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USAASCOM Technical Report

IMPROVED MANUFACTURING METHOD FOR PROCESSES FOR SUPER FINISHED SPUR AND HELICAL GEARS

Final Report

By

Neil De Bruyne

Prepared by

CURTISS-WRIGHT CORPORATION
Wood-Ridge, New Jersey 07075

for

U.S. ARMY AVIATION SYSTEMS COMMAND
P.O. BOX 209
ST. LOUIS, MISSOURI 63166

SUMMARY

This report presents the results of an experimental program which evaluates the scuffing resistance properties of a conventional (AISI 9310) and an advance high hot hardness steel Vasco-Jet 1000-2) gear material when various surface treatments and methods of surface finishes are used.

The program consisted of manufacturing roller and spur gear test specimens from the two materials. Evaluations of surface treatments were conducted utilizing both rollers and gears that were carburized and ground, carbonitrided and ground, and then black oxided and silver plated. The evaluation of methods of surface finishing consisted or ground, ground and honed, ground shot peened and ground, ground shot peened and honed, ground and harperized, and ground shot peened and harperized. These methods were all applied at the same surface finish level. In addition, the effect of various amounts of involute tip relief was evaluated utilizing the AISI 9310 gears.

Results of the test program are as follows:

1. Material Effects

   Vasco-Jet 1000-2 shows a significant increase in resistance to scuffing over AISI 9310 material. This increase, when using ground carburized gears, amounts to approximately 85%.

2. Surface Treatment Effects

   Silver placing of AISI 9310 gears also shows a significant increase in resistance to scuffing. This increase amounts to approximately 80%.

3. Profile Modification Effects

   Profile modification by tip relief to the true involute form can provide up to approximately 50% increase in resistance to scuffing.

4. Surface Finishing Effects

   Finishing by a honing process, at the same surface finish tends to provide moderate increases in the resistance to scuffing.

FOREWORD

This report covers an evaluation of the scuffing resistance of two gear materials, AISI 9310 and Vascojet 1000-2. Evaluation covers surface treatments, surface finish, and tooth profile. Preliminary screening of surface treatments was accomplished utilizing a roller rig while final evaluation of surface treatment, finish and tooth profile was accomplished on a full scale gear rig. The program was conducted during the 19 month period from 7 August 1969 to 7 March 1971, for the United States Army Aviation Systems Command, St. Louis, Missouri, under Contract DAAJ01-70-C-0171(IG)

Technical direction was provided by Mr. Ron Evers, of the U.S. Army Aviation Systems Command.

The program was conducted at the Wood-Ridge Facility of the Curtiss-Wright Corporation, under the Technical Direction of Mr. Neil De Bruyne, Senior Project Engineer, Transmission Technology Department.

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INTRODUCTION

The requirements of gearing for advanced helicopter and VSTOL Aircraft have become increasingly demanding as requirements for lighter weight and greater reliability are continuously accentuated. One of the areas of gear technology directly affected by these requirements is that of scuffing or scoring. Improvements in resistance to scuffing through improved manufacturing methods or materials is the subject of the current investigation.

Four categories of variables were investigated, namely:

1. Effect of surface coatings
2. Effect of methods of surface finishing
3. Effect of profile modification
4. Effect of material

In each of these areas selections were made based on Curtiss-Wright and available industry background.

Testing was conducted utilizing full scale gears in each of the investigation areas. In the evaluation of surface coatings testing was also conducted with the two materials utilizing rollers.

TECHNICAL APPROACH

In attempting to optimize the surface durability of gear teeth to resist scuffing, numerous manufacturing approaches are available. In the work being reported on, the following different combinations were proposed.

1. Carburized - Ground
2. Carburized - Ground - Black Oxide
3. Carburized - Ground - Silver Plate
4. Carbonitride - Ground
5. Ground
6. Ground and Honed
7. Ground - Shot Peened Ground
8. Ground - Shot Peened Honed
9. Ground and Harperized
10. Ground - Shot Peened and Harperized
11. Ground with Involute Tip Modification

In addition to the standard AISI 9310 material evaluated above, a second high hot hardness tool steel Vascojet 1000-2 was also evaluated. The Vascojet material was selected as an alternate material on the basis of favorable bending fatigue characteristics previously developed.

Gear testing was conducted utilizing the circulating power principle of the Ryder Gear Test System. A method of evaluation utilizing the Step Load Technique similar to a basic Ryder rating was utilized.

TEST METHOD

TEST PROCEDURE - ROLLERS

The following Test Procedure was used for all roller tests:

1. Install test rollers.
2. Circulate oil with a minimum of 15 minutes of circulation after reaching test temperature.
3. Start rig and run 15 seconds with zero load.
4. Inspect rollers.
5. Start rig run 15 seconds at first load point.
6. Inspect rollers.
7. Continue to run 15 second test points with increasing load points and inspection until a failure is detected.

Inspection of rollers on each of the various combinations that were tested was conducted as follows:

1. Visual
2. On the first of a set, for each surface coating, after each test load point a trace of the surface was made and failure confirmed by a trace showing surface distress. A typical trace of this procedure is shown in Figure 1. This trace shows the difference between the roller surface as manufactured and at the failure point of 760 pounds.

In all testing ten sets of rollers were run against each other thus providing ten data points upon which to make the average determination.

TEST PROCEDURE - GEARS

Testing of gears is conducted to the procedure as listed and outlined below:

1. Install gears both test and slave into the test rig.
2. Circulate oil until operating temperature is reached.
3. Allow a minimum of 15 minutes at temperature prior to test initiation.
4. Start test rig and set load point number 1.

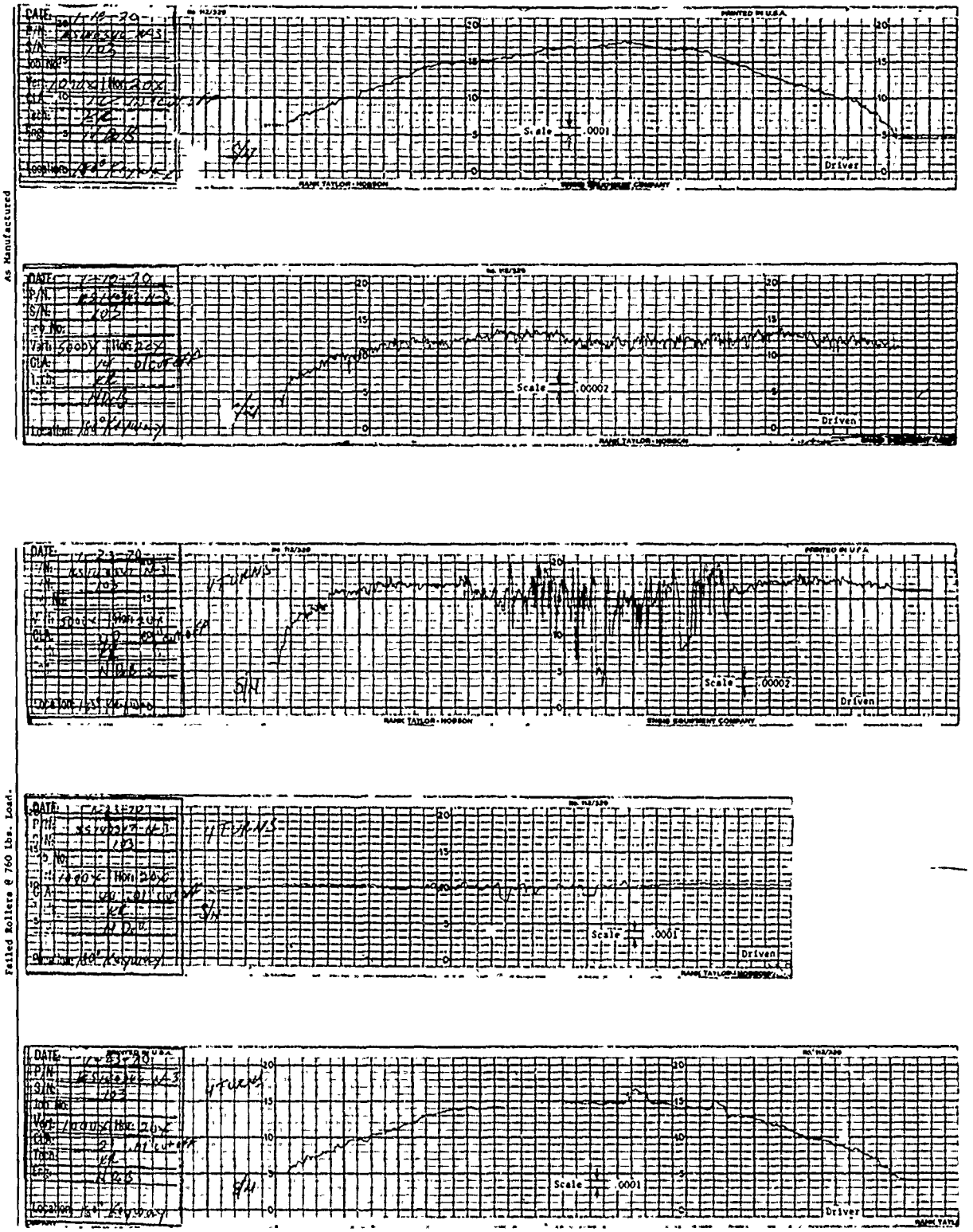


Figure 1. Roller Traces AISI 9310 Carburized.

5. Run 10 minutes at this load and speed and shut down for inspection.

6. Inspect gear teeth for scuffing and record percentage where applicable.

7. Run 10 minutes at the second load point.

8. Inspect.

9. Run steps 5 and 6 at increasing loads until at least 22.5% of the active gear face has scuffed.

Inspection of test gears is accomplished from a visual examination utilizing the monocular shown in Figure 12. The active face of the gear tooth is divided in squares by a grid in the instrument. Percentage of scuffing is determined by counting whole and partial squares in which scuffing appears.

In all testing five gear sets were run against each other and utilizing both faces of the gear provided ten data points for each evaluation. As in Ryder gear evaluations 22.5% scuffing was considered a failure and was used as the rating point.

SPECIMEN DESIGN ROLLERS

The rollers as fabricated for this program are described dimensionally and defined in Table I. A typical set of driven and driver rollers is shown in Figure 2. Rollers were designed to be compatible with the Buckingham rig used for this testing. Table II shows the operating parameters utilized in the testing.

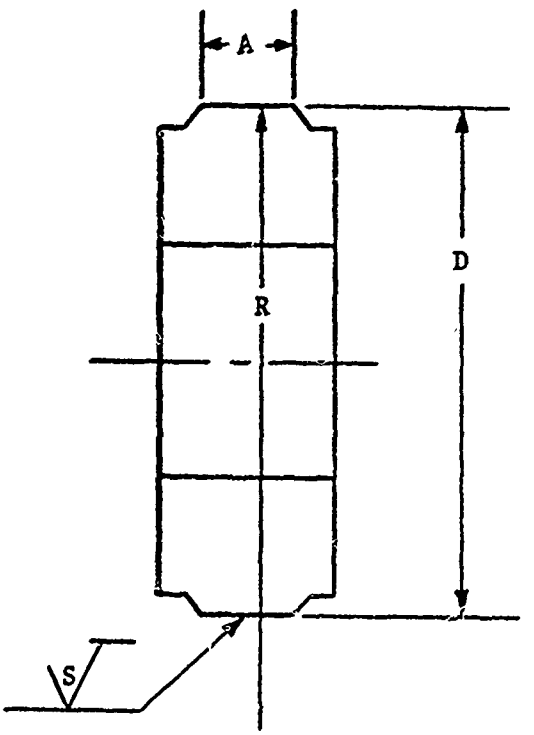
A crown was utilized on the driven roller in order to minimize effects of any misalignment and provide as nearly as possible the same contact stresses in all tests for the various load levels.

SPECIMEN DESIGN GEARS

The basic test gear for this program was fabricated by a nongenerated-form ground method to the dimensions shown in Figure 3. Various involute profiles were utilized for these test gears and are shown in Figure 4. Basic tests were all conducted with the unmodified tooth profile shown by Chart 1 of Figure 4. The other profile modification which consisted of varying amounts of tip relief were all used to the effect of profile modification. A typical involute profile, as manufactured, is shown in Figure 5. Test gears were manufactured from round upset pancake forgings.

Test gears were designed utilizing a coarse pitch in order to insure producing scuffing and scoring as a primary mode of failure, thus not influencing results with extraneous other types of failures. While various methods were proposed for surface finishing, in all cases the measured surface finish was maintained constant at 10-12 AA in order to keep test

TABLE I. TEST ROLLER GEOMETRY.



	DRIVER	DRIVEN
DIAMETER D	2.053"	3.053"
WIDTH A	.500"	.500"
CROWN RADIUS R	∞	20.0"
SURFACE FINISH S	12 RMS	12 RMS

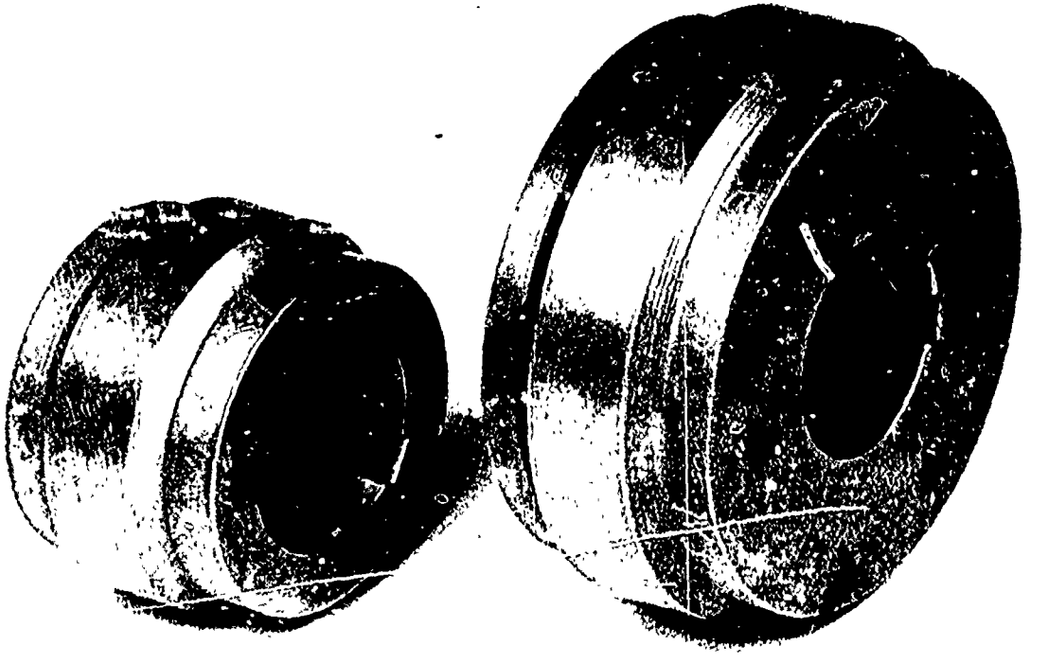
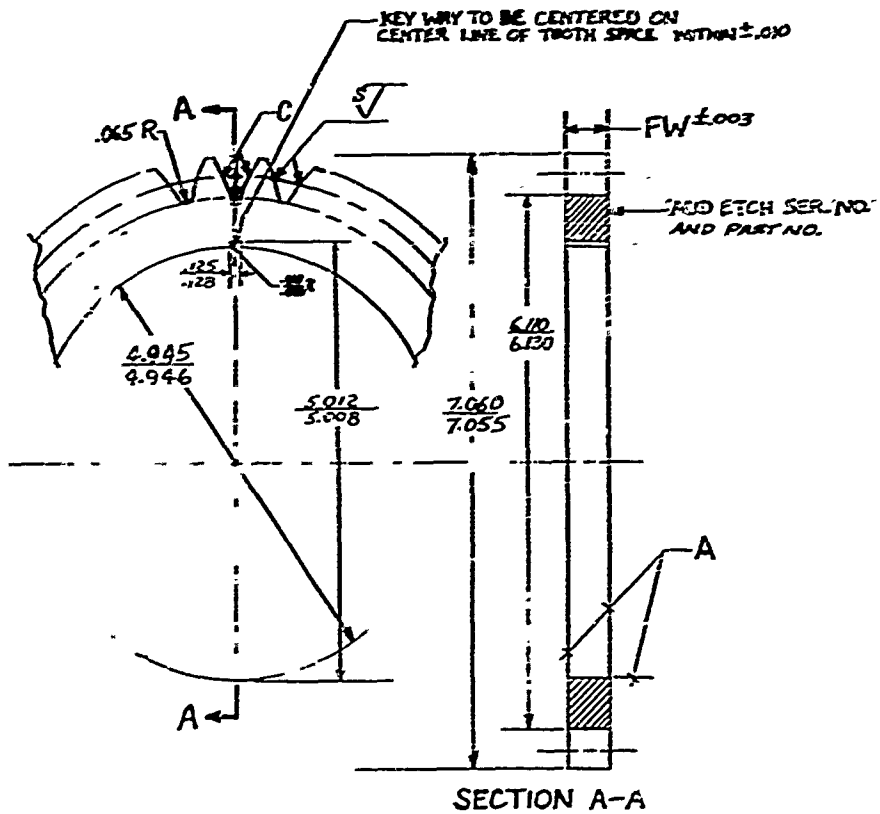


Figure 2. Test Rollers



REFERENCE GEAR DATA		GEAR DATA	
DIAMETRAL PITCH (MFG)	5	NO. OF TEETH	33
PRESSURE ANGLE (MFG)	28°	NORMAL PITCH	5
PITCH DIA (MFG)	6.6000	BASE CIRCLE DIA.	5.5816
PRESSURE ANGLE (ROLL)	25.10°	OVERWIRE MEASUREMENT USING TWO .3466 DIA. WIRES	7.0931-7.0975
PITCH DIA (ROLL)	6.6179	TOOTH TO TOOTH SPACING MUST BE ACCURATE WITHIN	.0003
NO. OF TEETH IN MATING GEAR	33	TOOTH SURFACES MUST BE PARALLEL WITH ROTATIONAL AXIS PER INCH WITHIN	.0004
CENTER DISTANCE TO MATING GEAR	6.6179		
MINIMUM CONTACT DIA.	6.2936		
BASIC CIRCULAR TOOTH THICKNESS AT 6.6000 DIA.	.3279		
MACHINE CIRCULAR TOOTH THICKNESS TO	.3239-.3253		
BACKLASH	.002-.004		

Figure 3. Test Gear Drawing.

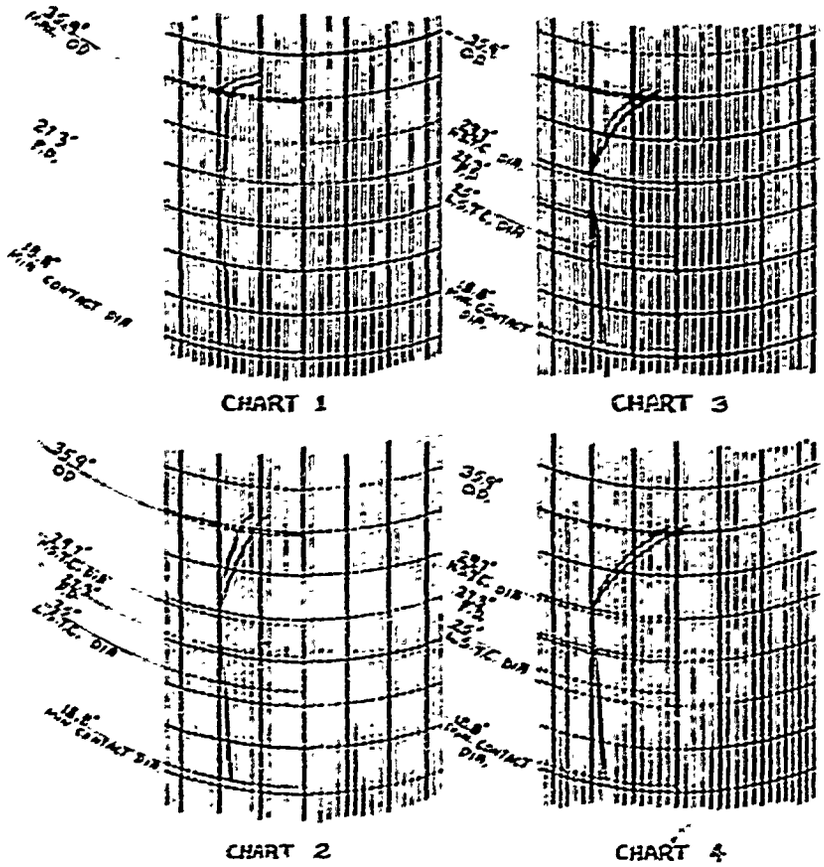


Figure 4. Test Gear Involute Charts.

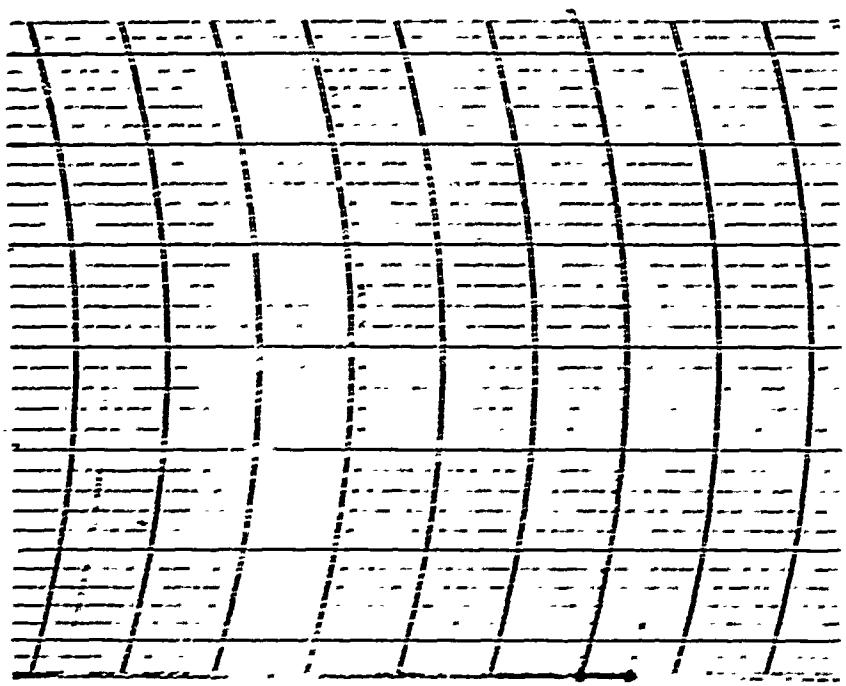


Figure 5. Typical Involute Chart Test Gears

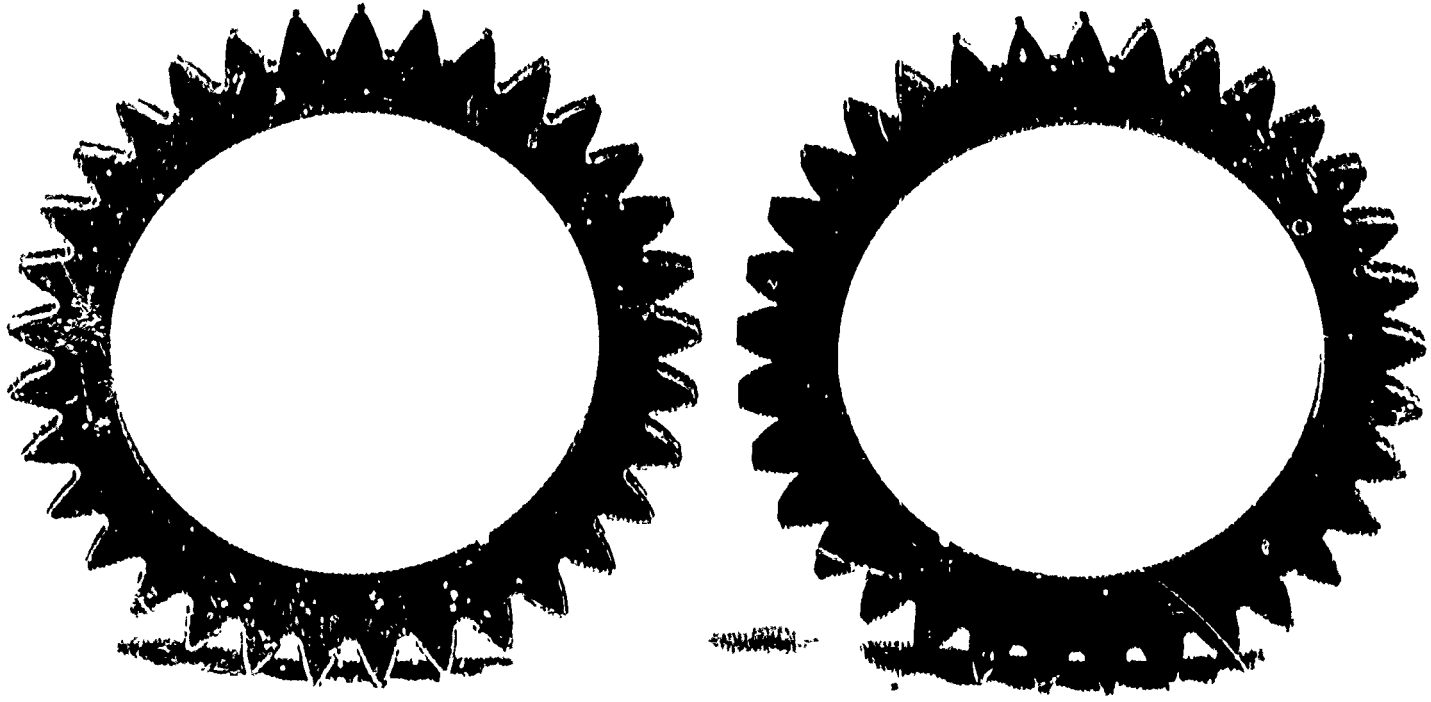


Figure 6. Test Gears

TABLE II. ROLLER OPERATING PARAMETERS	
Input Speed	2300 RPM
Gear Ratio	1.55 to 1
Number Teeth - Driver	31
Number Teeth - Driven	20
Roller Diameter - Driver	2.055
Roller Diameter - Driven	3.055
Roller Ratio	1.49 to 1
Total Ratio	2.31 to 1
Driver Velocity	247 in./sec
Driven Velocity	571 in./sec
Slip Velocity	324 in./sec

variables to a minimum. A gear of 33 teeth with a diametral pitch of 5, and a normal pressure angle of 25 degrees was used for both the test and slave gears. The only difference between the two gears being the width. A picture of the finished test and slave gears is shown in Figure 6.

