube	Fine turning of the faces, and rifling and slide surfaces
19.	Fine turning of faces, and rifling and slide surfaces	Finish metal working operations and technical control of the tube

The tube stock goes into the lathing operation. The interior surface of the tube's bore serves as the base for its installation on the machine for the lathing operation. The steps of the lathing operation for machining the stock and the sequence of their performance are shown by the numbers on Fig. 80, b. After turning of the exterior surface of the stock and steps (1) through (5), fine turning takes place on the cheeks (6), which will later serve as the technological bases for its installation on the machine for coarse turning of the bore. Fine trimming then takes place on the stock faces from the muzzle (7) and breech (8) parts, with a margin on the stock length ℓ_1 being left for its final fine machining and later operations. During the lathing operation, a layer of metal of the largest possible thickness is removed and at the same time residual stresses which arose during its heat treatment are eliminated. During the lathing operation, as already stated, the tube stock, freed from internal stresses, will change its form (perhaps warping), and it is therefore recommended that the turning of the base cheeks (6) takes place after machining of the exterior surface of the stock.

The next machining operation of the tube stock will be the coarse turning of its bore (see Fig. 80, c). For this operation, a tube is installed on the turning machine according to the technological base surfaces, the cheeks (6) whose position during lathe turning of the stock is determined with consideration for its future installation on the turning machine. During coarse turning, as already stated above, the basic defects in the tube bore are eliminated.

The next operation after coarse turning will be the semi-fine turning of the exterior tube surface (see Fig. 80, d) and trimming its faces to dimension ℓ. This operation for many gun tubes, with the exception of tubes of great length and liner tubes (thin-walled), replaces the completing fine operation. In this operation the interior surface of the tube bore serves as the base for installation and centering of it on the machine.

Then the semi-fine, and immediately after it the fine turning of the tube bore takes place. Installation of the tube on the machine does not change during either of these operations, and only the cutting head and its setting are changed. The technological base for installation of the tube on the machine during semi-fine and fine turning is its exterior surface, and turning of the cheeks is not performed for this purpose, especially if the tube has already been final machined along its exterior surface.

After fine bore turning, the charge chamber of the tube is reamed, leaving a margin throughout the bore for the finishing operation, or polishing. In some instances the final completing operation is the fine turning of the exterior tube surface. As an example, we will take the basic machining operations of an interior tube of a built-up barrel and a free liner, and the sequence of their performance (Table 26).

#24. Setting of Boring Operations During Tube Boring

The successful accomplishment of the boring operation during boring of tubes largely depends on the preparation and setting of this operation. These following tasks go into the preparation and setting of the boring operation:

Preparation and setting of the machine;

checking the straightness and parallelness of the machine shaft relative to the direction of its base;

installation, centering, and fastening the tube on the machine;

installation, centering (relative to the shaft and tube), and fastening of the boring head;

preparation of the boring head -- sharpening and installation of the cutters to the assigned dimension, setting the guiding keys to the assigned dimension;

preliminary turning of the tube to the diameter d and depth ℓ for setting of the head and preparation of the face cut of the tube (Fig. 81).

The boring machine must have a smooth main direction of feed, reliable and easy control of movement, and stands which are parallel in the vertical and horizontal planes. Throbbing of the spindle (drum) of the main movement box must be within the limits of assigned machining accuracy (see Chapter IX). The rigidity of mechanisms and lunettes on which the tube is installed and fastened on the machine should be checked before boring.

The machine shaft, which bears the boring head on its end, must be cylindrical and have no curvature, and its axis must coincide with the axis of the spindle (drum) of the main movement transmission. During movement of the frame, the shaft must remain strictly parallel to the guiding stand.

The tube being bored is fastened into a chuck or a special attachment of the major movement transmission and rests on lunettes of the stand. The surfaces of the base cheeks of the tube must be concentric relative to the axis of the spindle (drum) of the main movement transmission. This provides the concentricity of the tube and shaft.

For concentricity of the turning head and shaft, it is necessary to have the mass of the head equally distributed relative to the axis of rotation, which provides smooth (without dents) guiding surfaces and threading on the tail portion of the head during its preparation.

Insignificant d iations in concentricity or loose fastening of the boring head on the shaft will lower the quality of machining of the bore during boring.

If the boring head has two or three cutters, the front cutter (2) is sharpened like a moving cutter, and cutter (3), following it, is sharpened like a fine cutter (Fig. 81). With this, the front cutter (2) is displaced relative to the fine cutter inasmuch as it has a cutting depth t_1 equal to approximately

65 to 70% of the overall margin t for one pass on a side for the given operation, and the fine cutter (3) has a cutting depth t_2 equal to approximately 30 to 35% of the same margin t on a side. Installation of the fine cutter must provide attainment of a hole of diameter d assigned for the given operation, with deviation from this diameter only on the plus side, and especially for coarse boring up to +0.2 mm, and for fine boring up to +0.1 mm. The head cutters must be securely fastened to the head, and their cutting edges must be accurately installed along the center of the bored hole.

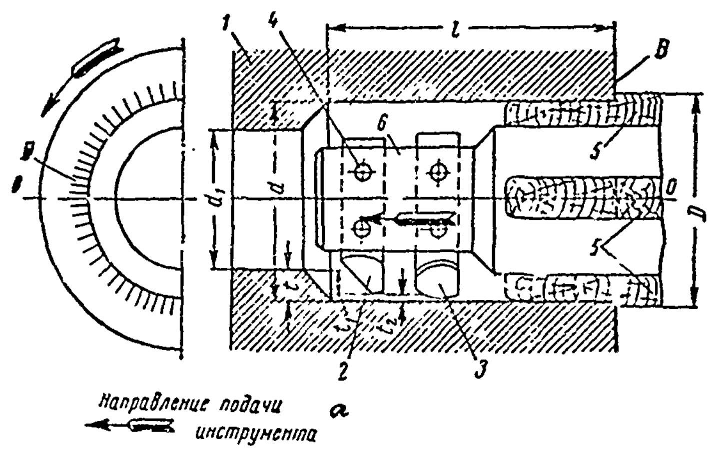


Fig. 81. Schematic of operation setting for boring deep cylindrical holes

Key:
- 1. stock
- 2 & 3. cutters
- 4. cutter fastening screw
- 5. guiding keys
- 6. head body
- a. direction of tool feed

External diameter D of the guiding keys (5), securely fastened into slots in a boring head, must be larger in diameter than the hole d by a strictly determined amount (see Figs. 81 and 94). This difference in diameters must be equal to 1 to 2 mm for coarse boring and 0.5 to 1 mm for semi-fine and fine boring. The smaller of these limits is for tubes 50 to 100 mm in diameter, and the larger is for tubes greater than 100 mm in diameter.

After the keys are fastened into the slots of the boring head, their exterior surfaces are ground on a machine to their required dimensions and must be clean and smooth.

Before the tube is bored, it undergoes preliminary boring to a diameter d assigned for the given operation, up to a depth ℓ = (1.0 to 2.0)d, which assures entry into its bore of the boring head to the entire length of its guiding keys, or to no less than 70% of their length. Diameter d of the preliminary hole is determined technologically in dependence on the type of boring (coarse, semi-fine, or fine) and the tolerance on this diameter must be half that of the given operation, or +0.1 mm for the coarse operation and +0.06 mm for the fine operation. The axial line (or center of stock face) of the hole attained must, throughout its entire length ℓ, strictly coincide with the axial line along which the base cheeks of the exterior surface of the stock are turned. Besides this, this preliminary hole must be strictly cylindrical because the direction of its axial line is the direction of feed for the boring head during tube boring. A center of the preliminary hole of diameter d on length ℓ may not coincide with the center of the hole of diameter d_1 which was already drilled or earlier bored in the stock.

After preliminary boring of the tube to length ℓ, notches B (see Fig. 81) are formed on its face with a thin chisel. The part of the wooden guiding keys (5) exceeding exterior diameter D is cut off during entry of the boring head into the preliminary hole along these notches which have the appearance of sharp ridges, inclined to the side of tube rotation.

The preliminary hole of depth ℓ and diameter d which is prepared by this means serves as the technological base (in plant practice it is often called the incubator) for installation of the boring head into the initial position and for its direction in the process of tube bore boring.

The boring head, fastened onto the machine shaft, is inserted into the opening under the action of feed force with simultaneous tube rotation. During entry of the boring head into the hole, its guiding keys (5), under action of the feed force, will be compressed and the small remaining difference between diameters D and d will be eliminated by having the keys cut by the sharp ridges B on the tube face. If the difference between diameters D and d is significant, as it sometimes reaches up to 4 to 10 mm, then cutting of the keys' surfaces will turn out coarse and uneven, resulting in their significant loss of purpose, direction of the boring head.

Setting up the boring operation, and especially preparation of the preliminary hole in the stock and preparation of the boring head, are very important throughout the boring operation. A correctly prepared boring head, especially the accurate and smooth turning of its guiding keys to the required dimension, assures normal conditions for accomplishment of boring and elevate its quality.

§25. Setting of the Boring Head

Coarse and fine boring operations, regardless of differences in conditions and boring head, work rate, and other factors, also have much in common, which eases planning and usage of boring heads. Boring heads differ basically by the following:

1) Number and location in them of cutters -- one-cutter, two-cutter, and multi-cutter, with one-sided and two-sided cutter locations;

2) fastening of the head and machine shaft and fastening of the cutters in the head body;

3) distribution of the thickness of shavings removed between separate cutters according to cutting depth and type of shaving crushing for their exhaust under pressure of the cooling liquid;

4) purpose of the head -- for coarse and fine boring operations.

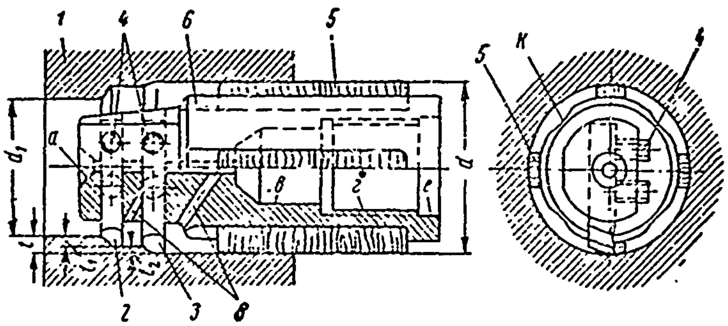


Fig. 82. Two-cutter boring head with one-sided cutter location

Key: 1. tube
2 & 3. cutters
4. screws
5. key

Fig. 82 shows construction of a two-cutter boring head with one-sided cutter location. The body (6) of this head, as in other type heads, is manufactured of medium-hard steel and is most often hollow. The interior surfaces ϐ, i, and b of the body serve for intallation and centering of the head on the machine shaft, and the linear opening in it, for supply of cooling liquid to the cutters. The cooling liquid, moving through the inner hollows in the shaft and head, then moves through canals (8) to cutters (2) and (3). In the front part of the head, its linear opening and a conic expansion a, which is the technological base for installation of the head on the special machine for regulation on and of cutter position and turning of the guiding keys. During turning of the tube, this opening is closed with a special threaded plug. Cutters (2) and (3) of the boring head are distributed in its front part, and each of them is fastened to the body by two screws (4). Four guiding keys (5), providing head direction and stability in the hole boring process, are fastened into slots in the exterior surface of the head body. To lighten the head, four channels K are formed between the keys (5) on its body. These are especially important for large diameter boring heads. For joining the boring head with the shaft, a strong fastening in the form of a two- or three-course thread i is used, assuring, besides this, convenience in installation and screwing the head onto the machine shaft.

Centering services b and e of the boring head and corresponding services of the shaft are most often machined to third class sliding precision with a minimum clearance, about 0.05 mm, for sufficiently easy installation and removal of the head from the shaft at maintenance of their coinciding axes (centering). Besides this, surfaces b, i, and e also serve for installation of the head on a mandrel with which the centering hole a of the head can be installed on a lathe for turning the exterior surfaces of its guiding keys (5) and checking the position of cutters (2) and (3).

On the outside the boring head must have a smooth and clean surface, and all edges must be rounded with large radii. This provides normal conditions for work of the boring head, eases cleaning of the shavings, and eliminates adherence of the shavings to the head body and to the guiding keys, with which deep scratches may be formed in the surface of the tube. The described boring head works by the compression method (pushing through) with shavings exhaust by a stream of cooling liquid under pressure of 3 to 5 atm, and can be used for both coarse and fine boring.

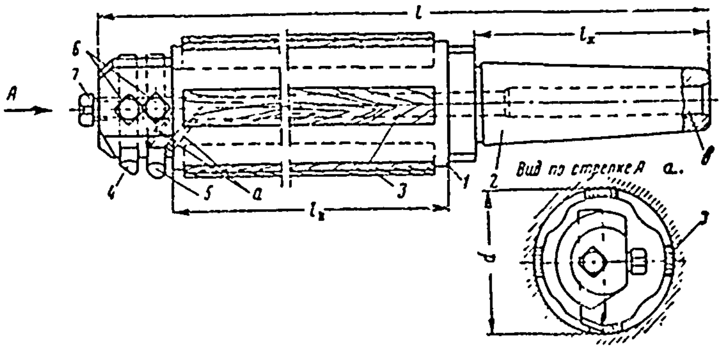


Fig. 83. Two-cutter boring head with one-sided cutter distribution and conic tail

Key: 1. head body
2. head tail
3. guiding keys
4 & 5. cutters
6 & 7. cutter fastening screws
a. view along arrow A

A two-cutter boring head with one-sided cutter location and a conic tail section to connect it with the machine shaft is shown in Fig. 83. The head body is hollow and has a longitudinal d and lateral a channel along which the cooling liquid is conducted to the cutters and is exhausted together with shavings. The front part of the hole of canal b is covered with cutters (4) and (5) and screw (7). The first cutter (4), removing the largest thickness of shavings (close to 70% of the thickness of the metal layer removed), is fastened to the head body by screws (6) and (7), and the second cutter (5), which encounters significantly less cutting effort than the first, is fastened by only one screw (6). Fastening the second cutter by one screw, however, is allowable only in boring heads less than 80 mm in diameter. In cutting heads greater than 80 mm in diameter, each of the cutters should be fastened with two screws. To provide strong and reliable fastening of the cutters, holes for them in the head body should be accurately machined, and, if necessary, the cutters should be fit to the holes with grinding.

For direction of the head, four guiding keys (3) are used each of which is of length approximately $0.8\ell_K$, which is the body length.

Head body length ℓ_K for all types of boring heads is determined by the relationship

$$\ell_K = (1.0 \text{ to } 2.0)d,$$

where d equals the diameter of the bored hole.

The smallest of these limits (1.0d) should be used for boring heads of large diameter (d = 200 mm), and the large limit for heads of small diameters (d = 40 mm).

The boring head is joined to the machine shaft with a conic tail section (see Fig. 88). This type of connection is simple and convenient in manufacture and in assembly of the head with the machine shaft, and also provides proper centering of the head on the shaft and reliable fastening. With insufficiently smooth contact surfaces of the head and shaft and with the presence of grease on them, the head will be poorly centered and will be displaced during its work, which may cause highly undesirable results and even ruin of the tube. To increase fastening reliability of the head and machine shaft, an additional fastener in the form of a wedge is sometimes used (see Fig. 88, position 8). Tightening of such a wedge with hammer blows may lead to splitting of the wedge and the edges of the hole in the shaft, and to the appearance of dents in the shaft surface. Turning of the head guiding keys on a lathe is conducted with installation of the head on the centering hole in its front face and on the tail face. The conic tail section of the head ℓ_X usually has a length of 0.8 to 1.7d.

The overall length ℓ of this type of boring head is equal to 2.1 to 4.4d, with the smaller limit used for large diameter boring heads, and the large limit used for small diameter boring heads.

The overall dimensions of two-cutter boring heads with one-sided cutter position and conic tails for various diameters are presented in Table 27, from which it is evident that the presence of the tail significantly increases the overall length of the boring head, which is also a deficiency. For this reason, boring heads with conic tails for boring holes greater than 150 mm in diameter are used very rarely. The head with threaded fastening to the machine shaft is most widely used (see Figs. 85 and 87).

TABLE 27

Dimensions of Two-Cutter Boring Heads with One-sided Cutter Position and Conic Tail (see Fig. 83)

No.	Dimensions in mm and coefficients characterizing their relationship	Diameter d of the bored hole in mm			
		50	100	150	200
1	Length of dimension ℓ_K Coefficient $K_K = \ell_K/d$	100 2.0	160 1.6	170 1.15	200 1.0
2	Length of tail section ℓ_X Coefficient $K_X = \ell_X/d$	80 1.6	130 1.30	150 1.0	160 0.8
3	Overall length ℓ Coefficient $K_y = \ell/d$	230 4.6	360 3.6	405 2.7	440 2.2

Boring heads with conic tails which are working with the method of compression (pushing) are widely used for coarse and fine operations. It is, however, completely impossible to use the method of fastening a boring head with a conic tail for heads working in the tension method, even with the presence of a wedge (see Fig. 88).

Among the multi-cutter boring heads in Fig. 84 is shown a three-cutter boring head with two-sided cutter position. This type of boring head is used for coarse and semi-fine (preliminary) boring of holes greater than 150 mm in diameter. In two-sided cutter position, the first cutter removes shavings of thickness close to 55% of the thickness of the margin to be removed by the head, and the other two cutters, located on the other side of the head, remove the remainder of the margin. With this cutter position, cutting effort is more evenly distributed. Coarse boring with three-cutter heads is more productive than with two-cutter heads, i.e., in one pass these heads can remove a layer of metal 12 mm thick on a side; and besides that, with three-cutter heads, shavings formed are lighter and cutter stability is increased. All these advantages of three-cutter heads are very important during boring of tubes greater than 6000 mm long. Otherwise, construction of the three-cutter head is similar to construction of those already described, and is sufficiently clear from Fig. 84.

Another type of multi-cutter boring head is the eight cutter boring head shown in Fig. 85. This type of high production boring head, with six or eight cutters, is used for coarse operations.

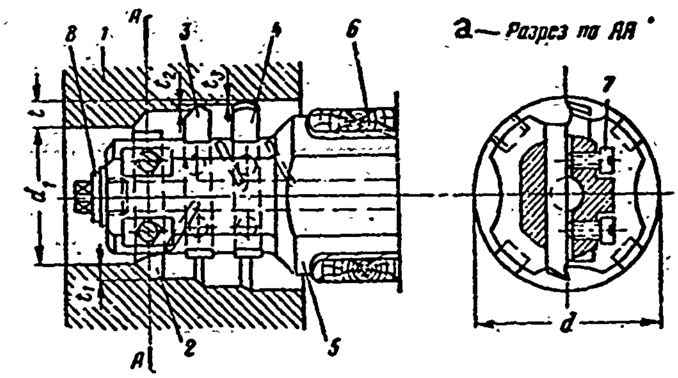


Fig. 84. Three-cutter boring head with two-sided cutter position

Key: 1. machined stock
2, 3 & 4. cutters
5. head body
6. guiding keys
7 & 8. cutter fastening screws
t_1. first cutter cutting depth
t_1 & t_2. second and third cutter cutting depth
a. cut across AA

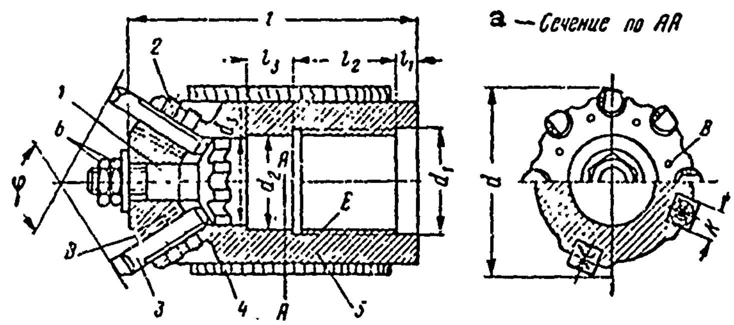


Fig. 85. Eight-cutter boring head

Key: 1. support cone for cutters
2. cutter fastening screws
3. cutters
4. guiding keys
5. head body
6. nut and stop nut for support cone position regulation and fastening
B. canals for cooling liquid supply
E. band threads for fastening head to shaft
a. section across AA

The six-cutter head is usually used for boring holes of the smallest diameter (d = 70 mm), and heads with a large number of cutters are used to bore holes of large diameters. The eight-cutter head, for instance, is used to bore holes 110 mm in diameter and larger. Multi-cutter heads sharply differ from one- and two-cutter heads in construction of cutters, their position, and their fastening. Cutters in these heads are round and calibrated. They are positioned evenly around the circumference of the head and are located in the nests at an angle of $\phi = 120^{\circ}$, as shown in Fig. 85. The cutters are installed in the nests, rest on the surface of the support cone (1) and are each fastened by two screws (2). The support cone has a thickening along diameter d_3, which is precisely fitted along the interior surface of the head. This thickening serves as the centering surface relative to the head body. With the help of a support cone, the nut and stop nut (6) can easily regulate the dimension of the projecting portion of the cutters, both initially and after they have been resharpened after wearing. Multi-cutter head cutter design is shown in Fig. 86. The front part of the cutter is manufactured from bronze of special fast-cutting tool steel, and its tail portion is manufactured of regular carbon steel. The parts of the cutter are welded together.

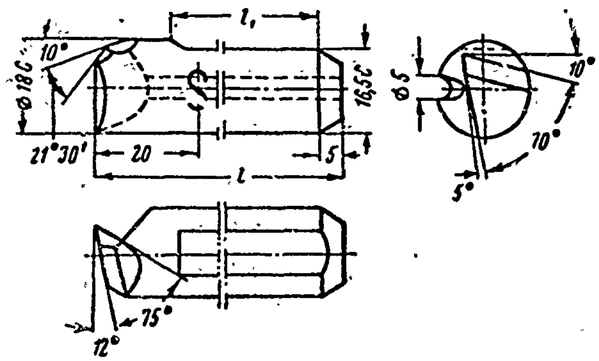


Fig. 86. Cutter for boring head shown in Fig. 85
(R9 steel)

The dimensions of the cutters shown in Fig. 86 have the following values:

For a hole diameter d = 70 mm, ℓ = 68mm, and $_{1}$ = 48 mm;
for a hole diameter d = 110 mm, ℓ = 75 mm, and $_{1}$ = 52 mm.

Four guiding keys (4) of the multi-headed boring head are located on the body and fastened to it by the usual means for all boring heads (see Fig. 85). The cutting edges of the cutters must be located on one plane, and feed per revolution is divided by the number of cutters. For multi-cutter boring heads, the following cutting rate is recommended: Cutting depth or thickness of metal layer removed, from 5 to 10 mm, cutting rate from 15 to 20 m/min, and feed from 1.0 to 2 mm per revolution. The basic dimensions of multi-cutter heads are shown in Table 28.

TABLE 28

Basic Dimensions of Multi-Headed Cutters in mm
(see Fig. 85)

d	d_1	d_2	l	l_1	l_2	l_3	$\varphi°$	K	d_3
70	$50^{+0.05}$	$38A_3$	190	20	50	40	120	15	$35A_3/C_3$
110	$80^{+0.06}$	$60A_3$	220	30	60	50	118	18	$56A_3/C_3$

Threads E, by which a multi-headed cutter is connected to the machine shaft, is a right, right-angled, two- or three-course thread (for heads 70 mm in diameter, exterior thread diameter is 48 mm, interior thread diameter is 40 mm; for heads 110 mm in diameter, exterior thread diameter is 75 mm, interior thread diameter is 65 mm). The cooling liquid is conducted along the internal canal of the machine shaft through a groove in the support body, and then through the inclined opining B.

Fig. 87 shows another type of multi-cutter boring head, the four-cutter boring head with the floating blade (2). Cutter (1) of this head is a wedge-shaped blade which is installed in the body nest from the front face portion of the head and fastened in it by the ribbed surface B. During cutting, the force applied to the cutting edge of the cutter A increases the rigidity of the blades' fastening in the head body nest. Regardless of these peculiarities in fastening, however, the blades should be fastened securely and with equal force. Otherwise, with blades loosely fastened into the head body nest, they might be displaced at the initial moment of boring and almost not take part in cutting. The cutting edges of cutter A are the principal ones in that they remove up to 70% of the thickness of the metal layer in one pass; and cutting edges C are auxiliary, and later remove up to 10% of the margin and calibrate the hole, making its surface smoother. To obtain a tube bore which is accurate in dimensions and smooth, the head has a floating blade (2) which in one pass removes a layer of metal whose thickness is approximately 20% of the margin. The floating blade (2) is not fastened in the head body (4) but is accurately fitted in a hole in it so that it moves freely in a radial direction and does not have vibration during the cutting process. The cutting edge K of the front part of the blade removes the base part of the shavings at the same time that its remaining part on length ℓ is the calibrating one and works as a reamer. The floating blade consists of two parts which are securely fastened together on ribbed surfaces with two screws (5). This blade's fastening construction allows regulation of its position according to the diameter of the bored hole, and also allows repeated sharpening after its wear. To crush shavings, grooves (shaving breakers) are formed on both laterial cutting edges of the blade. The distances between these grooves vary and do not coincide on the two opposite cutting edges. Cooling liquid is supplied to the cutters through an interior canal through opening F and through the inclined holes D. Small grooves are

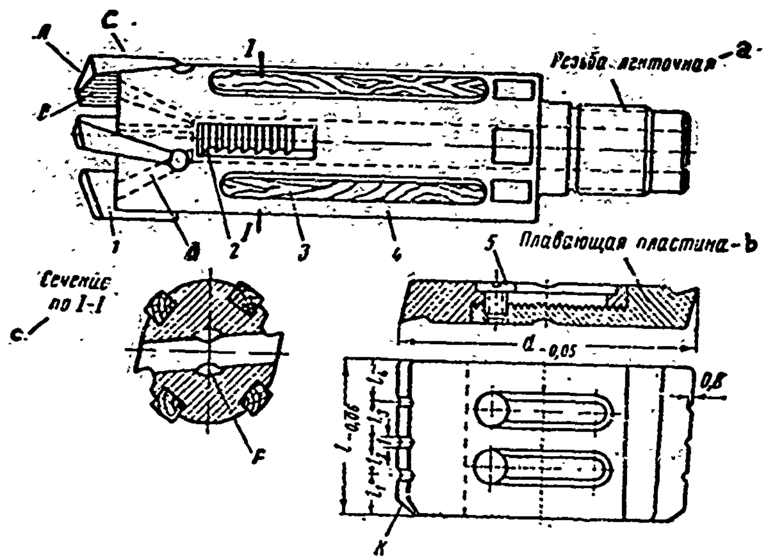


Fig. 87. Four-cutter boring head with floating blade

Key:
1. cutter
2. floating blade
3. guiding keys
4. head body
5. fastening screws for assembled floating blade
A. main cutting edge
B. ribbed surface
C. auxiliary cutting edge
D & F. canals for cooling liquid
K. main cutting edge of the floating blade
a. band thread
b. floating blade
c. section across I-I

formed on the exterior surface of the blade to increase the section of the passage canal hole F. The described boring head is used for semi-fine and fine boring. For another example of blade cutter use in boring heads, Fig. 88 shows a boring head with two cutter blades. The front blade (3) of this head securely fastened to the body (2) by screw (1), and the rear blade (5) is fastened in a stationary position in the body for coarse boring, and remains free-floating for semi-fine and fine boring. The boring head is fastened to the machine shaft with a conic tail section and wedge (8). This connection is reliable and is used for the compression method of hole boring. To remove the head from the machine shaft, it is necessary to extract wedge (8), and then, after unscrewing stop (6), which rests against the face of the shaft (7), the head easily moves relative to the machine shaft.

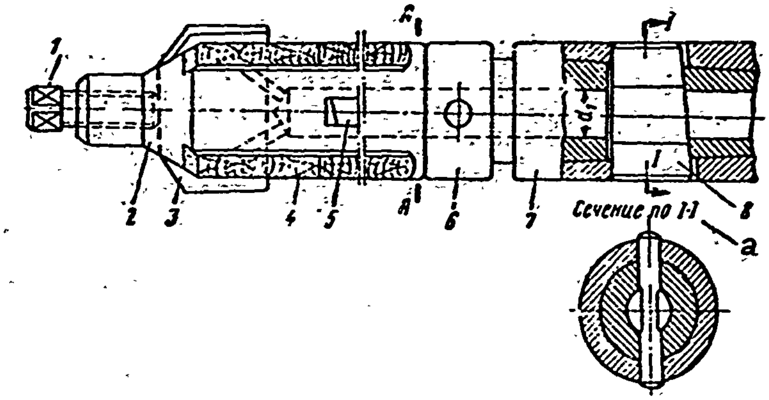


Fig. 88. Boring head with two blades

Key:
1. front blade fastening screw
2. head body
3. rigidly fastened blade
4. guiding keys
5. floating blade
6. threaded support stop
7. shaft
8. fastening wedge
a. section across I-I

Fastening of the boring head onto the machine shaft may also be accomplished with threads, as shown in Fig. 87. In this instance, the head may work by the tension method, and the stationary blade (2) should be located behind section AA, and it is necessary to somewhat lengthen the section of the head body between stop (6) and keys (4), and conversely, to shorten the end part of the body with screw (1)(see Fig. 88). Fastening of the blades in the head in this instance is accomplished with only lateral screws. This head construction is used primarily for drilling small holes, up to about 75 mm in diameter. For these holes, use of head construction with radially (laterally) located cutters, as shown in Figs. 82 to 84, is significantly more difficult and therefore use of floating cutters instead of them are more rational.

Fig. 89 shows two constructions of blades used in boring heads, with geometric information on their points. One of these blades (see Fig. 89, a) can be used both rigidly fastened to the head body and floating, and the other (see Fig. 89, b) is stepped and works only as a stationary one, rigidly fastened to the head body. In a stepped blade: Cutting edge (1) removes up to 50% of the thickness of the margin metal layer in the operation; cutting edge (2) is a cleaner, or removes an insignificant layer of metal and provides the required accuracy of hole dimension; cutting edge (3) removes up to 30% of the margin in the operation; cutting edge (4) cleans the surface; and cutting edge (5) removes thin shavings and provides smoothness and the required precision of the hole being bored. This edge is made longer and wears very little (see

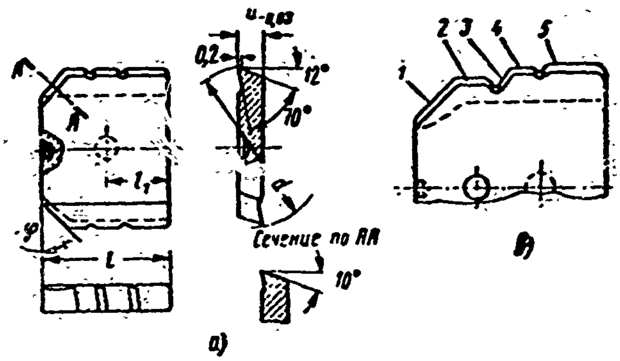


Fig. 89. Construction and geometry of blades for boring heads

Key:
- a. rigidly fastened front blade
- b. rigidly fastened stepped blade for division of cutting depth into layers
- 1. main cutting edge of first step
- 2. auxiliary cutting edge of first step
- 3 & 4. main and auxiliary cutting edges of second step
- 5. cutting edge for fine machining
- a. **section across AA**

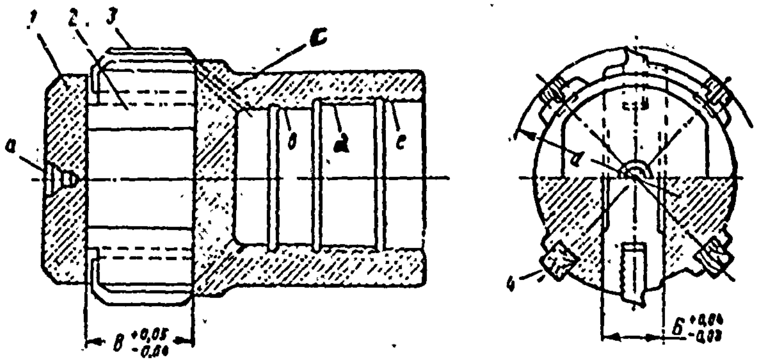


Fig. 90. Boring head with floating blade

Key:
- 1. head body
- 2. floating blade body (base)
- 3. cutters, rigidly fastened to the base
- 4. guiding keys
- a. centering hole
- c. cut-out for cooling liquid
- b & e. smooth centering surfaces of the head
- d. band thread

Fig. 89, b). The stepped blade, therefore, has in essence three cutters: Coarse, semi-fine, and fine. This blade crushes shavings well and is small in dimensions, which is its major advantage.

A boring head with a floating blade, used for fine boring of large diameter holes, is shown in Fig. 90. In this head the base ([illegible]) of the floating blade is manufactured of usual carbon steel, and the cutter blades ([illegible]) are manufactured of fast-cutting steel. Fastening of blade ([illegible]) into the head base is accomplished the same as in the boring head in Fig. [illegible].

The boring head with floating blade, working on the principle of reaming, provides a smooth cylindrical bore.

This head maintains the direction of the bore axis which was attained in previous operations, gives the sections the proper form, and provides uniform diameter throughout the length of the tube. This head is insufficiently productive, however, and therefore its use in production is limited. The cooling liquid arrives at the blades along the internal canal and through the inclined holes c.

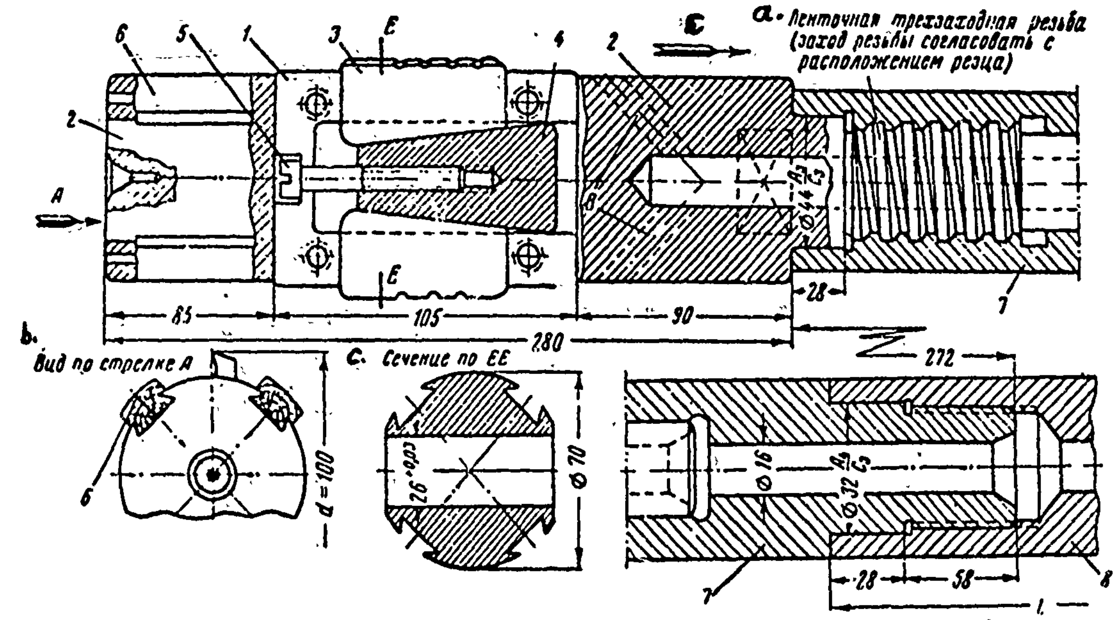


Fig. 91. Boring head with reamer for fine boring

Key:
1. assembled reamer body
2. head body
3. cutter blades
4. wedge for cutter position adjustment
5. screw
6. guiding keys
7. intermediate shaft
8. shaft
9. canals for cooling liquid
C. direction of feed working motion
a. three-course band thread (thread turns agree with cutter position)
b. view along arrow A
c. section across EE

Fig. 91 shows a boring head with a reamer for fine boring which works on the tension method. The reamer is an assembled floating blade with two cutter blades (3) (Fig. 92). The reamer is freely installed in the slot in head body (2). Adjustment of the cutter positions to the diameter of the hole being

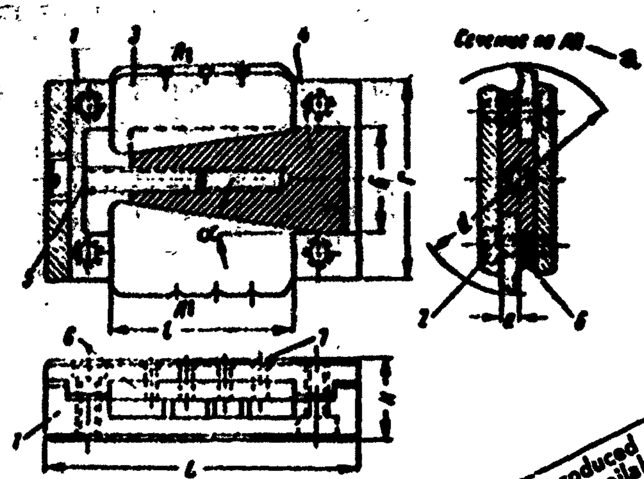


Fig. 92. Reamer

Key:
1. assembled reamer body
2. assembled body fastening screws
3. cutter blades
4. wedge
5. adjusting screw
6. spacers
7. spacer fastening screw
a. section across AA

bored is accomplished with wedge (4) and screw (5). The reamer has the properties of a floating blade and, besides this, has the following advantages over whole and composite blades. The cutting edges of the reamer cutters are all located in one section along the diameter, while in whole blades they are displaced by half the thickness of the blade, and therefore the point geometry of the blade is distorted. The reamer cutters can be set to the diameter of the hole being bored after their sharpening. The assembled reamer is significantly larger in dimensions (length L and height H) than whole blades and therefore it is used only for boring of holes 55 mm and over in diameter, and blades are used for boring smaller diameters. The reamer may be used both alone and in combination with the rigidly fastened blades shown in Fig. 88. Fastening of the boring head with reamer to shaft (8) of the machine is accomplished with the threaded tail and intermediate shaft (7), or immediately to shaft (8) of the machine without the intermediate shaft. The intermediate shaft allows use of various-sized heads on the same machine shaft. A boring head with reamer and conic tail section, working on the compression method (pushing through) is found in production. This does not work as well as the head working on the tension method.

TABLE 29

Basic Reamer Dimensions for Boring Heads in mm
(see Figs. 91 and 92)

a Обозначение размеров	Диаметр растачиваемого отверстия в мм b				
	54—62	76—85	92—102	118—127	126—135
L	80	96	105	115	115
$l \pm 0{,}02$	40	52	58	65	65
$a_{-0{,}025}$	5	6	6	7	7
$H \pm 0{,}05$	20	22	24	30	30
$6 \pm 0{,}02$	20	30	36	48	50
Г	48	68	82	102	105

Key: a. Dimension designation
b. Diameter of the bored hole in mm

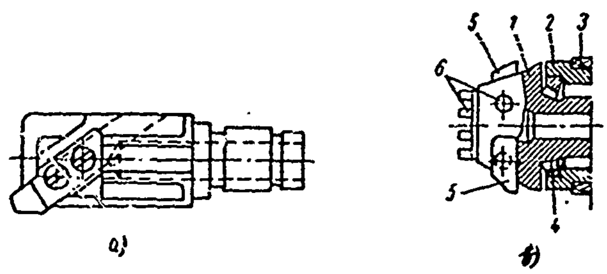


Fig. 93. Boring heads

Key:
- a. single cutter head for semi-fine boring with one-sided cutter position
- b. two-cutter head with two-sided symmetrical head position
- 1. head body
- 2. rotating jacket with keys
- 3, 4. rollers
- 5. cutters
- 6. screws

Constructions of other boring heads with reamers are sufficiently clear in Figs. 91 and 92. Table 29 presents the basic dimensions of reamers for the described type of boring heads. It should be noted that the working rate for boring head with a reamer or floating blades is somewhat smaller than for heads previously described.

A boring head with one-sided cutter position which is used for coarse and semi-fine hole boring is shown in Fig. 93, a. With installation in it of floating blades or a reamer, this head may also be used for fine hole boring. Fig. 93, b, shows the front part of a two-cutter head on which the guides (3) are fastened on a jacket (2) and rotate with the part on rollers (4) in relation to the hollow body of the head (1). The cutters (5) are fastened stationary relative to the head (1) by bolts (6).

126. Boring Head Guiding Keys

Guiding keys, fastened into the body of the boring head, give it support, absorb cutting force, and provide the direction for boring head movement in the tube (see Fig. 81).

Due to their property of elasticity in their slots, guiding keys ease vibration of the cutting head which arises during its cutting of the metal and smooth unevennesses in cutting force, especially during coarse boring. Fig. 94 schematically shows fastening of various guiding keys into boring head bodies. The materials from which guiding keys are manufactured are widely varied: Bronze, special wear-resistant alloys -- "Sormite", plastics, and hard types of wood (lignum vitae, box wood, oak, beech, and birch). The best of these materials is lignum vitae; however, it is used very rarely because of its expense and scarcity. The use of bronze guides does not give satisfactory results because it slides poorly along the rough (after coarse and semi-fine boring) surface of the bore, wears out quickly, and forms a clearance between the head and the bore walls, and during smooth boring, besides this, it leaves streaks on the surface of the bore. Guiding keys made of special alloys ("Sormite" and others) and of various plastics are free from these defects, and they therefore are widely used. Of all the materials listed, however, the most widely used in guiding keys are special types of oak, lignum vitae, and hard species of birch.

Hardwood has a good property of elasticity, as the result of which almost no clearance is formed between the machine's surface and the key. Besides this, the high degree of adaptability and sliding properties of wood smooth out unevennesses in the dynamic loads during cutting.

Guiding keys must be manufactured and fastened into the slots in such a way that the face of the keys' working surfaces coincides with the macined surface of the bore. In this instance, solidity of key fastening in the head slots, wear resistance, and sliding properties of the keys are significantly increased.

Sections of the slots for guiding keys in head bodies may be right angled or in the form of a dove tail. For boring heads up to approximately 100 mm in diameter, it is expedient to make these slots in the form of a dove tail, with an angle of inclination of 70°. Because in this instance, with relatively small slot dimensions B and t, fastening of the keys in them will be sufficiently reliable. In drilling of holes greater than 105 mm in diameter, it is expedient to use slots of right angled section in that these slots are easier

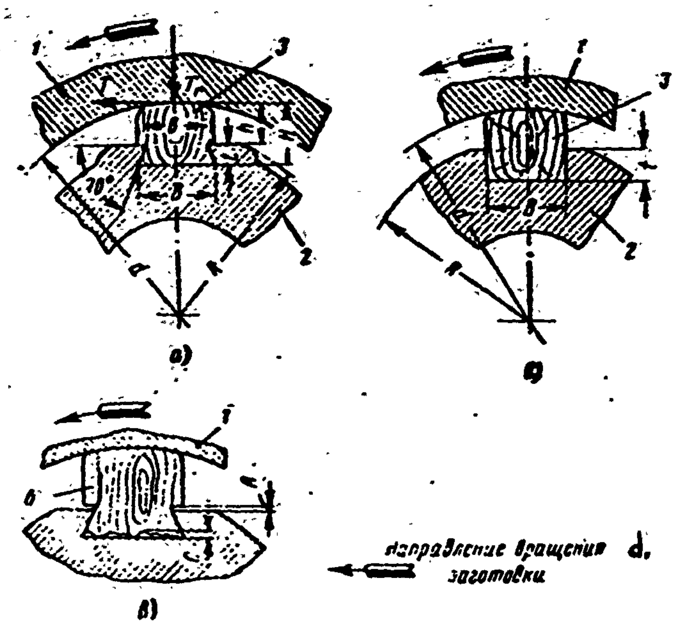


Fig. 94. Boring head guiding keys

Key:
- a. dove-tailed fastening of keys in slots
- c. slots for fastening keys of right-angled section
- b. improper key press fit
- d. **direction of stock rotation**
- 1. machined stock
- 2. boring head body
- 3. guiding key

to machine and key-fastening stability in them is sufficiently reliable. Slot width B for large heads must be no less than 20 mm with its sufficient depth t. Key dimensions B, t, h, and H (see Fig. 94, a) should always be chosen corresponding to the construction of the boring head and the diameter of the hole being bored. The base of the key, on which it sits in the head slot, should be machined smooth with a small margin for press fit.

Guiding keys are pressed into the slots so that there is no clearance A or free space C (see Fig. 94, b). With an inaccurate fit into the slot, key fastening will weaken during work of the head, and a clearance will appear between the key and surface of the tube. As a result of this, the key will not fulfil its purpose of guiding the head. Sharp lateral edges on the key should be rounded or made flat so that dimension b is 5 to 6 mm smaller than dimension B. Otherwise the key will be split by action of the composite force of friction T. The splitting and formation of a fringe weaken the key, enhance adherence of shavings to it, and make cleaning of the shavings by the cooling liquid more difficult. Besides this, the shavings, falling onto the exterior surface of the key, scratch and damage the surface of the tube and destroy the action of the key as a head guide.

The exterior surface of the key should be machined smooth on a lathe with its diameter 1 to 2 mm greater than the diameter of the bored hole, with the larger difference being used for heads of large diameters. When keys of special alloys or plastic are used, a thin layer of rubber is laid beneath them to increase their elasticity. Keys of right angled section may be used repeatedly by laying thin shims in the slots of the head.

#27. Cutting Rates

In tube boring the cutting rate is the most responsible part of the entire technological process of its machining.

In the establishment of the cutting rate, the mechanical properties of the metal of the machine's tube, tube length and diameter of the bored hole, construction of the boring head, type of cutter material, requirements for dimension precision and surface smoothness of the bored hole, and machine time spent on the operation, which must be as small as possible, should all be considered. Besides these listed factors, it is necessary to consider the others which were presented above in detail, for instance: The type of machine and attachments, production experience of the plant, and others.

Significantly larger cutting rates are usually allowed for coarse and semi-fine boring operations than for fine operations. In all boring operations, besides this, it is necessary to consider the durability of the cutter and its wear in that the operation must be completed without pause on the entire length of the bore. A change of cutters and stoppage of the machine during boring can lead to undesirable results, and sometimes to ruin of the tube.

During coarse boring, if a first cutter of the boring head is worn more than by 1 mm, the load on the second cutter will sharply rise, and it will quickly wear out. As the result of wear on the second cutter, the tube will attain conicity. For these reasons, wear of the first cutter greater than 1 mm cannot be allowed, and this is also true for the second cutter whose allowable wear can be established only through production experience.

For semi-fine boring, wear of the first cutter must not be greater than 0.3 to 0.4 mm so that the second cutter can work in comparatively normal conditions.

For semi-fine boring operations on long tubes, it is highly undesirable to have one rigidly fastened cutter and expedient to have a two-cutter head.

Cutter wear during fine turning must be within the very smallest limits, namely, no more than 0.12 mm for the first cutter, and for the second cutter, most often a floating blade or reamer, no more than 0.04 to 0.06 mm for one working pass.

Approximate cutting rates, in which are considered production experience and results of scientific and technical research in machining of special purpose tubes (gun tubes, petroleum industry tubes, etc.) are shown in Tables 30-33.

TABLE 30

Cutting Rates During Coarse and Semi-Fine Tube Boring Using Two-Cutter Heads with One-Sided Cutter Position

a. Диаметр растачиваемого отверстия мм	b. Глубина резания мм	c. Механические свойства металла обрабатываемой трубы								
		σ_b=65—75 кг/мм²			σ_b=85—100 кг/мм²			σ_b=100—115 кг/мм²		
		v м/мин d	n об/мин e	s_0 мм/об f	v м/мин d	n об/мин e	s_0 мм/об f	v м/мин d	n об/мин e	s_0 мм/об f
100	5	22,5	71,7	0,4	18,5	59	0,35	14,5	46	0,35
150		21,5	45,7	0,55	18,0	40	0,45	14,0	30	0,45
200		20,5	32,6	0,60	17,0	27,3	0,50	13,6	22	0,50
250		20,0	26,6	0,62	16,6	21,2	0,52	12,3	15	0,52
100	10	20,0	63,6	0,35	17,5	58	0,3	12,5	40	0,3
150		18,4	40,0	0,40	17,0	37	0,4	11,5	25	0,4
200		18,0	28,6	0,45	16,3	26	0,45	10,0	16	0,45
250		18,0	23	0,5	16,0	20,4	0,48	9,6	12	0,48

NOTE: Cutters of R18 steel, cutter durability 4 to 5 hours. Tube length up to 5 m. The tube rotates, and the boring head feeds.