MATERIAL

The test components of the program were fabricated from two materials, nanely: Carburized AISI 9310 and Carburized Vascojet 1000-2, a high hot hardness tool steel.

Carburized Vascojet 1000-2 had previously shown promising properties as a gear material. It attains an excellent combination of high tensile strength along with good toughness. Optimum properties were achieved by utilizing consumable electrode vacuum melt steel which in turn was carburized.

Table III contains a listing of the specified chemical analysis of the two gear materials, Table IV lists the actual compositions of the test material. The carburizing of the Vascojet material in order to derive desirable case to core hardness relations is very critical. Figure 7 shows a hardness survey of the AISI 9310 gears. Figure 8 shows the same survey for Vascojet 1000-2 material. An outline of the Curtiss-Wright carburizing process for Vascojet 1000-2 material is shown in Appendix "B"

The lubricant used for all testing in this program was MIL-L-7808G. Sufficient quantity from one batch was procured to cover the complete test evaluation program. The lubricant is identified as Stauffer Chemical Company, Lot No. 29, November 1969.

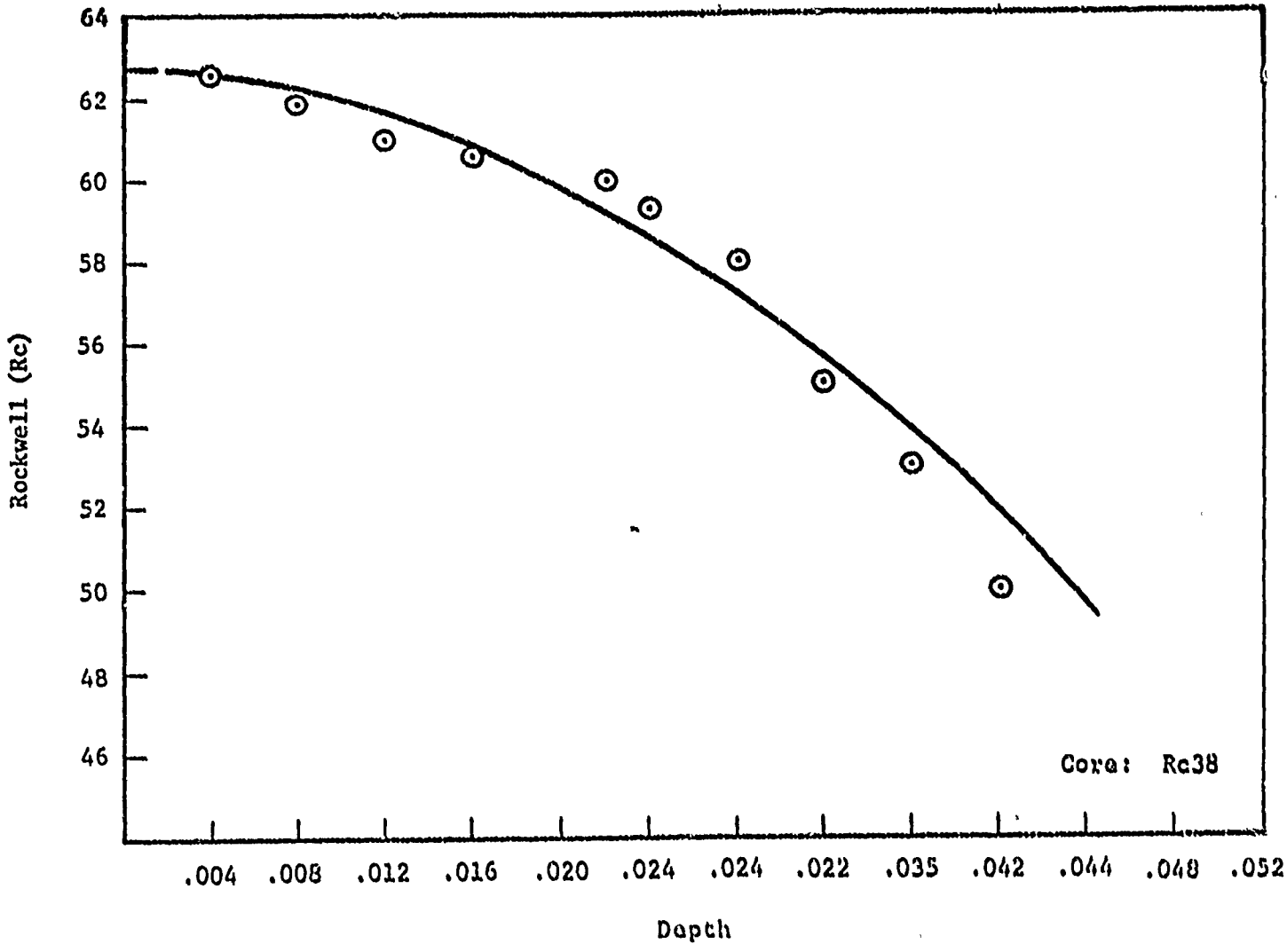


Figure 7. AISI 9310 Material Depth Vs. Hardness.

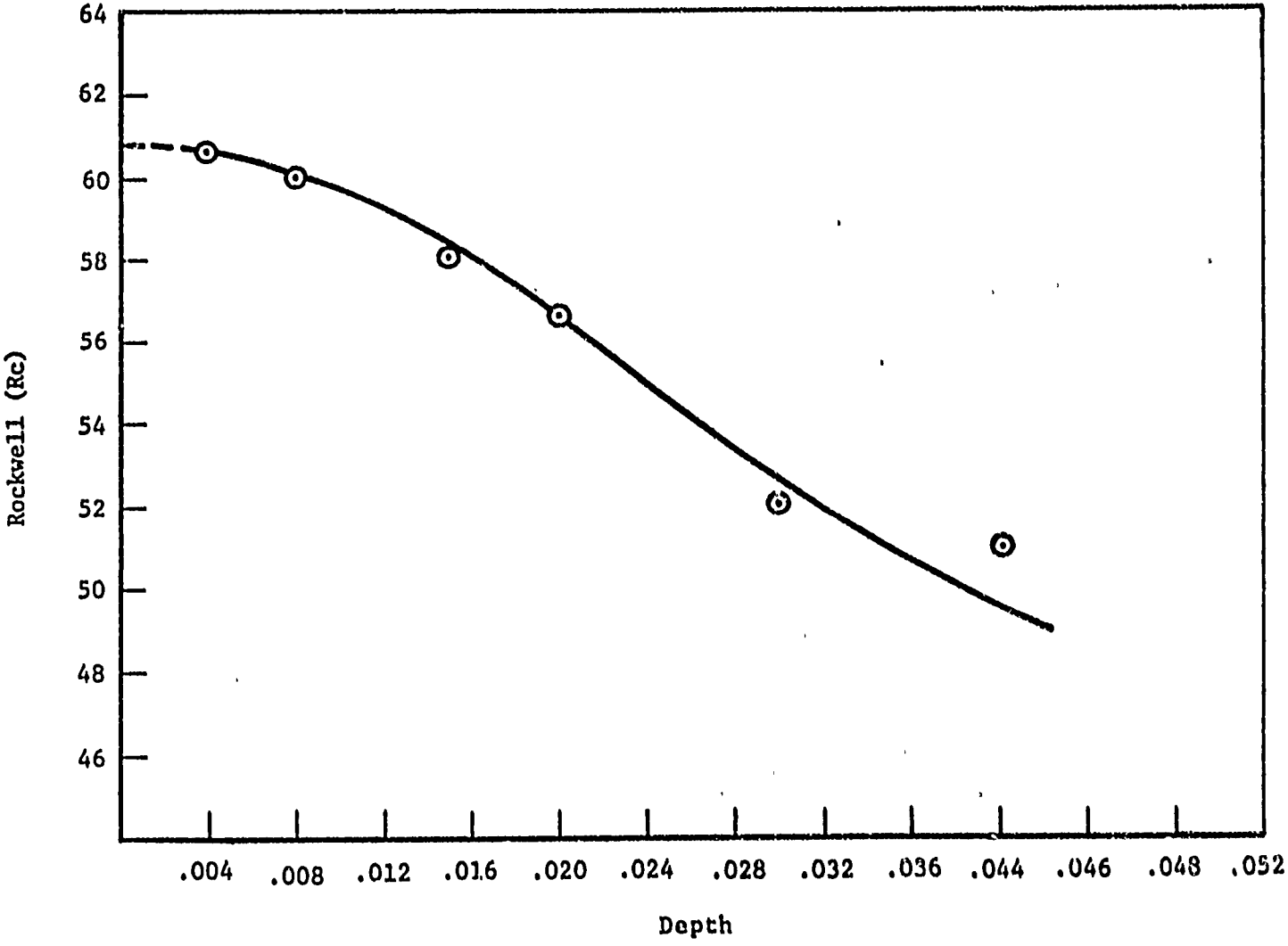


Figure 8. Vascojet 1000-2 Material Depth Vs. Hardness.

TABLE III. SPECIFIED CHEMICAL COMPOSITION			
Element	Symbol	AISI 9310	Vasco-Jet 1000-2 (X2)
Carbon	C	0.07 - -.13	0.20 - 0.25
Manganese	Mn	0.40 - 0.70	0.20 - 0.40
Silicon	Si	0.20 - 0.35	0.80 - 1.00
Chromium	Cr	1.00 - 1.40	4.75 - 5.25
Molybdenum	Mo	0.08 - 0.15	1.30 - 1.50
Vanadium	V	-	0.40 - 0.50
Tungsten	W	-	1.20 - 1.50
Nickel	Ni	3.00 - 3.50	-
Phosphorous	P	0.25 max.	0.25 max.
Sulfur	S	0.25 max.	0.25 max.
Copper	Cu	0.35 max.	-

TABLE IV. ACTUAL TEST SPECIMEN ANALYSIS			
Element	Symbol	AISI 9310	Vasco-Jet 1000-2 (X2)
Carbon	C	0.11	0.23
Manganese	Mn	0.52	0.30
Silicon	Si	0.28	0.94
Chromium	Cr	1.20	4.81
Molybdenum	Mo	0.10	1.36
Vanadium	V	-	0.47
Tungsten	W	-	1.37
Nickel	Ni	3.00	-
Phosphorous	P	0.01	0.009
Sulfur	S	0.01	0.008
Copper	Cu	0.16	-

TEST APPARATUS ROLLERS

The test rig utilized to conduct roller tests for this program is a modified Buckingham roller rig. The complete roller rig and the main elements of the machine are shown in Figures 9, 10 and 11. The test rollers are mounted on two arbors, which are driven by gears to give combined rolling and sliding action between the rollers. One arbor is mounted on a fixed frame, while the other is mounted on a pivoted swinging frame. The load on the rollers is applied by means of a calibrated spring. The test rolls and support bearings are lubricated by pressure oil, in this case the MIL-L-7808 test oil. For this testing rollers of 2.055 and 3.055 inch diameters were used. Drive gears of 31 and 20 teeth were used. This

provides a total slip to roll ratio of 2.31. At the test conditions a driving velocity of 247 in./sec and a driven velocity of 571 in./sec were used. This results in a slip velocity of 324 in./sec. Oil in temperature was maintained at 200°F with a flow of 150 cc/min directed at the test rollers.

TEST APPARATUS GEARS

The gear test rig was designed using the conventional principles of the basic Ryder gear rig and is shown in drawing LS34343, Figure 14. This rig operates on the power circulating principle. The two parallel shafts are connected through two slave gears and two test gears which form the circulating power path. The slave gears are helical and are used to load the test gears. Loading is accomplished by applying a hydraulic pressure in a load chamber which causes an axial movement of one shaft relative to the other. Because the slave gears are helical a torsional load is applied to the shafts which in turn loads the test gears. The load is determined from the geometry of the rig parts and the applied pressure. An assembly of the complete test rig is shown in Figure 12. Figure 13 then shows the test rig with the cover removed and the test gears exposed.

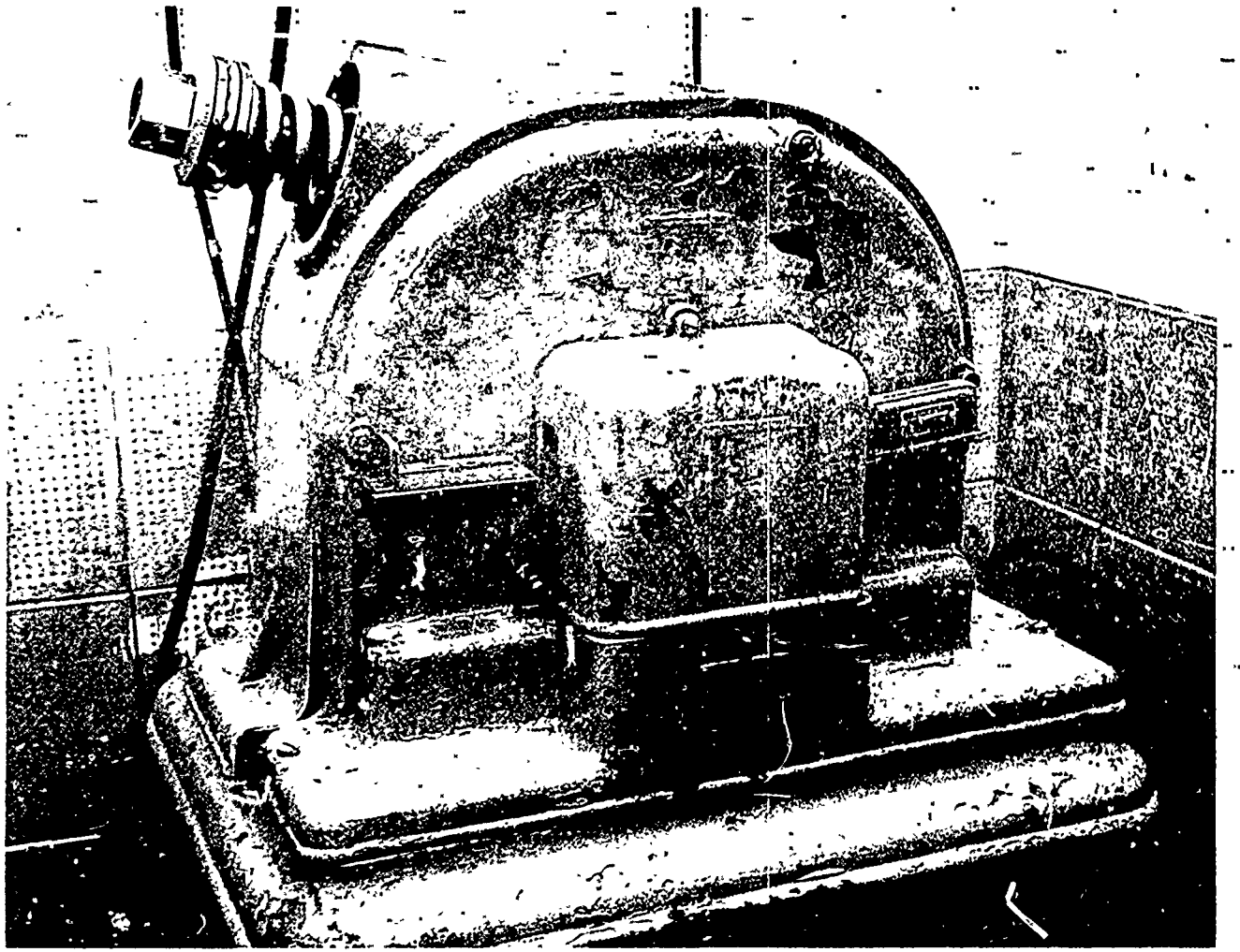


Figure 9. Roller Test Rig Assembly.

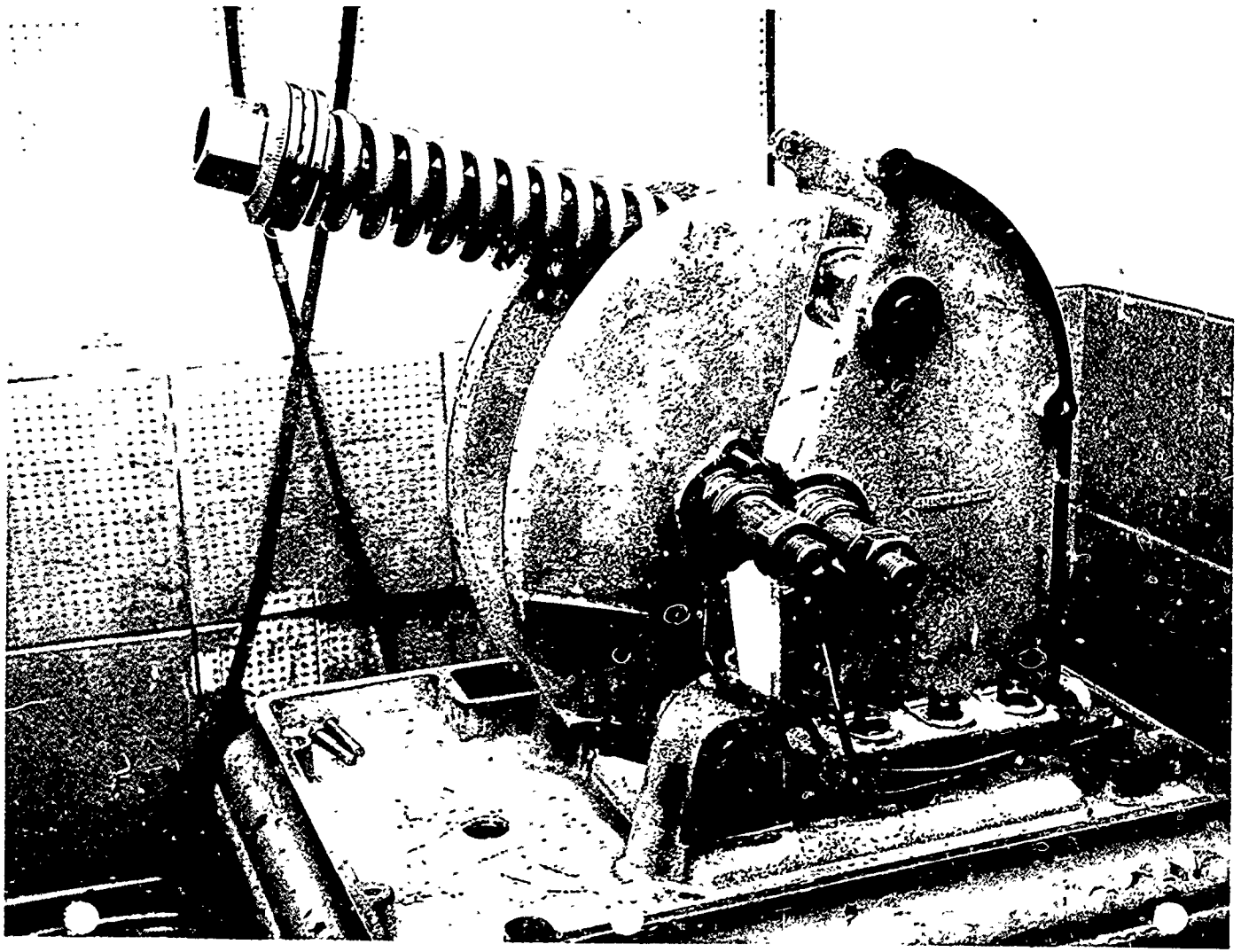


Figure 10. Roller Test Rig Covers Removed.

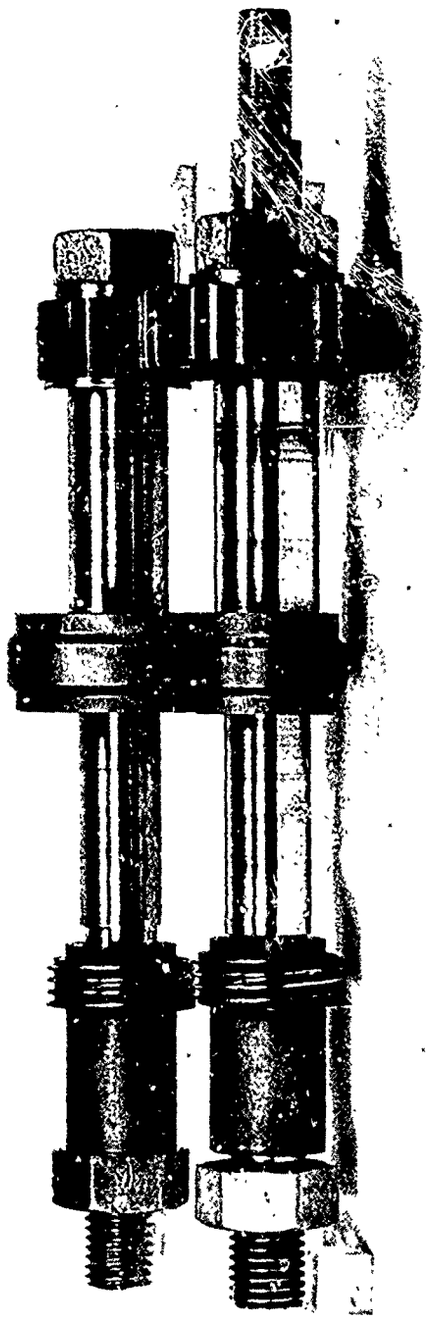


Figure 11. Roller Test Rig Shafts.

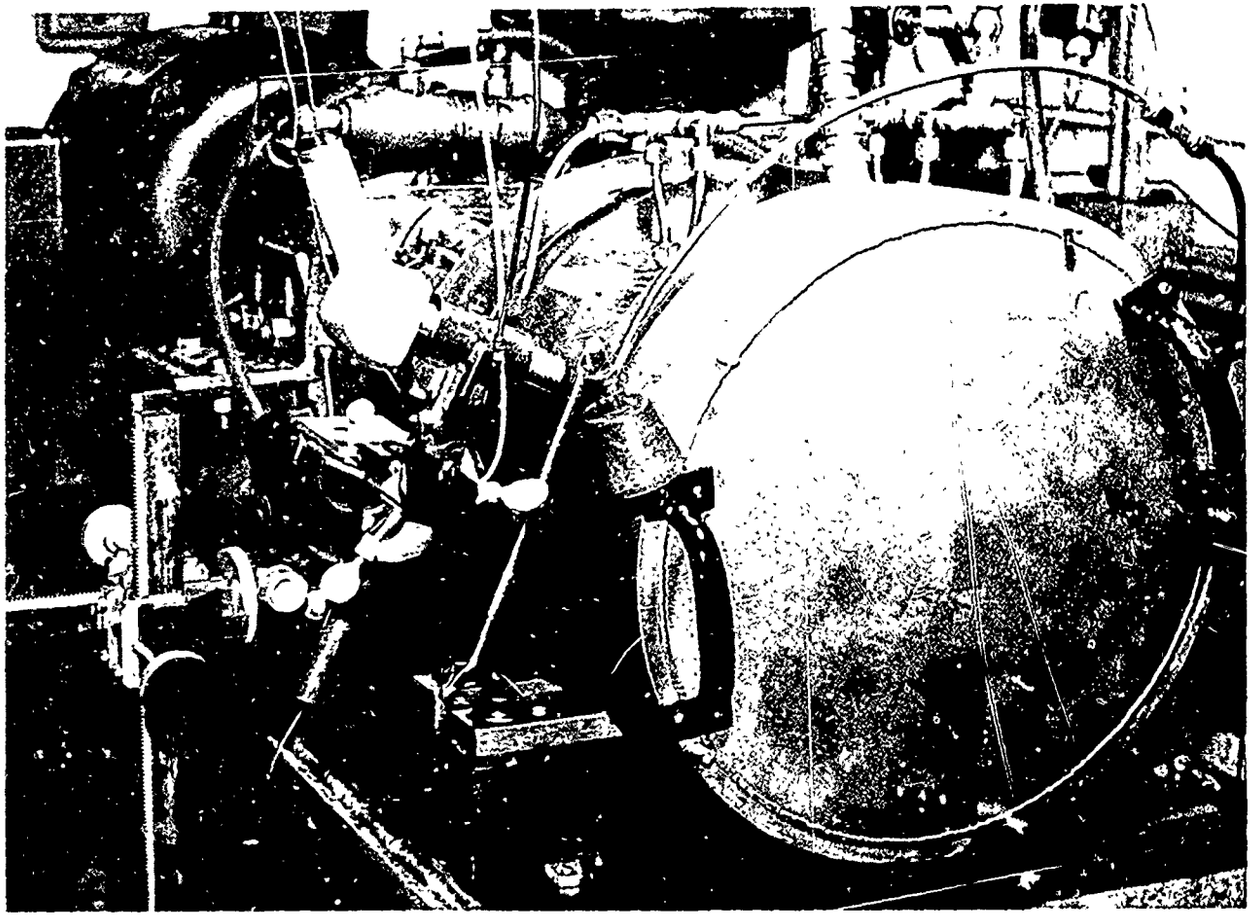


Figure 12. Gear Test Rig Assembly.

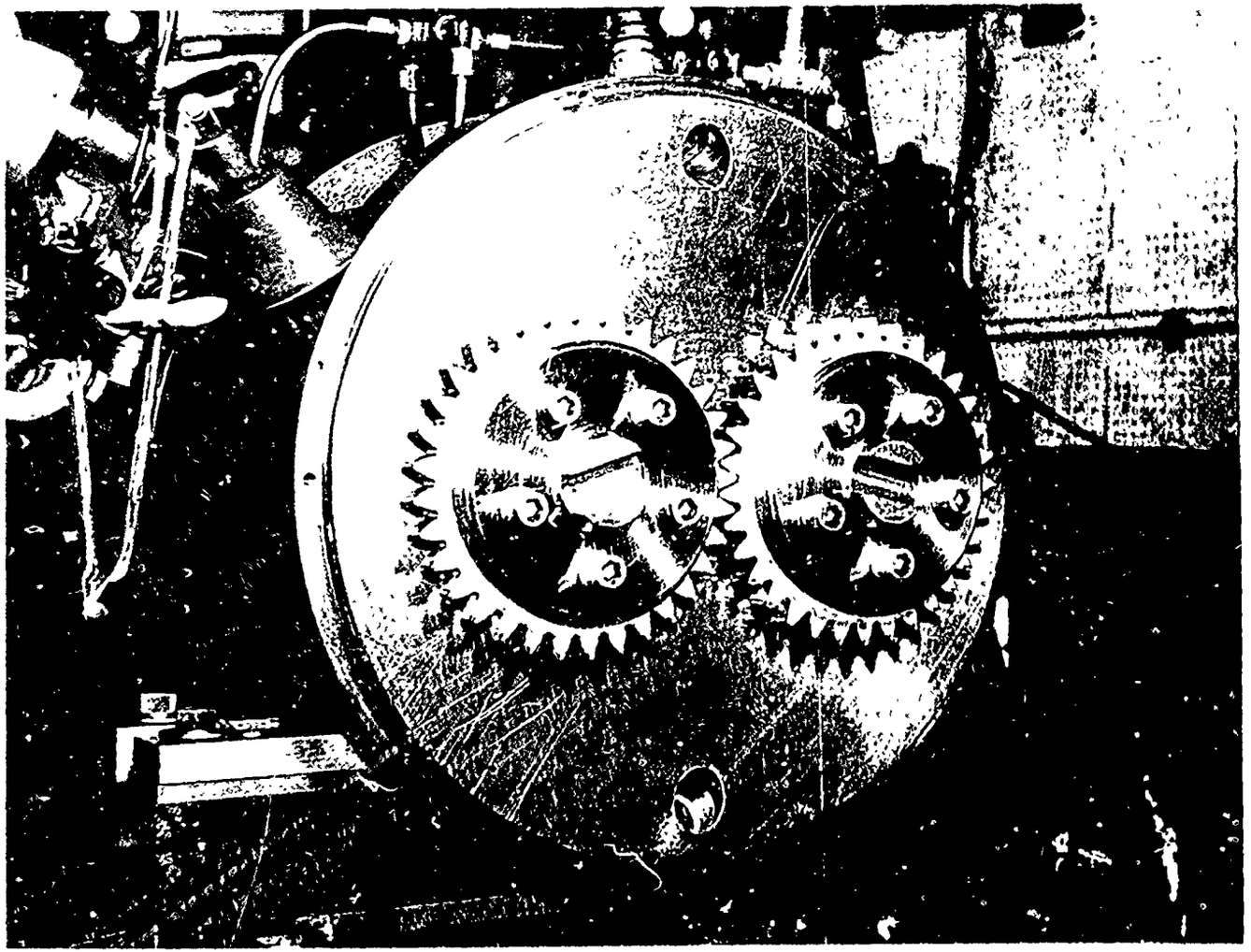
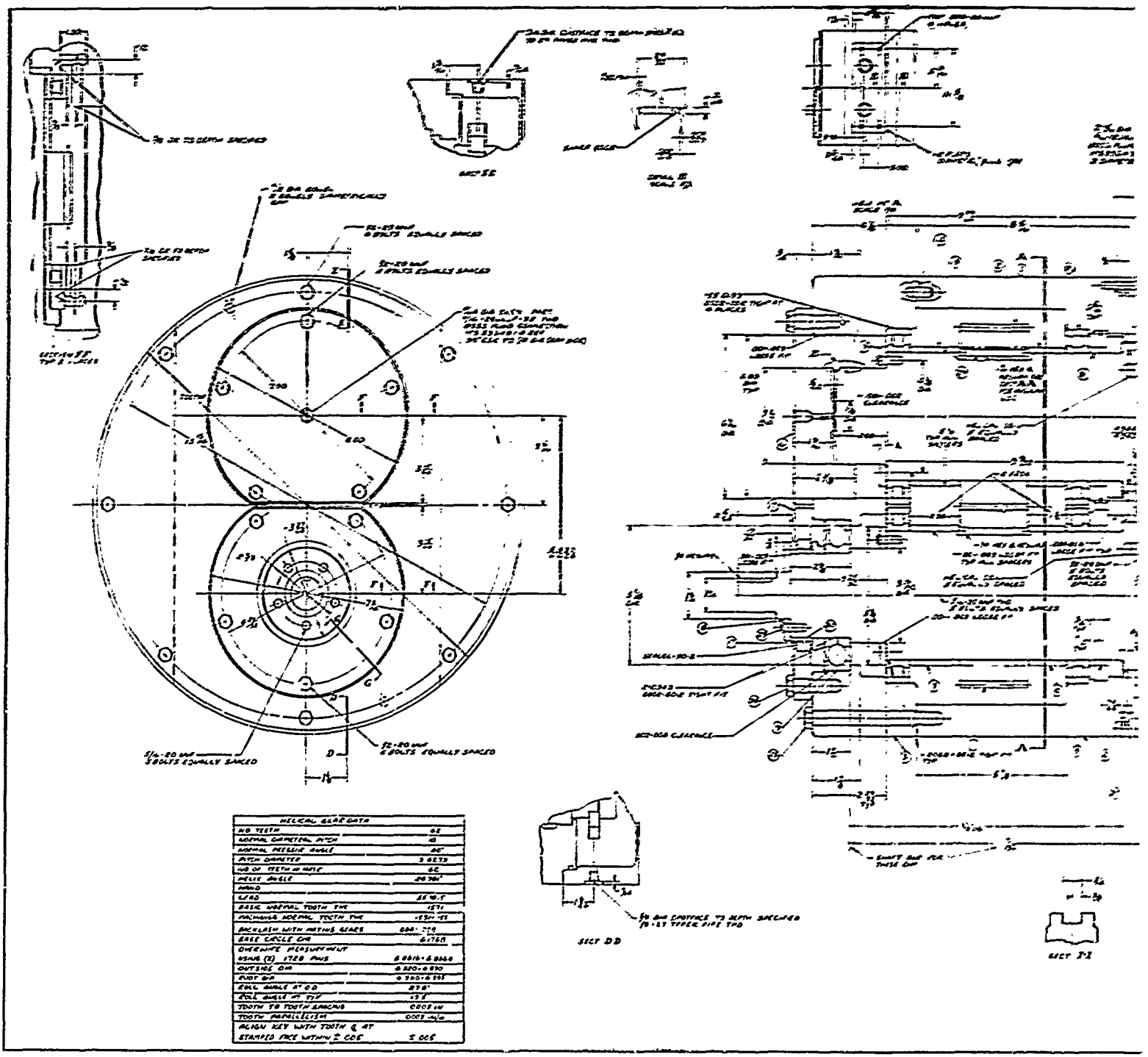


Figure 13. Gear Rig Cover Removed.



HELICAL GEAR DATA	
NO TEETH	62
NORMAL DIAMETRAL PITCH	10
NORMAL PRESSURE ANGLE	20°
PITCH DIAMETER	6.2000
NO OF TEETH IN MATE	62
HELIX ANGLE	20.796°
HAND	
LEAD	22.10.1
BASIC NORMAL TOOTH THK	.1571
MACHINE NORMAL TOOTH THK	.1531-.1571
BACKLASH WITH MATING GEARS	.004-.006
BASE CIRCLE DIA	5.8268
OVER WIRE MEASUREMENT	
NUMB (N) STEP PINS	6.8816-6.8868
OUTSIDE DIA	6.820-6.830
ROOT DIA	5.780-5.795
ROLL ANGLE AT OD	37.8°
ROLL ANGLE AT TIP	17.1
TOOTH TO TOOTH SPACING	.0803 in
TOOTH PARALLELISM	.0005 in/in
ALIGN KEY WITH TOOTH # 47 STAMPED FACE WITHIN ± .005	± .005

A

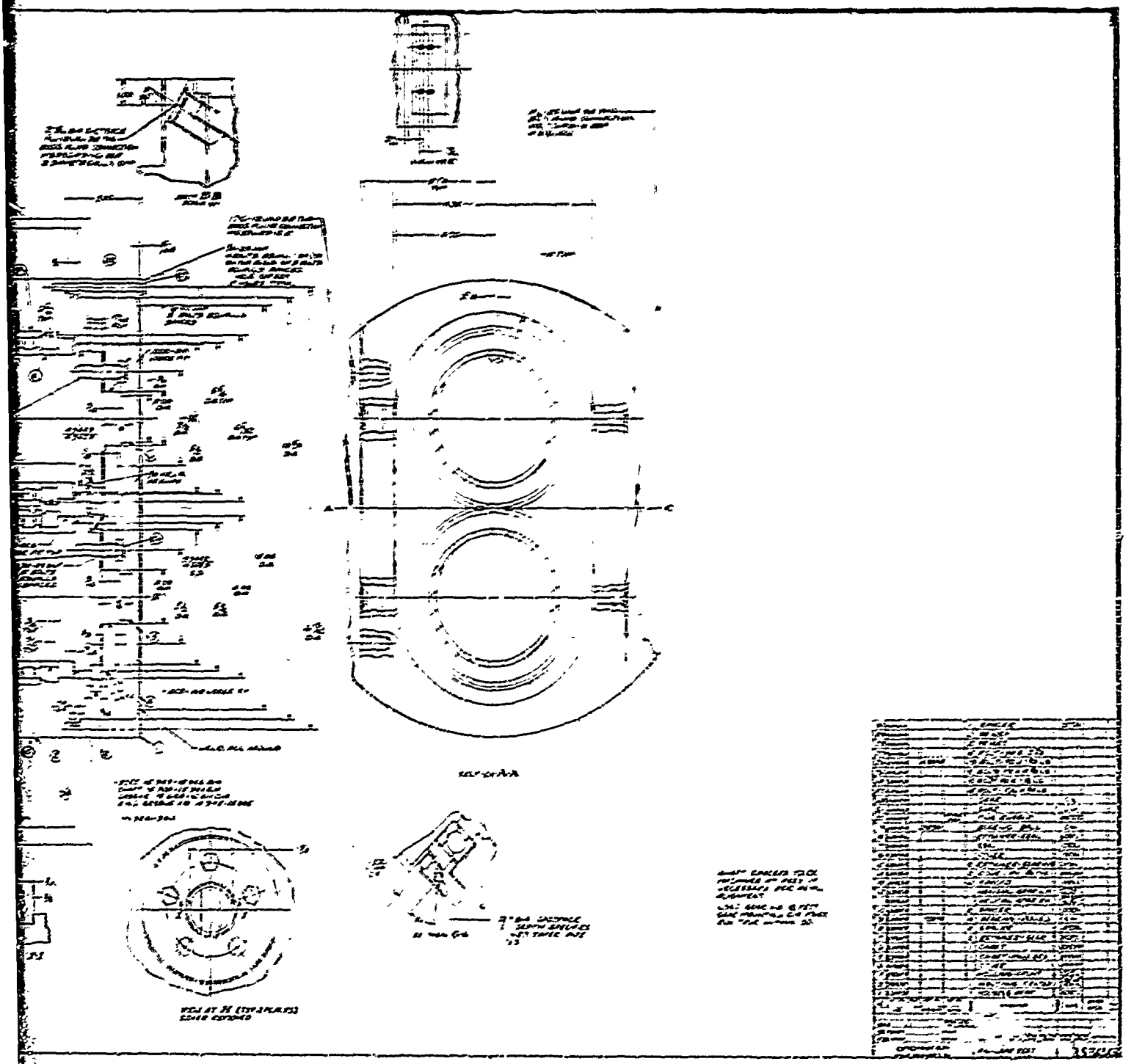


Figure 24. Gear Test Rig Layout.

TEST RESULTS

Roller Testing

The results of testing with both AISI 9310 and Vascojet 1000-2 rollers is shown by Figure 15. For this comparison chart carburized AISI 9310 has been chosen as the base line and assigned a value of 100 with all other materials and surface treatments being related to this value. From this chart it becomes obvious that silver plating provides a greater increase in resistance to scuffing than any other surface treatment used. It also indicates that AISI 9310 material carburized is superior to Vascojet 1000-2 material carburized. This finding was not confirmed by actual gear testing.

Figure 16 shows the actual average roller loading at failure of the various surface treatments for both materials and methods.

Gear Testing

The summary of comparative test results for the gear evaluation is shown by Figures 17 and 18. In both of these figures AISI 9310 material carburized and ground is used as a base line of 100 with all other materials, treatments, geometry and methods of finishing being related to this value.

Figure 17 shows the results of the three evaluation areas for AISI 9310. These include the effects of, surface treatment, surface finishing methods and profile modification. Results indicate that when the same basic surface finish is used silver plating (flash) produces significant increases in load carrying ability. It also indicates the value of optimizing involute modifications to account for deflections of gear teeth at operating loads.

Figure 18 shows the results of the evaluation areas for Vascojet 1000-2 material. These include the effects of surface treatment and methods of surface finishing. Results indicate the superiority of Vascojet 1000-2 material over AISI 9310 in resistance to scuffing.

Figures 19 through 23 show the actual average gear loading at various degrees of scuffing through the rating point of 22.5% scuffing. A typical picture of a scuffed gear after test is shown by Figure 24.

Since the silver plating of AISI 9310 gears had shows such a significant improvement in resistance to scuffing, when tested by step loading, it was recommended to USAASCOM that endurance testing be conducted to determine long term benefits. This was accomplished as an amendment to the existing contract. Two fifty hour endurance tests were conducted at two load levels. The first evaluation was conducted at 3600 lbs per inch of face width and the second at 3200 lbs. per inch of gear face width. Figure 25 shows a typical silver plate gear tooth after step load testing. As can be seen the silver has been worn and scuffed but the base material has not been damaged. The surface finish of the gear had improved from the manu-

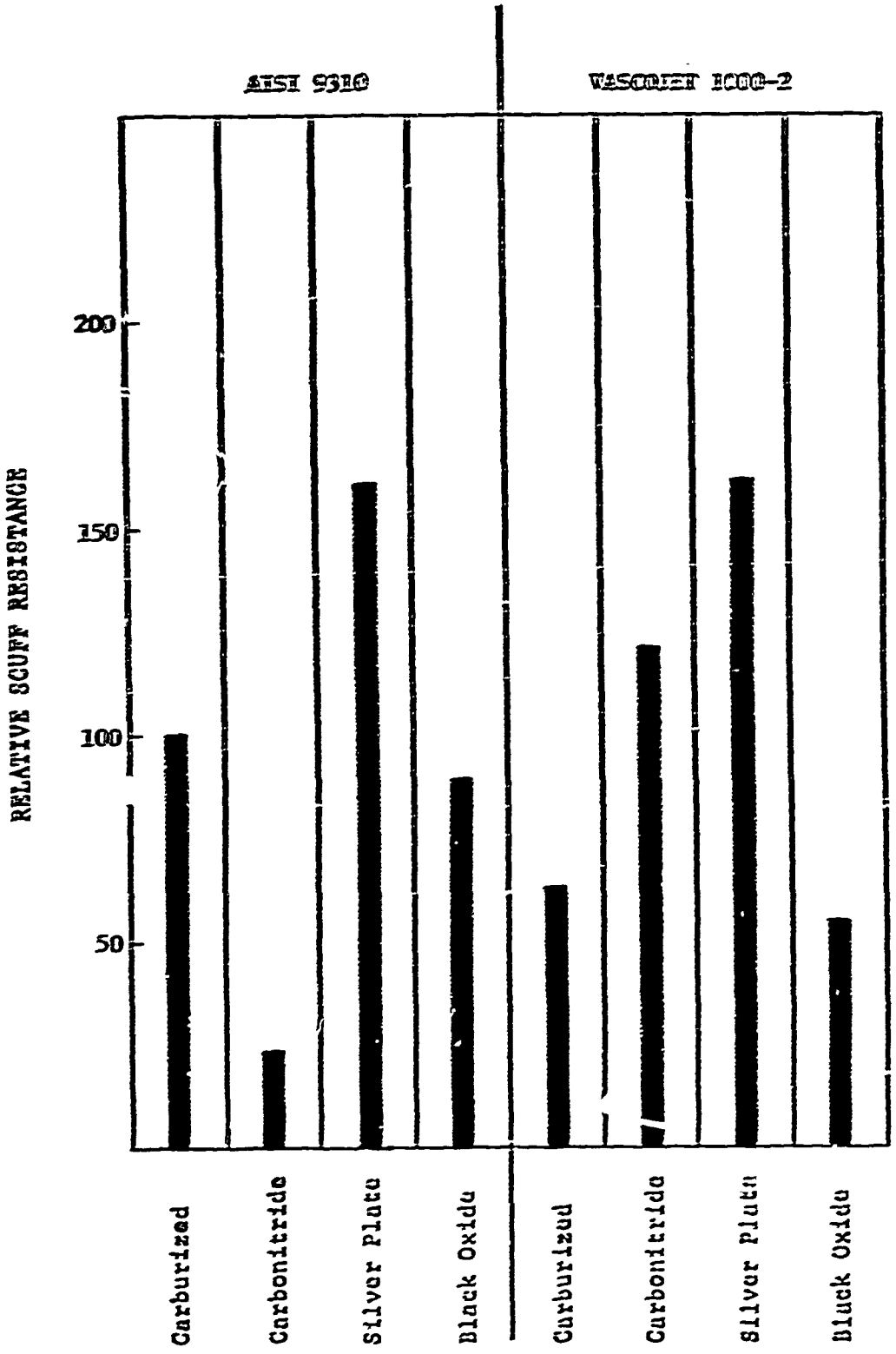


Figure 15. Roller Data Comparison.

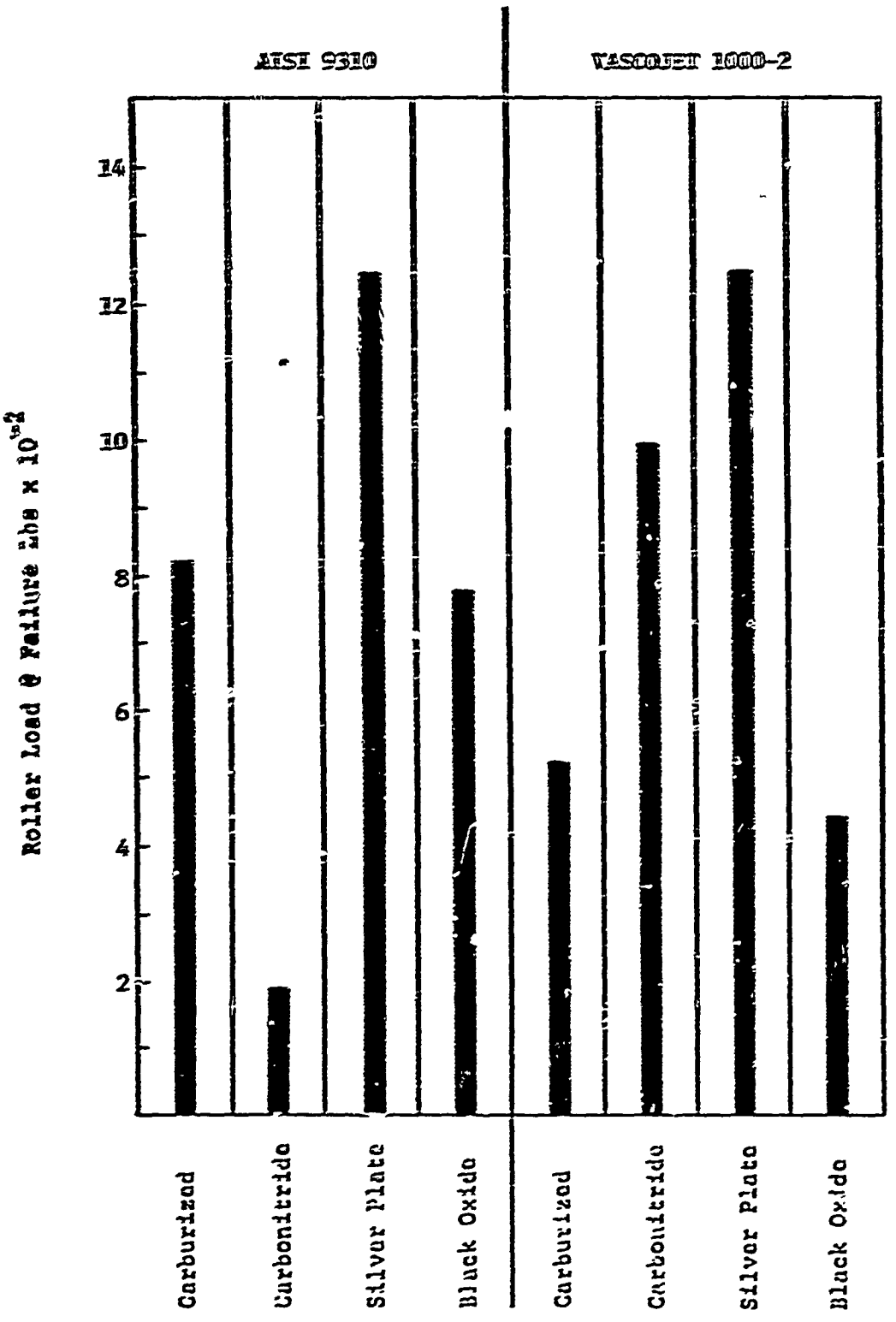


Figure 16. Roller Failure Load Comparison.

factored 12 RMS. to approximately 6 RMS. Figure 26 shows the silver plate gear tooth after 50 hours at 3600 lbs. per inch of face. In this case some damage had been done to the gear surface but not nearly to the extent of a plain carburized gear after 10 minutes at 3200 lbs. per inch of face. Figure 27 shows the second gear after 50 hours at 3200 lbs. per inch of face. As can be seen here the damage is very slight. Silver plate is defined for this program as .0002 - .0005 inches thick.

Roller and Gear Comparison

In the area of surface treatment effects both roller and gear test were conducted. With AISI 9310 material Figure 28 there is excellent correlation between the two methods of test with exactly the same ranking of variables. With the Vascojet 1000-2 material the correlation between roller and gear tests Figure 29 is not nearly as good.