Key:
- a. Diameter of bored hole in mm
- b. Boring depth in mm
- c. Mechanical properties of the machined tube metal
- d. m/min
- e. rev/min
- f. mm/rev

TABLE 31

Cutting Rates for Coarse and Semi-Fine Tube Boring Using Various Boring Heads
(Tube material σ_b = 85 to 100 kg/mm². Tube length up to 5 m)

No.	Boring head nomenclature	Bored hole diameter in mm	Cutter material	t mm	s_0 mm/rev	v m/min
1.	Two-cutter head with one-sided cutter position	118	R18	6	0.50	18.5
2.	Six-cutter head with round cutters	150	R18	6.5	1.3	18.0
3.	Two-cutter head with one-sided cutter position	118	hard alloy	6.0	0.5	75.0

TABLE 32

Cutting Rates for Fine Tube Boring Using a Two-Cutter Head
with One-Sided Cutter Position
(Cutter material R18. Tube length up to 5 m)

a. Диаметр растачиваемого отверстия мм	b. Глубина резания мм	c. Механические свойства металла обрабатываемой трубы								
		σ_b=70—80 кг/мм²			σ_b=90—100 кг/мм²			σ_b=100—130 кг/мм²		
		d. v м/мин	e. n об/мин	f. s_0 мм/об	d. v м/мин	e. n об/мин	f. s_0 мм/об	d. v м/мин	e. n об/мин	f. s_0 мм/об
110	0,75	18,6	59	0,6	15,6	50	0,5	12,0	38	0,5
200	1,25	17,7	28,2	0,7	14,3	22,4	0,6	10,8	17.0	0,6
400	2,0	16,6	13,2	1.0	13,0	10,4	0,9	10,0	8,0	0,9
500	2,5	12,8	8,2	1,2	12,0	8,0	1,0	8,5	5,4	1,0

Key:
a. Diameter of bored hole in mm
b. Boring depth in mm
c. Mechanical properties of the machined tube metal
d. m/min
e. rev/min
f. mm/rev

TABLE 33

Cutting Rates for Fine Tube Boring Using Various Boring Heads
(Tube material σ_b = 85 to 100 kg/mm², tube length up to 5 m)

No.	Boring head nomenclature	Bored hole diameter in mm	Cutter material	t mm	s_o mm/rev	v m/min
1.	Two-cutter head with one-sided cutter position	112	R18	1.6	0.5	18.5
2.	Floating reamer	85	R18	1.0	1.2	12.5
3.	Floating reamer with hard alloy cutters	85	special	0.5	2.5	110

In coarse and semi-fine tube boring, the most widely used cutting heads are two-cutter ones with one-sided cutter location, which provide maximum straightness of the bored hole. The cutting rate for coarse boring with these heads on tubes made of steel σ_b = 75 to 80 kg/mm², with cutters R18 is 16 to 20 m/min with a feed of 0.4 to 0.6 mm/rev.

The most productive cutting heads for coarse-tube boring are the multi-cutter ones with round cutters. Cutting speed for these heads in large diameter tube boring should be somewhat decreased, and feed increased to 0.8 mm to 1.2 mm. In boring tubes greater than 6000 mm in length, cutting rate should be decreased so that cutter durability is satisfactory for the entire length of the bored tube. The decrease should be by 10 to 20%. Cutting rates for fine tube boring using floating blades or reamers in the head should be lower, namely, cutting speed up to 12.5 m/min, feed up to 1 to 1.5 mm and cutting depth 0.3 to 0.6 mm.

Cutting rate and surface quality of the bored hole largely depend on the method of cutter cooling and shavings exhaust. A 5 or 10% solution of self-emulsifying oil or sulfofrezol most often serves as the cooling liquid. In some instances for fine boring, mineral oil mixed with kerosene is used.

The amount of cooling liquid used depends on the mode of tube machining (coarse or fine boring), the diameter of the hole being bored, and the cutting rate. For preliminary semi-fine boring of holes 100 to 120 mm in diameter, liquid should usually arrive under a pressure of 4 to 5 atm with an exhaust of up to 70 l/min. With large diameters and large tube lengths, cooling liquid supply should be increased.

#28. Defects Encountered During Tube Boring

Deviations in the actual dimensions of a machined tube which exceed the limits in tolerances assigned to it are called defects in its machining. In one case, tube defects might be eliminated by sequential operations (for instance, polishing) in its machining. In another case, a tube with defects according to its technical conditions, might be released into service, but its quality will be somewhat decreased; and in a third case, defects might be so significant that the tube is ruined.

Characteristic defects during boring of long tubes are:

- Bore conicity,
- variations in wall thickness,
- bore curvature,
- ellipticity in section,
- crude machined surface (streaks, scratches).

Tube bore conicity arises as a result of boring head, cutter, and guiding key wear during the boring process. The highest conicity in tube bores is observed during coarse boring, and in 30 to 40% of the bored tubes it reaches the maximum amounts shown in Table 34.

It is evident from the data in the table that bore conicity grows with an increase in boring depth. The diameter of the bored hole has practically no influence on bore conicity.

Production practice shows that during semi-fine tube boring, conicity in its bore decreases to one third, and during fine boring, it does not usually exceed 0.05 to 0.10 mm, and is easily eliminated by polishing or honing.

TABLE 34

Tube Bore Conicity, Received During Coarse Boring of Almost 30 % of All Machined Tubes

Diameter of bored hole in mm	85 to 120	100 to 1?0	150 to 250
Boring depth in mm	3000 to 4000	4500 to 5500	over 6000
Conicity in mm	1.0	1.3	1.6

Variation in tube wall thickness is a very serious production defect and may be sufficient reason for discard of a tube. If wall thickness variation does not decrease tube strength, and its bore is still straight, the tube is usually released into service with the defect. The reason for tube wall thickness variation is the deviation of the borin head from its assigned direction during the boring process. Boring head deviation occurs as the result of nonuniformity in thickness of shavings removed, which almost always occurs during coarse boring, and to some degree during semi-fine tube boring. If the hole in the tube becomes curved and has variations in wall thickness during preliminary solid or ring drilling, for instance, then as a rule, the thickness of the removed layer along the circumference and length of the tube will be nonuniform during sequential boring.

As stated earlier, the basic reasons for curvature and variations in wall thickness of a tube are: Boring head deviation and steps on the bore surface which are received during solid or ring drilling, and residual inner stresses in the tube walls, which arise during its heat treatment. These defects are consequently eliminated during coarse and semi-fine boring. When the boring operation setup is insufficiently accurately performed, however, curvature and variations in wall thickness of the tube may remain after coarse and semi-fine boring operations, but the amounts of these defects will not usually exceed allowable limits.

Ellipticity or ovality in the hole might arise as a result of nonuniformity in the tube material or incorrect turning of the established base cheeks on the exterior tube surface. The amounts of these defects are usually insignificant, and they are very rarely encountered in production.

Some streaks and scratches on the tube bore surface which are received during fine treatment may be of such depth that they cannot be successfully eliminated by polishing or honing. The reason for these defects is adherence to the guiding surfaces of the keys of small pieces of shavings, which are usually very hard after deformation. Wear and blunting of the cutting edges of fine cutters may also leave streaks on the tube bore surface. Damage to the tube bore surface can be eliminated with normal shavings cleaning by the cooling liquid stream, use of a wise cutting rate, and proper boring head preparation, especially of its fine cutters and guiding keys.

CHAPTER VIII

Boring Deep Conic Holes

#29. Tubes with Conic Bores

Tubes with bores whose sections change along their length are used for artillery gun barrels.

The conic holes (bores) with constant conic rate on the entire length of the tube usually have a conic rate within the limits of 0.002 to 0.004. Bore conic rate k is determined according to the following formula (Fig. 95):

$$k = \frac{d_1 - d_2}{\ell} = 2\,\mathrm{tg}\,\alpha, \tag{30}$$

where d_1 and d_2 are respectively the largest and smallest diameters of the conic bore; ℓ, length of conic bore; α, angle of inclination of the bore.

If the bore conic rate k = 0.002 to 0.004, diameter d_1 will be larger than diameter d_2 by 2 or 4 mm for a one meter's length of the bore. External tubes, casings with conic bores of constant conic rate and internal liner tubes, or free tubes with constant conic rate along the exterior surface, are used for gun barrels. In practice, length of the tubes with conic bores reaches 2500 to 5500 mm, and sometimes exceeds the latter of these dimensions. Tubes with conic bores of constant conic rate are simpler to manufacture than tubes with conic bores of non-constant conic rate, but more complex in manufacture by comparison with cylindrical tubes. Tubes whose bores have both cylindrical and conic sections are more complex in manufacture than tubes with conic bores of constant conic rate.

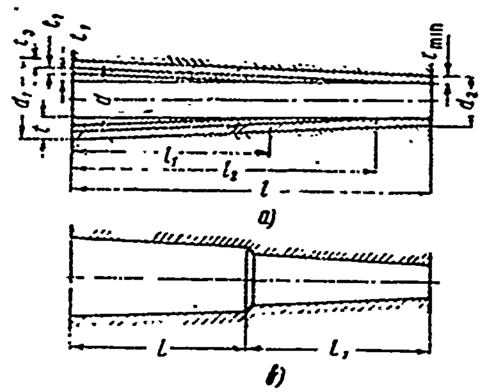


Fig. 95. Schematic of boring conic bores

Key: a. tube bore with one conic section
b. tube bore with two conic sections

With a length greater than 6000 mm, tubes most often have two conic sections of identical rate (see Fig. 95, b). These sections are divided by a small step which is at the same time the support for liner fastening, preventing its longitudinal displacement in the casing. Tubes with two conic bores are used most often for lined gun barrels of great length.

Gun charge chambers are also tubes with conic bores 500 to 2500 mm in length (see Figs.106 to 108). Conic rates of charge chambers and their dimensions are set forth above in detail.

The technical requirements for machining tubes with conic bores are basically the same as for cylindrical tubes. Fulfilment of these requirements, however, during deep conic hole boring, represents greater difficulty because of the necessity to maintain the assigned conic rate.

Before boring the conic bore, the tube must undergo the following machining operations: Coarse and semi-fine turning of the exterior surface, leaving a margin on it only for fine finishing of the jacket, and semi-fine cylindrical boring of the bore. Considering that the surface of the cylindrical serves as the technological base for its later conic boring, the cylindrical canal must be straight, and not have variations in wall thickness or ovality.

During conic boring of the bore, the minimum margin t_{min} on a side is determined from the expression (see Fig. 95)

$$t_{min} = \frac{d_2 - d}{2}, \qquad (31)$$

and the maximum margin t_{max} on a side, with consideration for formula (30), is determined from the relationship

$$t_{max} = \frac{kl}{2} + t_{min} \qquad (32)$$

where d equals the diameter of the cylindrical bore of the tube with margin for its conic boring; $k = 2tg\alpha$, conic rate of the bore.

For boring conic holes in tubes, margin t_{min} is assigned with consideration for the technological possibility of machining this hole, and in production practice the value of this margin is usually equal to 0.8 to 1.6 mm. Upon assigning margin t_{min}, it is possible, with the known dimensions of the tube, to determine the necessary maximum margin t_{max} for boring its conic bore, according to formula (32). For instance, with tube length l = 5500 mm, conic rate of its bore k = 0.004, and t_{min} = 1.2, then

$$t_{max} = \frac{kl}{2} + t_{min} = \frac{0.004 \cdot 5500}{2} + 1.2 = 12.2 \text{ mm.}$$

Removal of a layer of metal 12.2 mm thick in one pass during boring of the tube bore is very difficult because, as a result of the large load, the cutter will quickly wear out and the requirements for precision and smoothness of the bore surface will not be met.

With these considerations, if margin $t_{max} > 5$ mm, conic boring of the tube should be conducted with two or more passes so that the maximum thickness of metal layer removed in one pass does not exceed 5 mm. In this instance, the total margin for conic boring is determined approximately as shown in Fig. 95, a.

Here, the first working passes during removal of layers of thickness t_1 and t_2 on sections length l_1 and l_2 should be conducted with a higher cutting rate, and the sequential smooth pass during removal of the margin of layer t_3 must be conducted at a cutting rate such that the requirements for precision and surface smoothness of the attained hole are satisfied. Thickness of the last layer of metal removed must not be greater than 1.5 mm, or it must be close to margin t_{min}.

Boring of conic tube bores is sometimes conducted with sequential boring over several passes, first of cylindrical sections, arranged in ledges (steps) on length l_1, l_2, and l_3, and then in the final pass the cone is bored through the entire length of the tube l (Fig. 96, a).

This stepped method of conic bore boring has the following essential deficiencies: An independent technological preparation is required for each pass, as would be required for a separate operation; thickness of the metal layer removed in the final smooth pass would not be uniform, and cutting conditions would be significantly worse than those in the schematic shown in Fig. 95; total time expended on boring the bore would be significantly greater than in the schematic of Fig 95. The method of stepped boring can be used if the tube bore has a cylindrical section on length ℓ_b (see Fig. 96; b) and is conic on section k. The exterior surface of the tube may also consist of a cylindrical section ℓ_a and a conic one ℓ_d (see Fig. 96).

Boring of conic bores always begins at the end having the largest diameter and ends on the end having the smallest diameter. During boring of conic bores, the machine shaft must work with the tension method, which provides better conditions for the cutting process.

If expansion or polishing of the conic hole is necessary after boring, a margin, whose size is determined in dependence on the dimensions of the tube bore and the requirements for its machining accuracy, must remain for these operations. For instance, for expansion of the hole, margin on a side must not be greater than 0.3 mm, and for polishing or honing, it must not be greater than 0.1 mm. It is necessary to consider these margins during installation of the cutters for the final smooth pass in conic bore boring.

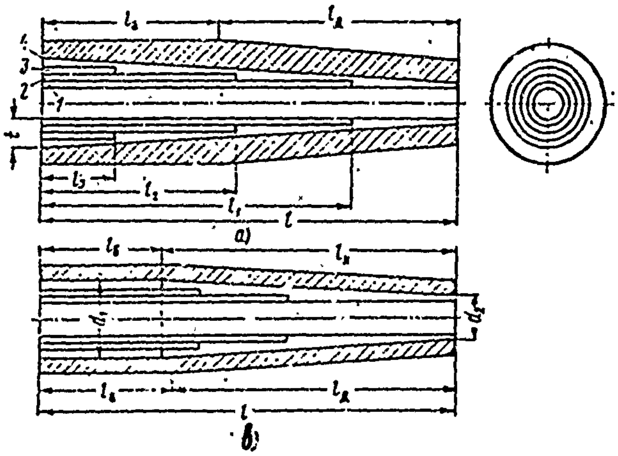


Fig. 96. Schematic of stepped boring of conic bores

Key: a. tube bore with constant conic rate
b. tube bore with cylindrical and conic sections

§30. Tools and attachments

For boring deep conic holes, instruments and attachments of various designs are used. We will look at the more typical of these for artillery production.

Attachment with Copier

The simplest device used for boring conic bores is the attachment with copier (Fig. 97).

The steel cylinder (copier) (2) of the attachment has a longitudinal slot of L-shaped section, whose base forms a cone with a slope of 0.0017, providing a conic hole whose conic rate is 0.0034. The conic rate of the copier slot base is assigned with consideration for attainment of the required conic rate of the conic bore. A cap (1) is screwed onto the front end of the copier (2) and is fitted as accurately as possible. This cap has a central hole U, and the copier also has a hole on its opposite end. These holes are the technological bases for centering and installation of the attachment on the machine.

The shoe (4) with cutter (5) and drawbar (12) can freely move along the slot of the copier (2). The shoe (4) of the cutter is fitted into the copier slot so that during the process of cutting, it and the cutter are a sufficiently rigid system so that there will be no vibration. The cutter (5) is fastened into the shoe by two screws (7), and additionally by supporting gibs, which are fastened to the shoe by screws and smooth pins (8).

Beneath the cutter (5) is installed wedge (6), by whose movement with screw (3) the cutter can be established in the required position. Due to this construction, the cutter may be repeatedly sharpened and established at the initial dimension during boring of the bore.

The shoe (4) is fastened to the drawbar (12) with the thrust lock (11) and screw (10). The opposite end of the drawbar (12) is fastened to the moving carriage of the machine tool holder and fixed by pin (13). The guiding ring (9) with four guiding keys (14) fastened to it are fit freely onto the cylindrical surface of the copier (2). The ring (9) is fit on the cylindrical surface of the copier in such a way that it moves freely on it, with a clearance of no more than 0.05 mm on the diameter dimension, and the exterior diameter of ring (9) along the guiding keys (14) must precisely correspond to the diameter of the bore which is prepared for conic boring. After assembly of the attachment, the bronze shoe (4) with cutter (5), the guiding ring (9) with keys (14), fastened onto the tail (4) of the shoe, and the drawbar (12) make up one unit so that the shoe can freely move along the copier slot and the ring can freely move along its exterior cylindrical surface.

In the process of boring the hole, the guiding ring (9) is the supporting surface for the copier (2). The guiding keys (14) absorb the cutting load which acts on the copier, and therefore the copier will not sag and its vibration will be decreased.

The copier has a slot B, which allows installation of the cutter in the shoe from the outside of the machine, or establishment of the cutter in the required position immediately on the machine (see Figs. 97 and 98).

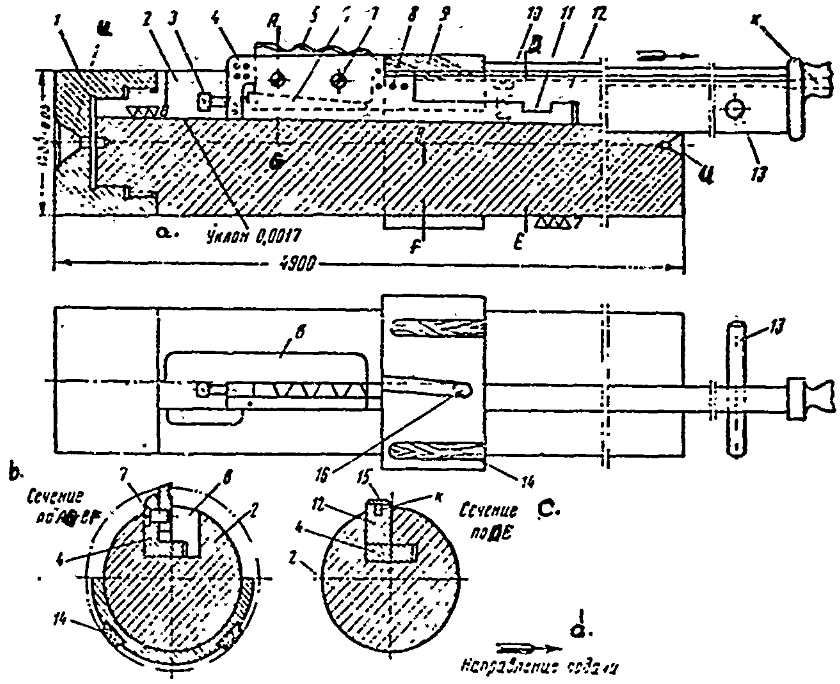


Fig. 97. Attachment with slotted copier for boring conic bores

Key:

1.	cap	11.	thrust lock
2.	copier	12.	drawbar
3.	screw	13.	pin
4.	shoe	14.	guiding key
5.	cutter	15.	cover plate
6.	wedge	16.	channel
7.	screw	a.	slope 0.0017
8.	pins	b.	section across AC & BF
9.	guiding ring	c.	section across DE
10.	screw	d.	direction of feed

The assembled attachment is installed in the tube which is prepared for boring (5) so that its end extends from it (see Fig. 96). After this, the end of the tube (5) with the boring attachment is installed in the attachment (6) by the set screws (4), and its other end is installed in the machine lunette. One end of the copier (3) is then installed on the center (2) of the front face plate (1) of the machine, and its opposite end is rigidly fastened in a special lunette. The copier (3), which is centered relative to the guiding mount and the axis of the machine spindle, is rigidly fastened and remains stationary during boring.

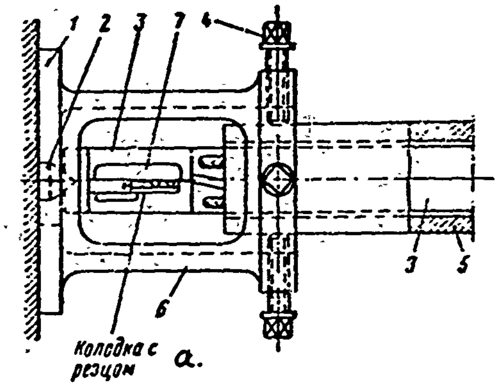


Fig. 98. Schematic of stock and attachment installation on the machine for boring the conic bores shown in Fig. 97

Key:
1. machine face plate
2. spindle center
3. cylinder with slotted copier
4. set screws
5. stock
6. frame
7. slot for servicing shoe with cutters
a. shoe with cutter

After installation of the copier, centering and final installation of the tube (5) relative to its exterior surface take place. During turning, the tube (5) is rotated by the main drive of the machine, while the front face plate, spindle, and copier remain stationary. Drawbar (12), fastened to the machine holder carriage, accomplishes a longitudinal movement, together with the shoe (4) and cutter (5), along the copier slot (see Fig. 97). The cooling liquid is conducted to cutter (5) along canal K in the drawbar (12) and along the inclined canal (16).

The essential deficiency in the attachment described is the complexity of the technological process of the manufacture of its copier. The slot in the copier is milled after its preliminary turning and heat treatment (annealing and tempering), due to which the copier is deformed as the result of residual stresses. To eliminate these deformities, the copier undergoes repeated machining, and its exterior surface and slot are ground. The copier is usually 1.2 m longer than the tube being bored, and its exterior diameter is smaller than the interior diameter of the bore by 25 to 35 mm. In Fig. 97, length and exterior diameter of the copier given are for boring a tube 4000 mm long with a bore diameter of 112 mm. The copier must have sufficient hardness to maintain the accuracy of its exterior contour and the form of the L-shaped slot.

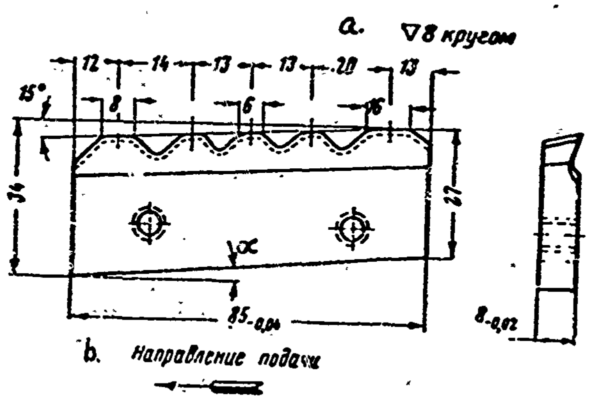


Fig. 99. Multi-bladed cutter plate

Key: a. all around
b. direction of feed

With wear of the guiding keys (14) during tube bore boring, a clearance is formed between them and the surface of the bore, which leads to the possibility of increasing the amplitude of copier vibration and its sagging. As the result, assigned conicity of the bore will not be maintained, and its surface smoothness will worsen during boring. The described attachment can be used only for boring tube bores with a constant conic rate throughout their length, which limits use of the attachment. The boring cutter for the attachment with slotted copier is shown in Fig. 99. It is a multi-bladed plate made of R18 or R9 fast-cutting steel.

There are figured grooves on the cutting edge of this plate, which form five independent teeth (cutters). The first tooth removes the largest part of the margin, always wears faster than the others, and is made longer and stronger. The last tooth removes the smallest part of the margin and must provide the required machining accuracy and surface smoothness of the tube bore. This tooth must not wear out, and so its cutting edge is twice as long as the cutting edge of the front tooth. Multi-bladed cutters of similar construction have performed very well in working practice.

Attachment for Conic Tube Boring (Fig. 100)

For boring conic holes of any conic rate in tubes up to 10 m long, the attachment shown in Figs. 100 and 101 is used. The attachment consists of a head (3), shaft (15), internal drawbar (14), and worm gear and rack and pinion drive mechanisms. The hollow head (3) is manufactured of medium hard steel, its interior surface is machined to third class precision, and the exterior surface where it fits with the part is machined to second class moving fit. The shoes (4) with cutters (5) and (6) are located in the right-angled slot of the head. These shoes fit in the slot as precisely as possible, but allowing free movement in a radial direction. There are four slots in the exterior surface of the head, into which the shoes (9) with wooden guides (10) are fastened with stops (13). The tail portion of the head is connected to shaft (15) of the machine with a threaded coupling, and its front part is closed off with a cover (1).

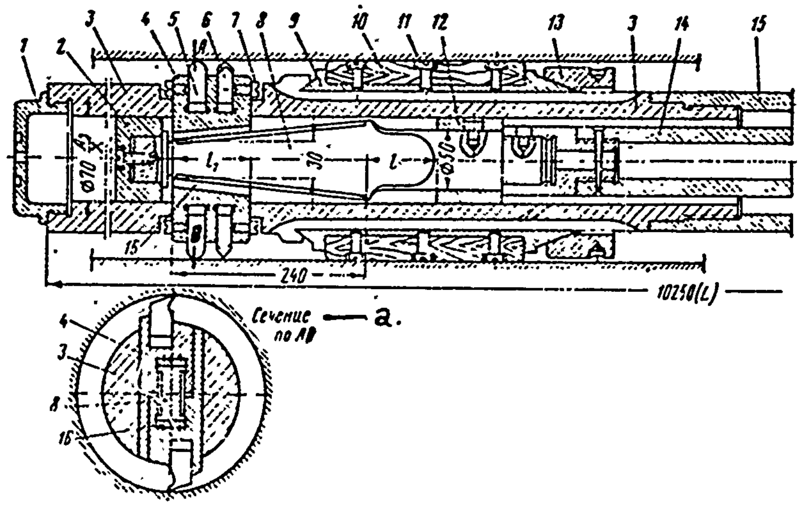


Fig. 100. Attachment for drilling conic bores

Key:
1. cover
2 & 12. guiding wedge cylinders
3. attachment head body
4. shoes
5 & 6. cutters
7. cutter fastening screw
8. wedge
9. shoes
10. wooden guides
11. screws
13. shoe fastening stop
14. internal drawbar
15. shaft
16. insert
a. section across AB

The shoes (4) with cutters set on the conic surface of the wedge (8). Bronze inserts (16), whose surfaces are fitted along the conic surface of the wedge, are placed between the shoes and the wedge. When the wedge (8) is moved to the left (on the drawing) shoe (4) with cutters are set at a maximum diameter d_1 of the bored hole, and when it is moved to the right (working move), the diameter of the bored hole will be decreased to diameter d_2. For provision of sufficient fastening stability of the shoes and heads, wedge (8) has two guiding support bushings (2) and (12) which are fastened by screws.

For installation of the shoe and cutters onto the guiding surfaces of the wedge, or for their removal, the wedge must be moved to the extreme left position so that the shoe moves away from the wedge guides on the section of length ℓ, so that this section length ℓ must be greater than the shoe length ℓ_1. Wedge (8) is threaded and pinned onto the internal drawbar (14), which passes through the hollow shaft (15) and can move in it, providing movement of the wedge.

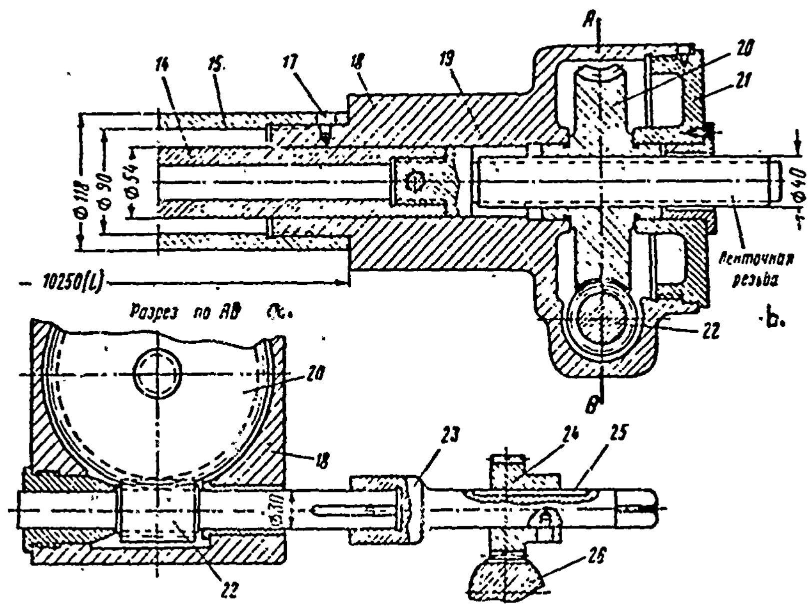


Fig. 101. Mechanism for longitudinal movement of drawbar and wedge relative to the attachment for boring conic bores shown in Fig. 100

Key:
14. drawbar
15. shaft
17. set screw
18. sleeve
19. screw, fastened to drawbar
20. worm gear
21. cover
22. worm shaft
23. sleeve
24. rack gear
25. key
26. rack
a. section across AB
b. band thread

The other end of the drawbar is connected by threads and a pin to screw (19), which has external band threads (Fig. 101).

The shaft (15) is securely fastened to the body of the sleeve (18), which is fastened to the moving carriage of the machine tool holder (27) (Fig. 102). Sleeve (18) simultaneously serves as the body for assembly of the worm pair (20) and (22) (see Fig. 101).

The bored tube (32) is installed on the machine on the body of the face plate (30) of main movement, and on the lunette (31) (see Fig. 102). The machine shaft, on the end of which the boring head (33), shown in Fig. 100, is fastened, is installed in the tube bore after its installation. With this installation of the attachment, conic hole boring begins from the large diameter and ends at the small diameter, and the machine shaft works by tension.

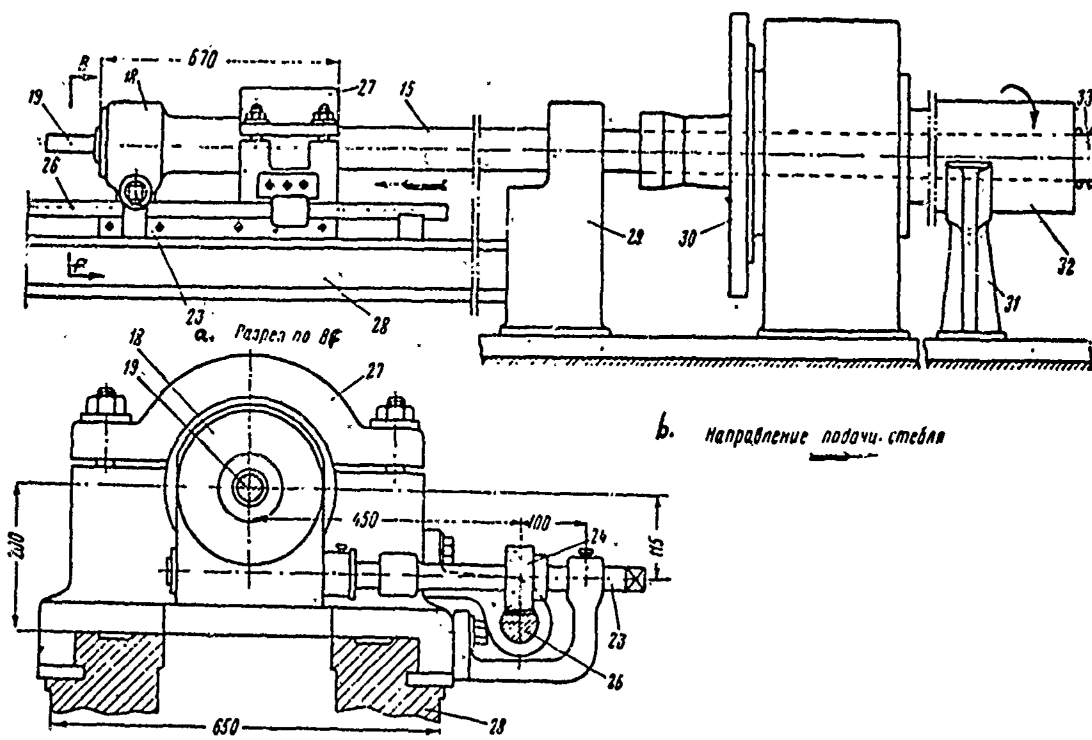


Fig. 102. Schematic of tube installation on the machine for boring a conic bore in it with the attachment shown in Fig. 100

Key:
- 15. shaft
- 18. sleeve
- 19. internal drawbar screw
- 23. sleeve shaft
- 24. pinion
- 26. rack
- 27. movable tool holder carriage clamp
- 28. machine mount
- 29. lunette
- 30. spindle face plate
- 31. lunette
- 32. tube stock
- 33. attachment boring head
- a. section across BF
- b. direction of shaft feed

During boring, the stock performs a rotary motion, and the movable carriage of the tool holder (27) with shaft (15), the boring head (33) and sleeve (18) have a constant feed movement in the direction of arrow E. With longitudinal movement of the carriage (27), sleeve (18), and shaft (15), the cylindrical gear (24), meshed with the stationary rack (26) of the machine, will move with a rotary motion while rolling along the rack. Rotation of the cylindrical gear (24), due to the key (25), will move a sleeve (23) and consequently the worm shaft (22) in that the latter is connected to the sleeve with a key (see Fig. 101). The rotary motion from the worm shaft (22) is transferred to the worm gear (20), which is screwed onto screw (19), which has a running band thread. The rotary motion of the gear (20) will be tranformed into the constant movement of the screw (19) in that gear (20), having limits in the form of sleeve (18) and cover (21), cannot move in a longitudinal direction.

In this way, with longitudinal displacement of the tool holder carriage (27) and shaft (15) along the guiding mounts of the machine, the internal drawbar (14) will move together with the shaft and, besides that, will be able to move in a longitudinal direction relative to the shaft due to the rotary movement of the worm shaft (20)(see Figs. 101 and 102). Simultaneously with the linear movement of the drawbar (14), the wedge (8) will move relative to the head (3), and shoes (4) with cutters (5) and (6) will be able to move in a radial direction, tightly butting against the support surfaces of the wedge (8) (see Fig. 100). As a result, the diameter of the bored hole will continually decrease, and at completion of boring will be equal to diameter d_2. When the cutting head emerges from the tube, its cutters will be in a position similar to that shown in Fig. 100.

In the described attachment, the conic rate of the bored hole of the tube is determined by the gear ratio of the kinematic chain from the cylindrical rack gear (24) to screw (19) of the drawbar (14), and the conic rate of wedge (8). If the characteristics of the cylindrical gear (24)(number of teeth $z = 18$ and module $m = 3$), the worm shaft (22)(for coarse module $m = 4$ and pitch $t = 20.26$ mm), and the worm gear (20)(number of teeth $z = 44$ and module $m = 4$ mm) of the machine are known, as is the pitch of the band thread of the screw (19) and conic inclination of the wedge (8) of the attachment, the overall gear ratio between the longitudinal movement of the shaft (15) with the boring head and the radial movement of the shoe (4) with cutters, is easily determined. For any other value of bored hole conicity, interchangeable parts which are simpler in manufacture can be selected: For instance, the cylindrical gear (24), screw (19), and gear (20), which can be made with changeable inner hubs.

Cooling liquid in the attachment is supplied to the cutters through the space between shaft (15) and the inner drawbar (14). Boring of conic tubes with the described attachment takes place in one working pass, and direction of the head motion is provided by the cylindrical surface of the bore. During boring of the bore, the first two cutters must remove shavings whose thickness is up to 80% of the thickness of the metal layer removed, and the two following fine cutters remove a thinner layer of metal, providing the required precision and surface smoothness of the conic bore.

Attachment with a Floating Plate

The attachment with assembled floating plate (cutters) is a complex assembly of the machine, and has front guides (20) along the cylindrical surface, and rear (behind the floating plate) guides (11) along the conic surface (Fig. 103). The hollow body (5) of the attachment, manufactured of medium-hard steel, is rigidly fastened to the shaft (17) of the machine with the sleeve (19). Two shoes with cutters (14), blades of fast-cutting steel, and three guiding keys (11), fastened on shoes (6), are assembled in the right-angle slots of the body (5). To increase rigidity of the body (5), where it is weakened by slots, and create sufficient support surface for the shoes, steel bosses (9) and (13) are welded to the body. The floating plate is an assembly consisting of blade (15) with two T-shaped inclined slots and two shoes, in which cutters (14) are fastened by screws (12). The plate is closely fitted into the mandrel slot and the slot in body (5).

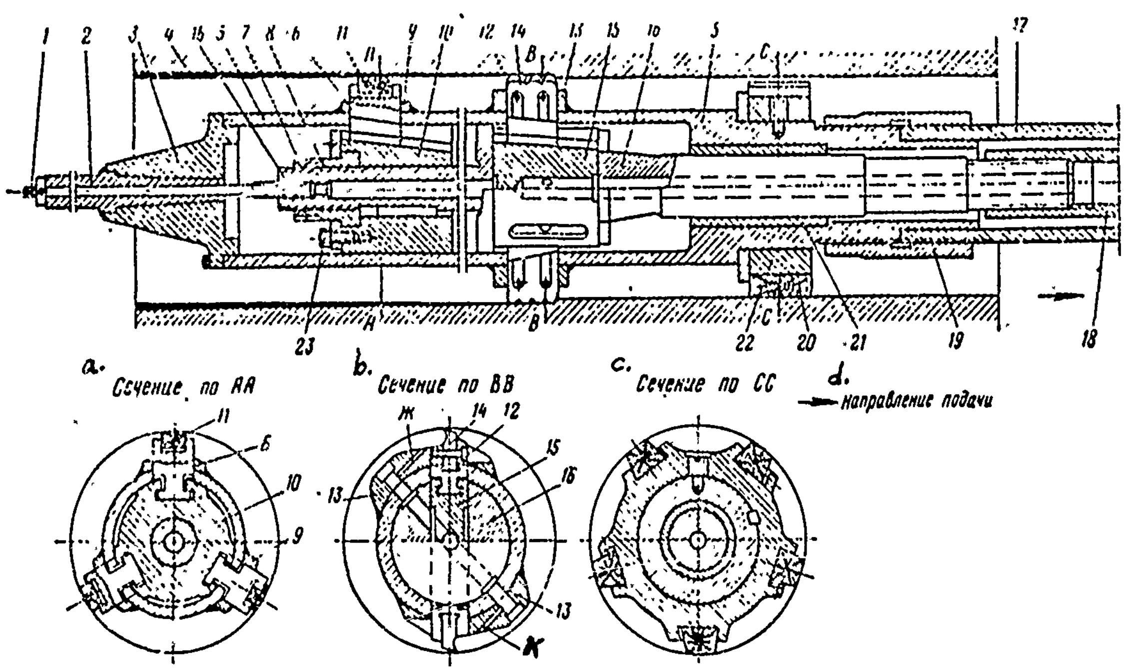


Fig. 103. Attachment with floating blade for boring conic bores

Key: 1.	screw	11.	rear guiding keys	21.	bushing
2.	hollow rod	12.	screw	22.	clamp
3.	cap	14.	cutters	23.	screw
4.	machined stock	15.	plate	K.	canal supplying cooling liquid
5.	attachment body	16.	mandrel	a.	section across AA
6.	shoes	17.	shaft	b.	section across BB
7 & 8.	nut and stop nut	18.	drawbar	c.	section across CC
9 & 13.	bosses	19.	sleeve	d.	direction of feed
10.	sleeve	20.	frong guiding keys		

The mandrel (16), assembled inside the body, is the part with whose help the cutter, shoe position, and shoes of the rear guiding keys (11) are regulated. It is centered relative to the body (5) at its mid-part by bushing (21), and at its front part by sleeve (10). The contact surfaces of these parts and the interior surface of the body are machined to high accuracy. The sleeve (10) is immovably fastened onto the mandrel (16) by nut (8), stop nut (7), and screw (23), and therefore it and the mandrel may move only in a longitudinal direction relative to the body (5) of the attachment.

On the exterior surface of the sleeve (10) there is a T-shaped slot with an incline on a cone for shoes (6) with wooden guides (11). In its middle part, the mandrel (16) has a right-angle slot for the blade (15), which moves freely in a radial direction relative to the axis of the mandrel. The blade (15) has a T-shaped slot with an incline on a cone for two shoes with cutters (14).

The mandrel (16) is connected to the drawbar (18), running through the inside of the machine shaft (17) with a threaded tail. As a result, the mandrel (16) together with plate (15) and sleeve (10) may be moved by the drawbar (18) in a longitudinal direction relative to the attachment body (5). During movement of the mandrel (16), the shoos with cutters (14) and shoes (6) with guiding keys (11), moving along their own conic T-shaped slots in blade (15) and in sleeve (10), will move down (during operation) or move out in a radial direction relative to the body (5).

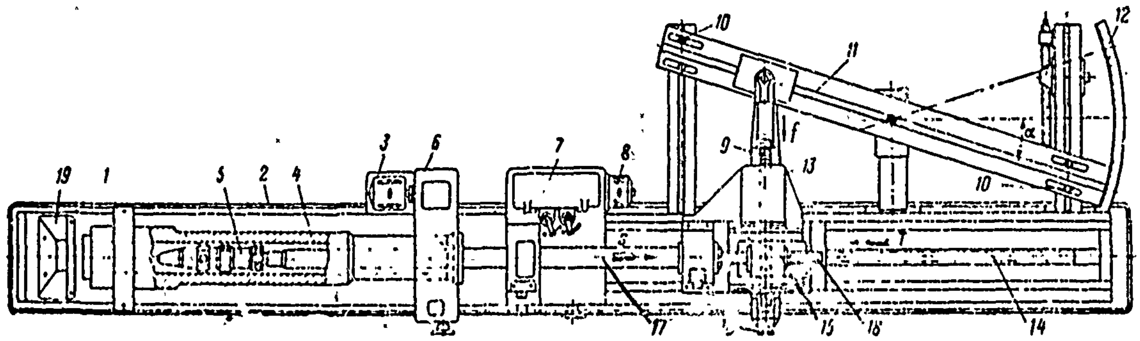


Fig. 104. Machine for boring deep conic holes

Key:

1. lunette
2. mount
3. electric motor for main movement
4. machined stock
5. attachment head (see Fig. 103)
6. main movement transmission
7. feed transmission
8. feed electric motor
9. toothed rack
10. stop screw
11. copier gauge
12. gauge scale
13. tool holder
14. moving screw
15. bearing
16. rack adjusting screws
17. shaft
18. shaft drawbar
19. support brace

The front face surfaces of the body (5) are covered with cap (3), in whose central conic opening hollow rod (2) is set and then welded. The exterior cylindrical surface of rod (2) serves as the supporting guiding (centering) base of the attachment at the beginning of tube boring, until such time as the rear guiding keys (11) become the supporting base.

The clamp (22) with guiding keys (20) direct the attachment along the cylindrical part of the bore.

In this way, at the beginning of boring, the attachment is directed into the bored tube by the front guides (20) and the exterior cylindrical surface of the rod (2), which rests in the bearing of the support brace (19) of the machine (Fig. 104). When the tube is bored enough so that the rear guides (11) are located in its conic surface, rod (2) moves from the bearing of the support brace, and the attachment is directed by the front (20) and rear (11) guides (see Fig. 103). The cooling liquid is routed to the cutters through internal channels in the drawbar (18) and mandrel (16) and through inclined holes K.

Fig. 104 shows the layout of a special machine on which conic bore boring with the attachment shown in Fig. 103 is conducted. One end of the bored tube (4) is installed on the lunette (1) and the other is installed on the face plate of the primary motion transmission (6). The primary motion is performed by the electric motor (3) so that tube (4) rotates along arrow ν'. Electric motor (8) rotates moving screw (14) through the feed transmission (7). With rotation of screw (14), tool holder (13) of the machine, together with shaft (17), and the toothed rack (9) and internal drawbar (18) perform a longitudinal movement along the guiding mount of the machine according to arrows during working movement, or in the opposite direction during free movement of the tool holder. The machine has a copying guage (11), which is installed on special supporting brackets which are rigidly connected to the machine base. The angle of inclination α of the copying guage relative to the guiding mounts of the machine may be changed by screws (10). The reading of the amount of angle α takes place along the scale (12), which, having a large radius of curvature, allows setting of the guage (11) with high accuracy.

The copying guage (11) is attached with a slide to rack (9), which is meshed with a gear, which is in turn mounted on bearing (15). This gear has an internal band running thread for the tail portion of the drawbar (18). The rack (9) consists of two parts which can be moved relative to each other by screw (16), and this allows elimination of slack in the toothed engagement and increases accuracy in work of the mechanism.

In this way, with movement of the support (13) along the guiding mount of the machine, shaft (17), drawbar (18), and rack (9) move together with it in the same direction. Simultaneously with movement of the support, the slide of the rack (9), sliding along the copier guage (11), will move it in a direction perpendicular to the guiding mounts of the machine (along arrow F), and in doing this will rotate the gear, into which the tail portion of the drawbar (18) is screwed. During rotation of the of the gear, drawbar (18) will move in a longitudinal direction along arrow T. As a result of the complex movement, drawbar (18) together with shaft (17) and tool holder (13) will move along arrow s, and simultaneously away from rack (9), then as a result of the rotary movement of the rack gear, it is displaced relative to the tool holder and shaft in the opposite direction (along arrow T). The resultant speed of the longitudinal movement of drawbar (18) along arrow s will be smaller than the shaft movement speed.

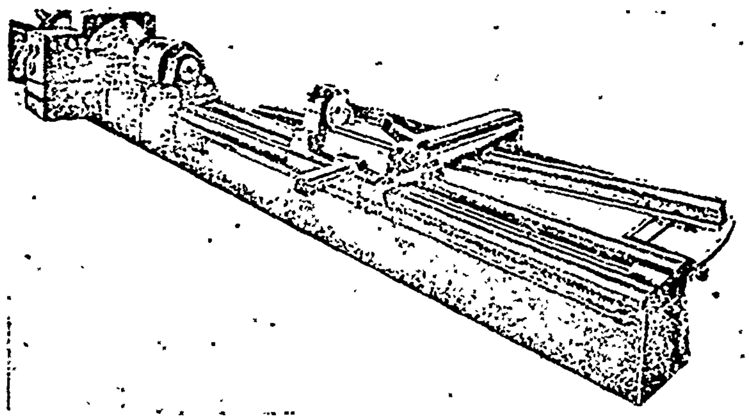


Fig. 105. Machine for boring conic bores, whose drawing appears in Fig. 104

The attachment and machine described allow conduct of several working passes during conic boring of tubes with unchanged tube installation, and machine and attachment setting. For each pass, only the mandrel (16) has to be moved relative to the head body (5) using the regulating screw (1), which, during performance of the boring operation, is removed (see Fig. 103). If the cutters (14) are dulled after the first pass, they can be changed or sharpened, and then installed at the required dimension. The machine copying guage (11), which can be easily set at the required angle α, allows boring of tubes of various conic rates.

The overall view of the machine for boring conic bores is given in Fig. 105.

#31. Boring of Special Profile Conic Holes

Special purpose conic holes include charge chambers of gun barrels 500 to 2500 mm in length, having a profile which corresponds to the reamer shown in Figs. 106 and 108. The charge chamber bore profile is usually formed by several conic sections of various conic rates, and sometimes of both conic and cylindrical sections. In artillery production practice, besides charge chambers, tubes for other purposes, having bores with conic and cylindrical sections are encountered. Reaming of these does not principally differ from reaming of charge chambers. The technical requirements for construction and machining of charge chambers was set forth previously in Chapter III. Charge chambers for cartridge loading up to 1000 mm deep are machined in two stages, mainly preliminary boring of the cylindrical section is first accomplished, and then, final reaming is done.

In the first stage of machining these bores, the boring cutter is installed on the mandrel of length ℓ_2, which is fastened to the machine tool holder. Boring of the cylindrical section of a chamber on length ℓ_3 to a diameter somewhat smaller than diameter d_5 takes place during the first pass, and leaves a margin of up to 0.4 mm on a side for its later reaming.