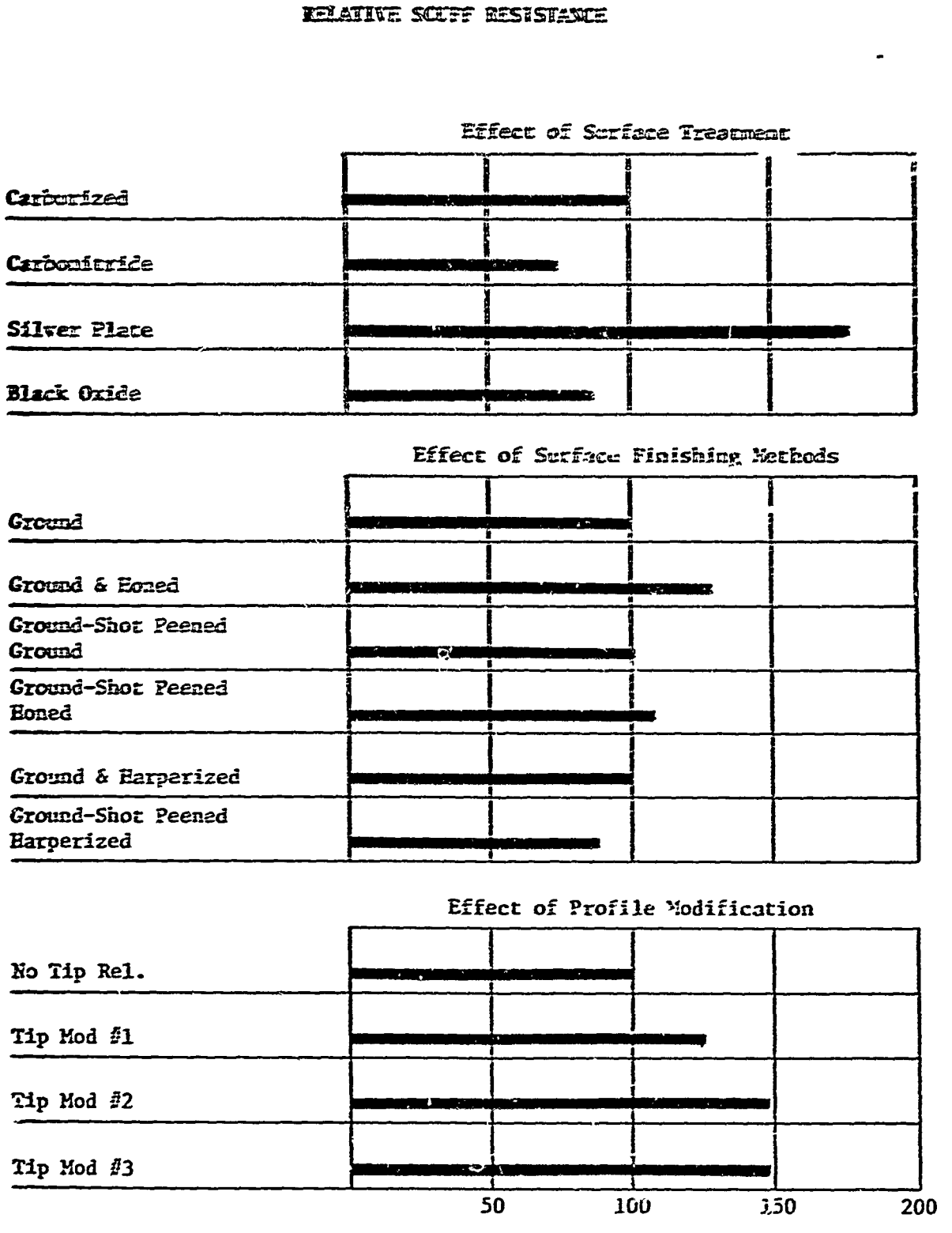


Figure 17. AISI 9310 Gear Test Summary.

RELATIVE SCUFF RESISTANCE

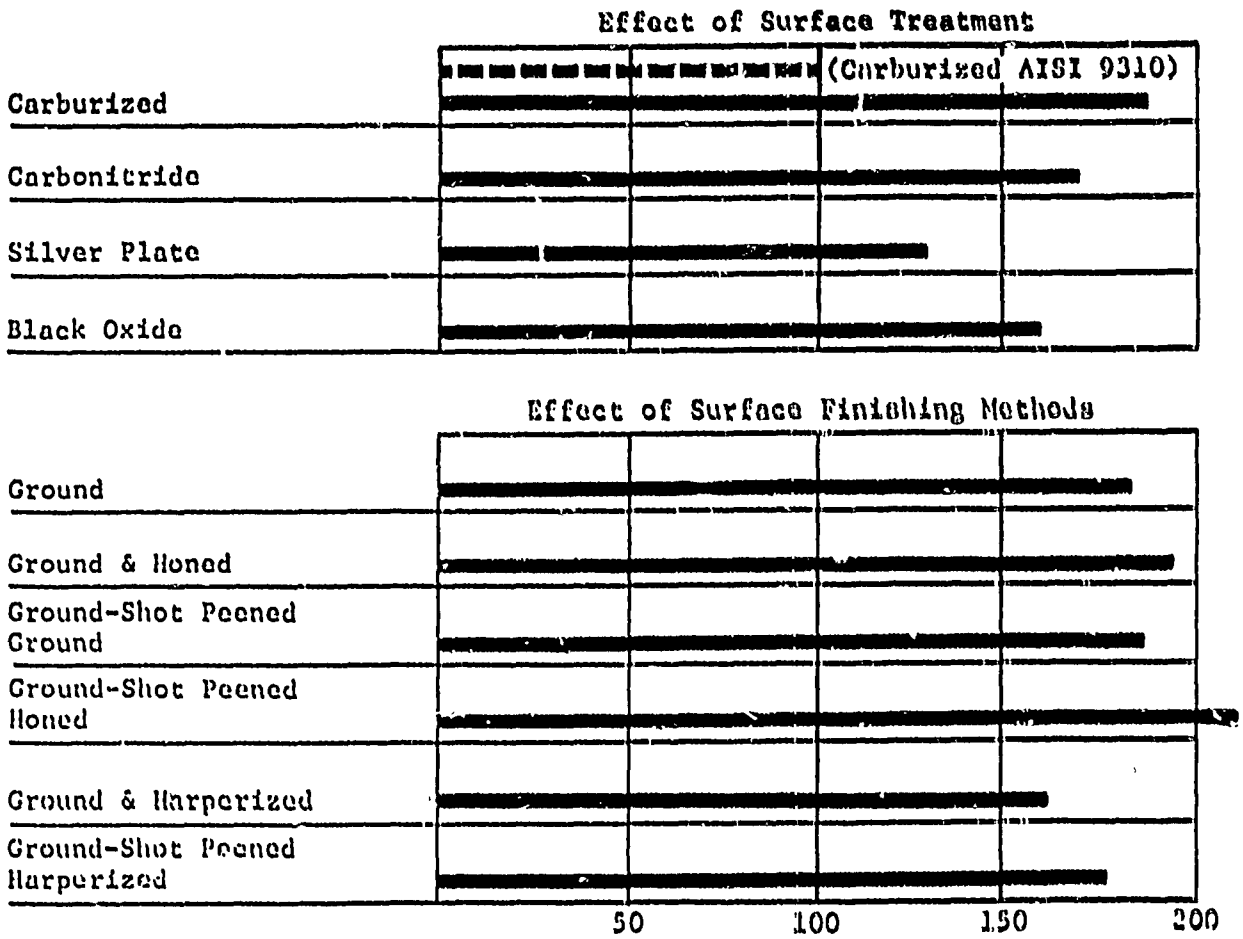


Figure 18. VASCOJET 1000-2 Gear Test Summary.

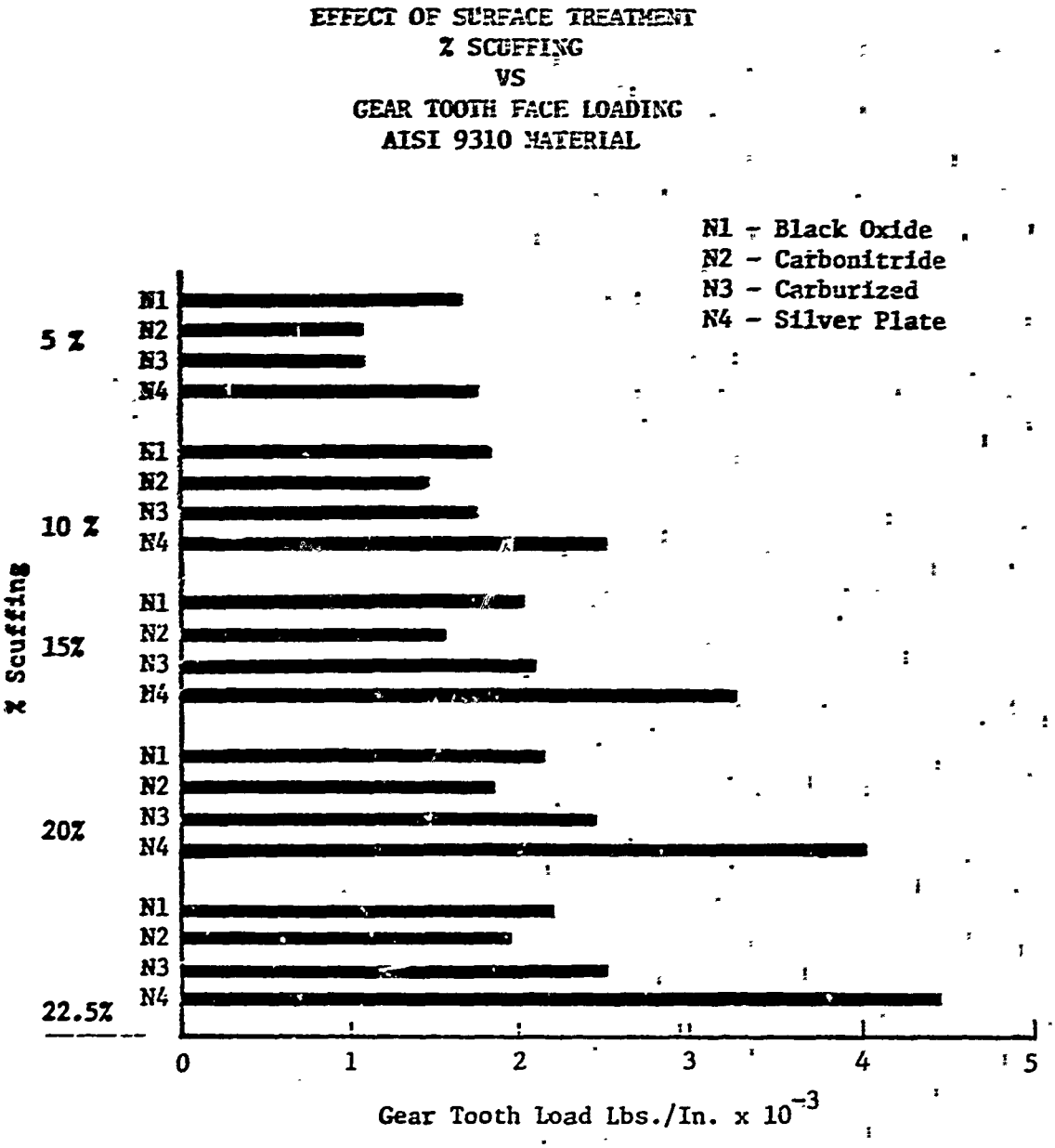


Figure 19. AISI 9310 Surface Treatment Failure Loads.

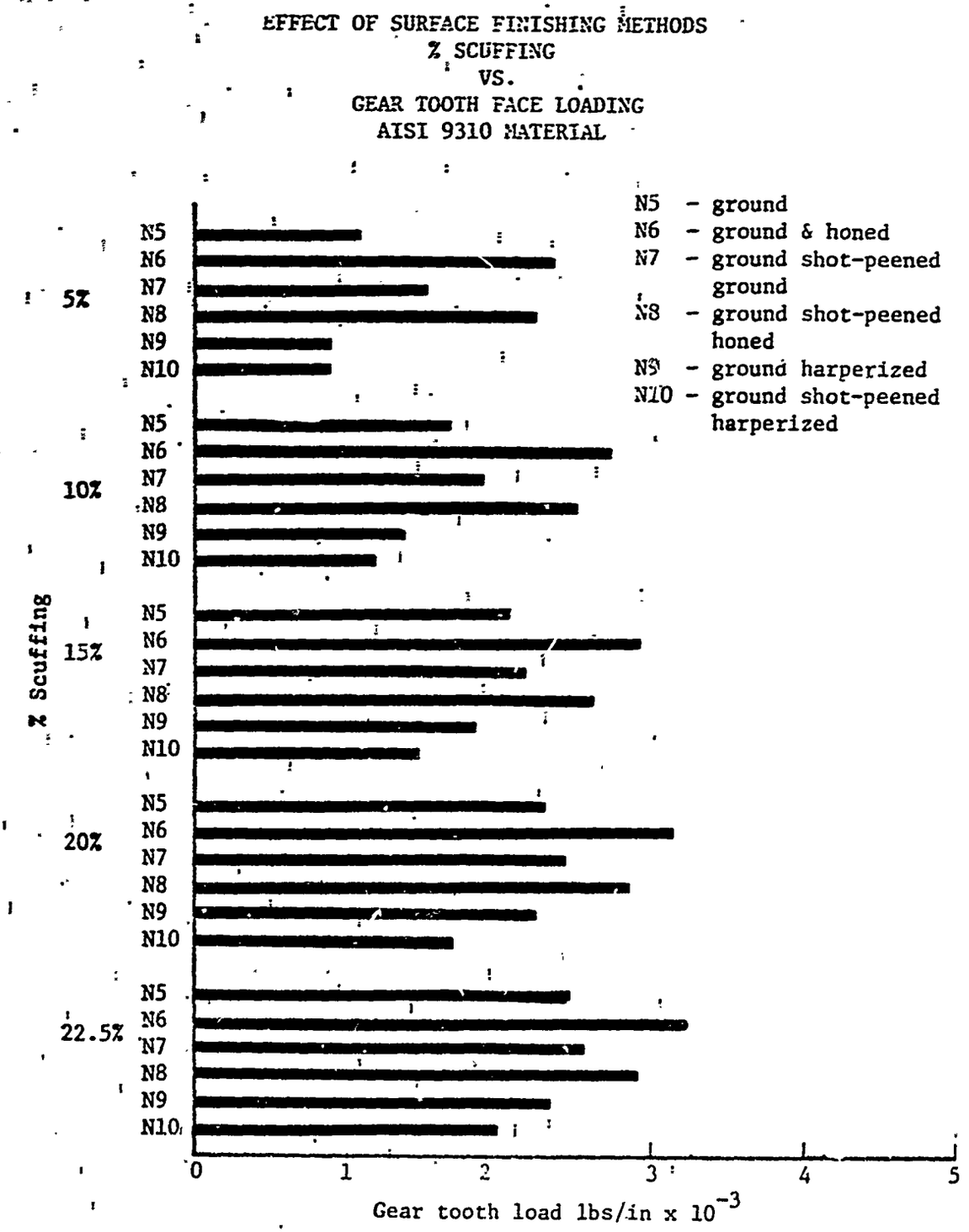


Figure 20. Surface Finishing Methods Failure Loads.

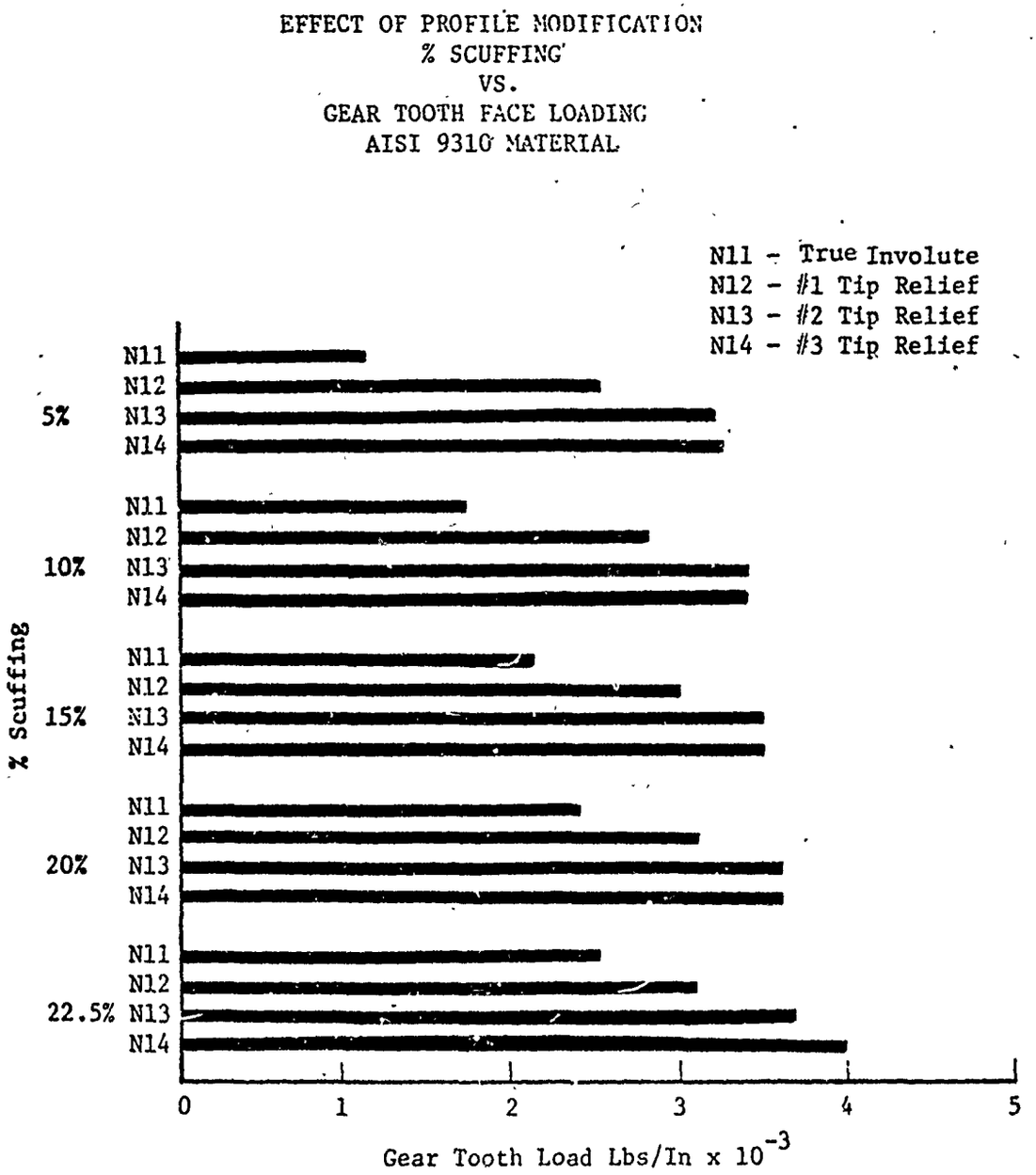


Figure 21. AISI 9310 Profile Modifications Failure Loads.

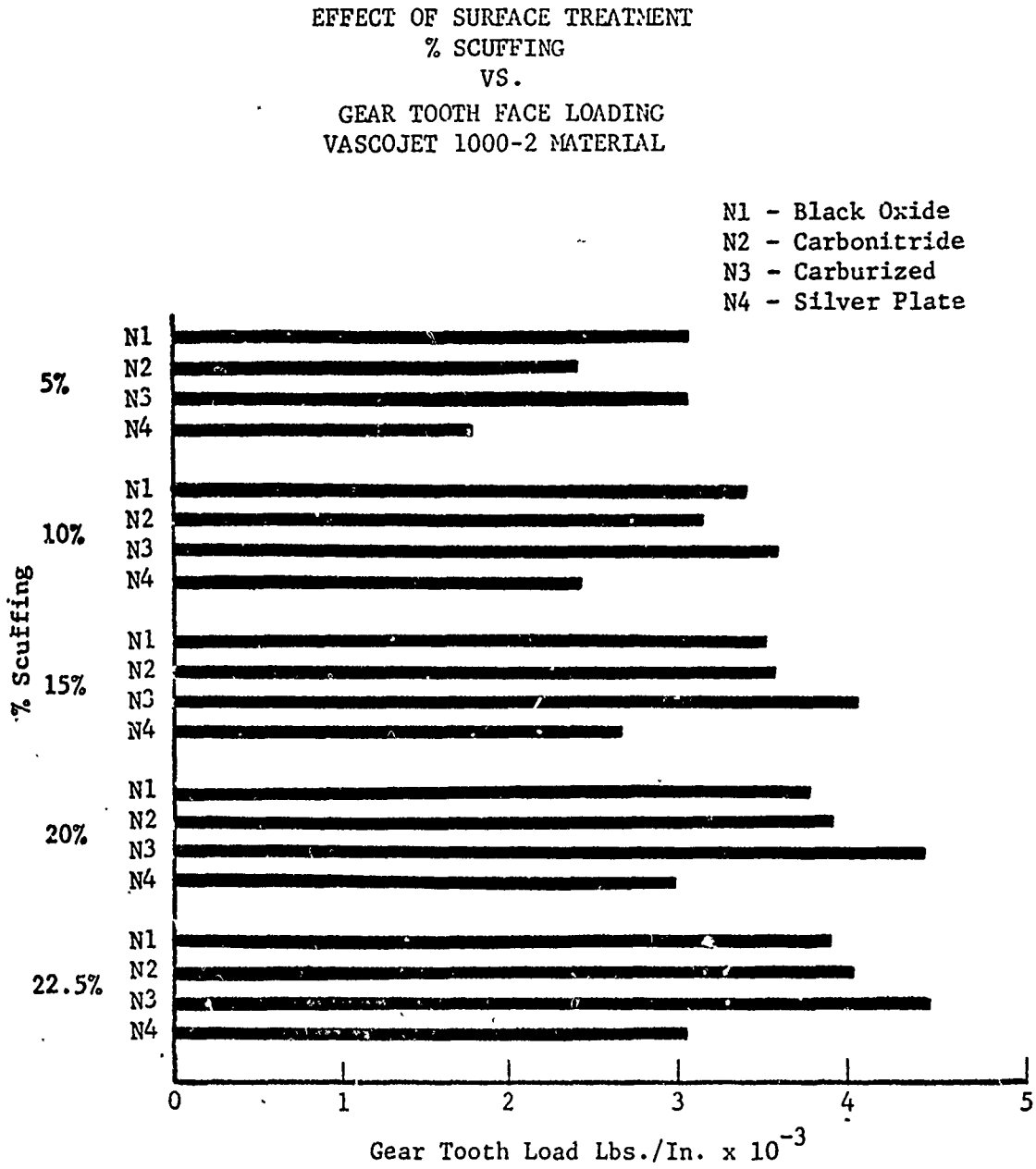


Figure 22. VASCOJET 1000-2 Surface Treatment Failure Loads.

EFFECT OF SURFACE FINISHING METHODS
% SCUFFING
VS.
GEAR TOOTH FACE LOADING

VASCOJET 1000-2 MATERIAL

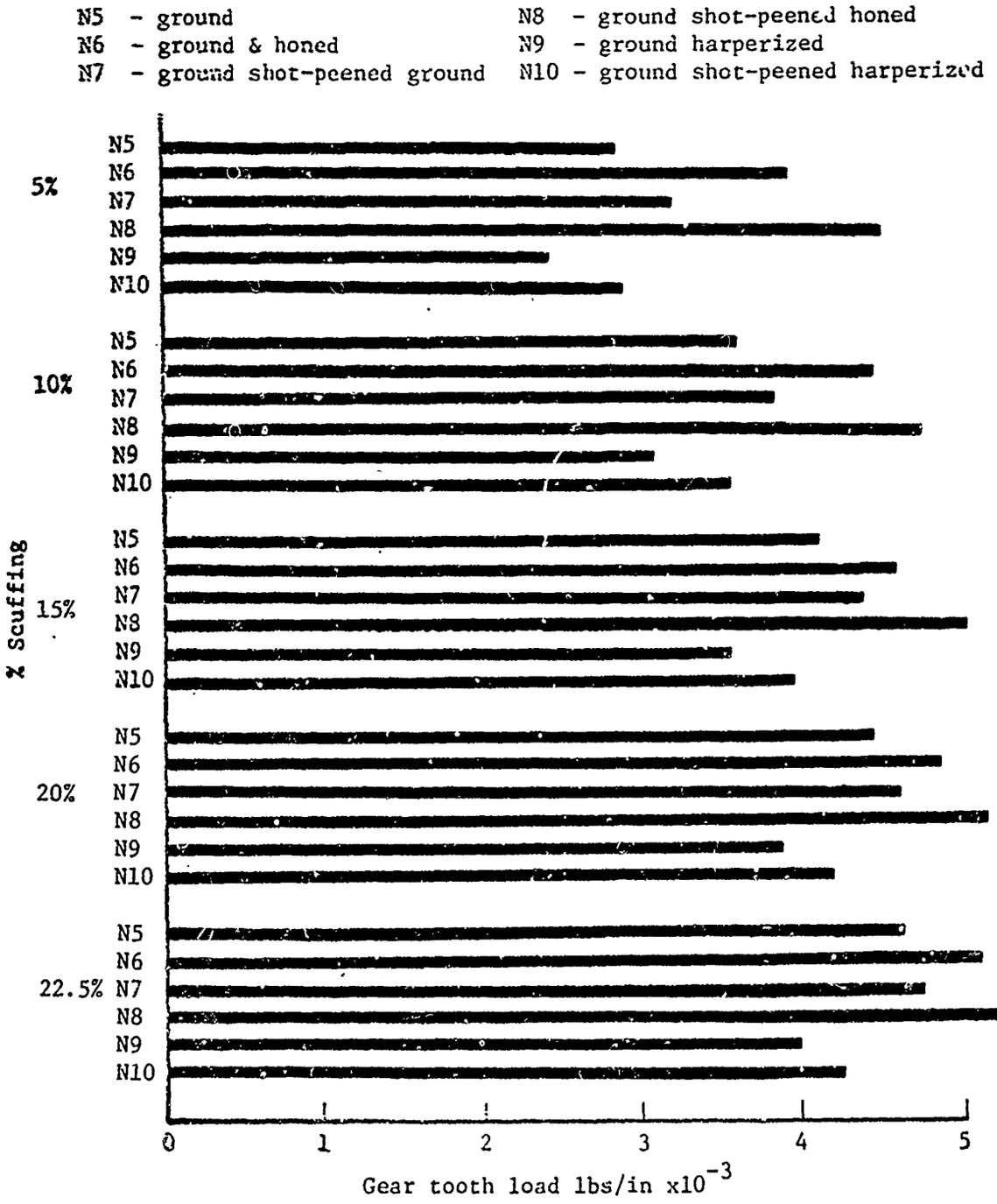


Figure 23. VASCOJET 1000-2 Surface Finishing Methods Failure Loads.