In the second pass, the cylindrical section is reamed to a depth of ℓ_1 to a diameter of $d < d_3$ with a remaining margin of 0.4 mm on a side (see Fig. 106, b).

In the third pass, boring of the cylindrical section to a depth of $0.5\ell_1$ takes place, leaving the same amount of margin as in the second pass. Preliminary boring gives a preliminary stepped profile to the chamber, which consists of separate cylindrical sections, on each of which the minimum margin for reaming remains. Each cylindrial section must be concentric (co-axial) relative to the tube bore. More accurate bore boring may be accomplished with the help of the copying guage used on universal screw lathes and boring machines.

After preliminary boring, reaming of the bore takes place in two passes with coarse and fine reamers. These reamers must have the profile of a charge chamber, and have on their front parts a changeable guiding cylinder for centering and guiding the reamer relative to the cylindrical part of the bore. Construction of the reamer is shown in Fig. 106. It is desirable that the reamer teeth are made slanted and arranged in a spiral for improved cutting conditions. One-piece reamers are used for reaming small diameter tubes, and reamers for machining deep charge chambers are assemblies with changeable blades (Fig. 107). The assembled reamer is a mandrel one with a right-angle slot, in which the plate (5) with blades (2) are installed. The changeable cylinder, of length $\ell_H = (2 \text{ to } 2.5)d$, having two guiding sections B whose exterior diameter is equal to diameter d of the cylindrical part of the bore, is fitted onto the front end of the mandrel. The blade (5) is accurately fitted into the right-angled slot of the mandrel and during coarse passes, is fastened rigidly into the mandrel, and for fine passes, remains free (floating) in it. Fastening of the blades (2) onto the plate (5) allows regulation of their position according to the assigned reaming diameter, and allows them to be repeatedly sharpened. The blades may be one piece or composite, and it is more expedient to use blades consisting of two parts, namely: One part for reaming the basic cone on length ℓ_1, and the other part for the remaining sections of the bore. Sharpening of the assembled plate blades to profile must accurately correspond to the profile and dimensions of the chamber. The blades are manufactured of bars of fast-cutting steel.

Charge chambers for bag loading have a more complex profile, consisting of several sectioned cones and cylindrical parts (Fig. 108, b) than chambers for cartridge loading.

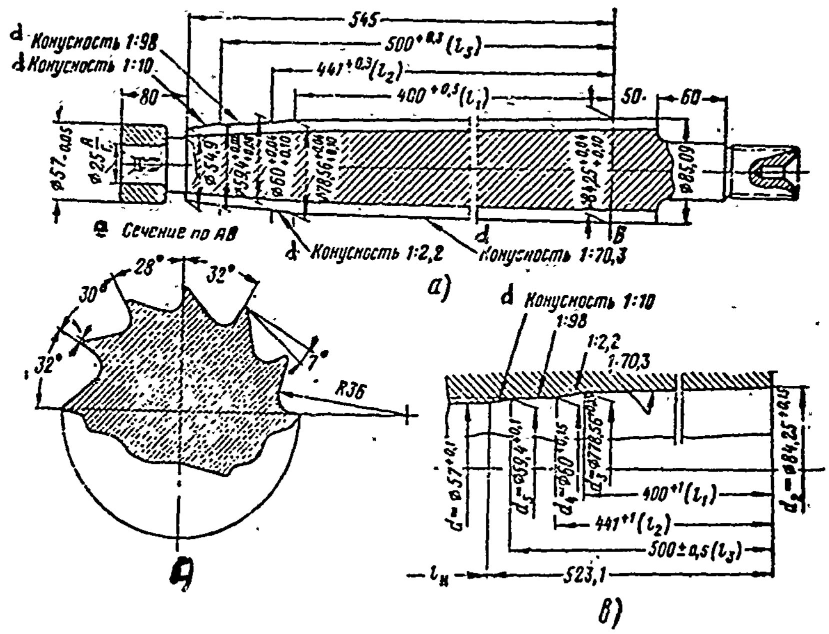


Fig. 106. Reamer for charge chamber fine machining

Key: a. longitudinal cut
b. charge chamber profile
c. reamer cross section
d. conic rate
e. section across AB

The attachment for reaming bag charge chambers consists of a hollow tube (3) which simultaneously serves as the machine shaft. The exterior surface and bore of tube (3) are machined to high accuracy, as shown in Fig. 108. A ring (1), whose length is close to two diameters d, is installed on the front cylindrical part of the tube. It centers the tube (3) relative to the cylindrical part of the bore and is simultaneously the support base, absorbing the cutting load acting on the shaft.

The copier (4), with guiding bushings (6) pressed onto both of its cylindrical ends, is assembled in the inner hollow of tube (3). The copier (4) is strictly fixed in the determined position in tube (3) by the keyed slot D, on its surface and on the surface of the guiding bushings (6), and by the pins (5) going into it.

The ridge E of right angle section, which is the copier itself, remains on the center part of the copier (4). The profile of the copier accurately corresponds to the profile of the chamber, and its center cylindrical section of length ℓ is shorter than the same section of the chamber. Copier rigidity

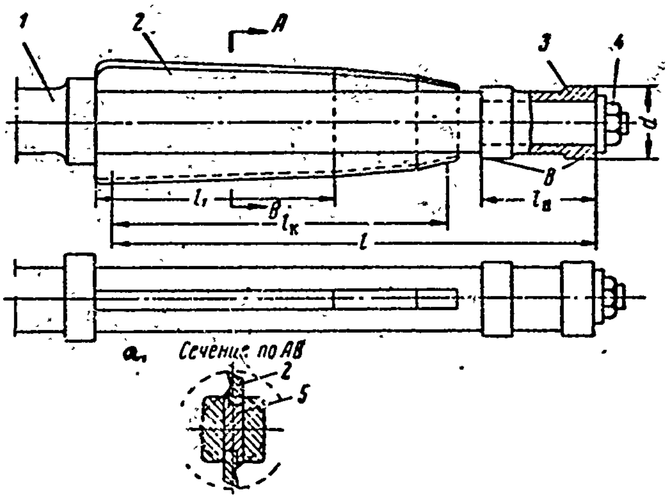


Fig. 107. Reamer with floating plate for charge chamber fine machining

Key:
1. mandrel
2. blades
3. guiding cylinder
4. nut
5. plate
a. section across AB

is increased in this manner. The machine shaft has a right-angled slot, in which the shoe (2) with cutters is installed. The shoe has a slot, with which it is connected to the right-angled ridge E -- the copier (see section AB). The copier (4) is connected to the drawbar (7) from which it also receives its longitudinal movement relative to the shaft (3) during chamber boring.

During chamber boring, the machined tube rotates (primary movement) and the shaft (3) moves along it. During movement of the shaft (3), drawbar (7) with copier (4) remains stationary, at the same time that shoe (2) with cutters will have a longitudinal movement together with shaft (3) and laterally in relation to the incline of the copier.

During movement on section ℓ, the shoe (2) does not move any radial direction. Considering that the length ℓ of the copier is significantly smaller than the length of cylindrical section of the chamber, it is necessary to assure the simultaneous (colocated) movement of shaft (3) and drawbar (7) on the section equal to the difference between these dimensions, which is easily obtained by the regulating supports on the machine.

For installation of the cutters on the shoe, the copier (4) must have a free section of length ℓ_2, and its length must be greater than length ℓ_1 of the cutting shoe (2).

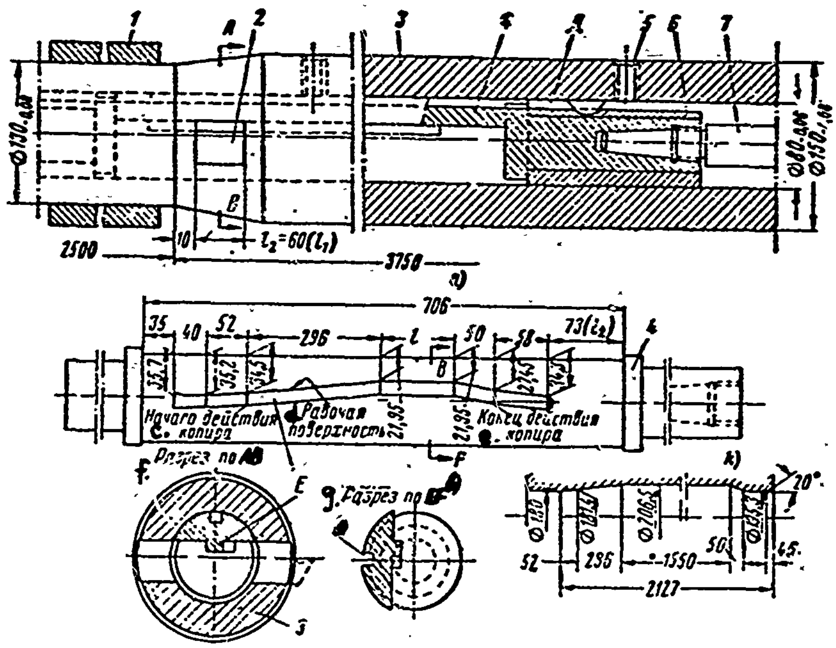


Fig. 108. Attachment for boring bag loading charge chamber

Key:

a. attachment in assembled form
b. copier
k. charge chamber profile
1. guiding ring
2. shoe with cutters
3. shaft
4. copier
5. screw
6. bushing
7. drawbar
E. copier profiled step
D. slot
c. beginning of copier action
d. working surface
e. end of copier action
f. cut across AB
g. cut across CF

Boring complex profile holes with the described attachment is sufficiently accurately performed with preliminary adjustment of the operation, i.e., of the machine, the attachment, the machined tube, and the correct choice of cutting rate.

CHAPTER IX

Machines for Drilling and Boring Deep Holes

#32. Machine Classification and Overall Working Principle

Metal-cutting machines for drilling and boring deep holes belong in the group of overall drilling and boring machines. In artillery production, these machines are divided according to differences in their types of construction into:

Horizontal single spindle drilling and boring machines, which in turn are divided into machines for one-sided and two-sided drilling;

horizontal two-spindle drilling and boring machines;

multi-spindle (six and twelve spindles) semiautomatic drills, intended for drilling bores of relatively small diameter from 5 to 18 mm, up to 1600 mm deep. These machines may be horizontal and vertical.

Depending on their weight and dimensions, horizontal drilling and boring machines divide into three groups:

Medium weight up to 10 t and length to 8 m;
medium heavy weight from 10 to 30 t and length up to 20 m;
heavy weight over 30 t and length to 40 m.

The overall length of the machine must be 2.1 to 2.4 times the length of the machined stock.

According to degree of specialization of technical work fulfilled, machines for drilling and boring deep holes are considered special machines, performing determined operations with the help of the special tool.

Besides basic operations in drilling and boring of deep holes, other operations can be performed on these machines, for instance, turning of exterior surfaces of tubes, base cheeks, and trimming of face surfaces. These operations are performed with the use of the lathe-type tool holders which these machines have; however, these lathing operations are performed relatively rarely and are not basic for the given machines.

The machine stock is installed on these machines and fastened in a chuck or on the spindle face-plate, and additionally on one or two lunettes. All motion on the machine divides into working and auxillary. Working motion includes the primary motion and feed motion.

Primary motion of the machine is determined by the cutting speed in the process of stock machining. This motion is transferred from the machine motor through the transmission to the machine spindle. The primary motion is most often transmitted to the stock, and only in some instances to the cutting tool. The largest part of the machine motor power is expended on realization of the primary motion.

Feed motion is determined by one of the dimensions of a section of shavings which are removed from the stock by the cutting blades of the tool. Feed motion is a longitudinal movement of the cutting instrument for one revolution of the stock during drilling and boring or a lateral one during turning of faces.

Metal-cutting machines have speed and feed transmissions, with which the various speeds of primary motion and feed motion are set.

Auxillary motion includes that connected with installation of the stock and tool on the machine, for instance, moving the tool into the initial position before the working pass, accelerated withdrawal of the tool, changing the speed of the primary motion and feed, and starting and stopping the machine. All these motions may be accomplished by hand or automatically. On new modern machines or old modernized ones, these movements are automated and their control is effected from one pushbutton electric panel or from a control apparatus, which significantly increases the productivity of the machine's work.

In recent years, electrification of metal-cutting machines has received widening acceptance so that each machine is equipped with an individual electric motor which transmits motion to the machine spindle (primary motion), through the speed transmission, and from it motion is transmitted to the machine tool holder through the feed transmission. Large machines have several electric motors, for instance, an electric motor for primary motion and feed, and electric motors for quickly moving the tool holder or carriage with the shaft and feed of cooling liquid.

The basic characteristic of each electric motor is its effective power N_B and number of its shaft revolutions n. For motors furnishing the working movement of the machine, one of the basic requirements is its constant or insignificantly changed shaft revolutions with large changes in load. Electric motors usually have reversing mechanisms to change the direction of their rotation.

Starting and stopping the machine is accomplished by a knife switch, mounted on a special panel, or by pushbutton control. Pushbutton control is more convenient for location on the machine, and in service of especially large machines, such control may be duplicated at both ends of the machine, shortening time for the accomplishment of the control operation. Control mechanisms also include hand wheels and levers for changing speed and reversing the motor, and protection and blocking devices which prevent overload or the possibility of simultaneously switching on two feeds or movements.

#33. TS-90 Horizontal Drilling Machine

The TS-90 drill is a horizontal lathe drilling machine intended for drilling deep holes in solid stocks, and for drilling and boring holes in machine spindles, hollow shafts, and special tubes up to 3800 mm long (Figs. 109 and 110). The height of the machine's center is 300 mm, and consequently the machined shaft (tube) may have an exterior diameter of up to 450 mm.

Basic Machine Information

Characteristic of the main electric motor M_1:	
Power	7 kW
Rotation speed	950 rpm
Number of speed levels of main movement	8
Spindle rotation speed	19 to 412 rpm
Number of working feeds:	
Forward	6
Reverse	6
Feed range	0.05 to 1 mm/rev
Characteristics of the M_2 electric motor for accelerated movement of the rear tool holder:	
Power	1.2 kW
Rotation speed	1480 rpm
Speed of accelerated feed	2.2 m/min
Pitch of moving screw thread (XB)	8 mm

Machine Layout (See Figs. 109 and 110)

The machine consists of the following basic parts: Mount (1), primary movement transmission (2), feed transmission (3), front (10) and rear (19) supports.

The machine mount is assembled out of two parts which are connected with pins and bolts. The overall dimensional length of the machine is close to 10,000 mm. The primary movement transmission (2) is installed on the guiding mounts and fastened solidly on it.

The front support (10) can move along the machine on the guiding mounts under power of the feed transmission or manually by rotation of the star wheel (11). There is a lever (17) on the cover of support (10) for engaging and disengaging the friction sleeve Ф in the primary movement transmission, which accomplishes starting and stopping the machine. The hand wheel (18) serves to engage and disengage the feed mechanism if the rear support (19). During drilling and boring of holes, the front support (10) of the machine is fastened solidly, and during the working run, rear support (19) can be moved along the guiding mounts by running screw XB with engagement of the split stop F by lever (23). For movement of the rear support manually, it is necessary to use the star wheel (24), having previously turned on the friction sleeve m. The rear support moves along the machine by electric motor M_2 faster than the front one, which is necessary for the quick removal and installation of the cutting tool on machine shaft C. To engage the accelerated movement of the rear support, it is necessary to first disengage stop F of the running screw XB and engage gear (20) by a turn of lever P. In this way, sleeve m of the star wheel (24) will be disengaged, gear (20), manufactured in one piece with sleeve e, will be moved forward and engaged with gear (66) and with gear (20), which is on the same shaft with the worm gear (40). When turned on, the electric motor M_2 will turn the single course worm and, through the worm gear, the cylindrical gear to the rack gear (15).

The machined part (product) (8) is installed on the machine and fastened into the chuck (7) and lunette (9). The hollow shaft C is solidly fastened into the bearing of the rear support (19) with lever (20) and bolts. The front part of the shaft with the cutting tool is centered relative to the mount guides and may move freely in bearing (15) of the front support (10).

The primary movement of the machine is accomplshed by electric motor M_1. This movement is transmitted by drive belt (5) (from a pulley 235 mm in diameter) to pulley (6) (310 mm in diameter) and to the primary shaft of the primary movement speed transmission. Gears (45) and (53), sitting freely on the shaft, can transmit rotation only with engagement of the friction sleeve Ф by levers (14) and (17). There is a band brake interlinked with friction sleeve Ф for quick stoppage of the primary movement. When the machine is turned on and the friction sleeve is engaged, the band brake disengages, and when the sleeve is disengaged, it automatically engages and quickly stops movement. With various positions of levers A, B, and G, eight different rotation speeds within the limits from 19 to 412 rev/min can be transmitted to the machine spindle. To increase smoothness of transmittal of motor torque to the spindle, cylindrical gears (32) and (80) have slanted teeth.

The hollow-bodied machine spindle rotates in conic bronze bearings. The axial cutting force acting on the spindle is absorbed by the support ball bearings.

Rotation from the spindle is transmitted to the feed transmission through a belt drive from pulley E (200 mm in diameter) to a pulley 245 mm in diameter and then to gears (35) and (95). By moving the block of gears (35), (73), and (53) with lever (4), it is possible to set three different feed speeds, and by moving the block of gears (43) and (91) by lever (12), it is possible to set and additional three feed speeds.

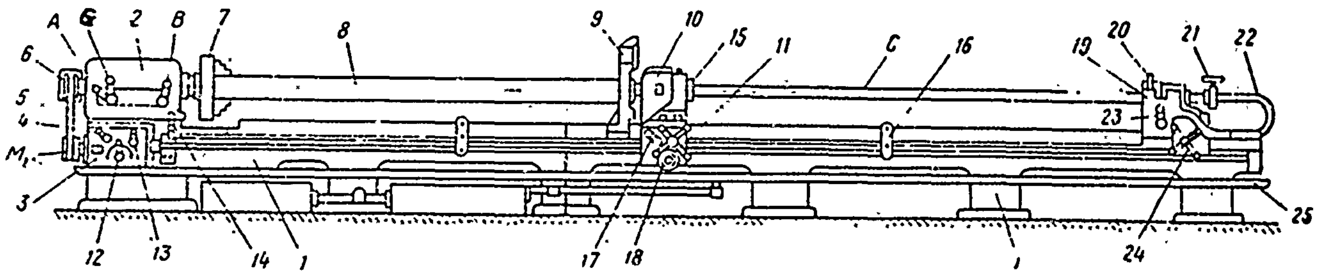


Fig. 109. TS-90 Lathe Drilling Machine

Key:

- 1. mount
- 2. speed transmission, A, B, and G, speed changing levers
- 3. feed transmission
- 4 & 12. feed changing levers
- 5. drive belt
- 6. pulley
- 7. chuck
- 8. stock
- 9. lunette
- 10. front support
- 11. front support movement star wheel
- 13. feed reversing lever
- 14 & 17. lever for engaging and disengaging friction sleeve Φ (see Fig. 110)
- 15. bearing
- 16. support
- 18. support engaging and disengaging flywheel
- 19. rear support
- 20. lever for fastening shaft in the support
- 21. valve
- 22. fluid line
- 23. lever for engaging and disengaging running screw nut
- 24. hand wheel for manual movement of rear support (19)
- 25. drip pan
- C. shaft
- M_1. electric motor

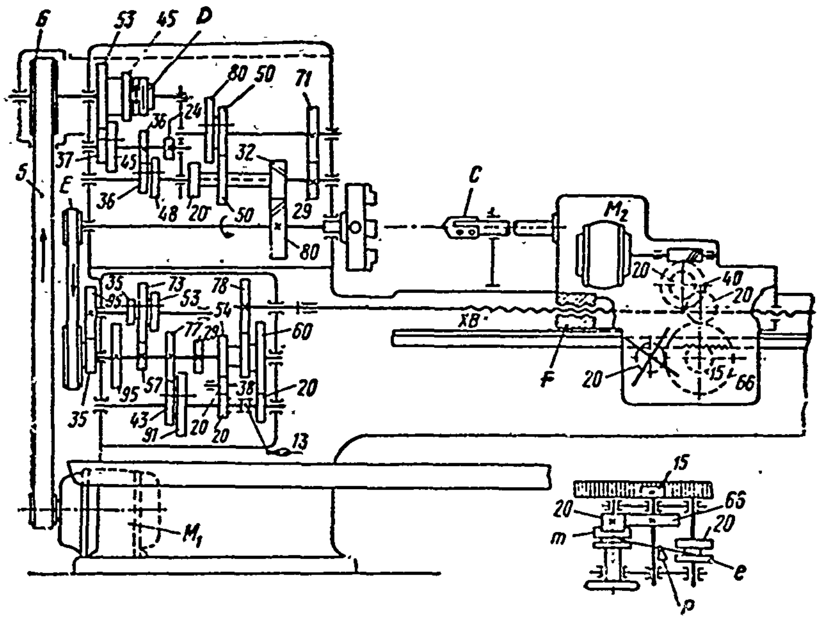


Fig. 110. Kinematic layout of TS-90 machine

Key:
C. shaft
XB. running screw
F. screw stop
P. lever
D. friction sleeve
e & m. changing sleeves
(remaining positions according to Fig. 109, numbers on gears are number of teeth)

In this way, the feed transmission has six different speeds, but with the reversing mechanism lever (13) on the running screw XB, it is possible to transmit a total of twelve different speeds with longitudinal tool feed from 0.05 to 1.0 mm for one spindle revolution, and these speeds may be either forward or reverse. Automatic disengagement of feed is provided by stops (16), which are set at any position, depending on the required depth of drilling or boring.

The running screw XB rotates in bronze bearings and is located in a groove between the guiding mounts. It has a thread pitch of 8 mm.

The machine is equipped with a pumping device, consisting of an electric motor, a geared pump, and pine lines. The cooling liquid flows along pipe (22) which attached to the rear end of the shaft C. The supply of cooling liquid is regulated by valve (21). Cooling liquid pressure may be brought to 40 atm. Used cooling liquid pours off into the trough (25) of the machine, from it into a holding tank, and then again goes to the pump.

#34. Horizontal Two-Sided Drilling and Boring Machine -- 2

The horizontal two-sided drilling and boring machine -- 2 is used for solid and ring two-sided drilling of deep holes (Fig. 11). It is possible to also conduct one-sided solid and ring drilling on the machine, as well as tube reaming; however, the overall depth of drilling or boring in this instance would be smaller than with two-sided drilling. The machine is used most productively with two-sided drilling of deep holes.

Basic Machine Information

Dimensions:	
Length	15,600 mm
Width	1950 mm
Height	1600 mm
Weight of assembled machine	26,500 kg
Internal diameter of the spindle head stock drum	450 mm
Exterior diameter of the machined tube:	
Maximum	400 mm
Minimum	110 mm
Distance from the spindle head stock drum faceplate to the upper mount in their extreme positions:	
Along right mount	10,000 mm
Along left mount	7000 mm
Machine movement:	
a) Longitudinal movement of movable upper mount (supports C):	
Right	4250 mm
Left	1450 mm
b) Longitudinal movement of carriages C_1 along the upper movable mounts:	
Right	2800 mm
Left	2800 mm
Length of nonworking shaft section on each end	1500 mm
Maximum diameter of shaft W	120 mm
Maximum diameter of drilled hole	170 mm
Maximum distance from the spindle head stock drum faceplate to the bearing of support C:	
On right side	5350 mm
On left side	2500 mm
Characteristics of the primary movement electric motor M_1:	
Power	24.5 hp
Rotation speed	950 rpm
Characteristics of electric motors M_2 and M_3 of the supports C:	
Power	5 hp
Rotation speed	1420 rpm
Characteristics of the pump electric motors M_4 and M_5:	
Power	5.5 hp
Rotation speed	1420 rpm

Range of primary motion revolutions of the spindle faceplate drum (16 speeds total) . . . . 2.7 to 134
Range of shaft working feeds for one revolution of the drum Φ (12 feeds total) . . . . 0.027 to 2.07 mm/rev
Accelerated nonworking feeds:
For carriage C_1 with shaft relative to the upper movable mount . . . . 1835 mm/min
For upper mount (support C) relative to the lower mount . . . . 1500 mm/min

Machine Layout

The machine consists of the following major parts and mechanisms: Two lower mounts, right (8) and left (10), installed on the foundation and fastened with bolts; two upper movable mounts, left (1) and right (7); spindle head stock (5), rigidly installed on the lower mount; hollow drum Φ with two faceplates and primary motion speed transmissions H, located on the body of the spindle head stock (5); two supports C, in which are located the feed mechanisms and front bearings for centering and guiding the machine shaft W; two carriages C_1, often called rear supports, in which shaft W is fastened; two pumps, providing cooling liquid to the cutting tool; electric motors, mechanisms and instruments for control; and lunettes (3) (see Fig. 11).

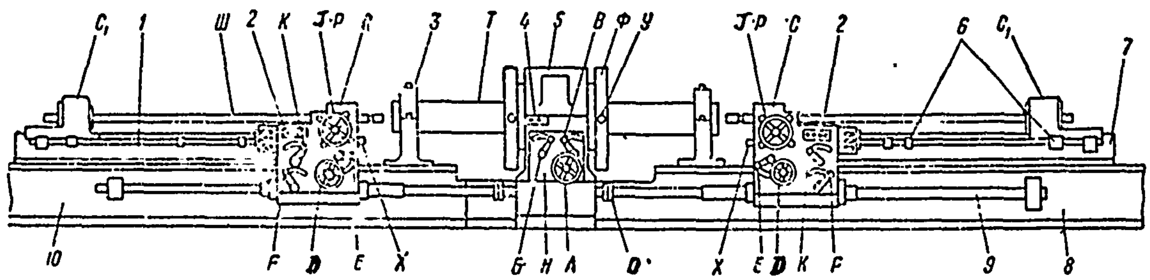


Fig. 111. Horizontal two-sided drilling and boring machine -- 2

Key:
1 & 7. upper movable stands
2. feed button panel
3. lunette
4. speed button panel
5. spindle faceplate
6. supports
8 & 10. machine mounts
9. running shaft
T. machined stock (tube)
Φ. spindle faceplate drum
Y. drum lugs
C. front supports
C_1. carriages
O. sleeve
W. shaft
H. speed transmission
J-P. flywheel for quick movement of upper stand and quick movement and working feed of carriage C_1 and shaft
f. feed direction changing lever
K & D. lever hand wheel for changing amount of feed
E. gearbox lever
A, B, & G. speed changing lever
X. gearbox shaft for manually moving carriage C_1

The machined tube T is installed in the two faceplates of the drum Φ and fastened in them with lugs γ, and additionally, into lunettes (3). It is centered relative to the guiding mounts and axis of rotation of the drum.

The movable upper mounts of the machine (1) and (7) can move along the guiding lower mounts, and the carriages C_1 with shaft W can move along the guiding upper mounts. This layout of the machine provides for deep drilling with its given dimensions. The right mount (8), as shown in the basic machine data given, is significantly longer than the left mount (10), which, in two-sided drilling, allows preliminary disengagement of the left support and finishing of drilling from the right side, and during one-sided drilling or boring of long tubes, allows removal of the upper left mount (1) and installation of the machined tube in the spindle head stock drum faceplates and on the lunettes of only the left mount.

The primary motion of the machine is accomplished by electric motor M_1 and speed transmission H, which is located in the body of spindle head stock (5). Rotation of the electric motor is transmitted to the primary shaft of the speed transmission, on which are two blocks of cylindrical gears on sliding keys, allowing transmission to the secondary shaft of four different rotation speeds (Fig. 112). The block of gears on the primary shaft is moved by hand wheel A. On the third shaft there is a block of two gears on a sliding key, which is moved by lever G. As a result of the various combinations of meshing the gear blocks on the four shafts, the speed transmission transmits eight different speeds. On the fifth shaft of the transmission is a block of two gears on a sliding key, which is moved by lever B. Sixteen different rotation speeds will be transmitted from this shaft to gears (19), (20), and (21) of the final shaft of the transmission. Gear (21), located in engagement with gear (22), which is on the shaft of the spindle head stock drum Φ, will turn the drum Φ, and the machined tube T with it.

The equation which determines the transmission of motion will have the following appearance:

$$n_6 = n_o i_k, \tag{33}$$

where n_6 equals the number of revolutions of the spindle head stock drum in a minute; n_o is the number of revolutions of the speed transmission primary shaft in a minute, equal to the number of revolutions of the motor (950 rev/min); and i_k is the transmission ratio of the speed stransmission, having sixteen different values.

Data on gears, worm screws, and rack engagements of the machine are given in Table 35.

The largest transmission ratio of the speed transmission i_1 of the machine under scrutiny is determined from the following relationship:

$$i_1 = \frac{z_7}{z_8} \frac{z_4}{z_{11}} \frac{z_{14}}{z_{15}} \frac{z_{15}}{z_{18}} \frac{z_{19}}{z_{20}} \frac{z_{21}}{z_{22}}. \tag{34}$$

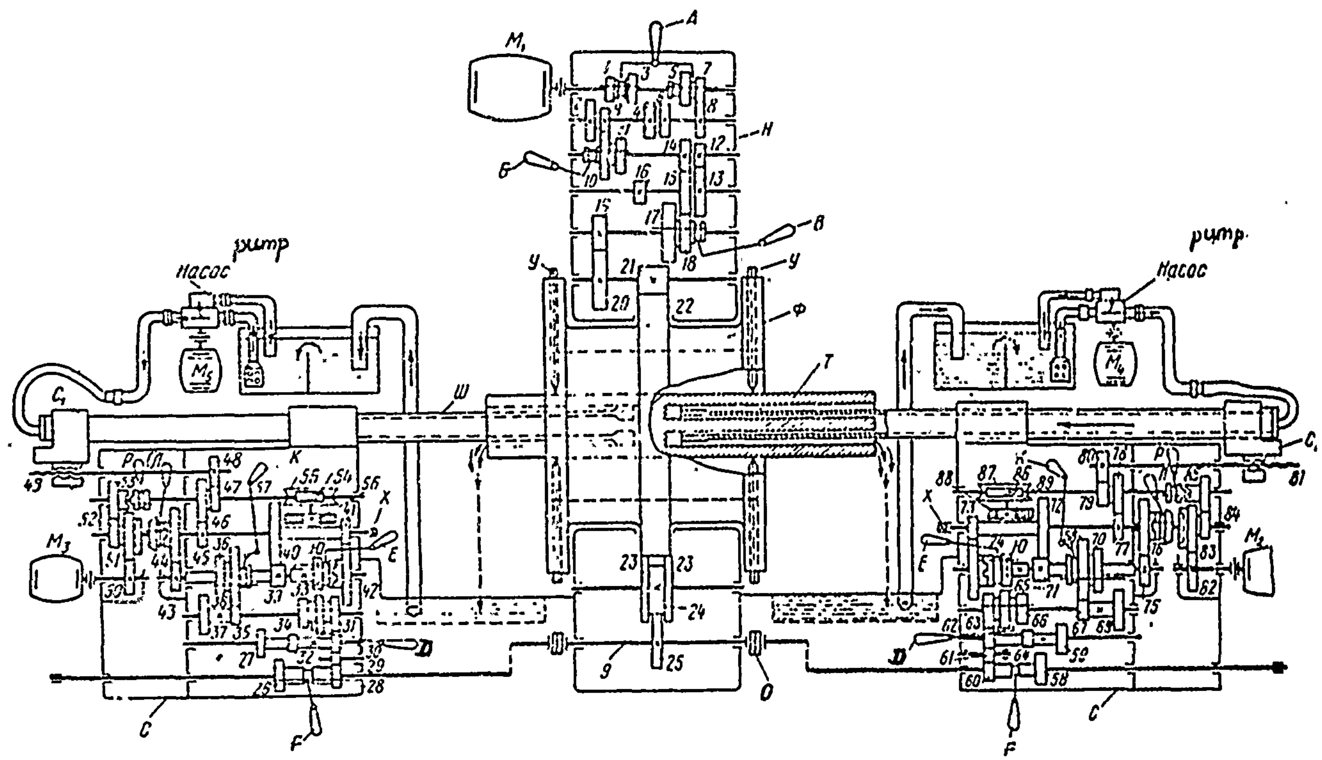


Fig. 112. Kinematic scheme of horizontal two-sided drilling and boring machine -- 2 shown in Fig. 111 (letters, positions according to Fig. 111; numbers, gear number)

Table 35

Data on Gears. Worm Screws, and Rack Engagements on Horizontal Drilling and Boring Machine -- 2
(See Fig. 112)

a № позиций	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
b Число зубцов z	25	55	30	50	35	45	40	40	21	59	50	21	63	32	45	20	59	35	35	44	21	108	36	44	56	39	39	30	30	30
c Модуль m	4	4	4	4	4	4	4	4	5	5	4	5,5	5,5	6	6	6	6	6	7,5	7,5	8	8	8	6	6	4	4	4	4	4
d Длина зуба b в мм	48	48	48	48	48	48	48	48	55	55	48	60	60	65	65	60	60	60	90	90	118	118	30	60	60	30	30	30	30	30

a № позиций	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
b Число зубцов z	48	22	56	39	26	102	48	48	32	96	[illegible]	93	20	75	25	50	25	36	e Однозаходный шаг 9,525 мм	36	92	27	48	e Однозаходный шаг 9,525 мм	60	13	f Рейка	39	39	30
c Модуль m	4	4	4	4	3	3	4	[illegible]	3	3	3	3	4	4	5	5	6	6		3	3	5	5		—	7		4	4	4
d Длина зуба b в мм	30	30	30	30	30	30	30	30	48	30	40	30	40	40	50	50	50	50		40	40	40	40		60	60		30	30	30

a № позиций	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
b Число зубцов z	30	30	48	22	56	39	26	102	48	48	32	96	35	93	20	75	25	50	25	36	e Однозаходный шаг 9,525 мм	36	92	27	48	e Однозаходный шаг 9,525 мм	60	13	f Рейка
c Модуль m	4	4	4	4	4	4	3	3	4	4	3	3	3	3	4	4	5	5	6	6		3	3	5	5		—	7	
d Длина зуба b в мм	30	30	30	30	30	30	30	30	30	30	48	30	40	30	40	40	50	50	50	50		40	40	40	40		60	60	

Key:
a. Position number
b. Number of teeth z
c. Module m
d. Tooth length b in mm
e. Single course pitch 9525 mm
f. Rack

Substituting in expression (34) the numerical values of the teeth on the gears from Table 35 (see page 226), we get

$$i_1 = \frac{40}{40} \cdot \frac{50}{50} \cdot \frac{32}{45} \cdot \frac{45}{35} \cdot \frac{35}{44} \cdot \frac{21}{108} = 0.1414.$$

From here the maximum number of revolutions of the spindle head stock drum n_1 from formula (33) will be equal to

$$n_1 = 950 \cdot 0.1414 = 134.3 \text{ rpm.}$$

The transmission ratio of the speed transmission for the eighth speed will have the appearance

$$i_8 = \frac{z_7}{z_8} \frac{z_9}{z_{10}} \frac{z_{14}}{z_{15}} \frac{z_{15}}{z_{18}} \frac{z_{19}}{z_{20}} \frac{z_{21}}{z_{22}}. \tag{35}$$

After substitution in this expression of the numerical values of the number of teeth on the gears from Table 35, we get

$$i_8 = \frac{40}{40} \cdot \frac{21}{59} \cdot \frac{32}{45} \cdot \frac{45}{35} \cdot \frac{35}{44} \cdot \frac{21}{108} = 0.0503.$$

The number of spindle head stock drum revolutions at the eighth speed will be

$$n_8 = n_0 i_8 = 950 \cdot 0.0503 = 46.6 \text{ rpm.} \tag{36}$$

The smallest transmission ratio for the sixteenth speed will be

$$i_{16} = \frac{25}{55} \cdot \frac{21}{59} \cdot \frac{21}{63} \cdot \frac{20}{59} \cdot \frac{35}{44} \cdot \frac{21}{108} = 0.00284,$$

and the smallest number of spindle head stock drum revolutions is

$$n_{16} = n_0 \cdot i_{16} = 950 \cdot 0.00284 = 2.7 \text{ rpm.}$$

Calculating the intermediate transmission ratio in this same order, it is possible to find all sixteen values of the number of drum revolutions.

Feed motion is accomplished by several methods: By the primary movement of the spindle head stock drum Φ, working feed by gear pairs (22) and (23), and (24) and (25) of the speed transmission, and from the shaft of gear (25) on the right and left supports C. Accelerated feed (nonworking movement) is accomplished by electric motors M_2 and M_3.

The right and left supports C have identical feed control units, consisting of (Fig. 113):

1) Hand wheel J-P, whose three positions control:
   Rapid movement of the upper mount;
   rapid movement of the carriage C_1 and shaft;
   working feed of the carriage C_1 and shaft;
2) lever F for changing feed direction;
3) hand wheel D for changing amount of feed;
4) lever K for changing amount of feed;
5) lever E for engaging and disengaging the gearbox during changing of feed amounts.

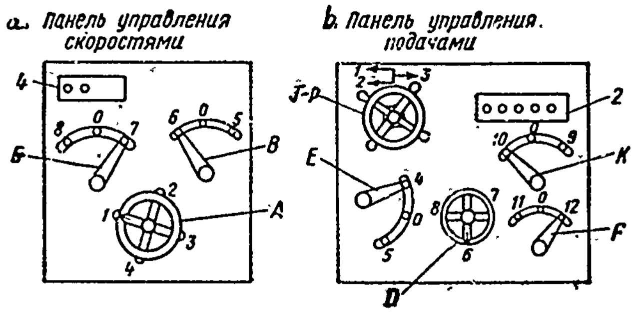


Fig. 113. Control panel of horizontal drilling and boring machine -- 2 (see Fig. 111)

Key: a. speed control panel
b. feed control panel

The gearbox shaft has a square X, with which it can be turned, transmitting this motion to the running screw and manually moving carriage C_1 with the shaft into its initial position (see Fig. 112). For limiting travel of carriage C_1 with the shaft and automatically disengaging its movement, there are stops on the machine which can be moved and installed in the required place (see Fig. 111).

The feed mechanism of the left support C has the following peculiarities:

1) Working feeds of the carriage C_1 and shaft are accomplished through transmittal of rotation from gear (25) to the common shaft of the supports and, consequently, to the block of two gears (26) and (28), sitting on the shaft on a sliding key. From gears (26) and (28), rotation is transmitted in a forward or backward direction through the idler gear (29) to the block of three gears (27), (32), and (30), which are solidly fastened on an open hub. The motion is then transmitted to the block of three gears (31), (33), and (34), which are on the third shaft on a sliding key, and from it to the block of two gears (35) and (37), which are on the shaft on a stationary key. From this block, motion is transmitted to the block of gears (36) and (38), which are on a hollow shaft on a sliding key. Gear (39), having 1.7 times the number of teeth on gear (40), is fastened rigidly on this same shaft.

In this way, gears (36), (38), and (39) rotate freely on their shaft and do not transmit rotary motion to it. The shaft receives its motion from sleeve γ, which is moved by lever E to the right (according to the drawing), through a cluster of gears (39), (40), (41), and (42) or through straight transmission with movement of the sleeve γ to the left and engagement of the external teeth of the left side of the sleeve with gear (39). Sleeve γ is on its hub on a sliding key, and its hub is on the shaft on a stationary key.

From the block of gears (36) and (38), movement will be transmitted to gears (43) and (44), and with engagement of the sleeve controlled by lever J, motion from gear (44) will be transmitted to gears (45), (46), (47), and (48). The block of gears (46) and (47) moves freely on the shaft, and gear (48) is fastened solidly to the running screw (49), whose rotation is transformed into a constant motion of feed of the carriage C_1 and shaft W. The single thread running screw (49) has a pitch of 2 2/3 threads per inch. With the described kinematic chain, it is possible to get twelve different feeds of forward and backward carriage movement;

2) accelerated movement of carriage C_1 and the shaft is accomplished by electric motor M_3 through gears (50), (51), (45), (46), and then to the running screw (49). During this, the sleeve controlled by lever J is connected to gear (51) with a friction cone, and the sleeve controlled by lever P is not connected to gear (53);

3) accelerated movement of support C is also accomplished by electric motor M_3 through gears (50), (51), (52, and (53). In this, the sleeve controlled by lever J must be disengaged and located in the neutral position, and the sleeve controlled by lever P must be connected with gear (53). Rotation of gear (53) through the sleeve controlled by lever P is transmitted to the shaft and worm screw (54), from which the motion is transmitted to the worm gear (55) and gear (56) which are engaged with rack (57).

The feed mechanism for the right support C and the kinematic feed chain for its movement are analogous to the one described.

The equation determining the working feed s_p of the carriage C_1 for one revolution of the spindle head stock drum Φ will have the following appearance

$$s_p = i_1 t_k t_x \text{ mm/rev}, \qquad (37)$$

where i_1 is the transmission ratio between gear (22) of drum Φ and gear (25) of shaft (9), transmitting movement to the supports. According to the data in Table 35,

$$i_1 = \frac{z_{22}}{z_{23}} \frac{z_{24}}{z_{25}} = \frac{108}{36} \cdot \frac{44}{56} = \frac{33}{14};$$

i_k is transmission ratio of the feed transmission, which may have twelve different values; t_x is pitch of running screw (49), having an average diameter of 72.5 mm

$$t_x = \frac{127\cdot 3}{40}\ \text{mm}$$

The maximum value of transmission ratio i_k

$$i_{k\ max} = \frac{z_{26}}{z_{27}}\frac{z_{27}}{z_{34}}\frac{z_{37}}{z_{38}}\frac{z_{43}}{z_{44}}\frac{z_{45}}{z_{46}}\frac{z_{47}}{z_{48}}.$$

Substituting data from Table 35 in this expression, we get

$$i_{k\ max} = \frac{39}{39}\cdot\frac{39}{39}\cdot\frac{48}{48}\cdot\frac{20}{75}\cdot\frac{25}{50}\cdot\frac{25}{36} = \frac{5}{54}.$$

Similarly, the minimum value for the transmission ratio i_k

$$i_{k\ min} = \frac{39}{39}\cdot\frac{22}{56}\cdot\frac{20}{102}\cdot\frac{32}{96}\cdot\frac{35}{93}\cdot\frac{20}{75}\cdot\frac{25}{50}\cdot\frac{25}{36} = \frac{1}{1116}.$$

Knowing $i_{k\ max}$ and $i_{k\ min}$, we see, using formula (37), that the maximum feed of carriage C_1

$$s_1 = \frac{33}{14}\cdot\frac{5}{54}\cdot\frac{127\cdot 3}{40} = 2.08\ \text{mm/rev},$$

and the minimum feed

$$s_{12} = \frac{33}{14}\cdot\frac{1}{1116}\cdot\frac{127\cdot 3}{40} = 0.02\ \text{mm/rev}.$$

The remaining ten working movement feeds of carriage C_1 can be determined be a similar method.

The equation determining the accelerated feed s_k of carriage C_1 and shaft has the appearance

$$s_k = n_o i t_x\ [\text{mm/min}], \qquad (38)$$

where n_o is the number of revolutions per minute of electric motors M_3 and M_2 (n_o = 1420 rpm); i is transmission ratio from the electric motor to the running screw (49); and t_x is pitch of running screw (2 2/3 threads in one inch, or 9.525 mm).

According to the data in Table 35, the transmission ratio is

$$i = \frac{36}{92}\cdot\frac{25}{50}\cdot\frac{25}{36} = \frac{25}{92\cdot 2} = 0.136.$$

As a result, the accelerated feed of carriage C_1 is

$$s_k = 1420 \cdot 0.136 \cdot 9.525 = 1835\ \text{mm/min}.$$

The equation determining accelerated feed of support C and the upper mount will have the appearance

$$s_c = n_o i_c \pi m z \ [\text{mm/min}], \tag{39}$$

where i_c is the transmission ratio from the electric motor to gear (56) of the rack engagement; m is the module of gear (56); and z is number of teeth on pinion (56).

In that the transmission ratio is

$$i_c = \frac{z_{50}}{z_{51}} \frac{z_{52}}{z_{53}} \frac{z_{54}}{z_{55}} = \frac{36}{92} \cdot \frac{27}{48} \cdot \frac{1}{60} = 0.0037,$$

support feed is

$$s_c = 1420 \cdot 0.0037 \cdot 3.14 \cdot 7 \cdot 13 = 1500 \text{ mm/min}.$$

Control elements of the machine are located on the front side of the spindle head stock, cover (4) with two buttons for starting and stopping primary movement electric motor M_1, and on supports C, with buttons on covers (2) for starting and stopping electric motors M_2 and M_3, for moving the supports to the drum (forward feed) or away from the drum (Fig. 113).

Cooling liquid in the right and left supports is moved by pumps, which are activated by electric motors M_4 and M_5. Each unit pumps 50 l/min with a pressure up to 16 atm. Reservoir volume for cooling liquid is 1150 l. A schematic of cooling liquid feed is shown in the kinematic machine layout in Fig. 112.

The overall view of the machine is presented in Fig. 114.

The weak link in the feed system of the machine is the sleeve 0 of shaft (9). The coefficient of efficiency of the machine may be taken as equal to 0.75.

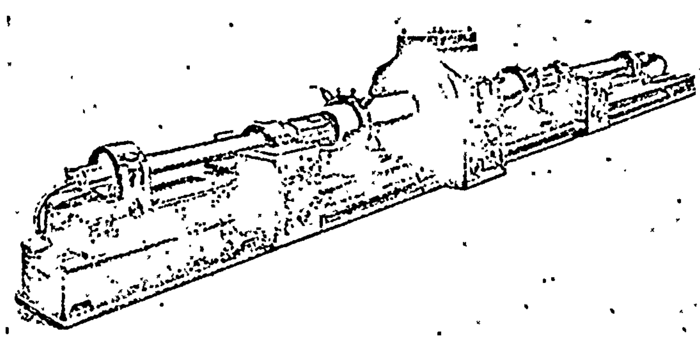


Fig. 114. Horizontal drilling and boring machine for two-sidsed ring drilling

#35. Horizontal Two-Sided Drilling and Boring Machine -- 3

The horizontal two-sided drilling and boring machine -- 3 is intended for solid and ring drilling of deep holes and reaming of tubes. Using supports, it is possible to perform some operations of lathe machining, turning of cheeks, trimming of tube faces, and boring of the preliminary hole before drilling or reaming operations on the machine.

It is expedient to perform solid drilling of holes over 30 mm in diameter on the machine in that drilling of holes less than 30 mm in diameter, it is impossible to attain a cutting speed greater than 40 m/min.

It is more expedient to use the machine for two-sided solid and ring drilling.

Due to the fact that the right mount is significantly longer than the left one, it is possible also to effectively perform one-sided drilling and boring on the machine to a depth that is somewhat greater than during two-sided drilling.

Basic Machine Information

Dimensions:	
Length	18,500 mm
Width	2750 mm
Height	1850 mm
Diameter of rotating drum opening	460 mm
Maximum exterior diameter of machined tube, fastened in the spindle drum faceplate	440 mm
Distance from spindle drum faceplate to mount:	
Along right side	10,200 mm
Along left side	6300 mm
Maximum travel of carriage with shaft:	
Along right side	7400 mm
Along left side	3800 mm
Linear travel of supports:	
Right	5200 mm
Left	1500 mm
Maximum drilling depth during simultaneous drilling from both ends	6000 mm
Maximum depth of drilling or boring from only the right side with removal of the carriage and support from the left mount and installation of lunettes only on the left side	7200 mm
Characteristics of the primary motion electric motor M_1:	
Power	30 hp
Rotation speed	1440 rpm

Characteristics of accelerated feed electric motors M_2 and M_3:

Power	3 kW
Rotation speed	1440 rpm

Characteristics of pump electric motor M_4:

Power	6.5 hp
Rotation speed	1420 rpm
Pump productivity with pressure to 12 atm	to 55 ℓ/min
Speed range of the primary motion — spindle drum (8 speeds)	7 to 127 rpm

Feed range for one revolution of the spindle drum faceplate:

For carriage	0.087 to 3.2 mm/rev
For support	0.17 to 6.5 mm/rev
Accelerated feed of carriage with shaft	up to 3305 mm/min
Coefficient of efficiency of the machine	0.8

Machine Layout

The machine consists of the following parts and mechanisms: Mounts A (middle, left, and right); spindle head stock G, in which is located the rotating drum with two faceplates Φ and the primary motion feed transmission; two front supports C with support feed transmission, lateral slides, and cutting heads F; two carriages K (rear supports) with shaft T; two front bearings O, fastened on plates of the front supports and serving to guide the shaft; feed transmissions D; two feed transmissions E; lunette J and control elements (Fig. 115).