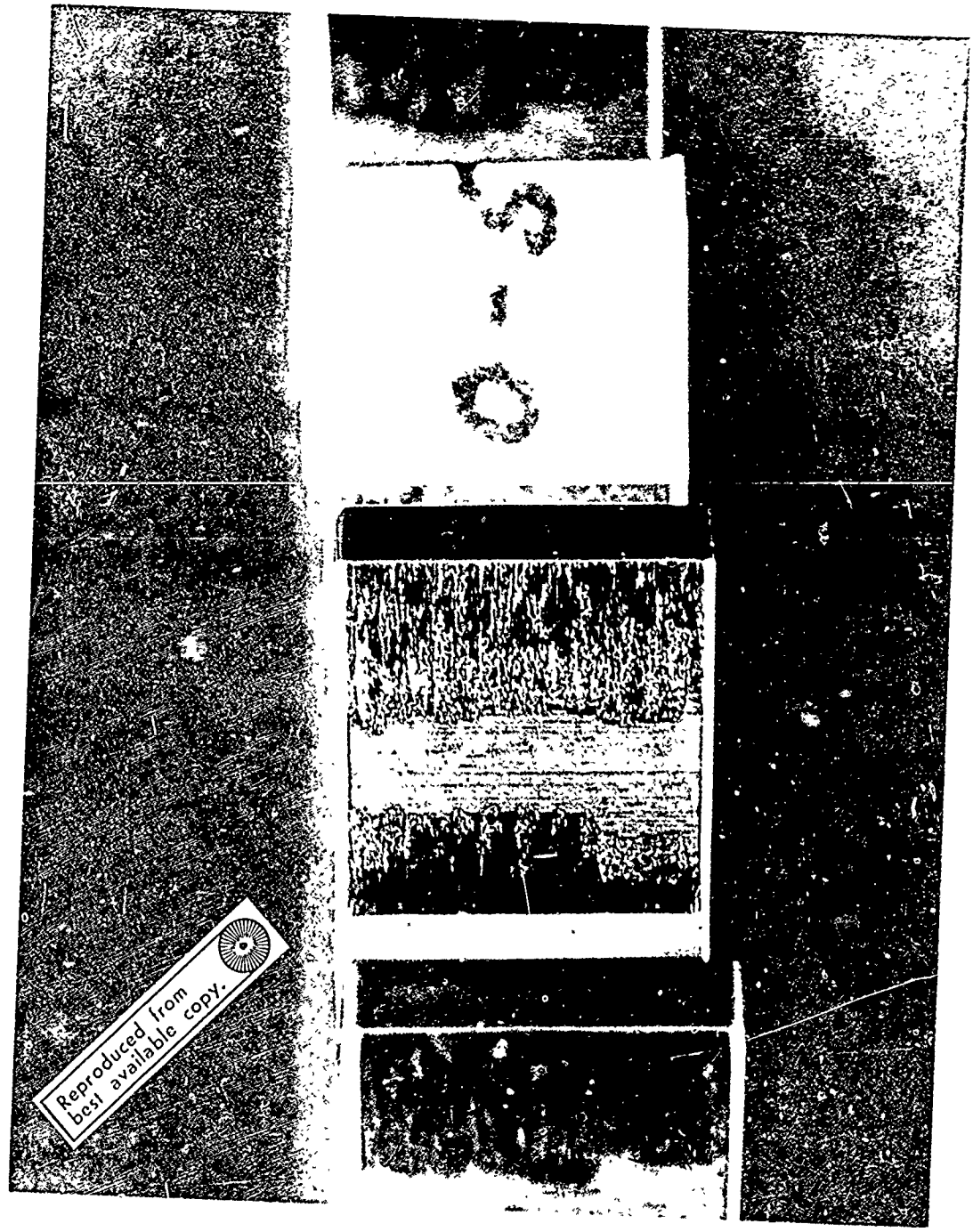


Figure 24. Typical Gear Tooth After Test.

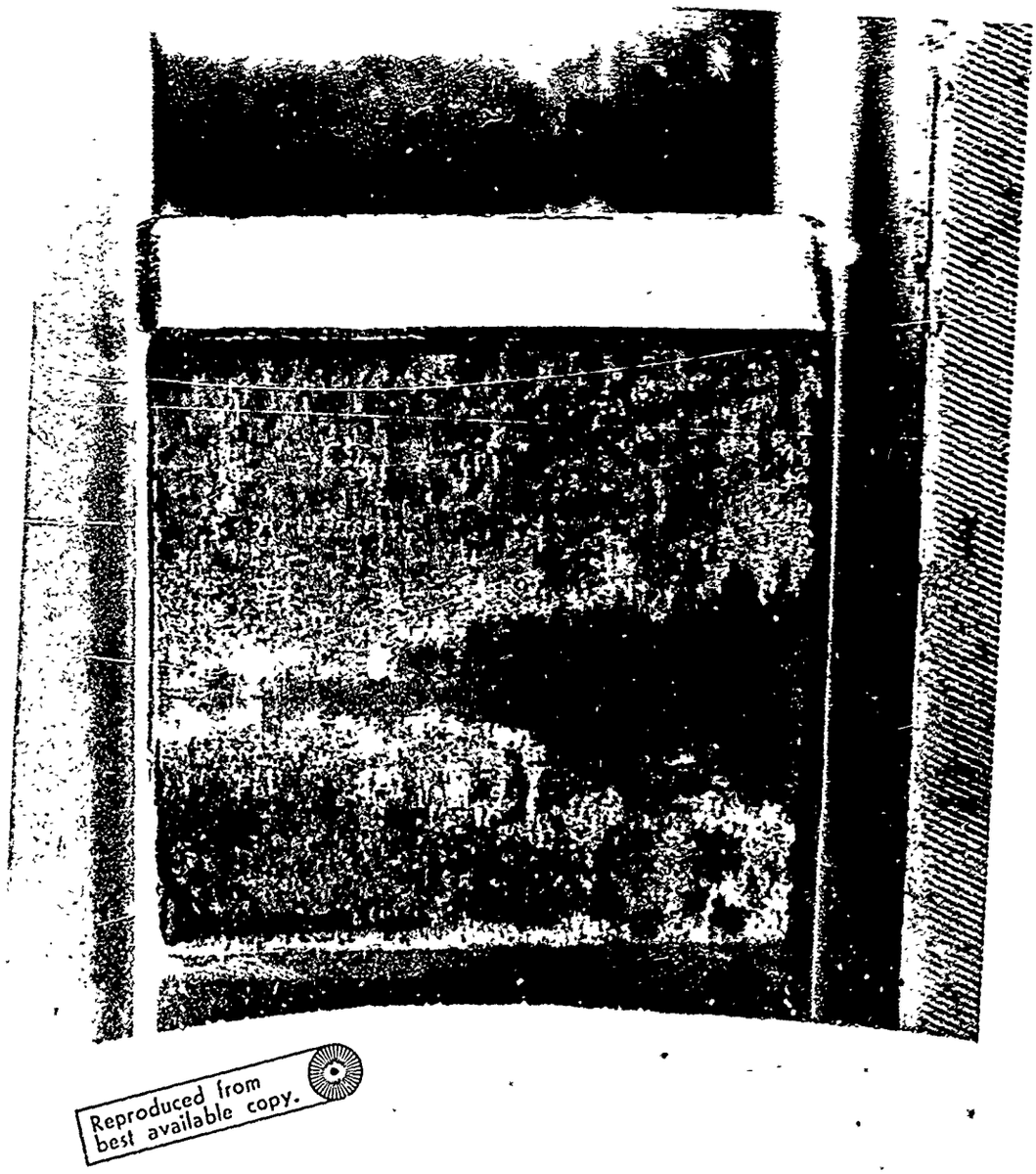


Figure 25. Typical Silver Plate Tooth After Step-Load.

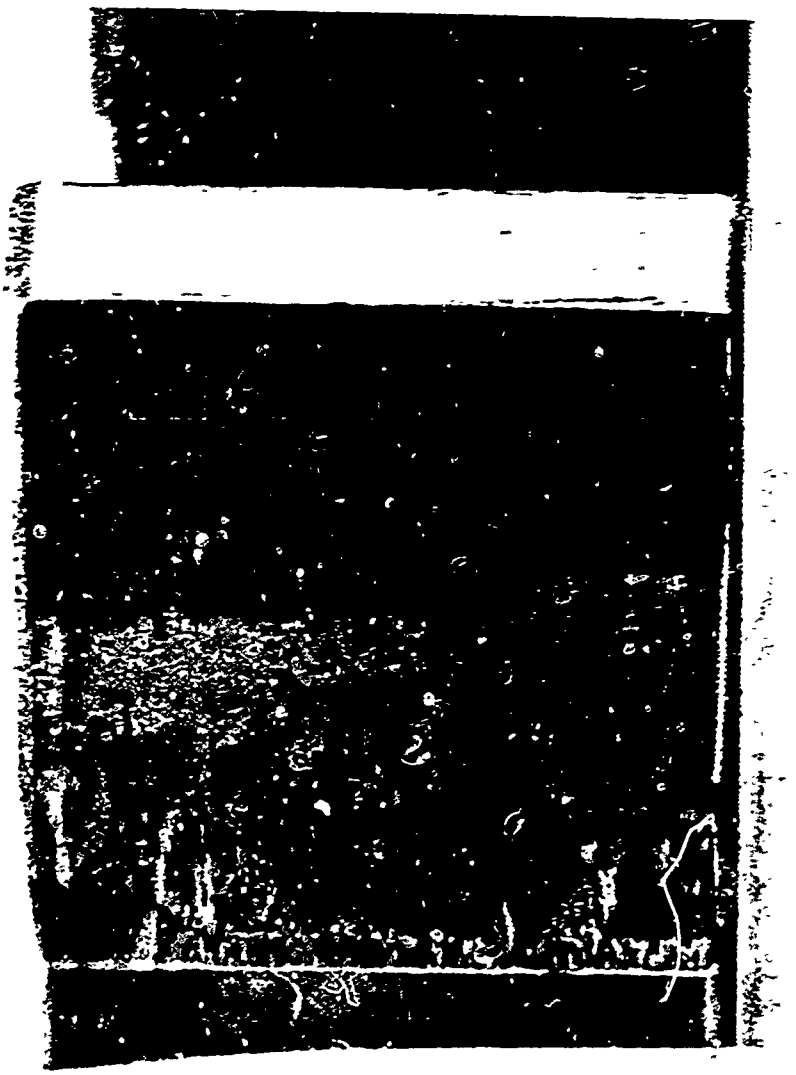


Figure 26. Typical Silver Plate Tooth After 50 Hours @ 3600 Lbs/In.

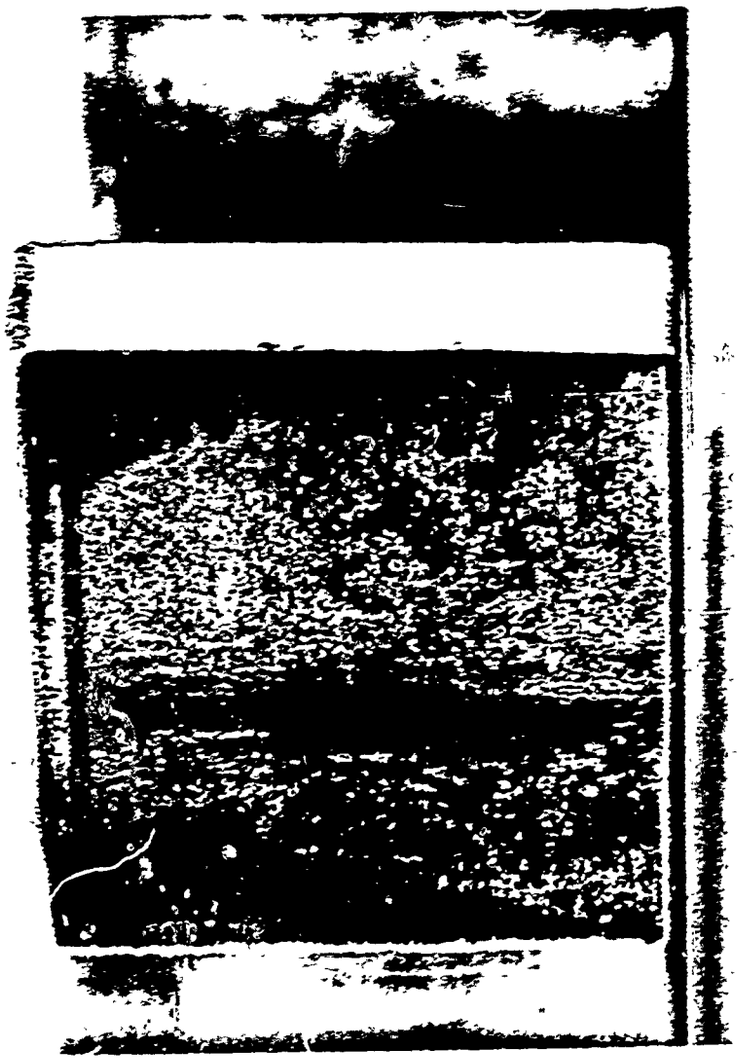


Figure 27. Typical Silver Plate Tooth After 50 Hours 3200 Lbs/In.

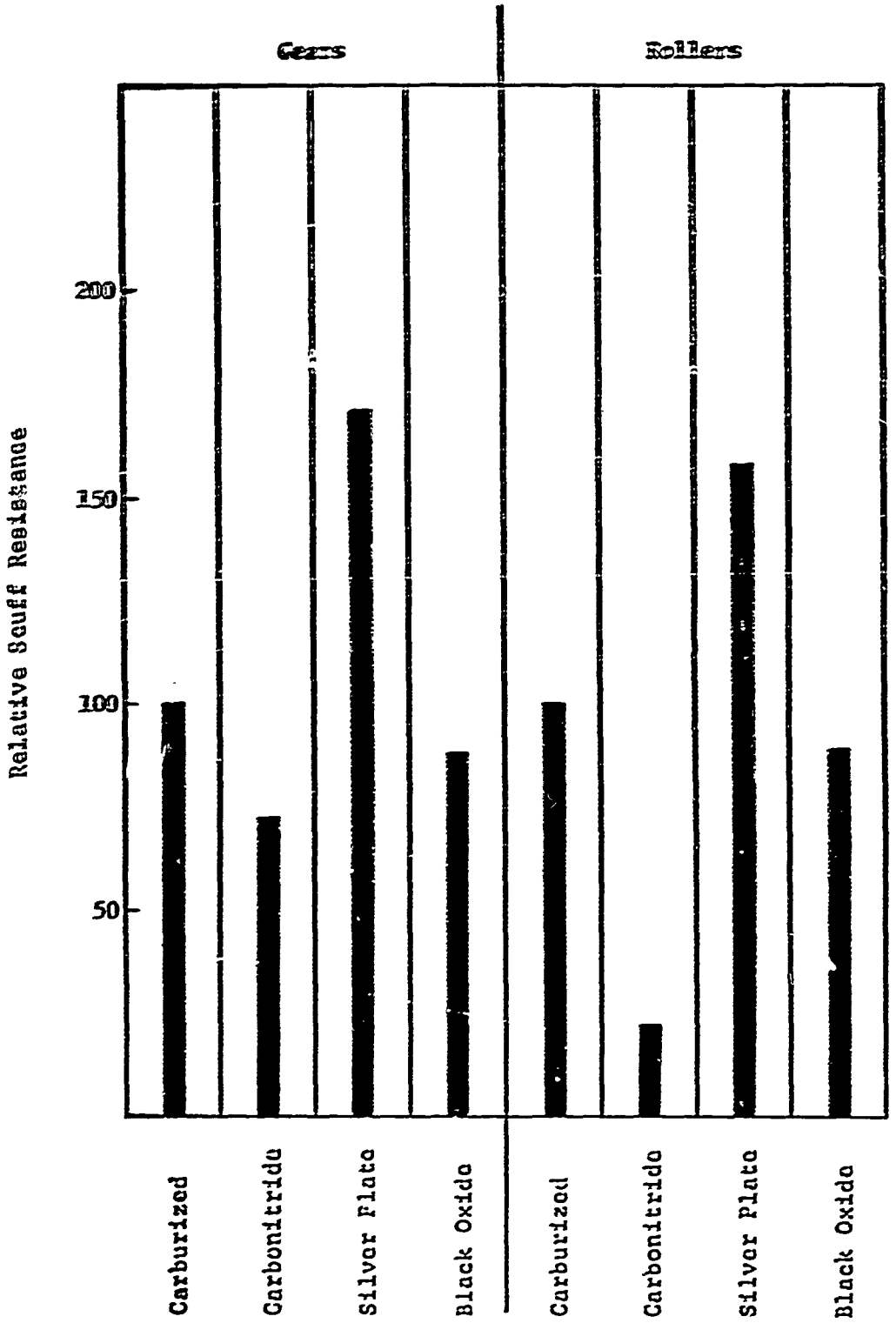


Figure 28. AISI 9310 Material Surface Treatments Effects.

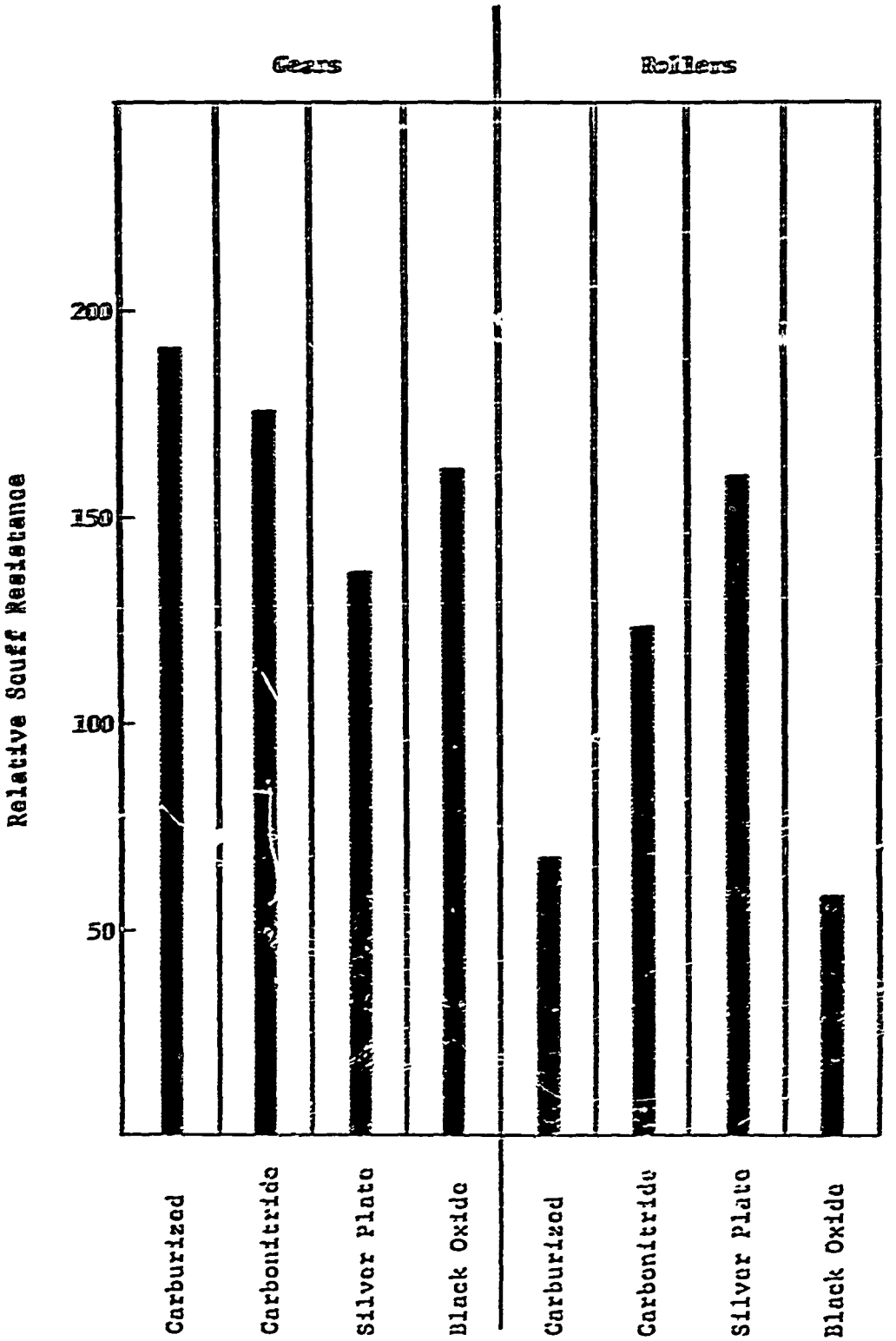


Figure 29. VASCOJET 1000-2 Material Surface Treatment Effects.

MANUFACTURING METHODS

A typical sequence of operation sheets for procuring test gears for use in this program is included as Appendix A. This shows that all gears are processed in the same manner up to a certain point at which time they are segregated to procure separate test lots of the desired configuration and or finish.

CONCLUSIONS

1. On the basis of test results it is apparent that gears made from Vascojet material carburized to a surface hardness of R_C 60 are far superior to current gear material in resistance to scuffing.

2. The resistance to scuffing of conventional gear materials is significantly improved when a thin plate of silver is applied to the gear teeth after finish machining.

3. Honing of gear teeth as a final gear manufacturing operation can improve resistance to scuffing even at the same surface finish level.

RECOMMENDATIONS

Based on the results obtained from the current evaluation and testing performed, it is recommended that certain manufacturing processes be implemented and that additional areas be further explored.

1. Implement silver plate on current gear applications where scuffing is a problem.

2. Implement Vascojet materials for advanced gear applications.

3. Implement honing as a manufacturing method of improving scuff resistance.

4. Investigate the properties of carburized Vascojet materials for other gear operating parameters such as bending and surface fatigue durability. This will determine if a full potential for resistance to scuffing that was demonstrated by this program can effectively be utilized in practical gear applications.

5. Investigate the possibility of utilizing silver plate as a means of relaxing some of the very stringent manufacturing restrictions now placed on certain helicopter gearing.

6. Investigate the utlimate capability of honing to increase resistance to scuffing.

7. Investigate the possibility of replacing honing (which is recommended in items 3 and 4) with a new state-of-the-art development in grinding, such as hydrostatic spindles and ways, that is potentially capable of providing an equally good surface finish.