The machined tube N is mounted and fastened on two faceplates Φ of the spindle drum, and additionally on one or two lunettes. During drilling, the tube end performs only rotary motion, and the cutting tools, fastened onto the shaft, performs only longitudinal feed.

The machine's control elements (see Fig. 115) are:

Levers (1), (2), and (3), located on the front side of the spindle head stock, serve to change primary motion speed, or the number of revolutions of the drum faceplate Φ;

levers (4) and (5) change feed of supports C or working feed of carriages K;

lever (6) changes the direction of feed;

lever (7) engages the mechanical working, manual, or accelerated feed of carriages K;

lever (8) engages feed of the supports or carriages during manual action (see Fig. 116);

hand wheel (9) controls the manual feed of supports or drilling carriages K;

hand wheel (10) controls the lateral manual feed;

lever (11) engages the longitudinal or lateral feed of supports C.

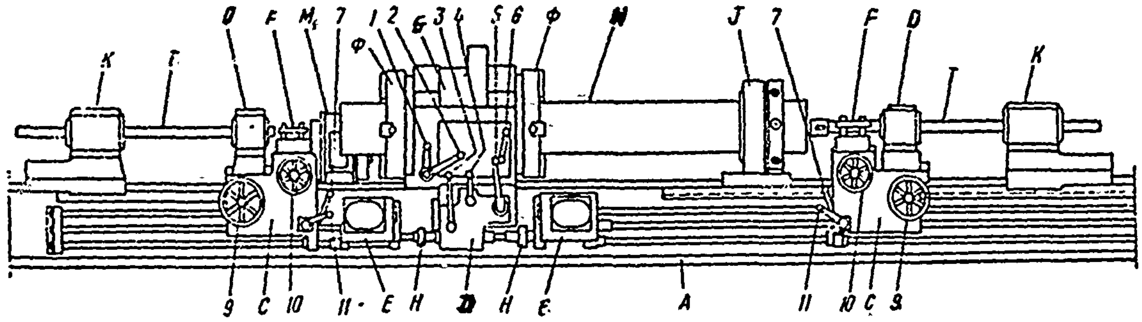


Fig. 115. Horizontal two-sided drilling and boring machine -- 3

Key: 1, 2 & 3. levers for changing primary motion speed
4 & 5. levers for changing amount of feed of supports C or carriages K
6. lever for changing the direction of feed
7. lever for engaging working, accelerated, or manual feed of carriage K
8. engaging support feed
9. hand wheel for manual feed of support C or carriage K
10. hand wheel for manual lateral
11. lever to engage longitudinal or lateral feed of support C
A. mount
G. spindle head stock faceplate
F. cutter head
K. drilling and boring carriage (rear support)
T. shaft
O. front shaft bearing
D. feed transmission
E. feed transmission
J. lunette
N. stock (tube)

The kinematic layout of the machine is shown in Fig. 116, and data on the gears and worm screws appears in Table 36.

In this schematic:

Primary motion is accomplished by electric motor M_1 and transmitted through the speed transmission G to the spindle head stock drum ϕ, on whose faceplates the machined tube end is fastened. Eight different numbers of revolutions per minute may be obtained in primary motion.

The expression determining the transmittal of primary motion has the following appearance

$$n = n_o i = [\text{rpm}], \qquad (40)$$

where i is the transmission ratio of the speed transmission; and n_o is the electric motor M_1 (n_o = 960 rpm).

The maximum transmission ratio of the speed transmission is

$$i_1 = \frac{z_1}{z_2}\frac{z_3}{z_4}\frac{z_6}{z_7}\frac{z_{10}}{z_{11}}\frac{z_{11}}{z_{14}}\frac{z_{14}}{z_{15}}.$$

Substituting the number of gear teeth from Table 36 into this expression, we get

$$i_1 = \frac{21}{33}\frac{27}{27}\frac{34}{34}\frac{20}{46}\frac{46}{23}\frac{23}{96} = 0.133.$$

From this, the number of revolutions of the spindle drum faceplate ϕ is

$$n_1 = 0.133 \cdot 960 = 127 \text{ rpm}.$$

The remaining values for primary movement revolutions are determined by the same method and appear in Table 36.

Feed motion is accomplished by the primary motion mechanism and transmitted to the feed transmission D, or from gear z_{15} to gear z_{16} (see Fig. 116). From gear (16), rotation is transmitted to gears (17), (18), (19), and (20), and to the shaft on which a block of four gears is located on a sliding key. From this block of gears, motion is further transmitted to the block of gears (22), (24), (26), (28), and (29), which are rigidly fastened on a common hub, which freely rotates on the shaft. This shaft is rotated by gear (32), which fits on the shaft on a sliding key, from gears (30) and (31) of the selector, or during forward feed, in connection with the dogged sleeve of lever (4) from gears (32) and (29).

The movement is further transmitted through gears (33) and (34) and sleeve H to the common shaft of feed transmissions E, from which the motion is transmitted to the supports or carriages K. It is possible to change the direction of feed to either forward or backward with lever (6) of the feed transimssion D.

From gear (38) (or 76) of the feed transmission E, movement is transmitted first to gear (40) and the conic gear (41) paired with it, and then to conic gear (42), which is fitted freely on its shaft. Gears (43) and (44) are rotated after the cogged sleeve on the sliding key is engaged relative to gear (42) and disengaged relative to gear (71) by movement of lever 7. In this sleeve position, the frictional length for accelerated feed is not engaged because lever (7) is in another position for this engagement.

With this position of lever (7), movement from the shaft of gear (44) will be transmitted to the worm shaft (45), the worm gear (46), and the running screw (47). Due to a stop on the running screw (47), carriage K will receive constant motion.

Feed on support C is accomplished by rotation of gear (38) (or 76), which is transmitted to gear (39) (or 77) and on to gear (50).

Table 36

Data on Gears, Worm Screws, and Rack Engagements of the Horizontal Drilling and Boring Machine -- 3 (See Fig. 116)

a. № позиции	b. Число зубцов z	a. № позиции	b. Число зубцов z	a. № позиции	b. Число зубцов z	a. № позиции	b. Число зубцов z	a. № позиции	b. Число зубцов z
1	21	24	40	47	c. Шаг 38,1 мм	70	28	93	26
2	33	25	32	48	22	71	28	94	Однозаходный d
3	27	26	48	49	46	72	22	95	36
4	27	27	20	50	34	73	46	96	21
5	20	28	60	51	42	74	54	97	54
6	34	29	27	52	26	75	14	98	14
7	34	30	82	53	d Однозаходный	76	28	99	Шаг c 5,08 мм
8	20	31	27	54	36	77	28	100	26
9	48	32	82	55	21	78	42	101	Трехзаходный e
10	20	33	54	56	54	79	21	102	36
11	46	34	55	57	14	80	42	103	31
12	21	35	50	58	Шаг c 5,08 мм	81	36	104	30
13	48	36	33	59	26	82	36	105	26
14	23	37	51	60	e Трехзаходный	83	f Шестизаходный	106	Шаг c 12,7 мм
15	96	38	28	61	36	84	48	107	34
16	32	39	28	62	31	85	Шаг c 38,1 мм	108	34
17	38	40	42	63	30	86	22	109	28
18	54	41	21	64	26	87	46	110	28
19	59	42	42	65	Шаг c 12,7 мм	88	46	111	28
20	54	43	36	66	34	89	34	112	28
21	46	44	36	67	34	90	34	113	22
22	34	45	f Шестизаходный	68	28	91	34	114	46
23	40	46	48	69	28	92	42	115	54
								116	14

Key:
a. position number
b. number of teeth
c. pitch
d. one course
e. three course
f. six course

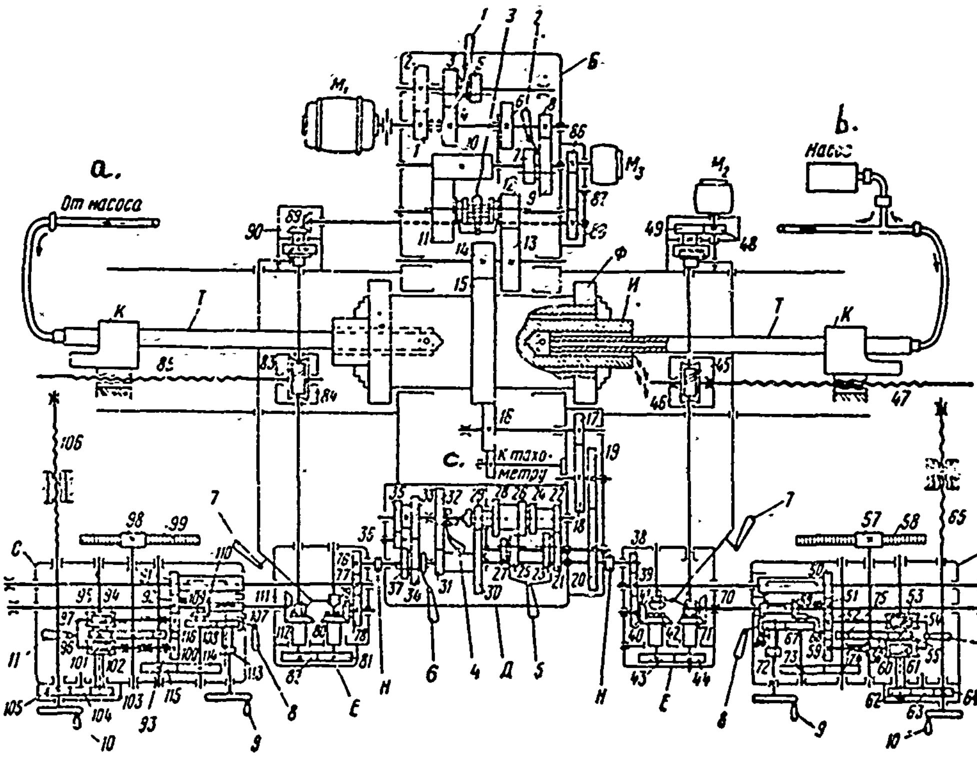


Fig. 116. Kinematic layout of two-sided horizontal drilling and boring machine -- 3 (letters, positions according to Fig. 115; numbers, gear numbers; M_1 and M_2, electric motors

Key: a. from pump
b. pump
c. to hand wheel gauge

The latter leads to movement of gears (51) and (52), the worm pair (53) and (54), gears (55) and (56) and gear (57) of the rack engagement, which, rolling along rack (58), transmits a longitudinal movement to the support.

It should be noted that worm gear (53) and cylindrical gear (55) are mounted on keys on a common hub which moves freely on the shaft. Worm gear (61) and cylindrical gear (62) are also fitted on a common hub and rotate freely on their shaft. Lever (11) has two positions to engage one or the other worm pair, and, depending on this, the support feed is longitudinal or lateral.

Table 37

Number of Revolutions of Spindle Head Stock Drum of a Horizontal Drilling and Boring Machine -- 3 (See Fig. 116)

a Ступени	b Положение рукояток			c Число оборотов барабана в минуту
	1	3	2	
1	1	1	1	127
2	2			75
3	1		2	53
4	2			31
5	1	2	1	28
6	2			16,3
7	1		2	11
8	2			7

Key: a. speed
b. lever position
c. drum revolutions per minute

The equation determining working feed of carriage K for one rotation of the drum Φ of primary movement will have the following appearance:

$$s_o = i_1 i_2 i_3 i_4 t_x \text{ mm/rev} , \tag{41}$$

where i_1 is the transmission ratio from the drum to the feed transmission D.

This relationship is constant and has the following value:

$$i_1 = \frac{z_{15}}{z} \cdot \frac{z_{17}}{z} \cdot \frac{z_{19}}{z} = \frac{96}{32} \cdot \frac{38}{54} \cdot \frac{39}{54} = \frac{19 \cdot 13}{9 \cdot 18} ;$$

i_2 is the transmission ratio of the feed transmission D, which may have eight different values. The maximum of these is

$$i_{2max} = \frac{z_{21}}{z_{22}} \cdot \frac{z_{33}}{z_{34}} = \frac{46}{34} \cdot \frac{54}{55} ;$$

i_3 is the transmission ratio of the feed transmission E and will be constant. It is determined from the relationship

$$i_3 = \frac{z_{38}}{z_{40}} \frac{z_{41}}{z_{42}} \frac{z_{43}}{z_{44}} = \frac{28}{42} \cdot \frac{21}{42} \cdot \frac{36}{36} = \frac{1}{3};$$

i_4, transmission ratio of the worm pair (45) and (46) ($i_4 = 6/48$);

t_x is pitch of two-course running screw (47 ($t_x = 38.1$ mm);

$$s_o = 0.084 \cdot 38.1 = 3.2 \text{ mm/rev.}$$

The equation determining feed $s_{o.c}$ of the support C for one revolution of drum Φ of primary motion will have the appearance

$$s_{o.c} = i_1 i_2 i_c \pi m z \text{ [mm/rev]}, \qquad (42)$$

where i_1 and i_2 are the transmission ratio having the same value as in the working feed of carriage K; i_c is transmission ratio of toothed and wormed pairs of the rack. Considering the transmission ratio of gears (38) and (39) of the feed transmission E equal to one, we see that

$$i_c = \frac{z_{38}}{z_{39}} \frac{z_{50}}{z_{52}} \frac{z_{53}}{z_{54}} \frac{z_{55}}{z_{56}} = \frac{28}{28} \cdot \frac{34}{26} \cdot \frac{1}{36} \cdot \frac{21}{54} = 0.014,$$

or it will be a constant value; m, module; z is number of teeth in the pinion.

The overall transmission ratio i to the pinion with maximum value of the transmission ratio i_2 will be determined by the relationship

$$i = i_1 \cdot i_2 \cdot i_c = 0.029.$$

With the resultant value of total transmission ratio i and data from Table 36

$$s_{o.c} = i \cdot \pi \cdot m \cdot z_{57} = 0.029 \cdot 3.14 \cdot 5.08 \cdot 14 = 6.5 \text{ mm/rev.}$$

where m = 5.08, module; z = 14, number of teeth in the pinion.

The remaining values of carriage and support feed, calculated by a similar method, are given in Table 38.

The accelerated feed of carriage K (right and left) is accomplished by electric motors M_2 and M_3. On the right carriage, rotation of the electric motor is transmitted through the cylindrical gears (48) and (49) with engagement of lever (7) of the friction sleeve of the worm pair (45) and (46), and the running screw (47). There is an additional conic gear pair (89) and (90), whose gear ratio is equal to one, on the left carriage for transfer of rotation of the electric motor M_3.

Table 38

Feeds of Carriages K and Supports C for One Revolution of the Spindle Head Stock Drum on a Horizontal Drilling and Boring Machine -- 3
(See Fig. 116)

a. Ступени	b. Положение рукояток		c. Подача каретки K мм/об	d. Подача суппорта C мм/об
	5	4		
1	1	1	3,2	6,5
2	2		2,36	4,7
3	3		1,58	3,13
4	4		0,79	1,56
5	1	2	0,35	0,715
6	2		0,26	0,5
7	3		0,17	0,37
8	4		0,087	0,17

Key: a. speed
b. lever position
c. feed of carriage K in mm/rev
d. feed of support C in mm/rev

The expression determining the accelerated feed of carriage s_{min} has the following appearance:

$$s_{min} = n_o i_y t_x \text{ [mm/min]},$$

where n_o is revolutions of the electric motor M_2 or M_3

$$(n_o = 1440 \text{ rpm});$$

i_y is the gear ratio of accelerated feed

$$\left(i_y = \frac{26}{46} \cdot \frac{6}{48} = 0.06\right);$$

t_x is pitch of running screw (47) (t_x = 38.1 mm).

With these data, we see that

$$s_{min} = 1440 \cdot 0.06 \cdot 38.1 = 3305 \text{ mm/min.}$$

Manua feed of carriage K is accomplished by hand wheel (1), whose rotation is transmitted to gears (66), (67), (68), (69), (70), (71), the worm pair (45) and (46), and the running screw (47).

Manual movement of support C is also accomplished by the hand wheel (9), whose rotation is transmitted to gears (72), (73), (74), (75), and (56). The motion is transmitted from gear (56) to gear (57) of the rack engagement.

Lateral feed of the upper slides with the cutting head of support C is accomplished from the primary motion or manually. With accomplishment of feed from the primary motion, rotation of gear (50) is transmitted to gears (51), (52), and (59), then to the worm pair (60) and (61), and to the final gears (62), (63), (64), and on to the running screw (65). All data set forth relating to the right side of the machine apply identically to its left side, as is evident from Fig. 116.

CHAPTER X

Rifling Gun Bores.

#36. Layout of Gun Barrel Riflings

Durings its firing from an artillery weapon, a projectile in a rifled bore will be moved both progressively and rotationally. The latter movement provides maintenance of the normal projectile on the trajectory of its flight and the required accuracy of fire.

Riflings in gun bores are spiral paths, or channels, which compose angle α of rifling deviation or angle of rifling curvature to the direction of the bore axis. If the projectile, moving in the barrel bore, accomplishes a clockwise rotational movement (looking from the opened end of the bore), then the riflings of this weapon are called right, and their mapping on plane yOx will have the appearance of those depicted in Figs. 117 and 118. In both figures, axis Ox is directed along the barrel bore. Domestic weapons have right hand riflings, and the weapons of some European countries have left hand riflings.

Riflings differ according to their character of curvature:

1) Constant curvature, if angle α of inclination of the riflings is constant throughout the length of the rifled portion of the bore (see Fig. 117);
2) changing curvature, or progressive riflings, if angle α of rifling deviation changes throughout the length of the rifled portion of the bore, and increases toward its muzzle part (see Fig. 118).

Progressive riflings may be determined with quadratic or cubic parabolas or with a sine curve. In weapons of domestic production, progressive riflings are determined with a quadratic parabola. The Germans, in their weapons, used all forms of progressive riflings.

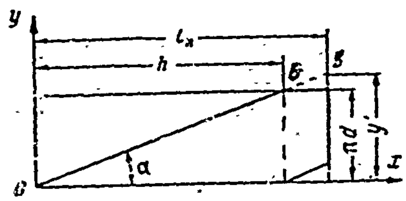


Fig. 117. Mapping of riflings of constant curvature

Key: l_H. length of rifled portion of bore
α. angle of rifling curvature
OB. rifling mapping
d. gun caliber

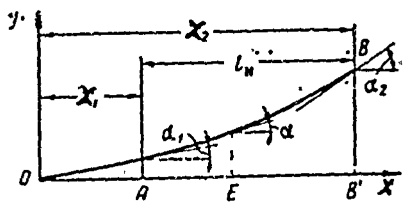


Fig. 118. Mapping of riflings of progressive curvature

Key: l_H. length of rifled portion of bore
α_1. angle of inclination of riflings at the beginning of riflings
2. angle of inclination at the muzzle section of the bore

Movement of the projectile along the bore takes place due to action of the powder gas pressure force on the bottom of the projectile. It is determined by the following expression:

$$P = p_{CH}F,$$

where P is force of powdered gas pressure in kg; p_{CH} is pressure of powder gases on the projectile bottom in kg/cm^2; F is area of barrel bore section including riflings in cm^2. $F = (0.8 \text{ to } 0.82)d^2$. Here d is the diameter of the barrel bore along the lands or the gun caliber in cm.

During progressive and rotational movement of the projectile in the gun bore, the following forces arise (Fig. 119):

The force of normal pressure of the projectile rotating band on the edge of the lands of the bore N;

force of friction arising on the edge of the projectile rotating band and the edge of the land νN (coefficient of friction for copper on steel is equal to 0.17);

the equally acting force Φ of normal pressure of the rotating band on the surface of the bore along the lands and grooves. The amount of the equally acting force does not usually exceed 10 to 12% of force N;

force of friction arising as the result of the action of the force of normal pressure Φ. This force, because of its small size, is ignored in calculations;

the equally acting force of resistance of the air pushed out of the barrel bore by the projectile. Because of its small size, this force is not included in calculations.

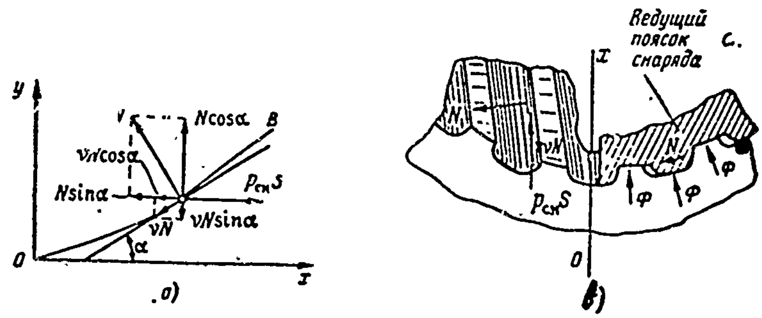


Fig. 119. Schematic of forces arising on the edge of the lands OB during movement of the projectile along the bore. OX, direction of barrel bore axis

Key:
- a. principal schematic
- b. forces arising in the barrel bore
- c. projectile rotating band

Movement of the projectile in the weapon bore is determined by the following equations:

a) During constant motion

$$\frac{q}{g}\frac{dv}{dt} = P_{CH}F - n\,(N \sin\alpha = N \cos\alpha); \qquad (44)$$

b) during rotational motion

$$j \frac{d\omega}{dt} = nr\ (N \cos \alpha - \nu N \sin \alpha).$$

In both equations: q is projectile weight in kg; g, acceleration of the force of gravity ($g = 9.81\ m/sec^2$); j, moment of projectile inertia relative to the axis of its rotation.

$j = \mu \frac{q}{g} r^2$; here μ is the coefficient of inertia for artillery projectiles. Usually, μ = 0.47 to 0.64, and it is taken as equal to 0.57 in calculations; r, radius of the barrel bore at the point of force application. Usually, r = (0.5 to 0.508)d with a depth of riflings $t_H = 0.015d$ mm; n, number of riflings in the barrel bore.

Angular acceleration dω/dt of rotational motion of the projectile may be expressed in the following form:

$$\omega = \frac{\nu tg\alpha}{r},$$

$$\frac{d\omega}{dt} = \frac{d(\nu tg\alpha)}{rdt}.$$

Considering the last expression, the equation of rotational movement of the projectile (45) may be written in the following form:

$$\frac{q}{g} \mu r^2 \frac{d(\nu tg\alpha)}{rdt} = nr\ (N \cos \alpha - N\nu \sin \alpha). \qquad (46)$$

Solving equation (46) with respect to N, after a number of transformations, we get the following calculated formulae for determination of the normal pressure of the projectile rotating band on the edge of the lands:

a) For riflings of constant curvature

$$N = \frac{\mu}{n} p_{CH} F tg\alpha, \qquad (47)$$

b) for riflings of progressive curvature according to the law of the second degree (square) parabola

$$N = \frac{\mu}{n} \left(p_{CH} F tg\alpha + K_\alpha \frac{q\nu^2}{g}\right), \qquad (48)$$

where $K_a = \frac{tg\alpha_2 - tg\alpha_1}{\ell_H}$. Here α_1 is the angle of deviation of the riflings where they begin, ($\alpha_1 = 2$ to 4^o); α_2 is angle of inclination of the riflings at the muzzle part of the barrel (α_2 = 7 to 12°); ℓ_H is the length of the rifled portion of the bore.

Upon reviewing formulae, i.e., (47) and (48), we see that the normal pressure of the projectile rotating band N depends on the following factors:

1) Distribution of projectile mass, which is calculated by the coefficient of inertia μ;
2) amount of powder gas pressure on the projectile bottom p_{CH};
3) area of the bore cross section F;
4) angle of rifling curvature α; and
5) amount of kinetic energy of the progressive motion of the projectile along the bore.

Fig. 120 shows the curving changes of normal pressure N along the length of the weapon bore. Curve A, representing riflings of constant curvature, has a uniform conformity with the curve of pressure changes of outer gases in the barrel bore. It is evident from Fig. 120 that on the bored section of length $\ell_3 = \ell_1 + 5d$ from the beginning of the riflings, curve A is located significantly higher than curve B, which represents riflings of progressive curvature. Powder gas temperature will also have a higher value on this section of the bore. The coincidence on curve A of the action of normal pressure N and gas temperature of maximum value has an unfavorable effect on the riflings, and will increase their wear and pitting. Curve B provides a smoother increase in normal pressure than does curve A, with lower absolute value, which creates more favorable conditions for work of the projectile rotating band, although for this, the rotating band of most projectiles, because of their width, must consist of two independent sections (see Figs. 22 and 23).

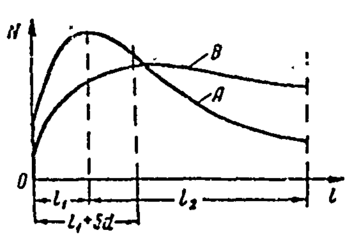


Fig. 120. Changes in normal pressure N on the working edge of the groove along the length of the barrel bore

Key: A. constant twist groove
B. progressive groove
o_ℓ: direction of bore axis
ℓ_1. ordinates of point of maximum powder gas pressure in the barrel bore

The comparison of curves A and B, and also curves of powder gas temperature and pressure changes along the length of the bore form the basis for the conclusion that progressively curved riflings are more advantageous than constantly curved riflings. With this, the small size of angle α in progressively curved riflings decreases the normal pressure N by 20 to 25% on the bore section of length $\ell_3 = \ell_1 + 5d$, and so wear and erosion of the riflings lands in this section also decrease. The consequent increase in angle of curvature of riflings α toward the muzzle part provides the required angular speed of rotational movement of the projectile at the moment of its exit from the barrel bore.

Length of Course and Angle of Twist of Riflings

The mapping of constant twist riflings on plane yOx has the appearance of a straight line OB (see Fig. 117). The riflings are characterized by twist, which is determined by angle α between the axis of the barrel bore Ox and the direction of riflings, and the length of rifling course h, which is the distance along the barrel axis on which the riflings make one revolution. From Fig. 117, it is evident that the length of rifling course h and angle of twist α are tied by the dependence

$$tg\alpha = \frac{\pi d}{h},$$

or

$$h = \frac{\pi d}{tg\alpha}.$$

The length of rifling course is quite often expressed in gun calibers d according to the relationship

$$\frac{h}{d} = \eta = \frac{\pi}{tg\alpha}. \quad (49)$$

In progressive twist riflings, the angle of rifling twist α changes (see Fig. 118). Twist of these riflings is characterized by angles α_1 and α_2 at the beginning and end of the riflings respectively, and the change in angle in the interval between these functions of the angles.

Progressive twist riflings which are constructed according to a second degree (quadratic) parabola, are determined by an equation of the following type:

$$y = \alpha x^2. \quad (50)$$

During mapping of progressive twist riflings, determined by formula (50), on plane yOx:

The origin of the coordinates is located on the top of the parabola, the axis Ox is directed along the axis of the bore, and the length of the arch corresponding to the spin of the projectile around its axis on central angle ϕ is plotted on the axis Oy. Point A on the boring of the riflings is the beginning of the riflings, to which the initial angle of twist α_1 corresponds, and point B' is the muzzle shear of the rifled portion of the bore, to which twist angle α_2 corresponds, and ℓ_H is the length of the rifled portion of the barrel bore.

We will find the expression which determines coefficient α in formula (50), for which we take the first derivative, which is the tangent of the angle of inclination touching curve OB (see Fig. 118)

$$\frac{dy}{dx} = 2\alpha x = tg\alpha.$$

From the last expression, it follows that with $x = x_1$

$$tg\alpha_1 = 2\alpha x_1,$$

and with $x = x_2$

$$tg\alpha_2 = 2\alpha x_2.$$

Considering that

$$x_2 - x_1 = \ell_H,$$

we can write

$$tg\alpha_2 - tg\alpha_1 = 2\alpha(x_2 - x_1) = 2\alpha\ell_H,$$

and thence

$$\alpha = \frac{tg\alpha_2 - tg\alpha_1}{2\ell_H}. \tag{51}$$

Knowing the parameter of parabola α, it is easy to determine section x_1 and, consequently, the top of the parabola. The previous expression also shows that multiplier K_α, going in to the second term of equation (48), is equal to the doubled value of parameter α, or $K_\alpha = 2\alpha$.

Knowing the parameter of parabola α, then the initial angle of the changing rifling twist α_1, and setting the coordinates of an arbitrary point E, it is easy to determine the angle of riflings twist at this point α according to $tg\alpha$.

In this way, according to the known initial information (α, α_1), it is possible to construct rifling reaming of progressive parabolic twist on a plane to build a rifling machine copier for it and check the machine before rifling the bore.

The choice of rifling twist, as known from a course in external ballistics, is conditioned by the requirement for providing the necessary maintenance of the projectile on its trajectory by its rotation around its longitudinal axis at the moment of its flight from the bore. The angular speed of this rotational movement of the projectile is determined according to the formula

$$\omega = 2\pi n \qquad (52)$$

or according to the formula

$$\omega = \frac{v \operatorname{tg} \alpha}{r}, \qquad (53)$$

where n is the turns of rotational movement of the projectile in the barrel bore in a time unit; v is progressive velocity of the projectile in the barrel bore, which at the moment of its flight from the bore is equal to the initial velocity of the projectile v_0; α is angle of rifling twist; and r is the radius of the circumference through which the projectile rotates, or half caliber.

It is evident from formula (53) that the angular velocity of projectile rotation at the moment of its flight from the barrel bore depends on the velocity v of progressive motion and on the angle of rifling twist $\alpha = \alpha_2$.

Therefore, in weapons having a low initial projectile velocity (500 to 650 m/sec), for instance in howitzers, the angle of rifling twist α_2 should be increased, and in weapons having a high initial projectile velocity (850 to 1000 m/sec), the angle of rifling twist α_2 should be decreased.

From data on artillery systems used and manufactured in the period of the second world war, it is known that:

1) Field, tank, and antiaircraft cannons of caliber 50 to 120 mm with barrel length of up to 55d and initial projectile velocity (v_0 = 850 to 1000 m/sec) had, as a rule, riflings of constant twist $\alpha = 6^\circ 30'$ to 7°, and only certain of their models had riflings of progressive twist $\alpha = 3^\circ/7^\circ$ (in the numerator of the initial angle, twist $\alpha_1 = 3^\circ$, and in the denominator, the angle of twist at the muzzle shear $\alpha_2 = 7^\circ$);

2) field howitzers and light field cannons with a relatively small barrel length and initial projectile speed v_0 = 550 to 750 m/sec similarly had riflings of progressive curvature $\alpha = 4^\circ/8^\circ$ or $\alpha = 4^\circ/10^\circ$. In some instances, the rifling of progressive curvature $\alpha = 5^\circ/12^\circ$ was used in these weapons.

Tolerances on Twist Angle Size In Rifling Barrel Bores

The twist of riflings shown in the drawings is the assigned calculated or nominal twist. The actual twist of riflings of gun barrels attained in production will always deviate from the calculated. The amount of deviation between the actual twist of riflings and the nominal depends on various factors:

Accuracy of manufacture of the cutters and adjustment of the rifling machine, especially of its copying mechamism; accuracy of the measuring instrument used for checking the rifling twist, and method of measuring; and methods of checking the rifling machine.

Modern rifling machines, including their copying mechanisms, can attain manufacture of riflings to an accuracy of ±5' in twist in that the optical star wheel of these machines gives a reading of rifling twist to an accuracy of up to ±5'. Therefore, technical capabilities of production provide accuracy in rifling twist to ±5', which can also be attained in separate barrels if it becomes necessary because of the assigned ballistic properties of the cannon, in serial weapon production, considering the expediency of checking the rifling machine, not for separate gun barrels, but for entire lots of them, the tolerance (or manufacturing accuracy) on rifling twist should be increased, and in production experience it is usually taken as ±10'. Practice has shown that this tolerance satisfies the requirements for operation and use of artillery barrels and does not noticeably influence the ballistic properties of the weapons (accuracy of fire).

It is necessary to note that the tolerance of ±10' relates only to the angles of twist of weapon barrel riflings, and the tolerance for checking the rifling machine, including checking installation of its copier, must not exceed ±5', and only in certain cases can it be equal to ± 10'.

The amount of recommended tolerance on the angle of deviation of riflings α (or rifling twist) is easy to calculate with constant twist riflings, but for progressive twist riflings, calculation of this tolerance presents some difficulty in that for each section of rifling length, it is necessary to first determine angle α corresponding to it. In breaking down the riflings into separate sections, lengths greater than 250 mm should not be taken. It is significantly easier to construct progressive twist rifling reaming as shown in Fig. 121. In this case, knowing the initial parameters α_1, α_2, and ℓ_H, the ordinates y, which are the lengths of the arcs corresponding to the rotation of the projectile on the given section on central angle ϕ, are determined for each section of the rifled portion of the bore. In constructing analysis of the tolerance on the angle of rifling twist, it is more expedient to use central angle ϕ in that such a tolerance, together with the calculated values y and ϕ, would allow more convenient checking of rifling machine copier installation accuracy in production.

The size of the tolerance on the central angle ϕ for each section of riflings must not be greater than ±40'. This amount of tolerance will correspond to the recommended value of tolerance ±10' on angle α of the rifling deviation.

The manufacturing processes for riflings of constant and progressive twist are analogous in operations and are not complicated. In a technological sense, riflings of constant twist have a number of advantages, namely: Simplified copying mechanism construction and installation of it on the machine, convenience of adjustment and checking of the rifling machine, simplified checking of rifling twist in weapon bores in the process of their manufacture, and decrease in design and technological expenses.

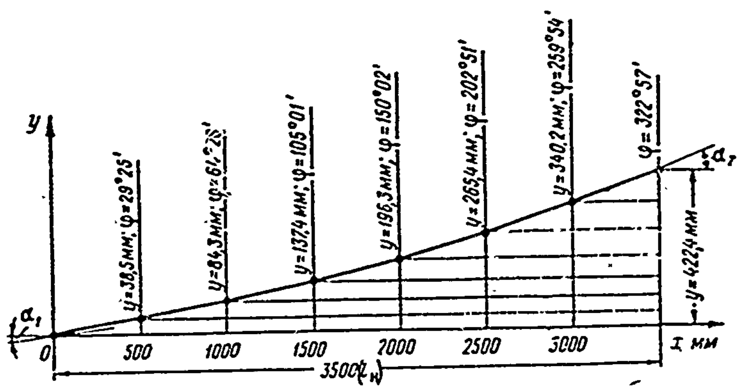


Fig. 121. Mapping of progressive twist riflings, constructed according to the equation $y = \alpha x^2$

Key: ℓ_H. length of rifled portion of the bore
α_1. initial angle of twist ($\alpha_1 = 4^o$)
α_2. angle of twist at the muzzle part ($\alpha_2 = 9^o\ 46'$)
y. ordinates of length of arch (circumference)
Φ. central angle

Profile of Riflings

The form or profile of weapon bore riflings is determined by the dimensions of their separate elements (Figs. 122 and 150). The following types of weapon bore riflings differ according to profile:

Normal profile riflings;
trapeziform riflings;
special profile riflings (with a beveled free edge under the ridges of the projectile rotating band and others).

Normal profile riflings are used most widely in all types and calibers of weapons.

In choosing a profile and riflings of weapon bores, it is necessary to consider the weapon caliber, the amount of powder gas pressure, the initial velocity of the projectile, the method of loading, the strength of the rifling lands, and the projections formed on the rotating band of the projectile after its cutting in the riflings.

But in modern weapons, rifling dimensions are tied with the following relationship (see Fig. 122):

$$b = (1.5 \text{ to } 2.0)c, \qquad (54)$$

where b is width of rifling (grooves); and c is width of lands.

The basic dimension is the groove width b; however, if the land width c in a given dimension of width b does not satisfy requirements for durability, then all dimensions of the riflings must be reviewed.

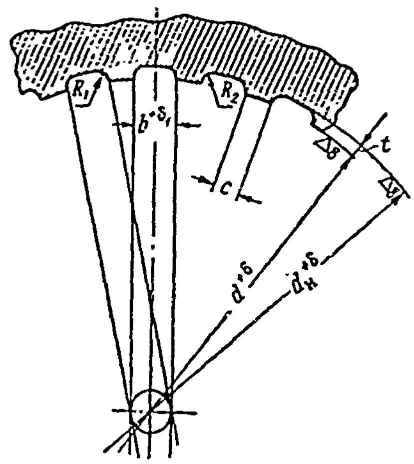


Fig. 122. Rifling profile

Key:
- d. diameter of bore along the lands (weapon caliber)
- d_H. diameter of the bore along the grooves
- b. groove width
- c. land width
- t. groove depth
- δ. tolerance on bore machining along diameters d and d_H
- δ_1. tolerance on groove width

According to technological considerations, the number of grooves in a weapon bore must be even so that rifling of the bore can be performed by manifold cutting heads, having six or eight cutters.

The approximate number of grooves n can be determined according to the following empirical formulae:

a) For small and medium caliber weapons

$$n = 3.5d + 2, \tag{55}$$

b) for large caliber weapons over 200 mm

$$n = 2.5d + 2, \tag{56}$$

where d is caliber in cm.

From formulae (55) and (56), it follows that the number of grooves increases with an increase in weapon caliber. When choosing a groove profile, grooves which positively recommend themselves in operation of existing gun barrels should also be considered.

After preliminary calculations of rifling profiles have been completed, it is necessary to round off the nominal dimensions of land width c and groove width b obtained to tenths of a millimeter.

Groove depth t is usually determined by the following relationship:

$$t = (0.01 \text{ to } 0.02)d. \tag{57}$$

For the majority of modern weapons with a powder gas pressure $p \geq 3000$ kg/cm^2 and an initial projectile velocity $v_0 \geq 900$ m/sec, to increase weapon barrel life, groove depth

$$t = (0.015 \text{ to } 0.02)d.$$

The correct choice of a rounding-off radius R_1 increases durability of the lands, excludes the possibility of cutting the tube body, improves bore cleaning conditions, and decreases the possibility of dirt accumulation and rust formation. The rounding-off radius R_1 should usually be determined from the relationship

$$R_1 = (0.5 \text{ to } 0.6) \cdot t. \tag{58}$$

The sharp edges of the lands are rounded off to a radius of $R_2 = 0.1$ to 0.15 mm, which is attained by the technological polishing of the bore.

Table 39 presents dimensions and tolerances characterizing the bore riflings of several models of weapons.

The basic dimensions of rifling according to the drawings are its width and depth because these dimensions are attained immediately in the process of rifling cutting, and besides this, its width depends on the corresponding dimension of the cut. Machining tolerance on groove width should be assigned with consideration for the accuracy of the machine, the degree of cutter wear during the machining process, and decreases in groove width in connection with this.

Table 39

Characteristics of Bore Riflings
of Several Weapons of the 1941-1944 Period

Characteristic nomenclature	57 mm cannon Mod. 1943	85 mm cannon Mod. 1943	203 mm howitzer Mod. 1931	75 mm German cannon Mod. 1942	88 mm German cammpm Mod. 1945	105 mm German cannon
Weapon caliber d in mm	57	85	203.2	75	88	105
Projectile weight q in kg	3.14	9.2	100	6.8	10.2	15.1
Initial projectile velocity v_0 in m/sec	990	797	607	935	1000	790
Maximum powder gas pressure p_{max} in kg/cm^2	3100	2550	2350	2850	3000	2700
Length of rifled portion of bore ℓ_H in mm	3421	3496	3981	4357	5150	3694
Bore diameter along grooves d_H in mm	58.8	86.7	207.2	76.8	90.4	107.6
Tolerance δ on bore diameter d_H in mm	+0.1	+0.15	+0.2	+0.2	+0.2	+0.2
Number of grooves n	24	24	64	32	32	32
Groove width b in mm	5.35	7.5	6	3.86	5.04	6.8
Tolerance δ_1 on groove width b in mm	±0.3	±0.3	±0.3	±0.2	±0.5	±0.2
Land width c in mm	2.1	3.62	3.97	3.5	3.6	3.5
Groove depth t in mm	0.9	0.81	2	0.9	1.2	1.3
Rifling twist α in degrees	6°	7°09'	8°56'	6°31'	6°31'	4°/6°
Tolerance on rifling twist in minutes	±10'	±10'	±10'	±40'	±40'	±40'

NOTE. 1) Tolerances on rifling twist for German weapons are given relative to central angle ϕ of rotation of the projectile in Fig. 121. 2) Rifling dimension designations are given in Fig. 122.

In assigning the tolerance on groove width, the possibility of decreasing the width of lands because of working instability of the spacing mechanism of the rifling machine should also be considered. For instance, if a sixth or a fourth of all the riflings are cut simultaneously, it is necessary to rotate the barrel each time during transfer from one group of grooves to another by an angle of 360° + n, which is the angle whose arc is equal to the width of a land and a groove. It is necessary to rotate the barrel until the final rifling of the last group of grooves, and mistakes in angles of rotation may vary in size and direction, as the result of which the width of one group of lands may turn out smaller than the width of another group.

Tolerances δ_1 on groove width dimensions should be assigned with consideration for the barrel caliber; for instance, for barrels up to 100 mm in caliber, tolerance $\delta_1 = \pm 0.2$ mm; for barrels 100 to 180 mm in caliber, tolerance $\delta_1 = +0.3$ mm; and for barrels over 200 mm in caliber, tolerance $\delta_1 = +0.4$ mm. Analogous tolerances on land width dimensions will have a minus sign.

Table 39 presents tolerances δ_1 for some weapon models. Tolerances δ on bore diameters d (along the lands) and d_H (along the grooves) are also assigned with consideration for the barrel caliber, namely:

Gun caliber in mm	Tolerance δ in mm
50 - 85	+0.1
100 - 152	+0.15
152 - 210	+0.2
over 210	+0.3

As a rule, machined smoothness of the groove surface must be the same as the surface of the machined lands and charge chamber, or ∇8.

#37. Machines for Rifling Gun Barrels

Machines for rifling gun barrels (rifling machines) belong to the special machines used to obtained spiral channels (grooves), which may be divided into three groups according to dimensions: Machines of small length to 10 m, machines of medium length from 12 to 21 m, and machines of large length over 25 m. The last type of machines may reach a length of up to 50 m.

Dimensions of the rifling machines are determined by the length and weight of the weapon barrels rifled on them, and the length of the machine must be 2.4 times that of the rifled barrel, in that only with this length relationship are the normal conditions of the rifling process provided.

In their layouts, the various rifling machines have much in common, both in construction and in kinematic scheme, which eases their learning and installation of working processes on them.

The gun barrel, installed and fastened on the machine in lunettes, remains stationary during rifling. It is rotated by the spacing mechanism only upon finishing rifling one group of grooves and transferred to rifling another set of grooves.

During rifling of the barrel, the shaft with the rifling head performs a combined straight forward and backward motion along the axial direction, and a rotary one, turning at the angle corresponding to the rifling twist of the machined section of the barrel bore. Machines of similar kinematic layout are most widely used in all countries.

In some single examples, rifling machines, usually of large dimensions, are encountered in which the rifled barrel remains stationary in the lunettes from the beginning to the end of the cutting process of all the grooves, and the shaft with the rifling head performs a progressive and rotational movement with consideration for changes in the rifling twist angle along the barrel length. If, on this machine, not all the riflings are machined simultaneously, but only part of them, during transfer from one group of riflings to another, the shaft with its rifling head is rotated to the required angle by the spacing mechanism instead of rotating the barrel, leaving the barrel stationary.

The rifling machine usually consists of the following basic (components): Mounts, lunettes for installing and fastening the machined barrel on them; carriage (movable support) with the shaft, carrying the rifling head fastened in it; copying mechanism; speed transmission, regulating the speed of the running screw movements; drives and machine control mechanisms.

We will become familiar with technical data and layouts of some types of rifling machines.

Rifling Machines of the Krasnyi Proletarii Plant

The rifling machine of the Krasnyi Proletarii plant is characterized by the following basic technical data:

length	20 m
width	2.7 m
height	1.6 m
maximum length of rifled bore	6000 mm
maximum external diameter of the rifled barrel fastened into lunettes	375 to 425 mm
maximum diameter of rifled bore	160 mm
maximum diameter of swivel opening of base lunette with spacing mechamism	500 mm
working speeds of longitudinal shaft feed:	
first rate	6.5 m/min
second rate	3.9 m/min
third rate	3.4 m/min

maximum speed of shaft return	16.6 m/min
productivity of pump supplying cooling liquid to cutters	20 ℓ/min
power of main three-phase current electric motor	10.4 kW at 1440 rpm
two-course running screw, 32 mm pitch	
riflings	right
total machine weight	19,000 kg

The machine has two mounts A and B, which are installed on the base and fastened together with bolts (Fig. 123). The rifled barrel (1) is installed on lunettes G and E of mount A. The breech part of the barrel is installed, centered, and fastened in lunette G, which has usual construction. This is achieved with its movable lugs (37) (Fig. 124). Lunette E is intended for installation, centering, and fastening of the muzzel part of the barrel. In this lunette, the barrel is installed in the swivel (2), lined up, and fastened in it with lugs, as shown in Figs. 125 and 126. The lug (2) is an accurately machined cylinder, located in a bearing of the lunette body (see Fig. 125). On the exterior surface of the swivel is fastened a toothed crown wheel, which is engaged with a worm screw, and this worm pair is the spacing mechanism with which the barrel may be rotated to the required angle in the lunettes (see Fig. 126). The swivel (2), and the gun barrel with it, are rotated by hand wheel (5) (see Figs. 123, 124, and 125). The position of the swivel in the lunette is fixed by a special stop, and the angle of its rotation is determined according to indicator (3) (see Fig. 125).

Lunettes G and E may be moved along the guiding mount of the machine by hand drives, which rotate gear (36), which is engaged with rack (35), fastened rigidly to mount A (see Fig. 124).

The spacing mechanism of the machine must rotate the swivel and barrel to the required angle with an accuracy of up to ±10', which, with the swivel diameter over 500 mm in linear dimensions, will correspond to ±1.0 mm. This scale, mounted on a ledge of the face surface of the swivel, is convenient for manual setting and observance by the naked eye. The accuracy of ±1.0 mm, with which in linear dimensions it is possible to set the swivel and barrel to the assigned angle by rotating them, is not outside the limits of tolerances, assigned on groove width, namely ±0.2 mm. The swivel, during rotation in the lunette body bearing, must not move in an axial direction, just as the rifled barrel during rifling and during rotation around the longitudinal axis of the lunette, must not move in the swivel lugs or together with the swivel relative to the lunette body.

The allowable movement of the swivel in an axial direction during its rotation must not exceed ±0.05 mm. Movement of the barrel about the circumference during rotation of the swivel or in an axial direction during bore rifling might lead to partial cutting of separate groups of rifling lands, and consequently, to ruin of the barrel. These factors should be considered during adjustment and changing of the rifling machine.

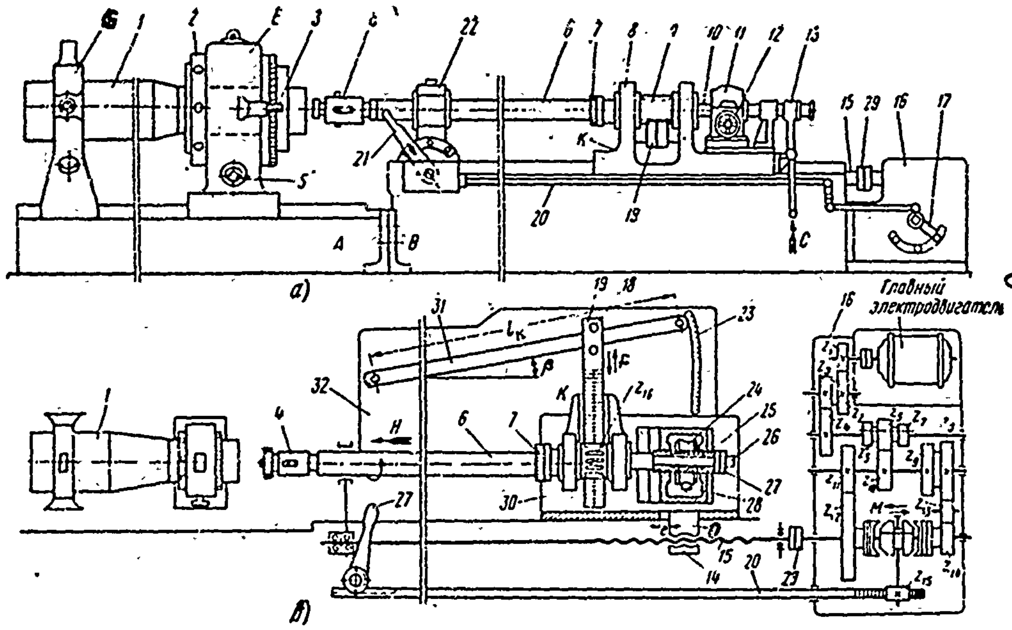


Fig. 123. Rifling machine of the Krasnyi Proletarii plant

Key:
- a. overall view of machine
- b. kinematic scheme
- A. left mount
- B. right mount
- G. lunette
- E. lunette with spacing mechanism
- K. machine carriage
- H. direction of carriage longitudinal feed
- M. sleeve
- F. direction of lateral motion of rack (19)
- O. ridge of bearing (11) with stop (nut) (14) of the running screw
- 1. rifled barrel
- 2. lunette swivel
- 3. spacing mechanism indicator
- 4. rifling head
- 5. shaft for spacing mechanism hand wheel
- 6. machine shaft
- 7. sleeve with spacing ring
- 8. carriage bearing
- 9. shaft with external teeth (z_{16})
- 10. internal drawbar
- 11. running screw nut bearing
- 12. hand wheel for longitudinal movement of drawbar (10)
- 13. strut with liquid supply pipe and valve
- 14. running screw nut
- 15. running screw
- 16. speed transmission
- 17. speed changing lever
- 18. rollers of rack (19)
- 19. rack, engaged with shaft (9)
- 20. drawbar
- 21. lever for engagement of sleeve M
- 22. front shaft bearing
- 23. adjusting scale for copying guage (31)
- 24 & 28. worm mechanism for longitudinal movement of drawbar (10)
- 25. bushing
- 26. screw
- 27. stop nut
- 29. connecting sleeve
- 30. carriage plate
- 32. plate of copying guage (31)
- c. main electric motor

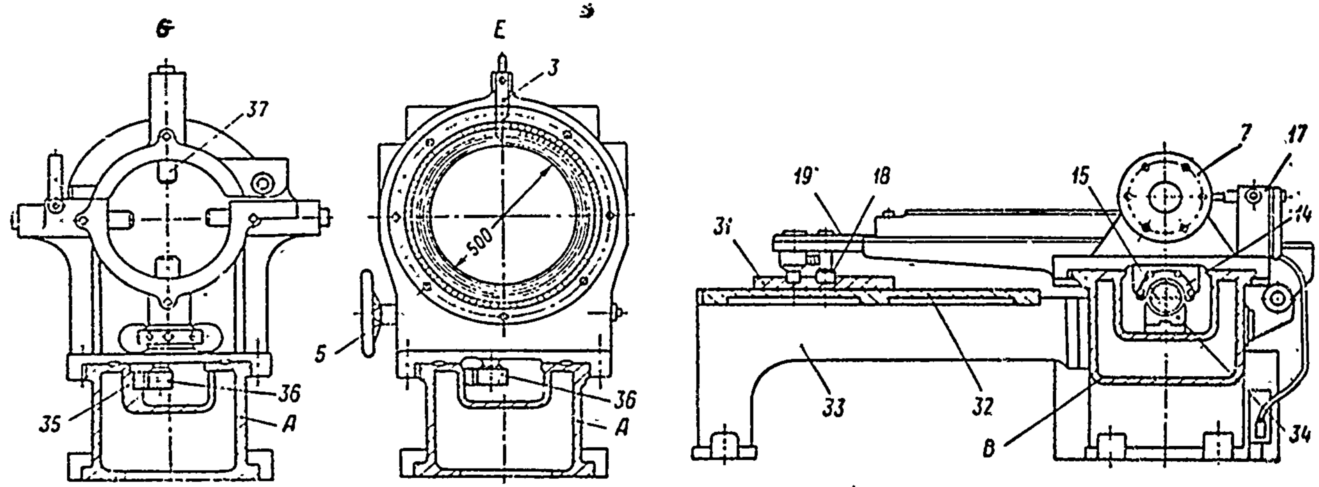


Fig. 124. Sectional cut of mount of rifling machine shown in Fig. 123

Key:

A. left mount
B. right mount
G. lunette
E. lunette with spacing mechanism
3. indiaator
5. spacing mechanism hand wheel
7. carriage sleeve
14. nut of running screw (15)
18. rollers of rack (19)
31. copying guage
32. plate
33. plate brackets
34. running screw bearing
35. rack of mount A
36. rack gear for manual lunette movement
37. lug

All the components and mechanisms accomplishing the bore rifling process itself are assembled on mount B. The machine mounts are iron castings of box form, which have sufficient rigidity (see Fig. 124). The guiding mounts are the fundamental technological basis for checking the machine and installation of the barrel on it. Besides this, during barrel rifling, the table of the movable carriage K together with shaft (6) and other obvious mechanisms move along the guiding mounts, and therefore the composition of the latter influences machine accuracy (see Fig. 123, a).

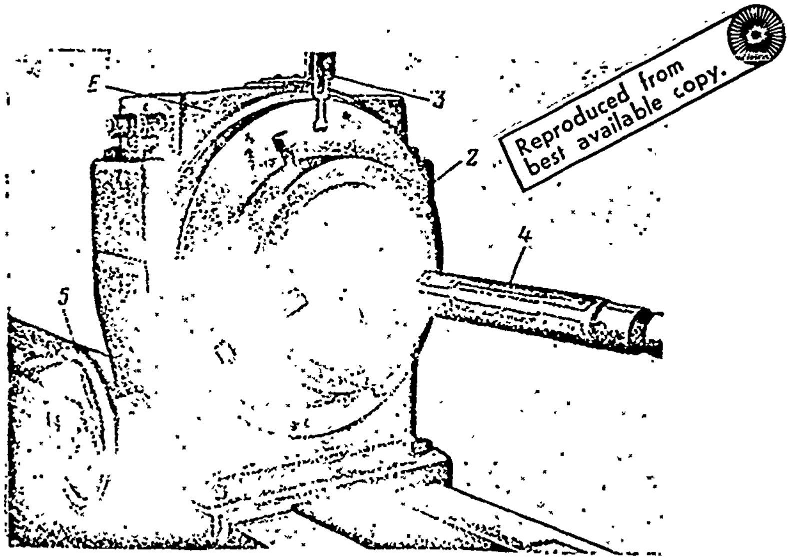


Fig. 125. Lunette E with spacing mechanism of the rifling machine shown in Fig. 123

Key:
2. swivel with lugs for installation and fastening of the rifled barrel
3. scale indicator
4. rifling head
5. spacing mechanism hand wheel

The guiding mounts must above all be straight, horizontal, and parallel to each other, with their nonparallelness not exceeding 0.04 to 0.05 mm on a length of 1500 mm. Deviation of the guiding mounts from the horizontal must not exceed 0.04 mm on a length of 1000 mm. This is checked with a level and straight edge. The external lateral surfaces of the guides must also be straight and parallel to each other, with an allowable deviation no greater 0.04 mm on a length of 1000 mm. The surfaces of the guiding mounts must be machined to a smoothness of $\nabla\nabla\nabla 9$. The positions of the axes of rotation of the guiding surfaces of carriage K, shaft (9), shaft (6), front bearing (22), intermediate bearings, lunettes, and the running screw are checked relative to the guiding mount (see Fig. 123, a). Deviations in the positions of these responsible parts of the machine relative to the guiding mounts must not exceed the tolerances established for them.

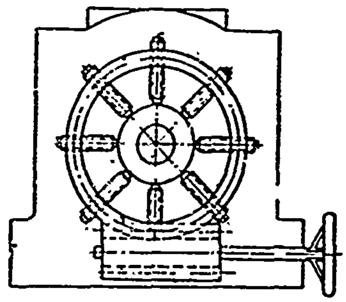


Fig. 126. Rifling machine lunette E with worm-type spacing mechanism (see Fig. 123)

Carriage K, assembled on the plate (30), is the tool support of the machine (see Fig. 123). The hollow shaft, gear (9), rotating freely on the bearings (8) of the carriage, absorbs the composite force of cutting, acting in an axial direction, and the twisting moment, created by the rotation of shaft (6). Shaft (6) is connected to shaft (9) by sleeve (8). The drawbar (10) freely moves inside shaft (9) and shaft (6). Steps on the cheeks and adjusting nuts prevent axial displacement of shaft (9). The shaft has $z_{16} = 27$ teeth and module $m = 4$. The rack (19), freely moving in a lateral direction in the guiding table (30), is meshed with the teeth of shaft (9) (gear z_{16}). In some machines, rack (19) consists of two parts, and slack in its engagement with the gear -- shaft (9) -- can be eliminated by moving them relative to each other

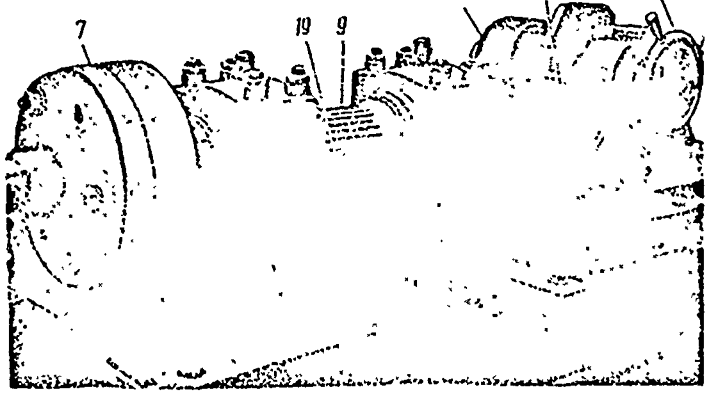


Fig. 127. Carriage K of the rifling machine shown in Fig. 123

Key:
7. sleeve for fastening the shaft with shaft (9)
9. shaft with rod gear (z_{16})
12. hand wheel for the longitudinal movement mechanism of drawbar (10)
19. copying guage rack
38. fastening plates of bearing (11)

The overall view of the described carriage of the rifling machine is shown in Fig. 127. The bearing (11), which is a strong iron casting of box form (see Fig. 123), is installed on the table of the carriage. The stop (25) is fitted on the exterior end of the drawbar projecting from bearing (11), and it is fastened stationary on it by nut and stop nut (27). Gear (24), fastened on stop (25) with an exterior band thread, may rotate on it, but may not move in an axial direction, being limited by the walls of the bearing and the parts regulating its position.

With rotation of the hand wheel (12), the worm screw (28) and gear (24) which is engaged with it also begin to rotate. With this, as a result of rotation of gear (24), stop (25) will be screwed on to or screwed off of it and consequently, drawbar (10) will also be moved in a longitudinal direction relative to shaft (6) and the rifling head. This drive allows installation of the rifling head cutters in the initial position and setting of the feed depending on the required thickness of shavings layer removed in each working pass.

Changing the amount of feed on thickness of layer removed can take place manually or automatically, using the principle of the longitudinal movement of the drawbar (see Fig. 127).

The tongue O of bearing (11) runs from a right-angle slot in plate (3) to the outside and has a bronze nut-housing (14) on its end, which holds the running screw (15) (see Fig. 123). The nut (14) has a free sector of about 150 to 155°, and holds the running screw through an angle of 205 to 210°. This is necessary so that the running screw, having a large length (over 7000 mm), can have intermediate support bearings (34) with a contact angle of close to 140°, and so that a clearance is maintained between the nut and the bearings on both sides at an angle of close to 5° (see Fig. 124).

The tongue O must be sufficiently strong and rigid to accept the tensile load of the running screw (15), transferred to plate (30) of the carriage K. The right-angle slot in plate (30) of the carriage is somewhat larger in length than the corresponding dimension of the tongue O. Clearance e, which is the difference between these dimensions of the slot and tongue O, is recovered at the initial moment of carriage movement or change of its direction from a straight forward one to a backward one, due to which bearing (11) and drawbar (10) are moved by the amount of clearance e relative to the carriage table and shaft (6) of the machine. This movement of bearing (11) and drawbar (10) automatically causes withdrawal of the cutters into the rifling head body at the initial moment of carriage free motion and extrusion of the cutters into their original position at the initial moment of its working movement. In this way, bearing (11) is not rigidly fastened on the table of the machine, but is installed on the surface of the table and fixed by guiding strips (38), and the amount of clearance e is regulated with consideration for the peculiarities of the rifling machine and head (4), fastened to the shaft (see Figs. 123, 127, and 131).

Shaft (6) of the machine, a hollow tube, the running screw (15), and some gears are manufactured of medium-hard steel (σ_b = 75 to 85 kg/mm^2). The drawbar (10) has an internal canal, through which cooling and lubricating liquid is conducted to the cutters. This liquid is driven by a pump along pipe (13), as shown by arrow C, and its quantity is regulated by a valve, installed on tube strut (13). The exterior surface of the shaft (6) is machined to high accuracy by grinding so that its smoothness corresponds to ∇∇∇ 7. Parallelness of the shaft relative to the guiding mounts and its possible eccentricity in the bearings are checked during machine adjustment so that non-parallelness of the shaft in the mounts may not be greater than 0.05 mm.

The copying gauge (31) is assembled on plate (32) (see Fig. 123), installed on special brackets (33) (see Fig. 124). Fig. 124 shows the copying guage (31), rack (19), and rack rollers (18).

The copying gauge may be installed at a variance from the longitudinal axis of the machine at an angle of β, corresponding to the rifling twist and measured along scale (23) with consideration for the gear ratio of the rack pair (19) -- z_{16} and the pitch of the running screw (15) (see Fig. 123). Rigidity of copying gauge installation on plate (32) is achieved with regulating supports.

Straightness of the copying gauge during constant twist rifling is checked by a straightedge. During progressive twist rifling, the copier adjustment is applicable only for the given rate of twist.

The rack (19) is connected to the copying gauge (31) with two rollers (18), which hold the copying rack from two sides, and the rollers are rigidly fastened to the rack, but the distance between their axes may be regulated so that they roll freely along the lateral surfaces of the gauge.

In order to eliminate the possibility of formation of clearance between the rollers and the gauge, on some machines, one of the rollers is not rigidly fastened and a spiral spring is placed between the rollers as shown in Fig. 124, which recovers the clearance between the rollers and the copier gauge.

During movement of carriage K along the guiding mounts of the machine, the rack (19) will move together with it, and simultaneously following along the copier gauge, rack (19) will have a lateral movement in a direction of the arrow (see Fig. 123). As the result of a simultaneous movement of the carriage and rack, shaft (9) and shaft (6) with it will receive a progressive movement along the mounts and a rotational motion around their axes, which is necessary during rifling of the bore.

Fig. 128 shows the kinematic scheme of the moving connection mechanism of rack (4) with the copier gauge (2). According to this scheme, the copier gauge (2) is fastened rigidly on plate (1). The rack (4) has a right-angle slot, in which slide (7) can freely move. The axle of roller (6) is fastened in the body of this slide, and rotating freely on its axis, the roller and slide are moved relative to the rack by screw (8). Screw (8) freely moves through the axis of roller (5) and is screwed only into slide (7) of roller (6).

The distance between the axles of rollers (5) and (6), fastened on the rack (4), may be regulated with screw (8), and this usually eliminates clearance between the rollers and copying gauge edges, providing free travel of the gauge rollers along the copying gauge.

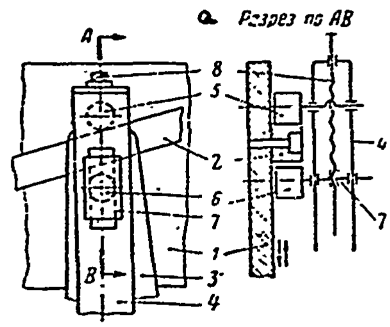


Fig. 128. Copier roller regulating mechanism of rifling machine (see Fig. 123)

Key:
1. copier gauge plate
2. copier gauge
3. toothed rack base
4. toothed rack
5 & 6. rollers
7. slide
8. screw, changing the position of slide (7) and roller (6) relative to the rack and copier gauge
a. cut across AB

The installation schematic of a rigid copier is shown in Fig. 129. In this copier, the gauge (2), having a dove-tail section, is installed on plate (1) at the required angle β. The slide (4) moves along the guides of the copier gauge, and clearance between the gauge and slide are regulated by wedge (5) and adjusting screws. The rack (3) is connected with slide (4) as shown in the schematic. This mechanism is simple in construction, but may not be used for progressive twist copiers in that large friction forces arise between the slide and gauge.

The machine drive and its speed transmission (16) are assembled on the foundation plate, and the transmission body is fastened to the machine mount (see Fig. 123). The shaft transmitting rotation to the running screw is connected with it by a sleeve (29).

Changing direction of running screw rotation from working movement to a backward one is accomplished with lever (21), with the help of drawbar (20) and sleeve M, and changes in speed are accomplished by lever (17), which has three positions.

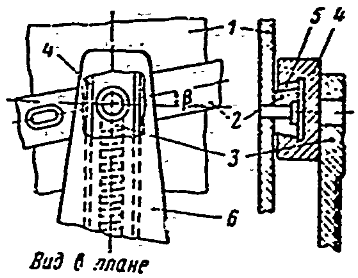


Fig. 129. Rigid copier of rifling machine

Key:
1. plate
2. copier gauge
3. toothed rack
4. slide, connected with rack and copier gauge
5. adjusting wedge
6. rack base
a. plan view

Kinematic Schematic of the Rifling Machine

The rifling machine works in the following manner (see Fig. 123):

After adjustment of the machine, the process of barrel bore rifling begins with the machine's free movement, during which shaft (6) and rifling head (4) are simultaneously given a longitudinal movement along arrow H and a rotational one.

When the rifling head traverses a path equal to the length of riflings, and moves into the hollow of the barrel charge chamber, the machine is changed into the working mode, either manually by lever (21), or automatically with changing by sleeve M.

During the machine's working run, carriage K and shaft (6) and rifling head (4) together with it, move in a backward direction. During this, the shaft and cutting head perform a rotational movement according to the assigned twist of the riflings.

When the rifling head fully emerges from the barrel bore, movement of the carriage is stopped manually with lever (21) or automatically by sleeve M.

The machine work cycle is later repeated, with the machine being changed into its free motion only manually so that shavings can be removed from the rifling head while the machine is stopped.

Machine stoppage is necessary for no more than 10 to 12 seconds.

The shaft of the electric motor, which provides the primary movement of the machine, is connected by a sleeve to the primary shaft of the speed transmission (16), from which the rotational movement is transmitted to gear z_1 and then to gears z_2, z_3, and z_4. A block with three cylindrical gears z_5, z_6, and z_7 is located on a sliding key on the third shaft of the speed transmission. Three varying speeds of rotation can be transmitted to the fourth shaft of the speed transmission and further to gear z_{12} by these gears, using lever (17).

Gear z_{12} fits freely on to the fifth shaft of the speed transmission, and therefore it transmits a twisting moment to the shaft only during engagement of the friction sleeve M. Sleeve (29) transmits motion from the fifth shaft of the speed transmission to the running screw (15), whose rotation is transformed into the progressive motion of carriage K along the mount guides by the nut (housing).

During progressive movement of carriage K, rack (19), being connected to the copying gauge (31) by its rollers or slide, will receive lateral movement in the direction of arrow F. The lateral progressive motion of rack (19) through shaft (9), having teeth of the type of gear z_{16}, is transformed into the rotational motion of shaft (6) along the assigned angle of twist of the riflings.

The free pass of the machine is accomplished from gear z_8 of the fourth shaft of the speed transmission, and further through gears z_{13} and z_{14}. The latter gear sits freely on its shaft, and the shaft receives a rotational motion during engagement of the friction sleeve M. During engagement of the sleeve M for the free pass, gear z_{12} will rotate idly.

If sleeve M is located in the middle position, rotation is not transmitted to the running screw, although all gears of the speed transmission will rotate.

Data on the machine gears are given in Table 40.

Speed v of longitudinal feed of the carriage K during the working pass of the machine is determined according to the formula

$$v = \frac{n_M i t_X}{1000} \,[\mathrm{m/min}], \qquad (59)$$

where n_M is the number of rotations of the electric motor (1440 rpm); i is the transmission ratio of the speed transmission. This relationship may have three different values; and t_X is running screw pitch (32 mm).

The transmission ratio of the speed transmission for working passes of the machine according to data on its gears (see Table 40) is determined from the following relationships:

$$i_1 = \frac{z_1}{z_2}\frac{z_3}{z_4}\frac{z_6}{z_{10}}\frac{z_{11}}{z_{12}} = \frac{24}{60}\cdot\frac{28}{67}\cdot\frac{34}{29}\cdot\frac{36}{54} = 0.137;$$

Table 40

Data on Rifling Machine Gears
(See Fig. 123)

a. Обозначение шестерен	b. Число зубцов z	c. Модуль m мм	d. Ширина шестерни b мм	a. Обозначение шестерен	b. Число зубцов z	c. Модуль m мм	d. Ширина шестерни b мм
z_1	24	5	50	z_9	38	6	60
z_2	60	5	50	z_{10}	29	6	60
z_3	28	5	50	z_{11}	36	6	60
z_4	67	5	50	z_{12}	54	6	70
z_5	27	6	70	z_{13}	30	6	55
z_6	34	6	70	z_{14}	25	6	55
z_7	25	6	70	z_{15}	e. Двухзаход.	f. Шаг 32 мм	—
z_8	46	6	55	z_{16}	27	1	—

Key: a. Gear designation
b. Number of teeth z
c. Module m mm
d. Gear width b mm
e. two-pass
f. pitch 32 mm

$$i_2 = \frac{z_1}{z_2}\frac{z_3}{z_4}\frac{z_5}{z_{11}}\frac{z_{11}}{z_{12}} = 0.0836;$$

$$i_3 = \frac{z_1}{z_2}\frac{z_3}{z_4}\frac{z_7}{z_9}\frac{z_{11}}{z_{12}} = 0.0733.$$

Substituting the transmission ratio values received into formula (59), we get: $v_1 = 6.5$ m/min, $v_2 = 3.9$ m/min, and $v_3 = 3.4$ m/min.

The maximum transmission ratio of the speed transmission for the free (reverse) pass of the machine

$$i_4 = \frac{z_1}{z_2}\frac{z_3}{z_4}\frac{z_6}{z_{10}}\frac{z_8}{z_{13}}\frac{z_{13}}{z_{14}} = \frac{24}{60}\cdot\frac{38}{67}\cdot\frac{34}{39}\cdot\frac{46}{30}\cdot\frac{30}{25} = 0.36.$$

Substituting this transmission ratio into the same formula (59), we get the maximum speed of the reverse pass of the machine

$$v_4 = 16.6 \text{ m/min}.$$

Cutting speed of the rifling head will be greater than speed of the progressive feed of carriage K in that the cutters simultaneously perform a progressive and rotational motion, rotating at the angle of twist of the riflings. Cutting speed v_p may be determined according to the formula

$$v_p = \frac{v}{\cos} \text{ [m/min]}, \tag{60}$$

where v is speed of carriage progressive motion; and α is angle of twist of barrel bore riflings.

For instance, with a rifling twist angle $\alpha = 9^\circ$ ($\cos\alpha = 0.988$), according to formula (60), cutting speed for the first feed speed stage

$$v_1 \; v_p = \frac{6.5}{0.988} = 6.58 \text{ m/min.}$$

Consequently, cutting speed with an angle $\alpha = 9^\circ$ is larger than longitudinal feed speed v_1 by 1.2%, and with a smaller rifling curvature, this increase will not exceed 1%. This increased cutting speed over feed speed may be ignored in calculations.

The angle of copying guage installation β is determined by the following means. From what was set forth above, we may write that

$$\ell_H = h = \frac{\pi d}{tg\alpha}, \tag{61}$$

where ℓ_H is the longitudinal pass of the shaft or length of the rifled portion of the barrel in mm; h is length of groove course in mm; d is barrel bore diameter in mm; and α is rifling twist angle.

For the described machine, besides this, we have the following dependence:

$$\ell_H = \frac{\pi d_H}{tg\beta} \tag{62}$$

where d_H is the initial average diameter of the circumference of shaft (9) with gear z_{16}, which is engaged with rack (19); and β is angle of installation of copier guage.

For rifling machines which have, connected with the rack, a cylindrical gear fitted stationary on a key on the shaft (see Fig. 131), d_H will be the initial diameter of the rack gear (1) which may be determined from the expression

$$d_H = \frac{t}{\pi} z = mz,$$

where t is the pitch of toothed engagement; z is the number of teeth of shaft (9) (rack gear); and m is module of toothed engagement for the given machine and this shaft ($m = 4$, $z_{16} = 27$).

Setting the right sides of equations (61) and (62) equal, and solving them relative to angle β, we get

$$tg\ \beta = tg\alpha \frac{d_H}{d}$$

or

$$tg\beta = tg\alpha \frac{mz}{d}. \tag{63}$$

The last expression is a calculated formula for adjustment and checking of the position of the copier gauge (31) on plate (32) of the machine (see Fig. 123).

If progressive twist riflings are being cut, angle β should be determined for each of its sections, no more than 200 mm in length, and correspondingly angle α should also be taken.

Forces Acting on the Machine and Tools During Barrel Bore Rifling

In the forces acting on the tools and machine, the process of barrel bore rifling is analogous to the process of broaching curved grooves. The cutting forces doing barrel bore rifling may be approximately determined according to the formula for broaching slotted holes, namely:

$$P_z = c_p s^{0.85} bn, \tag{64}$$

where P_z is the cutting force in kg; and c_p is the constant coefficient depend-on the properties of the machined material.

For steel σ_b = 70 to 80 kg/mm^2, c_p = 285, and for steel $\sigma_b > 80$ kg/mm^2, c_p = 320; s is feed for one working pass, or thickness of shavings removed in mm. During bore rifling s = 0.05 to 0.10 mm; n is number of simultaneously working cutters of the rifling head; and b is width of grooves in mm.

Formula (64) is for the case of determining cutting loads during straight-line movement. During rifling weapon bores, the rifling head, besides the progressive straight-line motion, also has a rotational motion, corresponding to angle α of the rifling twist, and therefore the cutting load P during bore rifling may be approximately determined by the relationship

$$P = 1.12P_z.$$

Power N_p expended on the cutting process, is determined according to the formula

$$N_p = \frac{Pv}{60 \cdot 102}\ [\mathrm{kW}], \tag{65}$$

where v is cutting speed in m/min.

The power of the machine or power of its electric motor expended in the cutting process will be equal to

$$N_e = \frac{N_p}{\eta} \text{ [kW]}, \qquad (66)$$

where η is the coefficient of efficiency of the machine. For rifling machines, $\eta = 0.7$ to 0.75 is used.

The total feed force P_p during the working pass of the machine, absorbed by the rifling machine running screw stop, is determined according to the formula

$$P_p = P + fQ. \qquad (67)$$

Here Q is the weight of the moving parts of the carriage (support), including weight of the shaft, in kg; and f is the coefficient of friction in the machine guides (usually $f = 0.18$ to 0.2).

In determining the amount of cutting feed during barrel bore rifling, it is necessary to proceed from condition of the maximum cutting rate, the allowable stability of the running screw nut (housing), and the maximum number of simultaneously working cutters.

Rifling Machine of the Nema Firm

The overall layout of the machine is given in Fig. 130. The machine consists of the right (19) and left (23) mounts, with the right mount longer than the left. The rifled barrel (1) is installed in lunettes (2) and (3) on mount (23), and fastened in them by lugs g. The freely rotating swivel (5) is assembled on the body (4) of the front lunette. The swivel has screw-type lugs a, with which the barrel is centered relative to the mount and to the shaft (8), which has the rifling head on its end. The swivel (5) together with the barrel (1) are rotated to the required angle with hand wheel (22) of the spacing mechanism, and fastened in the required position by stop d.

The movable carriage (10), kinematically tied to the machine running screw, is installed on the guides of mount (19). The carriage together with shaft (8), the front bearing (9), and rear bearing (11), can move along the mount. Layout of this carriage (support) is shown in Fig. 131. Shaft (8) of the machine rests in bearings (7) and (9), and in some instances may also have an intermediate movable bearing (see Fig. 130). The primary motion speed transmission of the machine is located in the body (14). The number of revolutions of the machine running screw is changed by lever (15), and the direction of its rotation and, consequently, the direction of carriage movement is changed with lever (21), drawbar (20), and lever (16).

The electric motor (17), 7.5 kW in power with 945 rpm, is installed on one plate with the speed transmission. Cooling liquid is conducted from the pump along pipe (18) and then to the cutters along the internal hollow of the shaft.

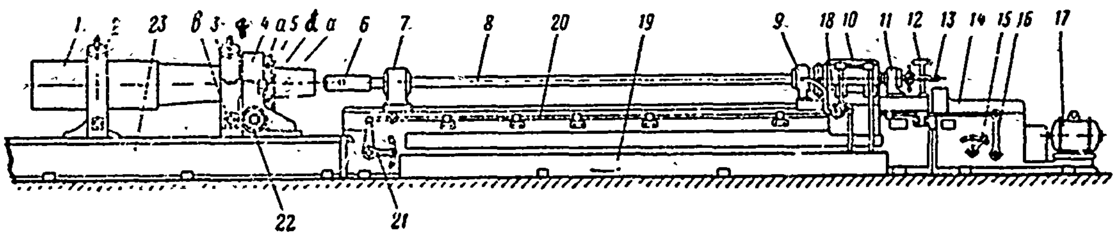


Fig. 130. Rifling machine of the German firm Nema

Key:

1. rifled barrel
2 & 3. lunettes
4. front lunette body
5. swivel
6. rivling head
7 & 9. bearings
8. shaft
10. machine carriage
11. rear bearing
12. indicator of the longitudinal movement mechanism of drawbar (13)
13. drawbar
14. speed transmission
15. lever changing the number of running screw revolutions
16 & 21. levers for changing the sleeve from forward to reverse carriage travel
17. electric motor
18. valve
19 & 23. mounts
20. drawbar
22. spacing mechanism hand wheel

The machine carriage (support) consists of the following parts (see Fig. 131): Table (22), installed on the mount guide; front (4) and rear (17) bearings; hollow shaft (10) with gear (9); rack (20) and mechanism with hand wheel (14) for moving the internal drawbar (16) relative to the shaft (10) and machine shaft (1).

Shaft (10) may freely rotate in the carriage bearings, without moving longitudinally. Cylindrical gear (9) is fitted on it on a key, and is engaged with rack (20). Machine shaft (1) is connect with shaft (10) by sleeve (6). Cooling liquid is conducted along pipe (3) in the hole in front bearing (4), and then in the circular clearance between the shaft and drawbar (16).

The rear bearing (17) is freely installed with its base A on the plate of the carriage table, and its tongue, protruding through the right-angle slot of the table, projects from the carriage. The nut (housing) is installed in the tongue, and is in kinematic connection with the running screw (19). The length of the right-angle slot in the carriage table is larger than the dimension of the tongue of bearing (17) by an amount of clearance e, whose dimension can be regulated.

At the initial moment of rotation of the running screw (19), nut (18) and bearing (17) together with stop (12), connected to sleeve (13) and drawbar (16), move relative to the carriage table and machine shaft by an amount of clearance e. After recovery of this clearance, the carriage and machine shaft begin to move along the machine. This layout allows automatic movement of drawbar (16), and the consequent withdrawal of cutters into the body of the rifling head during the nonworking run of the machine or, conversely, their projection into the required position before the working run. Cutter feed into the assigned thickness of removed layers is done by rotation of hand wheel (14). Sleeve (13) is screwed on to drawbar (16) and connected with stop (12) in such a way that it can rotate inside it. Stop (12), having a smooth internal canal, is connected by key (11) with shaft (10), relative to which it can move only longitudinally, but may not turn. Hand wheel (14) is rigidly fastened to the body of stop (13), which has a scale with divisions for determination of the cutter position in the head on its flange. When hand wheel (14) is turned, sleeve (13) will rotate and move drawbar (15), with which the cutters will change their position in the rifling head.

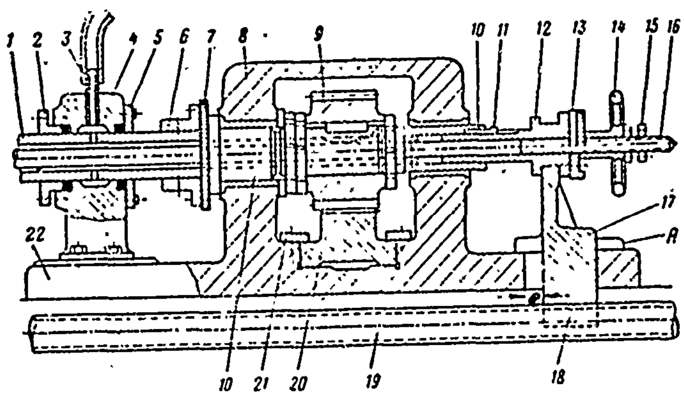


Fig. 131. Carriage of rifling machine of the firm Nema (longitudinal cutaway)

Key:

1.	machine shaft	12.	stop
2 & 5.	adjustable gland bushings	13.	sleeve
3.	pipe, carrying cooling liquid	14.	hand wheel
4.	front bearing	15.	nut with stop-nut
6.	sleeve	16.	drawbar
7.	spacing ring	17.	bearing
8.	carriage cover	18.	running screw housing
9.	rack gear (z = 40, m = 3.5 mm)	19.	running screw
10.	carriage shaft	20.	rack
11.	key	21.	rack guide rail
		22.	carriage plate (base)

The kinematic scheme of the machine is shown in Fig. 132. In this scheme, (2) and (4) are the lunettes, in which are installed the rifled barrel (3), shaft (5), plate (6), copying guage (7), carriage (8), rack (9), speed transmission (10), and electric motor (11). Rack (9) is engaged with a gear having 40 teeth and a module of 3.5 mm. The electric motor transmits rotation to the running screw through the speed transmission.

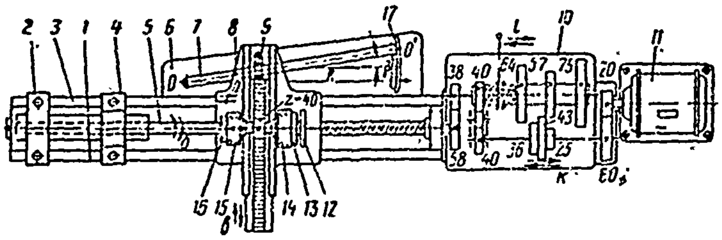


Fig. 132. Kinematic schematic of Nema rifling machine

Key: 1.	mount	11.	electric motor (N = 7.5 kW, n = 945 rpm)
2 & 4.	lunettes		
5.	barrel	12 & 13.	drawbar longitudinal movement mechanism
5.	shaft		
6.	plate	14 & 15.	bearings
7.	copier gauge	16.	ring with divisions
8.	carriage	17.	gauge scale
9.	rack (m = 3.5 mm)	18.	two-course running screw
10.	speed transmission		

This motion is transformed into progressive motion of the carriage and shaft in the directions shown by arrows a. Movement of the carriage causes lateral progressive movement of the rack (9) in the directions shown by arrows b, which in turn are transformed into rotation of the shaft. As the result, the machine shaft, having the rifling head on its end, has not only a progressive movement along the mounts, but also rotation by angle α, corresponding to the twist of riflings. The remainder of the machine's kinematics are sufficiently clear from the schematic. The number of teeth of each gear is designated on the schematic by numbers, and the machine running screw is two-course with a pitch of 31.42 mm.

Rifling Machine of the Nails Firm

This rifling machine is intended for rifling bores of large weapon barrels, having a length of bore rifled portion up to 10 m with an overall barrel length of up to 14 m.

The basic technical data of the machine:

Machine dimensions:	
length	32 m
width	8.18 m
height	3.3 m
Height from shaft axis to mount	762 mm
Diameter of rifled barrel bore	200 to 400 mm
Copier gauge length	11,500 mm
Range of copier gauge angle setting	0 to 17°
Lateral rack movement, up to	2800 mm
Rack engagement gear:	
module	2.54 mm
number of teeth	180
Running screw, three-course, with pitch	114.3 mm
Spacing mechanism allows rotation of the shaft to an angle 0 to 360° with accuracy of ±0.1°	
shaft length	14,500 mm
Longitudinal shaft feed speed range (speed regulated by electric motor)	2.7 to 16.3 m/min
Machine primary motion electric motor:	
power	29.4 kW
number of revolutions	200 to 1200 rpm

The rifled barrel G is installed in lunettes (4) and centered by the rear stop (3) (Fig. 133). In the process of rifling, the barrel remains stationary. The lunettes (4) are fastened to the mounts of the machine by lugs (5). The machine carriage K together with shaft (11), having the rifling head on its end, accomplishes a progressive motion along the mount guides. The shaft and rifling head, besides moving progressively, rotate by angle α of the rifling twist. During the working run of the machine, the shaft works by the method of compression, although if necessary, rifling may also take place by the broaching method. The copier gauge is a flexible band (2?), fastened on the plate of the carriage by special stops. This layout of the copier gauge allows its use for riflings of both constant twist and progressive twist (Fig. 134).

After rifling one group of grooves, the machine shaft is rotated to the required angle with the spacing mechanism by the electric motor M, 1.5 kW in power, which is located in the front bearing. The rotational motion of electric motor M is transmitted to the worm shaft (16), worm gear (17), and then to worm shaft (18) and worm gear (19), which fit freely on the shaft (see Fig. 134).

Gear (19) is located in the body of the front bearing, and during rotation of the spacing mechanism, it is connected beforehand to the shaft by a clamping device. Accuracy of spacing mechanism rotation is 0.1°, which does not exceed the tolerance on the linear dimension of groove width.

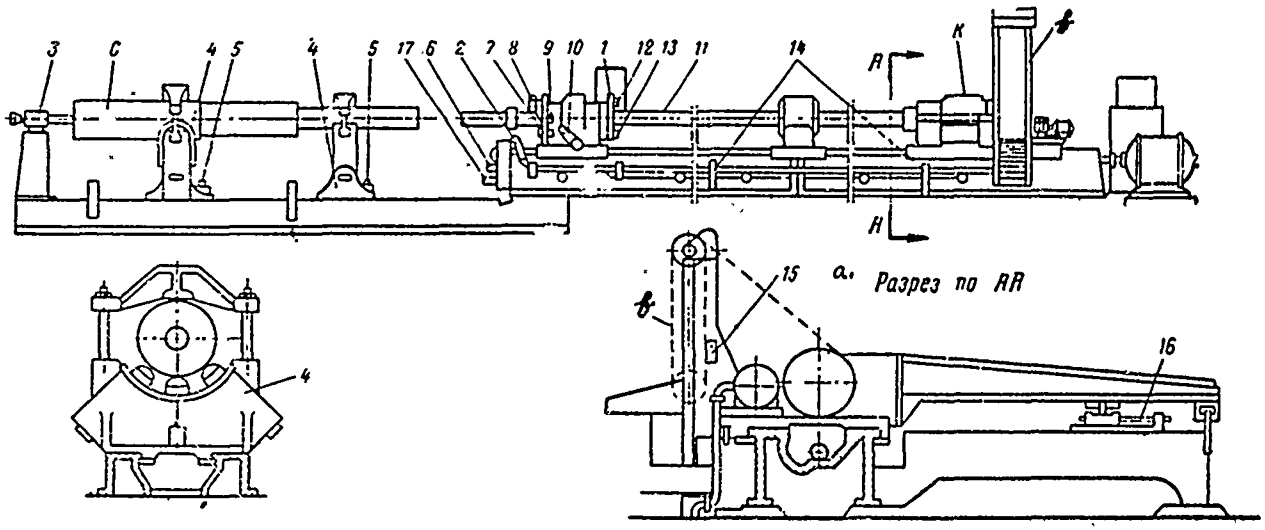


Fig. 133. Rifling machine of Nails firm

Key:
1. shaft chuck hand wheel
2. lever for reversing run of carriage K
3. stop, limiting movement of cutting head
4. lunettes
5. lugs for lunette levers
6. fingers for engaging mechanism for manual movement of carriage along mount
7. finger for shaft spiral copier
8. spacing disc catch
9. spacing disc micrometer screw
10. lever for engaging shaft rotation mechanism with motor or manually
11. machine shaft
12. button for starting and stopping shaft rotation
13. lever for moving spacing mechanism along mount manually
14. stops, limiting carriage travel
15. buttons for starting and stopping liquid feed
16. slides for installation of copier gauge
17. removable lever for moving carriage K along mount manually

b. tensioning device for removing slack between rack and copier
C. machined barrel
K. machined carriage (support)
d. cut across AA

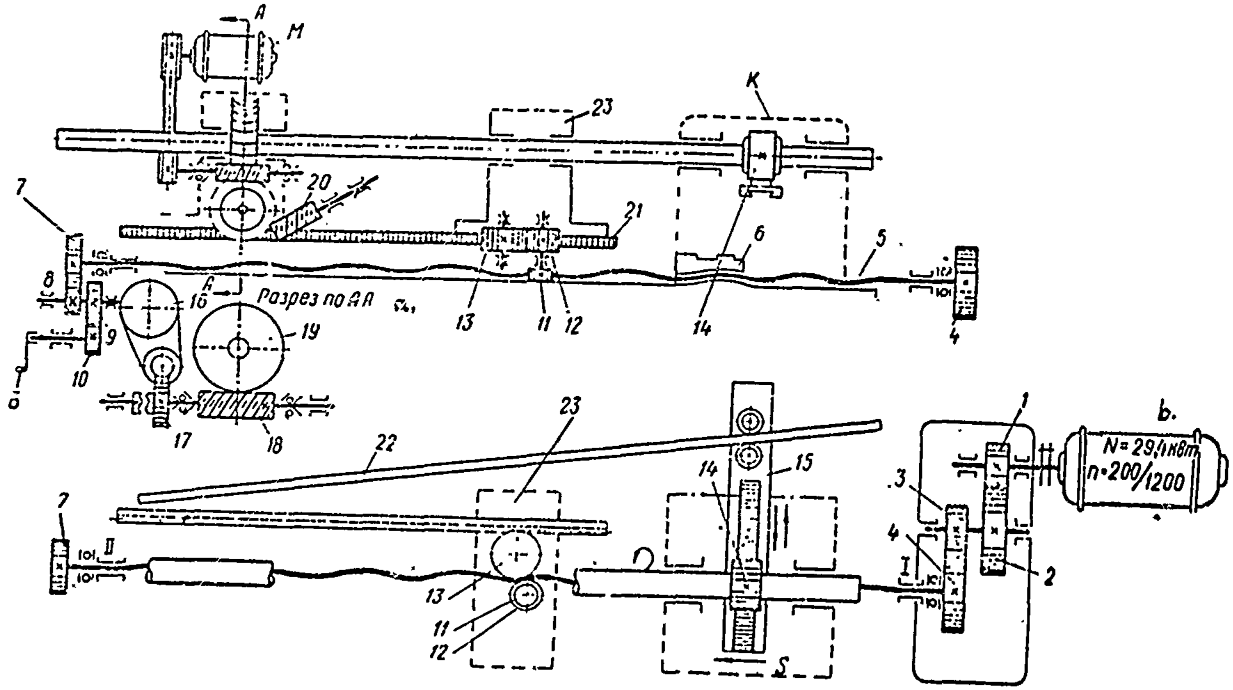


Fig. 134. Kinematic scheme of Nails machine

Key: a. cutaway across AA
b. N = 29.4 kW

During adjustment of the machine, carriage K may be moved manually, using lever B, whose rotation is transmitted through the cylindrical gears (9), (8), and (7) to the running screw. The front bearing of the shaft is moved along the mounts by worm screw (20), which is engaged with rack (21), and the intermediate bearing (23) is moved by the running screw.

Fig. 135 shows the schematic of installation and fastening of the copying gauge of the machine, which is a flexible steel band. A number of slide rails (2) are installed on plate (1) and fastened to it by screws (3). With rotation of screw (6), slide (5) moves along the guiding slide rails. The slide rails have screw stops (7) and (8) for fastening the steel flexible rail -- the copier gauge, which, with the help of the stops, can easily adapt a straight form for constant twist riflings or a curved one for progressive twist riflings. The kinematic tie between the lateral rack (15) and copying gauge (22) is usual, with the roller device in Fig. 134.

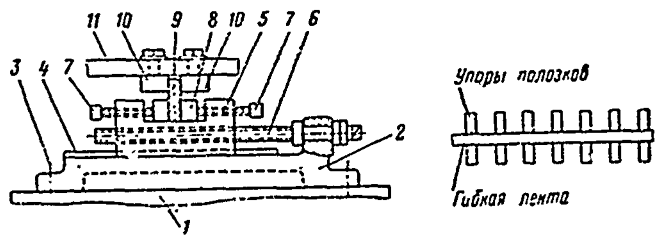


Fig. 135. Installation of schematic of copier flexible band of the Nails rifling machine

Key:
1. plate
2. slide rails
3. slide rail fastening bolts
4. guiding slide rails
5. movable slide
6. screw
7. stop screws
8. lugs
9. flexible band
10. rollers
11. rack
a. runner stops
b. flexible band

Control of the machine is effected with the levers and button panel shown in Fig. 133.

Data on gears, worm shafts, and screws of the machine are presented in Table 41.

Table 41

Basic Data on Gears, Worm Shafts, and Screws of the Nails Firm Rifling Machine (See Fig. 134)

a Обозначение шестерен	b Число зубцов z	Модуль m или c шаг t мм	Ширина шестерен d b мм	a Обозначение шестерен	b Число зубцов z	Модуль m или c шаг t мм	Ширина шестерен d b мм
1	19	7,26	127	12	22	6,35	64
2	71	7,26	127	13	48	6,35	64
3	20	12,7	165	14	180	2,54	158
4	45	12,7	165	15 i (рейка)	—	2,54	—
5 e (ходовой винт)	f четырехзаходный	114,3	—	16 j (червячный вал)	k однозаходный	5,05	—
6 g (гайка)	f четырехзаходный	114,3	630	17	k 70	5,05	64
7	60	8,47	82,5	18 j (червячный вал)	k однозаходный	16,93	—
8	12	8,47	82,5	19	50	16,93	90
9	50	6,35	60	20 l (червячный винт)	m двухзаходный	6,35	—
10	12	6,35	60				
11	15	28,57 h (винтовая)	64				

Key:
- a. Gear designation
- b. Number of teeth z
- c. Module m or pitch t, mm
- d. Gear width b, mm
- e. (running screw)
- f. four-course
- g. (nut)
- h. (screw)
- i. (rack)
- j. (worm shaft)
- k. one-course
- l. (worm screw)
- m. two-course

Some rifling machines have gear-type copier arrangements so that shaft rotation to the required angle of rifling twist is accomplished by changeable gears of the spacing quadrant. This arrangement has smaller dimensions than that described.

#38. Rifling Heads

For rifling weapon bores, a special tool, the rifling head with special cutters for it, is used.

The rifling head has a complex construction, which provides fastening of the cutters, their centering and direction, exhaust of shavings before withdrawal of the cutter from the barrel bore, and fastening of the head itself on the machine shaft.

The quality of rifling depends on the construction of the rifling head and the number of simultaneously working cutters on it.

In designing a rifling head, it is necessary to consider the following requirements:

1) The number of cutters must be as large as possible, and their geometry the most rational;
2) the correct and reliable maintenance of direction in the process of the head's work relative to the barrel bore;
3) convenience and reliability of fastening the head on the machine shaft;
4) convenient supply of lubricating and cooling liquid to the cutters and exhaust of shavings from them;
5) simplicity in parts construction, increased accuracy of their manufacture, and the least possible number of parts.

The number of cutters on a rifling head depends on the space for their placement and is tied to the caliber of the rifled barrel bore. At the present time, for weapon of caliber of from 75 to 105 mm, six- and eight-cutter heads are used, and only in some cases for small calibers are four-cutter heads still encountered. In rifling of weapon bores of caliber over 115 mm, there must be no less than 10 to 12 cutters. For rifling weapon bores over 150 mm in caliber, only heads with no less than 16 or 24 cutters should be used. In some instances, it is possible to use a number of cutters which is equal to the number of grooves.