APPENDIX I
SAMPLE GEAR MANUFACTURING OPERATION SHEETS
GEAR - SCORING TEST

DEPT.	OPER. NO.	OPERATION NAME	TYPE OF MACHINE
		* No Operation Sheet	
9222	10	*Normalize 6260-230	Normalizing Furn. with Endothermic or exothermic atmosphere
9222	20	*Temper 6260-209	Tempering furnace
9222	30	*Abrasive Blast - 400	Wheelabrator tablast
9222	40	Clean spot - 441	Grinder and polishing jack
3200 9222	50	Inspect Hardness (Q.C.O. 09-4)	Hardness testing equipment
7531	60	Face & Bore	14" Engine Lathe
7531	70	Face & Turn (Opp. end)	14" Engine lathe
7531	80	Grind I.D. & Face	1316J Bryant Hole & Face Gr.
7531	90	Grind Opposite Face	#18 Blanchard Grinder
7531	100	*Demagnetize	Demagnetizer
7531	110	Grind O.D.	10 x 36 O.D. Grinder
7531	120	Burr	Blount Speed Lathe
7531	130	*Wash	Washing Machine
3110 7531	140	Inspect before Copper Plate	Bench
9221	150	Copper Plate 2418-21 (All over)	Tanks
3200 9221	160	Inspect Copper Plate	Bench
7531	170	Semi Finish Cut Gear Teeth	14 - 15 Barber Colman Hobber
7531	180	Burr Gear Teeth	Bench
7531	190	*Wash	Washing Machine

GEAR ÷ SCORING TEST

DEPT.	OPER. NO.	OPERATION NAME	TYPE OF MACHINE
3110 7531	200	Inspect before Carburize	Bench
9222	210	*Degrease - 420 & Clean SPM 82	Degreaser & Tanks
3200 9222	220	*Inspect for Cleanliness	Bench
9222	230	Pack Load for Carburizing - 495 (-1)	Heat Treat Equipment
9222	240	*Gas Carburize Using Infra-Red Controlled atmosphere & Sub-critical anneal 6260-266-1A (Note: Contac Metallurgy Lab for exact case depth aim)	Gas Carb. Furn. Infrared Controlled, Endothermic, Gas Generator, Natural Gas, Nitrogen, Zero & Span Gasses, Carburizing Head, Cooling Pit, Blower Cooling.
9222	250	*Unpack Load - 496 (Note: Deliver test material to Metallurgy Lab (Loc. BB-48) One (1) slug is to accompany lot)	Heat Treat Equipment
3200 9222	260	*Inspect Test Piece - 478	Brinell Glass
9222	270	*Light Abrasive Blast - 403	Wheelabrator tablast
9222	280	*Copper Strip 2418-14A	Tanks
9222	290	Copper Plate 2418-21 (All over)	Tanks
3200 9222	300	Inspect Copper Plate	Bench
9222	310	Harden 6260-291 (Single Quench)	Hardening furnace with endothermic atmosphere die quench press
9222	320	*Wash - 431	Washing Machine
9222	330	Check 481	Bench
9222	340	*1st Temper 6260-362	Tempering furnace

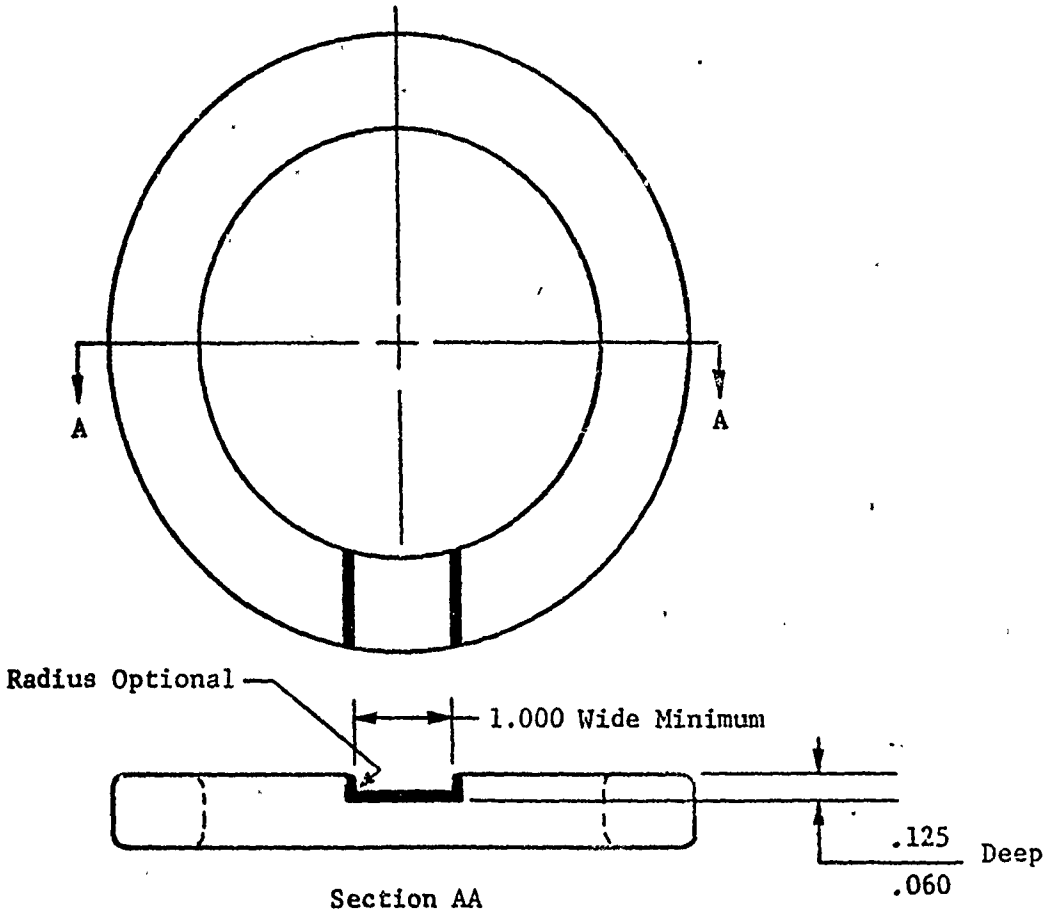
GEAR - SCORING TEST

DEPT.	OPER. NO.	OPERATION NAME	TYPE OF MACHINE
9222	350	*2nd Temper 6260-362	Tempering furnace
9222	360	*Copper Strip 2418-14A	Tanks
9222	370	*Light Abrasive Blast	Abrasive Blast Cabinet
3200 9222	380	Inspect Hardness (Q.C.O. 09-4)	Hardness Testing Equip.
9222	390	*Coat with Corrosion Preventative Oil per MIL-C-1617-GR-3	Tank
7531	400	Finish Grind I.D. & Face	1316J Bryant Hole & Face Gr.
7531	410	Finish Grind End Face (Opp. Side)	#18 Blanchard Grinder
7531	420	*Demagnetize	Demagnetizer
7531	430	Finish Grind O.D.	10 x 36 O.D. Grinder
7531	440	Finish Cut Keyway	10" Model B P&W Slotter
7531	450	Burr Keyway & I.D.	Bench
7531	460	Identify	Bench
3200 7531	470	*Magnetic Particle Inspect Oper. # 400 - 20% Oper. # 410 - 20% Oper. # 430 - 20%	Insp. Equipment
7531	480	*Wash	Washing Machine
3110 7531	490	Inspect	Bench
7531	500	*Coat with Corrosion Preventative oil per MIL-C-16173-GR-3	Tank

DELIVER TO FINISHED STORES

Clean Spot - 441	Oper. No. - 40

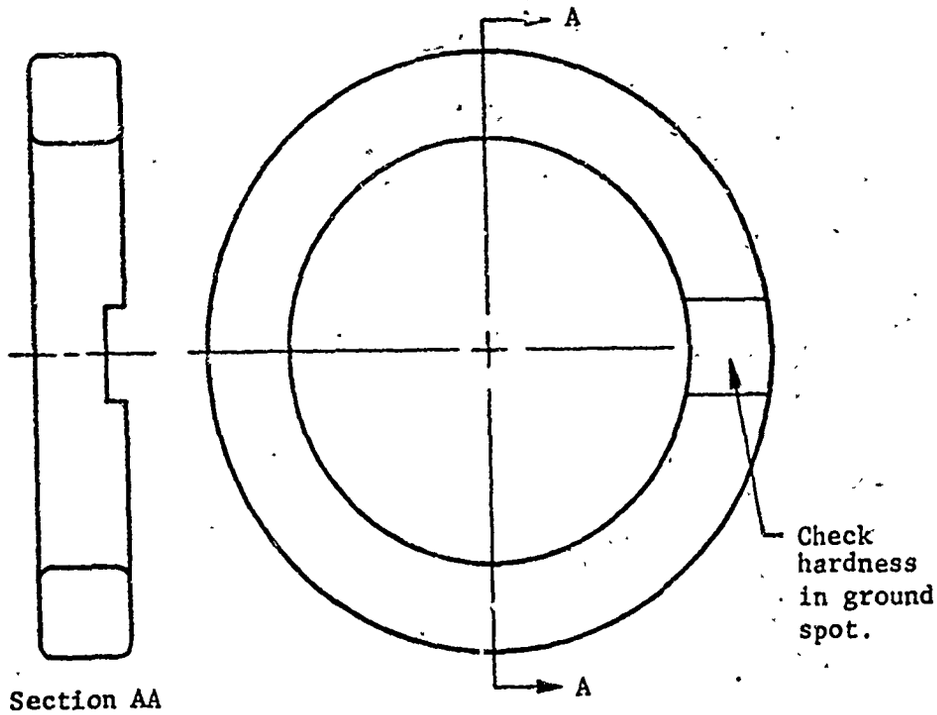
Grind & Wheel Spot Per Sketch.



Section AA

Inspect hardness (Q.C.O. 09-4)	Oper. No. - 50

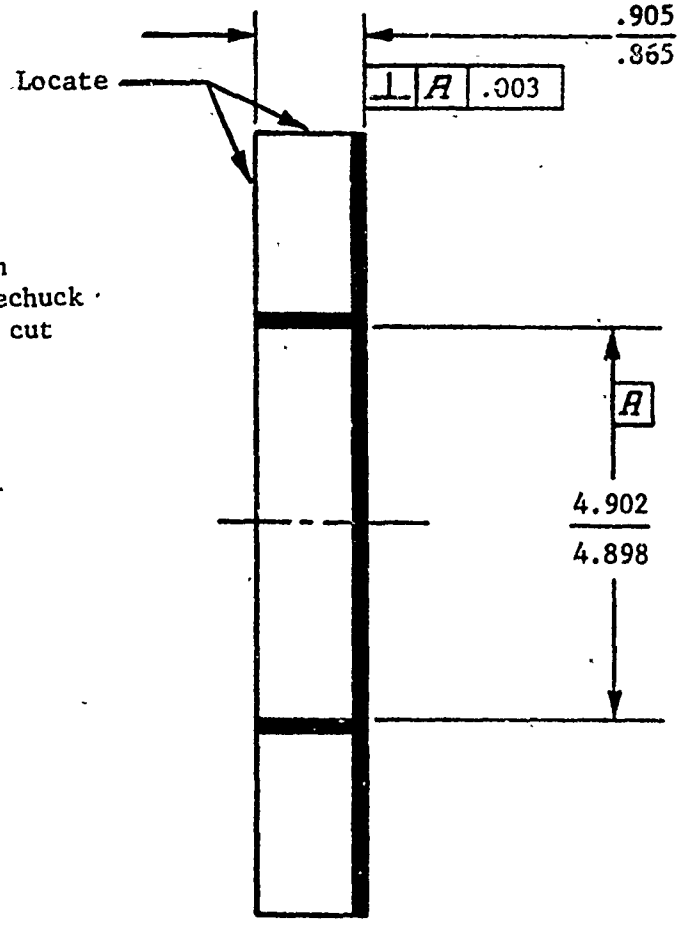
Brinell 223-255 (R_c 19-25)



Loc. on B/P	Gage of Equipment	Gage No.
	Hardness Testing Equipment	

Face & Bore	Oper. No. - 60

Hold forging in hard jaws - machine per sketch.

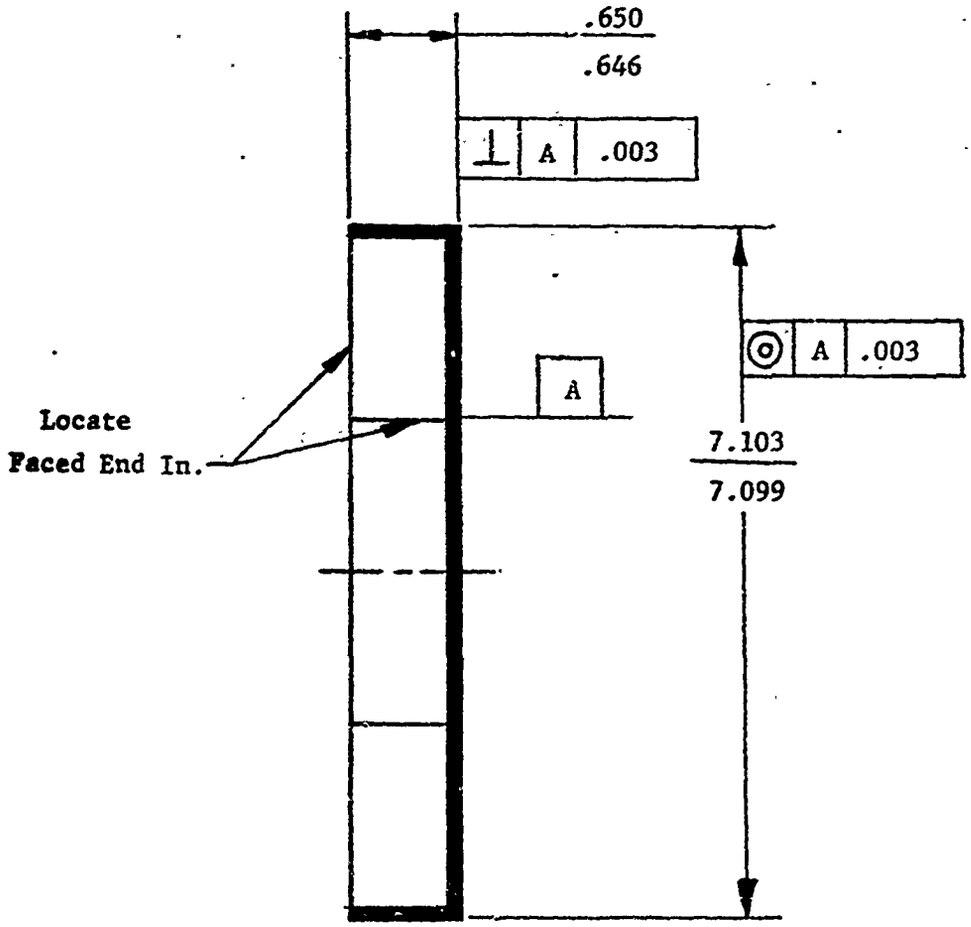


NOTE: Rough machine - rechuck & take skim cut to finish

Gage - Flat Plug 4.898 - 4.902	8G-41015

Face & Turn (Opp. End)	Oper. No. - 70

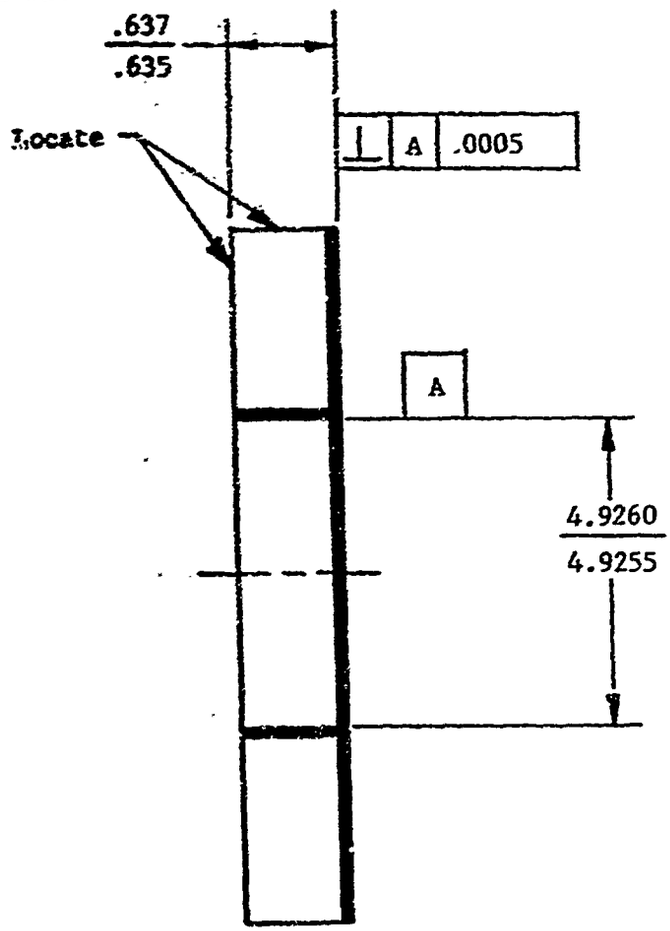
Hold part in soft jaws turned to suit
4.898 - 4.902 I.D. & faced to suit end face.
Machine per sketch.



NOTE: Rough machine.
Re-chuck & take
skim cut to finish.

Grind I.D. & Face	Oper. No. 80

Hold part in sliding chuck jaws ground to suit 7.099 - 7.103 O.D. & locating against tang face with stops.
Ground to suit.
Grind per sketch.



(*)Compensate for Undersize Master

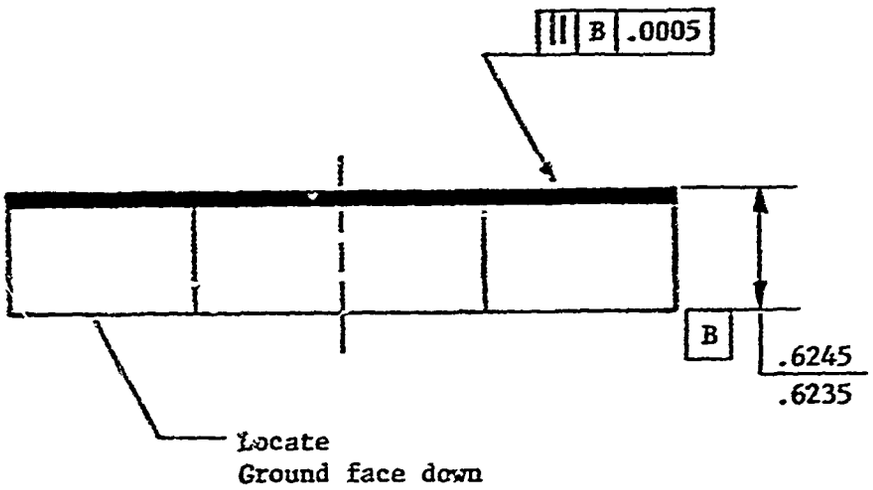
Gage - Int. Ind. 4" - 5" range	8G-57612
Gage - Master Ring (*) 4.923	G3-25982

Grind opposite face	Oper. No. - 90

Hold (15) parts on magnetic table at one time - ground face down.

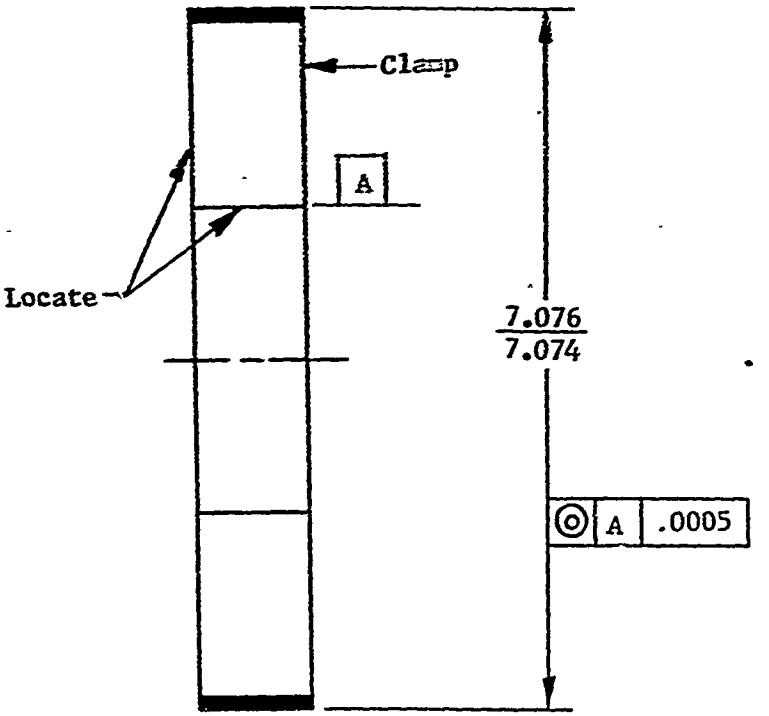
NOTE: Stone ground end face before placing part on magnetic table.

Grind per sketch.



Grind O.D.	Oper. No. - 110

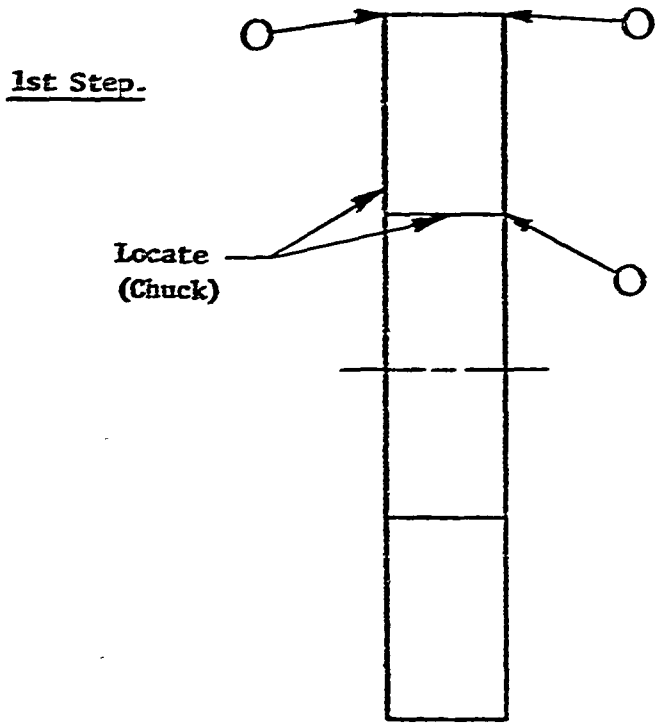
Hold (4) part on arbor at one time -
locating in 4.9255 - 4.9250 I.D. & against
either end face-clamp-hold arbor &
parts between centers -
grind per sketch.

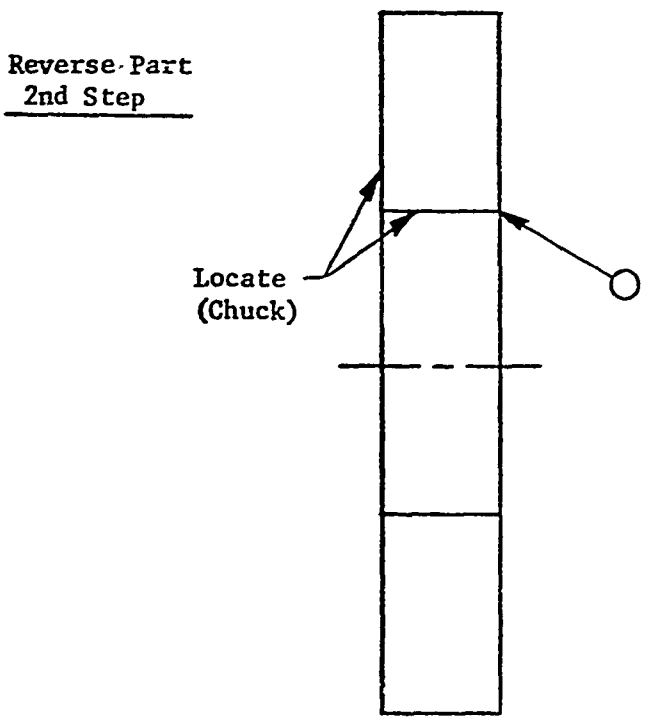


Tool	Tool No.
Arbor-Grinding	8T-78357

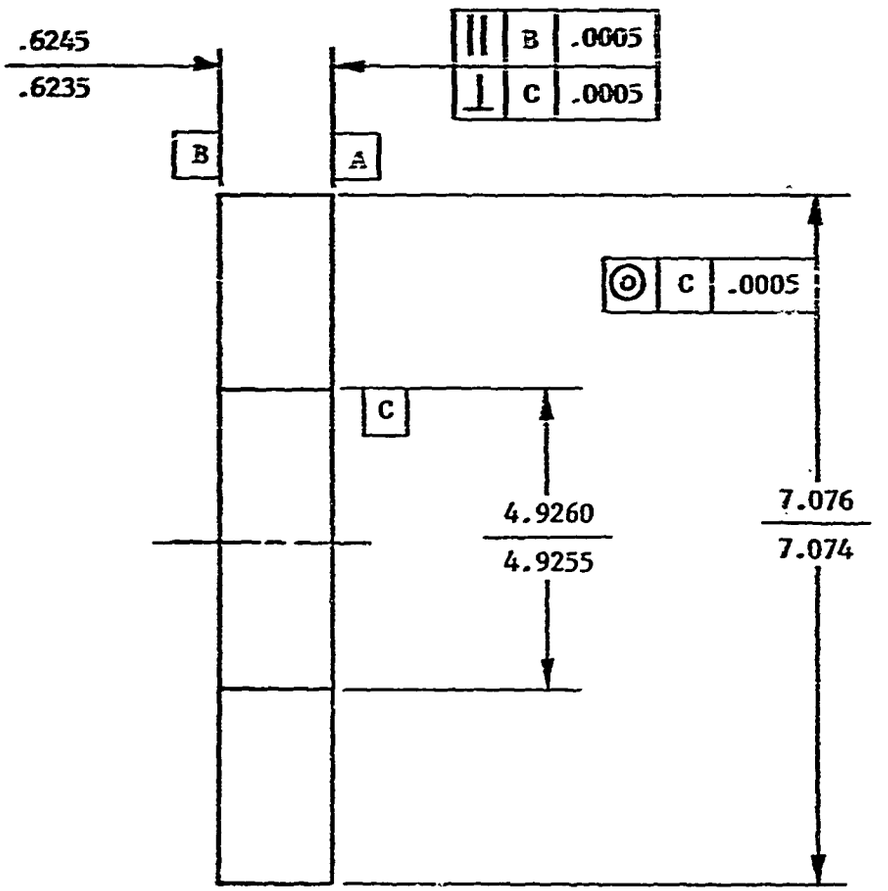
Burr	Oper. No. - 120

Break sharp edges where shown by ← ○ .003 - .015.





Inspect Before Copper Plate	Oper. No. - 140



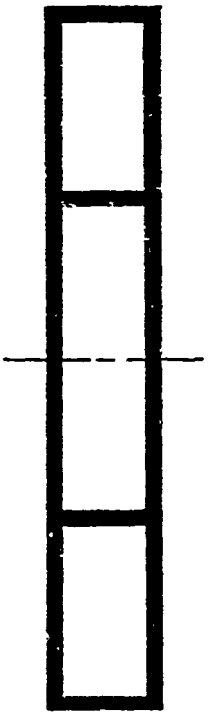
(*) Compensate for undersize master

Bench	
Gage - Int. Ind. 4" - 5" range	8G-57612
(*) Gage - Master Ring 4.923	G3-25982

Copper plate 2418-21 (all over).	Oper. No. - 150

Copper plate all over per 2418-21.
Thickness of copper plate .0008 - .0012.
Heavy lines denote surfaces to be copper plate.

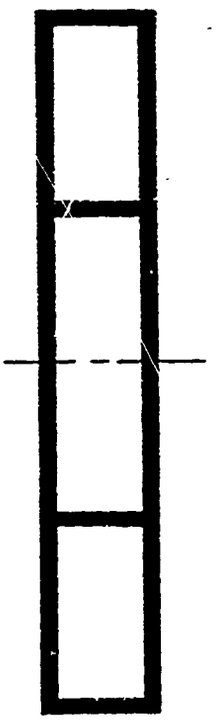
NOTE: Copper plate must be clean - even - & free of beads - for locating.



Inspect Copper Plate	Oper. No. - 160

Check for blisters, peeling, etc. - strip & replate if necessary.
Check .0008 - .0012 thickness of copper plate.

Heavy lines denote copper plated surfaces.