Construction of the rifling head and cutters depends on the method of work of the cutting instrument during bore rifling. The method of drawing bore rifling, during which the machine shaft works on tension and twist during the working run, is used most often. The other method, in which the head is pushed through the barrel bore during the working run (broaching method) and the machine shaft is subjected to compression, is used very rarely and only during rifling of bores of large calibers (over 180 mm) with sufficient shaft rigidity.

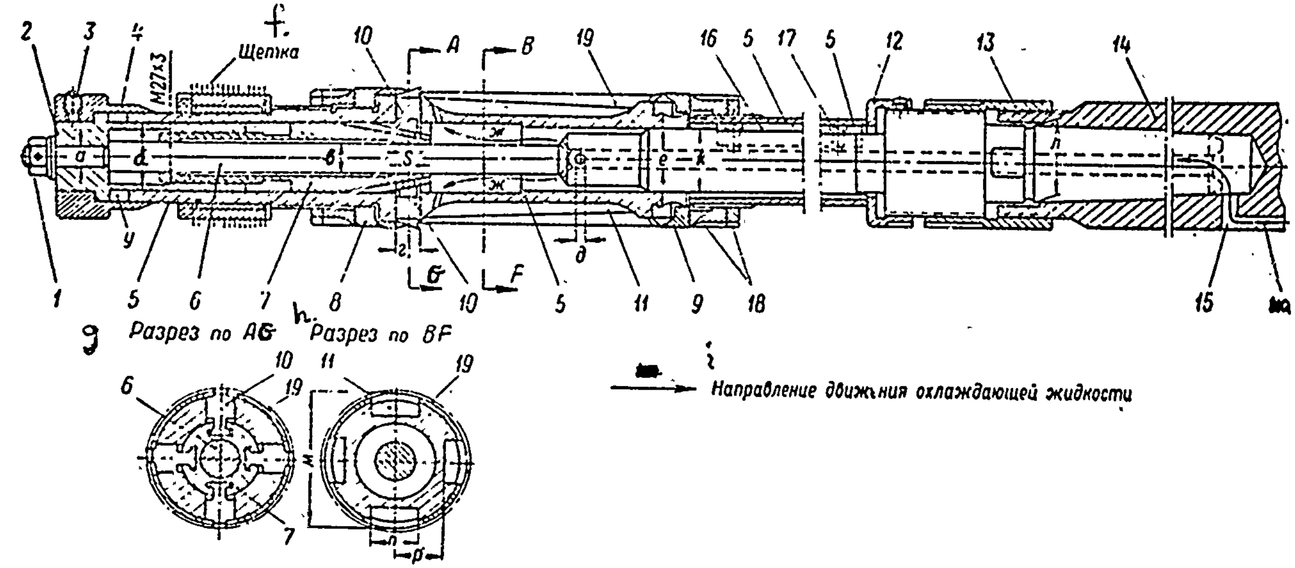


Fig. 136. Four-Cutter rifling head

Key:

1. nut
2. bushing
3. screw
4. ring
5. head body
6. arbor
7. wedge

8 & 9. support collars

10. cutter
11. longitudinal slot (pocket) for shavings exhaust
12. support ring
13. screw nut
14. shaft
15. cooling liquid pipe
16. key
17. set screw
18. nut with stop nut
19. skirt

f. brush

g. section across AG

h. section across BF

i. direction of cooling liquid movement

Four-Cutter Rifling Head

The head body (5) is a hollow body of high strength steel with an accurately machined cylindrical hole through it (Fig. 136). On the exterior conic (deviation 1° 26') surface of the head body is fitted a bronze skirt (19), having a length of 156 mm and four slots each 145 mm in length. The exterior diameter of the guiding surface of the skirt (19) may be changed by the collars (8) and (9) and stop nuts (18).

There must be a clearance of no more than 0.1 mm between the exterior surface of the skirt (19) and the surface of the barrel bore. The exterior surface of the skirt may be reground in case of wear.

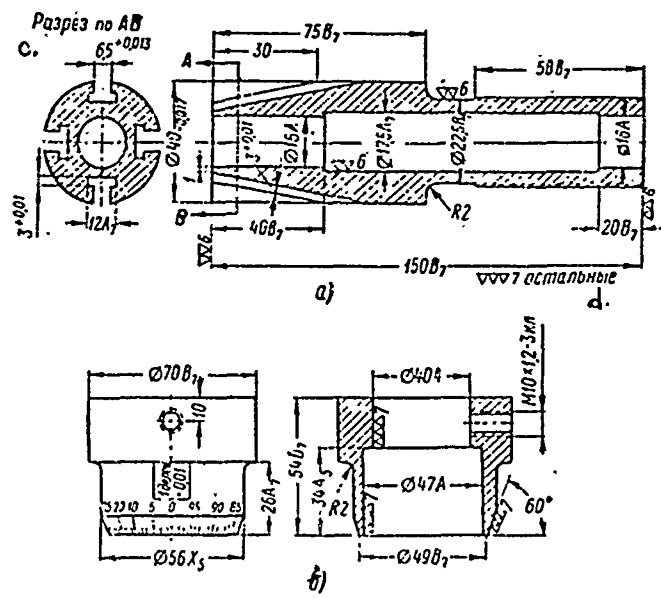


Fig. 137. Rifling head parts

Key:
a. wedge
b. ring
c. section across AB
d. remainder

In the middle portion of the head body (5) there are four cylindrical holes for cutters (10). The holes, of diameter g, for the cutters are machined to third class precision, and the exterior surface of the cutters are machined to second class sliding fit precision. For exhaust of shavings in front of the cutters, four longitudinal slots (11) are made in the head body and in the bronze skirt, and these are necessary for placement of shavings during the working run, each of them having a volume four times that of the shavings removed by the cutters.

A hairbrush with dense bristled filling is fitted and fastened by a nut behind the cutters on the head body. This brush, following the cutters, cleans small shavings and burrs from the surface of the bore, and these are removed from the brush upon withdrawal of the head from the barrel bore.

The arbor (6), wedge (7), and bushing (2) are installed in the cylindrical hole of the head body. The arbor is rigidly fastened to shaft (14) of the machine with a conic tail section, thrust ledges, and nut (13). The head body together with the cutters can freely move lengthwise relative to the arbor within the limits of circular clearance Y, and may not rotate due to key (16), which is fastened on it by screws (17).

Wedge (7), on whose threaded part is screwed bushing (2), fits freely on arbor (6). Ring (4) is fastened to the bushing by screw (3), and the bushing is fastened on the arbor by nut (1) and a cotter key.

The surfaces of the assembled parts of the head along dimensions a, d, b, and k are machined to second class sliding fit precision so that the parts will be correctly centered and can move freely relative to each other with minimal clearances. This condition is important and assures normal work of the head. Construction of wedge (7) and ring (4) are sufficiently clear from Fig. 137. The bases of the head cutters fit into T-shaped conic slots in wedge (7), in which they must be able to move freely. The slots have an inclination of $9^{\circ}\ 30'$. The amount of feed of the cutters according to thickness of shavings removed is established by rotation of ring (4), together with which bushing (2) also turns, and wedge (7) moves in a longitudinal direction (see Fig. 136). As the result, the cutters, sliding along the conic T-shaped slots, will move in a radial direction.

The amount of cutter feed in thickness of shavings removed is determined according to the formula

$$x = ns\,tg\alpha, \qquad (68)$$

where x is the feed of each cutter on thickness of shavings removed in mm; n is angle of rotation of ring (4) and bushing (2), measured in revolutions; α is the angle of wedge inclination, $\alpha = 9^{\circ}\ 30'$; $tg\alpha = 0.1673$; and s is thread pitch of wedge (7) and bushing (2) (s = 3 mm).

From formula (68) it follows that for one revolution for ring (4), the amount of feed

$$x = 1 \cdot 3 \cdot 0.1673 = 0.502 \text{ mm}.$$

With rotation of ring (4) by one division of its scale, or by 0.01 revolution, the amount of feed

$$x_1 = 0.01 \cdot 3 \cdot 0.1673 = 0.005 \text{ mm}.$$

The described construction of rifling head does not allow accomplishment of automatic cutter feed.

Cooling liquid is conducted to the cutters along special pipe (15), which is laid in the longitudinal slot of the shaft, and then along the internal canal and inclined holes in the arbor and the head body.

Eight-Cutter Rifling Head

The eight-cutter rifling head is used for rifling barrel bores 85 to 150 mm in caliber. The steel head body (5) serves as the basis for assembly of the part (Fig. 138). It is connected with shaft (11) of the machine by intermediate bushing (10). Bushing (10) and the entire head are centered relative to the shaft by smooth, accurately machined surfaces, and fastened with a two-course right-angle thread and set screw (13).

The head is guided in the rifled bore of the barrel by bronze slide rails (6), whose quantity corresponds to the number of cutters in the head. The bronze slide rails (6) are installed in slots in the head body. With longitudinal movement of the guide rails by nut (9), the required dimension along their external diameter may be set.

For maintenance of head body stability in the section where the holes for cutters are located, slots along this section are made conic, and the lateral edges of the slide rails on a length necessary for their longitudinal movement are cut obliquely.

The slide rails, accurately fitted in the slots of the head body, are set at the extreme left (according to the drawing) position, fastened by screws (7), and then turned and ground from the outside to the required dimension.

The slide rails are usually twice as long as the guiding bronze skirt, and therefore they are more conveniently located on the head body, have a large interval of regulation in their diameters, and all these things better provide guidance for the head in the barrel bore during its rifling.

Holes for the cutters in the head body are drilled and then reamed with a special jig. The angle between the two axes of the adjacent holes for the cutters is equal to $45^{\circ} \pm 5'$ for the eight-cutter head. The tolerance on the size of this angle should be assigned with consideration for the amount of tolerance on groove width, and namely the amount of tolerance on the angle in linear dimension must not exceed half the tolerance on the width of the groove.

Wedge (8) has T-shaped slots, in which the cutters are installed by their bases. With longitudinal movement of the wedge, the cutters slide along its inclined slots, moving in a radial direction. Bushing (4), which is rigidly fastened to drawbar (12), is screwed on to the threaded part of wedge (8). Ring (3) is fitted on to bushing (4) and fastened to it by screw (16). On the exterior surface of ring (3) is a scale, divided into 100 even parts. With

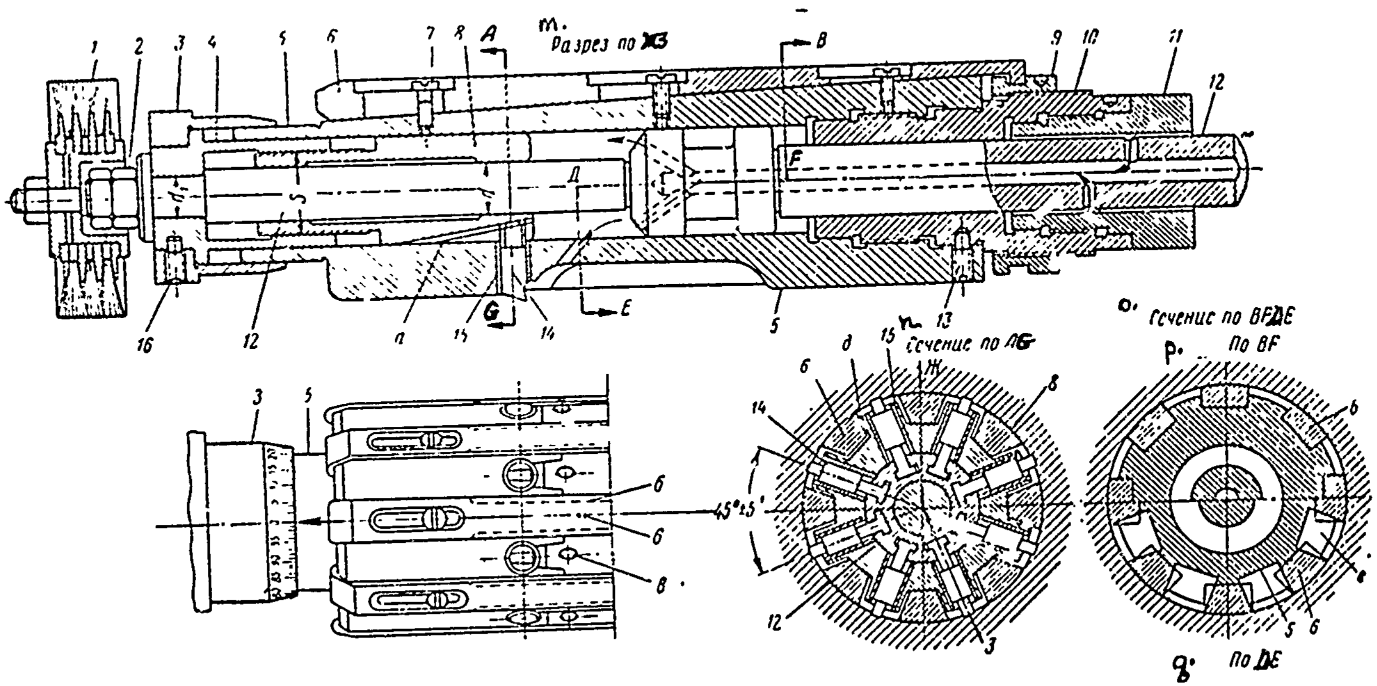


Fig. 138. Eight-Cutter rifling head

Key:
1. brush
2. nut and stop nut
3. ring, fastened by screw (16)
4. bushing
5. head body
6. bronze slide rails
7. screw
8. wedge
9. nut
10. bushing
11. shaft
12. internal drawbar (arbor)
13. stop screw
14. cutters
15. changeable bushing
16. stop screw
m. section across XZ
n. section across AG
o. section across BFDE
p. across BF
q. across DE

rotation of ring (3) and bushing (4), wedge (8) will be screwed on and move relative to the head body. The cutters are set in their initial positions with rotation of ring (3).

The assembly surfaces of the head body (5), wedge (8), bushing (4), drawbar (12), and bushing (10) are fitted as accurately as possible so as to provide their best centering and free movement relative to each other with minimal clearances.

Feed or radial movement of the cutters to the thickness of the layer removed for each working run is done manually or automatically with longitudinal movement of drawbar (12). The mechanism moving the drawbar is the same as in the Krasnyi Proletarii rifling machine (see Fig. 123, positions (10) and (12)) or in the rifling machine of the Nema firm (see Fig. 131, positions (14) and (16)).

Cooling liquid is supplied to the cutters along the circular clearance between the shaft and drawbar, and further along the internal canals and inclined holes in the drawbar and the head body. Otherwise, layout of the head is sufficiently clear from Fig. 138.

Sixteen-Cutter Rifling Head

The hollow body of the sixteen-cutter rifling head (10) is manufactured of alloyed steel, which has high strength and flexibility (Fig. 139). In the body are located arbor (3) and a two-sided cone (4), which is fastened immovably on the arbor with a support ring (2), and nut and stop nut (1). The internal surface of the head body and the exterior cylindrical surface of the cone (4), which fit together, are machined to high accuracy, and the mandrel together with the cone must move freely inside the body with a clearance between them of not more than 0.1 mm on the diameter. The exterior surface of cone (4) must be ground and have a strictly maintained calculated angle of inclination.

The right-angle section cutters (7) are installed in holes in the head body and may move freely in it in a radial direction, but are accurately fixed in the direction of the longitudinal axis of the head. The assembly surfaces of the cutters and holes for them in the head body are machined to second class sliding fit, with fit for maintenance of clearance on the dimension within the limits of 0.03 to 0.06 mm.

Elastic springs (5) serve to keep the faces of the cutters (7) tightly pressed against the support service of cone (4), and can be easily tightened by screw (6).

With this head construction, cutter thickness must be as small as possible, and namely, within the limits of 1.3 to 1.4 times the width of the groove. This allows placement of the required number of cutters in the head and maintenance of sufficient live section of the head body around the cutter holes to assure its required rigidity.

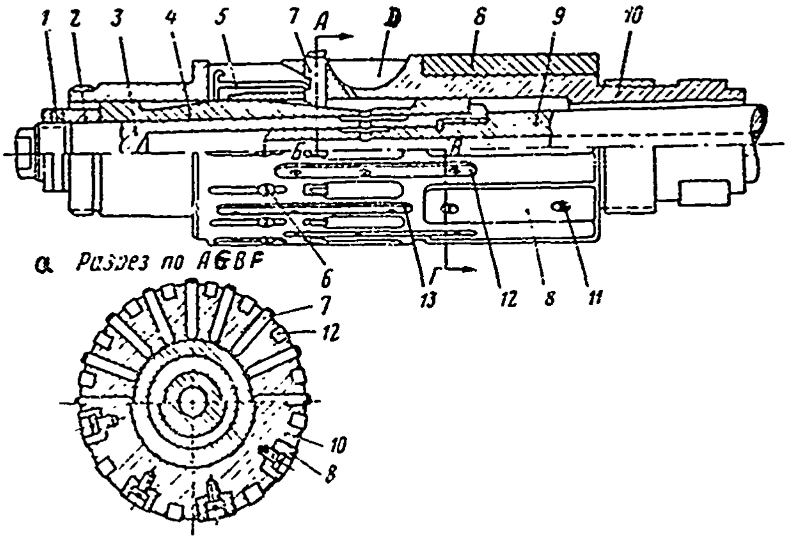


Fig. 139. Sixteen-Cutter rifling head

Key:
1. nut and stop nut
2. support ring
3. arbor
4. two-sided cone
5. spring
6. tightening screw
7. cutters

8, 12, & 13. bronze guiding keys

9. drawbar
10. head body
11. screw

D. receptacle (pocket) for shavings

a. section across AGBF

The distance between the cutters on the exterior surface of the head body must be 1.5 to 2.5 times larger than the cutter opening width, or the cutter thickness. With this consideration, only 10 to 12 cutters can be placed on a rifling head 100 mm in diameter, while installation conditions are met much more simply for heads over 100 mm in diameter, and difficulties do not arise.

The head is guided in the rifled bore of the barrel by bronze guides (8), (12), and (13) which are located in slots in the head body and fastened in it with screws. The bronze guides may be of various types according to their construction, location, and the method of adjusting their position. In the described sixteen-cutter head, the front guides (8) are half the size of the remaining ones, and they have a greater width than guides (12) and (13). The cutting head is connected to the machine shaft by its tail section and an intermediate sleeve. The receptacle in the machine shaft must be standard for possible use of various cutting heads. Rigidity of fastening and centering the cutting head in the connecting sleeve of the shaft is usually attained through the use of threaded and smooth sections on the assembly surfaces, or the same as in the boring and rifling heads described above.

The mandrel (3) is rigidly fastened to drawbar (9), which can freely move inside the shaft and the main shaft of the machine cradle. Adjustment of cutter position for initial dimension and changing their positions for each pass according to thickness of layer removed takes place from the carriage (support) side of the machine. Longitudinal movement of drawbar (9) together with mandrel (3) and cone (4) changes the position of the cutters in a radial direction, i.e., increases or decreases the exterior diameter of the head along the cutting edges of the cutters.

Cooling liquid moves to the cutters along the passage in drawbar (9) and then along radial holes in it, in the mandrel and cone and, finally, along the inclined passages of the body.

During a working pass, shavings are accumulated in depressions D (pockets), whose volume must be five to six times larger than the volume of shavings removed in one working pass. Arrangement of the head is otherwise sufficiently understandable from Fig. 139.

Some Problems in Rifling Head Construction

A multi-cutter rifling head which works on the tension method is shown in Fig. 140. The number of cutters in these heads is usually equal to half the number of grooves in the barrel bore, and only in some instances is it equal to the number of grooves. Multi-cutter heads are used for rifling weapon bores over 180 mm in caliber. At some domestic and foreign plants, such heads work on the method of pushing. Cutter construction, the method of their fastening and adjusting in the heads working on the pushing method is the same as for cutters in heads working on the tension method. Rifling heads working on the method of pushing, however, must have sufficiently high rigidity, which is possible only on heads for rifling bores greater than 180 mm in diameter. One of the most complex problems in multi-cutter rifling head planning is the exhaust of shavings and selection of the method of its accumulation in the process of the machine's working run, especially in heads working on the method of pushing.

In the construction of the rifling head shown in Fig. 139, the smooth surface of the round section cone serves as the support surface for the cutters, and the required accuracy of cutter position relative to the longidudinal axis of the head is achieved through the use of cutters of right-angle section. This head construction feature allows location of a larger number of cutters in one plane. Together with this, the round support surface of the cone does not provide sufficiently tight contact of the cutter bases to it.

Use of wedges with T-shaped slots (see Figs. 136 and 137) in the rifling head provides more correct installation and fixing of the cutters in it. The

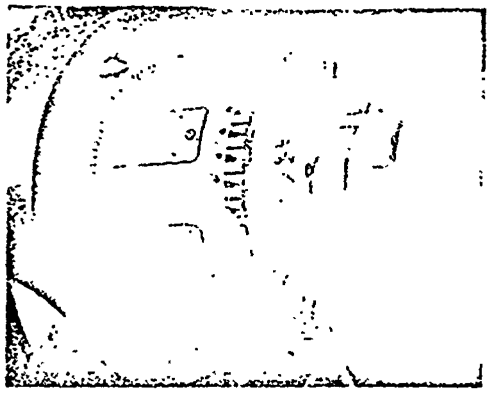


Fig. 140. Multi-cutter rifling head

T-shaped slots and cutter construction corresponding to them allow provisions for accurate fixing of the cutters in a radial direction, but in the sixteen-cutter rifling head, this requirement is filled by elastic springs, which give less satisfactory results and complicate construction.

The essential deficiency in a rifling head having a wedge with T-shaped slots consists of the fact that this construction does not allow use of a large number of cutters in it because with it the live section of the wedge is weakened and cutter location is made more difficult.

Rifling heads which are 75 to 105 mm in diameter and have wedges with T-shaped slots carry no more than six or eight cutters. For rifling heads with diameters over 120 mm, solution of the problem of locating a large number of cutters on them is made more simple.

The method of fastening and centering the rifling head relative to the machine shaft has a very important meaning for it in that it must assure accuracy of head direction in the rifled barrel bore, and this should be considered during planning of head and adjustment of the rifling operation.

#39. Rifling Head Cutters

Working Conditions and Cutter Geometry

Working conditions of rifling head cutters are similar to operating conditions in broaching slotted holes. Rifling barrel bores is a fine operation, differing from usual fine machining operations in the following:

1) The length of continuous cutter operation without resharpening is an average of four to eight hours, and in some instances longer. When the cutters are resharpened, a very thin layer of metal is removed to renew the sharpness of the cutter edge, and width of the cutter edge must not move outside the tolerance limit;

2) feed in one working pass or thickness of shavings removed by the cutters comprises 0.05 to 0.1 mm with a constant groove width;

3) the barrel bore rifling process must not be interrupted to change cutters, and cutter exchange can be resorted to only in extreme circumstances;

4) smoothness of groove surface after rifling must correspond to the requirements of the drawing and approach a value of ∇8;

5) cutting speed is usually maintained within the limits of 4.5 to 10 m/min. This cutter speed assures the necessary accuracy and smoothness in machining and is characteristic for many drawing operations;

6) cutter breakage or chipping of its cutting edge are not allowed in the process of rifling a barrel bore in that with these an incorrectable flaw in the rifled weapon barrel occurs in the majority of cases;

7) vibration or movement of the cutters is not allowed in the barrel bore rifling process because these phenomena decrease accuracy and smoothness of machining.

It is necessary to consider these cited basic peculiarities of the barrel bore rifling process during planning of the rifling head cutters and during setting of the cutting rate.

The shavings separated during barrel bore rifling have the appearance of thin, silky corrugated bands. These shavings are easily exhausted into special pockets (depressions) located in front of the cutter on the rifling head, where they are accumulated until the end of the working pass. Volume of the pockets must be five to six times greater than the volume of shavings removed during one working pass.

The lubricating and cooling liquid, which enhances the normal flow of the cutting process and achievement of the required machining smoothness, has essential influence on the working conditions of the cutter. During recent years, a mixture of mineral (85%) and vegetable (10%) oils and kerosene (5%) has been used as the cooling liquid.

Cutters do not usually wear significantly during the rifling of one barrel bore, and after rifling one or several barrels, they are trued with special whetstones. Cutter durability is determined according to the limit of their allowable wear on cutting edge width (groove width), which must not exceed 0.35 to 0.5 mm. The amount of this wear allows the cutters to be resharpened and repointed several times, understanding that this process means only thin dressing to eliminate nicks in the cutter cutting edge. One group of rifling head cutters allows rifling of 35 to 40 barrels, 85 to 100 mm in caliber, and up to 4000 mm in length. This cutter durability is economically expedient, and further use of the cutters is possible only after their heads are formed while hot, they are heat treated again, and resharpened to original dimensions.

Otherwise, the process of barrel bore rifling is similar to other types of metal work by cutting according to its accompanying physical phenomena.

During the process of rifle bore rifling, the rifling head cutters accomplish a motion along the spirals of the grooves. The cutters' main cutting edge AB must be located perpendicular to the direction of the groove O_H and lateral force moving the cutter to the side will not arise (Fig. 141).

If the main cutting edge of the cutter AB is located along line A_1B_1 perpendicular to the bore axis O_X, a lateral vector of the cutting force will appear during bore rifling and will divert the cutter to the side. Under action of this, the cutter will vibrate and cut into the lateral edges of the groove.

Therefore, the main cutting edge AB of the cutter should be positioned relative to its front edge A_1B_1 at angle α, the angle of rifling twist, and the width of this edge must be equal to groove width b.

The side surface of the cutter along the entire length of its head should be pointed so that angle β_1 between cutter edges AB and GF and the lateral edges of the groove subtend 4 to 5°. Excessively increasing angles β_1 weakens the cutting edge of the cutter near the top and consequently lowers cutter durability, and their excessive decrease increases the force of friction on these edges.

Lateral angles ω must be equal to 1.5 to 2° in all cutters.

The rear angle of the cutter α_1 should be determined from conditions of least wear of the rear cutter surface, and this angle is usually equal to 8 to 9°. A band f, 0.2 mm in width, should be kept on the rear surface of the cutter.

The front surface of the cutter may be flat or curved in form, and with a flat surface the front cutter angle γ = 14 to 18°, and with a curved surface γ = 18 to 22°. The remaining geometric parameters of the cutter are determined from the relationship: $n = 0.7r_1$ and $e = 0.4r_1$. The cutting edges of the cutters must be dulled at a radius of no greater than 0.03 mm to eliminated the possibility of their chipping.

The radius of cutter curvature near its tops R = 0.5t (t is the depth of groove), and the height of its head h = (3 to 5)t.

The cutter material must possess high strength and wear resistance. After heat treatment, the cutter head must have a hardness of R_C = 63 to 65. Fast-cutting R18 or alloyed KhV5 steels satisfy these requirements best of all. Smoothness of all cutter surfaces is no less than ∇9.

Cutter Construction

Cutters used for rifling barrel bores have a cutting portion or cutter head, a body, and a base (Fig. 142).

The cutter may have a round, right angle, or formed section, and be either one piece or composite

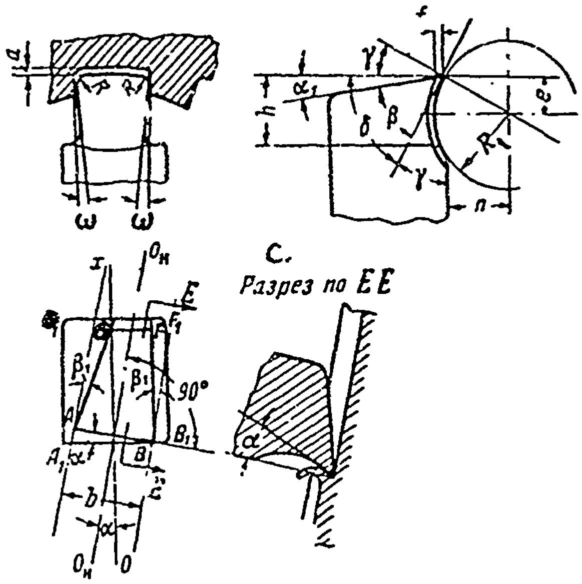


Fig. 141. Rifling head cutter geometry

Key:

O_X. direction of bore axis
O_H. direction of rifling development
AB. cutter main cutting edge
ABFG. cutter head contour
$A_1B_1F_1G_1$. cutter body contour
α. angle of rifling twist
b. groove width
β_1. side angle
α_1. rear angle
γ. front angle
δ. cutting angle
β. sharpening angle
f. control band
R. radius at cutter top
R_1. radius of front surface
c. section across EE

Round section cutters are rarely used in that the round hole for them decreases the live section in the head body and this in itself decreases its stability. Besides this, placement of these cutters in the head body causes difficulties as is seen from Fig. 138.

Cutters of right-angle section are more conveniently located in the rifling head body, maintain their direction relative to the barrel bore axis more accurately, and are more reliably fixed in the head body. Thickness of the cutter body must not be more than double the width of the groove, which allows placement of a larger number of cutters in the head body in a single cross-sectional plane without weakening the stability of the head body.

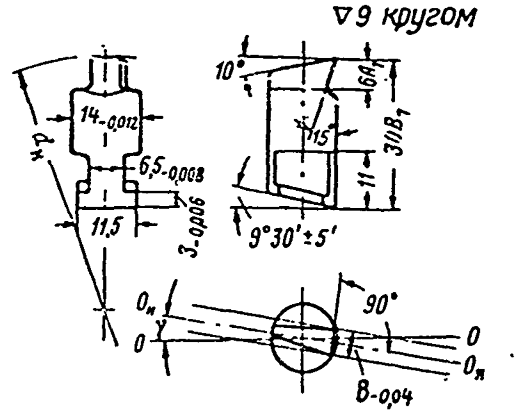


Fig. 142. Round section cutter

Key: a. ▽ 9 all around

The cutting edge of the cutter must have the width of the groove and be located perpendicular to the direction of the groove. Width of the main cutting edge is determined with consideration for groove width, tolerance on groove width, and the allowable norm for wear. The nominal dimension of cutting edge width must exceed groove width by half its tolerance. In this way, cutter service is increased and the possibility of performing thin resharpening (servicing) of the cutter head is present.

Dimensions and tolerances on cutter cutting edge width and groove width are given in Table 42.

Table 42

Nominal Dimensions and Tolerances on Width of Cutter Cutting Edges

a. Номинальная ширина нареза мм	b. Допуск на ширину нареза мм	c. Ширина режущей кромки резца мм	d. Допуск на ширину режущей кромки резца мм
5,5	±0,2	5,65	−0,04
6,5	±0,3	6,75	−0,04
7,6	±0,3	7,85	−0,04
9,15	±0,4	9,40	−0,05
20	±0,5	20,35	−0,05

Key: a. Nominal groove width, mm
b. Tolerance on groove width, mm
c. Cutter cutting edge width, mm
d. Tolerance on cutter cutting edge width, mm

Tolerances on diameters of round cutters or dimensions of cutters of right-angle section, and on cheek and collar dimensions of T-shaped cutters should be accepted according to second class sliding fit precision, and the corresponding dimensions of the holes in the head body and the inclined slots in the wedge, according to second class precision of base dimensions, which, according to their numerical value will be half again as large as the value of the tolerances for the cutters.

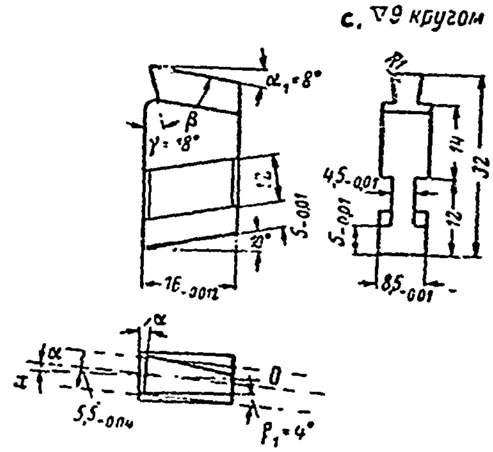


Fig. 143. Cutter of right-angle section with flat front surface

Key: c. ∇9 all around

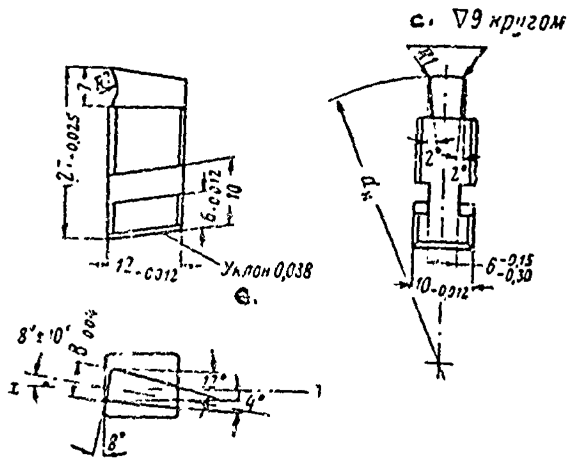


Fig. 144. Cutter of right-angle section with curved front surface

Key: c. ∇9 all around
e. incline 0.038

Exemplary dimensions and tolerances on the dimensions presented for cutters of various sections are shown in Figs. 142, 143, and 144.

A composite cutter, whose head is manufactured of fast-cutting steel, and whose shoe (base) is manufactured of type U8 or U9 carbon tool steel is shown in Fig. 145. This cutter construction allows its shoe to be kept after the head wears out. Composite cutters are more complex in manufacture and are usually used in large diameter rifling heads, when width and depth of groove are sufficiently large.

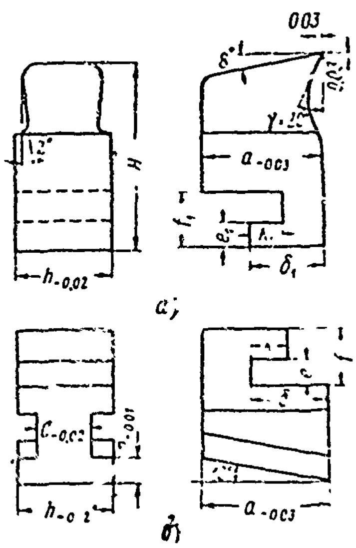


Fig. 145. Composite cutter

Key: a. cutter head
b. cutter base

The composite cutter must tightly and accurately fit along the assembly surfaces of the head body, and therefore the following tolerances are given on its dimensions: On shoe dimensions $K^{+0.01}$ mm, $f^{+0.01}$ mm, $\delta^{+0.01}$ mm, $e^{+0.01}$ mm; on cutter head dimensions -- 0.01 mm. The remaining nominal tolerance dimensions are shown in Fig. 145. Attention should be paid to the fact that the main cutting edge of the composite cutter must have facets 0.02 or 0.03 mm in width along the front surface, parallel to the base dimension line, and along the rear surface the facets are champtered at an angle of 3 to 4^{o}. Cutter stability is increased with this.

Besides the described constructions, cutters of other constructions are encountered in production practice. The overall principles of cutter layout are maintained in any constructions however.

#40. The Technological Process of Rifling Weapon Bores

Bores of rifled weapons may be rifled by various methods:

1) On rifling machines, by drawing or pushing rifling heads along the barrel bore;
2) on special broaching or usual rifling machines with simultaneous broaching of all grooves by special broaches;
3) by milling the grooves or rifling by the rolling method.

The method of broaching riflings with special broaches has special significance for rifling bores of small and medium diameters (up to 85 to 100 mm). Much experience in the use of this method in production condition at domestic and foreign plants has given positive results. For instance, a third to a fourth of the time is required for broaching bore riflings as is required for their rifling with a deep-cutter rifling head, and the quality of machining fully satisfies the requirements for rifling. Cost of the broach itself is, however, much higher than for a rifling head with two sets of cutters. For this reason, the broaching process of rifling is little used in production to the present time.

The method of milling riflings, encountered only in foreign-source literature, is not used in production.

The technological process of weapon bore rifling largely depends on the correct adjustment of the rifling head and tool, selection of cutting rate, and circulation of cooling and lubricating liquid.

Adjustment of the Rifling Head

Before rifling the bore of a weapon barrel, it is necessary to adjust the rifling machine and tools, and install the barrel on the machine. All these preparatory tasks should be fulfilled in the following sequence:

1) Check all data and machine characteristics shown on the rating plate;
2) check parallelness and horizontalness of the guiding mounts of the machine, and then parallelness of its shaft relative to the guiding mounts;
3) check the action of all mechanisms, the dividing scale, stops, and the working and nonworking speeds of the machine;
4) install the barrel on the machine and adjust its position relative to the guides and shaft of the machine;
5) prepare the rifling head and install it on the shaft, and then check the position of the head relative to the shaft and barrel;
6) check the correct installation of the rifling machine copier;
7) adjust the cooling liquid feed and lubrication of the machine mechanisms.

Preparatory tasks are performed by shop technicians and the production foremen, who are responsible for machining and technical control of gun barrels. Parallelness of the shaft relative to the mount guides must be checked along the entire length of the mounts, and for this, the shaft must accomplish a longitudinal movement and rotation on an angle of 360°. Wobbling (eccentricity) of the shaft, which is nonparallelness of its axis relative to the mount guides, must not be more than 0.04 to 0.05 mm.

In some instances, shaft checking may be limited to checking it along the front bearing and along the middle mount of the machine. For checking the shaft, a plate of an indicator instrument is installed on the mount guide, and its needle must touch the exterior surface of the shaft.

All parts, fastening sleeves, regulating slide rails, hand wheels, valves, and bearings of the machine carriage must be in good condition and reliably fastened. During performance of the preparatory tasks, it is also necessary to regulate clearance e (see Figs. 123 and 131), which provides automatic withdrawal of the cutters into the head body for the idle run of the carriage and their projection into initial dimension before its working run.

The action of the pump, and pressure and flow of the cooling liquid should then be checked. We will look at the most responsible preparatory tasks in machine adjustment and in installation of the barrel on it.

Checking the Copier

During checking the copier, the correct installation of its lateral rack (19) (Fig. 123) is first checked along clearances between the rack and slide rails, between the rack rollers and copier, for free play in the toothed engagement of rack and gear (9), which must not be outside the limits of the allowable norms.

The copier gauge is installed at an angle β along the angular sector scale (23) and fastened on a plate. It is then necessary to check the straightness of the copier gauge with a straight edge, moving the latter along the working surface of the copier gauge.

Barrel bore rifling twist is not usually checked under production conditions, and only in very rare circumstances is it checked with the help of an optical star wheel.

Checking of angle β of inclination of copier deviation on the machine is simultaneous with checking the angle of barrel bore rifling twist. The rifling machine is usually adjusted and checked for rifling a whole series of weapon barrels.

The tolerance on the amount of angle β of the copier installation, determined from formula (63), must not exceed ±5', or it must be equal to half the tolerance on the angle of rifling twist. This angle in copier installation during reading of the amount of tolerance on the sector scale (23) is fully achievable in production. For instance, with a copier gauge length, or radius of arc of scale (23) of 2500 mm, arc length of a scale section corresponding to a central angle of $0^{\circ} 5'$, will be equal to 3.64 mm, which fully provides the required accuracy of copier gauge installation with the naked eye along the sector scale (23).

Arc length on scale (23), corresponding to a central angle of one minute, is determined according to the following formula:

$$\ell = \frac{2\pi \ell_K}{360 \cdot 60} \qquad (69)$$

where ℓ is arc length in mm; and ℓ_K is copier guage length in mm.

If the length of the copier gauge for a rifling machine of medium dimensions $\ell_K = 5000$ mm, then the distance on the sector scale (23) between the large graduation lines, equal to 5 mm, will correspond to a central angle of four minutes, and the distance between the small and large graduation lines, equal to 2.5 mm, will correspond to an angle of two minutes. To be seen well by the naked eye, the graduation line need not be wider than 0.3 mm.

More accurate rifling twist in a barrel bore is checked on the rifling machine in the following manner.

Let us take, for instance, a barrel bore diameter across the lands d = 203.2 mm, the bore rifled portion length $\ell_H = 3981.6$ mm, rifling twist angle $\alpha = 8^{\circ} 55' 37''$, with a tolerance of $\pm 10'$, and initial diameter of the machine gear which is engaged with the rack, $d_H = 161.6$ mm, number of teeth z = 32, and module of engagement of the gear and rack m = 5.05 mm.

We put graduation lines on the guiding mount of the machine through every 250 mm of length. We set the machine carriage in the extreme left position so that readings of its movement during its working run may be conducted from the first graduation line at the front bearing (22) (see Fig. 123). For determination of rifling twist, we use formulae which we already know

$$tg\alpha = \frac{\pi d}{\ell_H},$$
$$tg\beta = \frac{\pi d_H}{\ell_H}. \qquad (70)$$

The nominal value for length of rifling course with the given initial data

$$L = \frac{\pi d}{tg\alpha} = \frac{3.14 \cdot 203.2}{0.1565} = 4076.98 \text{ mm}.$$

The limiting value of the rifling twist angle with the given tolerance of ±10':

$$\alpha_1 = \alpha + 10' = 9^{\circ}05'37'' \text{ and } \alpha_2 = \alpha - 10' = 8^{\circ}45'37''.$$

The limiting values of rifling course length which correspond to the values of rifling twist angles:

$$L_1 = \frac{\pi d}{tg\alpha_1} = \frac{638.048}{0.1595} = 4000.3 \text{ mm};$$

$$L_2 = \frac{\pi d}{tg\alpha_2} = \frac{638.048}{0.1535} = 4156.2 \text{ mm}.$$

It is then easy to calculate the angle of rotation of the shaft and rifling machine or the rotations corresponding to it with the given length of the rifled portion of the bore ℓ_H; the nominal and limiting values of the rifling twist angles α, α_1, and α_2; the nominal and limiting values of the length of rifling course L, L_1, and L_2, and then compare the results with the actual angle of shaft rotation on the given length. The actual angle of shaft rotation is determined on the scale of bronze ring (7), which is fastened to the shaft near the carriage, and the length corresponding to it is calculated along the mount guides (see Fig. 131).

For the received values of rifling course length and angle of their twist, the angles of rotation in revolutions of the shaft and rifling head will have the following values:

1) With the nominal angle of rifling twist α

$$n = \frac{\ell_H}{L} = \frac{3981.6}{4076.98} = 0.9766 \text{ rev};$$

2) with an upper limit rifling twist angle α_1

$$n_1 = \frac{\ell_H}{L_1} = \frac{3981.6}{4000.3} = 0.995 \text{ rev};$$

3) with a lower limit rifling twist angle α_2

$$n_2 = \frac{\ell_H}{L_2} = \frac{3981.6}{4156.2} = 0.963 \text{ rev}.$$

We now determine the angle of rotation of the shaft and rifling head ϕ in degrees with the given length of bore rifled portion ℓ_H, and the various values of rifling twist received:

1) For the nominal rifling twist angle

$$\phi = 360^\circ,\ n = 360 \cdot 0.9766 = 352^\circ 48';$$

2) for the upper limit rifling twist angle α_1

$$\phi_1 = 360^\circ,\ n_1 = 360 \cdot 0.995 = 358^\circ 48'';$$

3) for the lower limit rifling twist angle α_2

$$\phi_2 = 360^\circ,\ n_2 = 360 \cdot 0.963 = 346^\circ 40' 48''.$$

In this way, the angle of rotation of the shaft with the upper limit value of rifling twist angle α_1 will be larger than its nominal value by an amount of

$$\phi'_1 = \phi_1 - \phi = 358^\circ 12' - 352^\circ 48' = 5^\circ 24',$$

and with the lower limit value of the rifling twist angle α_2, it will be lower than its nominal value by an amount

$$\phi'_2 = \phi_2 - \phi = 346^\circ 40' 48'' - 352^\circ 48' = -6^\circ 07' 12''.$$

The angle of shaft rotation ϕ_α on a section of the rifled portion of the bore of length $\ell_1 = 500$ mm, can be determined by analogy with formulae (70) according to the following formula:

$$\phi_\alpha = \frac{\ell_1 \operatorname{tg}\alpha\, 360}{\pi d}. \qquad (71)$$

According to formula (71), the angle of rotation of the shaft will have the following values:

With a nominal rifling twist angle α

$$\phi_2 = \frac{500 \cdot 0.1565 \cdot 360}{638.048} = 44^\circ 09';$$

with an upper limit angle of rifling twist α_1

$$\phi_{\alpha_1} = \frac{500 \cdot 0.1595 \cdot 360}{638.048} = 44^\circ 59' 53'';$$

and with a lower limit angle of rifling twist α_2

$$\phi_{\alpha_2} = \frac{500 \cdot 0.1535 \cdot 360}{638.048} = 43^\circ 19' 46''.$$

As a result, the limiting deviations of rotation angles of the shaft on a bore rifled section length $_1$ = 500 mm, will be equal to:

$$+\Delta\phi_1 = \phi_{\alpha_1} - \phi_\alpha = +0^\circ 50' 53'';$$

$$-\Delta\phi_2 = \phi_{\alpha_2} - \phi_\alpha = -0^\circ 49' 14''.$$

Angles of shaft rotations on other length sections of the rifled portion of the bore are similarly determined every 500 mm. The calculated values of shaft rotation deviation received go into a table, with whose use the rifling machine is also checked. The allowable maximum $+\Delta\phi_1$ and minimum $-\Delta\phi_2$ deviations in machine shaft rotation angle appear in the table for each 500 mm long section of the rifled portion of the bore. Comparing the actual angles of shaft rotation, read on the scale of ring (7) (see Fig. 123) with the calculated ones, quality of installation and adjustment of the machine copier is judged.

Angle β of the copier guage installation, determined according to formula (63), will have the following value in our example:

$$tg\beta = 0.1565 \cdot \frac{161.6}{203.2} = 0.124,$$

$\beta = 7^\circ 08'$.

This angle may also be determined according to data on the kinematic scheme of the machine by the following method.

The length of the lateral movement of the copier rack ℓ_p for the time of the longitudinal movement of the machine shaft on the entire length of the rifled portion of the bore ℓ_H and with rotation of the shaft according to revolutions on value n, is determined from the expression

$$\ell_p = \pi d_H n = 3.14 \cdot 161.6 \cdot 0.9766 = 492 \text{ mm}.$$

Here

$$tg\beta = \frac{\ell_p}{H} = \frac{492}{3981.6} = 0.124,$$

$\beta = 7^\circ 08'$, which is the same result received according to formula (63).

The described brief calculations are a type methodical scheme for checking the rifling machine, and are applicable to all types of rifling machines and rifled bores having constant twist riflings.

With a progressively changing rifling twist, calculation and machine checking are more complex, but the principal schematic of the calculation remains the same.

Checking Installation of the Barrel and Rifling Head

The barrel, installed in the lunettes, must be centered relative to the mount guides and machine shaft. The exterior surface of the barrel, along which its position is checked relative to the mount guides, is the base for preliminary checking of barrel installation on the machine, and the interior surface of the barrel bore serves for final checking. The parallelness of the barrel relative to the machine mount guides is first checked with an indicator, for which the barrel is rotated 360° around its axis, and the indicator needle is pressed against the internal surface of the barrel bore. Depending on results of the reading, the barrel is moved into the required position by the supports and lunette lugs.

When the barrel is finally installed relative to the machine mount guides, the coaxiality of its bore relative to the shaft and rifling head are then checked.

The longitudinal axis of the shaft and the axis of the barrel bore must coincide. Axis displacement or barrel oscillation must not exceed 0.04 mm.

In checking installation of the rifling head, it should be considered that assembly of the head takes place by the method of selecting and fitting its separate parts in place, and the finally-assembled head is ground along the bronze guide rails so that their exterior surfaces are strictly concentric, and the difference in external diameters in various lengthwise sections must not exceed 0.03 to 0.02 mm.

The rifling head, installed on the shaft, is checked relative to the mount guides and machine shaft. Deviation in head installation along the exterior surfaces of the slides and along the cutting edges of the cutters must not exceed 0.04 to 0.03 mm. The exterior diameter of the head, along the bronze guides, must correspond to the diameter of the barrel bore with a strictly determined clearance on diameter between the bore surface and the head. The amount of this clearance for weapon bores up to 100 mm in caliber must not exceed 0.05 mm, and for weapon bores 200 mm in diameter, it must not exceed 0.10 mm.

The concentricity of the position of the cutting edges of the head cutters should then be checked relative to the exterior surface of its bronze guiding slides. This checking takes place with a special ring and indicating instrument (Fig. 146).