NOTE: Copper plate must be clean - even - & free of beads - for locating.

Location On B/P.	Gage Or Equipment	Gage No.
	Bench	

GEAR - SCORING TEST

MACHINE NAME: 14-15 Barber Colman Hobber

OPERATION NAME: Semi-Finish Cut Gear Teeth OPERATION NO.: 170

Hold(4) parts on Adapter locating in 4.923 - 4.9235 I.D. & against end faces (Use spacers dets 12 & 13)

Indicate Adapter to run true within .0005 or full indicator reading.

Semi-Finish Cut Gear 33 teeth. 5 pitch. 25° pressure angle to measure 7.128 - 7.130 over .3456 Dia. Wires.

Note: Check Number of teeth using Template.

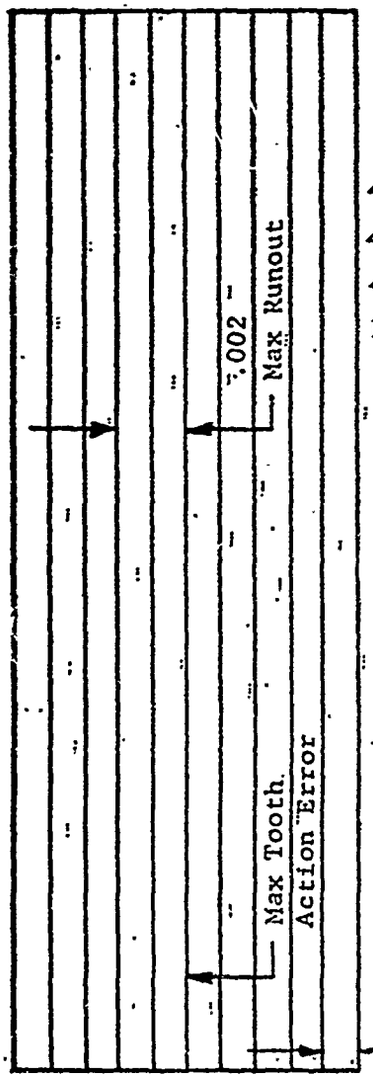
Note: Check Root Dia. to 6.144-6.146 using Spec. Micr. (Adj. for odd No. of teeth)

Note: Check Fillet Radius to .065 min.

TOOLS	TOOL NO.
Adapter-Cutting	T3-28542
Hob-5p-25° P.A. Det.#7	T3-25446
Gage - Micr. Spec.	G3-25518
Template-CKG. 33T,5P, Det.#211	8G-34513
WIRES GAGING (2)	
.3456 Dia. Det.#101	5T-14110

Check Gear Teeth (Semi-Finish Cut Gear Teeth) — Oper. No. - 170

Red Line Chart



Gear Data

33T 5 P 25°P.A.

∠O-I 35.9°

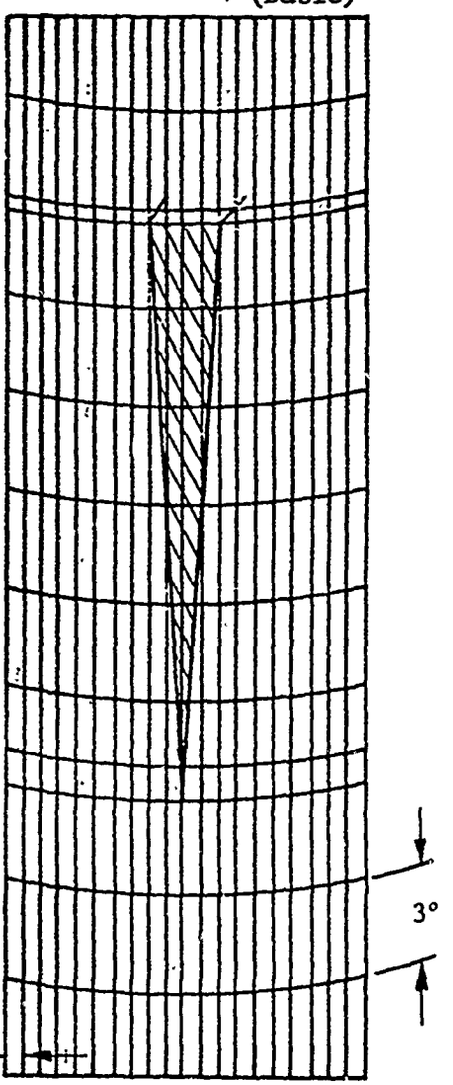
∠P

∠C 18.8°

Base Radius 2.9908

NOTE: Check tooth parallelism on both sides of teeth to be within .0003 F.I.R.

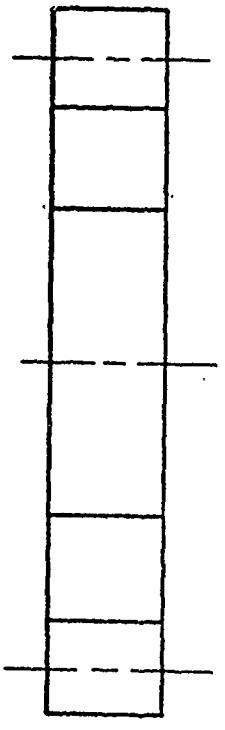
Involute Chart (Basic)

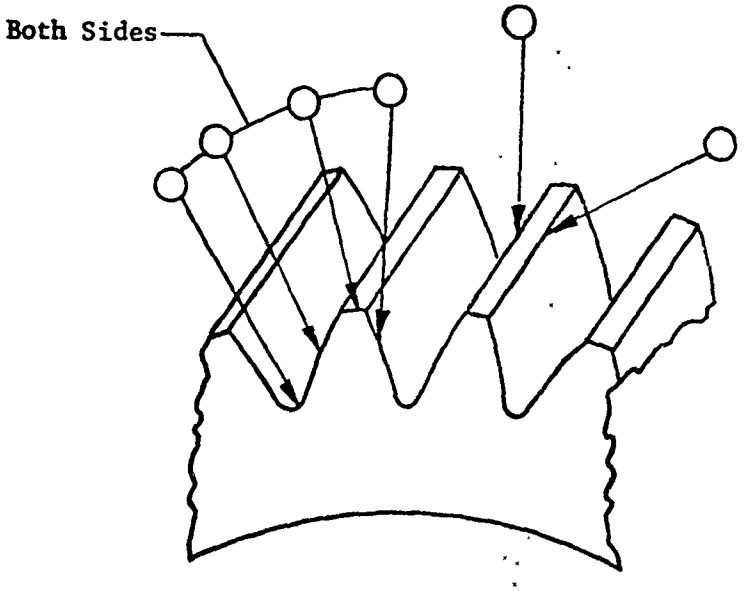


Tools	Tool No.
Arbor Checking	T3-26296
Gear - Master	2MG114D2076-1
Arbor - Master Gear	E-10141
Chart - Comparator XI .065R Det. No. 46	8G-29141

Burr Gear Teeth	Oper. No. - 180

Burr & break sharp edges where shown by ←○ .003 - .015

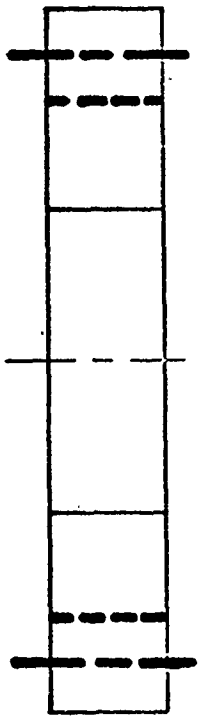




CAUTION: Do not mar copper plated surfaces.

Inspect Before Carburize	Oper. No. - 200

Copper plate must be removed from surfaces indicated by heavy lines and intact on all other surfaces



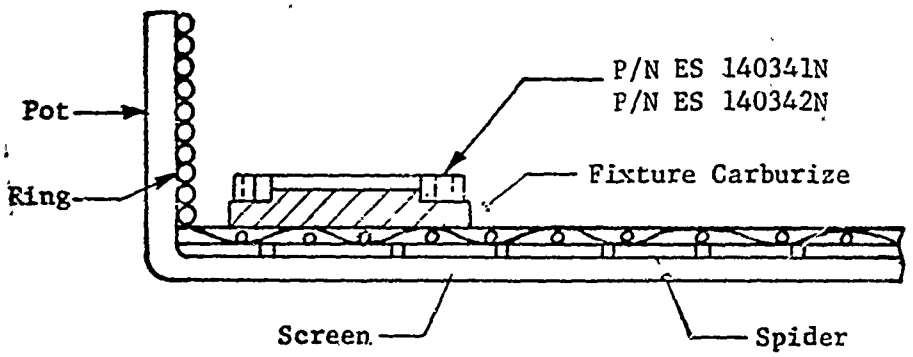
Inspect for break edges on gear teeth to .003 - .015 per B/P.

Location On B/P.	Gage Or Equipment	Gage No.
	Bench	

Pack Load for Car rizing - 495(-1)	Oper. No. - 230

1. Use rings to build up layer deep enough for part to clear bottom of pot.
2. Place metal spider on rings of pot.
3. Place wire screen on the spider.
4. Place (1) test piece on screen in bottom part.
5. Place parts in pot as per sketch, uniformly to minimize shifting and marring from vibration and also providing circulation for carburized surfaces.
6. Use rings to build up layers in the pot - make sure layers do not touch.
7. Place (1) test piece in the third pot.
8. On completion of loading the 5th pot is to have (1) test piece and (1) part - stamp load number on test pieces.

NOTE: Contact metallurgy lab personnel on required test slugs and carbon bar material to be packed.

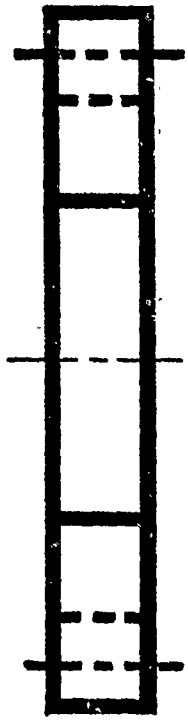


CAUTION: Do not load parts into furnace. Contact R. Grootenboar (tool trouble man in heat treat) for carburizing fixture.

Copper Plate 24-18-21 (All Over)	Oper. No. - 290

Tanks

Copper Plate all over per 2418-21.
Thickness of copper plate .0005 - .0012.
Heavy lines denote surfaces to be copper plated.



Inspect Copper Plate	Oper. No. - 300

Check for blisters - peeling etc. - strip
& replate if necessary.
Check .0005 - .0012
thickness of copper
plate.

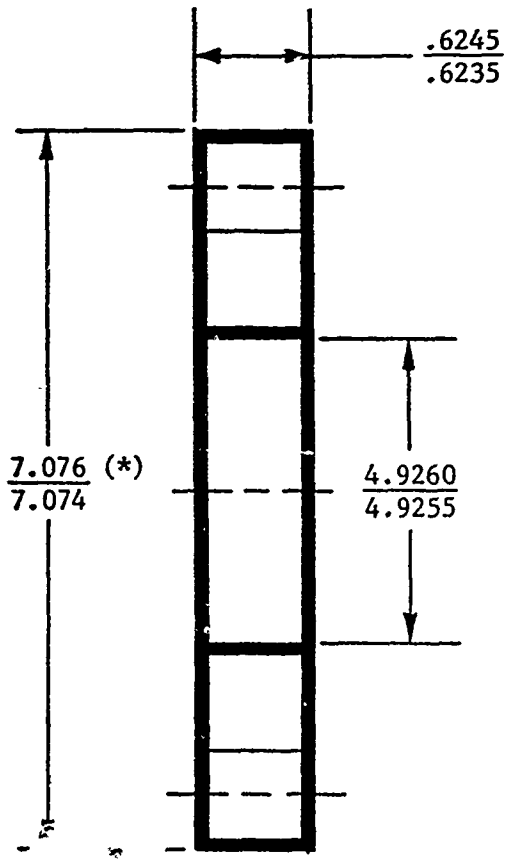
Heavy lines
denote copper
plated surfaces.

Loc. on B/P	Gage or Equipment	Gage No.
	Bench	

Harden 6260 - 291 (Single Quench)	Oper. No. - 310

NOTE: Dimensions shown on part are before copper plate & carburize.

NOTE: Heavy lines denote die locating surfaces.

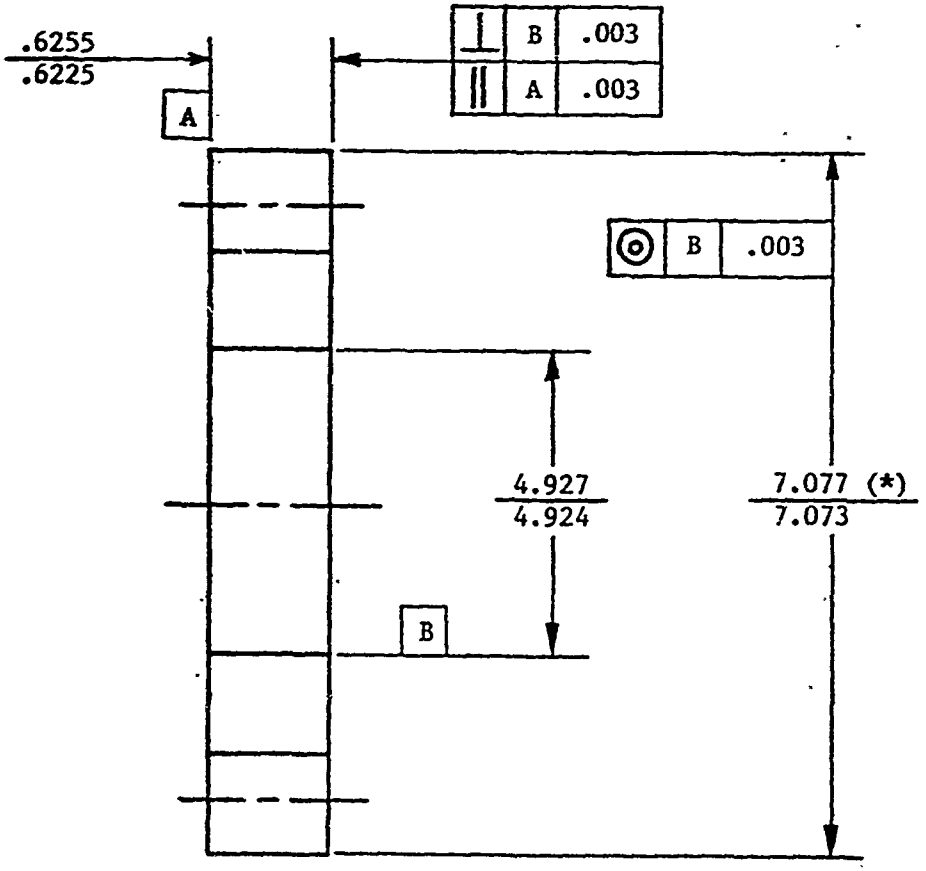


CAUTION: Do not load parts into furnace. Contact R. Grootenboar (Tool Trouble man in Heat Treat) for quenching die.

(*)NOTE: Dimension over odd number of teeth is 7.066 - 7.068.

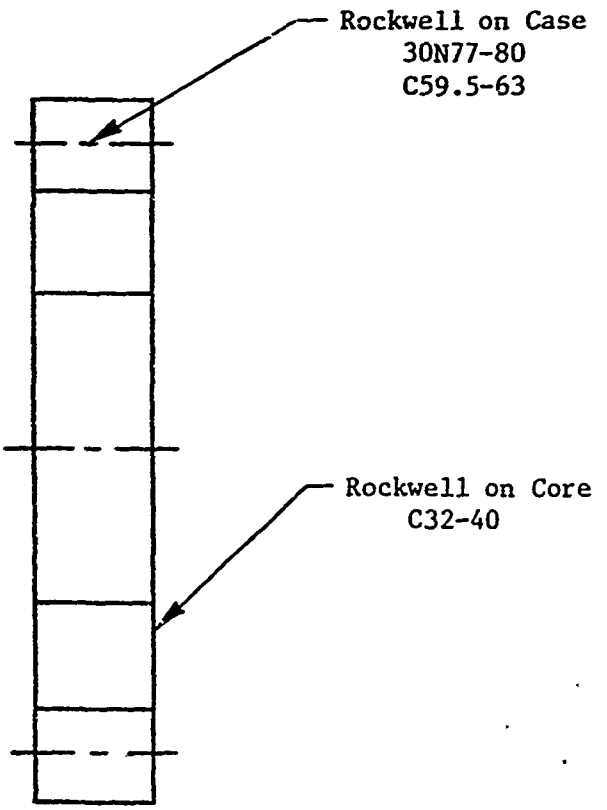
Tools
Die - Quenching

Check 481	Oper No. - 330



(*)NOTE: Dimension over odd number of teeth is 7.065 - 7.069.

Inspect Hardness (Q.C.O. 09-4)	Oper. No. - 380

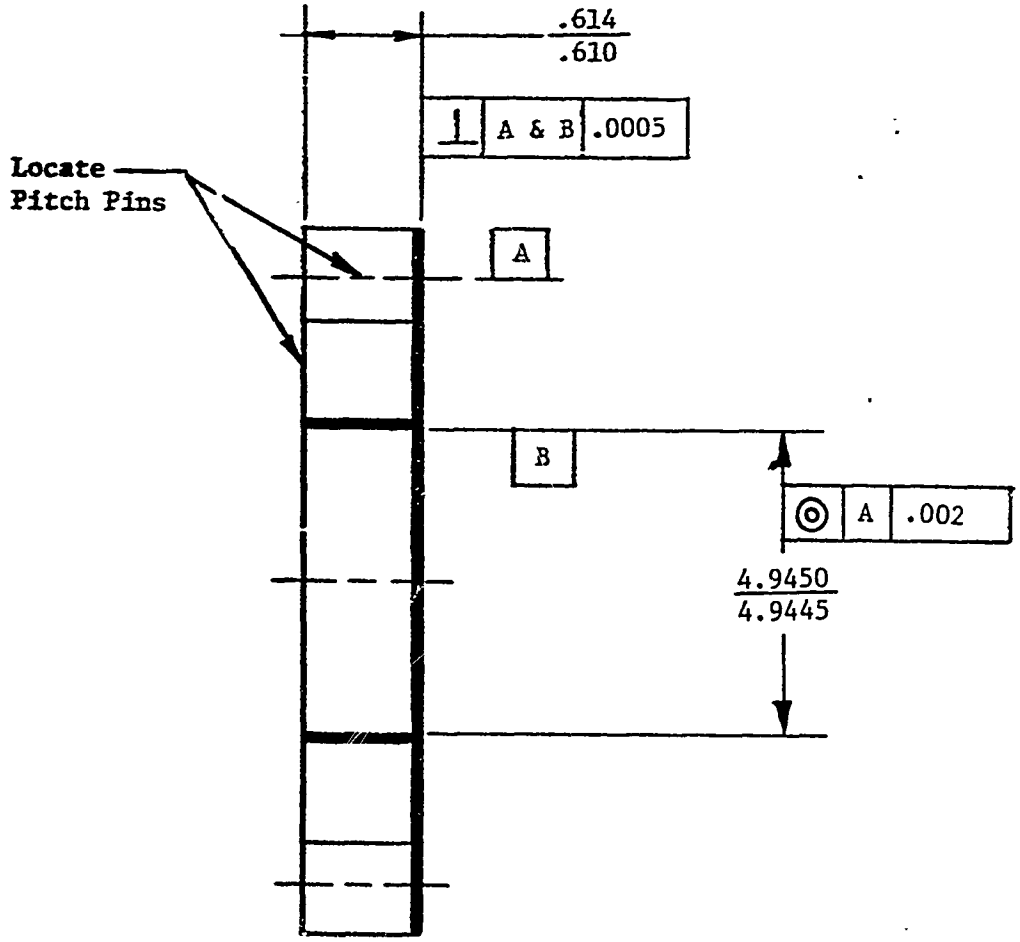


Stone high spots left by indentation. All parts, anvils, fixtures etc., must be clean and dry before hardness test is performed.

Loc. on B/P	Gage or Equipment	Gage No.
	Hardness Testing Equipment	

Finish Grind I.D. & Face	Oper. No. – 400

Hold part in sliding chuck jaws ground to suit 7.129 P.D. of part with gaging wires & locating against end face with stops ground to suit.



NOTE: Magnetic particle inspect per Oper. No. 470 shown on traveler.

(*)NOTE: Master ring is .0005 under low limit – compensate on internal indicator.

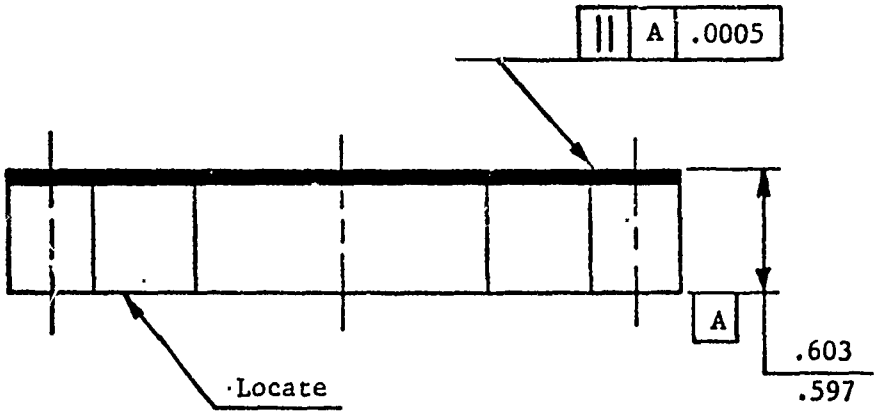
Tools	Tool No.
Wires - Gaging .3456 Det. #101	5T-14110
4" - 5" Range Gage-Master Ring 4.944 (*)	8G-57612
	8G-52378

Finish Grind End Face (Opp. Side)	Oper. No. - 410

Hold (15) parts on magnetic table at one time - ground face down.

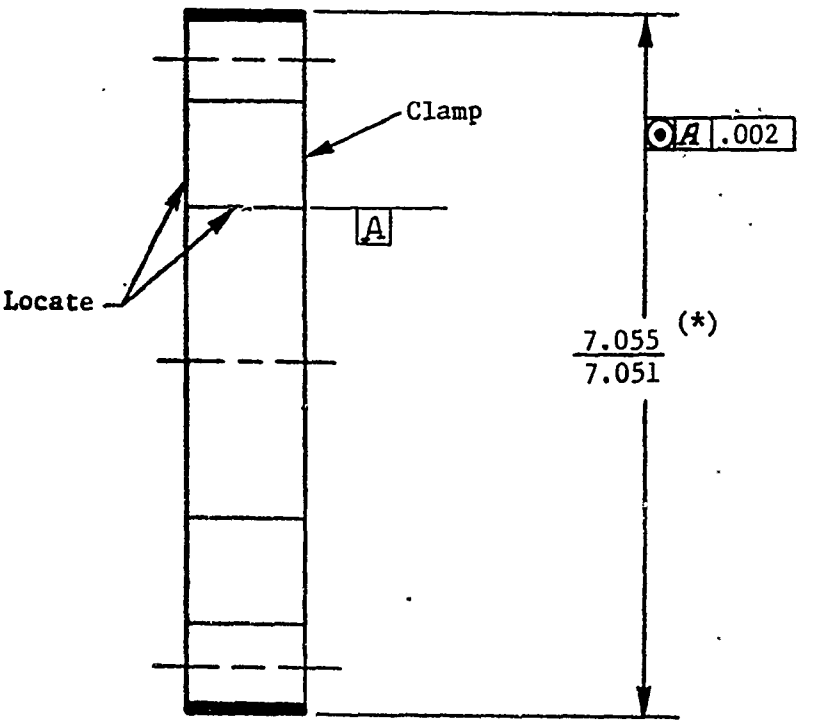
NOTE: Stone ground end face before placing part on magnetic table. Grind per sketch.

NOTE: Magnetic particle inspect per Oper. No. 470 shown on traveler.



Finish Grind O.D.	Oper. No. - 430

NOTE: Magnetic particle inspect per Oper. No. 470 shown on traveler.