The ring has grooved channels, whose quantity is equal to the number of cutters on the rifling head. The width of each channel is equal to the upper limit groove width so that the cutter may move freely in it. The internal diameters of the ring correspond to the diameter of the barrel bore across the lands d and the diameter across the grooves d_H with tolerance on these dimensions no greater than 0.04 mm, which is a tolerance three times more accurate than the tolerance on machining the barrel bore. The ring is put on the rifling head and centered along its bronze guiding slides. With the cutters moved out, and using a feeler gauge, it is possible to establish a uniform amount of clearance between the ring and the cutting edges of the cutters along diameter d_H. Some cutters, projecting from the slots by a dimension larger than that required by norms, fit against the ring. As the result, the cutters, in diameter, will be set strictly concentrically. Cutter installation is additionally checked with an indicator, turning the head on the machine's center, with the indicator needle touching the cutting edges of the cutters. This checking is necessary to assure uniform depth of all grooves in that during measuring of the barrel bore, only the diameters across the lands and the fields are checked, and groove depth is not measured.

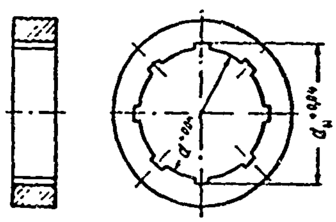


Fig. 146. Ring for checking rifling head cutter installation

The Technological Process of Bore Rifling

The most widely used method of barrel bore rifling is that of drawing, using a multi-cutter rifling head. The working run of the machine begins with insertion of the rifling head into the bore chamber, and ends with its emergence from the muzzle part of the bore.

If groove width does not exceed 10 to 12 mm, barrel bore rifling is conducted with one group of cutters, having a width along the cutting edges equal to the groove width.

With a groove width over 10 mm, the bore is grooved sequentially by two rifling heads with different groups of cutters, namely, the bore is first grooved with cutters having cutting edges of width b_1 = 7 to 10 mm, with a groove depth H, leaving a margin along the groove width of 4 to 5 mm, or 2 to 2.5 mm on a side, and a margin on depth of up to 0.4 mm. A second group of cutters then give the grooves their final form and dimensions on width and depth (Fig. 147).

In this way, the process of barrel bore rifling by two sets of cutters is an operation which is similar to coarse and fine broaching. During preliminary rifling of the barrel bore, the maximum cutting speed, no less than 10 m/min, is allowed with a thickness of shavings removed of 0.10 to 0.12 mm for each working pass, and during fine rifling, cutting speed is 6 to 9 m/min with a thickness of shavings removed up to 0.06 to 0.08 mm, also on each working pass. On the last three passes, giving the grooves their final form (cleaning), thickness of shavings removed must be greater than 0.05 mm.

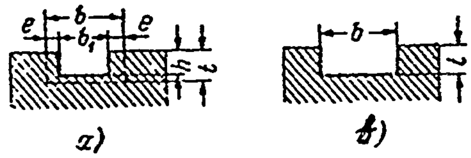


Fig. 147. Scheme of sequential groove formation (along groove width) by two sets of cutters

Key: a. preliminary grooving
b. final grooving
b_1 & h. width and depth of grooving by first group of cutters
b & t. width and depth of final grooving

It should be noted that rifling weapon bores with two sets of cutters is used only with groove width greater than 10 mm and depth greater than 2.5 mm, or in rifling weapon barrels of large caliber, which have riflings over 8 m in length and a special groove.

Selection of Cutting Rates

The cutting rate for rifling weapon bores is characterized by the cutting speed, width of shavings removed, or feed on each working pass, and width of grooves, whose size remains constant during the rifling process.

The first one or two establishing working passes are accomplished with small cutting rates, namely: With a cutting speed of 4 to 5 m/min and thickness of shavings removed of 0.03 to 0.04 mm. During this, the working run of the process, the exterior appearance of the shavings removed, the condition of the cutter cutting edges, and fastening of the barrel and rifling head are carefully checked.

Upon receipt of positive results in this checking, the normal rifling process begins, with cutting speed being increased to 8 to 9 m/min and thickness of shavings removed in each working run increased to 0.05 to 0.08 mm, and in some instances up to 0.10 mm.

The last two or three working passes during bore rifling must be cleaning ones to attain the required smoothness of machining. For these passes, thickness of shavings removed must not exceed 0.04 to 0.05 mm.

Bore rifling is usually the last fine machining operation of barrel bore. If the barrel bore is polished after rifling, the aim of this operation is other than in the normal polishing of smooth bores, in which a previously left margin is removed and the bore dimensions are changed. In polishing a barrel bore after rifling, only small burrs are removed and a previously left margin is not.

This is why the cutting rate during barrel bore rifling must provide the required accuracy and smoothness of machining of its surface without polishing. During bore rifling, the cooling liquid must aid the normal flow of the cutting process as much as possible, or ease separation of the shavings, lower the cutting force, and decrease friction and cutter wear. The cooling properties of the liquid during bore rifling are less important than their lubricating properties, with which they form a firm, thin film on the surface of the metal, and easily penetrate into the micropores at the sections of the metal's plastic deformation. The cooling and lubricating properties of the liquid are active factors of the cutting rate and enable attainment of the best smoothness of the machined surface.

Vegetable oils have the best lubricating properties; however, for economic considerations, the liquid, which is a mixture of 20 to 15% vegetable and 75 to 80% mineral oils, and 5 to 6% kerosene is used during rifling barrel bores. This liquid must be clean and not have mechanical impurities.

Machine time during rifling barrel bores is an accumulation of the time of the machine's working run, during which shavings are removed, and the time of its idle (reverse) run, whose speed is 50 to 100% greater than the speed of the working run.

Machine time T_M is determined according to the following formula:

$$T_M = \frac{2\ell_H}{1000\nu_{cp}} x \frac{n}{k} \text{ [min]}, \quad (72)$$

where ℓ_H is the length of the rifling head run, which is equal to the rifled portion of the bore plus (2.5 to 4)d for entry and exit of the rifling head from the rifled portion of the bore, in mm; ν_{cp} is average cutting, which is the average arithmetic speed of the working and idle runs of the machine in m/min; x is the number of double runs (working and idle) for a group of simultaneously grooved riflings; n is the number of grooves in the barrel bore: and k is the number of rifling head cutters.

We will determine, as an example, the machine time for rifling a barrel bore with the following data: d = 100 mm, ℓ_H = 4630 + 320 = 4950 mm, t = 1.5 mm, b = 5.3 mm, n = 40, and k = 8.

We will rifle the barrel bore on a Krasnyi Proletarii plant machine, and for the first two runs we will take a working run speed for each group of eight cutters ν = 3.4 m/min, and for all other passes, ν_p = 10 m/min. Speed of the idle run of the machine ν_x = 16.6 m/min. The number of rifling groups $\frac{n}{k}$ = 5. We will first determine the number of double runs for each group of riflings, which depends on the thickness of the shavings removed (feed) in each working pass. For the first two and last two passes, we will take a thickness of shavings removed of 0.04 mm, and for all other passes, 0.07 mm. In all, then, the working passes for each group of grooves x = 23. We will take average speed as equal to v_{cp} = 12.5 m/min. Machine time will then be equal to

$$T_M = \frac{2 \cdot 4950}{1000 \cdot 12.5} \cdot 23 \cdot 5 = 91.1 \text{ min.}$$

Auxiliary time during weapon bore rifling comprises a significant part of the machine time. During auxillary time, the following actions are performed: Starting and stopping the machine, cleaning shavings from the cutting head, setting feed for thickness of shavings removed, changing speed, rotating the barrel with the spacing mechanism after grooving each group of riflings, and cutter inspection. Preparatory, finishing, and additional increases in time comprise a very small amount, usually no more than 5% of the machine time T_M.

On the basis of work experience and under conditions of automatic setting for each working pass, we take all additional time as equal to $0.24T_M$.

Then the time per piece T_{WT} for rifling one barrel bore will be

$$T_{WT} = T_M + 0.24T_M = 91.1 + 21.84 = 115.94 \text{ min} \approx 1 \text{ hr } 56 \text{ min.}$$

If we also count the time for installation and checking each barrel on the machine, then in two work shifts, six gun barrel bores can be rifled. With a twelve-cutter rifling head, during two shifts, up to nine barrels can be rifled on the machine.

In the example reviewed, all head cutters on the rifling machine remove, in one working pass, shavings of the following section:

$$F = s \cdot b \cdot k = 0.07 \cdot 5.3 \cdot 8 = 2.968 \text{ mm}^2.$$

The volume of shavings removed in one working pass

$$Q = 0.02968 \cdot 463 = 13.742 \text{ cm}^3,$$

and its weight is

$$q = 13.742 \quad 7.9 = 108.6 \text{ g.}$$

During barrel bore rifling, cutting force is generated on the machine shaft and, consequently, on the cutters, and it is determined according to formula (64), with the following value:

$$P_z = c_p s^{0.85} bk = 320 \cdot 0.105 \cdot 5.3 \cdot 8 = 1424 \text{ kg.}$$

Considering that the cutting process takes place along a spiral, the total cutting force with consideration for head friction on the bore surface is

$$P = 1.12P_z = 1600 \text{ kg.}$$

Using a twelve-cutter rifling head, the total cutting force is

$$P = 320 \cdot 0.105 \cdot 5.3 \cdot 12 \cdot 1.12 = 2400 \text{ kg}.$$

Feed force P_s, absorbed by the running screw nut, may be determined from the expression

$$P_s = P + fQ_K = 2400 + 0.2 \cdot 1000 = 2600 \text{ kg},$$

where Q_K is weight of the moving parts of the carriage and shaft, which can be taken as $Q_K = 1000$ kg for medium machines; and f is the coefficient of friction of the machine guides (usually f = 0.2).

With this feed force, cutting speed of 10 m/min and coefficient of efficiency of the machine $\eta = 0.6$, an electric motor for primary motion of the rifling machine is required with power

$$N = \frac{P_s v}{60 \cdot 102\eta} = \frac{2600 \cdot 10}{60 \cdot 102 \cdot 0.6} = 7.1 \text{ kW}.$$

On medium rifling machines, power of the primary motion electric motor is usually 8 to 10 kW, and on large machines it reaches 30 kW.

After rifling and control measuring, gun barrel bores undergo polishing and honing operations, which will be described in Chapter XII.

Defects Encountered During Rifling Weapon Bores

The following machining defects are encounter during rifling bores: Unevenness at the start of riflings, depressions and scratches in the surface, groove distortion, cuts in the lateral edges of the grooves, and cuts in the lands. All these defects are results of improper adjustment of the machine and rifling head and incorrect selection of cutting rate. We will look at the composition and reasons for appearance of these defects.

Unevenness at the start of riflings consists of the fact that the grooves on the rifled slope of the charge chamber do not begin in the same cross-sectional plane, but are displaced relative to each other (Fig. 148).

The reasons for this defect may be eccentricity relative to the geometric axis of the bore or ovality of the rifled slope of the chamber, a large clearance between the guiding slides or bronze skirt of the rifling head and the surface of the bore, or increased circumference of some cutters relative to the others. Unevenness of start of rifling within the limits of up to 3 mm in length have no practical significance, but with a larger value they have essential influence in that they enhance formation of cuts of the lands at the rifled slope, speed the process of wear and pitting of the riflings, and decrease the quality and length of service of the barrel.

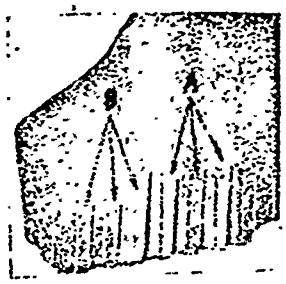


Fig. 148. Unevenness of start of riflings

Key: A. group of riflings displaced in length to the breech part
B. group of riflings with normal location

Depressions and notches on the surface of the bore have the appearance shown in Fig. 149. They are wavy surfaces with sharply cut impressions of the cutting tool. These defects are received as a result of vibration of the rifling head or cutters due to unevenness of cutting force on the cutters, presence of large clearances between the guide rails of the head and the bore surface, or between the cutters and their centering surfaces. Shaking of the rifling head usually arises with great guide wear.

Another type of depressions and notches are left on the surface of the grooves and lands by small hard particles of shavings which adhere to the surface of the bronze guides and on the cutting edges of the cutters. These defects may be eliminated if the shavings are exhausted into the head pocket properly during the working run and are well cleaned from the pocket after each working run. These defects decrease the quality of bore cleanliness, which speeds its wear and deformation of rust in it during use of the gun.

Fig. 149. Depressions and notches in grooves

With an increased cutting rate (width of savings removed over 0.1 mm and cutting speed over 10 m/min), a sharp increase in shaking of the rifling head is observed. In each actual instance, the cutting rate must be the most favorable. Depressions and notches on the grooves and lands may be partially eliminated by polishing the bore after rifling.

Distortion of the rifling lands depends on the condition of the working surface of the copier gauge. During barrel bore rifling, a force arises and acts on the copier, attempting to displace or drive away the copier gauge If the copier gauge is insufficiently solid, rifling twist will change on some sections of the rifled portion of the bore, which is in itself distortion of the riflings. Small local distortions may also occur as the result of shavings falling between the guiding surface of the copier and the rack roller. In this, the roller, rolling across the shaving, changes the speed of the lateral movement of the rack, as the result of which the angle of rotation of the shaft changes by comparison with that adjusted, and makes a local, but sharp distortion in the riflings.

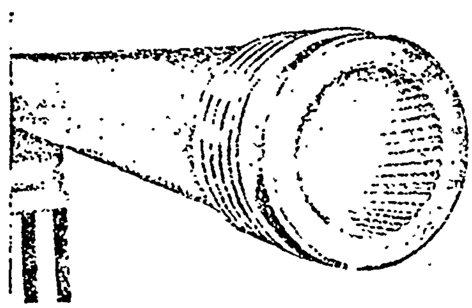


Fig. 150. Riflings in a barrel bore

Cutting the lands, or decreasing land width on some section of the riflings occurs as the result of movement of the gun barrel in the process of bore rifling. During bore rifling, the composite forces of cutting act on the weapon barrel in an axial direction, attempting to rotate the barrel around its axis. If the barrel is fastened into the lunettes weakly or there is slack in the fastening, the barrel may move, and as a result, cutting of the lands occurs.

The defects presented show that adjustment of the machine, the rifling head, and the correct installation of the barrel are very important for receipt of the required quality of bore rifling.

The overall view of riflings in a gun barrel bore is shown in Fig. 150.

CHAPTER XI

Building Up and Tearing Down Gun Barrels

#41. Preparation of Barrel Tubes for Building Up

Increasing the strength of a single layer gun barrel (monobloc) is possible through increasing the limits of strength of the metal and increasing the thickness of the gun barrel wall. During firing, however, the internal layer of metal of the monobloc barrel experiences significantly greater stress than does the exterior one, and therefore the high mechanical qualities of the metal of the exterior layer are not fully used.

A built-up barrel consists of several tubes which are fitted one on the other with stretch. With this building up of tubes, the internal tube experiences the stress of compression, and the exterior tube, usually called the jacket, experiences the stress of tension. Due to this, strength of the gun barrel is increased during firing, and the internal and external layers of metal of the barrel will experience more evenly distributed stresses. The built-up barrel has sufficient barrel flexibility resistance during firing, even with lower mechanical properties of the metal making up its tubes. These peculiarities of a built-up barrel have important practical significance for production of especially large howitzer and cannon barrels.

Built-up barrels may be two-layer and three-layer, and in some cases also four-layer (Figs. 151 and 152). With three- and four-layer barrels, their intermediate tubes (layers) usually consist of two parts in length, as shown in Fig. 152. Long multi-layered barrels have intermediate tubes, consisting of three parts, covered by a jacket. This in itself eases manufacture of barrels.

In a built-up barrel, the internal tube is under constant pressure, created by the tension during fitting of one tube on to another. The amount of stretch is determined by a calculation and for small weapons (up to 76 mm) in caliber, does not practically exceed 0.20 to 0.10 mm, and for large weapons 250 to 305 mm in caliber, 0.5 to 0.25 mm. Stretch is distributed evenly along the length, and namely: In places where more powder gas pressure is generated during firing, the tube has more stretch, and on sections closer to the muzzle part of the bore, it has less stretch.

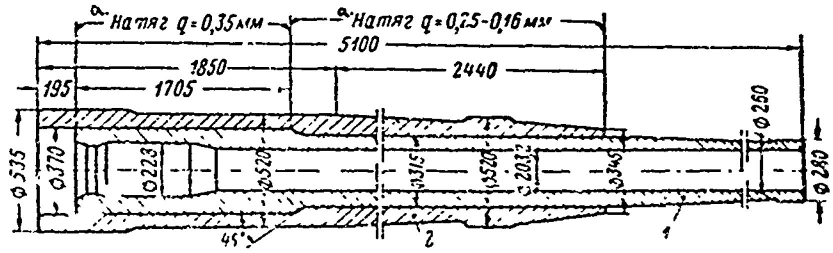


Fig. 151. Two-layer built-up gun barrel

Key: 1. internal tube
2. jacket
a. stretch

For instance, the two-layer field howitzer gun barrel shown in Fig. 151 has a stretch of 0.35 mm on the section of length 1705 mm with diameter 370 mm, and on the other part of diameter 315 mm, has a stretch of from 0.25 to 0.16 mm with further decreases in the amount of stretch toward the muzzle part of the barrel. A step at an angle of 45° is made on the assembly surfaces of both barrels and is used to more conveniently provide fixing of the jacket position on the internal tube. During use of the barrel, the step prevents movement of the inner tube relative to the jacket.

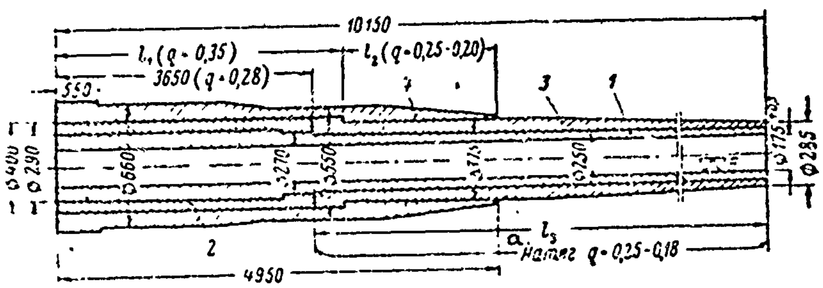


Fig. 152. Three-layer built-up gun barrel

Key: 1. inner tube 4. jacket
2. rear tube (sheath) q. stretch in mm
3. front tube (sheath) a. stretch

Before building up, the exterior surface of the inner tube and the interior surface of the jacket are final machined. In this, the exterior surface of the tube is fitted according to the actual dimensions of the internal surface of the jacket, and this in itself provides the maximum accuracy of the assigned value of the stretch. A margin remains along the bore of the internal tube for final boring and machining the charge chamber, and along the exterior surface of the jacket, a margin from 2.0 to 2.5 mm on the diameter remains for fine machining after building up. A small margin also remains on tube length for fine machining. The exterior contour of the jacket of a built-up barrel must be as simple as possible in form, without sharp steps, depressions, or raised places so as to provide evenness of the stretch force during building up of the tubes, and more correctly distribute stresses in them during tube building up and during firing.

Tolerance on the amount of stretch during tube building up for the majority of tubes is maintained equal to ±0.04 mm, and only in rare circumstances is it taken as ±0.06 mm. The achievement in production of such amounts of tolerances with large dimensions, diameters, and weights of tubes is a very difficult problem. This problem is solved comparatively easily in production with individual fitting of the exterior surface of the internal tube to the actual dimensions of the previously machined internal surface of the jacket. With this, the nominal diameter of the assembly surface may vary within the limits of up to 1 mm, but difference between the actual diameters of the tubes for a given assembly must not exceed the amount of tolerance given for stretch.

For example, let us take a tube assembly which has a nominal diameter of 370 mm with a stretch of 0.35 mm on length of 1705 mm, and a tolerance on the amount of stretch of ±0.05 mm (see Fig. 151). The diameter of the previously machined internal surface of the jacket is determined according to the formula

$$D = (D_H + E) \pm \delta, \quad (73)$$

where D_H is the nominal diameter of assembly (in the example examined, $D_H = 370$ mm), E is the allowable amount of deviation of the nominal diameter, with which the calculated strength of the built-up barrel is not destroyed. In production, E = 0.5 to 1.0 mm, with the lower limit used for $D_H \leq 180$ mm, and the upper limit for $D_H > 400$ mm; and δ is machining tolerance, whose amount must not exceed the tolerance for stretch (in the example examined $\delta = \pm 0.05$ mm).

In the example examined, we take E = 0.7 mm, so the nominal diameters assemby for all gun barrels of the given type must not move outside the limits 370 to 370.7 mm. Consequently, any other tube in assembly having, for instance, an actual diameter after final turning of 370.2 mm, will satisfy the requirements of formula (73), if its diameter on the determined length of assembly surface does not move outside the limits 370.2 ±0.05 mm. Smoothness of corresponding surfaces of built-up tubes after their machining must correspond to ∇6.

The step (inclined or right angle) in tube assembly is formed according to the drawing, but there must not be cuts or curved surfaces on it.

All remaining interior surfaces of the tubes (jackets and intermediate sheaths) comprising the built-up barrel should be machined in the described method.

After machining, the tube undergoes technical inspection of its interior surfaces, and diameters are measured in two perpendicular directions on its entire length on sections every 100 mm, and a mold is taken of the step, on which its actual dimensions are determined. A pattern is made from the dimensions received and from the mold, and is used to check the step on the exterior surface of the internal tube or sheath.

If the dimension of the internal diameter of the jacket is measured at 370.24 mm, then that is taken as the nominal assembly dimension of the built-up elements, and is used to set the dimensions for machining the exterior surface of the inner tube or sheath, with consideration for the amount of stretch.

The dimension of the exterior diameter of the inner tube d_{TP} will be determined from the expression

$$D_{TP} = (D + q) \pm \delta, \qquad (74)$$

where D is the actual dimension of the internal diameter of the jacket (in the example examined = 370.24 mm); q is the calculated amount of stretch (q = 0.35 mm); (q = 0.35 mm); and δ is the machining tolerance on the exterior surface of the tube, which must be smaller than or equal to the calculated amount of tolerance on stretch (δ = 0.05 mm).

In practice, machining tolerance on the exterior surface of the inner tube is taken at 0.01 mm smaller than the tolerance on machining the exterior surface of the jacket or sheath. In the example of tube assembly examined, the exterior diameter of the inner tube must be equal to 370.59 mm with a tolerance ±0.05 mm, which is to say its actual dimensions must be within the limits of 370.54 to 370.54 mm.

This order of amount of tolerances in individual machining of tubes for built-up barrels should be maintained in all assemblies of their surfaces.

The high power three-layer built-up cannon barrel shown in Fig. 152 is calculated according to strength at a powder gas pressure in the barrel bore of P_{max} = 3250 kg/cm^2. The inner tube (1) of this barrel, which is one piece for the entire barrel length, is manufactured of high quality material, having a limit of proportionality of σ_p = 80 kg/mm^2, and in some instances even higher than this amount. A sheath or intermediate tube, consisting of two tubes, rear (2) and front (3), in length, is put on the exterior surface of the inner tube with stretch. Both tube sheaths are fixed relative to the inner tube by right-angle profile steps. The process of fastening them to the inner tube takes place sequentially, namely: The surface of the tubes is first prepared on a section 3650 mm long, having a stretch q = 0.28 mm, and diameters 290 and 270 mm, and the remaining surface sections of the inner tube (1) and rear part (2) of the intermediate tube are only preliminarily machined. Before its assembly with the intermediate tube, the bore surface of inner tube (1) is machined to a diameter of 175 mm, but sufficiently accurately, as shown from data in Fig. 152, and has a margin for fine boring of the bore and machining of the charge chamber after assembly.

After assembly of the inner tube (1) with tube-sheath (2), technical inspection of the assembled elements occurs and surfaces of tube-sheath(3) and tube (1) are prepared on the section of its length ℓ_3, 250 mm in diameter, to be assembled with a stretch of q = 0.25 to 0.18. The amount of stretch in this section is gradually decreased in the direction toward the muzzle part of the barrel. The assembly of barrels consisting of separate tubes eases the process of tube machining and the process of their assembly. The material of the intermediate tube-sheaths of the second layer has an approximate limit of proportionality $\sigma_p = 65$ kg/mm^2, which is significantly lower than for the material of the inner tube.

Then, when internal tube (1) is assembled with tube-sheath (3), technical inspection of the assembled elements takes place, as does preparation for assembly of the internal surfaces of jacket (4) and the external surfaces of tube-sheaths (2) and (3) on the section of length ℓ_1, 400 mm in diameter, with stretch q = 0.35 and ℓ_2, 375 mm in diameter, with stretch q = 0.20 to 0.25 mm. The sequence of machining the surfaces of these assembled barrel elements is the same as described, i.e., turning of the exterior surfaces of rear (2) and front (3) tube-sheaths of the second layer takes place according to the actual internal dimensions of jacket (4), with observance of the amount of assigned stretch.

Jacket (4) is manufactured of a material having a limit of proportionality $\sigma_p = 55$ kg/mm^2, or somewhat smaller than the material of the second layer.

#42. Building Up and Tearing Down Gun Barrel Tubes

The process of building up barrel tubes consists of the fact that a heated sheath or jacket is mounted, while hot, in a vertical position on the cold inner tube, which has the temperature of the surrounding medium of the shop.

There are two caissons in the form of deep pits in the part of the shop where barrel tube assembly takes place. Heating of sheaths and jackets takes place in one of these pits, and the process of tube assembly and consequent cooling takes place in the other. The necessity for construction of the caissons in the form of pits is caused by limits in the height a load can be raised by cranes and a desire to decrease the overall height of the shop building where tube assembly takes place. The overall height of the shop building depends on the necessary height for raising the tubes out of the caissons and lowering them into the caissons. In particular, for the barrel shown in Fig. 152, the height nedessary to raise the tube with a crane must be 14 m and, consequently, overall height of the shop building must reach 20 m, and in some cases significantly more.

The caisson for heating the tubes is usually a vertical electric resistance oven, and only in rare cases is it an electric induction oven of more complex construction. The tube is installed in a caisson in a strictly vertical position, and during tube heating, the caisson is tightly closed with a cover.

Tube heating temperature does not usually have to exceed 400° C, and only in some instances does it reach 450° C. Tube heating to higher temperatures is not desirable in that with this, the mechanical properties of the metal from which it is manufactured can be lowered. Length of tube heating depends on its dimensions and weight. For the tubes shown in Figs. 151 and 152, time for heating them to 400° C is 2.5 to 3.5 hr with a hold after heating to heat the entire mass of the tube metal. Time of the hold is usually 1.5 to 2 hr. Before heating, the inside surface of the sheath or jacket is carefully cleaned of lubrication and rubbed dry.

During heating, tube temperature is checked with instruments every 15 min, and the results are recorded in a special journal. After final heating and holding, the caisson cover is removed, the tube is grasped with a crane and somewhat raised, and the internal diameter of the tube is measured at its upper face. The tube is then fully raised from the caisson, which is immediately covor, and the tube internal diameter at its lower face is checked. For checking, the measuring tool is previously adjusted to the minimum limit of the dimension allowable for tube assembly. This dimension must be larger than the external diameter of the inner tube by 0.15 to 0.20 mm, and is set for each tube by a calculation. With satisfactory measuring results, the jacket or tube-sheath is mounted on the inner tube.

The entire operation of the assembly process, meaning opening the caisson cover after heating, raising the tube-sheath, measuring its internal diameters at the upper and lower faces, moving the tube-sheath to the second caisson and lowering it for mounting on the inner tube, must occupy the least possible time. Time for performance of all these operations must not exceed 3.0 to 4.5 min.

During heating of the jacket or tube-sheath, preparation of the inner tube for assembly, including the following, takes place. The inner tube is installed in the caisson on a special support, which has a cylindrical spindle for fixing the tube in a strictly vertical position. This caisson has a cooling apparatus in the form of sections, consisting of hollow rings, which surround the built-up barrel. The sections (rings) are distributed along the height of the barrel at a distance of approximately 0.8 m from each other. The hollow rings have a number of holes which are directed at the surface of the built-up barrel. Cooling water is fed to these sections at a pressure of 1.3 to 1.5 atm, and streams of it intensively wet down the surface of the barrel. During cooling of the barrel, any one of these sections or all of them are turned on simultaneously.

The exterior surface of the inner tube is carefully rubbed dry, and then lightly lubricated with mineral oil or a special graphite lubricant. The lubricant, in a very thin layer, eases the process of mounting the jacket or tube-sheath on the inner tube.

Too much lubricant and the appearance of moisture may make mounting of the tube-sheath on the inner tube more difficult, and the tube-sheath may not be fully mounted on the tube, consequently ruining the entire barrel.

Lowering the jacket or tube-sheath during its mounting on the inner tube takes place without interruption over 2 to 3 sec, and for the last section, 300 to 400 mm in length, the jacket is lowered as quickly as possible so as to best assure its seating on the tube step.

During cooling of the built-up barrel, the jacket (or tube-sheath) will shrink, and consequently, its lengthwise movement relative to the inner tube is possible. As the result of this, a clearance up to 10 to 12 mm can form at the steps or joints of the tubes, and should not be allowed. To eliminate this clearance, cooling the built-up tubes takes place according to a previously-worked-out scheme. According to this scheme, intensive artificial cooling first takes place on the section of the tubes at the steps or joint, to provide bonding (seizing) of these sections and attain a tight fit (touching) of the jacket on the step of the inner tube. Cooling of the barrel surface is then increased, with its thin walls at the muzzle part being cooled last.

Artificial cooling of the barrel takes approximately 15 to 20 min. Sharp metallic cracks heard one or two minutes after the beginning of cooling, and continuing throughout the entire cooling of the barrel, even after it is removed from the caisson, are phenomena indicating that movement is occurring in the bonded surfaces of the jacket or sheath relative to the tube. Instances of movement of a barrel's tubes occur during firing, sometimes several years after manufacture of the barrel. Preparation of tubes for assembly and the process of their assembly are complex operations, requiring accurate performance of all requirements of the technological process. In economic considerations, manufacture of built-up barrels is less profitable, in that more time is required for tube machining and the assembly process. For this reason, the majority of artillery weapon barrels are manufactured in the form of monoblocs.

With wear of the rifled portion of the bore of a built-up weapon barrel, the inner tube is usually removed, or retubing takes place. Removal of the worn-out inner tube may take place by two methods: Unbonding or boring.

Boring the barrel bore, leading to gradual cutting of the inner tube and converting it into shavings, occupies much time. The more profitable method is tearing down the barrel, which consists of first heating the built-up barrel to a temperature of 400° C in an oven, and then extracting the inner tube from it. Tearing down a barrel takes place in the following manner.

After heating, the barrel is installed in a caisson for assembly on a special guiding rod with the muzzle part down, and is solidly fastened to the rod with a special attachment (drawbar). The barrel breech is first unscrewed. The barrel bore is then covered from above with a solid plug. The barrel jacket is then connected to the elevating crane with a collar and cable and prepared for raising. A stream of cold water is directed under pressure into the barrel bore from below and must energetically wet down the entire surface of the bore without falling on the jacket. Due to the intensity of cooling of the internal tube, and the resultant decrease in its diameter, stretch between the exterior surface of the inner tube and the inside surface of the jacket (or tube-sheath) is destroyed. The jacket (or tube-sheath) is then removed from the inner tube.

A more reliable and convenient method of removing the jacket (or tube-sheath) from the inner tube is the use of a hydraulic or more simply constructed screw press. In this case, barrel breakdown is done in a horizontal position.

During barrel breakdown, the accurate determination of the moment of interference disruption between the tubes for their movement from each other is a highly important factor. The breakdown rate must be as accurate as possible and correctly calculated theoretically, but in some instances production experience of shops and certain foremen should be considered. This experience has essential influence on the successful performance of the operation.

In some instances, during preparation of tubes for assembly, their exterior surfaces are machined with a very small conicity, formed as the result of decreasing their exterior diameters by 0.06 to 0.12 mm in the direction of the muzzle part of the barrel, which is achieved by corresponding regulation of the amount of stretch. This method of barrel tube fastening is more complex in production, but it assures a stronger tube fit and eases gun barrel breakdown.

CHAPTER XII

Finishing Operations in Tube Machining

#43. Broaching Deep Holes

Broaching is the highly productive technological process of machining surfaces with a multi-bladed tool, the broach.

This process is used for machining flat exterior surfaces and forming various channels and grooved slots in exterior, flat, and round surfaces. The broaching process is more widely used during machining of smooth round holes and holes with grooves of square, multi-edged, or shaped section.

The broaching process is often the final fine operation providing high accuracy in dimensions (to second and third classes of precision) and good surface smoothness. Broaching takes place on horizontal and vertical broaching machines.

During broaching, the primary working motion, determining cutting speed, is performed by the cutting tool, or broach, while the machined part is fastened stationary on the machine.

Broaching machines do not have a feed movement in that feed is accomplished by construction of the broach itself, which has gradually raised cutting teeth.

Broaches are multi-bladed tools in the form of long bars or rods with a section corresponding to the form of the machined hole.

Artillery production broaching, which are special technological processes differing from broaching processes used in general machine construction, include the following: Broaching smooth cylindrical weapon bores up to 70d in in length, broaching smooth cylindrical holes in various cylinders and rods over 12d in length and broaching grooves in gun barrel bores of small and medium calibers.

The special broaching processes also include broaching the flat surfaces of the wedge hole of the breech block, broaching the exterior flat surface of the breech block wedge, and a number of other operations.

The special broaching operations listed are complex in construction and large in dimensions, both of the machined parts and surfaces, and of the broaches themselves. For one technological broaching process, it is often necessary to have a group of several broaches.

We will look at the technological processes of broaching which are typical for artillery production.

Broaching Smooth Cylindrical Bores

For broaching smooth cylindrical bores, a complex of two, three, or four assembled broaches is necessary. As already stated, during the described processes of boring cylindrical deep holes in gun tubes after heat treatment, coarse, semi-fine, and fine boring take place. Broaching takes the place of fine boring in gun tubes, and allows attainment of a cylindrical bore of the required precision on diameter and surface smoothness with less time being expended than on fine boring.

For use of broaching, the tube bore must be straight and not vary in wall thickness, i.e., it must have undergone coarse and semi-fine boring, during which which these defects may be eliminated.

For the broaching process, therefore, the tube bore must be prepared the same as for fine boring. The broaching process eliminates conicity and slight bore curvature and whole section ovality, and provides receipt of a cylindrical bore with high accuracy of dimension and the required surface smoothness.

The amount of margin on the diameter for the broaching process is assigned with consideration of the mechanical properties of the machined metal, and the length and diameter of the tube. The diameter margin for tubes 55 to 105 mm in diameter and up to 5000 mm in length is usually 0.8 to 1.5 mm with a group of three broaches.

A broach for deep cylindrical holes has a hollow arbor (3) of high strength construction steel, and a tail which is connected to an adaptor of the drawing machine (Fig. 153). Eight to ten blades are mounted on the arbor, whose exterior surface is machined to second class precision. The blades are divided on the arbor by steel rings (4) and pressed from both ends by guiding cylinders (10) and (11). Four guiding keys (2) and (9) are fastened on each of these cylinders. The external diameter of the arbor along the guiding surfaces of the keys is fitted to the dimensions of the machined tube bore, namely: The exterior diameter of the keys (2) of the front cylinder must correspond to the internal diameter of the tube bore before its broaching, and the external diameter of key (9) of the rear cylinder must correspond to the diameter of the tube bore after its broaching. Clearance on the diameter with these considerations is usually 0.04 to 0.06 mm. With this clearance, the broach must not wedge in the bore and a great deal of friction must not arise along the surfaces of the guiding keys.

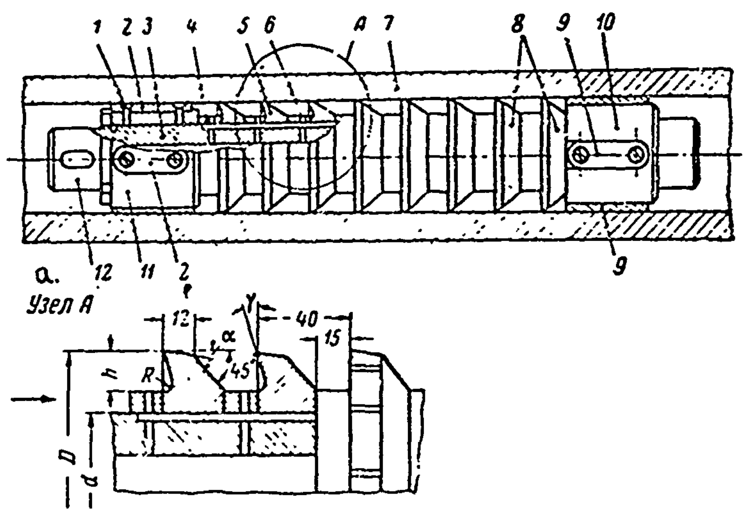


Fig. 153. Broach for deep cylindrical holes

Key:
1. set screw
2. guiding key
3. arbor
4. ring
5 & 8. blades
6. hole, supplying liquid to blades
7. machined tube
9. guiding key
10 & 11. front and rear cylinders
12. front tail
a. sector A

Cooling liquid is supplied to the blades along the internal hollow of the arbor (3) and then through the radial hole (6) in the arbor and rings (4). The geometry of the cutting part of the blade is sufficiently clearly seen in Fig. 153. The blades are the most responsible parts of the broach and are manufactured of fast-cutting R18 or R9 tool steel.

After heat treatment and sharpening, the blades must have a hardness of $R_C = 63$ to 64. The front angle of the blade point $\gamma = 15^\circ$, and its rear angle $\alpha = 3$ to 5°. The front and rear surfaces of the blade are ground, and the smoothness of these surfaces must be greater than that of the remaining surfaces of the blade, which have a smoothness of ∇7. The first six or eight blades of the broach are of varying diameter, and are the working ones in that they remove the basic part of the margin, and the other two or three blades are of uniform diameter, and are calibrating ones. All the calibrating blades together remove a layer of metal nor more than 0.03 mm thick on a side.

The first working blade has the smallest diameter and removes shavings within the limits of the margin of the preceding operation (0.02 to 0.04 mm) while all the following working blades remove shavings which are thicker. In broach machining steel tubes of high strength, thickness of shavings must not exceed 0.07 mm on a side. It should be noted that with a shaving thickness of 0.02 mm, scraping is observed, wear of the cutting parts of the blade is accelerated, and assignment of this shaving thickness for working blades is not recommended. A very important factor in broaches is the volume of the cavity between the blades (teeth), which is determined by tooth height h of the working part of the blade and pitch t, which is the distance between the blades (see Fig. 153). The volume of this cavity must be four to six times greater than the volume of shavings removed in that with this condition, normal conditions will be provided for distribution of the shavings removed from the beginning to the end of the working process of broaching the bore.

There are eight or nine depressions on the exterior surface of the working blades which are up to 0.5 mm in depth and up to 1 mm in width. These depressions, which are staggered in arrangement, are intended to crush the shavings. The rear surface of the calibrating blades are smooth.

Otherwise, construction of the blades is sufficiently clear in Fig. 153, on which are given blade dimonsions $h \approx 11.5$ mm and $t \approx 40$ mm as an example for a nominal bore diameter $D = 100$ to 110 mm.

The mandrel (3) is manufactured of 45Kh steel and heat treated to a hardness of $R_C = 40$ to 45. The guiding cylinders (10) and (11), and ring (4) are manufactured of medium-hard construction steel, and the guiding keys (2) and (9) are manufactured of bronze or textolite.

When dull, the blades may be resharpened, with the exterior blade diameter being decreased by 0.02 mm in each resharpening, and therefore they can only be resharpened four times. Four spare blades are manufactured for each broach, and have a smooth back surface and an exterior diameter equal to the maximum diameter of the calibrating blades.

When the blades are all worn out, the first working blade is removed from the arbor, the remaining blades are moved forward, and one spare blade is installed as the last calibrating one. A set of two broaches can machine up to 35 to 40 weapon barrel tubes without resharpening, and with resharpening and use of the spare blades, they can machine 550 to 600 tubes.

The most labor-consuming part of the task is the process of manufacturing the broach and adjusting the broach and machine operation.

During broaching normal shallow holes, cutting speed is maintained within the limits of 4 to 12 m/min, and for deep holes, it is reduced to 3 to 8 m/min, and depends on the dimensions and material of the machined tube, construction of the broach, and other factors.

Cutting force during broaching smooth cylindrical holes can be determined according to recommended experimental formulae, for instance of the following type:

$$P = c_p s_z^{0.85} D z_p, \tag{75}$$

where P is the cutting force; c_p is the coefficient calculating the mechanical properties of the machined material (with σ_b = 70 to 80 kg/mm², c_p = 840; with σ_b = 80 kg/mm², c_p = 890); s_z is thickness of metal layer removed on each side by one working blade in mm; D is the nominal broach diameter in mm; and z_p is the number of working blades (teeth).

Production practice shows that in machining smooth cylindrical bores, the broach is more productive and gives better deep-hole machining quality than fine boring operations. With broaching, deep-hole machining time, including adjusting and starting the machine, decreases by one third to one fifth.

The total margin on hole diameter, 1 to 1.5 mm, is removed by two or three broaches. There are eighteen working and nine calibrating blades in a set of three broaches. Total broaching time for one barrel, including time for adjustment and changing broaches, does not exceed 35 to 45 min. while fine boring of the tube 100 mm in diameter and up to 5000 mm long takes up to 3.5 hr.

However, the complexity of manufacture of assembled large dimension broaches, the high power requirements for the broaching machine, and the complexity of adjustment of the operation all still limit the wide usage of them for machining long tubes.

Broaching Riflings in Weapon Bores

Experience in broaching riflings in weapon bores has given good results with barrels of calibers 76.2 mm and 85 mm. Riflings for barrels of this caliber are most often broached with a set of two broaches, and only in some instances are three broaches used for rifling one barrel.

The broaches used were of assembled and one-piece construction, with the one-piece broaches becoming unfit for further use after two or three resharpenings. The assembled broaches are more profitable, especially for rifling weapon bores over 50 mm in diameter.

Construction of the assembled broach for broaching riflings in the 85-mm barrel of Table 39 is shown in Fig. 154. The broach consists of an arbor (1), front guiding cylinder (2), bronze guiding slides (3), intermediate discs (4), disc blades (5), rear guiding cylinder (6), bronze guiding slides (7), longitudinal key (8), and other secondary parts.

The mandrel (1) is a hollow cylinder, accurately machined along its exterior surface, on which all parts of the broach are centered. The disc blades (5) and intermediate discs (4) are fixed on the mandrel by the longitudinal key (8), which assures the unchanged position of the cutting teeth along the assigned spiral of the riflings. Position of the broach blade teeth must strictly correspond to the required twist of riflings, which is assured by pointing and grinding them on the assembled broach. The bronze guiding slides (3) are fastened in conic slots of the body (2), and their fastening allows regulation of the slide position in the slots corresponding to the diameter of the bore. Cooling and lubricating liquid gets to the blades along the internal hollow of the mandrel and along the radial holes in the broach body.

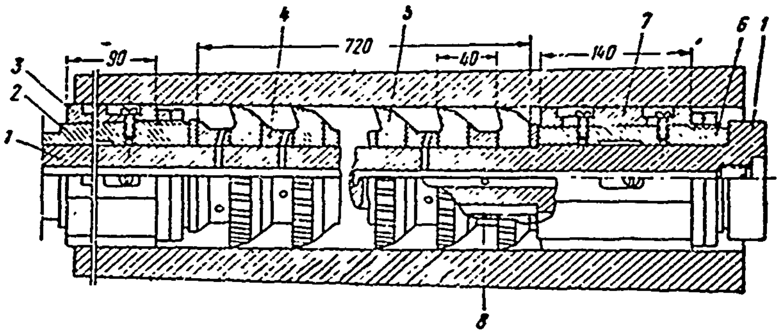


Fig. 154. Broach for broaching riflings in barrel bore

Key:
1. mandrel
2 & 6. front and rear guiding cylinders
3 & 7. bronze guiding slides
4. intermediate disc
5. disc blade
6. longitudinal key

The disc blade is manufactured of R18 fast-cutting steel (Fig. 155). The blade is the most responsible part of the broach, and is machined with high accuracy agreeing to its geometry on the drawing.

The number of teeth on the blade must be equal to the number of grooves in the bore, and the width of each tooth is the width of the groove. Profile of the blade teeth must be the same as groove profile, and depth of the depression between teeth must be somewhat larger than groove depth.

Preliminary pointing and grinding of the front and rear surfaces is done separately for each blade, and pointing and grinding of tooth profile is done on the assembled broach so as to strictly maintain the form of the teeth on all blades to correspond to the assigned rifling twist. Fine sharpening of the blades to the required diameter also takes place on the assembled broach.

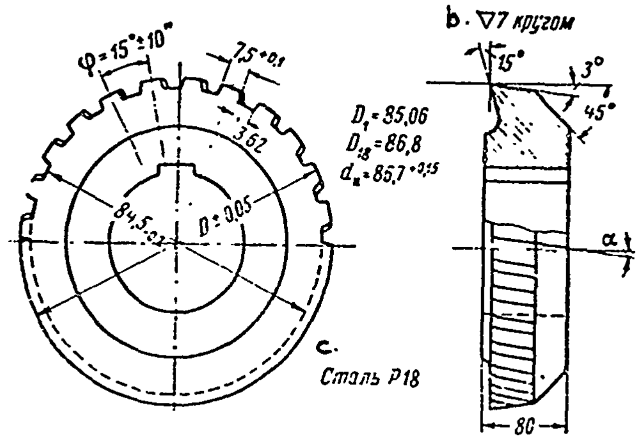


Fig. 155. Broach disc blade for 85-mm barrel bore

Key: bore diameter along the grooves (d_H (d_H = 86.7 mm)
D. external diameter of broach blade (D_1 = 85.06 mm)
ϕ. central angle between teeth
α. angle of rifling twist, deviation of broach teeth
b. ∇ 7 all around
c. R18 steel

In some instances, the number of teeth on a blade may be equal to half the number of grooves in a bore. In this case, the depressions between the teeth are wider, and equal to the width of a groove and double the width of a land (b + 2c), and angle ϕ of the blade is doubled. With this construction, one blade machines only half the number of grooves, while the blade following it machines the other half of the grooves.

Decreasing the number of teeth on a blade to half the number of grooves is caused by the necessity for distributing shavings between the blades when broaching bores of great length. For machining bores with blades having a decreased number of teeth, there might be three or four broaches in one set, with the total number of blades being doubled. Besides this, the total number of blades on one broach and in the set of broaches depends also on the depth of the weapon barrel bore riflings.

The exterior diameter of the broach along the first blade D_1 is usually equal to the caliber of the barrel bore, or larger than it by only 0.03 mm, or

$$D_1 = (d + 0.03) \text{ mm},$$

and its exterior surface along the last blade D_H must be 0.1 mm larger than the nominal diameter of the bore along the lands, or

$$D_H = (d_H + 0.1)\ \text{mm}.$$

Thickness of shavings removed by each tooth of a blade, or the margin removed from each side, must not exceed 0.08 mm. In production, increases in the diameters of adjacent blades are allowed within the limits of 0.12 to 0.14 mm, but the last calibrating blade has no increase.

If shavings greater than 0.08 mm thick are removed during broaching riflings, the broach will begin to vibrate and streaks and depressions will appear on the surface of the grooves.

A cutting speed in the limits of 3 to 5 m/min may be allowed during broaching riflings, and only in some instances can it reach 8 m/min.

It must be noted that in broach construction and rates for broaching riflings, there is still not sufficient experience and future research on this process is necessary. The overall length of the broach depends on the number of blades on it and the length of its front and rear guiding slides. Length of the front guiding slide must usually be equal to (1.0 to 1.3)d, with length of the rear slides at (1.2 to 1.8)d, with the larger of these limits being used for bores under 50 mm in diameter. All dimensions in Figs. 154 and 155 relate to a broach 85 mm in diameter with a total of eighteen blades and an overall length of 1100 mm.

In production practice, broaches have from 15 to 22 blades, depending on the actual conditions of their use, and a broach length of greater than 1250 mm is not recommended in that with an excessively large length, the adjustment operation and the process of rifling broaching are made more complicated.

Extremely high cutting force is needed for broaching riflings, just as in broaching smooth cylindrical holes. The axial cutting force P may be determined sufficiently accurately for practical purposes according to the following empirical formula:

$$P = c_p' s^{0.85}\ bnz \qquad (76)$$

where c_p' is the coefficient calculating the mechanical properties of the machined material (with σ_b = 70 to 80 kg/mm^2, c_p' = 285, and with $\sigma_b > 80$ kg/mm^2, c_p = 320); s is the thickness of metal layer removed from each side by one working blade in mm; b is groove width in mm; n is number of simultaneously machined grooves; and z_p is the number of working blades. When adjacent blades machine different grooves, this number should be multiplied by coefficient 0.50.

During broaching of riflings in an 85-mm tube with a set of two broaches, the total cutting force for each broach may reach 51,000 kg. Working machine time during broaching riflings is very small; however, the time for adjustment of the operation and servicing, which go into the per-piece time of each operation, are much larger than the machine time.

The total per-piece time for broaching riflings is one third to one fourth the per-piece time for rifling a bore with an eight- or twelve-cutter rifling head. In rifling machining accuracy and smoothness of machined surface, broaching not only stays abreast of bore rifling with rifling heads, but often exceeds it.

Construction-wise, broaches are more complex and somewhat more expensive in manufacture than rifling heads.

#44. Honing the Barrel Bore

Honing is the mechanical process of final machining a surface with an abrasive block, which is fastened to a special head or attachment. In essence, it is a process of abrasive grinding of the machine surface.

Honing is most widely used during machining smooth cylindrical holes (cylinders of motors, compressors, pumps, etc.). In artillery production, honing is used for machining smooth gun barrel bores before their rifling, mortar tube bores, antirecoil mechanism cylinders, cylinders of equilibrators and stabilizing mechanisms, and rifled bores after their rifling.

The honing head for cylindrical bores is shown in Fig. 156. The head body (5) is a hollow cylinder having two or three rows of longitudinal slots, in which shoes with abrasive blocks (3) and (4) are located. From four to twelve abrasive blocks, depending on the head diameter around its periphery, are located in each row of longitudinal slots. The blocks in adjacent rows are displaced at an angle of 20 to 30° relative to each other. Inside the head body is a formed shaft (8) with conic surfaces which serves as support for the shoes. The shoes with abrasive blocks are held on the exterior surface of the head body (5) by spiral springs (6), which hold them against the support surfaces of shaft (8). With longitudinal movement of shaft (8) in the head body, the exterior diameter of the head around the abrasive blocks increases or decreases, and this is how the blocks are first set at their initial dimension and their position regulated during the bore honing process. Guiding keys (2) and (7) are installed on both ends of the head. The head body is connected to the machine shaft by its tail (1). Horizontal honing machines are used for honing barrel bores.

In the honing process, the machined tube rotates with a speed of 4 to 7 m/min in one direction, and the honing head rotates in the opposite direction with a speed of 20 to 40 m/min, and simultaneously moves back and forth along the bore with a speed of 4 to 12 m/min. Usually, during preliminary honing, speed of longitudinal head feed is 10 to 12 m/min, and during final finish honing, it is decreased to 4 to 6 m/min. Honing sometimes takes place with the tube stationary and the head both rotating and moving backward and forward. This method of honing is used only for shallow holes with a vertical head position in that honing deep holes with a horizontal tube position can form an ellipse as the result of more development of the bottom surface of the tube under action of the weight of the head.

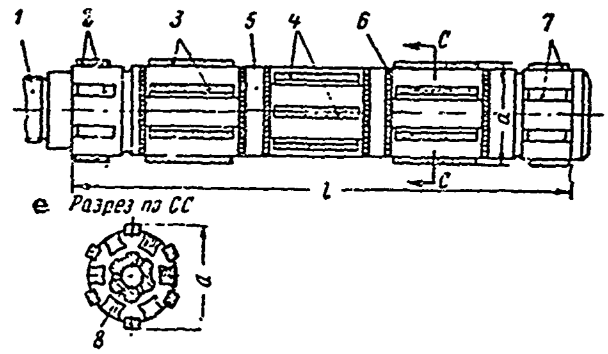


Fig. 156. Head for honing cylindrical bores

Key:
1. tail
2 & 7. guiding keys
3 & 4. abrasive blocks
5. head body
6. spiral spring
8. formed shaft
e. section across CC

On some machines, the longitudinal feed of the honing head and dispersal of the blocks into their required dimension are accomplished by a hydraulic instrument, which allows smoother regulation of the force pressing the blocks against the machined surface of the tube.

Honing is conducted with an abundant supply of lubricating liquid, which washes down the exterior surface of the entire head. The liquid must have a high degree of lubricating properties, with cooling properties to a lesser degree, and together with this it must also not glaze the abrasive blocks and decrease their cutting properties. A mixture of equal parts of kerosene and mineral-spindle oil is most often used for the lubricating liquid. In production practice, other lubricating liquids, among which are various oils, paraffin, kerosene, and others, are also used.

The cutting tools in honing heads are abrasive corundum or carborundum blocks on ceramic bindings. The blocks used are of square section, 10x10, 12x12, or 15x15 mm. Length of the blocks may vary, and this depends on construction and purpose of the head, namely, blocks 100 and 150 mm long are used for cylindrical bores. Preliminary honing is done with medium-soft blocks of grain size 80 to 120, semi-fine honing is done with blocks of grain size 180 to 230, and fine-finish honing is done with soft blocks of grain size 280 to 400.

A margin from 0.05 to 0.30 mm is left on the diameter for honing. During preliminary honing, the cutting process is more intensive, and a layer of metal up to 0.004 to 0.001 mm is removed during one double run of the head.

The honing process provides attainment of cylindrical holes with first to second classes of accuracy and surface smoothness to ∇9 to ∇10. The following bore defects are eliminated during honing: Conicity remaining after fine boring, hole ovality, and to some degree, bore curvature.

Honing rifled bores, as work experience has shown, is more productive in that the treated surface is decreased by one half to two fifths, and the service period of the abrasive blocks is increased. After honing, the bored surface along the lands turns out clean and smooth, and does not have grooves or notches. Honing rifled bores may be used after their polishing.

In artillery production, as in general machine construction, honing is also used for machining formed surfaces, for instance, charge chambers, whose profiles are formed by honing heads.

During the honing process, the abrasive blocks wear out unevenly, as do abrasive grinding wheels, and they therefore require periodic servicing. According to production experience data, abrasive block durability during honing averages 3.5 to 6 hr of working machine time.

Working time during honing T_M may be determined according to the following formula:

$$T_M = \frac{2(L + 2e)n}{s1000} \text{ min,} \qquad (77)$$

where L is bore length of the honed hole in mm; e is the coefficient calculating entry and exit of the head whose average can be taken as e = 50 to 75 mm; n is the number of double passes accomplished by the head in the process of full treatment of the bores; and s is the speed of the back and forth motion of the head in m/min.

#45. Polishing the Barrel Bore

Polishing is a process of machining a surface with small-grained abrasive powders or special pastes, which evenly cover a small polishing wheel, a special head, or polishing attachment.

Polishing has the purpose of giving the surface a high degree of smoothness, and in some instances also providing the required accuracy of dimensions. Polishing after chroming, nickeling, and application of other coverings gives the surface a beautiful decorative appearance.

Polishing tube bores under the liner, smooth gun tube bores before their rifling, smooth barrel tube bores, antirecoil mechanism cylinders, and polishing bores after rifling are special polishing operations in artillery production.

During polishing of smooth bores of various cylinders of gun tubes, the machined part rotates in one direction, and the polishing head in the opposite direction, additionally performing a longitudinal forward and back movement. In some instances, the polishing head may not rotate.

The polishing head body is made of birch, oak, maple, or elm. Construction of the head is shown in Fig. 157. The head has a thick portion of length ℓ = 60 to 100 mm, and a tail which is fastened to the machine shaft. The length of arc A of the working part of the head surface is one fourth to one sixth of the circumference, and the whole working surface is 0.5 to 0.3 of the circumference. During polishing conic holes, length ℓ of the working part of the head must not exceed 50 to 60 mm.

During preliminary (semi-fine) polishing, the working surface of the head is covered with leather, and during fine and finish polishing, it is covered with a two-layer cloth boot. The surface of the leather or cloth is then covered with abrasive grinding powder, with their abundant lubrication with machine or spindle oil.

The polishing process is divided into preliminary, fine, and finish. During preliminary polishing, the major part of the margin, equal to 0.10 to 0.15 mm on a diameter is removed, and a surface smoothness $\nabla 6$ to $\nabla 7$ is attained. Grinding powders for preliminary polishing have a grain size of 120 to 150. Fine and finish polishing are used for final treatment of the surface, and surface smoothness corresponds to $\nabla 8$ to $\nabla 10$. The grinding powders for these types of polishing have a grain size of 200 to 280. During fine and finish polishing, the margin of 0.1 to 0.005 mm on the diameter is removed.

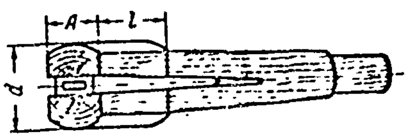


Fig. 157. Polishing head for bore polishing

In some instances, for attainment of surface smoothness to 12, micropowders M20, M10, and M5 or special pastes are used in polishing.

A margin on the diameter within the limits of 0.05 to 0.15 mm is left for polishing smooth bores of gun tubes and cylinders.

If the machined part and polishing head are rotated in opposite directions, polishing speed is 40 to 100 m/min, and with a nonrotating shaft and head, it is decreased to 15 to 40 m/min.

The longitudinal feed of the head, which is the speed of the forward and backward motion of the machine shaft is usually 4 to 10 m/min.

During polishing, it is necessary to periodically renew the grinding powders and lubricants, and watch over the temperature of the machined tube. With an increased polishing rate and force of pressure of the working surfaces of the head against the bore, heating of the barrel sharply increases, which makes the polishing process more difficult. Therefore, in case of increased barrel temperature, the polishing speed should be decreased and the grinding powders and lubricants renewed.

It should be noted that polishing is also used to eliminate some defects of the barrel bore boring process, for instance, ovalness in the bore hole on part of its section, eccentricity of the charge chamber relative to the cylindrical part of the tube bore, and others. In this case, the machined tube does not rotate during polishing, and the head accomplishes a rotational and forward and backward motion.

CHAPTER XIII

Technical Control of Manufacture and Assembly of Parts

#46. Organization of Technical Control

The overall task of the department of technical control (DTC) of a plant is the technical checking of the quality of products put out by them and analysis of the reasons for spoilage in production. In practice, the DTC has wider functions, namely:

Technical reception of materials, semi-finished parts and stocks, delivered to the plant;

between-operation and between-shop control of semi-finished parts, finished parts, and assemblies;

technical control of finished production and conduct of testing in production;

technical preparation of control technology, which is the development of the technical and bookkeeping documentation for technical control;

calculation and analysis of reasons for production spoilage;

periodic checking of the control and measuring production means in the central measuring laboratory, which is subordinated to DTC;

participation in development of general and specific operational technical conditions for parts manufacture and assembly.

Control and measuring instruments, tools, and attachments used for checking production quality may be divided into the following groups:

1) The checking control tool: Working limit gauges, templates, and patterns;
2) mechanized and automated installations and attachments;
3) universal measuring tools and instruments;

4) the control tool for checking the technical condition of working limit gauges and templates.

In time expenditure, the between-operation and between-shop control using limit gauges and patterns are the most labor-consuming operations. The operations of DTC, totally duplicating similar operations by working and production foremen in serial and heavy-serial production, may be totally eliminated. Work experience in some shops and plants in this direction has given positive results.

The problems of rational organization and selection of means for technical control and decreasing time spent on technical control continue to be real for any production.

Besides the control operations which are typical for general machine construction, artillery production has a number of special technical control operations which require use of universal measuring tools and instruments or special ones. Among these technical control operations are checking cylindrical smooth and rifled weapon bores, checking conic bores and charge chambers, determining tube curvature and variations in wall thickness, checking the control surface on the breech and cross on the muzzle face, checking interchangeability of breech blocks, barrels, and that of barrels among cradles, checking the work and testing the mechanisms of the assembled artillery system, and some other control operations. All these operations are complex and specialized, requiring qualified control masters of DTC.

#47. Checking of Cylindrical Bores

After fine boring, finish operations, and rifling, tube bores undergo the following control operations: Inspection of the machined surfaces, measuring of diameters, and removal of surface imprints with a stamp.

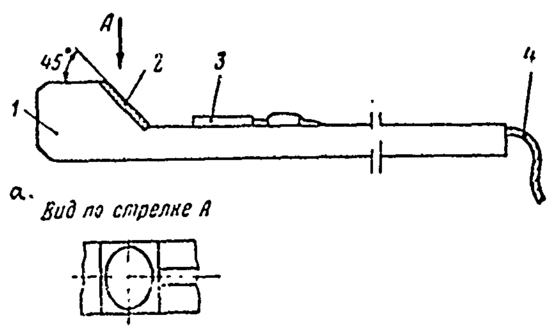


Fig. 158. Instrument for inspecting bore surface

Key: 1. rod
2. mirror
3. electric lamp
4. electric wire
a. view along arrow A

Inspection of the machined bore surface may be conducted with the mirror instrument whose layout is shown in Fig. 158.

The instrument consists of a mirror (2) and rod (1), which is of semicircular section, having a groove for placement of lamp (3) and electric wire (4).

Optical tubes with electric illumination are used for more detailed bore inspection. These tubes have two interchangeable objectives, or heads: General inspection and secondary inspection. The optical tube with the general inspection head, which has little magnification, is intended for inspection of the bore surface around the entire circumference to a length of up to 700 mm. This head allows inspection of the entire bore surface and determination of location of defects on it, and if necessary, can take photographs of them.

For more careful examination of the character of the defect and determination of its dimensions, the secondary head, having a small field of view, is used. This head allows the qualitative character of the defect revealed to be learned sufficiently easily, as shown in Fig. 158. In this way, using the mirror instrument and the optical tube, it is possible to inspect the entire surface of the tube up to any length in detail and, if necessary, photograph the defect revealed.

The interior diameter of smooth barrel bores and diameters of rifled bores along the lands and along the grooves are measured with a star gauge. In production, four types of star gauges are used: Mechanical, optic, automatic, and electromechanical.

The draw-type mechanical star gauge consists of the following parts: The head (1), shaft (9), and retainer (13), with a vernier (Fig. 159). The head is a hollow cylinder, covered with cap (2). It has a body (3), two shoes (4), two changeable measuring tips (5), which are threaded into shoes (4), and two springs (6), fastening them into the head cylinder. The head body is rigidly fastened to the hollow shaft (9), on whose end retainer (13) with the vernier apparatus is fastened with bushing (11). The guiding cone (7) moves freely inside the hollow head and is connected with a universal joint to drawbar (8), which, together with the cone, can move freely along shaft (9) and head body (3).

The overall view of the head with the tips projecting from it is shown in Fig. 160.

The retainer (13) has a gauge (15) with divisions, which is moved in a longitudinal direction relative to the retainer and shaft by the micrometer screw (16), and is fastened by stop screw (17). The vernier gauge (12) is fastened to the face side of the drawbar by two screws.

The shoes (4), together with the measuring tips (5) are pressed tightly against the guiding surface of cone (7) by springs (6). When the drawbar is

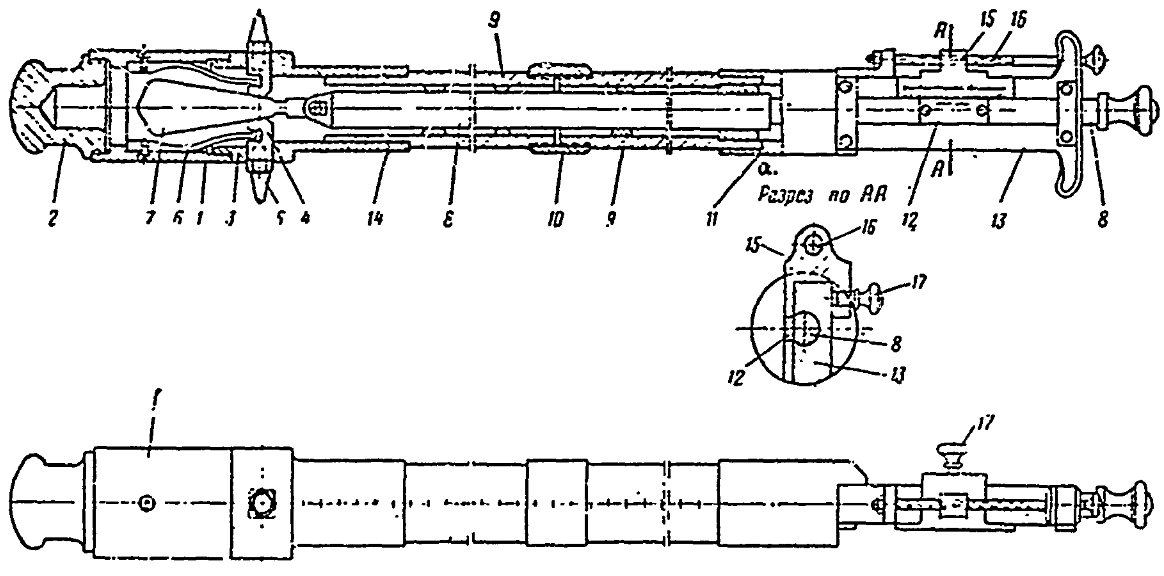


Fig. 159. Mechanical star gauge

Key:

1. star gauge body
2. cap
3. cone
4. shoes
5. measuring tips
6. spring
7. conic wedge
8. drawbar
9. shaft
10. threaded sleeve
11. bushing
12. vernier gauge
13. retainer
14. set screw
15. retainer gauge
16. micrometer screw
17. stop screw

a. section across AA

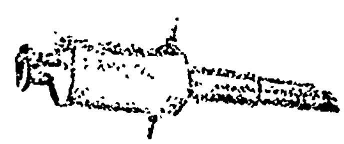


Fig. 160. Mechanical star gauge head (overall view)

moved to the right (on the drawing), distance between the ends of the tips (5) will increase, and when it is moved to the left, the distance will be decreased by amount

$$\Delta = \ell k \tag{79}$$

where ℓ is linear movement of drawbar and cone in mm; k is inclination of cone (7) (k = 0.2); and Δ is linear change in dimension between ends of tips (5) in mm.

The vernier mechanism of the mechanical star gauge, which is analogous to the same installation on other measuring instruments (for instance, on a slide gauge), consists of the base gauge (15) and vernier gauge (12), which has divisions to the right and left of zero (0) up to 20 mm. Every 0 to 20 section on the vernier gauge (12) has a length of 19 mm, and therefore the distance between the adjacent graduations is equal to 1 to 0.05 mm, and between the extreme graduations on the section (1 to 0.05)20 = 19 mm. Therefore, the value of one division of the vernier is equal to 0.05 mm.

The dimension measuring accuracy of the mechanical star gauge with a value of one vernier graduation of 0.05 mm and a conicity k = 0.2 is

$$\delta = \left(1 - \frac{19}{20}\right) k = 0.05 \cdot 0.2 = 0.01 \text{ mm.} \qquad (80)$$

Optical and automatic star gauges have the same accuracy as mechanical ones. Some star gauges with inch scales are encountered, and these have a measuring accuracy equal to 0.0254 mm. The star gauge shaft has the length of the measured tube, but it must not be shorter than 5000 mm. There are marks every 50 mm of length on the exterior surface of the star gauge shaft, beginning from the tips. This allows fixing of the section in which tube diameter changes at any length of the barrel from its muzzle face through each 50 or 100 mm section.

During measuring the diameters of the rifled bore, the measuring tips of the star gauge must follow along two opposite spiral grooves or along lands. For this, there is a bronze guide ring having several projections which follow the grooves, mounted in front of the measuring points on the exterior cylindrical surface of the head and fastened by a screw. The ring is final tightened on the head after the guiding tips are set on their corresponding lands or grooves.

The star gauge measures only deviation of the actual diameter of the tube bore from its nominal value, and the nominal diameter, or distance between the ends of the measuring tips along the lands or along the grooves, is set with a special bracket (Fig. 161).

The bracket has setting marks and diameter dimensions along the lands or along the grooves, and this allows more accurate setting of the star gauge measuring tips into their assigned dimension, with the vernier scale of the star gauge on 0.

Tube bore diameters beginning from 35 mm, up to the largest dimensions, for instance, up to 500 mm in production practice, are measured with the star gauge. One star gauge with one set of measuring tips, however, can measure diameters and differences between them of only 4 to 10 mm. With the presence of the corresponding set of measuring tips, guide rings, and setting brackets, a star gauge may be used for measuring diameters from approximately 85 to 155 mm.

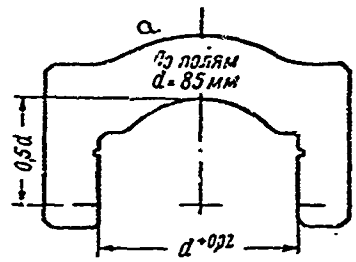


Fig. 161. Bracket for setting the vernier gauge of a mechanical star gauge on 0

Key: a. across the lands

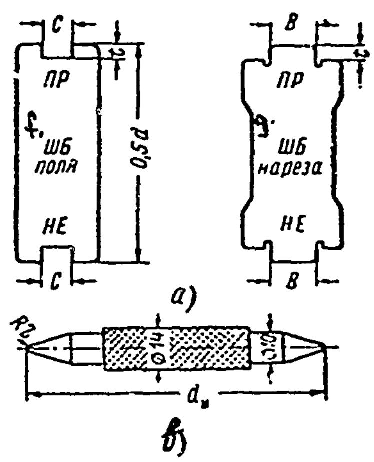


Fig. 162. Control measuring tool

Key:
- a. template for checking width of grooves and lands
- b. pin gauge for checking diameter along the grooves
- f. land tem.
- g. groove tem.

During measuring of bore diameter along the grooves with a star gauge, actual groove depth cannot be established. Groove depth t can only be approximately evaluated according to measuring information from the star gauge, using the relationship

$$t = \frac{d_H - d}{2}. \tag{81}$$

Actual groove depth is checked with special templates from the barrel muzzle face, and their evenness is provided by checking tne setting of rifling head cutters, as stated above.

Rifled bore diameters are measured in a vertical and horizontal plane along the lands and along the grooves, and measurement begins from the barrel muzzle face. In some cases, the nominal diameter can be set on star gauge tips with a slide gauge or micrometer. Errors in star gauge measuring depend on the accuracy of setting the nominal dimension on its measuring tips and on the vernier scale, on the pressure of the measuring tips at the points of contact, which in turn depends on the effort applied to the drawbar lever, and on the smoothness of the barrel bore surface. Sufficient measuring experience and accuracy in using the instrument is necessary to decrease the amount of these errors.

A pattern is used for checking width of grooves and lands of rifled weapon bores, and two end gauges (one through, for the dimension lower limit, and the other not through, for the dimension upper limit) are used to check diameter along the grooves (Fig. 162). Dimension checking with these instruments is done from the muzzle part of the barrel bore.

Nominal diameter dimensions of the bore along the grooves d_H, groove width B, land width C, and tolerances on them for barrels of caliber 85 and 203.2 mm, and also the nominal dimensions of templates and pin gauges for these barrels are given in Table 44.

#48. Checking Conic Bores and Charge Chambers

Surface quality of conic bores and charge chambers is checked with the same optical instruments as are cylindrical bores.

Bore diameter in its various sections is measured with usual star gauges, the special complex tool with a set of calibrated rings, smooth gauges with the charge chamber conic hole profile, control sleeves having the limiting dimensions of the chambers, and other special instruments.

Special complex instruments for measuring basic dimensions of conic bores are planned according to the schematic depicted in Fig. 163. In this schematic, using formula (30), we may write

$$d = D - kl, \tag{82}$$

Table 44

Nominal Rifling Dimensions for Barrel Bores Caliber 85 and 203.2 mm and the Dimensions of the Corresponding Templates and Pin Gauges for Checking the Riflings (See Fig. 162)

Dimension designations according to Fig. 162 / Dimension and size in mm	Barrel caliber d = 85 mm			Barrel caliber d = 203.2 mm		
	d_H	B	C	d_H	B	C
Nominal dimension	86.7	7.6	3.62	207.2	6	3.97
Tolerance on nominal dimension	+0.15	+0.3	--	+0.2	+-.3	--
Nominal dimension of template or through pin gauge	86.73	7.60	3.62	207.22	6.02	3.97
Tolerance on nominal dimension of template or through pin gauge	-0.02	-0.015	+0.015	-0.02	-0.015	+0.015
Nominal dimension of template or not through pin gauge	86.84	7.85	3.37	207.38	6.25	3.72
Tolerance on nominal dimension of template or not through pin gauge	±0.02	±0.015	±0.015	±0.015	±0.015	±0.015

where d is the nominal diameter of the chamber or conic bore in mm, measured in a given section; D is the maximum diameter of the conic bore in mm; ℓ is the distance from the tube breech face to the section in which bore diameter is determined; and k is the conic rate of the given bore section.

We will determine the limiting dimensions of a calibrated ring of diameter d and length of the section on which bore diameter can be measured with these rings for a given section of a conic bore.

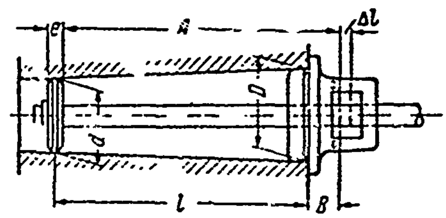


Fig. 163. Schematic for checking a conic bore

For solution of the problem presented, we use the charge chamber dimensions presented in Figs. 20 and 21, namely: $D = d_2 = 124.6 + 0.2$ mm, $d = d_3 = 118.2 + 0.2$ mm, $\ell = \ell_1 = 670$ mm, base section conic rate $k = 0.00955$, amount $B = 80$ mm, and width of calibrating disc $e = 10$ mm. With the given data, distance to the first mark of the bar is

$$L_1 = \ell + B = 670 + 80 = 750 \text{ mm}$$

or will be equal to $\ell + 0.5e$ (see Fig. 163). If the actual dimension of the charge chamber accurately corresponds to its nominal dimensions, parts of the complex instrument are manufactured with tolerances in the limits of ± 0.02 mm, and this error may be ignored, then during measuring, the first mark on the rod will coincide with the zero mark on the instrument frame.

If the charge chamber is manufactured to the highest dimension limits with a tolerance $\delta = +0.2$ mm, or its diameter $d = 118.4$ mm, during measuring, the rod with the calibrating ring will project to a depth of

$$L_2 = \ell + B + \Delta\ell.$$

The value of $\Delta\ell$ may be determined from the expression

$$\Delta\ell = \frac{\delta}{k} = \frac{0.2}{0.00955} = 20.94 \text{ mm}$$

We lay out length L_2 on the rod and set the second mark on it. The calibrating measuring ring is machined to an accuracy of 0.02 mm along dimension e, and to 0.01 mm along dimension d.

A special instrument for checking conic bores of any length can be manufactured on the basis of the schematic reviewed.

A special instrument, whose schematic construction is shown in Fig. 164, can be used for measuring tube conic bore diameters of great length, and in some cases, measuring can also be done with a normal mechanical star gauge.

The instrument for measuring diameters of long conic bores consists of two measuring tips (1) and (4), stand (2), spring (3), which presses against

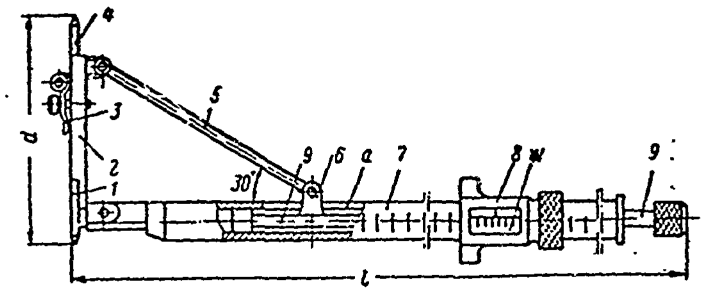


Fig. 164. Instrument for measuring diameters of deep conic bores

Key:
1. stationary tip
2. stand
3. spring
4. movable tip
5. hinged connecting rod
6. eye
7. external tube
8. frame
9. internal drawbar
W. vernier scale
d. measured diameter dimension
α. slot

the base of movable tip (4), external tube (7), internal bar (9), and connecting rod (5), which is a hinged connection between guiding rod (2) and rod (9) with eye (6) (see Fig. 164). On the exterior surface of the tube are marks with divisions and the frame (8). Before measuring, dimension d along the tip is set somewhat higher than expected, and then the internal drawbar (9) is moved to the left (on the drawing) and stand (2) with the tips is put into a horizontal position. The instrument is inserted into the bore with stand (2) in the horizontal position, and moved along it to the determined length, after which rod (9) is moved to the right to the mark on the scale which indicates that the tip is in a vertical position. At this time, tip (4) under action of drawbar (5), moves relative to the stand and it takes a position in which the distance between the tips is equal to the bore diameter at the given section. Rod (9) is then moved to the left so that stand (2) again assumes a horizontal position, and the instrument is then removed from the bore and the distance between the points is taken with a micrometer. Accuracy of this measurement is no greater than 0.05 mm.

For checking dimensions of conic holes which have complex profiles, similar, for instance, to charge chamber profiles, it is more convenient to use the instrument whose construction is presented in Fig. 165 and corresponds to the schematic of Fig. 163.

This instrument consists of a set of calibrating measuring rings (1), rod (2), movable frame (3), set screw (4), lever (5), which is fastened to the rod, and a nut and washer for fastening the calibrating ring to the rod. The quality of calibrating rings manufactured is such that quality of bores or charge chambers having conic sections can be judged with the least number of measurements being taken.

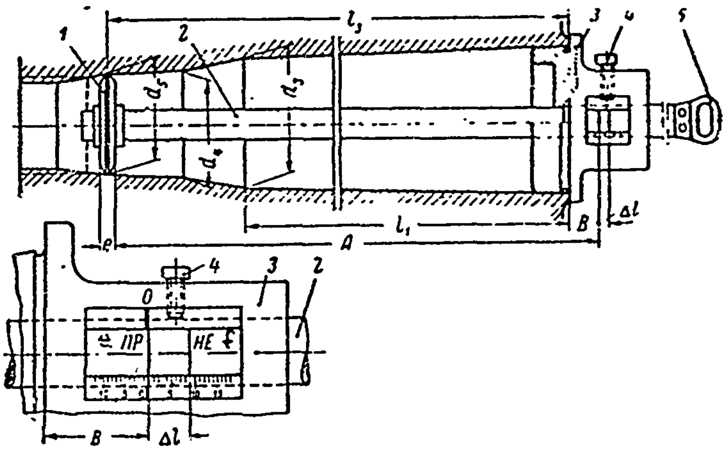


Fig. 165. Instrument for measuring charge chamber dimensions

Key: 1. calibrating ring
2. rod
3. frame
4. stop screw
5. drawbar handle
d_2, d_3, d_4, d_5. chamber diameters checked (diameter d_2 is seen in Fig. 21)
e. through
f. not through

For cartridge loaded charge chambers, measurements should be taken on a basic cone on sections $0.5\ell_1$ and ℓ_1 along diameter d_3, and then on the sections along diameters d_4 and d_5 (see Figs. 20 and 165). If necessary, the number of measurements may be increased.

The exterior diameter of the calibrating ring (1) must be equal to the nominal diameter of the chamber at the given section with a tolerance of 0.01 mm.

For each chamber section on which measurements are taken, there are two marks on the rod indicated by letters ПР [through] and НЕ [not through]. The ma. dicated by ПР correspond to the length of the chamber section having the . nal calculated diameter dimension, and must coincide with the 0 mark on the instrument frame, or be somewhat displaced to the left of the mark.

The other rod mark, indicated by letters HE and placed at a distance $\Delta \ell$ from the first mark ПP, must not pass through the 0 mark on the instrument frame.

With this position of the ПP and HE marks relative to the 0 mark on the frame, the actual diameter dimensions and charge chamber length will not be outside their limiting dimensions. Otherwise, layout of the instrument and method of its use is sufficiently understandable from Fig. 165.

Besides dimensional accuracy and surface smoothness, concentricity of charge chamber conic sections are checked relative to the cylindrical rifled portion of the barrel bore. This checking is very important in relation to the base and connecting (rifled slope) cones which provide normal seating of the cartridge during loading of the weapon.

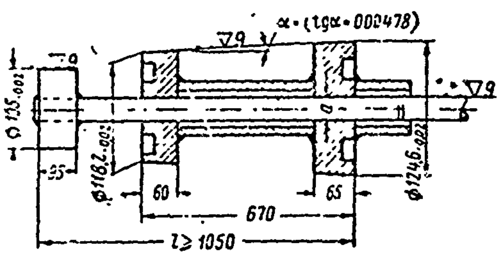


Fig. 166. Instrument for checking chamber concentricity relative to bore axis

The schematic of the instrument for checking concentricity of the charge chamber relative to the bore axis is shown in Fig. 166. In this instrument, there are two steel heat-treated discs, 60 to 65 mm in thickness, which are rigidly connected by being welded onto a tube. To lighten them, the discs have circular grooves on their faces. The internal holes in the discs, of diameter α = 50 mm are machined to second class precision with a tolerance of +0.02 mm. The external surfaces of the discs are machined into a precise arbor, observing the conic rate and nominal dimensions of the charge chamber diameters shown in Fig. 166 and Fig. 20.

The instrument has a control guide cylinder, whose nominal diameter and length are equal to the barrel bore caliber. With a guiding cylinder length smaller than the barrel bore caliber, its centering in the bore would be insufficiently accurate, and if it were longer than the bore caliber, handling the instrument during measuring would become more difficult. The guiding cylinder is rigidly fastened to the rod in a position so that its axis of symmetry strictly coincides with the axis of the rod. For this, the exterior surfaces of the rod and cylinder are ground after they are assembled. When the instrument is inserted in the charge chamber, it is first centered along the chamber wall surfaces by the conic surfaces of the discs on a length of 670 mm, and then the rod is moved so that its guiding cylinder enters the rifled cylindrical portion of the barrel bore to a length no less than two of its calibers. This guiding cylinder position is determined by marks on the rod. The rod and guiding cylinder should then be withdrawn from the cylindrical section of the barrel bore, rotated 180°, and again moved forward to the control mark. After this, the entire conic disc instrument should be moved rearward, rotated 180°, and then the entire operation should be repeated.

If the guiding cylinder of the instrument moves into the rifled cylindrical portion of the barrel bore freely during all the described operations, the base cone of the charge chamber is concentric relative to the rifled portion of the bore. If defects are revealed, they may be eliminated by polishing separate sections of the charge chamber surface. Concentricity of the connecting cone (rifled slope) of the barrel bore may be checked by the same method with a complex (special instrument).

#49. Checking Tube Curvature and Variations in Wall Thickness

With gun tube length increased to over 50 calibers, and increases in projectile initial velocity and powder gas pressure (3000 kg/cm^2 and more), tube curvature and variations in wall thickness acquire great importance in that the influence of these defects on movement of the projectile along the bore and barrel durability is increased. In production, these defects must not exceed determined amounts, as already stated in Chapter III.

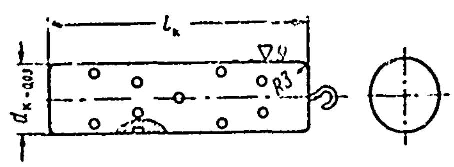


Fig. 167. Smooth control cylinder for checking bore curvature

Barrel bore curvature is determined with a smooth control guage (cylinder) or with an optical instrument. The smooth gauge is an accurately machined cylinder of length l_K = (3.5 to 5)d, which, for small and medium caliber guns, is made solid with holes along the exterior surface, and for guns of bore diameter over 100 mm, it is hollow, and also has holes along its exterior surface (Fig. 167).

The nominal dimension of the exterior diameter of the smooth control cylinder must be smaller than the nominal dimension of the bore diameter (caliber) of the barrel along the lands by one half the amount of tolerance for bore diameter along the lands, and machining tolerance on the cylinder diameter must be from 0.01 to 0.04 mm (latter values for large diameters).

Thus, for instance, the precise diameters for smooth control cylinders are:

For guns 76.2 mm, $\ell_K = 350$ mm and $d_K = 76.15_{-0.01}$ mm;
for guns 100 mm, $\ell_K = 450$ mm and $d_K = 99.94_{0.02}$ mm;
for guns 152.4 mm, $\ell_K = 560$ mm and $d_K = 152.33_{-0.03}$ mm.

With these dimensions, the smooth cylinder must freely move in the barrel bore of corresponding caliber after the barrel's final machining (bore rifling and polishing). Before checking, the surfaces of the barrel bore and smooth cylinder must be carefully cleaned and rubbed dry. If the cylinder passes through the barrel bore with a small amount of effort applied to its shaft, barrel bore curvature does not exceed allowable limits. Checking of bore curvature with a smooth control cylinder does not, however, give the actual amount of the barrel bore curvature.

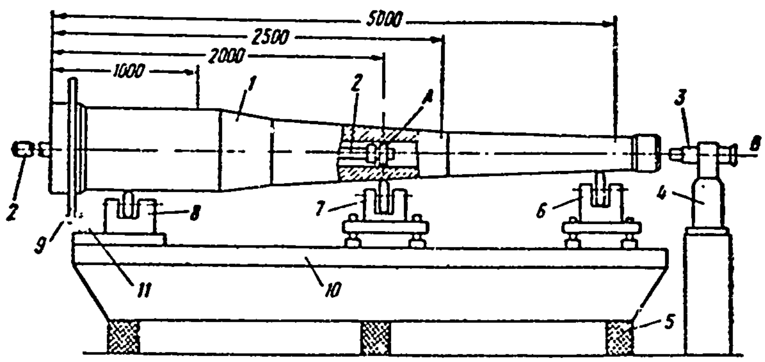


Fig. 168. Schematic of barrel installation on control bed for checking tube wall thickness variations

Key: 1. gun tube
2. rod
3. optical tube
4. stand
5. supports
6, 7, 8. roller support prisms
9. disc
10. bed
11. disc scale indicator
A. star guage head
B. tube eyepiece

Measuring the amount of barrel bore curvature both on its entire length and on its separate sections, is done with an optical instrument. For measuring bore curvature, the gun tube (1) is installed on the control bed (2) on special roller prisms (6), (7) and (8), which allow regulation of the tube's position according to height and direction (Fig. 168). The optical instrument consists of a special optical star guage, which is fastened on rod (2), and an optical tube (3), which has cross hairs in its field of view. Head A, which has an optical grid illuminated by an electric lamp on the rod, is fastened to rod (2). There are cross-hairs across diameters, and solid and dotted circles on the grid (see Figs. 168 and 169).

Radial distance between a solid circle and its adjacent dotted circle is equal to 0.5 mm, and this amount is the value of a grid division. The optical tube may be installed on a special stand at the muzzle part of the tube being checked, or on a special attachment in its muzzle part B (see Fig. 169).

Before measuring curvature, the barrel is installed on the bed in a horizontal position so that the center points of its bore axis at the breech and muzzle faces are on the same horizontal line. The optical star guage enters the bore from the breech part of the tube in section A, and the optical tube is installed in the muzzle part B of the barrel, and their centers must be located on one line (see Fig. 169).

Star guage head A is then pushed by the rod along the barrel bore to its etermined sections, 500 mm in length, and in each section, the relative position of grid and cross-hairs are determined by siting through the optical tube (3). If the barrel bore is curved, cross-hairs of head A of the star guage will be moved relative to the cross-hairs of optical tube B, which, remaining stationary, will move relative to the cross-hairs of the star guage. The distance x between these cross-hairs will be the actual amount of curvature for the given section, and the direction of curvature should be noted along the radius between the cross-hairs (see Fig. 169). On Fig. 169, the amount of curvature will equal $x = 3$ mm, and the accuracy of reading may be written to 0.25 mm, which fully satisfies technical requirements.

Measurement of weapon tube bore curvature allows a tube to be discarded if its curvature exceeds the limits of allowable norms, and allows exposure of the reasons for appearance of the curvature.

Measuring Barrel Muzzle Curvature

For increasing ballistic properties of weapon barrels with allowable bore curvature, barrel muzzle curvature attains special significance. Muzzle curvature of a barrel is curvature of its bore at the section 2.5 to 3 calibers in length from the muzzle face, or on the length occupied by the centering thickness of the projectile at the moment of its flight from the bore, when the front centering thickness approaches the muzzle face.

If barrel bore muzzle curvature is uniform in numerical value and varied in direction, it will affect deviation of the projectile during flight from the bore in various ways. It is more expedient for all barrels to have an allowable curvatur in any one direction (for instance, upward) to provide more

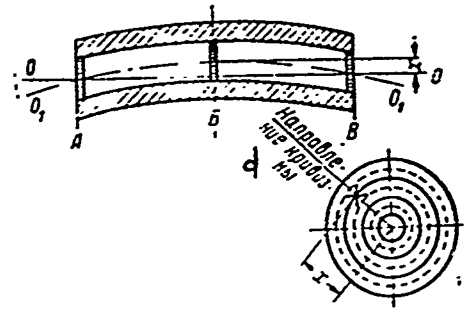


Fig. 169. Schematic of measuring gun tube bore curvature and grid on field of view of star gauge head

Key: d. direction of curvature

ballistic uniformity among weapons. For this reason, muzzle curvature of a barrel should be checked before assembly of the inner tube with the breech.

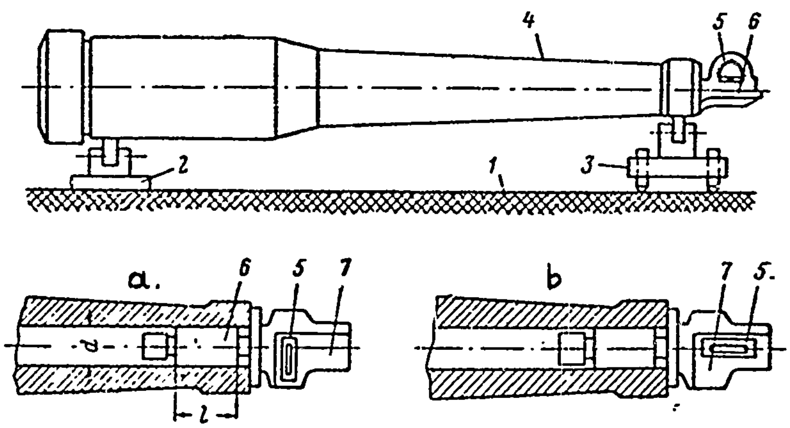


Fig. 170. Barrel installation during muzzle curvature measurement

Key:
1. bed
2 & 3. roller supports
4. barrel
5. quadrant
6. smooth cylinder of attachment
7. surface for quadrant with level
a. level installation in a lateral direction
b. level installation in a longitudinal direction

Muzzle curvature in a barrel is measured by the following means (see Fig. 170).

The gun tube (4) (barrel) is installed on roller regulating supports (2) and (3) of the control bed (1) so that the axis of its bore is horizontal. A smooth cylinder (6) of length $\ell = 2.5d$, having a space (7) for installation of the control level (quadrant)(5), is then inserted in the muzzle part of the bore. The exterior surface of the cylinder is finely machined, and its diameter is equal to the bore caliber.

First the quadrant (5) is installed laterally on space (7), with its scale being set beforehand to the 00 mark. For this, cylinder (6) is turned, moving the level bubble to the center (see Fig. 170, a). Then, not changing the horizontal position of the space of the cylinder, the quadrant is set in a longitudinal position on it (see Fig. 170, b), and the level bubble will move from the middle position. Changing the position of the quadrant scale, the level is moved to center and the reading is written in minutes. Then, rotating the barrel around its longitudinal axis by 90, 180, 270, and 360°, other readings are taken in the same order.

Differences in the readings among the various barrel positions show the amount of curvature of its bore and its direction. Barrel curvature is usually directed upward by the following means, and indicated on its muzzle face by a plus sign (+). During machining the slots for fastening keys between the tube and breech, and slots for the extractors, direction of the barrel bore curvature is considered so that after assembly it will be directed upward in all barrels.

Checking Variations in Tube Wall Thickness

Variations in tube wall thickness during machining holes occur as the result of deviation of the cutting instrument and residual stresses in the metal. For each tube section, variations in wall thickness e are determined according to formula (Fig. 171).

$$e = D - (d + 2a), \qquad (83)$$

where D is the exterior tube diameter; d is the interior diameter of tube hole; and a is the least dimension of tube wall thickness in given section.

The method of measuring variations in tube wall thickness is identical with the method of measuring curvature of its bore. The disc (9), with cross-hairs and marks every 45° (see Fig. 168) is fastened on the breech part of the barrel. In a given section, variations in tube wall thickness are measured every 90°, and along the length every 500 to 1000 mm.

Star gauge A, whose construction is similar to the one for measuring bore curvature, is inserted from the muzzle part of the tube. An optical tube with cross-hairs in its field of view is installed from the muzzle to a distance of 100 mm from the muzzle face. The first installation of star gauge head A in the bore is done to a distance of 100 mm from the breech face, where it is centered along the surface of the bore hole of diameter d so that the star gauge cross-hairs coincide with the center of the bore hole. The cross-hairs of tube B are sited on the cross-hairs of the star gauge, and then the tube is fastened stationary on stand (4).

After installation, the weapon tube (1) is rotated by an angle of 90° and fixed in the new position along the marks of disc (9) relative to the stationary indicator (11). Movement of the star gauge center to the left by an amount b and upward by an amount a relative to the cross-hairs of the stationary tube B confirms presence of a variation in tube wall thickness (see Fig. 171). The actual variation in wall thickness for the given section will be equal to e_1 along section OE. This variation in wall thickness is immediately read off on the star gauge grid in Fig. 169. The gun tube is then rotated at angles of 180, 270, and 360°, and variation in tube wall thickness will be determined through e_2, e_3, and e_4 and also counted off along the star gauge grid.

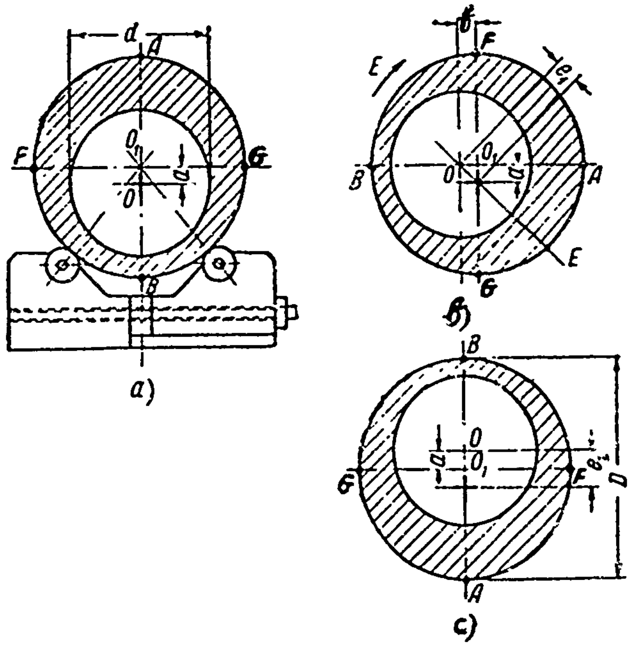


Fig. 171. Schematic for measuring variations in wall thickness of gun tubes

Key:
- O. center of inside circle
- O_1. center of outside tube circumference
- AB & GF. cross-hairs
- e_1. amount of measured wall thickness variation in section OE
- a. first position
- b. position after 90° rotation
- c. position after 180° rotation

Measuring by the described method is done for every section, 500 or 1000 mm apart in length. The allowable amount of wall thickness variation must be determined by calculation for each model of weapon barrel, emanating from its construction and work rate of the barrel during firing. It should be remembered that the actual decrease in tube wall thickness from its nominal value will be equal to half the amount of wall thickness variation determined by measuring, as seen in Figs. 169 and 171.

The largest amount of wall thickness variation goes into the measuring record with an indication of the distance from the breech face that it was discovered. Wall thickness variations up to 0.5 mm are usually not noted in the reporting documents because wall thickness of this size has no practical significance.

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