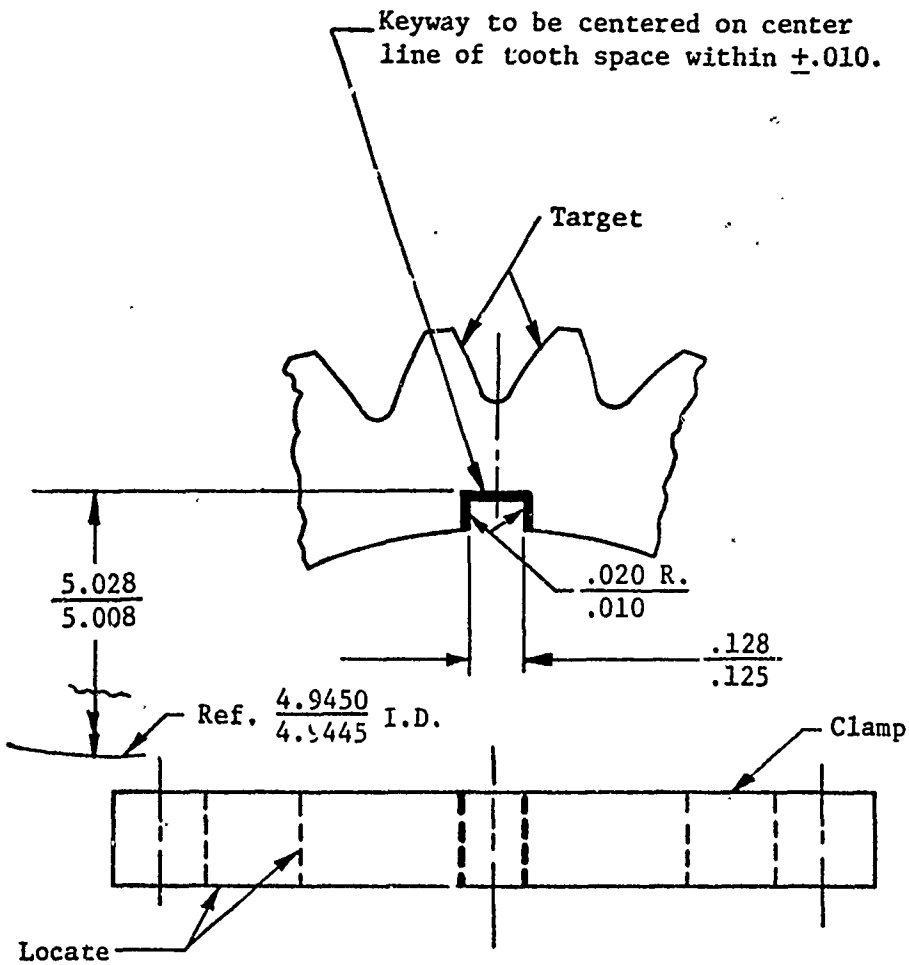
Hold (4) parts on arbor at one time - locating in 4.9445 - 4.9450 I.D & against either end face - clamp - hold arbor & parts between centers -
Grind per sketch.

(*)NOTE: Dimension over odd number of teeth is 7.043 - 7.047.

Tools	Tool No.
Arbor-Grinding	T3-31921

Finish Cut Keyway	Oper. No. - 440

Hold part on fixture - locating in 4.9445 - 4.9450 I.D. & against either end face - target one tooth space - clamp - machine per sketch.

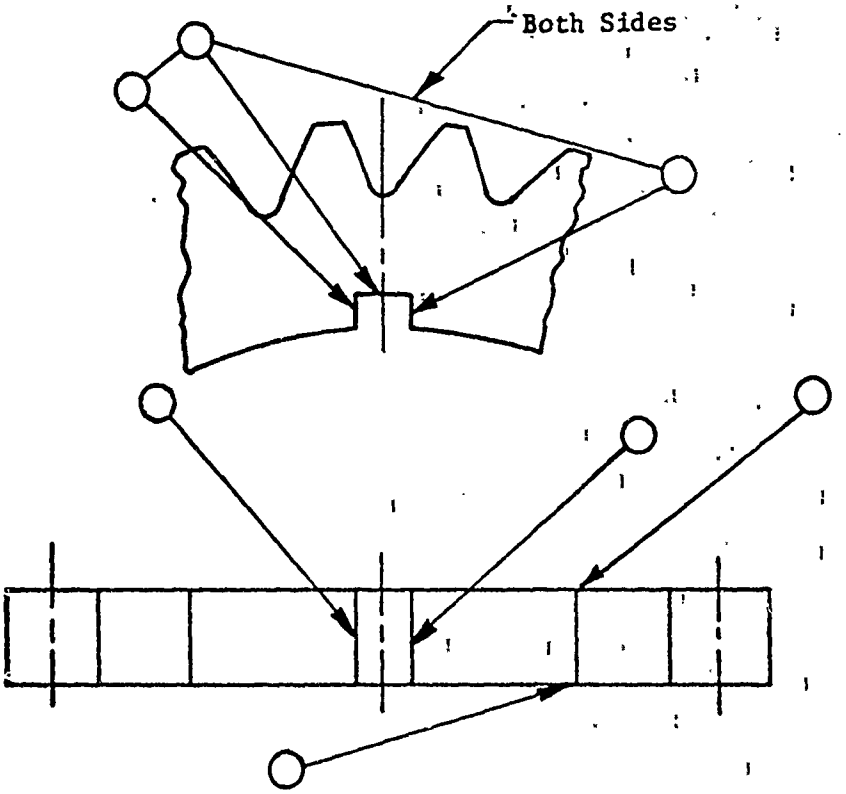


Tools	Tool No.
Fixture-Holding	8T-78351

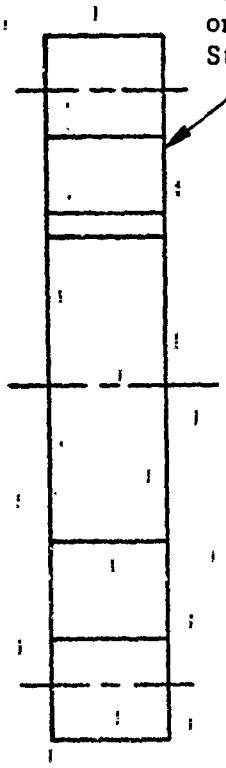
Tool-Slotting .1265 Wide .015R.	150-3170-025 8T-78354

Burr Keyway & I.D.	Oper. No. - 450

Burr & Break Sharp Edges Where Shown by ◄—○ .003 - .015

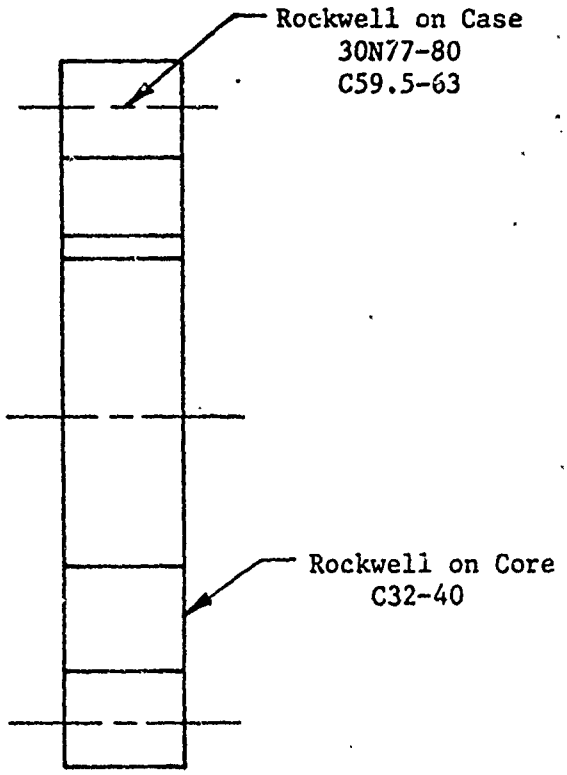


Identify	Oper. No. - 460



Vibro Peen Serial No. & Part No. ES 140341 N
on either end face per Mil Std. 130.
Stone face to remove raised metal only.

Inspect	Oper No. - 490



Stone high spots left by indentation. All parts, anvils, fixtures etc., must be clean and dry before hardness test is performed.

Loc. on B/P	Gage or Equipment	Gage No.
	Bench	
	Hardness Testing	
	Equipment	

GEAR - SCORING TEST

OPERATION NAME: Inspect OPERATION NO.: 490

ITEM NO.	CHARACTERISTIC	GAGE OR EQUIPMENT	GAGE NO.
1.	Identify Part to B/P.	Bench	
2.	Verify Eng. Chg. Letter on Oper. Sheet to B/P and Travelers.		
3.	Verify stamps on traveler for floor inspection operations.		
4.	Verify all pertinent stamps on parts.		
5.	Consult inspection data card.		
6.	Verify gages for date and color code.		
7.	Inspect parts visually for cleanliness. Mutilation & protective measures.		
8.	Material AISI 9310 Steel (ES140344) Hand Forging MIL-I-6868-Magnetic Particle Insp. MIL-C-16173 - Compound - Corrosion Preventative - Soft Film - Cold Application		
	CWC 9047 - Quality Control Standard 6260 HT 41 - Normalizing - Carburizing-Hardening & Tempering parts machined from forgings which require careful control of the carburized surfaces. MIL-STD-130-Identification -	Bench	
	NOTE: Parts as required will be drawn from fin. stores to fabricate the particular ES140341-N-Ser. Pin Req'd.		
	(X) Compensate for .0005 undersize master ring.	Bench	

GEAR - SCORING TEST
(Cont.)

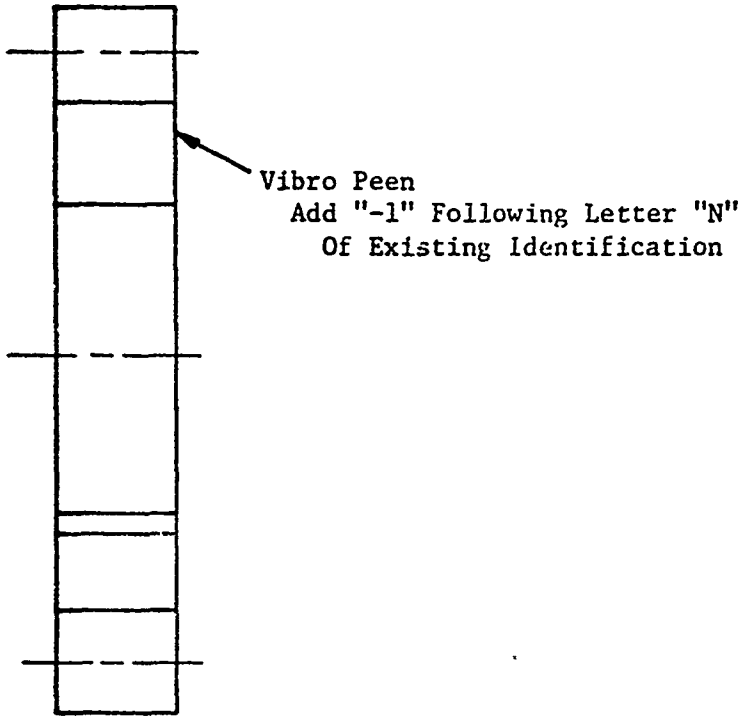
ITEM NO.	CHARACTERISTIC	GAGE OR EQUIPMENT	GAGE NO.
9.	Check *4.9445-4.9450 I.D.	Gage - Int.Ind. (4" - 5")	8G57612
	*Contrary to BIP for locating Gear teeth etc.	(X) Gage-Master Ring (r.944)	8G-52378
10.	Check 5.008 - 5.028 Keyway Dim.	Use Std. Instr.	
11.	Check .125 - .128 Keyway Width	Use Std. Instr.	
12.	Check Gear teeth, 33T, 5P, 25° P.A. to measure 7.128-7.130 over (2) .3456 wires	Wires gaging Det. 101	5T-14110
13.	Check .597 - (A) .603 Gear Width *Note: Dimension over odd number of teeth is 7.043 - 7.047.	Bench Use Std. Instr.	
14.	Check 7.051 - 7.055 Gear O.D. Dim.	Use Std. Instr.	
15.	Check all other dim's not listed		
16.	Stamp per Q.C.O. #10-3		
17.	Complete M.D.O. per Q.C.O #13-2		
18.	Deliver to finished stores		

GEAR - SCORING TEST

SPECIFICATION: AISI 9310 STEEL SIZE AND TYPE: ES-140344 HAND FORGING

DEPT.	OPER. NO.	OPERATION NAME	TYPE OF MACHINE
		*No Operation Sheet	
		Draw Parts (P/N ES-140341-N from Finish Stores)	
7531	10	*Wash	Tank
7531	20	Re-Identify	Bench
7531	30	Finish Grind External Gear Teeth	National Broach Gear Grinder
7531	40	Break Sharp Edges of Gear Teeth	Bench
7531	50	*Wash	Washing Machine
7531	60	*Degrease	Degreaser
7531	70	*Class Bead Clean all over	Abrasive Blast Cab.
3200 7531	80	Nital Etch Inspect SPM-42	Insp. Equip.
9221	90	*Clean SPM-169	Cleaning Equipment
9222	100	*Stress Relieve Per (A. Swirnow, Met. Lab. 2218) Heat to 300° ± 10°F. For (4) Hrs. Min. Air Cool	Furnace
3200 7531	110	*Magnetic Particle Inspect Oper. 30 - 100%	Insp. Equipment
7531	120	*Wash	Washing Machine
9229	130	*Black Oxide Per MIL-C-13924	Plate Equipment
3110 9229	140	Inspect Final	Bench
9229	150	*Coat with Corrosion Preventative Oil Per MIL-C-16173	Tank
		DELIVER TO FINISH STORES	

Re-Identify	Oper. No. - 20



GEAR-SCORING TEST

MACHINE NAME: NATIONAL BROACH GEAR GRINDER

OPERATION NAME: Finish Grind External Gear Teeth OPERATION NO.: 30

Hold (3) Parts on Arbor locating in 4.9445-4.9450 I.D. & against gear end face (Use .875 Wide Spacer)

Indicate Gear O.D. to run true within .001 of full indicator reading.

Finish Grind Gear 33 teeth. 5 pitch. 25° pressure angle to measure 7.0955-7.0969 over .3456 Dia. wires.

Note: 010 Max. Stock removal permissible from teeth on roots & flanks. .0237 111 feed for max. stock removal at p.d.

Note: Finish on gear teeth 9-11 (must be held)

Note: Grind root dia. to 6.130-6.132 (adjusted for odd No. of teeth) BIP adjusted root dia. is 6.121-6.141

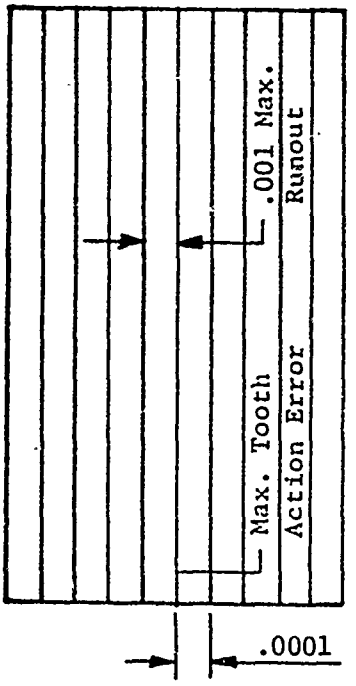
Note: Gear engineering must be present prior to & during running-100% checks

Note: Use grinding wheel "Robertson" Div. AL1003-G+10VL

TOOLS	TOOL NO.
Arbor-Grinding	T3-31921
Plate - Index 33T	T3-28161
Template - Hoglund	8T-78308
Micr. - Root Det #7	G3-25518
(Alternate)	
Blade - Micr. Det. #7	8G-76701
Plate - Index (Alt.)	T3-30275
Wires Gaging (2)	
.3456 Dia. Det. #101	5T-14110

Check Gear Teeth (Finish Grind External Gear Teeth) Oper. No. - 30

Red Liner Chart



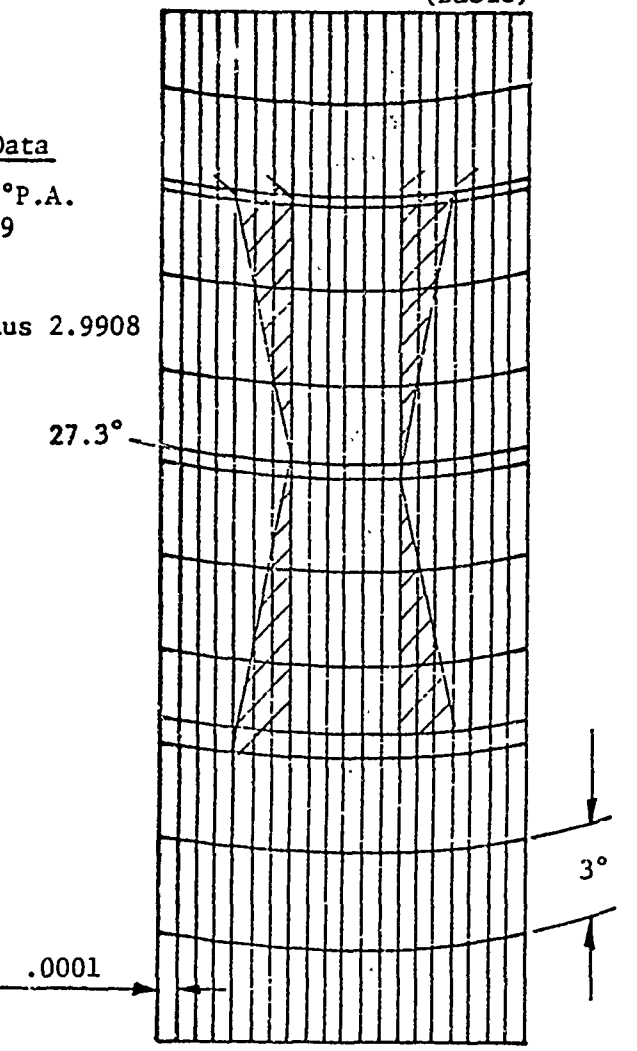
Gear Data

33T 5 P25°P.A.
0-1 35.9

C 18.8°
Base Radius 2.9908

NOTE: Check .055 - .075 radius using comp. chart.

Involute Chart
(Basic)



NOTE: This part is ground and black oxided.

Tools	Tool No.
Arbor-Grinding	T3-31921
Gear-Master	2MG114D2076-1
Arbor-Master Gear	E-10141
Chart-Comparator	
XI.065R.Det.#46	8G-29141

GEAR - SCORING TEST

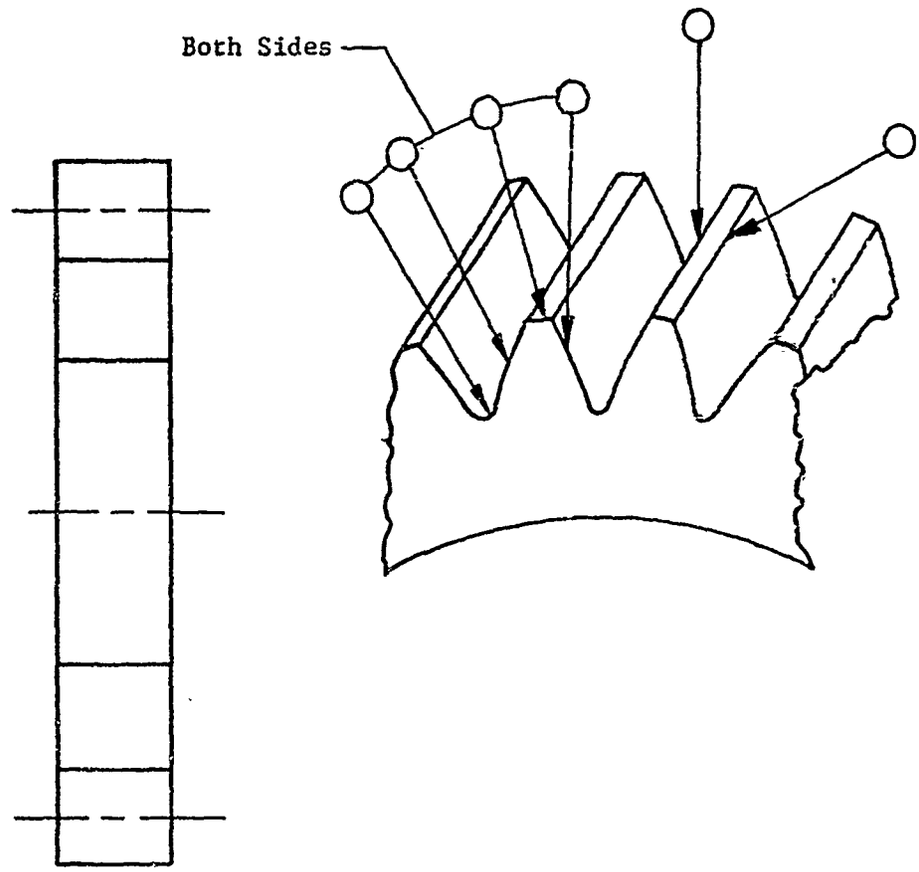
MACHINE NAME: PROFILOMETER & FELLOWS LEAD CHECKER

OPERATION NAME: Finish Grind External Gear Teeth OPERATION NO. 30

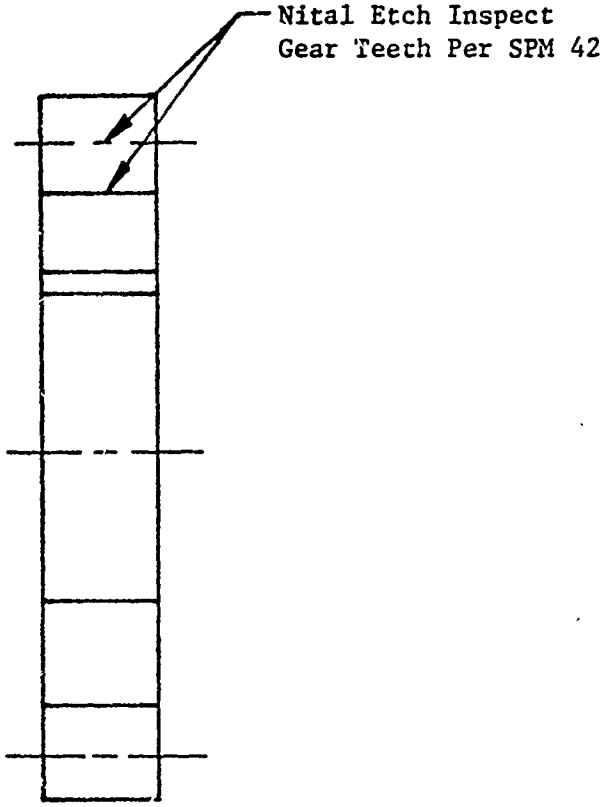
1. Check Lead Error to .0004 In./In. Max.
2. Check tooth to tooth spacing Error to .0003.
3. Check surface finish to 9-11 on Profilometer
4. Involute profile to be a smooth continuous curve from contact Dia. to O.D.

Burr Gear Teeth	Oper. No. - 40

Burr & Break Sharp Edges Where Shown By ←○ .003 - .015



Nital Etch Inspect SPM 42	Oper. No. - 80



Loc On B/P	Gage or Equipment	Gage No.
	Insp. Equip	

GEAR - SCORING TEST

OPERATION NAME: Final C-WW Mfg. Inspection OPERATION NO.: 140

ITEM NO.	CHARACTERISTIC	GAGE OR EQUIPMENT	GAGE NO.
1.	Identify Part to B/P.		
2.	Verify Eng. Chg. Letter on Oper. Sheet to B/P and travelers.		
3.	Verify stamps on traveler for floor inspection operations.		
4.	Verify all pertinent stamps on parts.		
5.	Consult inspection data card.		
6.	Verify gages for date and color code.		
7.	Inspect parts visually for cleanliness, mutilation & protective measures. MIL-C-13924 Black Oxide		
8.	Check visually		
9.	Stamp per Q.C.O. 10-3		
10.	Complete M.D.O. per Q.C.O. 13-2 Deliver to Finish Stores.		

APPENDIX II
VASCOJET 1000-2 CARBURIZING PROCESS
SPECIFICATION OUTLINE

The following procedure is to be used for CW parts made from VASCO (X-2) CVM.

This procedure is in compliance with applicable portions of CWW Heat Treat Carburizing Specifications and Military Specifications.

NORMALIZE

ROUGH MACHINE

LIGHT ABRASIVE BLAST

PLATE ALL OVER FOR CARBURIZE

Nickel strike and copper plate (.0008" min.) to be performed per Special instructions.

INSPECT PLATE

Check for proper thickness and usually check for blisters, peeling and poor adherence.

NOTE: Parts having poor plate have to be stripped and replated.

SEMI-FINISH MACHINE AREAS TO BE CARBURIZED

LIGHT ABRASIVE BLAST (Plus Test Pieces)

INSPECT FOR CLEANLINESS

PACK LOAD FOR CARBURIZE (Plus Test Pieces)

CARBURIZE (Plus Test Pieces)

Case depth aim: .025-.030.

NOTE: This operation to be performed under direct supervision of Metallurgical Processes

UNPACK LOAD (Plus Test Pieces)

SNAP TEMPER (Plus Test Pieces)

LIGHT ABRASIVE BLAST (Plus Test Pieces)

STRIP PLATE

PLATE ALL OVER FOR HARDENING (Plus Test Pieces)

Nickel Strike before copper plate.

HARDEN (Plus Test Pieces)

NOTE: This operation to be performed under direct supervision of Metallurgical Processes.

DEEP FREEZE (Plus Test Pieces)

1st TEMPER (Plus Test Pieces)

2nd TEMPER (Plus Test Pieces)

LIGHT ABRASIVE BLAST (Plus Test Pieces)

STRIP PLATE (Plus Test Pieces)

METALLURGICAL EVALUATION AND DESTRUCTIVE ANALYSIS OF TEST PIECES FOR CERTIFICATION

SIGNED:

APPROVED:

APPROVED:

PLATE ALL OVER FOR HARDENING (Plus Test Pieces)

Nickel Strike before copper plate.

HARDEN (Plus Test Pieces)

NOTE: This operation to be performed under direct supervision of Metallurgical Processes.

DEEP FREEZE (Plus Test Pieces)

1st TEMPER (Plus Test Pieces)

2nd TEMPER (Plus Test Pieces)

LIGHT ABRASIVE BLAST (Plus Test Pieces)

STRIP PLATE (Plus Test Pieces)

METALLURGICAL EVALUATION AND DESTRUCTIVE ANALYSIS OF TEST PIECES FOR CERTIFICATION

SIGNED:

APPROVED:

APPROVED: