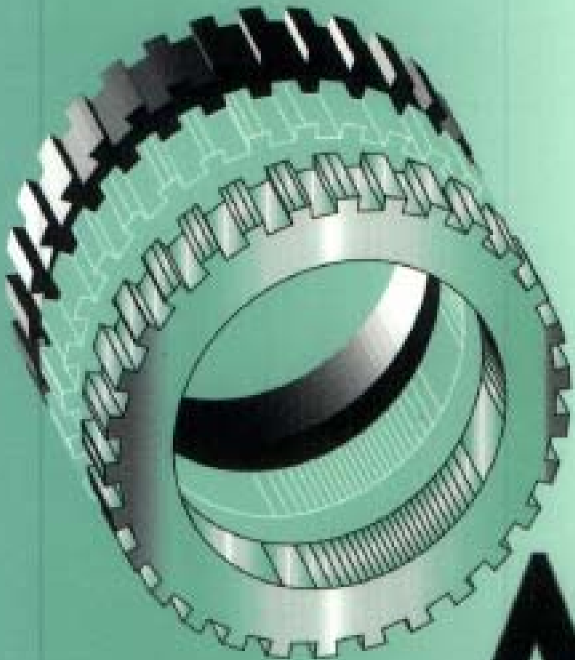
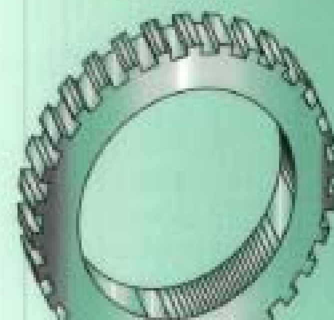


The ART of GEAR FABRICATION



Prem H. Daryani B.E.

RRT OF GEAR FABRICATION

By

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Dedication

This book is dedicated to
God's good men scattered around the world,
who taught me.
In turn, their knowledge
is being passed on to younger engineers.

Table of Contents

Preface		Vii
Chapter 1	**Types of Gears and Processing of Gears**	**1**
Chapter 2	**Gear Nomenclature**	**5**
Chapter 3	**Methods for Cutting Gear Teeth**	**13**
Chapter 4	**Gear Materials and Their Heat Treatment**	**87**
Chapter 5	**Processing of Gear Parts**	**113**
Chapter 6	**Checking of Gear Size**	**145**
Chapter 7	**AGMA Quality Numbers**	**153**
Chapter 8	**Producibility**	**159**
Chapter 9	**Finishes on Gears**	**171**
Chapter 10	**Useful Tables**	**175**
Chapter 11	**List of Useful Books**	**197**
Index		**207**

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Carl S. Rice, ***Retired Engineer, Fellows Corp.,***
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Lewis Weiss, ***Specialty Steel & Forge Co., 26 Law Drive, Fairfield, NJ 07004. http://www .steelforge.com***
Gleason Corporation, ***1000 University Avenue, P.O.Box 22970, Rochester, New York 14692-2970. (716) 473-1000, httpdwww.gleason.com***

Some of the information in Chapter 3, was taken from the following handbooks that are no longer being printed nor do the companies exist today. These companies were pioneers but due to global competition, they are no longer manufacturing products so it has not been possible to obtain their permission to use the information.

1. Barber-Colman Hob Handbook published in 1954
2. Van Keuren Handbook number 37 published by Van Keuren Company in 1979
3. Bethlehem Steel Corp., Bethlehem, PA 18016 for allowing reproduction of heat treatment graphs in Chapter 4.

Preface

This book is not a treatise from which to learn the operation of gear-cutting machines and equipment. Manufacturers of gear cutting machinery supply adequate information on operation of their machines, and the time required to cut, hob, shape, **or** generate a gear profile is small compared with the total time for fabrication of a gear **or** pinion as specified in a blueprint. This book will place more emphasis on teaching beginners and advanced planners how to process gears.

Furthermore, the purpose of this book is not to go into details of designing gears, stress analysis, or to repeat formulas that define various gears. That information is given in many excellent publications like Machinery's Handbook and other specialized books on gears (listed in the appendix). Speeds and feeds also are given in hundreds of publications like Machining Data Handbook and manuals distributed by individual machinery manufacturer's. This book will be useful for:

1. Entry-level manufacturing and processing engineers in the machine shop field, who want to either learn **or** enlarge their knowledge on processing of gears. It is assumed that the above categories of engineers have at least some knowledge of the various types of gears, their shape, and machining in general. A good machine shop engineer must have some practical experience on the shop **floor.**

2. Designers of gears in the USA and all over the world, by providing them with practical and useful hints about how they can assist in reducing the cost of fabrication. In today's hectic, competitive, world, where products have to be introduced in the shortest possible times, designers calculate stresses and lay out the dimensions of gears, but have no time to devote attention to subjects such as unnecessarily close tolerances. In these days of computerization, computer-aided design, without much effort, will give dimensions to the third decimal place, even where such accuracy is not necessary **or** required. The cost of manufacture increases with close tolerances, and with every decimal position. Many designers are not familiar with methods of heat treatment and their related cost. Though heat treatment is a speciality, it is essential for manufacturing and design engineers to have sufficient knowledge of various heat treatments. The author will endeavor to describe the subject of heat treatment in simple language.

Any manufacturing engineer who wants to process gears should order a copy of Catalog #2000 from:

Ash Gear & Supply Corporation
42650 Nine Mile Road Novi, Michigan **48375** U.S.A.
Tele. #: **(248) 374-6155.** Fax #: **(248) 374-6255**

Ash Gear & Supply claims to be the world's largest supplier of gear-cutting tools and it maintains a variety of both new and used tools. Catalog #2000 has the following technical information:

Selection of tools for gear cutting. Gear nomenclature .Formulas. Lists of books on gears published in the English language. Computer programs for gears. Partial directory of gear fabricating companies in the USA.

In the next few chapters, common gear nomenclature is defined and processing of six (6) typical gears is analyzed, to provide beginners with basic knowledge of various methods of processing. Instead of simply giving processing sheets for parts, logic and reasoning for every sequence of operation is explained. Based on this material, the beginners will be able to write processing steps without assistance from anyone.

Subsequent chapters describe production, selection of materials, heat-treatment, plating, methods of cutting, hobbing, shaping and grinding, in detail. To save beginners from having to search for information elsewhere, certain useful tables that the author has used in his career while processing gears, are attached.

In the chapter entitled, "Methods to Cut Gear Teeth," at the end of each process description, model numbers, capacity, and addresses of gear machinery manufacturers and suppliers are given. Some of these addresses may have changed. However, the companies can always be traced.

Where a company does not have sufficient capital to permit purchase of the latest machinery, Chapter 3 of this book lists model numbers for used equipment that is available in the used machinery market. It is possible to retrofit and recondition many of these old machines to give nearly equal-to-new quality of the end product. Retrofitting and reconditioning work must be performed by a skilled, knowledgeable person or organization. The lists given do not include all the different models available in the industry, but Manufacturing Engineers can easily get that information from the manufacturers. In addition to their expertise concerning machinery suppliers, Manufacturing Engineers have to apply impartial analysis of the field. They know the financial limitations of their companies and the nature of the jobs their company has to do.

Useful tables from commercial catalogs are given at the end of the book . These tables give cross-references of different US Standards. A table of American stainless steel materials, with equivalent German, British, French and Italian materials, is also given.

List of Useful Books Related to Gears

This book will enable a Manufacturing Engineer who is familiar with machine shop practice to be a specialist in the gear-manufacturing field.

1. Trigonometry Tables and Involute Functions published by Illinois Tool Co.
2. Involutometry and Trigonometry By Dr. Eng Werner F. Vogel
3. Machinery's Handbook by Erik Oberg, Franklin D. Jones and others
4. Gear Handbook: Design, Manufacture and Application of Gears by D. W. Dudley
5. Handbook of Practical Gear Design by D. W. Dudley
6. Gear Design, Manufacturing and Inspection Manual ISBN **1-56091-006-2**
7. Student's Shop Reference Book by Edward G. Hoffman
8. Metal Cutting Handbook by U.S. Cutting Tool Institute
9. Evolution of Gear Art by D. W. Dudley
10. Technical Shop Mathematics by John G. Anderson
11. Blueprint Reading Basics by Warren Hammer
12. Application of Metal Cutting Theory by Fryderyk E. Gorczya
13. Machine Shop Training Course by Franklin D. Jones
14. Machine Shop Practice by Karl H. Moltrecht
15. Manual of Gear Design by Earle Buckingham and Elliot Buckingham
16. Tables for Recess Action Gears by E. K. Buckingham
17. Metals Black Book Ferrous Edition ISBN **0-9696428-0-6**
18. Geometry of Involute Gears by J. R. Colbourne
19. Handbook of Dimensional Measurement by Francis T. Farago
20. Design of Worm and Spiral Gears by Earle Buckingham and Henry H. Ryffel
21. Analytical Mechanics of Gears by Earle Buckingham (paperback)
22. Gear Handbook -Design and Calculations by Alec Stokes
23. Gear Design Simplified by Franklin D. Jones aand Henry H. Ryffel
24. Basic Machining Reference Handbook by Arthur R. Meyers and Thomas Slattery
25. ISO **9000** Book by Quality Resources
26. Gear Geometry and Applied Theory by F. L. Litvin
27. Design Guide for Involute Splines by Robert W. Cedoz
28. Involute Splines and Inspection by the SAE and the ASME
29. Metric Module Involute Splines
30. AGMA Publications and Technical Papers (Refer to Tables **11-1** through **11 7**)

Chapter 1

TYPES OF GEARS AND PROCESSING OF GEARS

Gears come in all forms from tiny gears and pinions used in watches, toys, and aircraft actuators, to those used in heavy earth-moving machinery and coal-mining machinery.

Gears can be cast, forged, sintered from powdered metal, or made from solid rolled material. Forms of gears may be classified as bevel, helical, straight spur, pinion, worm and worm wheel. For some applications, gears are made from various grades of plastics materials.

The vast majority of gears are cut or ground on a production scale. Gears used in gear boxes of machine tools are generally ground because of the following two factors:

1. Low ultimate noise levels are required while operating in gearboxes.
2. Less friction is needed so that power consumption is reduced.

Gears used in turbine gearboxes are generally ground because of these same considerations.

Gears used in cranes and other lifting mechanism are generally cut or hobbed.

Gears fall in the following main types of categories:

1. Straight spur
2. Helical
3. Bevels
4. Worm and worm wheel
5. Splines
6. Sprockets

Types of Gears and Processing of Gears

Figures 1-1 and 1-2 show photographs of gears used in industry.

The teeth on straight and helical gears, on a production scale, are cut either on a hobbing machine, using a hob (tool), or shaped on a shaping machine. Fine gears can also be ground from solid blanks. However, the majority of ground gears are first rough-hobbed, or shaped, and then ground. Straight spur gears can also be cut using a rack type cutter on a Parkinson or Sunderland type machine.

Figure 1-1 Typical Gears.

There are many types of bevel gears, and their teeth are cut with reciprocating cutters or by a milling process. The Gleason Works of the **USA,** and Klingelnberg GmbH of Germany are two of the worlds leading bevel gear machinery manufacturers. Except for the method of cutting, processing is similar to that for the gears described in Chapter **5.** These two firms will willingly recommend types of machines and cutters for producing specific bevel gears depending upon production quantity.

Figure 1-2 Typical spiral gear.

Worms can be cut on a **CNC** lathe using a single-point form tool or may be rough-milled in a special thread-milling machine and finished by grinding.

Worm wheels are generally produced by hobbing.

Splines also are generally hobbed, and blind internal splines are usually shaped. Unrestricted internal splines on a production scale are best produced at low cost by broaching, provided that the Rockwell hardness of the part does not exceed 35°C.

On all the types of gears mentioned above, except sprockets, gears are specified by diametral pitch in the inch system and by Module in the metric system.

It is essential to understand the basic terminology of spur gears and to this end it may be worthwhile to understand and remember simple formulas pertaining to number of teeth (**N**) and diametral pitch (DP) for standard spur gears.

$$\text{Pitch circle diameter} = \frac{\text{Number of Teeth}}{\text{Diametral Pitch}} = \frac{N}{DP}$$

$$\text{Outside diameter of gear} = \frac{N+2}{DP}$$

In metric gears, DP is defined by Module (M), which can be summarized by the following formula:

$$M = \frac{25.4}{DP} = \frac{25.4}{\text{Diametral Pitch}}$$

Another important parameter is known as the pressure angle. In involute teeth, the pressure angle is often described as the angle between the line of action and the line tangent to the pitch circle. This angle can be **14-1/2** degrees, 20 degrees, **25** degrees or **30** degrees. The involute shape is best described in Van Keuren's Handbook #37 and this definition is reproduced in the next chapter.

Knowledge of the pressure angle is important in selecting the correct cutting tools for a particular gear. Many of the earlier large-diameter gears were cut with a rack-type cutter having a corresponding pressure angle.

Chapter 2

GEAR NOMENCLATURE

The most important parameters for manufacturing engineers to know are:

1. Diametral pitch
2. Pressure angle
3. Measurement over wires for checking gear sizes
4. AGMA Quality Number
   (standardized by American Gear Manufacturers' Association).

Measurement over wires and AGMA Quality are explained in detail in subsequent chapters.

Every gear engineer should also be familiar with gear nomenclature symbols and formulas for spur, worm, and helical gears, and splines. These symbols and formulas are explained in many publications and in the books listed in the appendix.

Beginners should start with an understanding of the formulas for external gears. Terminology for helical and bevel gears and splines is an extension of spur gear terminology. Tooth elements are described in Table 2- 1.

Most gear tooth profiles use the involute shape of tooth, as described by Van Keuren in Handbook # 37. An extract from this handbook is in Table 2-2. In short terms. the involute curve is generated by a point at the end of a cord as it is unwound from the surface of a cylinder known as the base circle.

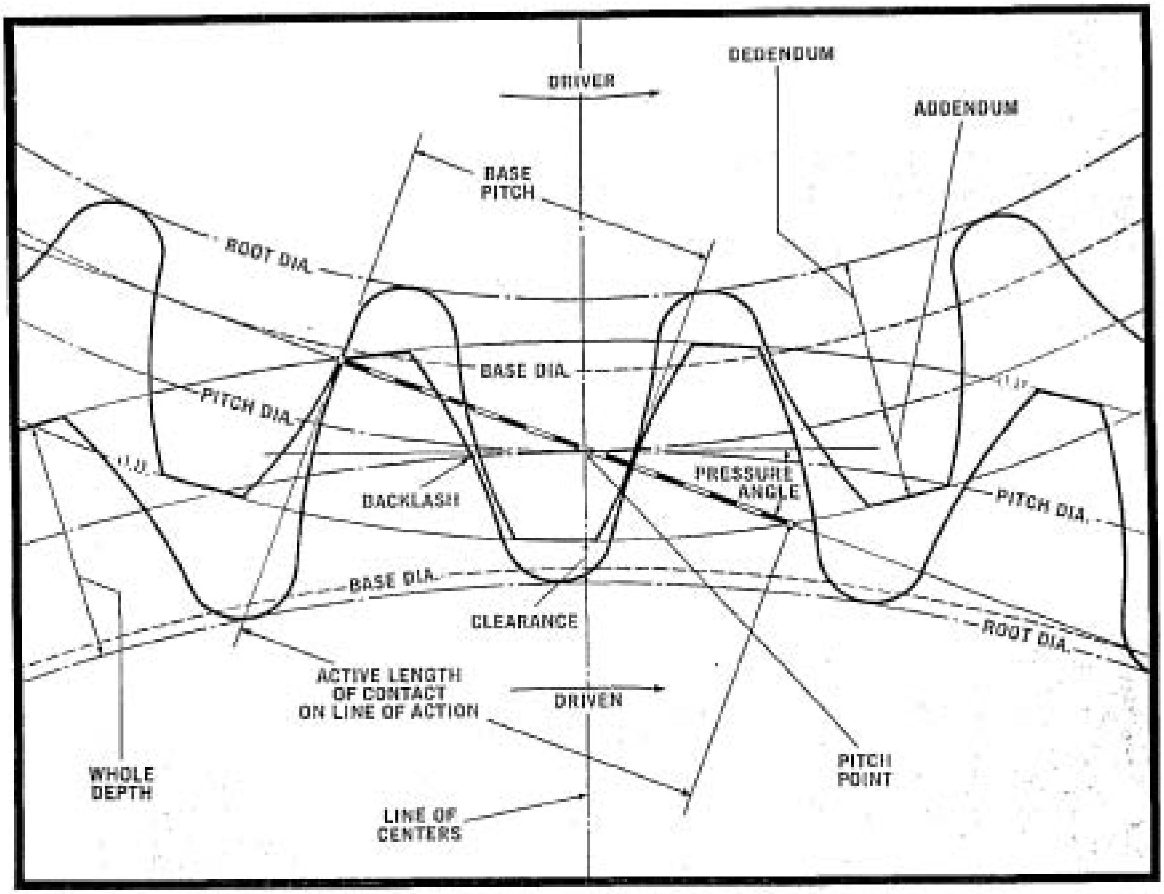
The diameter of the base circle equals the pitch diameter x cos of the pressure angle = D x cos O.

After familiarity is attained with the various methods to cut gears, it is necessary to know how to measure gears. Van Keuren has standardized the most commonly-used method of measuring over wires.

Wire size *G* is selected from Table **2-3**, which is reproduced from Van Keuren's Handbook #37. Wire size is different for enlarged pinions, standard external gears, and internal gears.

Tables **2-4** and **2-5** give tooth proportions for various gear systems such as the inch, module, diametral and circular pitch. Given this elementary knowledge, we can now go to the next chapter which describes in detail various gear-cutting methods.

TOOTH ELEMENTS



BASE DIAMETER: The diameter of the base circle or the circle from which the involute tooth profile is developed.

PITCH DIAMETER: The diameter of the pitch circle. In theory it is the imaginary circle that rolls without slippage with a pitch circle of a mating gear.

OUTSIDE DIAMETER: The diameter of the addendum or outside circle.

ROOT DIAMETER: The diameter of the root circle or the circle that is tangent to the bottoms of the tooth spaces.

LINE OF CENTERS: The line which connects the centers of the pitch circles of two mating gears.

PITCH POINT: The point of tangency of two pitch circles on the line of centers.

LINE OF ACTION: The straight line passing through the pitch point and tangent to the base circles. It is actually the path of contact of mating involutes.

BASE PITCH: The fundamental distance between adjacent curves along a common normal such as the line of action.

ADDENDUM: The radial distance between the pitch circle and the outside diameter.

DEDENDUM: The radial distance between the pitch circle and the root circle.

CLEARANCE: The amount by which the dedendum in a gear exceeds the addendum of its mating gear.

PRESSURE ANGLE: The angle between the line of action and the line tangent to the pitch circle at the pitch point. Since an involute has no specific pressure angle until brought into intimate contact with another involute, the operating pressure angle is determined by the center distance at which a pair of gears operate. For uniformity and economies, standard pressure angles are established for standard gear tooth systems.

WORKING DEPTH: The depth of engagement of two mating gears — in effect the sum of their addendums.

WHOLE DEPTH: The total depth of a tooth space, equal to addendum plus dedendum, or the working depth plus the clearance.

FACE WIDTH: The length of the teeth in an axial plane.

BACKLASH: The amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles.

For further clarification of definitions of "Gearometry" Elements, see AGMA Standard Number 112.03 entitled "Gear Nomenclature."

Table 2-1

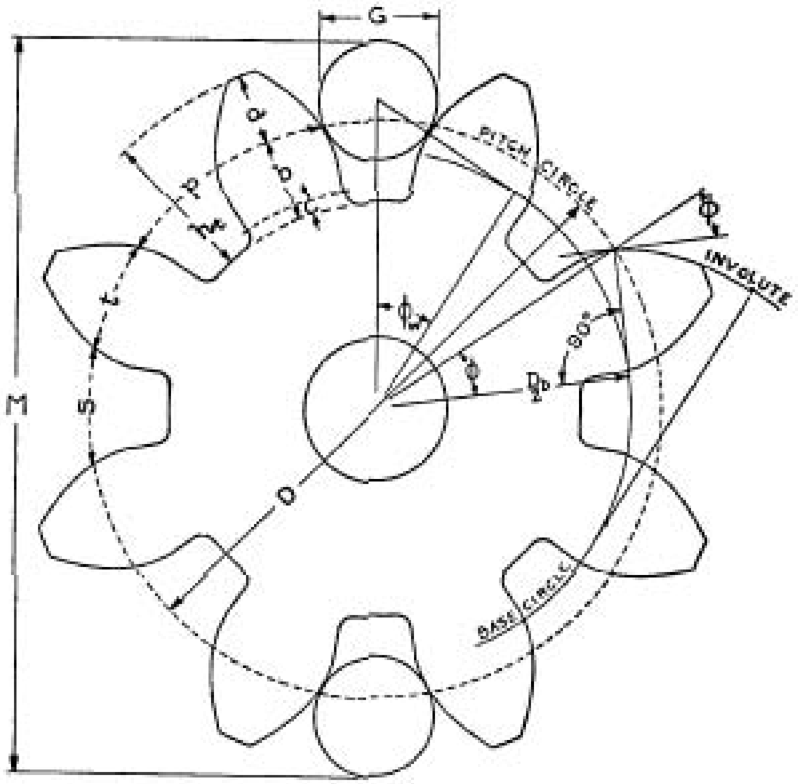


FIG. 68. SPUR GEAR TOOTH PARTS.

The following are four important definitions applying to spur gears:

1. PITCH DIAMETER (D). For purposes of design the pitch diameter of a gear equals the number of teeth divided by the diametral pitch. This is the basic or fundamental diameter used for all gear calculations. It should not be confused with the operating pitch diameter which is the diameter containing the pitch point. The pitch point is determined by the intersection of a line tangent to the base circles of both gears with the center line of the gears.
2. TOOTH THICKNESS AT PITCH DIAMETER (T). On standard gears with no backlash the tooth thickness equals the width of the space at the pitch diameter. On enlarged pinions the tooth thickness is greater than the space, and on reduced gears the tooth thickness is less than the space.
3. DIAMETRAL PITCH (P). The diametral pitch is the number of teeth per inch of pitch diameter. It identifies the size of the teeth.
4. PRESSURE ANGLE (ϕ). The pressure angle is the angle made by a line tangent to the gear tooth at the pitch diameter and a radial line drawn through this point of tangency. It is also the angle formed by the side of a tooth of the basic rack with a line perpendicular with its pitch line. The pressure angle determines the size of the base circle from which the involute curve is generated. Gears of 14½° and 20° pressure angles are in common usage. Other pressure angles such as: 17½°, 22½°, 25°, 27½° and 30" are used for special purposes

Table 2-2 Involute Form,

GEAR WIRE SIZES.

P	Wire Diameter Enlarged pinions. $\frac{1.92''}{P}$	Wire Diameter External gears. $\frac{1.728''}{P}$	Alternate Series $G = \frac{1.68''}{P}$	Wire Diameter Internal gears $\frac{1.44''}{P}$
1	1.92	1.728	1.68	1.44
2	.960	.864	.840	.720
2½	.768	.6912	.672	.576
3	.640	.576	.560	.480
4	.480	.432	.420	.360
5	.384	.3456	.336	.288
6	.320	.288	.280	.240
7	.27428	.24686	.240	.20571
8	.240	.216	.210	.180
9	.21333	.192	.18666	.160
10	.192	.1728	.168	.144
11	.17454	.15709	.15273	.13091
12	.160	.144	.140	.120
14	.13714	.12343	.120	.10286
16	.120	.108	.105	.090
18	.10667	.096	.09333	.080
20	.096	.0864	.084	.072
22	.08727	.07855	.07636	.06545
24	.080	.072	.070	.060
28	.06857	.06171	.060	.05143
32	.060	.054	.0525	.045
36	.05333	.048	.04667	.040
40	.048	.0432	.042	.036
48	.040	.036	.035	.030
64	.030	.027	.02625	.0225
72	.02667	.024	.02333	.020
80	.024	.0216	.021	.018
96	.020	.018	.0175	.015
100	.0192	.01728	.0168	.0144
120	.0160	.0144	.014	.012
128	.0150	.0135	.01312	.01125
200	.0096	.00864	.0084	.0072

GUIDE TO WIRE SELECTION

Series	Relation	Use
(1) $\frac{1.92''}{P}$		(a) Enlarged pinions. Wires project above outside diameter. (b) External involute splines. (c) Involute serrations. (d) Alternate for 14½° and 20° pressure angle standard addendum gears.
(2) $\frac{1.728''}{P}$	$\frac{(1.92 - 10\%)}{P}$	(a) External standard addendum spur and helical gears. Wires project above the outside diameter. (b) Internal splines above 8 teeth.
(3) $\frac{1.68''}{P}$	$\frac{(1.92 - 12½\%)}{P}$	(a) Suitable for 14½ Internal gears above 31 teeth and 20° gears above 29 teeth. Wires project below the inside diameter. (c) Alternate for standard addendum external gears.
(4) $\frac{1.44''}{P}$	$\frac{(1.92 - 25\%)}{P}$	(a) Internal standard addendum gears. Wires make good contact on gear teeth but do not project below the inside diameters.

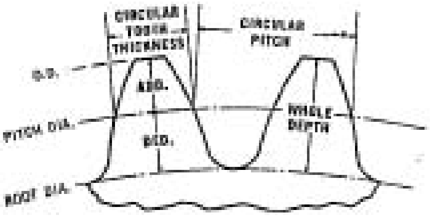
Table 2-3 Wire sizes for checking gears.

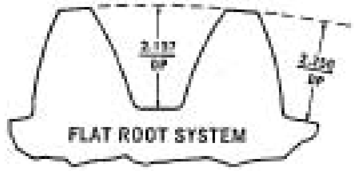
TABLE OF TOOTH PROPORTIONS FOR VARIOUS GEAR SYSTEMS

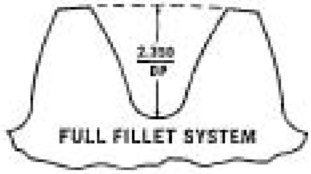
The Table lists the tooth proportions for various gear systems. The diametral and circular pitch, module, circular tooth thickness and addendum are given for all systems. The dedendum and whole depth are tabulated for the AGMA 14½ P.A. Composite System, the AGMA and ASA Standard Full Depth System, and the Full Fillet System.

3.1416/CP	3.1416/DP	25.40/DP	1.5708/DP	1/DP	1.157/DP	2.157/DP	1.250/DP	2.250/DP	1.350/DP	2.350/DP
				ALL SYSTEMS	AGMA 14½° PRESSURE ANGLE COMPOSITE SYSTEM		AGMA & ASA STANDARD FULL DEPTH SYSTEM		FULL FILLET SYSTEM (PRE-GROUND & PRE-SHAVED)	
DIAMETRAL PITCH	CIRCULAR PITCH	MODULE	CIRCULAR TOOTH THICKNESS	ADDENDUM	DEDENDUM	WHOLE DEPTH	DEDENDUM	WHOLE DEPTH	DEDENDUM	WHOLE DEPTH
2.5000	1.2566	10.1600	.6283	.4000	.4628	.8628	.5000	.9000	.5400	.9400
2.7500	1.1424	9.2364	.5712	.3636	.4208	.7844	.4545	.8182	.4909	.8545
3	1.0472	8.4667	.5236	.3333	.3857	.7190	.4167	.7500	.4500	.7833
3.1416	1"	8.0851	.5000	.3183	.3683	.6866	.3979	.7162	.4297	.7480
3.1750	.9895	8	.4947	.3150	.3644	.6794	.3937	.7087	.4252	.7402
3.3510	15/16	7.5798	.4687	.2984	.3453	.6437	.3730	.6714	.4029	.7013
3.3867	.9276	7-1/2	.4638	.2953	.3416	.6369	.3691	.6644	.3986	.6939
3.5000	.8976	7.2571	.4488	.2857	.3306	.6163	.3571	.6429	.3857	.6714
3.5904	7/8	7.0744	.4375	.2785	.3223	.6008	.3482	.6267	.3760	.6545
3.6286	.8658	7	.4329	.2756	.3189	.5945	.3445	.6201	.3720	.6476
3.8666	13/16	6.5691	.4062	.2586	.2993	.5579	.3233	.5819	.3491	.6077
3.9077	.8040	6-1/2	.4020	.2559	.2961	.5520	.3199	.5758	.3455	.6014
4	.7854	6.3500	.3927	.2500	.2893	.5393	.3125	.5625	.3375	.5875
4.1888	3/4	6.0638	.3750	.2387	.2762	.5149	.2984	.5371	.3223	.5610
4.2333	.7421	6	.3711	.2362	.2733	.5095	.2952	.5314	.3189	.5551
4.5696	11/16	5.5585	.3437	.2188	.2532	.4720	.2735	.4923	.2954	.5142
4.6182	.6803	5-1/2	.3401	.2165	.2505	.4670	.2707	.4872	.2923	.5088
4.7124	2/3	5.3900	.3333	.2122	.2455	.4577	.2653	.4775	.2865	.4987
5	.6283	5.0800	.3142	.2000	.2314	.4314	.2500	.4500	.2700	.4700
5.0266	5/8	5.0531	.3125	.1989	.2301	.4290	.2487	.4476	.2686	.4675
5.0800	.6184	5	.3092	.1968	.2278	.4246	.2461	.4429	.2657	.4625
5.3474	.5875	4-3/4	.2938	.1870	.2164	.4034	.2338	.4208	.2525	.4395
5.5851	9/16	4.5478	.2812	.1790	.2071	.3861	.2238	.4028	.2417	.4207
5.6444	.5566	4-1/2	.2783	.1772	.2050	.3822	.2215	.3987	.2392	.4164
5.9765	.5257	4-1/4	.2628	.1673	.1936	.3609	.2091	.3764	.2259	.3932
6	.5236	4.2333	.2618	.1667	.1929	.3595	.2083	.3750	.2250	.3917
6.2832	1/2	4.0425	.2500	.1591	.1842	.3433	.1989	.3580	.2149	.3740
6.3500	.4947	4	.2473	.1575	.1822	.3397	.1968	.3543	.2126	.3701
6.7733	.4638	3-3/4	.2319	.1476	.1708	.3185	.1845	.3321	.1993	.3469
7	.4488	3.6286	.2244	.1429	.1653	.3082	.1786	.3214	.1929	.3357
7.1808	7/16	3.5372	.2187	.1393	.1611	.3004	.1741	.3134	.1880	.3273
7.2571	.4329	3-1/2	.2164	.1378	.1594	.2972	.1722	.3100	.1860	.3238
7.8154	.4020	3-1/4	.2010	.1279	.1480	.2759	.1599	.2878	.1727	.3006
8	.3927	3.1750	.1964	.1250	.1446	.2696	.1563	.2813	.1688	.2938
8.3776	3/8	3.0319	.1875	.1194	.1381	.2575	.1492	.2686	.1611	.2805
8.4667	.3711	3	.1855	.1181	.1367	.2548	.1477	.2658	.1594	.2775

Table 2-4







$\frac{3.1416}{CP}$	$\frac{3.1416}{DP}$	$\frac{25.40}{DP}$	$\frac{1.5708}{DP}$	$\frac{1}{DP}$ ALL SYSTEMS	$\frac{1.157^{*}}{DP}$ AGMA 14½° PRESSURE ANGLE COMPOSITE SYSTEM	$\frac{2.157^{*}}{DP}$	$\frac{1.250^{*}}{DP}$ AGMA & ASA STANDARD FULL DEPTH SYSTEM	$\frac{2.250^{*}}{DP}$	$\frac{1.350^{**}}{DP}$ FULL FILLET SYSTEM (PRE-GROUND & PRE-SHAVED)	$\frac{2.350^{*}}{DP}$
DIAMETRAL PITCH	CIRCULAR PITCH	MODULE	CIRCULAR TOOTH THICKNESS	ADDENDUM	DEDENDUM	WHOLE DEPTH	DEDENDUM	WHOLE DEPTH	DEDENDUM	WHOLE DEPTH
9	.3491	2.8222	.1745	.1111	.1286	.2397	.1389	.2500	.1500	.2611
9.2364	.3401	2-3/4	.1701	.1082	.1253	.2335	.1353	.2435	.1462	.2544
9.4248	1/3	2.6950	.1667	.1061	.1228	.2289	.1326	.2387	.1432	.2493
10	.3142	2.5400	.1571	.1000	.1157	.2157	.1250	.2250	.1350	.2350
10.0531	5/16	2.5266	.1562	.0995	.1151	.2146	.1244	.2239	.1343	.2338
10.1600	.3092	2-1/2	.1546	.0984	.1139	.2123	.1230	.2214	.1329	.2313
11	.2856	2.3091	.1428	.0909	.1052	.1961	.1136	.2045	.1227	.2136
11.2889		2-1/4	.1391	.0886	.1025	.1911	.1107	.1993	.1196	.2082
12	.2618	2.1167	.1309	.0833	.0964	.1798	.1042	.1875	.1125	.1958
12.5664	1/4	2.0213	.1250	.0796	.0921	.1717				
12.7000	.2474	2	.1237	.0787	.0911	.1698	.0984	.1771	.1063	.1850
13	.2417	1.9538	.1208	.0769	.0890	.1659	.0962	.1731	.1038	.1807
14	.2244	1.8143	.1122	.0714	.0827	.1541	.0893	.1607	.0964	.1679
14.5143	.2164	1-3/4	.1082	.0689	.0797	.1486	.0861	.1550	.0930	.1619
15	.2094	1.6933	.1047	.0667	.0771	.1438	.0833	.1500	.0900	.1567
16	.1964	1.5875	.0982	.0625			.0781	.1406	.0844	.1469
16.7552	3/16	1.5159	.0938	.0597			.0746	.1343	.0806	.1403
16.9333	.1855	1-1/2	.0928	.0591			.0738	.1329	.0797	.1388
17	.1848	1.4941	.0924	.0588			.0735	.1324	.0794	.1382
18	.1745	1.4111	.0873	.0556			.0694	.1250	.0750	.1306
19	.1653	1.3368	.0827	.0526			.0658	.1184	.0711	.1237
20	.1571	1.2700	.0785	.0500			.0620	.1120	.0695	.1195
20.3200	.1546	1-1/4	.0773	.0492			.0611	.1103	.0684	.1176
22	.1428	1.1545	.0714	.0455			.0565	.1020	.0634	.1089
24	.1309	1.0583	.0654	.0417			.0520	.0937	.0583	.1000
25.1328	1/8	1.0106	.0625	.0398			.0497	.0895	.0557	.0955
25.4000	.1237	1	.0618	.0394			.0492	.0886	.0551	.0945
26	.1208	.9769	.0604	.0385			.0482	.0867	.0539	.0924
28	.1122	.9071	.0561	.0357			.0449	.0806	.0502	.0859
30	.1047	.8467	.0524	.0333			.0420	.0753	.0470	.0803
32	.0982	.7938	.0491	.0313			.0395	.0708	.0442	.0755
33.8667	.0928	3/4	.0464	.0295			.0374	.0669	.0419	.0714
36	.0873	.7056	.0436	.0278			.0353	.0631	.0395	.0673
40	.0785	.6350	.0393	.0250	.0320	.0570	.0320	.0570	.0358	.0608
48	.0654	.5292	.0327	.0208	.0270	.0478	.0270	.0478	.0301	.0509
64	.0491	.3969	.0245	.0156	.0208	.0364	.0208	.0364	.0231	.0387

* DEDENDUM 20 PITCH AND FINER $= \frac{1.200}{DP} + .002 \quad \frac{2.200}{DP} + .002$

** DEDENDUM 20 PITCH AND FINER $= \frac{1.350}{DP} + .002 \quad \text{———} + .002$

Table 2-5 Tooth proportions for various systems.

Gear Nomenclature

Chapter 3

METHODS FOR CUTTING GEAR TEETH

The most common method of cutting gear teeth is by means of a hob. Spur, parallel, and crossed axis (helical), spiral, and worm gears can all be produced by hobbing. Feeding the hob across the face width of a gear blank will serve to cut all gears except worm gears. To produce worm gears the hob is fed either tangentially past the blank or radially into the blank.

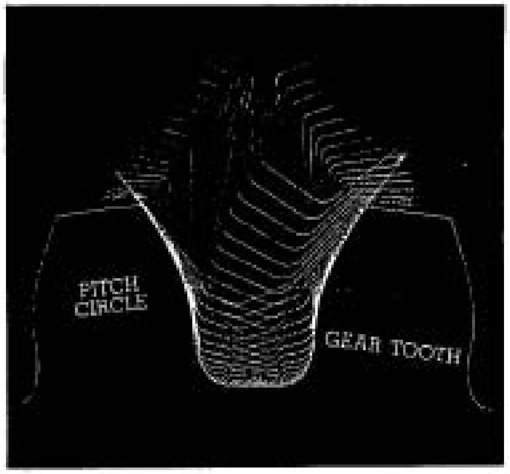
At this stage, it is important to understand what a hob is and how it is held.

What is a Hob?

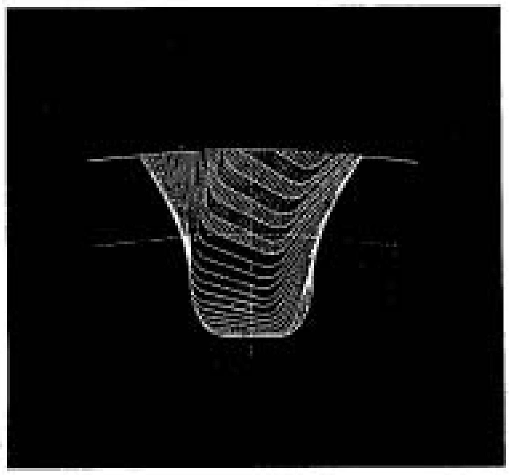
A hob is a worm thread that has been fluted and each tooth form relieved. The flutes provide the cutting edges. Each tooth is relieved radially to form clearance behind the cutting edge, allowing the faces of the teeth to be sharpened while retaining the tooth profile. The Barber-Coleman Company was one of the pioneer hob and hobbing machine manufacturers in the world, and in Germany, it was the Pfauter Co.

Fig. 3-2, from Barber Coleman's book Gear Hobs, 1954 Edition, shows a typical hob. Tables 3-1 and 3-2, also from the Barber-Coleman Company, show hob nomenclature and design elements. (Barber-Coleman no longer markets gear cutting machinery or hobs).

The cutting edges of the teeth on each flute of a straight-fluted hob may be considered to have the form of a rack. In an involute gear hob, the teeth have essentially straight sides and are equally spaced according to the pitch. The hob embodies as many of these racks as



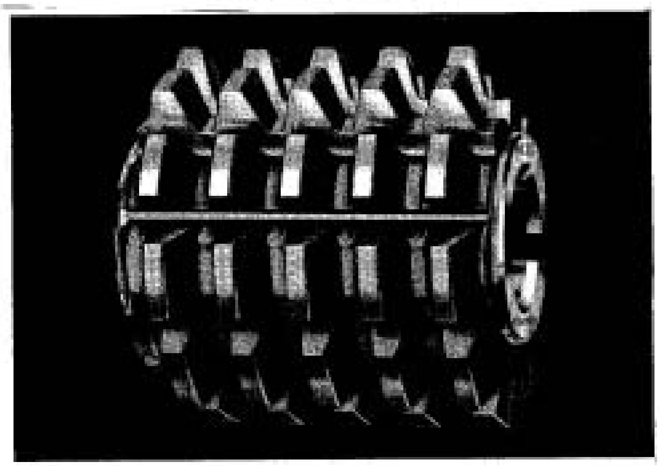
Schematic view of the generating action of a hob.



Schematic view of the performance of an individual hob tooth.

Figure 3-1 Generations of involute profile.

HOBS



Ground hobs for cutting spur and helical gears.

SHANK
WORM GEAR HOBS
AX. DP 20" PA

Shank Type, Topping
Right Hand

Figure 3-2 Pictorial view of typical hobs.

there are flutes. The racks are equally spaced around the periphery of the hob and each is axially displaced from the preceding rack by a fixed amount depending on the lead angle. As the hob and gear blank are rotated at a uniform rate, in general relationship to each other, each rack assumes the correct position relative to the blank to generate the required involute tooth profile as shown in Fig. **3-1.**

Types of Hobs

The range of hob pitches is from 1 to 180 dp, and hobs are made to the tolerances of one of the standard classes adopted by the Metal Cutting Tool Institute. These classes include:

Class A Precision Ground
Class B Commercial Ground
Class C Accurate Unground
Class D Commercial Unground

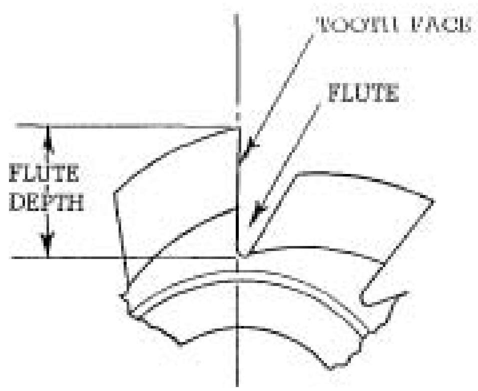
In addition, an ultra-precision hob, called Class AA, is generally available. Class AA hobs are used for the very finest gears, and are generally available in 3 dp and finer.

Special Finishing Hobs

The present trend is toward the increased use of special hobs, and the special features are usually considered to be more important than whether or not a hob is available from stock.

Any finishing hob that requires a modification of the standard form, is a special hob. In addition, hobs that deviate from the standard sizes or classes, are considered special. Special gear hobs are manufactured in any of the five classes of tolerances, depending upon the accuracy required in the gears to be produced.

Semi-topping hobs for cutting a chamfer on the tips of gear teeth are one type of special gear hob. The primary purpose of a chamfer is to reduce the possibility of nicks on the involute profile when large numbers of gears are being handled. In addition, de-burring operations are often reduced or eliminated because the burr is turned away from the involute profile.



The following definitions of hob terms are in agreement with the Metal Cutting Tool Institute Handbook.

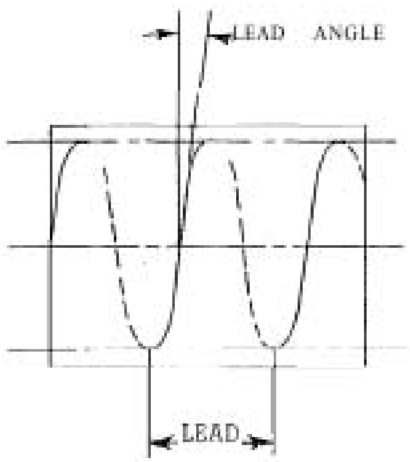
Outside diameter is the diameter of the circle which contains the top of the cutting edges of the teeth.

Root diameter is the diameter of the circle which contains the bottom edges of the tooth form at the cutting edges. For topping hobs, this diameter contains the edges which cut the outside diameter of the part.

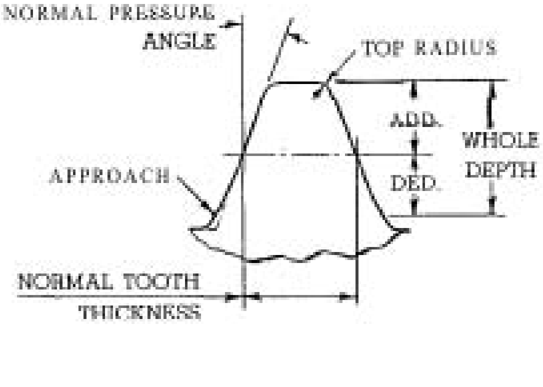
Pitch diameter is a reference diameter at which the lead angle and tooth thickness of the hob are determined.

Length of hob is the overall length.

Active length of hob is the distance across the cutting face.



face of the following tooth along the thread. It can be either straight or helical.



Axial pitch is the axial distance between corresponding points on adjacent teeth. For single-thread hobs, it is the same as the lead.

Normal helix is a helix on the pitch cylinder whose angle is equal to the lead angle.

Lead is the axial advance of a thread for one complete turn.

Lead angle is the angle between a tangent to the thread and the plane of rotation measured at the pitch line.

Table 3-1 Hob nomenclature.

Normal circular pitch is the distance between 'corresponding points on adjacent teeth measured along the normal helix.

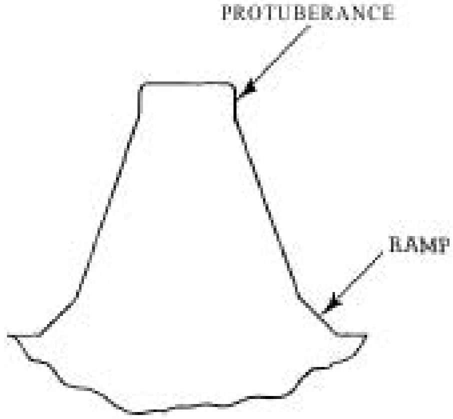
Normal diametral pitch is the ratio of π to the normal circular pitch.

Normal pressure angle is the angle between a line tangent to the tooth profile and the radial line at its pitch point, measured in the normal plane section.

Normal tooth thickness is the distance across the hob tooth face along a normal helix, usually measured at the pitch diameter.

Hob addendum is the radial distance between the top of the hob tooth and the pitch circle.

Hob dedendum is the whole depth of cut minus the hob addendum.



Whole depth of cut is equal to the whole depth of the gear tooth.

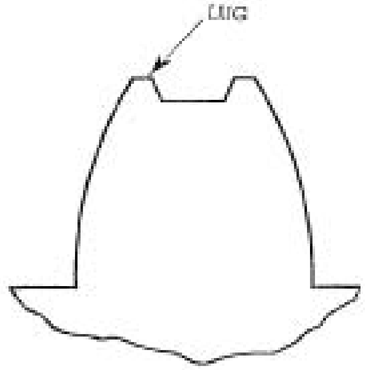
Cam relief is the relief behind the cutting edges to provide clearance and is produced by a constant-drop cam.

Side clearance is the amount of clearance provided for the sides of the teeth behind the cutting edges and is dependent upon the amount of cam relief and the tooth profile.

Protuberance is a modification of the hob tooth form at the top corner to produce undercut on the gear teeth.

Top radius is a radius to eliminate a sharp corner at the top of the hob tooth. It can also be a full top radius to produce a full fillet at the bottom of the part tooth,

Lug is an extension of the hob tooth profile beyond the basic depth.



Fillet is the blending of the side of the tooth into the bottom of the form to eliminate a sharp corner.

Approach is a modification of the hob tooth form near the bottom of the tooth to provide a small amount of tip relief on the gear tooth.

Ramp is a modification near the bottom of the hob tooth to provide a chamfer on the part tooth.

Table 3-2 Hob nomenclature continued.

The feature on the hob that cuts the chamfer is called a ramp, and this ramp must be designed for the specific chamfer to be cut. Therefore, the hob designer must know the number of teeth, the helix angle, and the size and angle of the chamfer in order to design a semi-topping hob accurately.

Topping hobs are required if the hob is to cut the outside diameter of the gear to finished size. A topping hob produces an outside diameter that is concentric with the pitch diameter. Such a hob is illustrated in Figure 3-3.

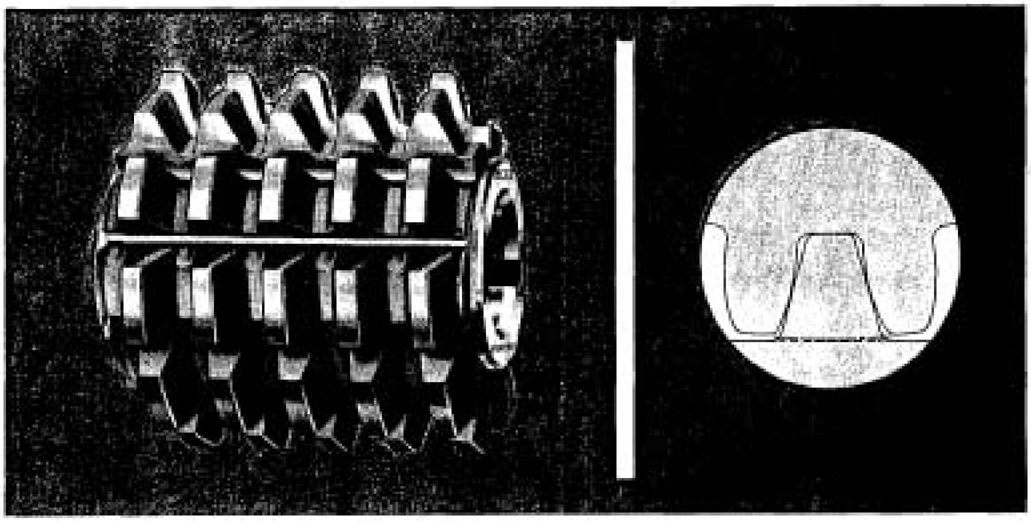
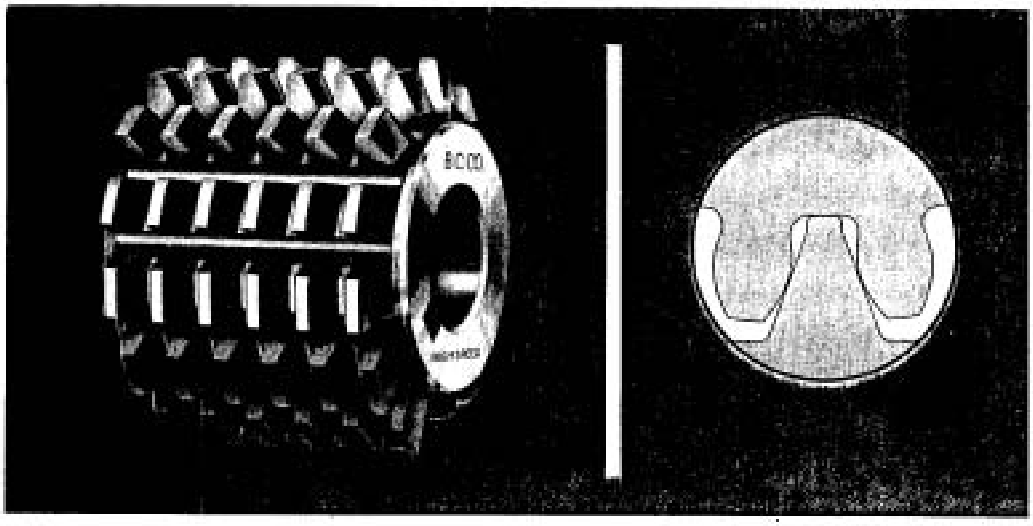


Fig. 3-3 Topping gear hob.

Semi-Pinishing Gear Hobs

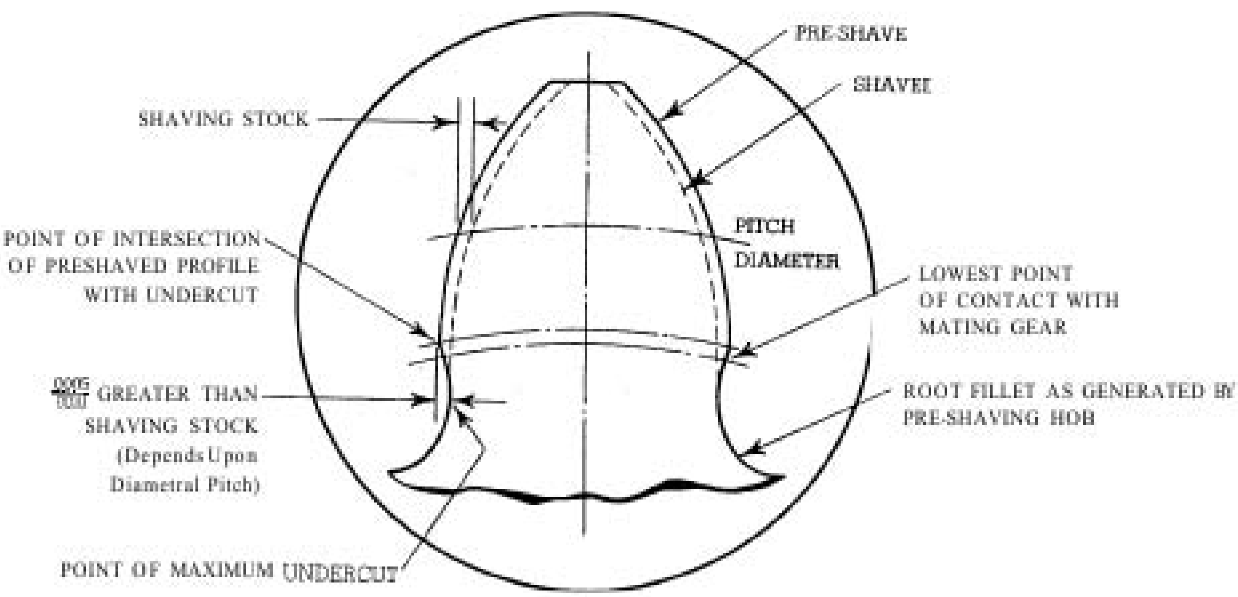
Semi-finishing hobs are used to cut gears that are later finished by shaving or grinding. The hobs can be either ground or unground in any of the standard classes, single or multiple-thread, and topping, non-topping, or semi-topping. Semi-topping hobs are distinguished from roughing hobs although they both require a secondary operation. A roughing hob is usually unground and less accurate than a finishing hob. On the other hand, a semi-finishing hob must be of approximately the same accuracy as a finishing hob. The semi-finishing hob must leave a minimum and uniform amount of stock for the finishing tool to remove. Consequently, many of these hobs are Class A Precision Ground or Class B Commercial Ground. However, many gear manufacturers have found that Class C Accurate Unground hobs are sufficiently accurate for semi-finished gears, providing lower tool cost per gear.

The Metal Cutting Tool Institute has recommended tooth forms and sizes for pre-shave hobs. On these cutters, the hob tooth has greater



Protuberance hob for semi-finishing.

Figure 3-5



Comparison between hobbed and shaved profiles.

Figure 3-6

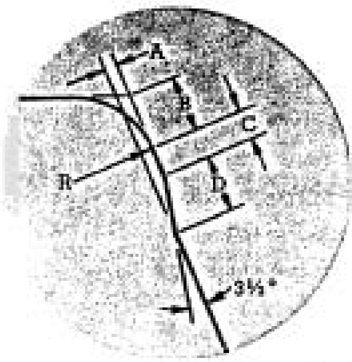
depth and less tooth thickness than on a corresponding finishing hob, and there is no approach. Greater depth is required to provide sufficient clearance for the shaving cutter, and a thinner tooth provides for shaving stock on the gear tooth. Data and dimensions pertinent to the standard 141/2-degree and 20-degree pressure angle, pre-shave hob tooth forms are shown in Tables **3-5** and **3-6.**

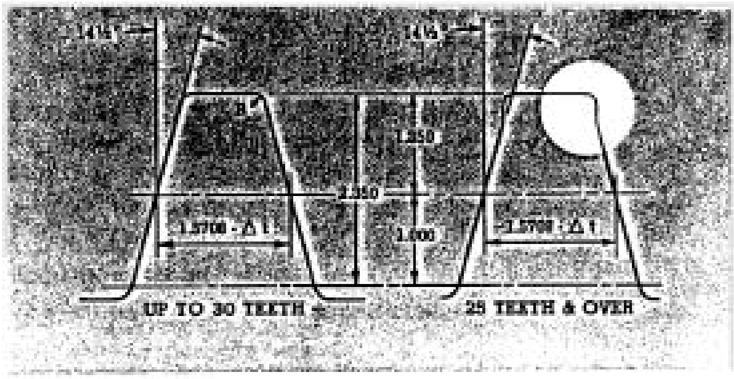
Protuberance is another important feature of tooth form found on many pre-shave hobs. The protuberance generates undercut at the bottom of the gear tooth to provide clearance for the shaving cutter and to prevent the formation of an abrupt change in profile with its resulting stress concentration. With small numbers of teeth, the tooth form cut with a hob without protuberance is often undercut enough, but a protuberance is required for larger numbers of teeth to eliminate contact between the tip of the shaving cutter and the fillet on the gear tooth. Ordinarily, the undercut should be from **0.0005** to 0.001 inch more than the amount of stock left for shaving. **As** shown in Figure **3-6,** the intersection of the shaved profile with the undercut fillet curve should always fall below the lowest point of contact with the mating gear.

For a given pitch, tables **3-5** and **3-6** indicate a fixed amount of protuberance for a range of numbers of teeth. With such a fixed protuberance, the amount of undercut will be greater on the smaller numbers of teeth in the range. When a definite amount of undercut is desired, the hob should be designed for the specific number of teeth in the gear. With a given protuberance, the point of intersection of the undercut with the involute form varies with the number of teeth. To insure that this point of intersection does not fall outside the true involute circle, the true involute form diameter should always be designated on the gear print. The restrictions imposed by the true involute form diameter often require a special protuberance.

Several different gear-grinding methods are in use, so special forms of pre-ground hobs are used for each application. The desired hob profile or the method of grinding should be indicated on the part print. Compared with the corresponding pre-shave hob form, tooth thickness is less because the amount of stock left for grinding exceeds the amount required for shaving. When a protuberance is required, it is greater than on pre-shave hobs.

Another modification of the hob tooth form is required on semi-finishing hobs if the gear teeth are to be chamfered. The chamfer on the gear tooth should be cut by the hob, not by the finishing tool. This procedure requires provision of a ramp on the hob tooth, which will produce the desired chamfer. This chamfer will change as the number of teeth or





recommended MCTI* pre-shave gear hob tooth dimensions

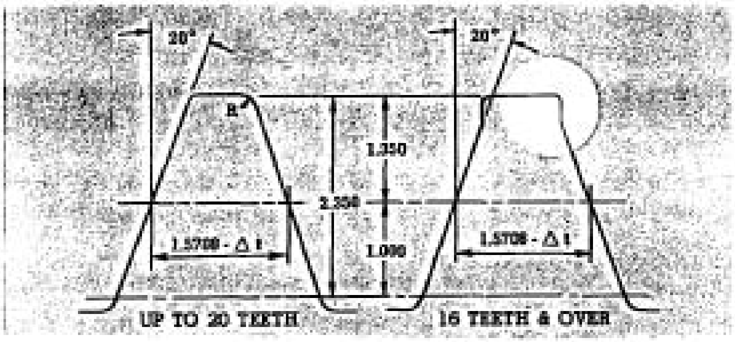
for 14½° Pressure Angle

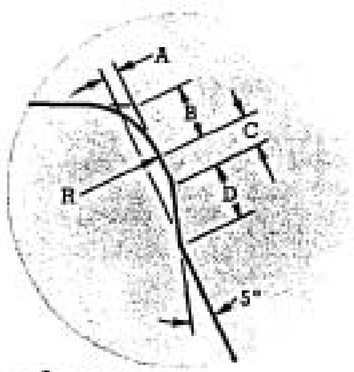
(All readings in thousandths of an inch)

Normal Diametral Pitch	A1	A	B	C	D	R
3	3–4	2.5–3	77	33–49	45	100
4	3–4	2.5–3	58	25–39	45	75
5	2.5–3.5	2–2.5	43	20–32	45	55
6	2.5–3.5	2–2.5	35	17–27	37	45
7	2–3	2–2.5	31	14–22	37	40
8	2–3	2–2.5	27	13–20	37	35
9	2–3	1.5–2	27	11–17	29	35
10	2–3	1.5–2	23	10–15.5	29	30
11	1.5–2.5	1.5–2	23	9–14	29	30
12	1.5–2.5	1.5–2	19	8–13	29	25
13	1.5–2.5	1.5–2	19	8–12	29	25
14	1.5–2.5	1–1.5	15	7–11	20	20
15	1–2	1–1.5	15	7–11	20	20
16	1–2	1–1.5	15	6–9.5	20	20
17	1–2	1–1.5	15	6–9.5	20	20
18	1–2	1–1.5	12	6–9	20	15
19	1–2	1–1.5	12	5–a	20	15

*Metal Cutting Tool Institute

Table 3-5





recommended MCTI* pre-shave gear hob tooth dimensions

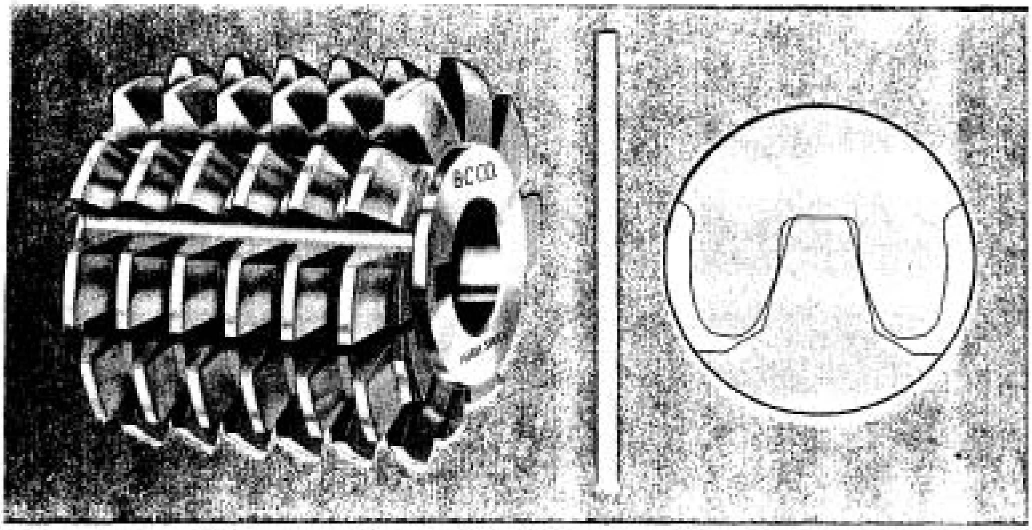
for 20° Pressure Angle

(All readings in thousandths of an inch)

Normal Diametral Pitch	Δt	A	B	C	D	R
3	3–4	2.5–3	70	33–49	31	100
4	3–4	2.5–3	53	25–39	31	75
5	2.5–3.5	2–2.5	39	20–32	26	55
6	2.5–3.5	2–2.5	32	17–27	26	45
7	2–3	2–2.5	28	14–22	26	40
a	2–3	2–2.5	25	13–20	26	35
9	2–3	1.5–2	25	11–17	20	35
10	2–3	1.5–2	21	10–15.5	20	30
11	1.5–2.5	1.5–2	21	9–14	20	30
12	1.5–2.5	1.5–2	18	8–13	20	25
13	1.5–2.5	1.5–2	18	8–12	20	25
14	1.5–2.5	1–1.5	14	7–11	14	20
15	1–2	1–1.5	14	7–11	14	20
16	1–2	1–1.5	14	6–9.5	14	20
17	1–2	1–1.5	14	6–9.5	14	20
18	1–2	1–1.5	11	6–9	14	15
19	1–2	1–1.5	11	5–8	14	15

*Metal Cutting Tool Institute

Table 3-6



Semi-topping hob to provide chamfer on gear teeth.

Figure 3-7

the helix angle vary. The hob designer must know the number of teeth, the helix angle, and the size and angle of the chamfer, in order to design the semi-topping hob accurately. One of the primary reasons for adding chamfer to gear teeth is to protect the tips against nicks when large quantities of gears are handled. Since so many semi-finished gears are made on a mass production basis, the use of a protective chamfer is often desirable. The chamfer also reduces the size of the burr and the effect of this burr.

Stub-Tooth Gear Hobs

Several systems of tooth forms are shorter than the full-depth system. All these forms produce a stubbier and stronger gear tooth than the standard full-depth tooth. Gears from these systems are used when full-depth tooth forms will not provide the required strength.

Of the several systems of stub-tooth forms, the adopted standard is the ASA stub-tooth system. This system has a standard 20-degree pressure angle. Both the addendum and dedendum are shorter than for a full-depth tooth. For pitches coarser than 20DP, the addendum is 0.8/DP and the dedendum is 1/DP. The whole depth is 1.8/DP. Basic dimensions for a 1-DP hob tooth are shown in Figure 3-8.

Tables 3-7 and 3-8 show the tooth parts for the standard ASA stub-tooth system. Hobs can be made to fit any of these specifications. The sides of the hob teeth are straight with no approach unless otherwise specified. These hobs can be made to any of the standard gear hob

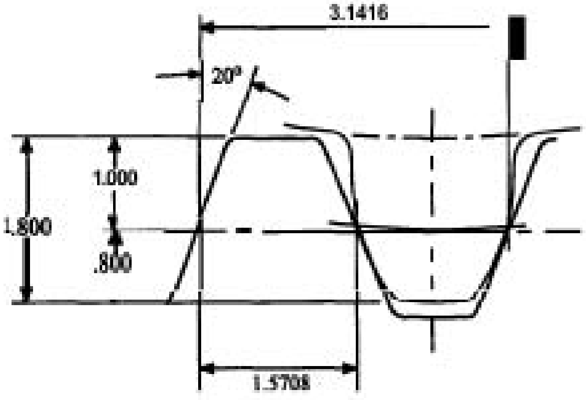


Fig. 3-8 Tooth proportions for standard 1 DP 20 stub-tooth hob.

tolerances. Hob manufacturers will design and make special hobs to fit any special requirements.

Hobs for the Fellows Combination-Pitch system are different from those for the **ASA** system. In the Fellows system, the characteristics of two pitches are combined in a single gear. For example, on a 3-4 DP gear, the pitch diameter, circular pitch, tooth thickness, and number of teeth are determined as for a standard 3-DP gear. The addendum and dedendum are calculated as for a 4-DP gear, making the tooth shorter than a standard 3-dp gear tooth but the same width at the pitch line. In pitches coarser than 20 DP, the addendum is 1/DP and the dedendum is 1.25/DP, where the DP is the second one indicated in the combination pitch. The pressure angle of this system is 20 degrees.

Hob Selection

Correct hob selection depends upon the following factors:

1. DP
2. Hardness of material
3. Final finish on the part.

Gears of coarse DP are best cut with **a** roughing hob, and finished with a finishing hob, provided the material to be hobbed is either soft or **of** hardness preferably not exceeding **40** Rockwell C..Finer DP gears and pinions of the above hardness category can be cut with a finishing hob. The number of passes will again depend on hardness and specific dp. If a drawing calls for ground teeth, a pre-grind standard or full fillet pre-grind hob is recommended.

tooth proportions for standard ASA 20° stub-depth involute system

$a = \frac{0.8000''}{P_n}$ addendum

$b = \frac{1.0000''}{P_n}$ dedendum

$c = \frac{0.2000''}{P_n}$ clearance

$h_k = \frac{1.6000''}{P_n}$ working depth

$h_t = \frac{1.8000''}{P_n}$ whole depth

Normal Diametral Pitch	Normal Circular Pitch	Circular Tooth Thickness	Addendum	Dedendum	Clearance	Working Depth	Whole Depth
½	6.2832	3.1416	1.6000	2.0000	.4000	3.2000	3.6000
¾	4.1888	2.0944	1.0667	1.3333	.2667	2.1333	2.4000
1	3.1416	1.5708	.8000	1.0000	.2000	1.6000	1.8000
1¼	2.5133	1.2566	.6400	.8000	.1600	1.2800	1.4400
1½	2.0944	1.0472	.5333	.6667	.1333	1.0667	1.2000
1¾	1.7952	.8976	.4571	.5714	.1143	.9143	1.0286
2	1.5708	.7854	.4000	.5000	.1000	.8000	.9000
2¼	1.3963	.6981	.3556	.4444	.0888	.7111	.8000
2½	1.2566	.6283	.3200	.4000	.0800	.6400	.7200
2¾	1.1424	.5712	.2909	.3636	.0727	.5818	.6545
3	1.0472	.5236	.2667	.3333	.0667	.5333	.6000
3½	.8976	.4488	.2286	.2857	.0571	.4571	.5143
4	.7854	.3927	.2000	.2500	.0500	.4000	.4500
5	.6283	.3142	.1600	.2000	.0400	.3200	.3600
6	.5236	.2618	.1333	.1667	.0333	.2667	.3000
7	.4488	.2244	.1143	.1429	.0286	.2286	.2571
8	.3927	.1963	.1000	.1250	.0250	.2000	.2250
9	.3491	.1745	.0889	.1111	.0222	.1778	.2000
10	.3142	.1571	.0800	.1000	.0200	.1600	.1800
11	.2856	.1428	.0727	.0909	.0182	.1455	.1636
12	.2618	.1309	.0667	.0833	.0167	.1333	.1500
13	.2417	.1208	.0615	.0769	.0154	.1231	.1385
14	.2244	.1122	.0571	.0714	.0143	.1143	.1286
15	.2094	.1047	.0533	.0667	.0133	.1067	.1200
16	.1963	.0982	.0500	.0625	.0125	.1000	.1125
17	.1848	.0924	.0471	.0588	.0118	.0941	.1059
18	.1745	.0873	.0444	.0556	.0111	.0889	.1000
19	.1653	.0827	.0421	.0526	.0105	.0842	.0947

Table 3-7

recommended tooth proportions for pre-shave involute system

$a = \frac{1.0000''}{P_n}$ addendum

$b = \frac{1.3500''}{P_n}$ dedendum

$c = \frac{0.3500''}{P_n}$ clearance

$h_k = \frac{2.0000''}{P_n}$ working depth

$h_t = \frac{2.3500''}{P_n}$ whole depth

Normal Diametral Pitch	Normal Circular Pitch	Avg. Cir. Tooth Thickness	Addendum	Dedendum	Clearance	Working Depth	Whole Depth
½	6.2832		2.0000	2.7000	.7000	4.0000	4.7000
¾	4.1888		1.3333	1.8000	.4667	2.6667	3.1333
1	3.1416		1.0000	1.3500	.3500	2.0000	2.3500
1¼	2.5133		.8000	1.0800	.2800	1.6000	1.8800
1½	2.0944		.6667	.9000	.2333	1.3333	1.5667
1¾	1.7952		.5714	.7714	.2000	1.1429	1.3429
2	1.5708		.5000	.6750	.1750	1.0000	1.1750
2¼	1.3963		.4444	.6000	.1556	.8888	1.0444
2½	1.2566	.6318	.4000	.5400	.1400	.8000	.9400
2¾	1.1424	.5747	.3636	.4909	.1273	.7273	.8545
3	1.0472	.5271	.3333	.4500	.1167	.6667	.7833
3½	.8976	.4523	.2857	.3857	.1000	.5714	.6714
4	.7854	.3962	.2500	.3375	.0875	.5000	.5875
5	.6283	.3172	.2000	.2700	.0700	.4000	.4700
6	.5236	.2648	.1667	.2250	.0583	.3333	.3917
7	.4488	.2269	.1429	.1929	.0500	.2857	.3357
8	.3927	.1988	.1250	.1688	.0438	.2500	.2938
9	.3491	.1770	.1111	.1500	.0389	.2222	.2611
10	.3142	.1596	.1000	.1350	.0350	.2000	.2350
11	.2856	.1448	.0909	.1227	.0318	.1818	.2136
12	.2618	.1329	.0833	.1125	.0292	.1667	.1958
13	.2417	.1228	.0769	.1038	.0269	.1538	.1807
14	.2244	.1142	.0714	.0964	.0250	.1429	.1679
15	.2094	.1062	.0667	.0900	.0233	.1333	.1567
16	.1963	.0997	.0625	.0844	.0219	.1250	.1469
17	.1848	.0939	.0588	.0794	.0206	.1176	.1382
18	.1745	.0888	.0555	.0750	.0194	.1111	.1306
19	.1653	.0842	.0526	.0711	.0184	.1053	.1237

Table 3-8

Hobs are of many different kinds. Standard stock hobs off the shelf are less expensive than special ones. They can be classified as follows:

1. Roughing, singlethread non-topping, right- or left- handed.
2. Topping finishing, single thread, right-hand, non-chamfer ing (unground and ground). The root of the hob will form the outside diameter of the part.
3. Pre-shave protuberance, single-thread, right-hand, non-chamfering (Available in classes A, B, C, and D).
4. Finishing-standard, single-thread, right-hand, non-topping. (Available in classes A, B, C, D and AA).
5. Full fillet finishing, right-hand, non-topping, (Available in classes A, B, C and D).
6. Combination-pitch finishing, non-topping (Available in classes A, B, C and D).
7. Full fillet pre-shave.
8. Pre-grind standard.
9. Full fillet pre-grind.

All the above hobs are listed in the Ash Gear & Supply Company's catalog. Manufacturing engineers can select the correct hob from the above catalog or from catalogs of other hob manufacturers and suppliers.

Hobs can be as small as 15/16 inch outside diameter, and, in some fine series, as low as 5/8 inch and 1/2 inch diameter. Heavier hobs generally are as large as 10 1/2 inches in diameter. Standard bore sizes are 1/2, 3/4, 1-1/4, 1-1/2 and 2-1/2 inches in inch-system hobs. In small hobs, the bore size is 8 or 10 mm. In metric countries, bore sizes are generally 12, 15, 30, 40 and 50 mm.

Method of Mounting Gears on Hobbing Machine

If the part is in the form of a shaft that has center holes, the best accuracy is obtained by hobbing between centers, using a drive to rotate the part. If heavier cuts are involved, one side of the part should be held in a collet. Hobbing machine collets are generally more accurate than ordinary commercial collets. For an ultra-precision part it is better to pre-grind the holding collet diameter, because ground diameters are more concentric than turned ones. The second side obviously is supported on the machine center.

For making ring gears, parts are generally held in ground, accurate, concentric bushes, located on the bore and clamped down with nuts. Hobbing machine manufacturers provide standard arbors for each machine.

When extremely large ring gears are to be hobbed, it is important that the gear blank internal or external diameter be concentric with the tooth face. In large ring-type gears, the blank is clamped with a special ring that is tightened to the machine arbor with a heavy-duty nut. Before finally tightening, it is absolutely essential to test the turned outside diameter with an indicator.

Hobbing Machines

Herman Pfauter of Germany invented the first hobbing machine in 1897. The Barber-Coleman Co. was one of the first US companies to start manufacture of hobs, in 1908.. Hobbing machines today are manufactured for hobbing miniature-sized gears for use in watches and clocks, and a range of gears from small to large gears up to 18 ft. in diameter.

For the convenience of manufacturing engineers, the following is a list of model numbers of hobbing-machine manufacturers throughout the world (except those from USSR). Manufacturing engineers can select suitable new or used machines to suit any specific requirement. Many of the older models listed below are not now being manufactured. With the advent of CNC machines, manufacturers are reducing the number of designs. CNC machines tend to be far more costly than manual machines. For a jobbing shop, a CNC machine is more versatile and more efficient than a manual machine. However, for long-running production jobs, cheaper manual machines may work out to be a better buy. Many of the manually-operated machines are no longer being manufactured, so it may be worthwhile to select used machines and get them reconditioned by skilled repairmen.

After selecting a particular brand and model of machine it is advisable to send prints to the fabricator of the machine that will produce the types of parts needed, to take advantage of the manufacturer's experience. It is not necessary to purchase all the accessories that the machine supplier recommends. The manufacturing engineer should decide which accessories to acquire, depending upon financial and other considerations. Obviously, some accessories are essential for a particular machine and should be purchased along with the machine.

Hobbing Machines for Small Gears and Pinions

1. Barber Coleman. number 1 (1-inch diameter), numbers 1-1/2, 2, 2-1/2, 3, 3-1/2, and 4
   These machines are not now in production, but used machines are available.
2. Mikron of Switzerland numbers 120, 122-01, and 131, semi- and fully-automated types.
   Marketed in the U.S.A. by Richlin Co., 77 Florida Street, Farmingdale, N.Y. 11735
3. Wahli Model number 80 (3.93-inch maximum diameter); number 90 (1-inch diameter)
   Marketed by Alina Corp., 175 Sunnyside Boulevard, Plainview, Long Island, N.Y. 11803
4. Morat Model B 90a (without magazine) 1-9/16-inch diameter maximum, and 3/4-inch with magazine
   Marketed by Eric R. Backmann Co., 25-09 38th Ave., Long Island, N.Y. 11101
5. Koepfer Universal fully automatic #172, 173 (4-3/4-inch without magazine and 2-inch with magazine); Number 140 (2-3/4-inch maximum); number 143
   Marketed in U.S.A. by Koepfer America Inc., South Elgin Illinois
6. Hamai Model #40 for watch, camera, shutter instruments, and gas meters
   Maximum diameter 30 mm (1-1/8-inch)
   Marketed by Hamai Co., Ltd., 5-5-15 Nishi-Gotanda, Shingawa-ku, Tokyo, Japan
7. Daido (Japanese) model D-112AA maximum 70-mm (2.75-inch diameter) Marketed by Daido Seiki, Sosavyo 1, 30 Chome, Kuwazu Cho, Higashisumiy Oshi-Ku, Osaka, Japan

Medium and Large Hobbing Machines

1. Staehely High Speed Model: SH 180 (7-inch), SH 02 (11-inch), SH 510 (20-inch), SHU 400 (15.7-inch), SH 651 (25.5-inch), SH 850 (33-inch)
   Marketed by Wolf Machine Co., 500 West Washington St., Montecello, CA 90640

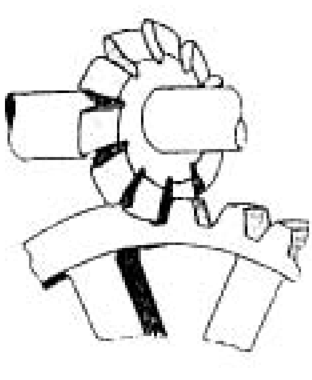
2. Drummond Maxicut number2A (7-inch), number 2B (6-inch), number 2C (5-inch)
   Drummond 12 HQ Hoblique for automobile industry - 4 DP max. 12 feet. OD
   Marketed by Staveley Machine Tools Inc., Box 3011 Hampton Station, Milwaukee, WI 53218
3. Mitsubishi types: GH 200 (7.8-inch), GA-250 NC (10-inch), GA 40-CNC (16-inch)
   Marketed by Mitsubishi Heavy Industries Ltd., 5-1 Marunchouchi 2-Chome, Chiyoda ku, Tokyo, Japan.
4. Liebherr (German) Models: L 100 (4.7-inch), L 401 (17.4-inch), LC 152 (6-inch)
   Marketed by W.H. Jones Co., P.O. Box 277, Wallingford, PA 19086
5. Nachi Models: HB-SH 180 (7-inch), HB-200H (11.8-inch), HB-400H (15-inch), HB-600H (23-inch) SH900 (35-inch), H1280 (50-inch)
   Marketed by Fujikoshi Ltd., World Trade Center, 2-4-1 Hamamatsu-cho, Shiba, Minato-ku, Tokyo, Japan
6. Koepfer Universal numbers150, 153 (max. dia. 5-3/4-inch)
   Koepfer fully automatic numbers172 and 173. 4-inch with out magazine, 2-inch with magazine
7. Morat type B110 (5.9-inch with magazine; (6.7-inch with out magazine)
8. Hitachi 600H-C1 (23.6-inch), 900H-C2 (35.4-inch), 1500H-C2 (59-inch)
   Marketed by Maruben-11 DA, 5-50 39th St., Long Island, N.Y. 11104
9. Toshiba type HHC-150C (59-inch)
   Marketed by Toshiba Machine Co., 7328 Niles Center Rd., Skokie, ILL 60076
10. Luigi Castiglioni type 5.3D-1500 mm (59-inch), 5.2D-1000 mm (39.3-inch)
    Marketed by Via Castelmorrine 45, 21052 Busto Arsizio, Italy
11. Lees-Bradner (USA) Model Nos. 7A, 7V, 12V (Used ones available)
12. Lorenz (German) type FL315 (12.4-inch), LS200 (7.8-inch), LS400 (15.6-inch)
    Marketed by Machinenfabrik Lorenz AG, 7505 Enlington, Lorenzstrasse 2, P.O. Box 166, West Germany

13. Pfauter PE 150 CNC (6-inch diameter maximum), Pfauter PA 320 NC
    Marketed by Gleason-Pfauter Maschinenfabrik GmbH, Ludwigsburg, Germany
14. Gleason G-Tech CNC 777 (6-inch diameter); 782 (10-inch diameter)
15. Kashifuji type: KS 14 (14.17-inch) KS 600 (23.6-inch), KR 1000 (40-inch), KH-150 (NC), KH-150 HD Carbide Hobber. Marketed by COSA Corp.
16. Pfauter P3000/5000
    Marketed by Gleason-Pfauter Maschinenfabrik GmbH, Ludwigsburg, Germany

Gear Milling

Spur gears, helical gears, and worms can also be cut on a milling machine using form cutters rather than by a generating process. These form cutters obviously have form relief. Milling requires approximation unless the milling cutter is specially tailored for the exact number of teeth required. The production rate is naturally lower than with hobbing, but the method has the advantage that the user is in a position to manufacture limited numbers of gears without the need for special gear cutting machine tools. A conventional milling machine equipped with a dividing head can be used to mill gear teeth.

In addition to sizes to match the dp and the hole size of the cutter, for a specific dp there are eight numbers of cutters. Each specific cutter number is suitable for a specific range of numbers of teeth. For 1 dp, the cutter diameter is approx. 8-1/2-inch and for a 64-dp the cut-



1		No. of Cutter	Range
[illegible]	135 to a rack	[illegible]	21 to 25 teeth
	55 to 134 teeth		17 to 20 teeth
3	35 to 54 teeth	7	14 to 16 teeth
4	26 to 34 teeth	8	12 to 13 teeth

Table 3-9 Milling Cutters

ter diameter is 1-3/4 inch. The exact number of cutter can be selected from Table 3-9, for any dp.

Shaping Gear Teeth with a Rack Cutter

Teeth on spur and helical external gears can be shaped with a rack cutter or shaper. The generating action of a rack shaper is more like that of a hob, but it is not as expensive as a hob. Maag and Parkinson Ltd. (Sunderland) are two manufacturers of machines for

The Shaping Process

The principle of shaping is very clearly described in Table 3-10, which is reproduced here with the permission of Mr. Carl S. Rice, retired engineer, Fellows Corporation. In the gear-shaping process, a cutter conjugating to the desired gear form is reciprocated parallel to the work piece and fed in as the tool and gear blank are rotated in opposite directions. The involute profile ground on the cutting teeth is subsequently reproduced in the work. The cutter spindle backs away from the work during the non-cutting return stroke to avoid tool drag.

The same generating process is also applied to produce internal spur gears, with the cutter and work rotating in the same direction. Gear shaping is one of the most economical methods of cutting internal gears ranging from small 1-inch to 200-inch pitch diameter and larger.

Helical teeth are produced with the aid of a special guide in which the tool reciprocates, the cutter or tool having the same lead as the guide. The guide imparts a twisting motion to the cutter as it reciprocates and rotates. Both internal and external helical gears can thus be made on the gear shaper.

Shaping tools are either disc or shank type as illustrated in Figure 3-10. Accessories for gear shapers include adapters, hollow spindle extensions, bore reduction rings, and button adapters. These accessories are listed in the Ash Gear & Supply Corporation's catalog, and can also be procured from shaping machine manufacturers.

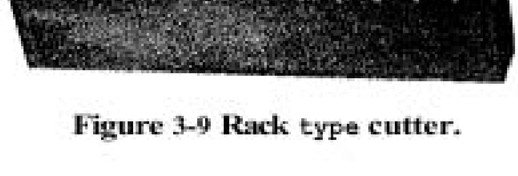
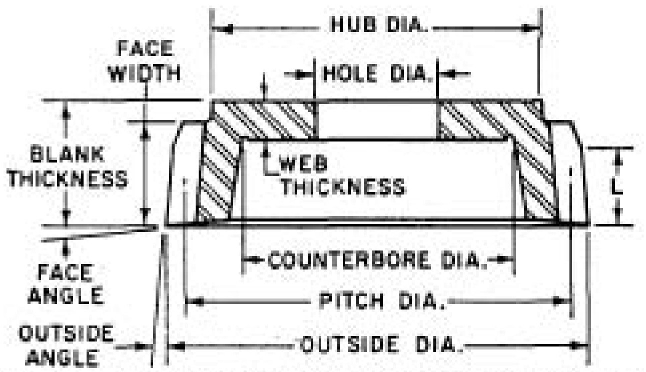


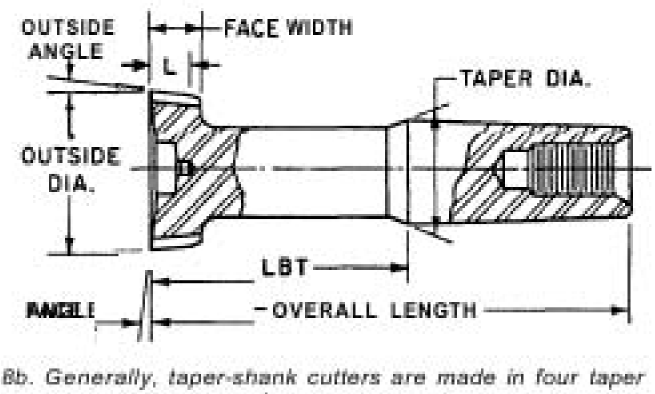
Figure 3-9 Rack type cutter.

shaping gears using rack type cutters. Machines are made to cut components of up to 20-inch maximum width. Figure 3-9 shows an example of a rack type cutter.

In their instruction manuals, manufacturers of shapers list standard tooling and will supply any special tooling needed for a specific job. For high-volume requirements, it is advisable to seek a manufacturer's recommendations for the entire tooling needed to produce a part.

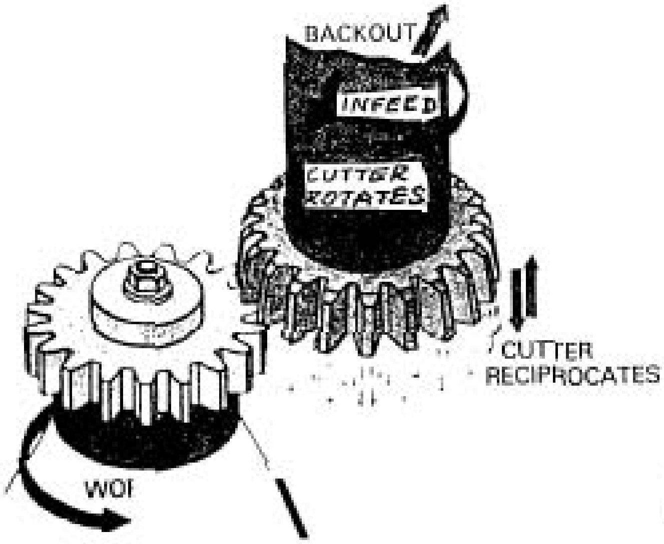


8a. Disc-type shaper cutter is shown. They are also used with adaptors, especially when the actual size required lies somewhere between a disc and a taper shank cutter.

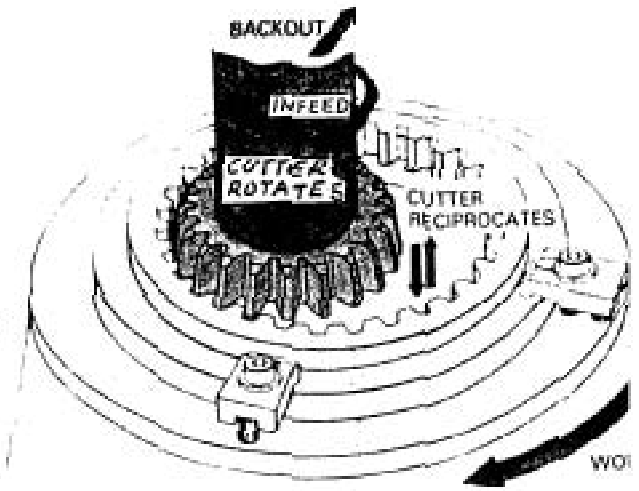


8b. Generally, taper-shank cutters are made in four taper diameters. As measured at the large end of the taper, standard sizes available are 1.0625", 0.700", 0.475" and 0.250". Pitch diameter of the cutter will approximate the taper diameter. Flutes can be added to long cutters of small pitch diameter to minimize deflection when cutting.

Figure 3-10 Shaping Tools.

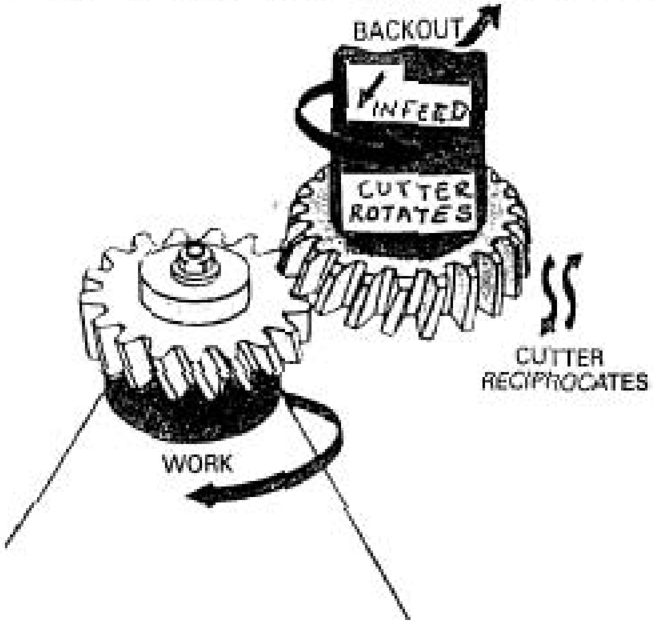


2. Illustration of generating an external spur gear on a geur shaper.



3. Illustration of generating an infernal spur gear by shaping.

4. Illustration of generating a helical gear by shoping. In Figures 2, 3 and 4 the cuffer spindle feeds info the workpiece and backs away (relieves) on the upstroke. Another commonly used motion involves feeding the workpiece info fhe cuffer spindle (the spindle still backs away an the upstroke).



5. Gear shaping is nof limited fo producing invalufe gears. If is capable of efficiently producing a variety of noninvolute shapes (i.e., cams, pump rotors, sprockefs, ratchefs, sfraighf-sided splines etc). This illusfration of a brake cam is represenfative. In fhis setup, the cenfer of fhe work is located in fhe approximate cenfer of its irregular shape (rather than ifs in-use cenfer of rotation) to simplify cuffer design and eliminafe undesirable undercut in fhe cuffer. The part is first rough-shaped by milling, and is then finished to close tolerances on fhe gear shaper.

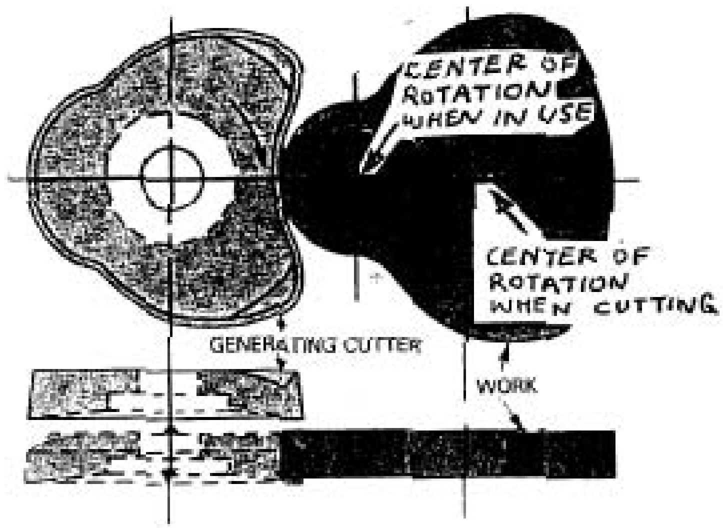


Table 3-10 Shaping process.

There are considerable differences in the prices for one and multiple cutters, so it is always advisable to order sufficient cutters at one time. Dull and worn out cutters can then be sharpened while the machine is running, which will keep the machine idle time to a minimum. Thus, it is better to order a minimum of two or three cutters. Before taking delivery of the machine, tooling and cutters it may be advisable to get samples of gears cut in the supplier's factory. This approach also offers an opportunity for the buyer's skilled operator to be present at the supplier's factory so that in-depth knowledge can be derived from the supplier's staff.

Where no catalogs are available for used machines, reference should be made to the original manufacturers who will be glad to send manuals and specifications at nominal prices.

Gear Shaping Machines

1. Fellows 3-2 (3-inch external) for small gears. 4 AGS (6-inch), 4A (10-inch maximum), 18-5 (18-inch maximum), 8 AGS (8-inch maximum), 36-6 (40-inch maximum), 7125 (7-inch maximum)
   Marketed by Fellows Corporation, Springfield, Vermont 05156, USA
2. Lorenz Shaper, LS 154 CNC 150 mm (6-inch), LS 154 K CNC 150 mm (6-inch), LS200 R, LS-180 MP Tronic CNC, (7-inch diameter), LS-154 V CNC 150 mm (6-inch)
   Marketed by Maschinefabrik Lorenz, Hertzstrasse 9-15, D-7505 Ettingen, P.O. Box 0551, West Germany
3. Liebherr Shaper. WS-1 (10.4-inch).
   Marketed by W. H. Jones Co., Inc. P.O. **Box** 277, Wallingford, PA 18974
4. Nachi Gear Shaper Model NSH-18M
   Marketed by Fujikosh Ltd., World Trade Center, Tokyo, Japan
5. Tokyo Kikai Model GS 1855, S-26-24 Shiba, Minalto-ku, Tokyo, Japan
6. Karatsu GSM-25, COSA Corp., 17 Philips Pkwy., Montvale, NJ 07645
7. Drummond Maxicut 3A (18-inch diameter), T.P.C. Inc., P.O. Box 626, Endicott, NY 13760
8. Yutaka Seimits Kogyo Shaper Model GPB-35 (9-inch Max.)
9. Lorenz, MCS 40 400 mm. LS 304 CNC 300 mm., LS 304 R CNC 300 mm., LS 424 CNC 420 mm., LS 424 S CNC 420

mm., LS 632 CNC 630 mm., LS 1002 CNC 1000 mm., LS 1252 CNC 1250 mm.

Gear Shaping and Shapers

The first shaping machine was developed and built in 1896 by E. R. Fellows in the **USA.** The Fellows Corporation was a pioneer in the shaping process, and they still supply standard and special shaping cutters. Lorenz of Germany is another reputable manufacturer.

Shaving of Gear Teeth

Shaving is a finishing operation that follows after shaping and hobbing. It is widely used for automobile gears, but with advances in the design of shaping machines and shaping tools for precision aircraft and missile gears, gear shaving is hardly used today for non-automobile gears. Compared with grinding, shaving is a faster operation. Shaving should preferable by done at a hardness of 32 Rockwell C maximum, though gears can be shaved even at **47** Rockwell C. At higher hardness, tool wear is very rapid.

Shaving is a corrective process. It does not make a bad gear good, but it will make a good gear better. Shaving improves surface finish and reduces gear run-out, profile accuracy, and tooth-to-tooth spacing.

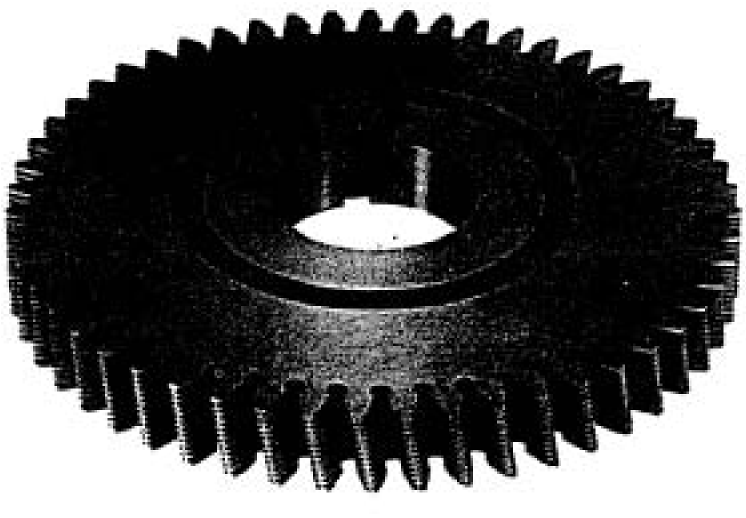
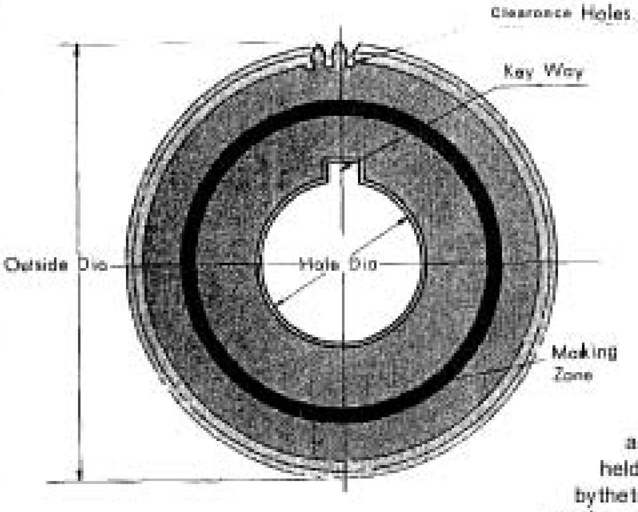


Figure 3-11 Typical shaving cutter.

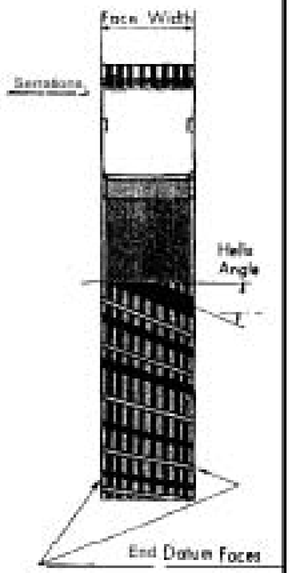
Methods for Cutting Gear Teeth



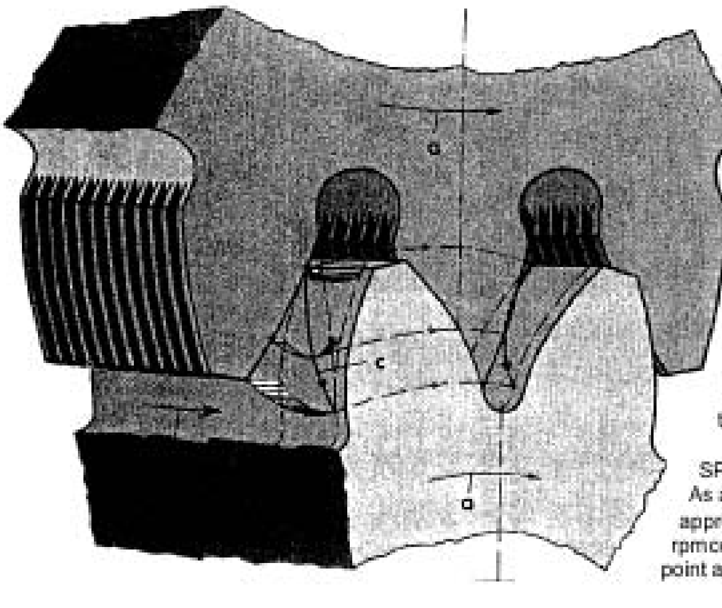
The shaving cutter nomenclature shown is considered standard throughout the industry.

THE SHAVING PROCESS

The gear shaving process is a means of finishing cut gears to a higher degree of accuracy in tooth profile and spacing, at the same time producing a smooth surface finish. The shaving cutter removes the feed marks produced by the cutter or hob in the generating type gear cutting operation and equalizes the deviations from the true profile.

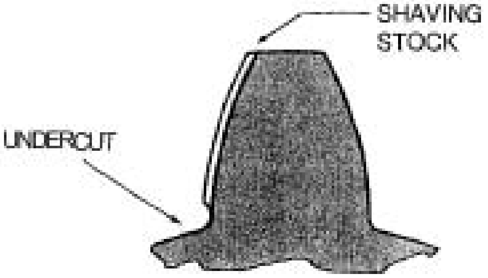


The cutter used in rotary gear shaving is a precision gear provided with a number of closely spaced grooves extending from the tip to roof of each tooth across the full cutter width. These grooves are called serrations. The work gear is held between tail-stock centers and driven by the tool. Both tool and work rotate in close mesh, under a certain amount of relative pressure and with their axes crossed, causing the teeth of the tool to slide along the teeth of the work and remove fine chips. By increasing or decreasing the crossed axes angle it is possible to provide the most desirable cutting conditions possible. The necessary contact pressure is obtained by radial infeed of the work gear. The shaving machine provides a relative transversing motion between the cutter and the work in order to cover the full width of the work gear teeth.



SPEEDS, FEEDS & STOCK REMOVAL

As a general rule, rotary shaving cutters are fun at a speed of approximately 400 surface feet per minute. Usually a cutter rpm corresponding to this surface speed is selected as a starting point and then the cutter's speed is increased or decreased as



Normal DP	Stock allowance on teeth thickness
2-4	.0030"-.0040"
5-6	.0025"-.0035"
7-10	.0020"-.0030"
11-14	.0015"-.0020"
16-18	.0010"-.0020"
20-48	.0005"-.0010"

National Broach & Machine Co., a division of Lear Siegler Inc. of Michigan, is an American gear shaving machine manufacturer and builds machines capable of shaving spur gears up to 180 inches in diameter. Gleason also markets shaving machines. (refer to end of chapter)..

The shaving process is further explained in detail in Ash Gear & Supply Company's technical sheet (see Table 3-11). A typical shaving cutter is shown in Figure 3-11.

Gear Grinding and Gear Grinding Machines

As pointed out elsewhere in this book, turbine gears and most of the gears used in machine tools are ground. Grinding is adopted to reduce the noise level and improve driving efficiency. With ground gears, maximum and minimum backlash between a set of gears is minimized. Sometimes, grinding becomes necessary because, on certain ranges of hardness, finishing of gears can be done only by grinding. If all gears were to be made from softer materials of lower hardness, the gear box size would be large. Designers therefore use hardened and ground gears to limit the size of the gear box and to limit backlash which is very critical, especially when it applies to gears used in aircraft and missiles.

There are two basic methods of grinding gear and spline teeth:

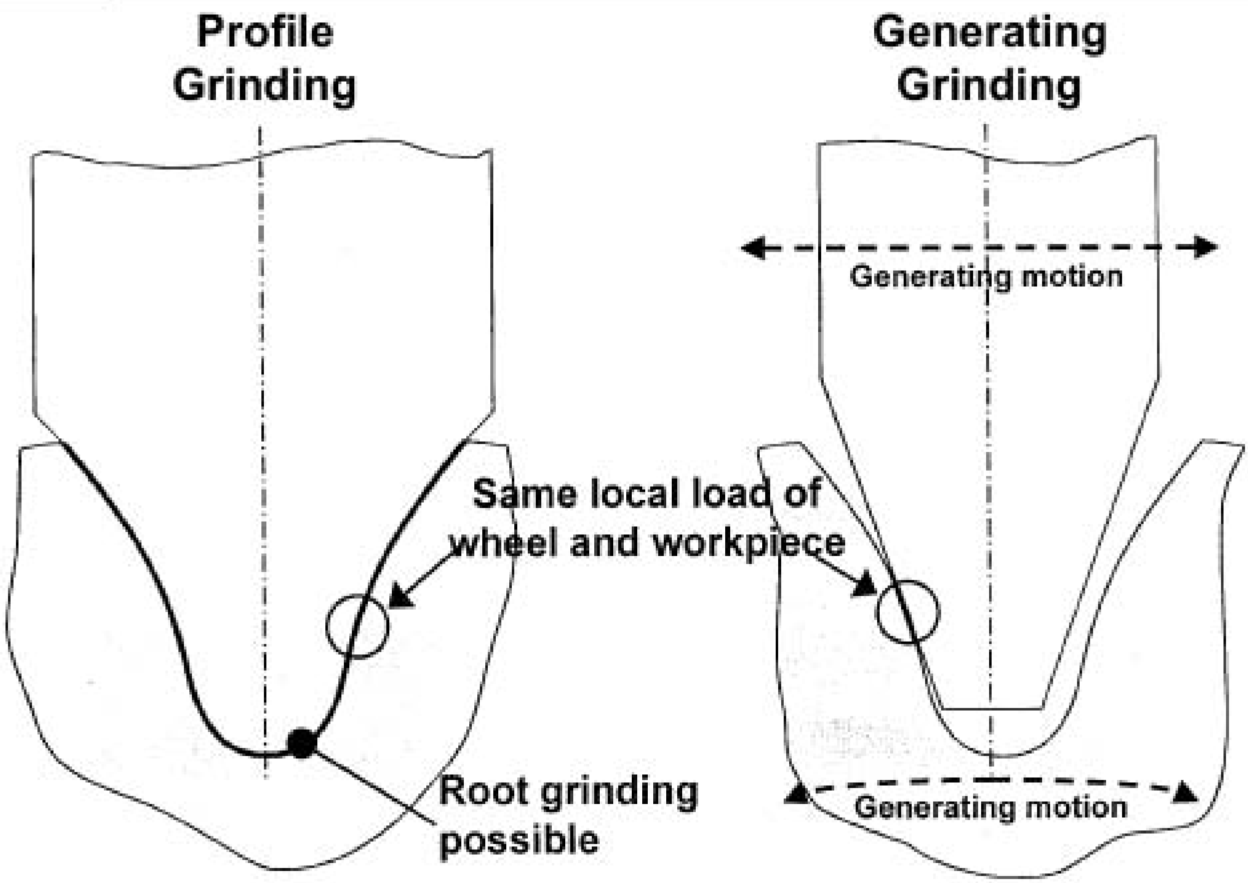
1. Form grinding method. Refer to Figures 3-12 and 13.
2. Generating method. Refer Figs. to 3-15, 16, 3-17 and 3-18.

National Broach Co., Liebherr, Kapp and Gleason manufacture form gear-grinding machines. These machines are capable of grinding both external and internal spur and helical gears up to 36 inches in diameter and even bigger to special order. In some of these machines the grinding wheel is dressed by templates with sufficient accuracy to produce a profile tolerance band of 0.0002 inch. Gears are indexed by accurately-ground, hardened index plates with numbers of gashes corresponding to the numbers of teeth in the gear to be ground.

Maag manufactures generating method gear grinding machines in horizontal and vertical configurations. These machines employ two saucer-shaped grinding wheels shown in Figure 3-15. The capacity of the machines is up to 187 inches and dp from 25 to 0.63 dp.

Threaded-wheel gear grinding machines are manufactured by Reishauer & Okamoto. These machines are designed for rapid production and they employ a thread grinding wheel of approximately 13-inch diameter. The threaded wheel section is an involute rack.

Profile Grinding
vs. Generating Grinding



Courtesy Of Gleason Corporation

Figure 3-12

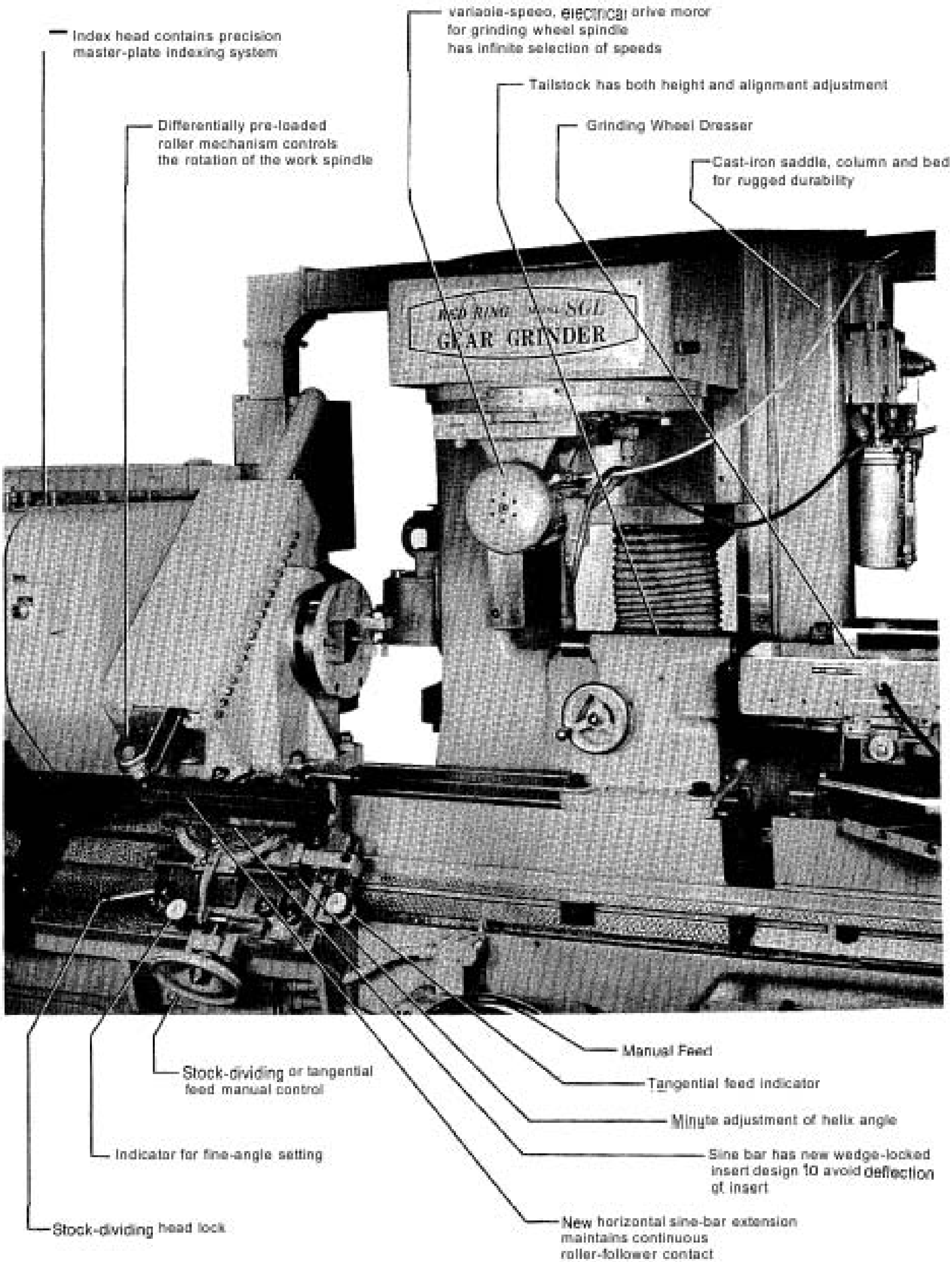
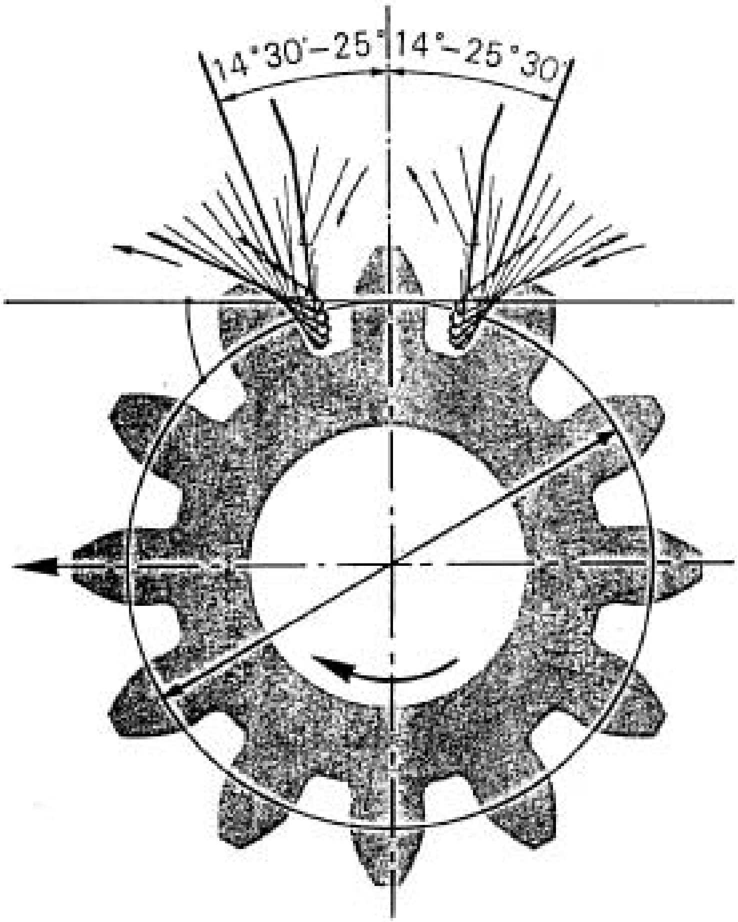
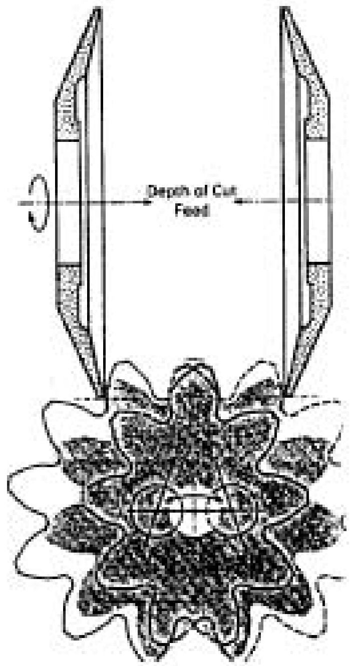


Figure 3-13 Formed-wheel gear grinding machine.



WHEELS SET TO PKESSUKE ANGLE



0° METHOD

Figure 3-14 Saucer Shaped Wheel Gear Grinding Method

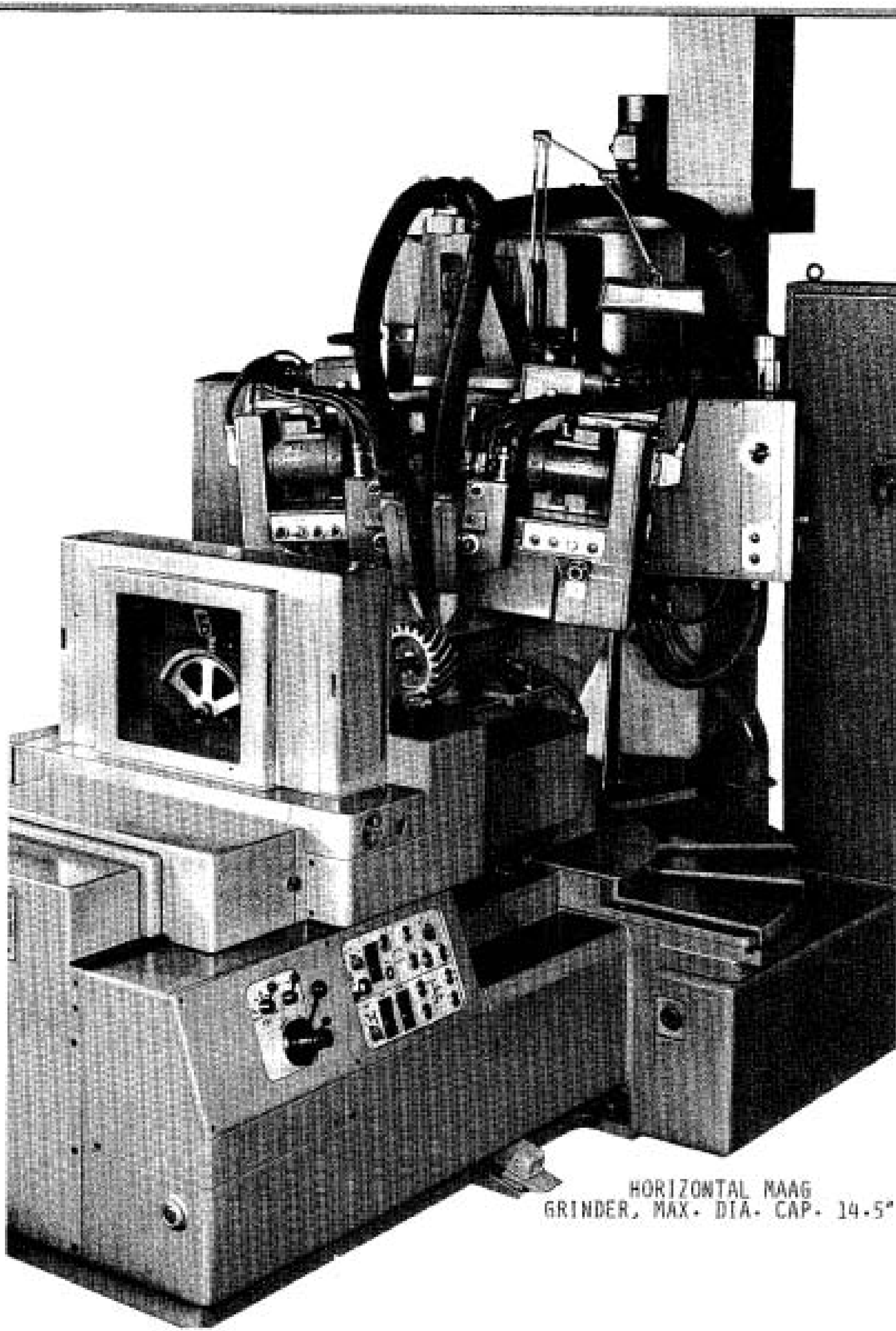
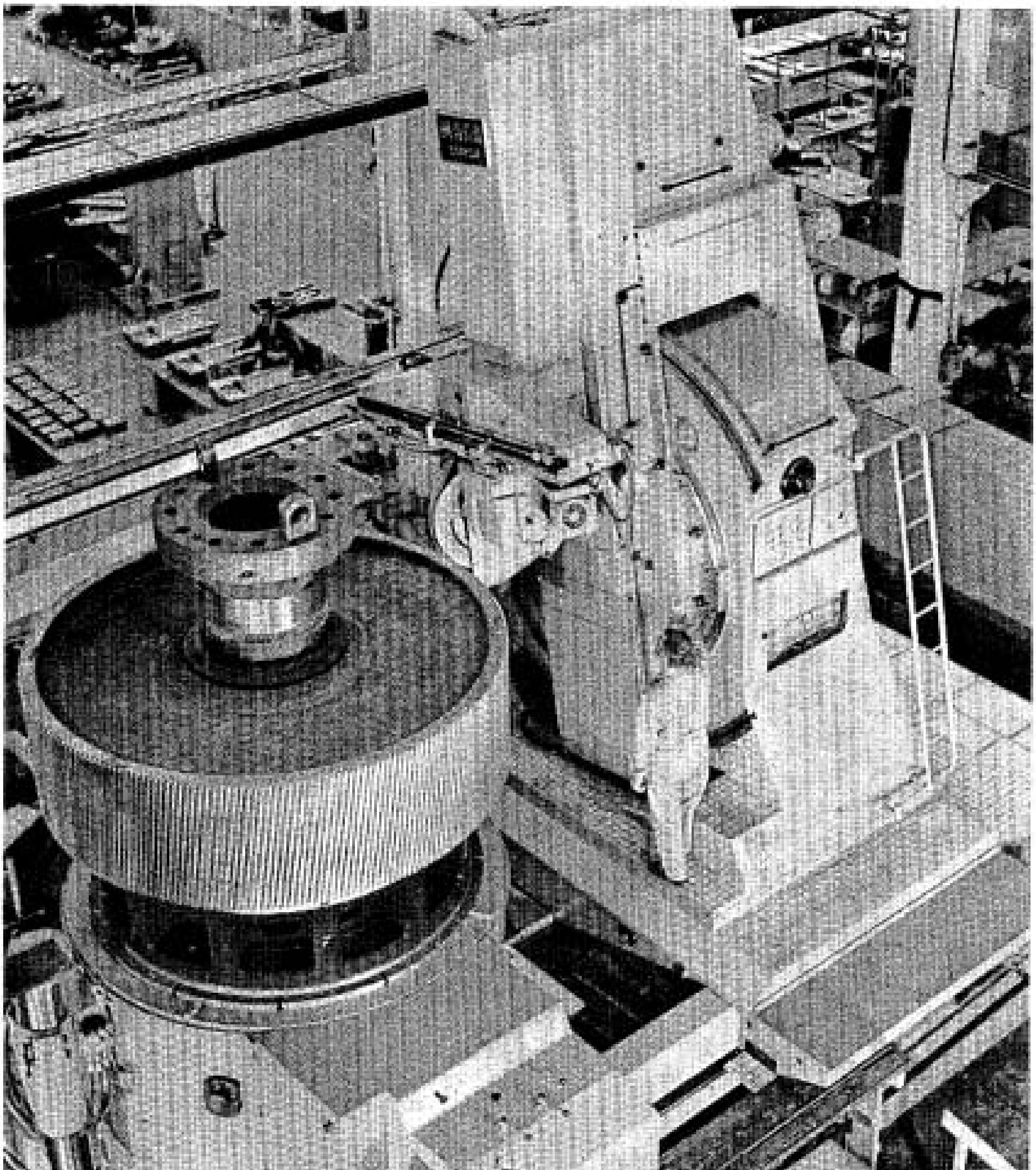


Figure 3-15



MAAG VERTICAL GEAR GRINDER MAX. DIA. CAP. 187"

Figure 3-16

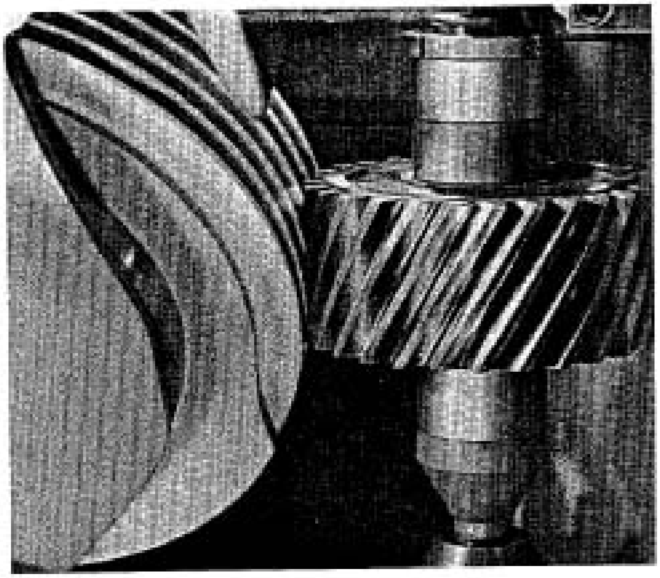
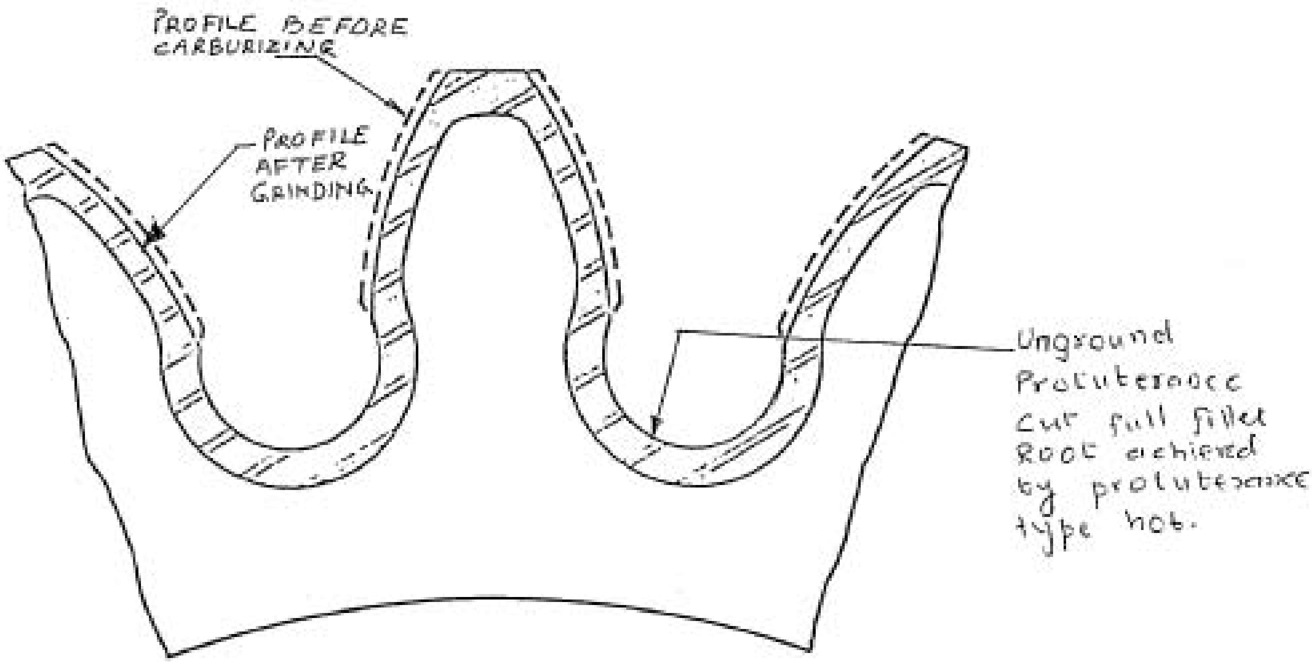


Figure 3-17



GROUND TOOTH PROFILE WITH
UNGROUND PROTUBERANCE
CUT FULL FILLET ROOT

Figure 3-18

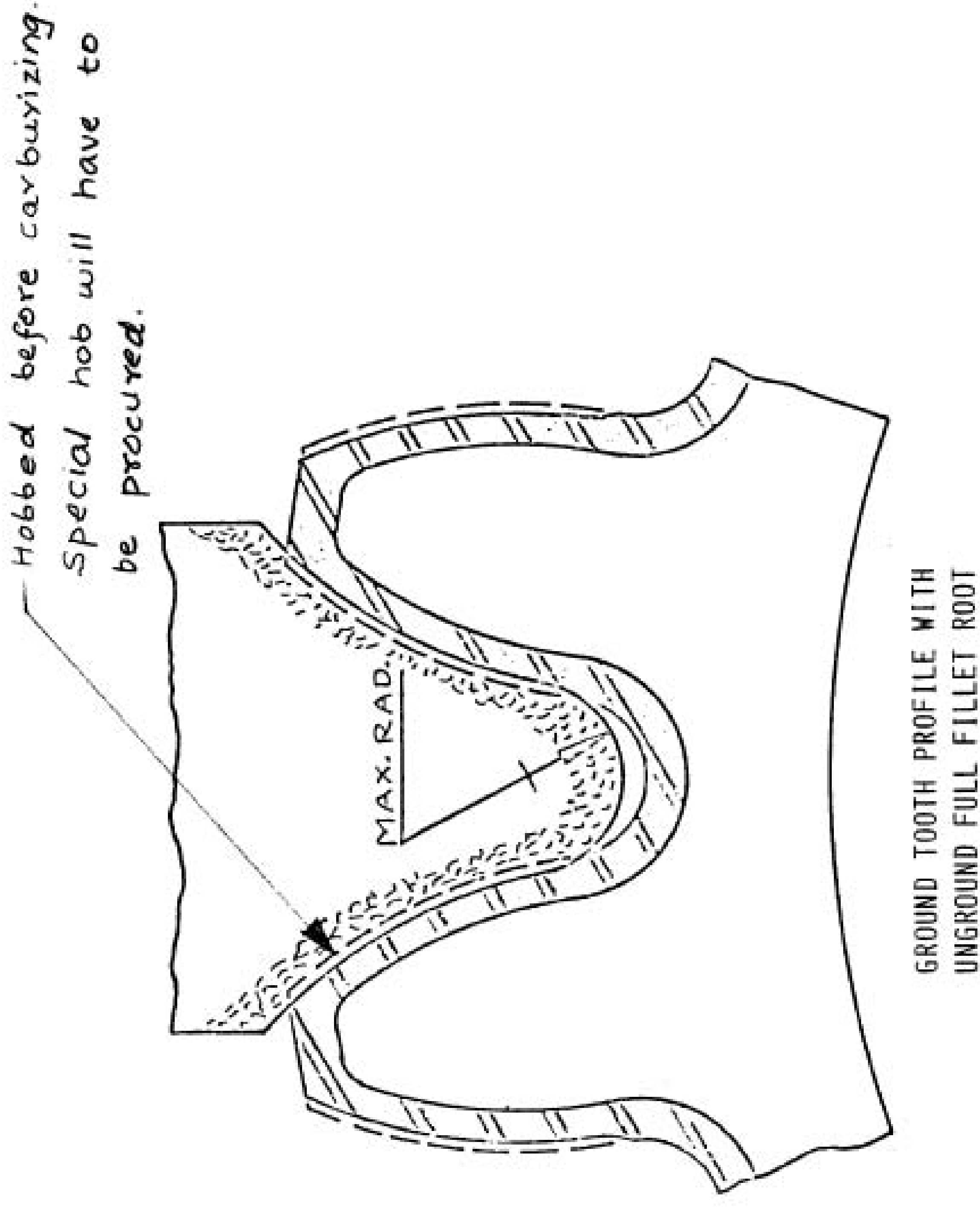

Hobbed before carburizing. Special hob will have to be procured.
MAX. RAD.
GROUND TOOTH PROFILE WITH UNGROUND FULL FILLET ROOT

Figure 3-19

Gear drawings generally specify AGMA or DIN numbers as a part of the gear specifications. The chart on Table 7-15 in Chapter 7 indicates the accuracy that can be achieved by grinding.

Figure 3-18 shows how a special hob with protuberance must be used to ensure that the gear is hobbed to the required contour before heat treatment. Figure 3-19 shows how full-depth carburization can be retained in the fillet.

List of Grinding Machine Manufacturers

1. Hoefler Gear Grinding Machines. H500 (20-inch) H630 (30-inch)
   Marketed by Dr. Ing. Hoefler Corporation, 65 Route 22, Clinton, NJ 08809
2. Reishauer number 12 (12-inch Max. Dia.), RZ 3015&ZB770
3. Okamoto Gear Grinding Machine Model SHG-3. Okamoto Machine Tools Works Ltd., 1000 Minowa-Cho, Kohoku-ku, Yokohama, Kanagawa, Japan
4. American Pfauter Grinding Machine Max. 200 inch
5. National Broach & Machine 36 inch Max.
6. Starcut Sales 12-inch Max.
7. C.O. Hoffacker 36-inch Max.
8. Klingelnberg Worm Grinding Machine Model HSS 33B
9. Maag, HSS-30A (11.8-inch outside diameter) HSS-30 Double Wheel Dresser HSS-60 (24-inch)
   R.O. Deadrick Co. Inc. P.O. Box 2526, Orlando, FL 32802
10. Reishauer 92inch Diameter, Reishauer Corp. Elgin Illinois 60123
11. Kapp YAS 431 and 481 CBN Form Grinder

Advanced Machines by Gleason

Special attention is drawn to machines marketed by The Gleason Works and its affiliates (sometimes collectively referred to herein as "Gleason", Pfauter Hurth Worldwide Sales who market the grinding machines shown in Table 3-13. The following tables contain details of these machines.

Table 3-12	Typical Automotive Gear Finishing Processes
Table 3-14	Features of P400G Grinding Machine

Spheric Horning

What are Typical Automotive Gear Finishing Processes?

- *SHAVING - Transmission Gears (Spur and Helical)*
- *GRINDING - Transmission (Spur and Helical) and Axle (Hypoid-Bevel) Gears*
- *HONING - Transmission Gears (Spur and Helical)*
- *LAPPING - Axle Gears (Hypoid Bevel)*
- *HARD HOBBING OR SKIVING - Engine Timing Gears*

Table 3-12

Gleason-Pfauter Grinder Models

- **P200G**
- **P300G**
- **P400G**
- **P600G**
- **P800G**
- **P800/1200G**
- **P1200G**
- **P1600G**
- **P1600/1800G**
- **P2000G**
- **P2400G**
- **P2000/3000G**
- **P3001G**
- **P4001G**
- **P300HG**
- **P500HG**

Courtesy Of Gleason Corporation

Table 3-13

Gleason-Pfauter
P 400 G Profile Grinding Machine — Courtesy Of Gleason Corporation

P *400* G Features...

- Can grind using plated CBN wheels and/or dressable vitrified wheels
- Integrated CNC controlled dresser
- Automatic stock alignment system
- Automatic gear measurement and evaluation system
- External/internal gear grinding capability

Table 3-14

Selection *of* Gear Finishing Processes
When to Grind versus Shave or Hone

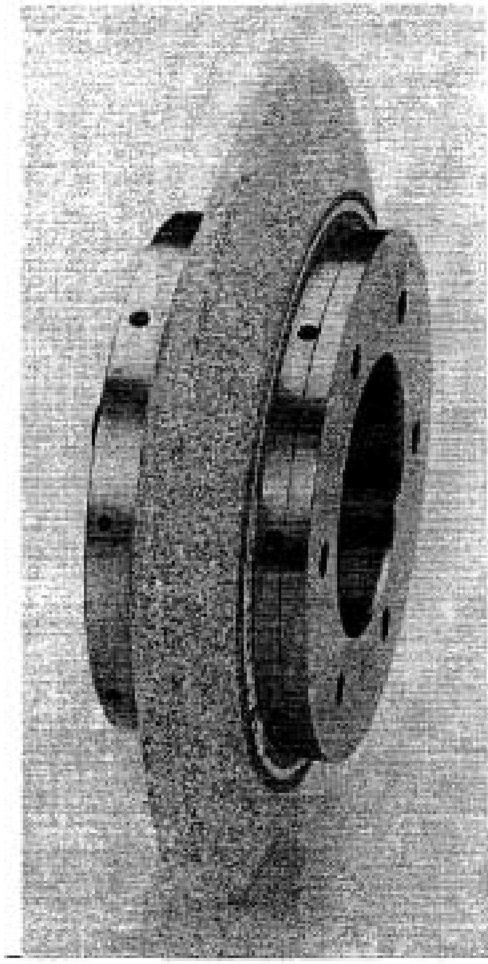
- GRINDING IF
  - Large amounts of stock to be removed (>65 µm)
  - Large module or very large face widths (Module >6)
  - Very high pressure angles
  - Very high profile and lead accuracy required (DIN 5 and better)
  - On-going profile and lead corrections
  - Mixed volumes and frequent changeovers
  - High variation of heat treatment distortions

Courtesy *Of* Gleason Corporation

Table 3-15

Table 3-15	Information on Grinding versus Shaving and Honing
Table 3-16	Specifications of a Typical Grinding Wheel
Fig 3-20	CBN-plated wheels
Fig 3-21	Typical External and Internal Grinding with CBN-plated Wheels

The Tool:



Type	Dressable wheel
Abrasive	Sintered Corundum (20 % SG)
Spec.	85A 80 H 15 V
Grid size	80 (Mesh)
Make	Winterthur, Swizerland
o.d.	300 mm

Courtesy Of Gleason Corporation

Table 3-16

Gleason-Pfauter
P 400 G Profile Grinding Machine

lated Grinding Wheels

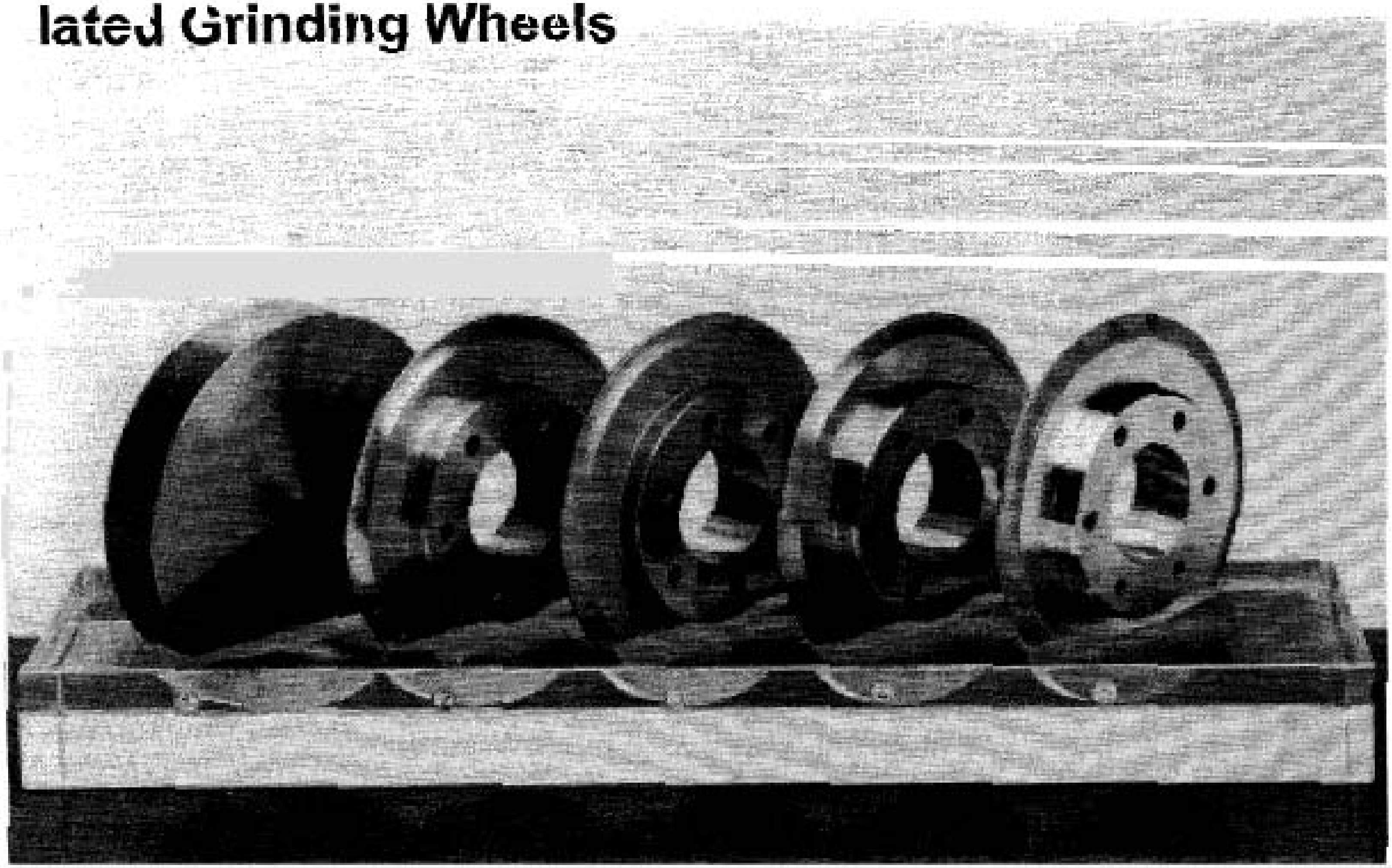
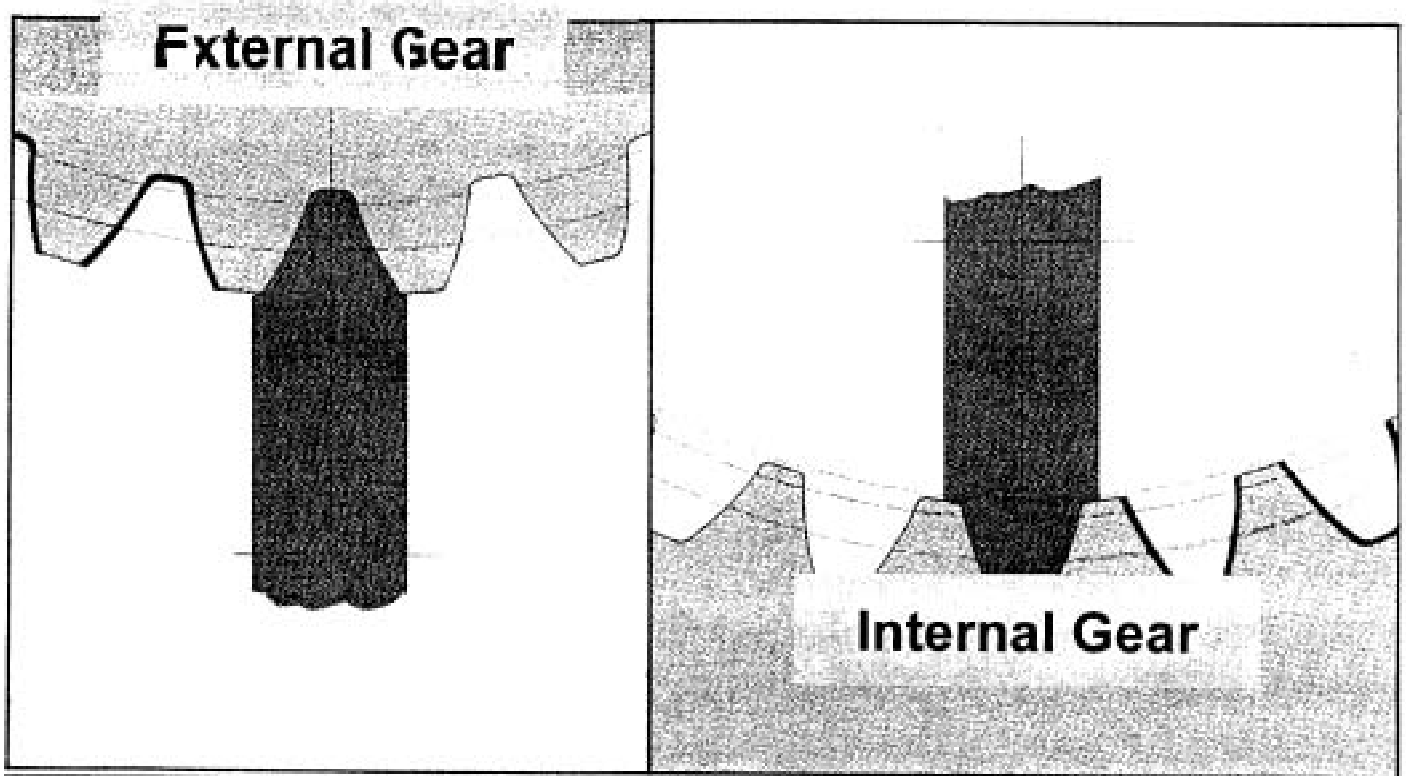


Fig. 3-20

Courtesy Of Gleason Corporation

Profile Grinding
External & Internal Grinding



Courtesy Of Gleason Corporation

Fig. 3-21

Figures 3-22, 3-23, 3-24, 3-25, and 3-26
Gives overall views of shaving machines

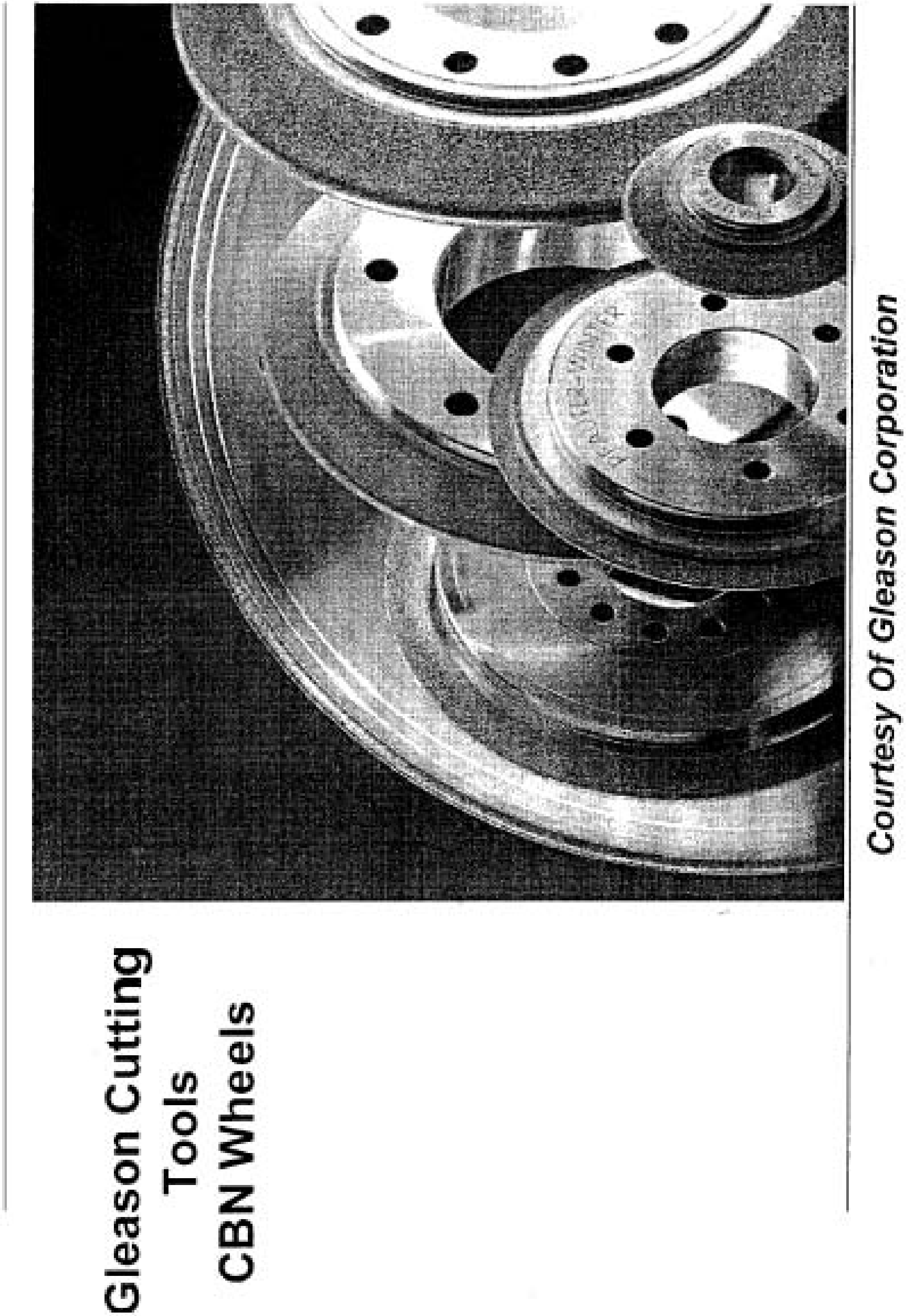
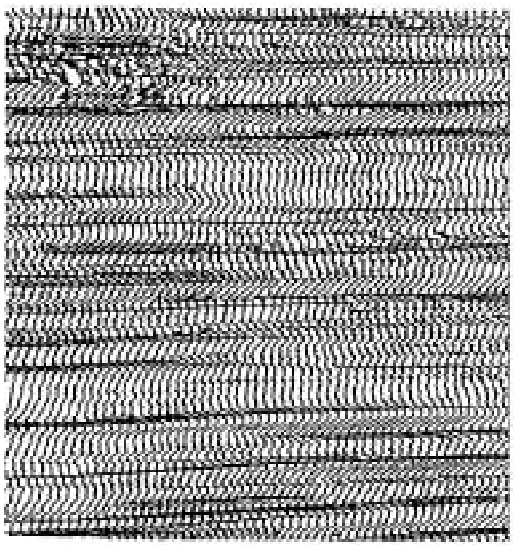
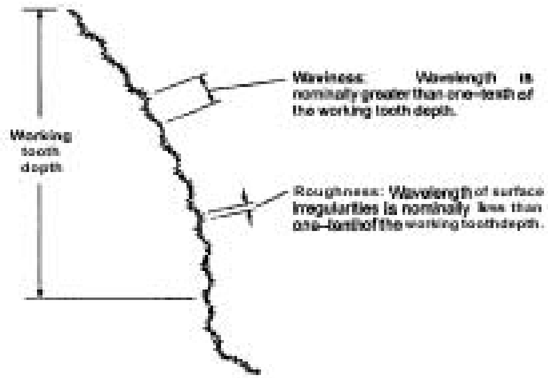

Gleason Cutting
Tools
CBN Wheels
Courtesy Of Gleason Corporation

Fig. 3-22

Different surface structures on gear flanks

ground





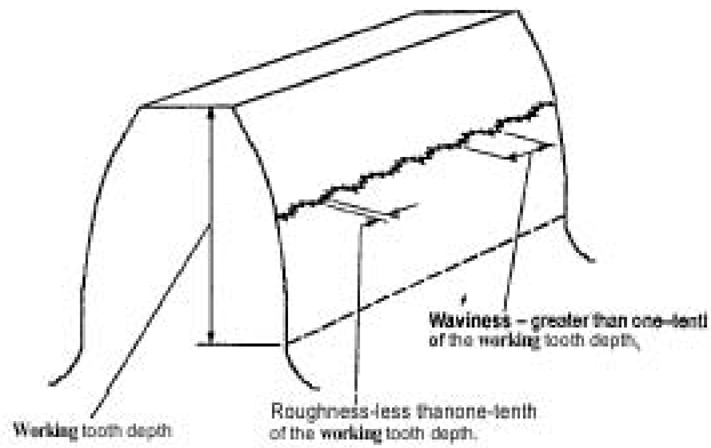


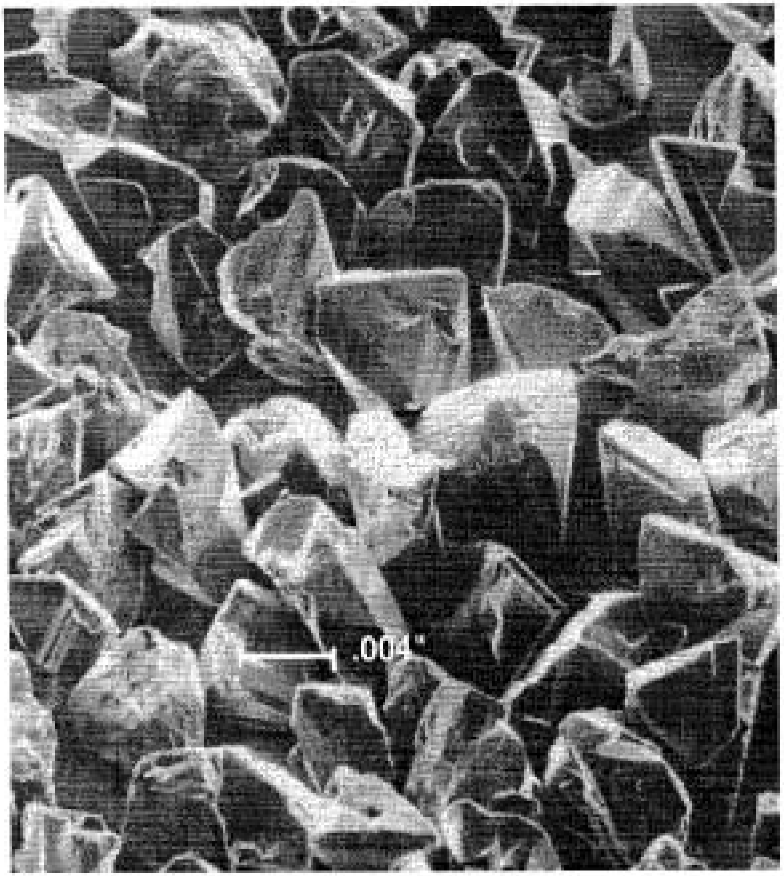
Fig. 8-23

Courtesy Of Gleason Corporation

Fig. 3-24

Gleason-Pfauter
P 400 G Profile Grinding Machine

CBN Crystals and Plating



CBN Crystals

CBN Plating

Courtesy Of Gleason Corporation

Selection of Gear Finishing Processes
When to Shave versus Grind or Hone

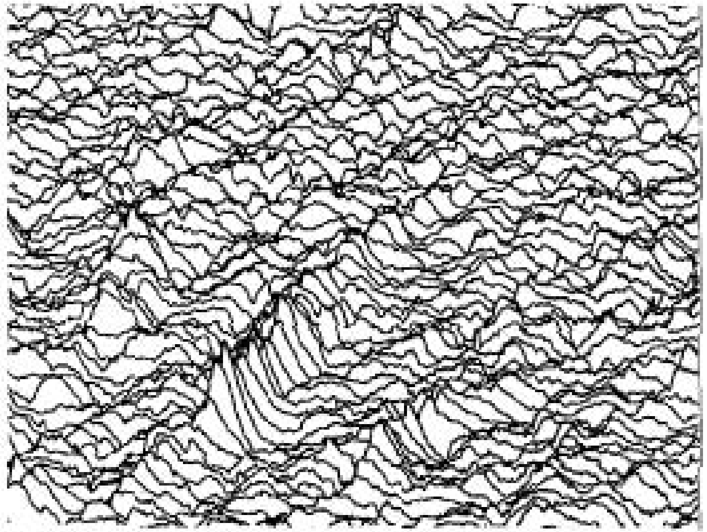
- SHAVING IF
  - Minimal heat treatment distortions expected
  - Less profile and lead accuracy required after heat treatment
  - High volumes of small gears (Module < 1,5) when plunge shaving is applicable (Pinions of automatic transmissions)
  - Mixed volumes and frequent changeovers
  - Noise reduction requirements not very high

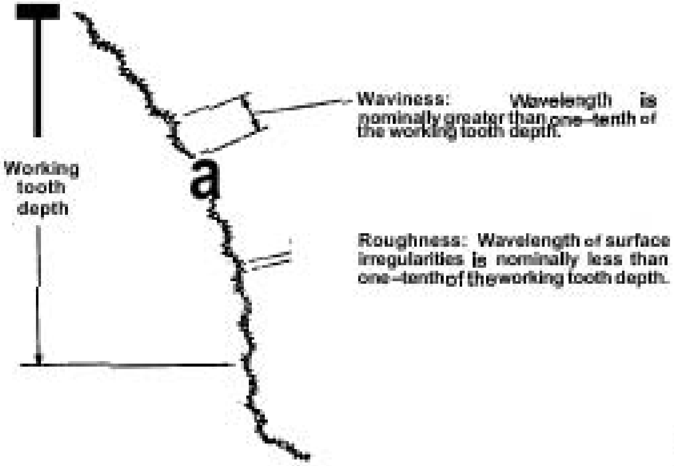
Courtesy Of Gleason Corporation

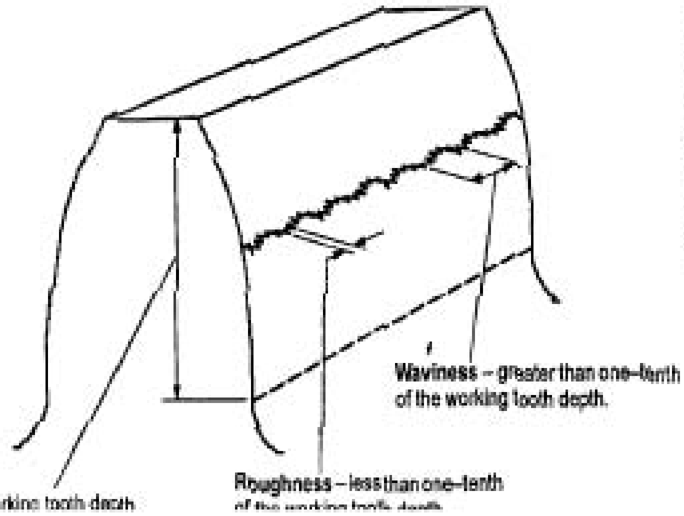
Table 8-11

Different surface structures on gear flanks

shaved and hardened



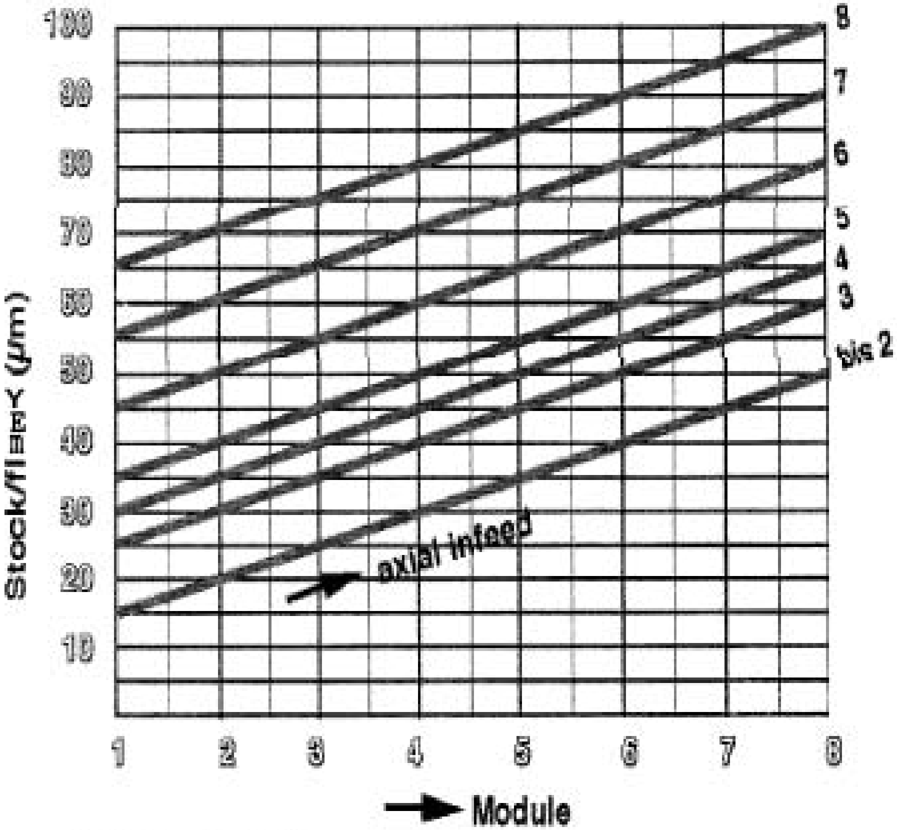


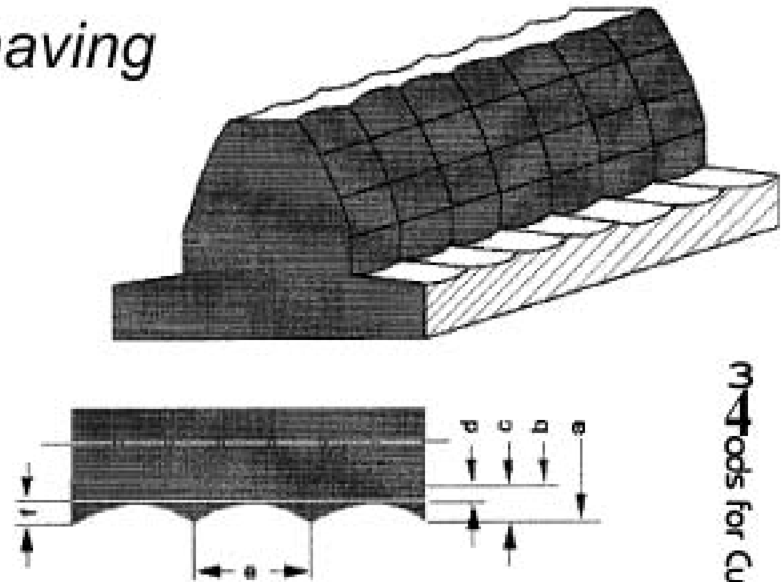


Courtesy Of Gleason Corporation

Figure 3-25

Stock allowance for gear shaving





a) size of hobbed gear

b) size of shaved gear

c) amount of stock/flank

d) amount of stock/flank at low infeed rates

e) infeed rate

f) depth

Figure 3-26

Courtesy Of Gleason Corporation

Chip removal by gear shaving

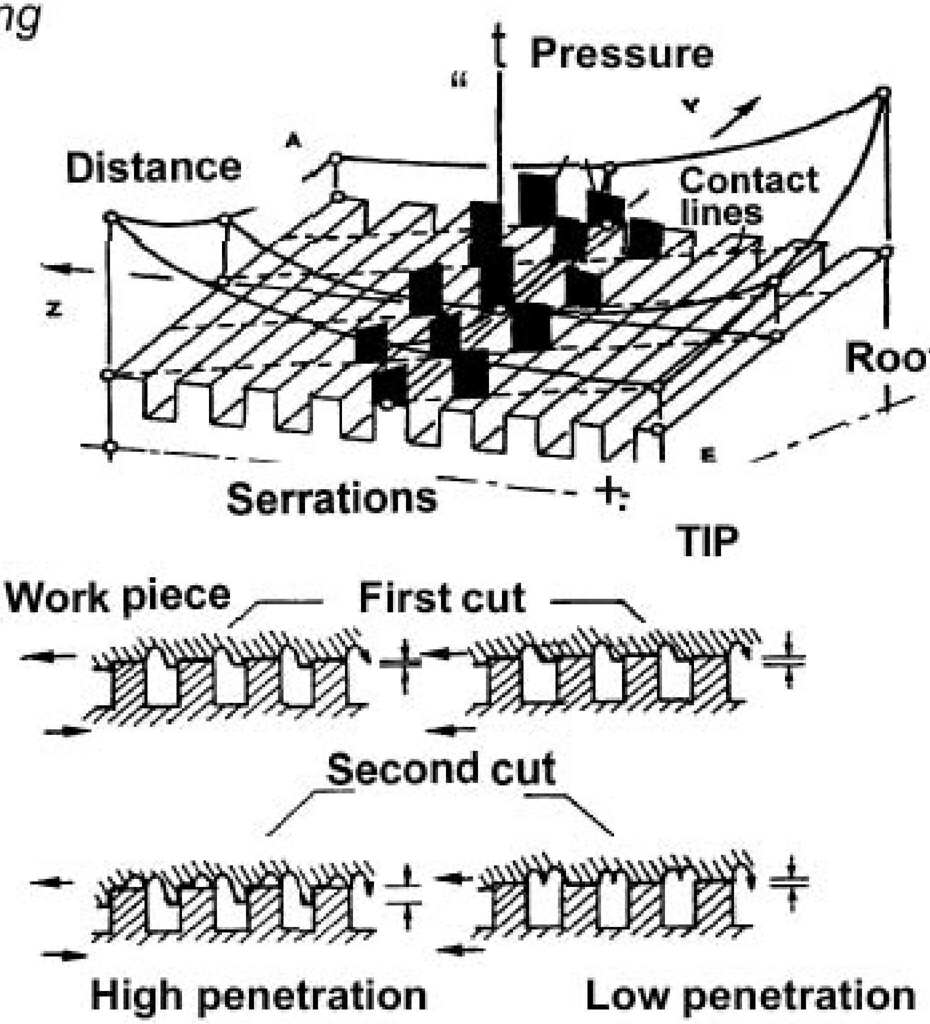


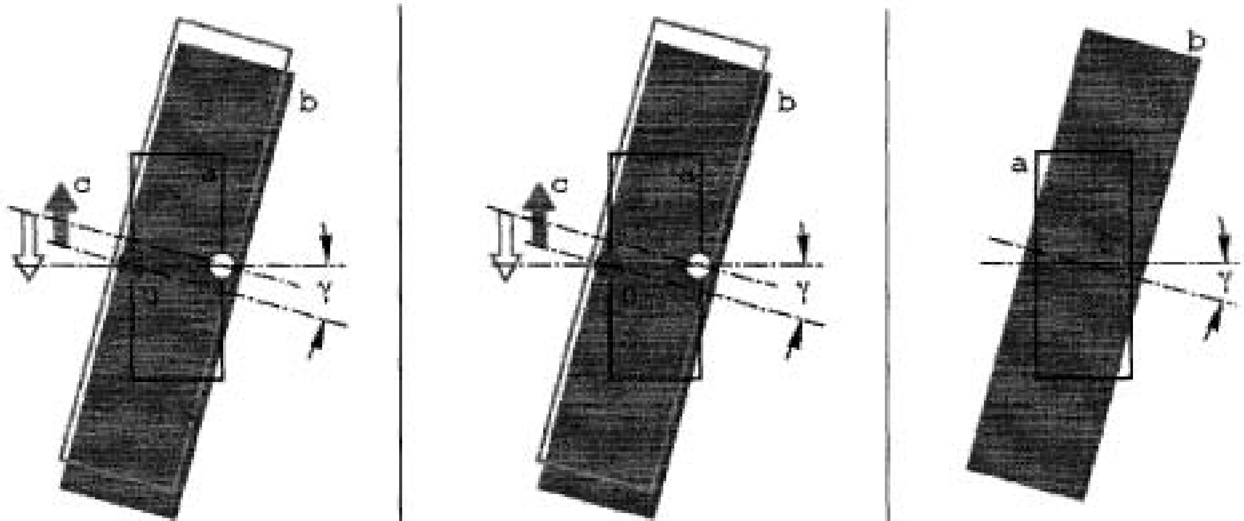
Figure 3-27

Courtesy Of Gleason Corporation

Comparison of shaving strategies

Table 3-18

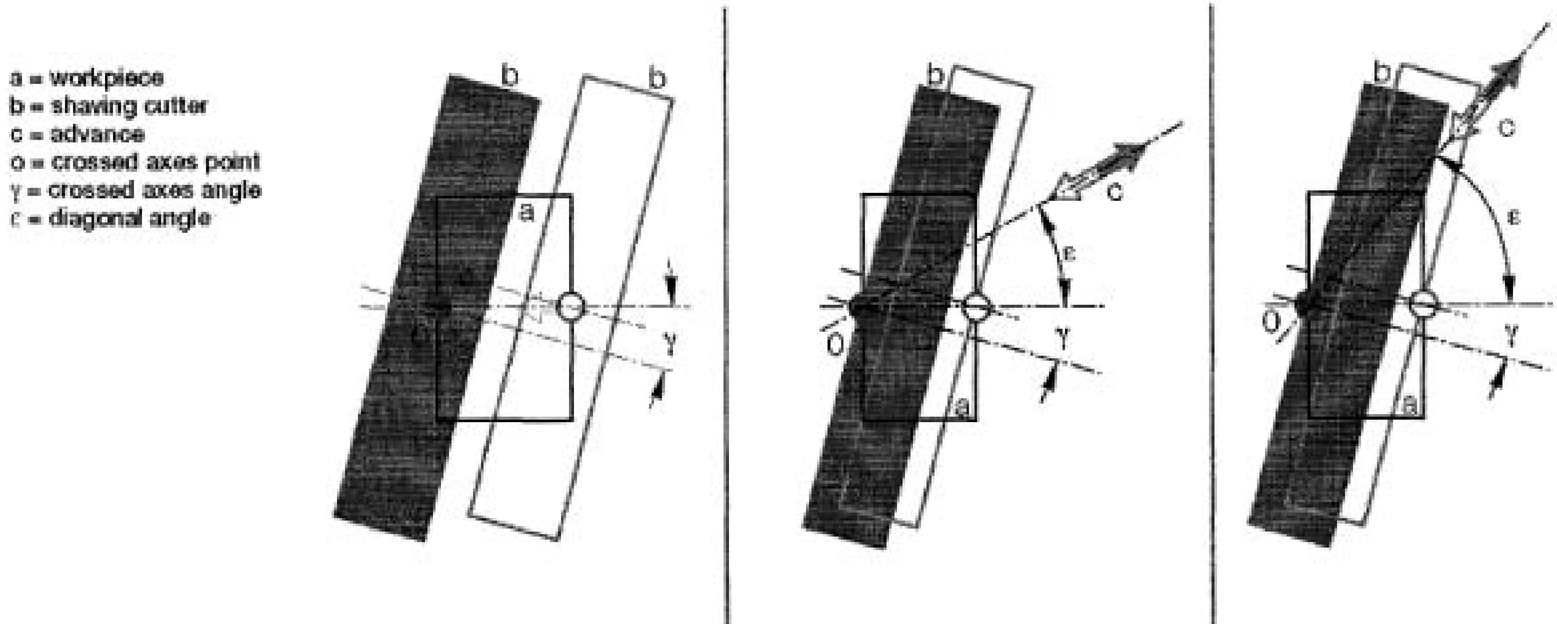
a = Workpiece
b = Shaving Cutter
c = Advance
o = Crossed axes point
g = Crossed axes angle
e = Diagonal angle



shaving methods	(Underpass)	Tangential	Plunge
diagonal angle	90°	60 - 90°	
serrations	staggered (shaving cutter width > workpiece		
max. width	~40 mm		

Courtesy Of Gleason Corporation

Comparison of shaving strategies



Shaving methods	parallel	diagonal	traverse
Diagonal angle	0°	>0° ÷ 40°	>40° ÷ <90°
Serrations	not staggered		staggered
max. width	∞	~50 mm	~45 mm

Courtesy Of Gleason Corporation

Hurth Power Shaving™ Machine ZS 130 T

Machine design

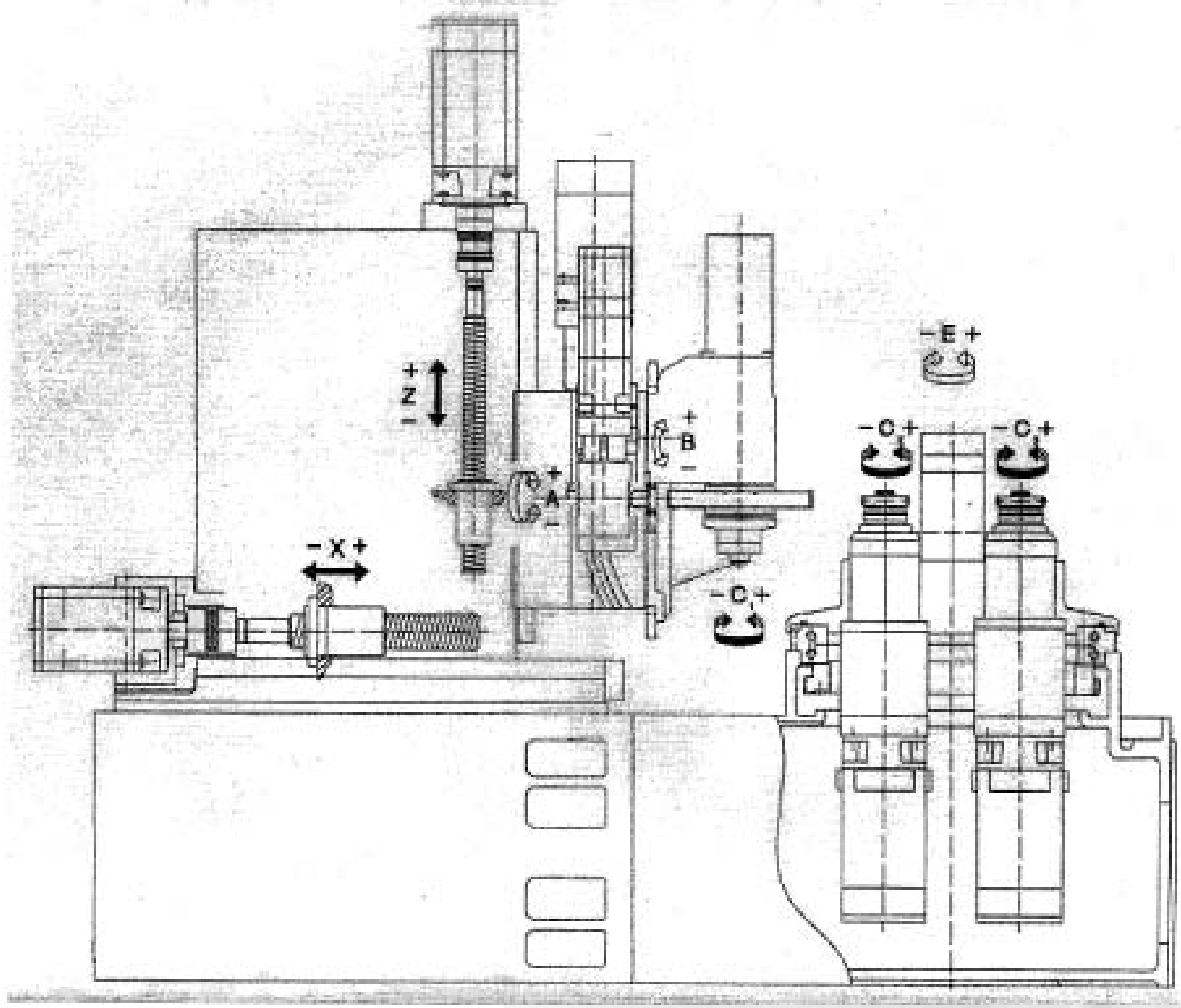
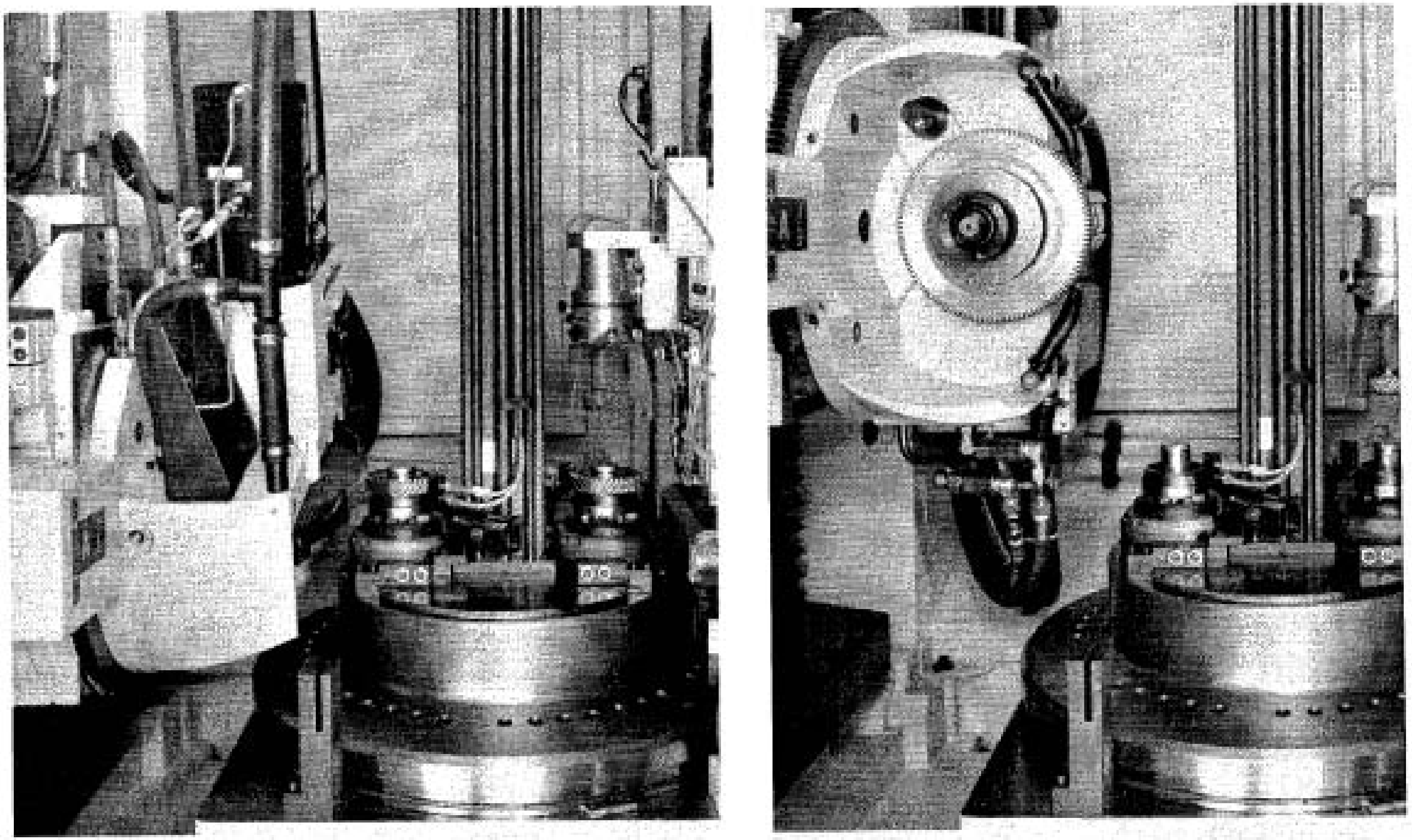


Fig. 3-28

Courtesy Of Gleason Corporation

Hurth Power Shaving™ Machine ZS 130 T

Working situation and loading



Courtesy Of Gleason Corporation

Fig. 3-29

Hurth ZSE 150 T CNC Gear Shaving Machine

Integrated deburring unit from single station deburring machine

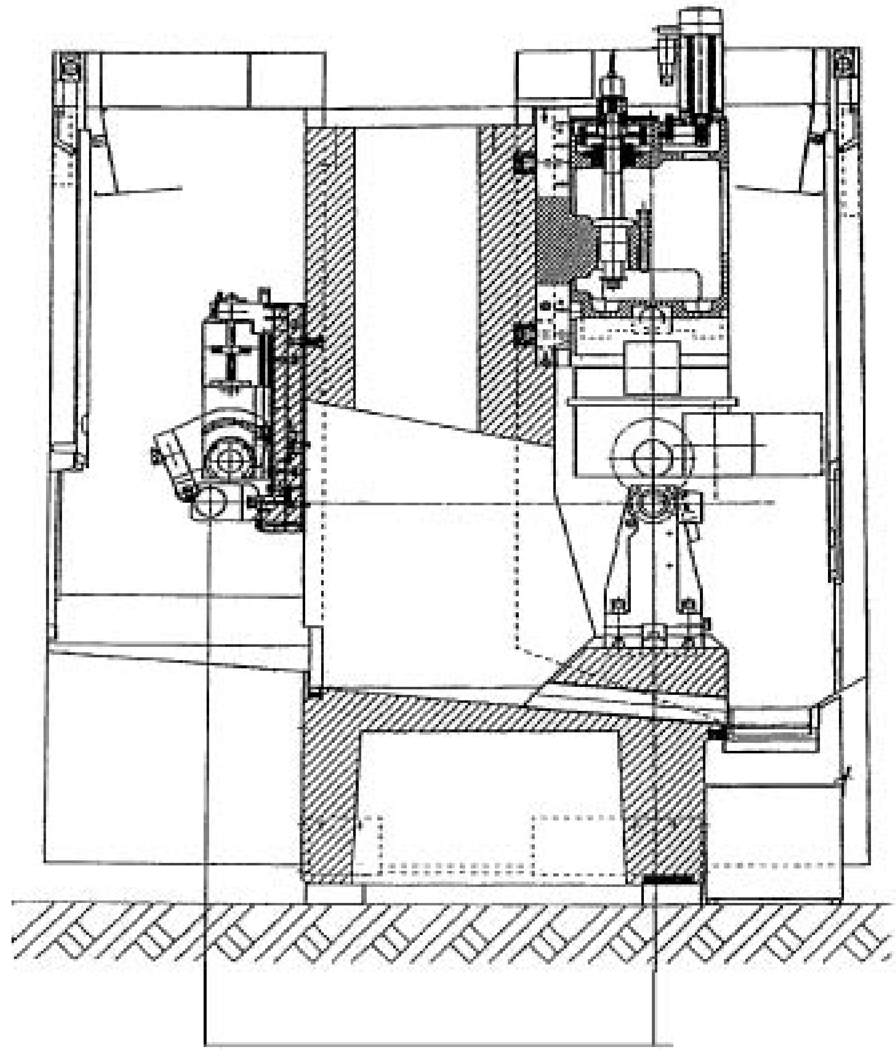


Fig. 3-30

Courtesy Of Gleason Corporation

ZS 240 - Machine Axes

Universal
Shaving Machine with five
CNC axes

Working axes

Z - infeed motion
X -traverse motion
w - cross motion
y - taper/crowning motion

Setting motion

U - cross-axis angle setting

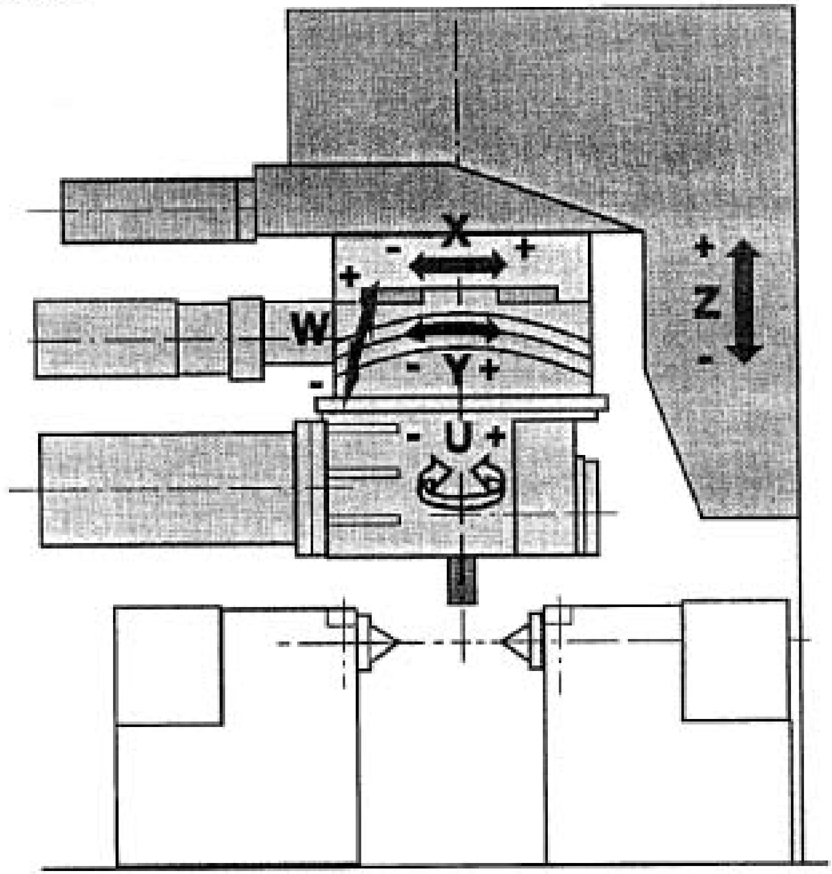
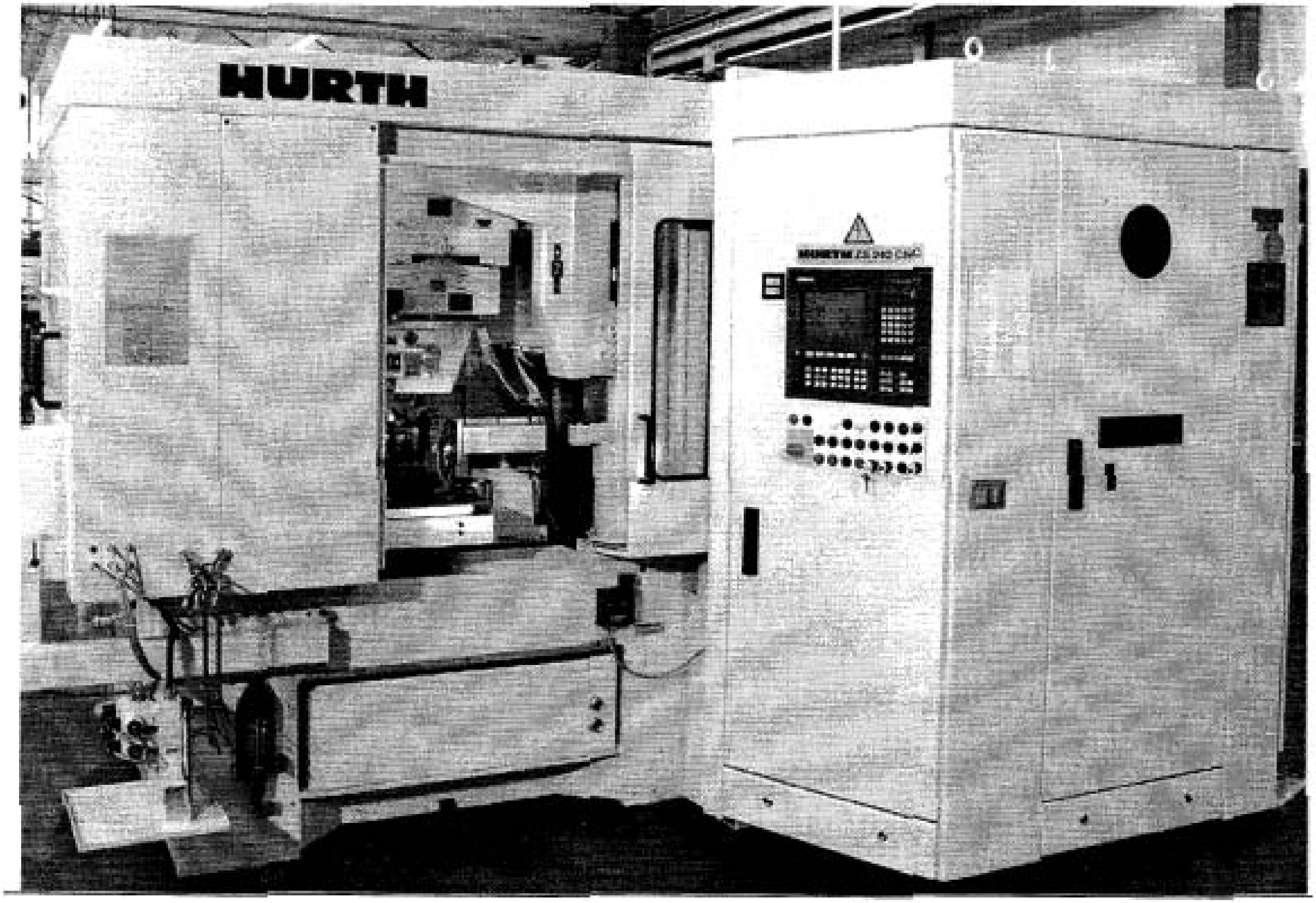


Fig. 1

Courtesy Of Gleason Corporation

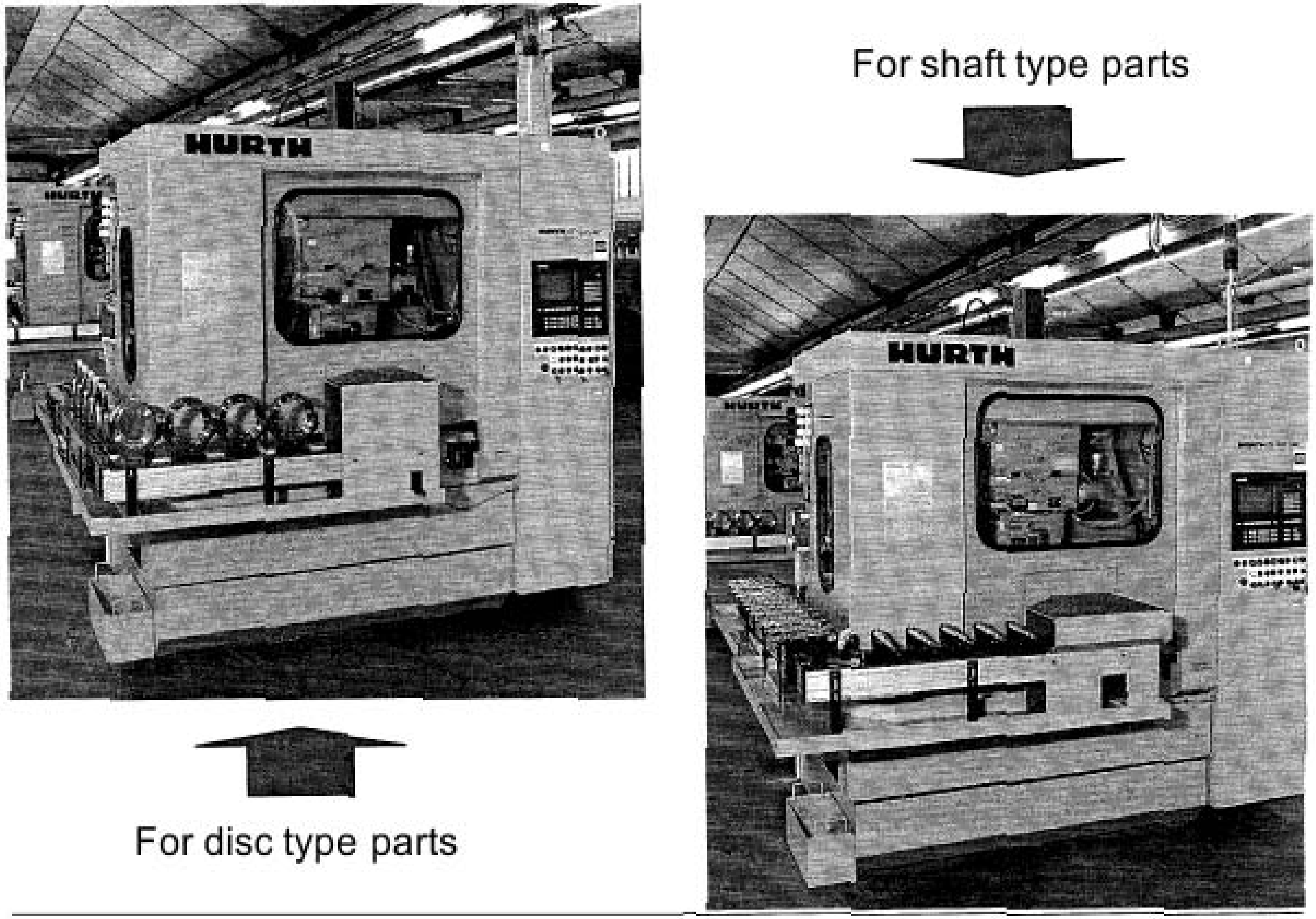
Hurth ZS 240 Gear Shaving Machine

Fig. 8-32



Courtesy Of Gleason Corporation

Fig. 3-33



Courtesy Of Gleason Corporation

Automotive Gear Finishing Processes

High-quality automotive gears have to be produced at low cost, so leading gear machinery manufacturers like Gleason, Gleason-Pfauter and Gleason-Hurth have evolved special machines for producing automotive gears. Practical information on shaving, honing, and grinding operations on machines built by these companies is given in the following tables.

Table **3-17** Describes when shaving is preferred to honing and grinding.

Fig. **3-26** Gives information on stock allowance for shaving.

Spheric™ Honing Machines and Processes

Basic kinematics of spheric honing process is shown in Fig. **3-34.** This process has extensively been used in machining typical transmission gears as shownon Fig. **3-35.** Machines for this process are being manufactured by Gleason-Hurth Maschinen and Werkzeuge Gmbh of Munich, Germany. Following tables and figures will be of use to manufacturing engineers.

Table **3-18** When spheric honing is advantageous

Table **3-19** Surface finish of honed gear

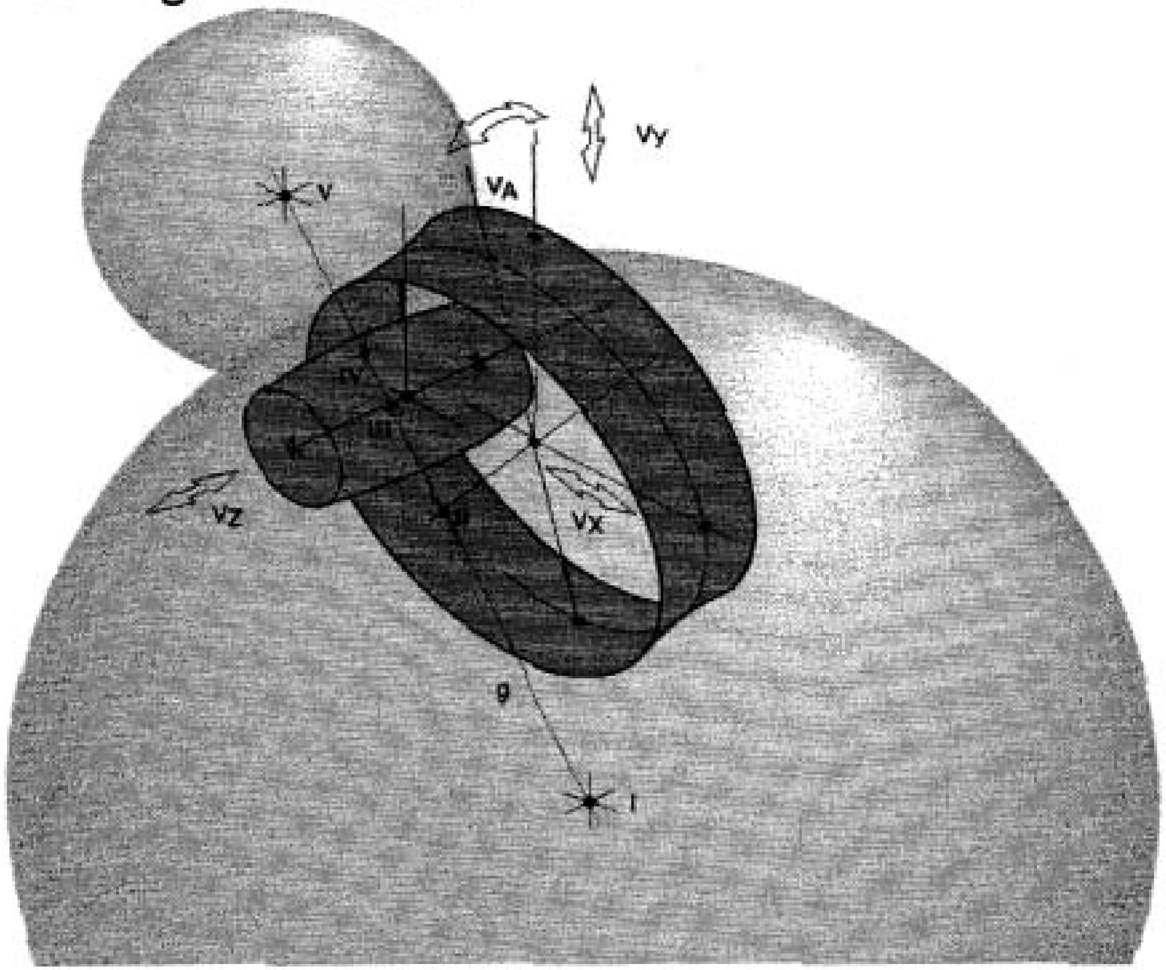
Table **3-20** Quality grades of honing in comparison to shaving and grinding.

Table **3-21** Steps before spheric honing

Table **3-22**

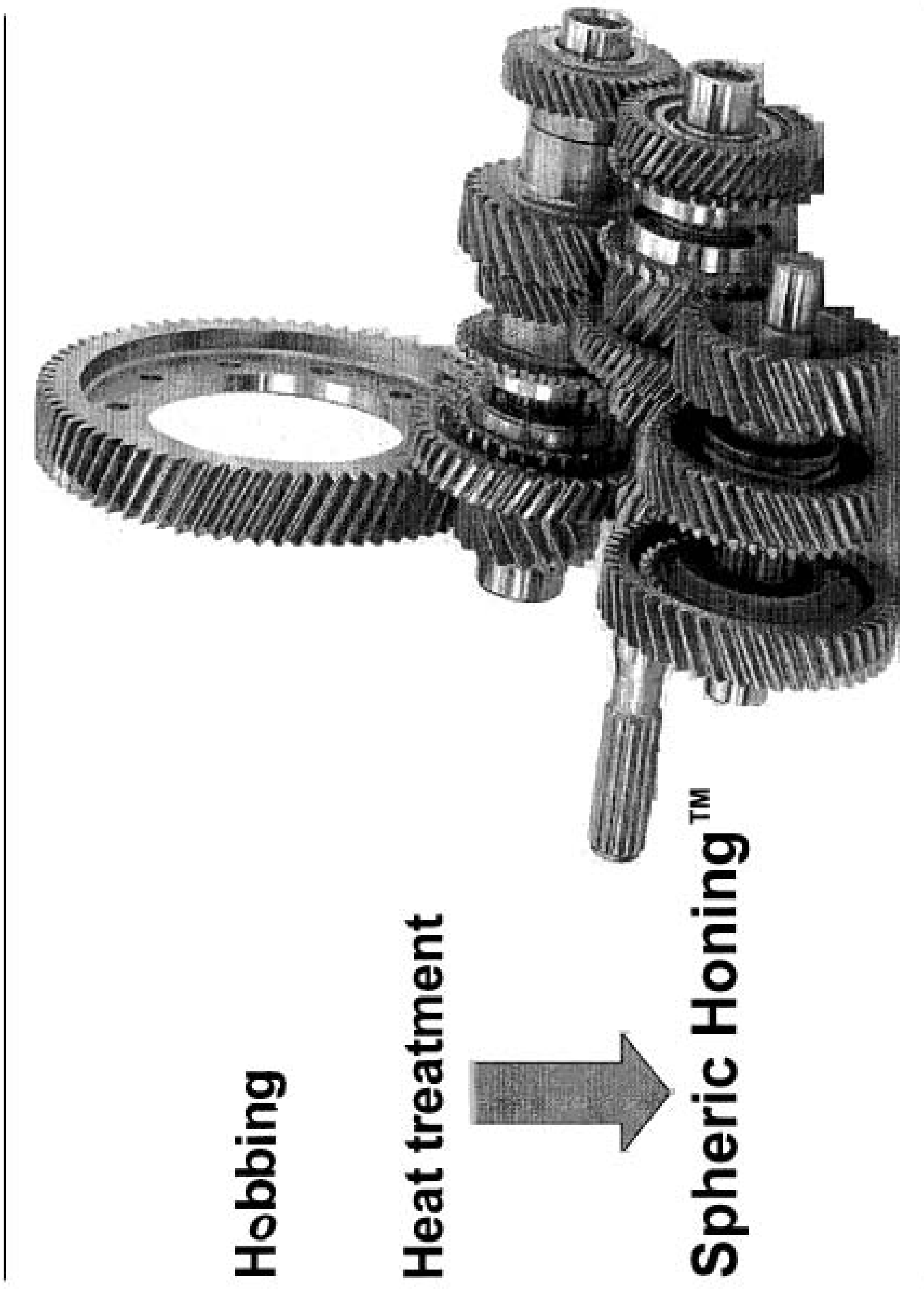
Figure **3-36** thru **3-46** Pictorial photos of different honing machines.

Basic Kinematics of the Spheric Honing™ Process



Courtesy Of Gleason Corporation

Fig. 3-34



Courtesy Of Gleason Corporation

Fig. 3-36 Transmission Gears

Table 3-18

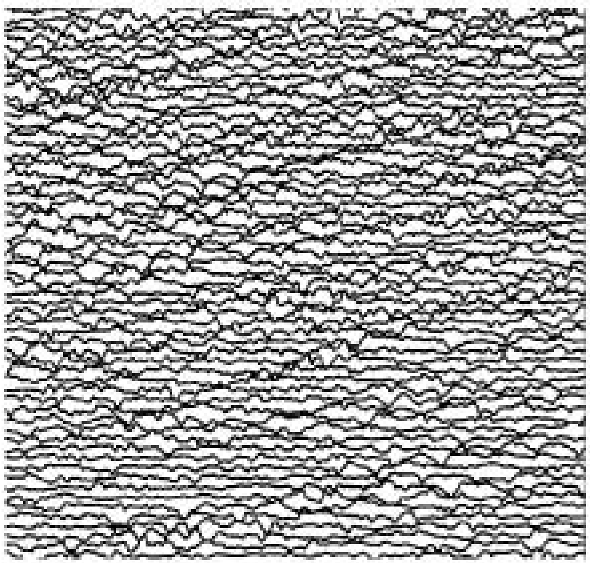
Selection of Gear Finishing Processes
When to Hone versus Shave or Grind

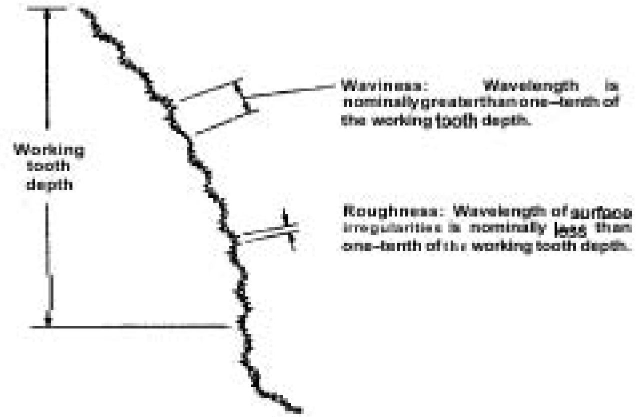
- SPHERIC HONING™
  - Stock removal = 65 µm per flank or less
  - High contact ratios, low pressure angles long addendum's
  - Noise reduction requirements
  - High surface finish requirements (Ra 0.2 pm)
  - Requirement for high levels of residual compressive stress (-800 to - 1200 N/mm^2)
  - resistance to wear & pitting under high loads
  - Lead corrections and targeted Bias lead corrections

Courtesy Of Gleason Corporation

Different surface structures on gear flanks

honed





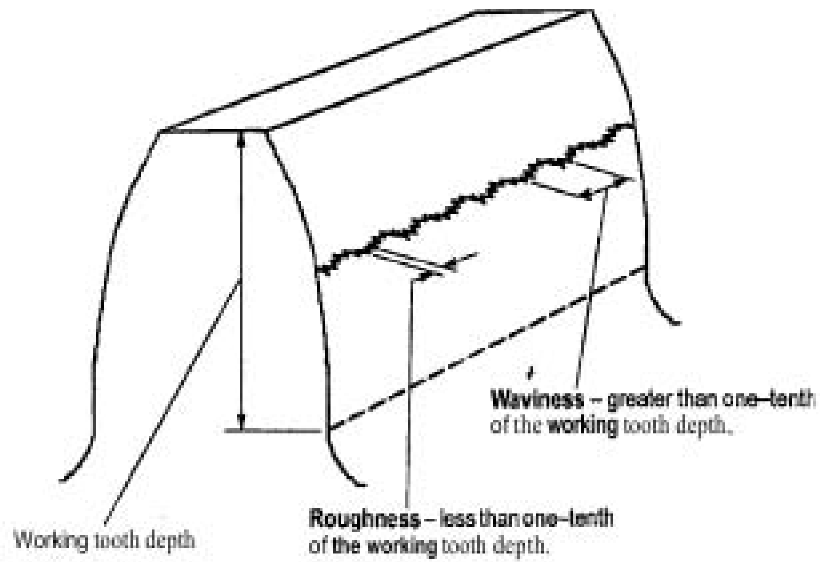


Table 3-19

Courtesy Of Gleason Corporation

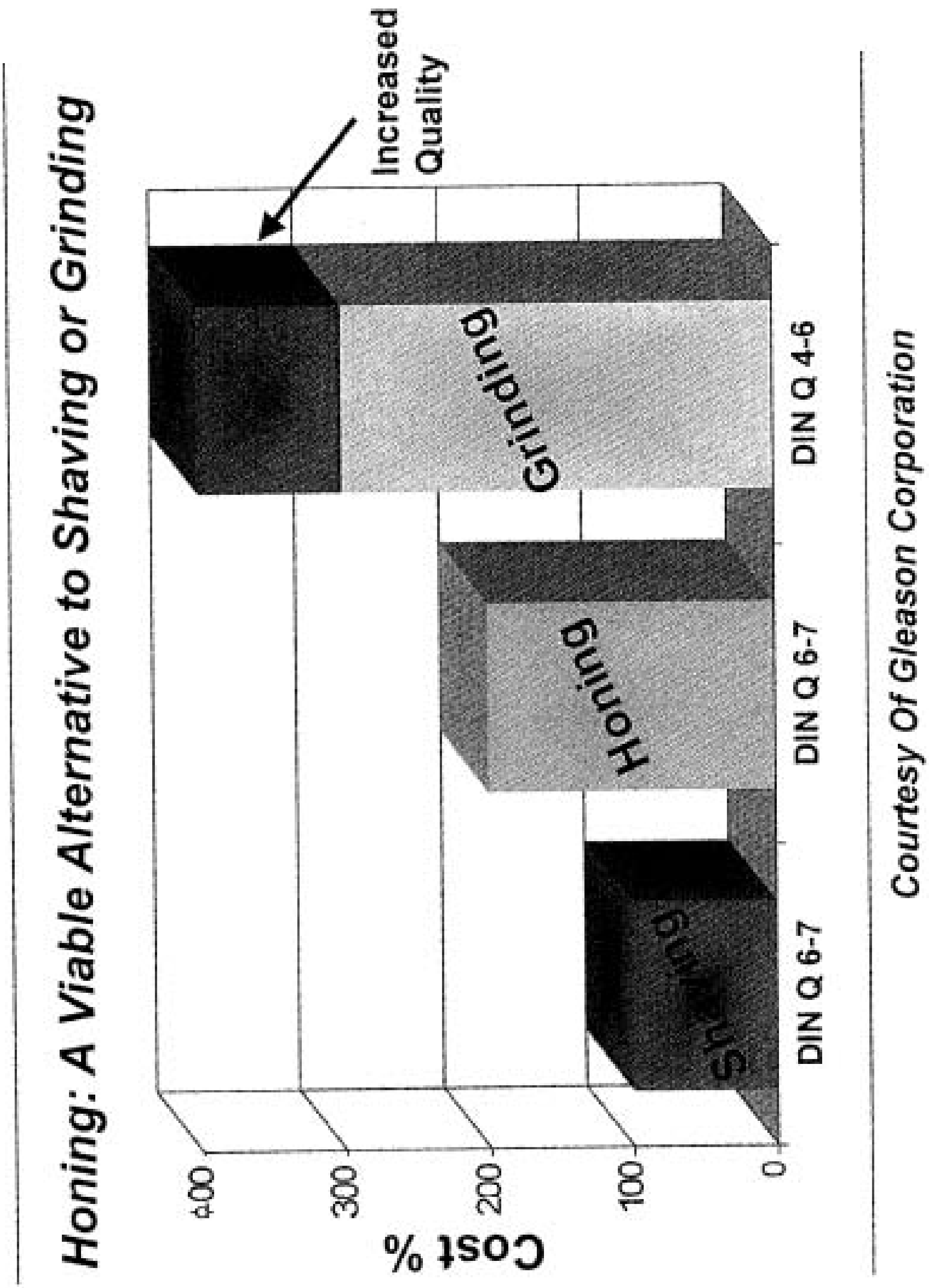

Honing: A Viable Alternative to Shaving or Grinding
Increased Quality
Cost %
400
300
200
100
0
Shaving
Honing
Grinding
DIN Q 6-7
DIN Q 6-7
DIN Q 4-6
Courtesy Of Gleason Corporation

Table 3-20

Gleason-Hurth
Spheric Horning

Gleason PFAUTER HURTH
WORLDWIDE SALES

No Shaving or Grinding before Spheric Honing

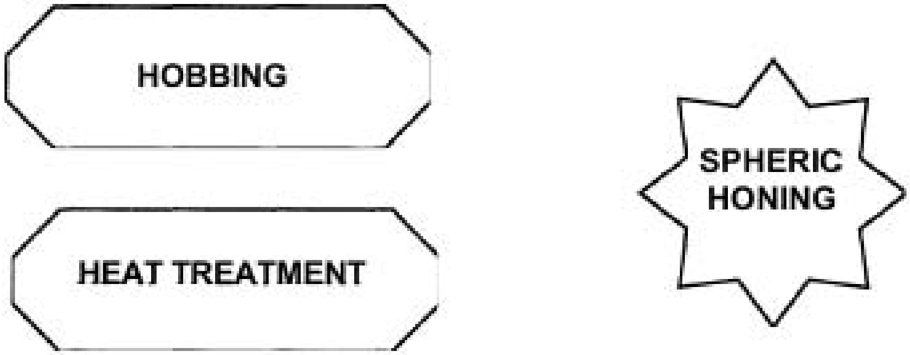


Table 3-21

Spheric Honing™ Machines

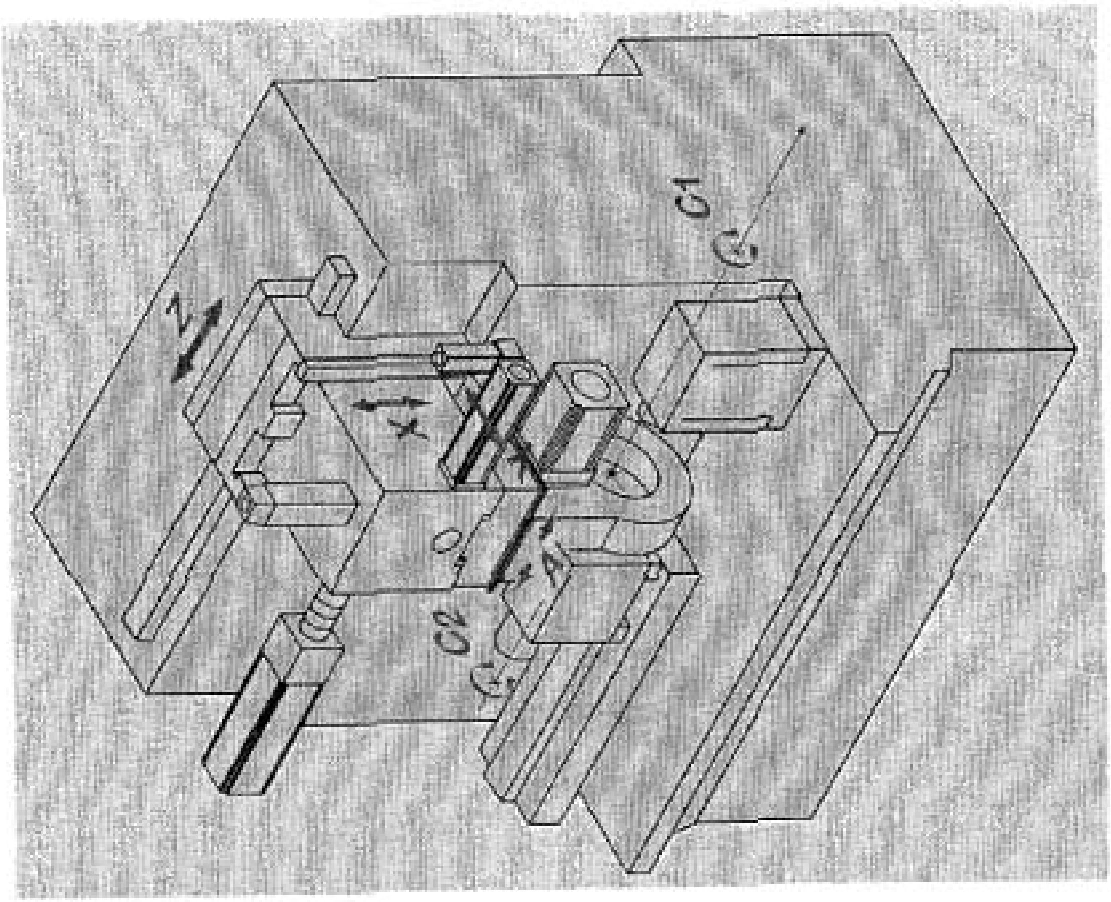
- **ZH 250 CNC**
  - for gears up to an O.D. of 250 mm and module 6
    - final drive ring gears, truck gears, etc.

- **ZH 125 CNC**
  - for gears up to an O.D. of 125 mm and module **4**
    - passenger car gears, pump gears, etc.

Courtesy Of Gleason Corporation

Table 3-22

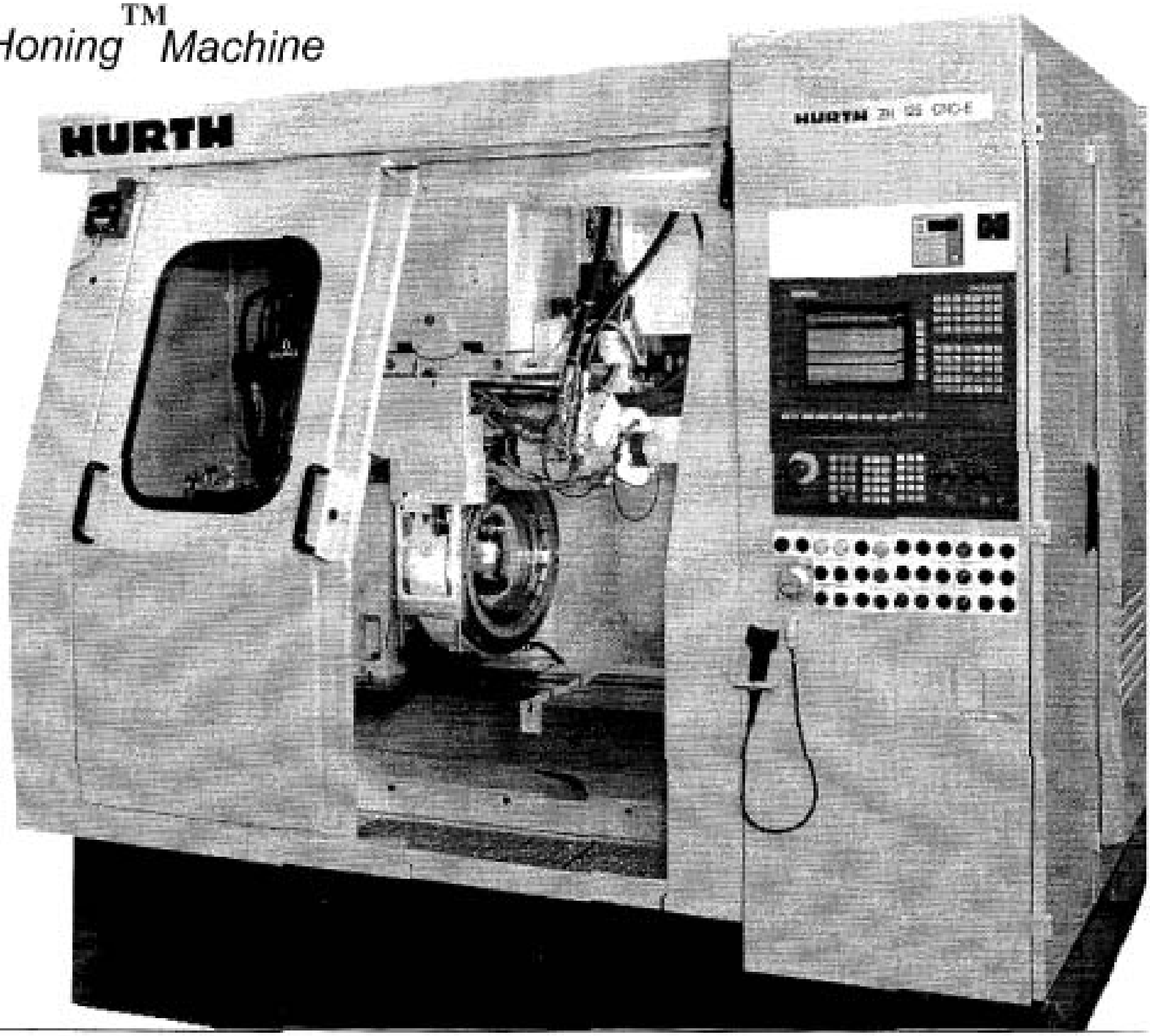
ZH 125 - Machine Axes



Courtesy Of Gleason Corporation

Fig. 3-36

ZH 125 Spheric Honing™ Machine

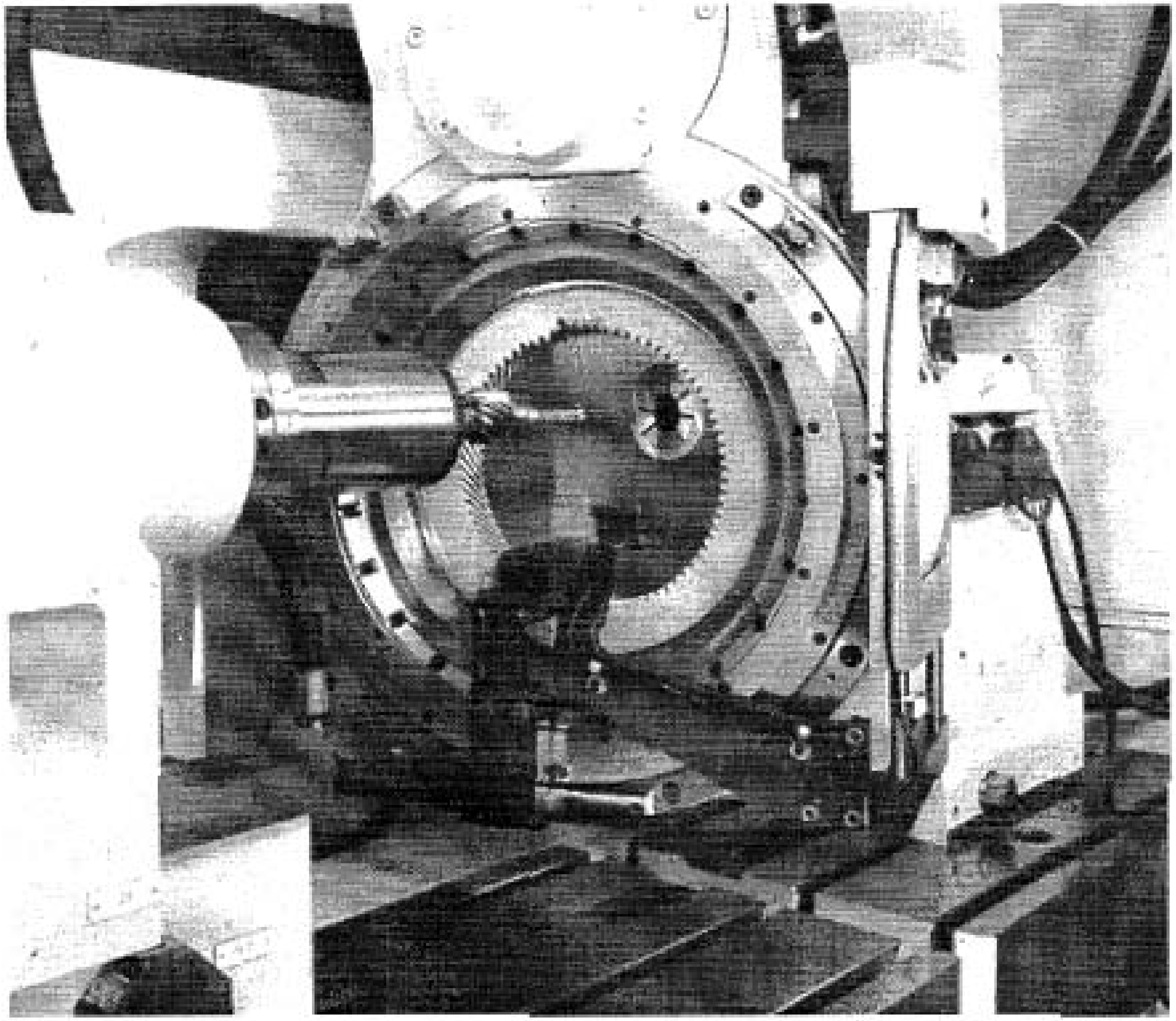


Courtesy Of Gleason Corporation

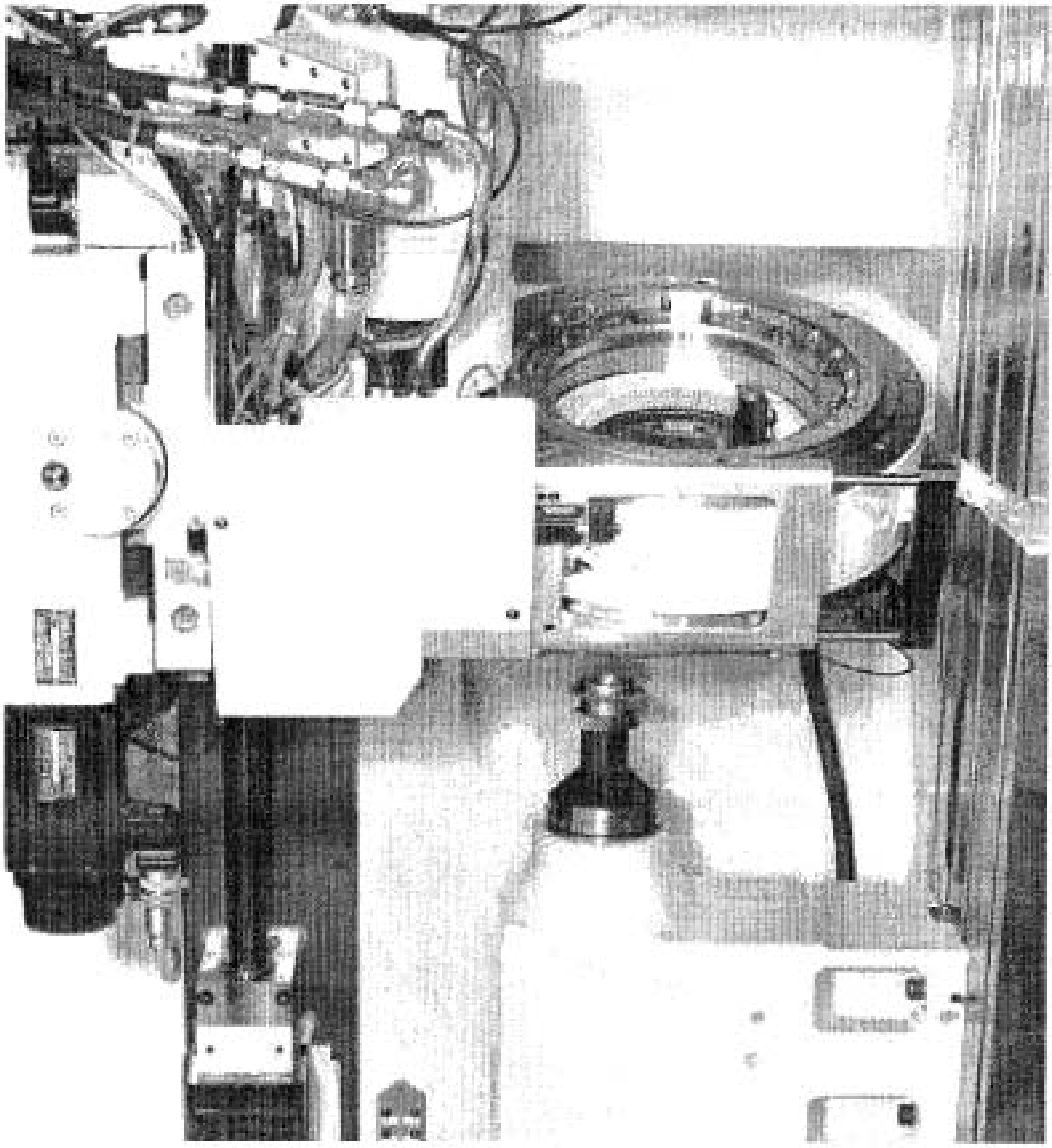
Fig. 3-37

Fig. 3-38

ZH 125
for Shaft Type Parts



Courtesy Of Gleason Corporation



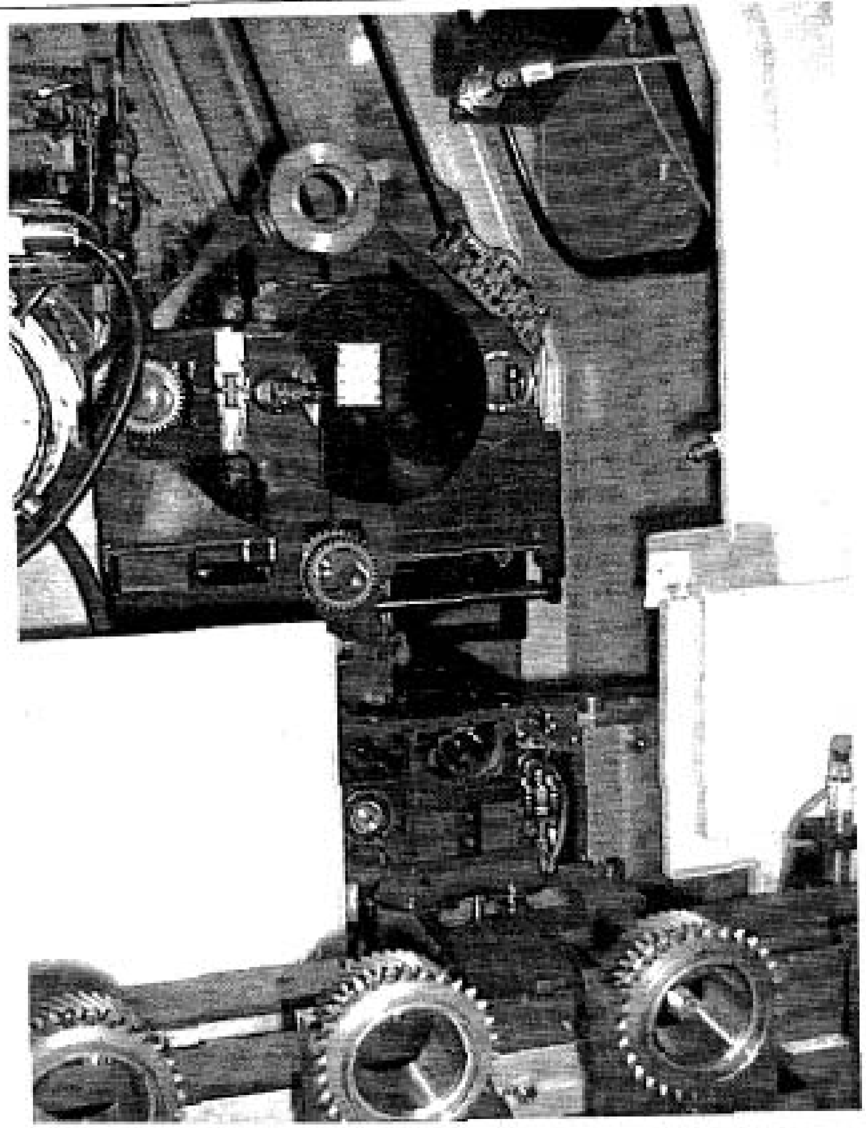
ZH 125
for Disc Type Parts

Courtesy Of Gleason Corporation

Fig. 3-39

ZH 125 Automation

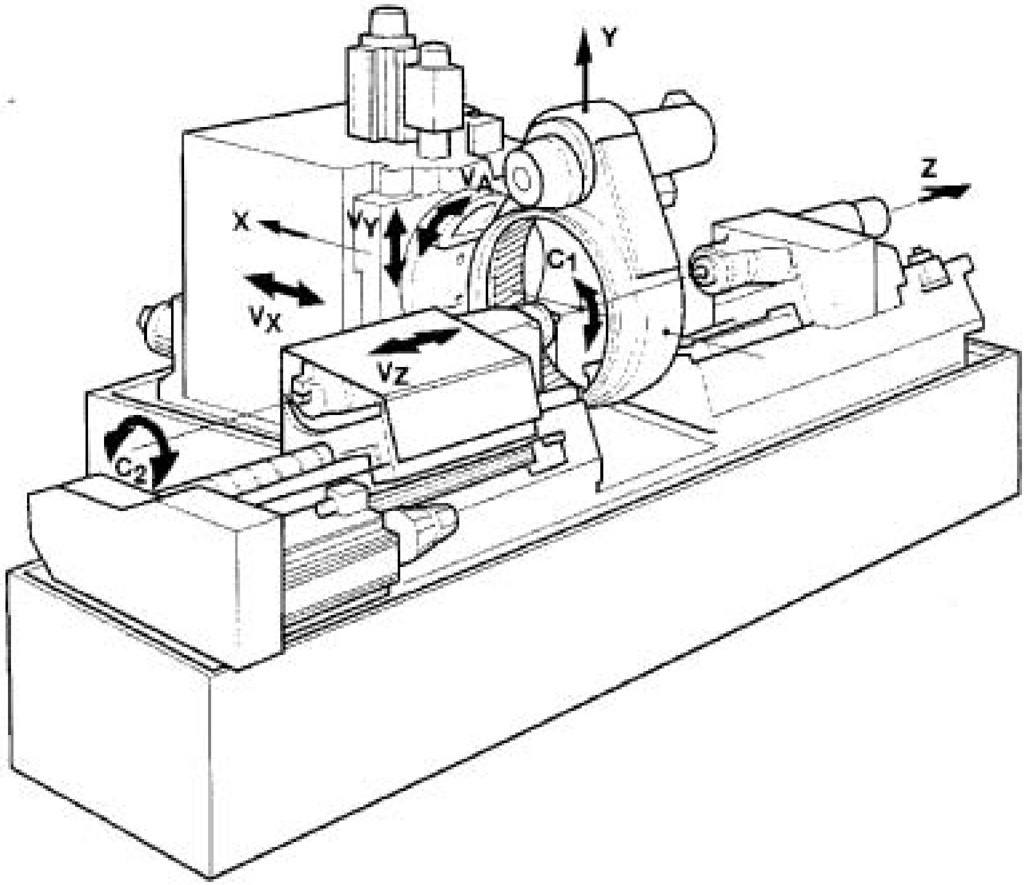
- Turret loader for handling the dressing tools and the workpieces
- Different conveyor systems with quick change pallets



Courtesy Of Gleason Corporation

Fig. 3-40

Hurth ZH 250 - Machine Axes



Machine **axes**
$V_X - V_y - V_Z - V_A$
for **Spheric** Honing

Drive **system axes**
$C_1 - C_2$ **with**
electronic gear
box drive

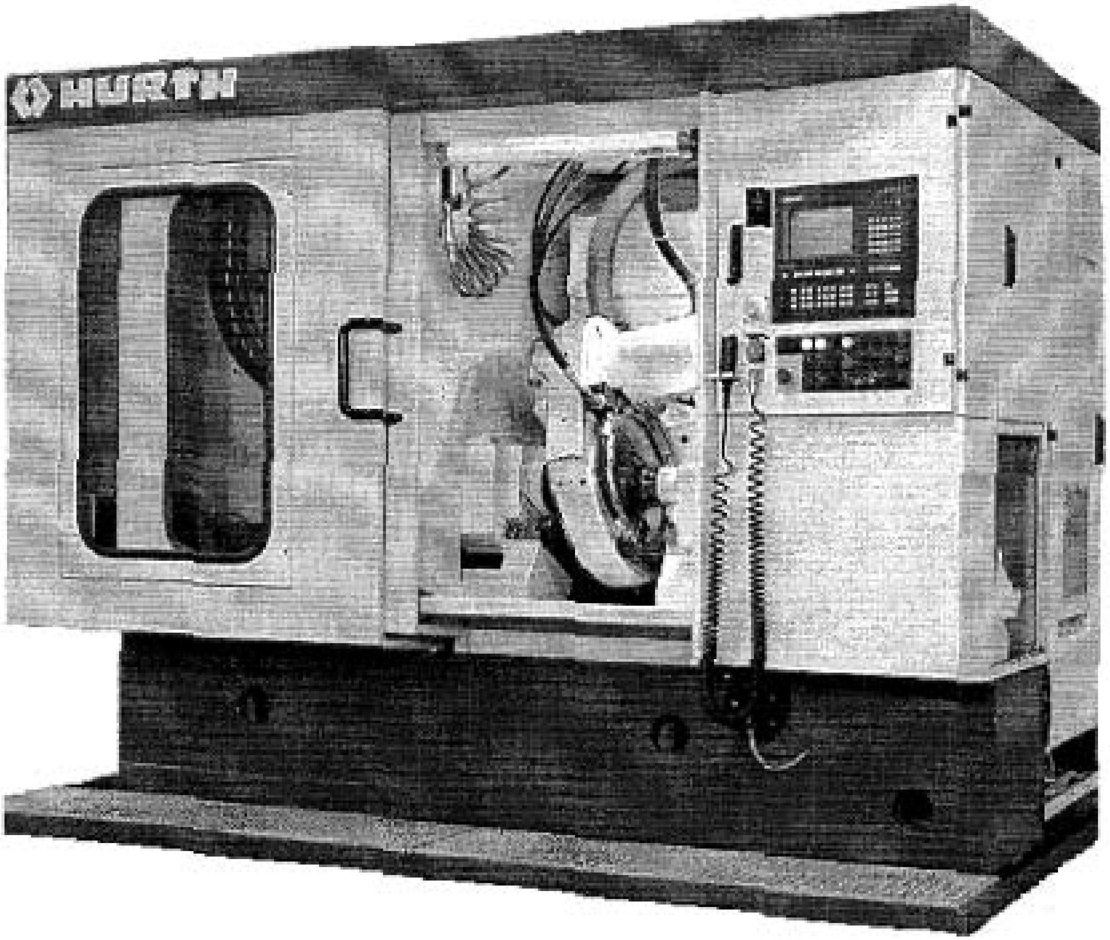
Fig. 8-41

Courtesy Of Gleason Corporation

Fig. 3-42

Hurth ZH 250 Spheric Honing™ Machine

- Compound design of the Spheric Honing Machine
- Oil tight machining compartment
- Compact electric cabinet
- Compact hydraulics
- Working and loading area separated



Courtesy Of Gleason Corporation

ZH 250 Spheric Honing™ Machine

- Machining compartment with sealed bulkhead of the ZH 250 CNC
- Two Tools installed
- Liquid cooled drive system for the honing tool

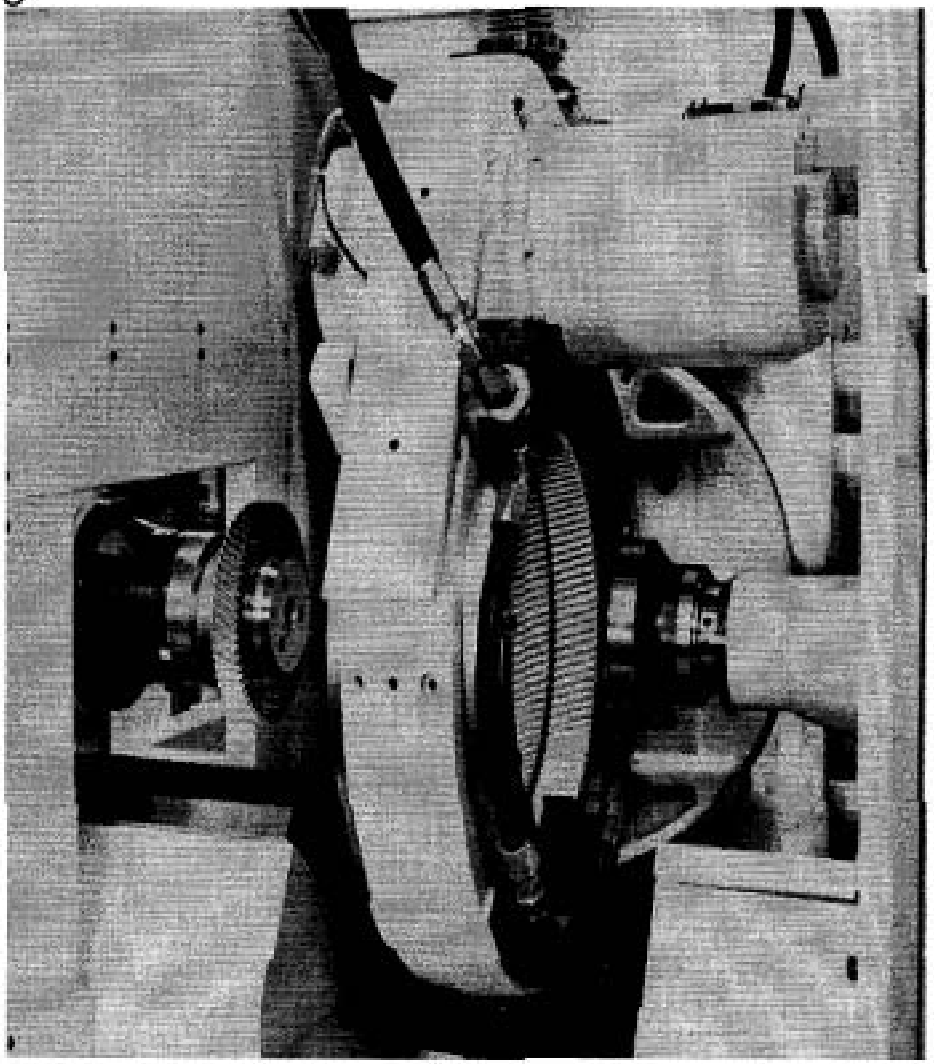


Fig. 8-3

Courtesy Of Gleason Corporation

ZH 250 Automation

- Loading and unloading outside the machining area

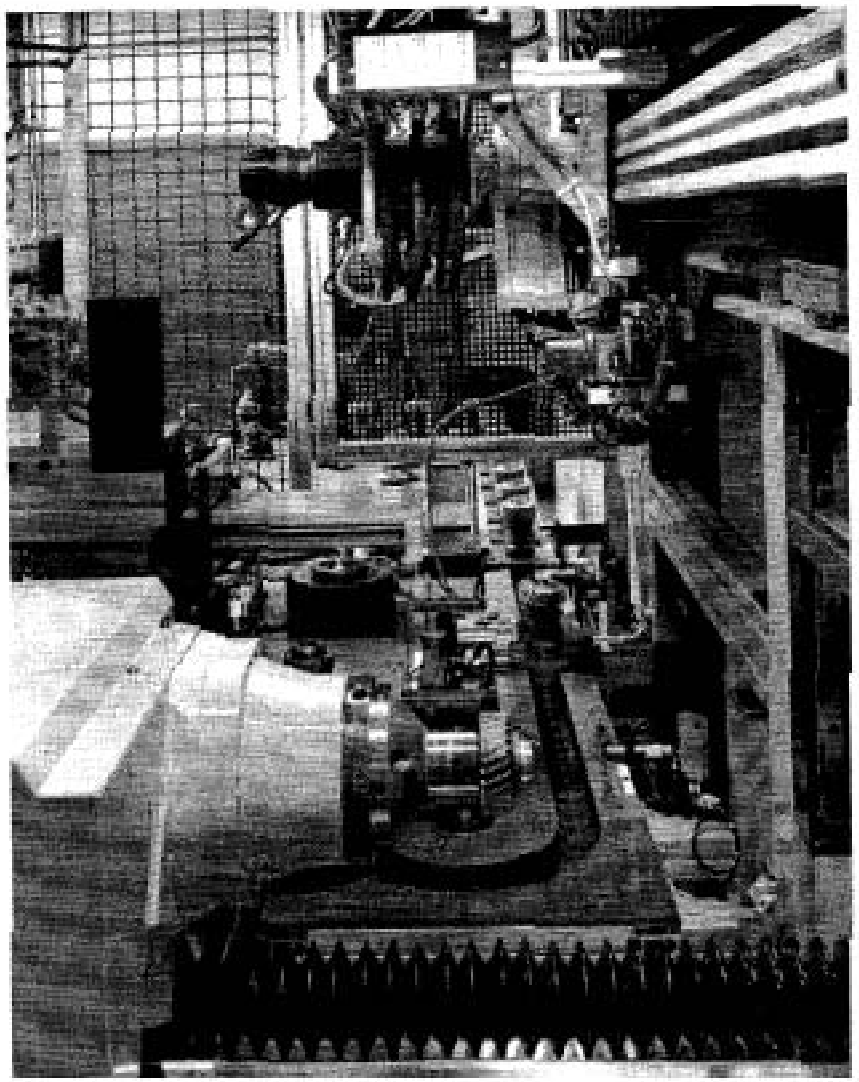
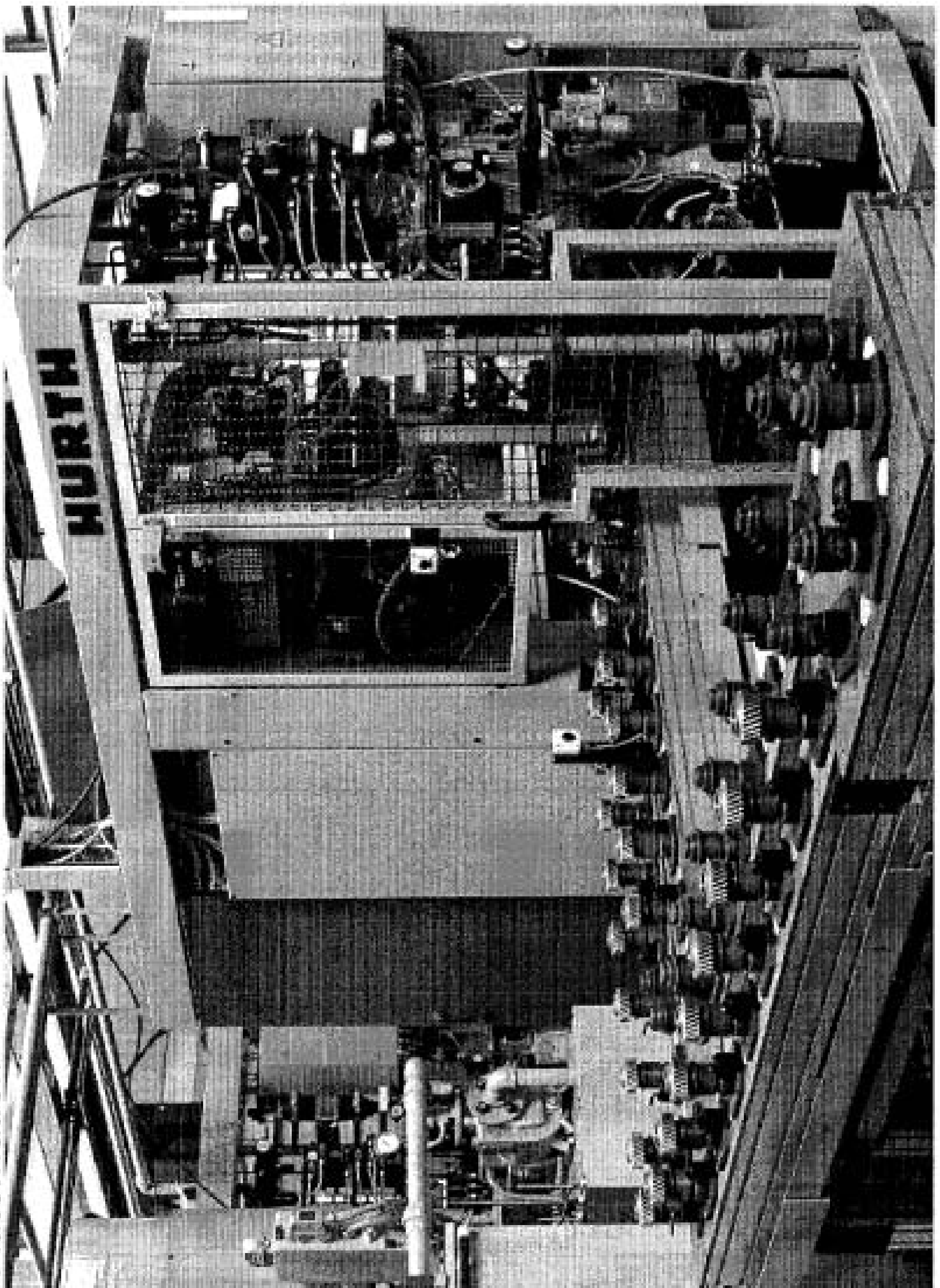


Fig. 3-44

Courtesy Of Gleason Corporation

ZH 250 Automation



Courtesy Of Gleason Corporation

Fig. 3-45

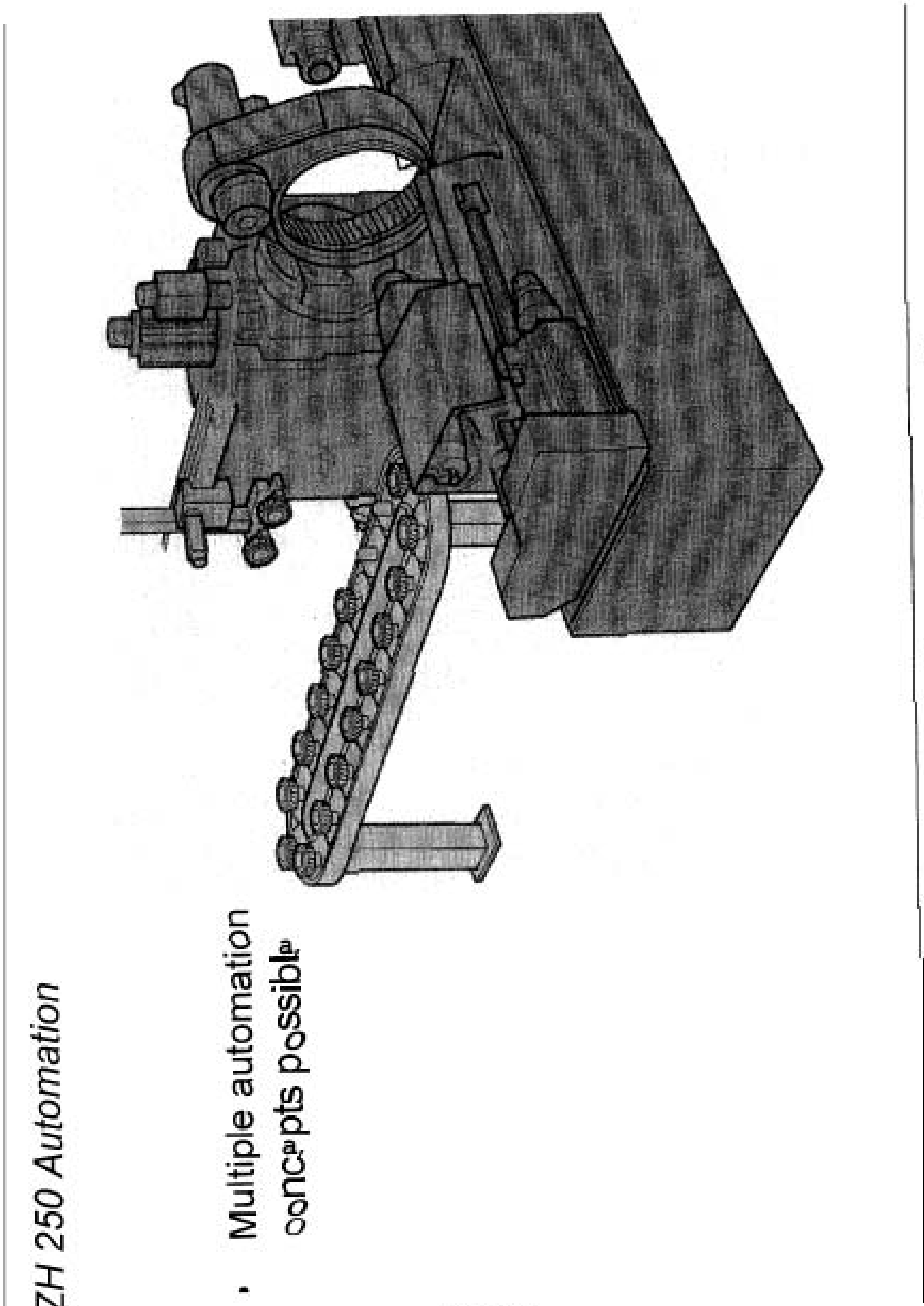

ZH 250 Automation
Multiple automation concepts possible
Courtesy Of Gleason Corporation

Fig. 3-46

Press Fit Allowances

Some large gears are conveniently made in two or more parts. They are joined by press fitting shafts inside the gear. The press fit allowance for these types of gear is as follows:

$$\text{Allowance per inch of bore diameter} = \frac{\text{Tonnage Required}}{1298 \times \text{bore diameter} \times \text{length of bore}}$$

Total allowance in bore = allowance per inch of bore x bore diameter

Total allowance for 50-ton force fit with bore of 5-inch diameter and length of bore will be:

$$\frac{50}{1298 \times 5 \times 5} = 0.0015 \text{ inch} \qquad \text{Total Allowance} = 0.0015 \times 5 = 0.0075 \text{ inch}$$

Shrink Fit Allowance

Large nitrided gears used in mining machinery are often held on the shaft by shrinkage. Assembly by shrink fitting is usually effected by heating the gear to expand the bore so that it will slide over the shaft, then allowing the gear to cool. It is usually not advisable to heat the gear beyond 400 degrees F, and the shaft is kept at room temperature (assumed to be 70 degrees F).

For the 5-inch nominal diameter shaft and bore, this allowance **A**, obtained from the above calculation, is 0.0075 inch. To calculate the required number of Fahrenheit degrees by which the steel gear is to be heated, the allowance **A** is divided by the coefficient of expansion for steel, multiplied by the nominal diameter of the shaft. The coefficient of expansion for steel is 0.00000636 inch per inch per degree F. The formula then becomes:

$$.0075 = .00000636 \times 5 \times (T \text{ minus } 70 \text{ degrees F})$$

$$T \text{ minus } 70 \text{ degrees F} = \frac{0.0075}{0.00000636 \times 5} = 235 \text{ degrees F}$$

$$T = 235 \text{ degrees F} + 70 \text{ degrees F} = 305 \text{ degrees F}$$

Thus, for a bore of 5 inch diameter and an interference fit of 0.0075 inch, the gear will have to be heated to 305 degrees F.

Bevel Gear Cutting Machines and Bevel Technology

The Gleason Works of USA and Klingelnberg GmbH.of Germany among the world's leading manufacturers of machinery for making bevel gears. The author does not have extensive bevel gear cut-bevel gears be referred to these two manufacturers. Processing of bevels is in no way different from processing of spur or helical gears, and initial steps to process bevels are the same as for spur and helical gears. The method of cutting bevel gear teeth however, is different.

Bevel cutting Machine Manufacturers

Following are the suppliers of bevel cutting machines, with identification of types available.

1. The Gleason Works, 1000 University Ave., Rochester, NY 14692 Gleason number 21 Coniflex*. Gleason number 3 for Straight Bevels, Gleason number 7, 12B, Gleason for Straight Bevels 34 inch, Gleason for Spiral 34 inch, Gleason for Spiral Bevel and Hypoid 34 inch, Gleason number 104 Coniflex* (8-inch outside diameter), Gleason number 2 Hypoid.
2. Klingelnberg Machines, marketed by National Tool Co., 11200 Madison Ave., Cleveland, OH 44102 Address:in Germany: Klingelnberg Corp., 15200 Foltz Industrial Parkway, Strongville, OH 44136
3. Oerlikon Machine Tool Works, Oerlikon-Buhrle Ltd., CH-8050, Zurich, Switzerland, Spiromatic number 0 (13 inch), number 2 (211/16 inch), number 4a (63 inch), S 17 APL/AGL for Hypoid
4. Yutaka Seimitsu Kogyo Universal for Spiral and Hypoid Model GH 35 (32 - 91/16 inch) 592 Kami Ochiai, Yono City, Saitama Pref. Japan.

Hardening Machine Manufacturers

Gleason Works	28-inchcapacity
Harper Co.	0 - 48 inch
Hoglund Tri-Ordinate Corp.	72 inch
Illinois Tool Works	12 inch

"Tooth Deburring Machine Manufacturers

Acme Manufacturing Co.	2 - 50 inch outside diameter
Chemtool Inc.	
Extrude Hone Corp.	
Fellows Works	9 - 14 inch
Gleason Works	7 inch
Hegenscheidt Corp., Germany	12 inch
Redin Corp., U.S.A.	72 inch

Chapter 4

GEAR MATERIALS AND THEIR HEAT TREATMENT

Gears are produced from a variety of materials including steels, cast and ductile irons, brasses, bronzes, other metals, and plastics such as nylon. The majority of gears for automotive, farm machinery, road equipment and machine tool applications are made from hardenable carbon-, low-alloy steels or cast iron. Gears for aircraft and missiles are generally made from non-corrosive stainless steels. However, many are made from the steels mentioned at the end of this chapter.

The selection of the material and the hardness is generally left to the designer, who knows the application for the gear. Manufacturing engineers may have greater knowledge than designers about the availability of particular steels. Design engineers generally know important parameters like hardness and stresses involved in a particular gear, and to be on the safe side, they specify only those steels with which they are familiar.

Many designers and machine shop manufacturing engineers do not have sufficient general knowledge about the costs involved in various heat-treatment processes. The extract below, from the Bethlehem Steel Corporation's Handbook number 3310 (currently out of print), contains important and valuable data on steel heat treatment. Bethlehem Steel Corp. has grouped SAE steels in the following five (5) categories; their heat-treatment characteristics will be given later.

Carburizing grades of steel
SAE 1015, 1020, 1022, 1117 and **1118**

Carbon water- and oil-hardening grades
SAE 1030, 1040, 1050, 1060, 1080, 1095, 1137,1141 and 1144

Alloy carburizing grades
SAE 4118, 4320, 4419, 4620,4820,8620 and E 9310

Alloy water-hardening grades
SAE 4027, 4130 and 8630

Alloy oil-hardening grades
SAE **1340,4140,4340,5140,8740,4150,5150,6150,8650,9255** and 5160

Steels Used in the Normalized Condition

For gears that carry small specific loads, unalloyed or lean alloy steels are used in normalized condition. Normalizing is the term applied to the process of heating the steel (after hot working) and allowing it to cool in air. This sequence causes austenite to transform into ferrite and pearlite at relatively high temperatures during cooling, with the result that no hardening takes place.

Heat Treatment

With the exception of surfaces requiring maximum wear resistance that are to be nitrided, hardness of at least Rockwell 60C is generally considered necessary for gears. Steel, which must attain hardness by formation of martensite, should contain a minimum of 0.45 percent carbon. Where a lower hardness of Rockwell 50C is acceptable, steel of lower carbon content may be used.

Two fundamentally-different, major processes produce a hardening action by formation of martensite. These processes are case hardening and through hardening. Steel that is to be through-hardened must contain a sufficient amount of carbon, which indicates that it is a through- or direct-hardening steel.

Case Hardening

Work pieces that are to be case hardened are made from steel with a carbon content **of** 0.1– 0.25 percent. The carbon in the surface layers of these steels is increased by diffusion at high temperatures from solid, liquid, or gaseous media containing carbon. The hardness of the carburized surface is then changed by such processes as local heating, using induction currents (induction hardening) or a gas torch (flame hardening).

Case-Hardening Methods

In the carburizing process, the medium that carries the carbon may be solid, liquid or gaseous. Each medium has its specific application and is selected to suit the user's convenience. Temperatures used are always above 1380 degrees F and usually between 1560 and 1830 degrees F (850and 1000degrees C).

The depth of the carburized layer depends on temperature and time. Higher temperatures produce a higher rate of diffusion of the carbon atoms from the media into the austenite lattice, under the influence of what is known as the carbon gradient. The carbon content in this carburized layer decreases gradually from the surface, where it is usually highest, toward the core. The depth at which the original carbon content is reached is called the total depth and it is to be distinguished from the effective carburizing depth. The latter is the perpendicular distance below the surface to the point at which the carbon content has dropped to 0.4 percent. This distance corresponds to the depth where Rockwell is about 55 Rockwell C, and is about one-half the total depth. The effective carburizing depth can be expressed for most carburizing processes as a function of time.

The effective depth is equal to $K_T\sqrt{t}$ inches (mm), where K_T is a constant dependent on temperature and material and t = the duration of the carburizing process in hours). With unalloyed steel at 1560 degrees F (850 degrees C), K_T is about 0.009 inch (0.22 mm). At 1650 degrees F (900 degrees C), K_T is about 0.013 inch (0.32 mm). At 1740 degrees F (950 degrees C), K_T is about 0.018 inch (0.45 mm). Thus, the effective carburizing depth at 1740 degrees F (950 degrees C) is about twice that at 1560 degrees F (850 degrees C).

Pack Carburizing

Carburizing in a solid medium is the oldest of the processes but is still currently in use for certain classes of work. Charcoal and certain kinds of specially treated coke are mainly used as the carbon-bearing medium. Alkaline earth carbonates, primarily barium carbonate, are added to these materials as energizers. The mechanism of carburizing involves combination of the oxygen that is present initially with carbon to form carbon dioxide (CO_2). This gas reacts with any excess carbon at higher temperatures to form monoxide, $CO_2+C \rightarrow 2\,CO$. Carbon monoxide then reacts with steel and delivers carbon atoms to the steel surface, $2CO \rightarrow [C]+CO_2$. The remaining C02 is regenerated by the carbon to CO, which is, therefore, a gaseous medium that carburizes steel.

Liquid Carburizing (Salt-Bath)

Carburizing baths contain molten salt mixtures, the effective constituent of which is sodium cyanide (NaCN). This salt melts at 1020 degrees F (550 degrees C) and decomposes at temperatures near 1830 degrees F (1000 degrees C) more or less rapidly, according to the nature of other additives. The field of practical application is between the above temperatures. Above 1650 degrees F (850 degrees C) the supply of carbon dominates.

At higher temperatures the carburizing effect increases, whereas below 1300 degrees F (700 degrees C) more nitrogen is released. At 1020 degrees F (550 degrees C) for instance, only nitriding takes place. In a medium-temperature range, both nitrogen and carbon are given off. This process is therefore called carbonitriding.

Oxygen, which is constantly present, combines with sodium cyanide to form sodium carbonate (Na_2CNO_3), sodium carbonate (Na_2CO_3), nitrogen (N) and carbon monoxide. The nitrogen diffuses into the steel in the lower temperature range; carbon monoxide acts in the higher temperature range in the same manner as during carburizing with solids. It is generally assumed that carburizing takes place via the gaseous phase.

Alkaline earth chlorides act as energizers to influence the intensity of carburizing in the form of higher or lower surface carbon contents and thus they control the penetration rate. A distinction is made between energized and non-energized carburizing baths. Heating of components in salt baths takes place quickly, in contract to gas carburizing. Case hardening baths are, therefore, of particular advantage when the heating time constitutes an appreciable proportion of the total time of treatment; i.e., for small case depths from 0.004 to 0.032 (0.1to 0.8 mm). Liquid carburizing is generally recommended for small- to medium-sized components.

Gas Carburizing

In gas carburizing, carbon is transferred to the surface of the steel mainly by the following reaction: $2CO \rightarrow [C]+CO_2$. There are mainly two types of processes: a) the generator process, and b) the granular process using solid gasifying compounds. In the generator process, gases are produced in a suitable gas generator from a town's or natural gas supply or from hydrocarbons such as propane or butane, and brought to the carburizing furnace either in the necessary composition or as a carrier gas.

When a carrier gas is used, a certain amount of a strong carburizing gas is added in the furnace. Such a carrier gas process has the advantage that it is possible to add more active carburizing medium automatically.

In the granular process, a solid carburizing medium is introduced in the furnace. Oxygen from the air reacts with the medium to form CO_2 at moderately low temperatures and CO at high temperatures. This CO carburizes the steel surface.

Case Depth

The following empirical formula is used to estimate the case depth:

$$\text{Case depth} = \frac{0.15}{P} + \text{grinding allowance in inches per flank.}$$

This formula is good for gears of **24** to **3** dp.

For pitches below **3** dp:

$$\text{Case depth} = \frac{0.0885}{P} + \text{grinding allowance in inches per flank.}$$

Nitrided Gears

The advantage of nitrided gears is that gear blanks can be fully machined. Teeth may be hobbed or ground to finished dimensions, then subjected to the ammonia nitriding process with a minimum of distortion. Variations in dimensional changes occurring in nitriding is frequently due to relief of residual stresses resulting from processing operations like rough machining. Distortion will be minimized if stresses are relieved by a stress relief anneal or by a heat treatment processing before nitriding. Finish machining operations must be carried out with great care to avoid residual stresses.

For a given part and a fixed nitriding cycle, the amount of growth is constant. Therefore, it is necessary to determine the dimensional changes experimentally and to make proper allowance in the finished machining operations prior to nitriding. The nitriding process is suitable for parts that require high wear resistance, high fatigue resistance, or both. Wear resistance results not only from the high hardness of nitrided surfaces but also from their ability to retain hardness in a temperature range at which conventionally hardened steels would soften.

Nitriding is a process of case hardening in which ferrous alloys, usually of special composition, are heated in an atmosphere of ammonia or put in contact with nitrogenous material to produce surface hardening by absorption of nitrogen without quenching. Without quenching, distortion is far less than occurs with the regular carburizing processes.

Nitriding is carried out by heating steels of suitable composition with a source of active nitrogen at temperatures from 925 to 1100 degrees F, for periods ranging from few minutes to 10 hours, depending upon steel being treated, and the depth of case required. Steels must contain elements in solid solution that are capable to forming nitrides such as aluminum, chromium, molybdenum, vanadium and tungsten. The parts nitrided will have a dull matte gray color.

In earlier times, salt bath nitriding was in common use. If shallow cases are to be produced (with short time cycles) and if parts are small and production quantity low, salt baths have a decided advantage. The mixture of salts used contains sodium cyanide and potassium cyanide (60:40) or alternatively sodium cyanide, sodium carbonate and potassium chloride (44:32:24). Case depths from 0.015 to 0.022 inch, can be achieved, with hardness from 90 to 93 on the Rockwell 15N scale.

In the **USA,** nitrided gears are generally made from Nitralloy 135, which is equivalent to DIN Specification 34 CrA1-MO5. The chemical composition is C 0.3, Al 0.8, Cr 1.0, and Mo 0.15 percent. The tensile strength is in the range of 115,000 to 140,000 lb./sq. inch.

Nitralloy 135 modified is equivalent to British Specifications En41B and French 45 CA-D6-12, and has the following chemical composition: C 0.35 to 0.45, A10.9 to 1.3, Cr 1.4to1.8, aand Mo 0.1-0.25. The tensile strength is 100,000 to 125,000 Ib./sq. inch.

Flame Hardening

Steels for flame hardening generally contain 0.3 to 0.6 percent carbon. Flame hardening is achieved by rapidly heating the work with a direct, high-temperature gas flame. The surface layer of the part is thus heated above the transformation range, and is followed by cooling with a quenching media usually sprayed on the surface at a short distance behind the heating flame. Immediate tempering is required to avoid cracking caused by residual stresses.

Induction Hardening

Heating of the workpiece for induction hardening is achieved by application of a high-frequency alternating current through a coil that embraces the steel part to be hardened. Frequencies of 10,00 to 500,00 cycles per second are used, and heating cycles are short. Lower frequencies and longer heating cycles are used for through hardening. Quenching is usually accomplished with a water spray. Following are minimum hardness values that can be expected:

Plain carbon steels	**1040**	**1045**	**1050**
Free machining steels	**1141**	**1144**	
Alloy steels	**4140, 4340,** 8740	**4145,8645,**	**4150, 5150, 6150**
Surface hardness After quenching	**52 RC**	**50 RC**	**60 RC**

Heat Treatment Characteristics of Certain Steels

Carburizing Grade SAE 1020.

This steel is low in cost and contains C 0.17 to 0.24, Mo 0.25-0.6, Mn 0.04, and 0.05 maximum phosphorus and silicon, percent. In some countries this steel is called mild steel; in Germany, the nearest equivalent is DIN Ck20. As rolled, the tensile strength is approximately 68,500 lb./sq. inch, the yield strength is 55,750 lb./sq. inch., and the hardness 137 Brinell.

Commercially, this steel is available in hot rolled, cold rolled, and centerless ground condition. Being of carburizing grade, a case depth of 0.046 inch is easily achieved. A case hardness of approx. 62 Rockwell C is produced by heating to 1675degrees F for 8 hours, cooling in a pot, reheating to 1425 degrees F, water quenching, and tempering at 35 degrees F .

Annealing this steel is carried out by heating to 1600 degrees F in the furnace, cooling to 1290 degrees F at the rate of 30 degrees F per hour, then cooling in air.

Normalizing, especially of forgings, is done by heating to 1700 degrees F and cooling in air. In normalized condition, the tensile strength will vary from 64,500 to 60,000 lb./sq. inch, yield from 40,750 to 50,250 lb./sq. inch and Brinell hardness from 121to 131 depending on the size of the bar.

Carbon Water Hardening Grades

SAE 1030.

This steel has the following chemical composition: C 0.28 to 0.34, Mn 0.6 to 0.9, phosphorous 0.04 maximum, and sulphur 0.05 percent. Annealing requires heating to 1550 degrees F, furnace cool to 1200degrees F at the rate of 20 degrees F per hour then cooling in air. This procedure will give 67,250 lb./sq. inch tensile strength and 49,500 lb./sq. inch yield strength.

Normalizing is performed by heating to 1700 degrees F and cooling in air, which will give a tensile strength of 77,500 to 72,500 lb./sq. inch, and a yield strength of 50,000 to 47,250 lb./sq. inch. The hardness is 156 to 137 Rockwell C, depending upon the size of the bar. This steel, also 1040 and 1060 steels, are often used in for gears subjected to induction and flame hardening of the teeth.

SAE 104 Water Quenching Steel. Table 4-1

Chemical Composition: C 0.37 to 0.44, Mn. 0.6 to 0.9, phosphorous 0.04 maximum and sulfur 0.05 maximum percent..

Annealing: Heat to 1450 degrees F, furnace cool to 1200 degrees F. Subsequently, cool in air, which will result in approximate tensile strength of 72,250 lb./sq. inch, a yield strength of 51,250 lb./sq. inch and Brinell hardness of 149.

Normalizing: Heat to 1650 degrees F and cool in air. (Refer to Table 4-2 for further technical details) This particular steel is ideal for induction hardening and flame hardening.

SAE 1050. Table 4-2

Chemical Composition: C 0.48 to.0.55, Mn. 0.6 to 0.9, phosphorus 0.04 maximum, and sulphur 0.05 maximum, percent.

Annealing: Heat to 1450 degrees F, cool to 1200 degrees F, and cool in air. This sequence will result in a hardness of approximately 187 Brinell.

Normalizing: Heat to 1650 degrees F, cool in air.

Water-Hardening *SAE* 4130. Table4-3.

Chemical Composition: C 0.28 to 0.38, Mn. 0.4 to 0.6, Si 0.2 to **0.35, Cr** 0.8 to 1.10, Mo 0.15 to 0.25 percent.

Water-quenched 1030

Treatment: Normalized at 1700 F; reheated to 1600 F; quenched in water, 1-in. Round Treated; .505-in. Round Tested. As-quenched HB 514.

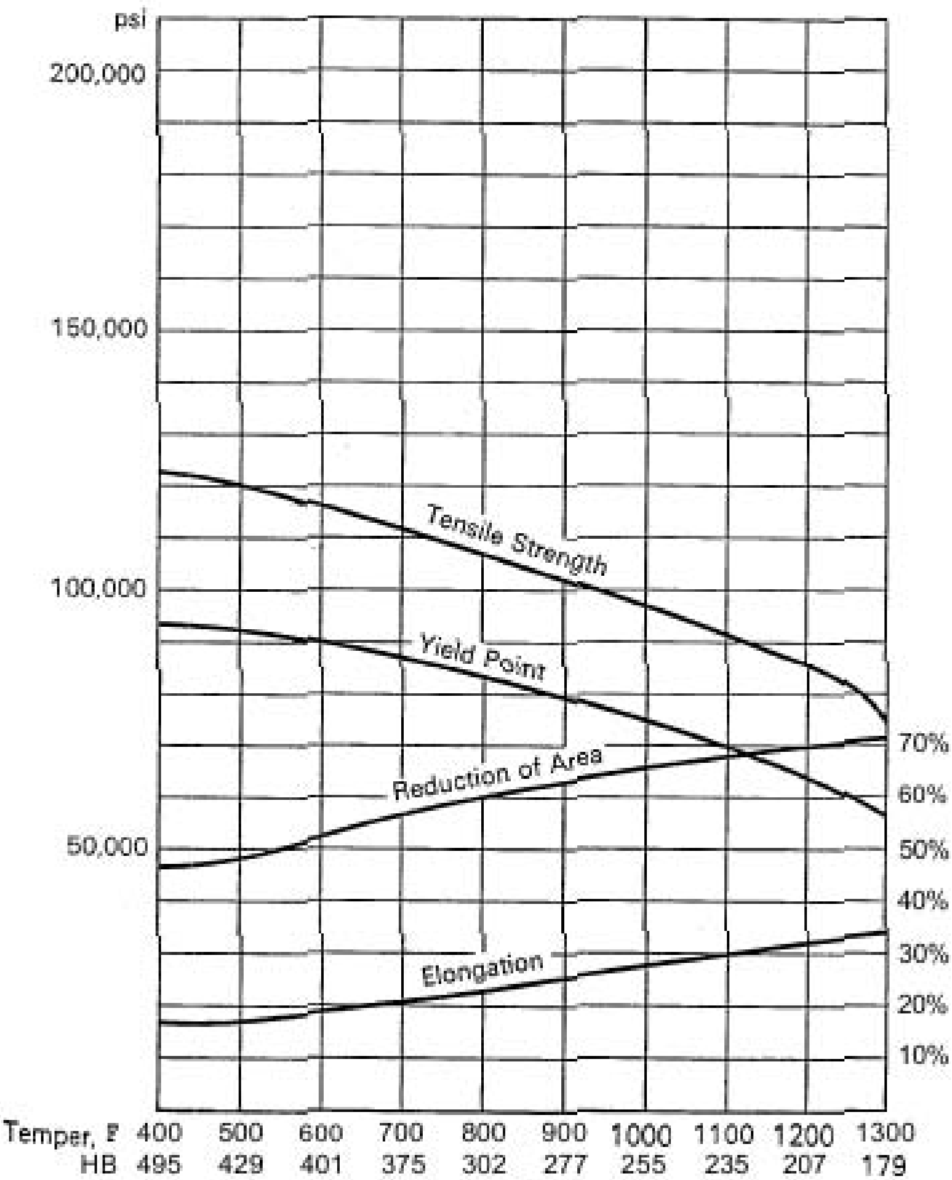


Table 4-1

Water-quenched 1040

Treatment: Normalized at 1650 F; reheated to 1550 F; quenched in water.
1-in. Round Treated ; .505-in. Round Tested. As-quenched HB 534.

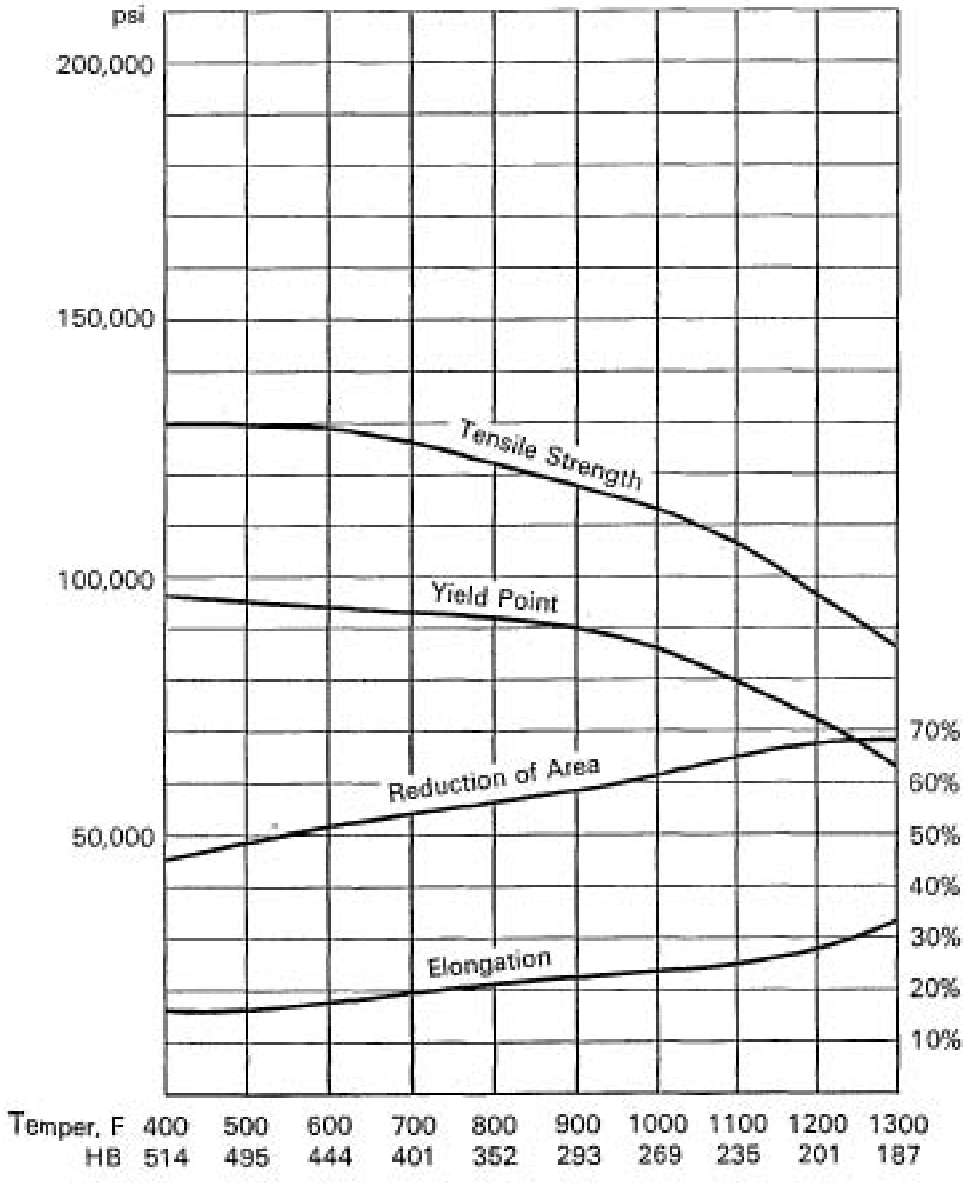


Table 4-2

Annealing: Heat to 1585 degrees F, furnace cool 20 degrees F per hour to 1255 degrees F and cool in air. Normalizing: Heat to 1600 degrees F and cool in air.

Tensile strength will be 197,000to 98,000 lb./sq. inch, and hardness 461 to 202 Brinell. Refer to Table 4-6 for further technical details.

Alloy Steel Oil-Hardening Grades

SAE 1060. Oil Hardening

Chemical Composition: C 0.55 to 0.65, Mn. 0.6 to 0.9, phosphorus 0.04 maximum, sulphur 0.05 maximum percent.

Annealing: Heat to 1450 degrees F, furnace cool to 1200 degrees F at the rate of 20 degrees F per hour and cool in air.

Normalizing: Heat to 1650degreesF, cool in air.Tensile strength after hardening in oil will vary from 160,000 to 103,000 lb./sq. inch, depending on tempering temperature. The Brinell hardness will vary from 321 to 212. (Refer to Table 4-4 for further technical information.)

SAE 104 Oil Quenched. Table 4-4

Chemical Composition: C 0.37 to 0.44, Mn 0.6 to 0.90; phosphorous 0.04 maximum, sulphur **0.05**, maximum percent

Annealing: Heat to 1450 degrees F, furnace cool to 1200 degrees F at the rate of 20 degrees F/hour and cool in air. This routine will give tensile strength of 75,250 lb./sq. inch, a yield strength of 51,250 lb./sq. inch, and a Brinell hardness of 149.

Normalizing: Heat to 1650 degrees F, cool in air. The tensile strength will be 88,250 to 83,500 lb./sq. inch, the yield strength will be 58,500 to 49,250 lb./sq. inch, and the hardness will be 183 to 167 Brinell (depending upon the cross-section).

After heat treatment, the tensile strength will vary from 114,00 to 88,000 lb./sq. inch, the yield strength from 86,000 to 62,000 lb./sq. inch, and the hardness from 262 to 183 Brinell, depending on the tempering temperature (which can vary from 400 to 1300 degrees F). (Refer to Table 4-3 for further technical information.)

Oil-quenched 1060

Treatment: Normalized at 1650 F; reheated to 1550 F; quenched in oil.
1-in. Round Treated; .505-in. Round Tested. As-quenched HB 321.

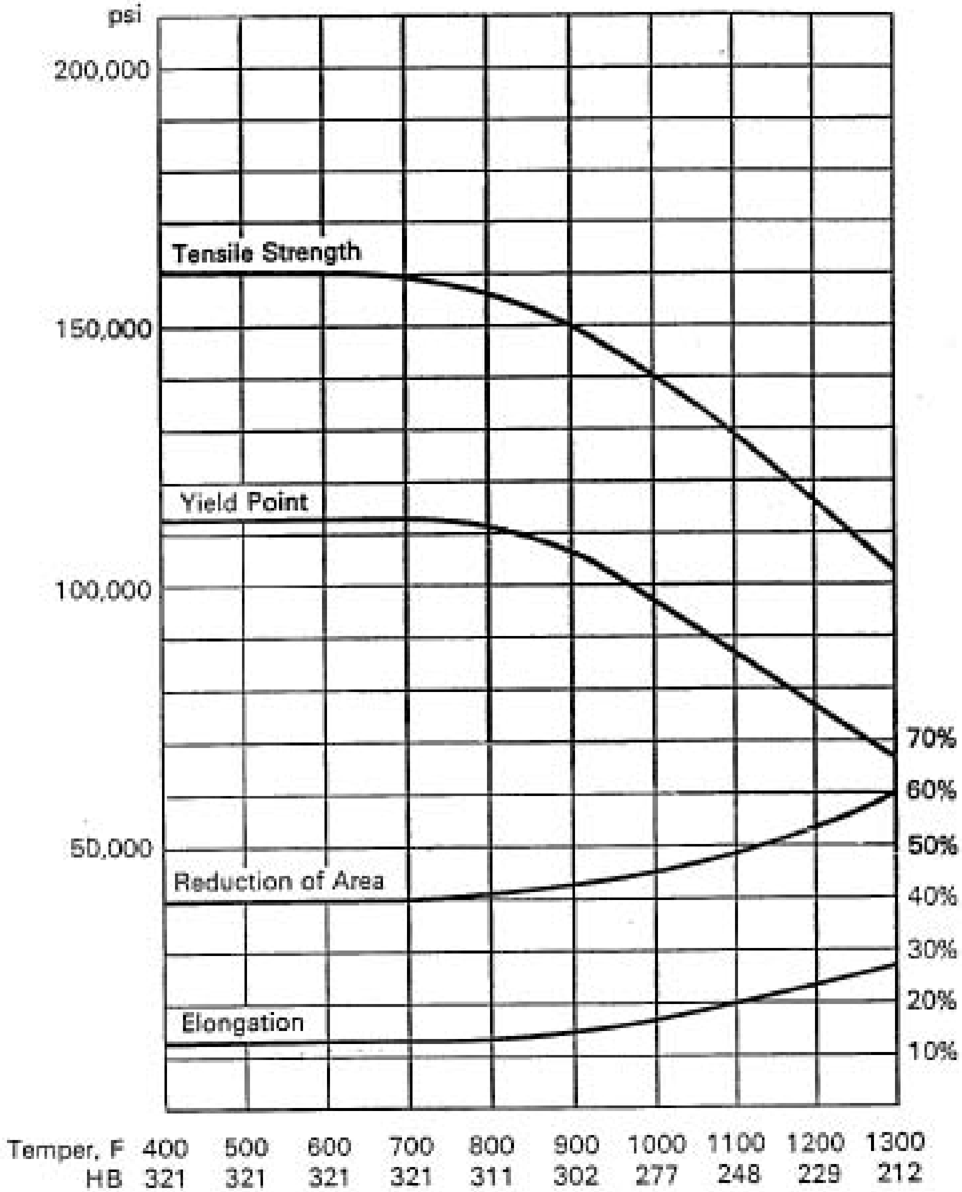


Table 4-3

Oil-quenched 1040

Treatment: Normalized at 1650 F; reheated to 1575 F; quenched in oil.
1-in. Round Treated ; .505-in. Round Tested. As-quenched HB 269.

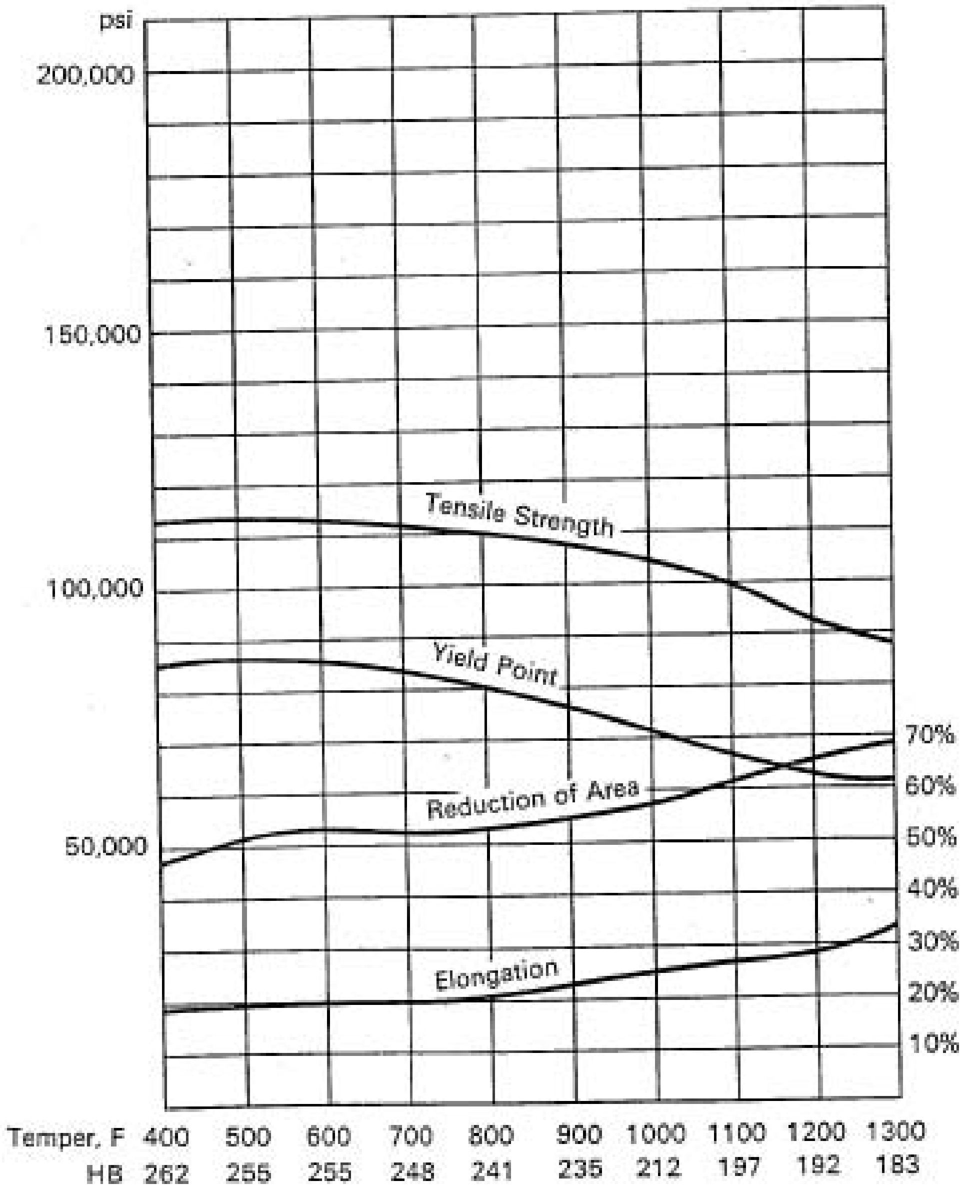


Table 4-4

Oil-quenched 4140

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	.41	.85	.024	.031	.20	.12	1.01	.24	6-8

Critical Points, F: Ac_1 1395 · Ac_3 1450 Ar_3 1330 Ar_1 1280

Treatment: Normalized at 1600 F; reheated to 1550 F; quenched in agitated oil. .530-in. Round Treated; .505-in. Round Tested. As-quenched HB 601.

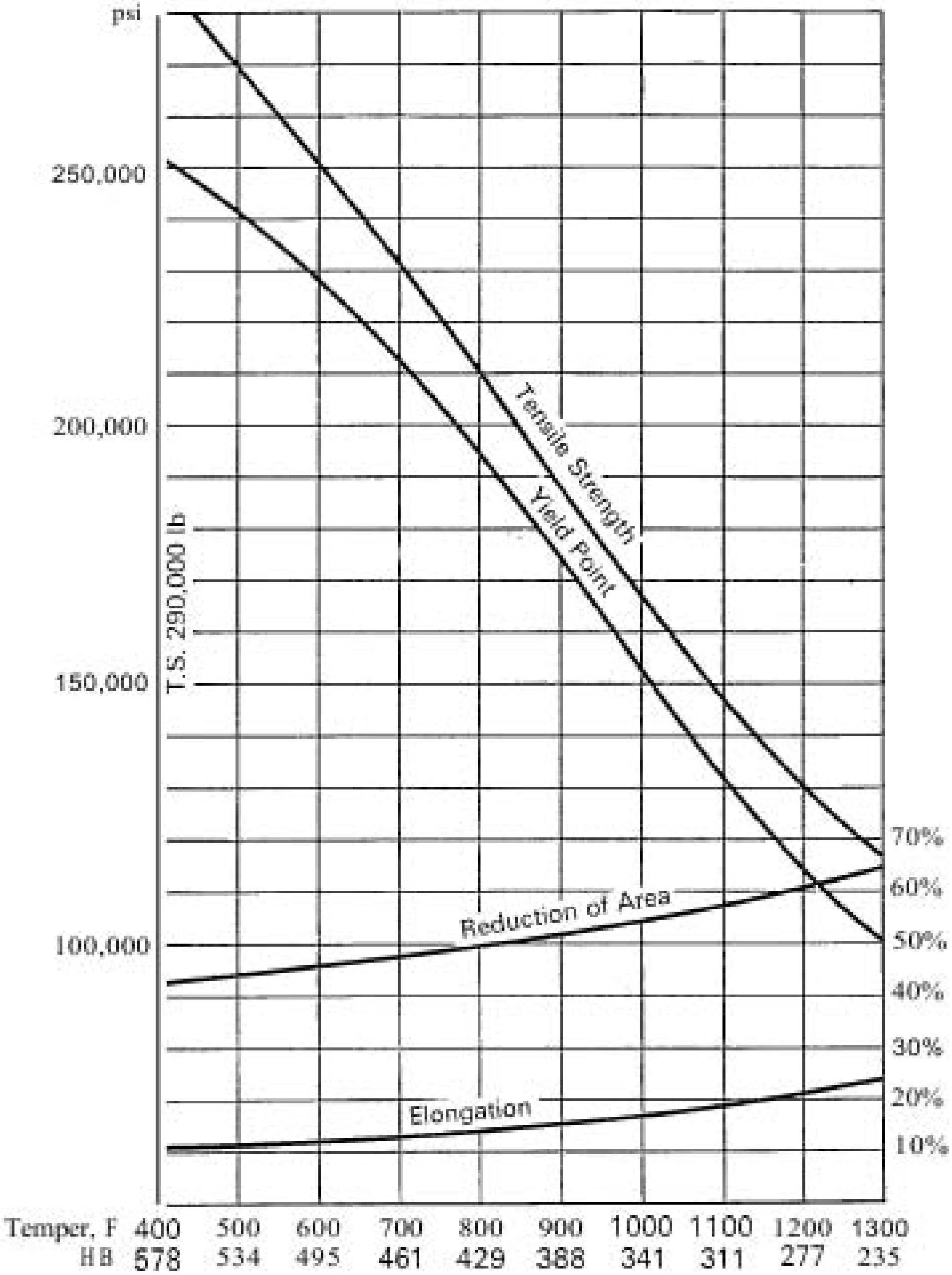


Table 4-5

Water-quenched 4130

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	.30	.48	.015	.015	.20	.12	.91	.20	6-8

Critical Points, F: Ac, 1400 Ac, 1510 Ar, 1400 Ar, 1305

Treatment: Normalized at 1600 F; reheated to 1575 F; quenched in water. .530-in. Round Treated; 505-in. Round Tested. As-quenched HB 495.

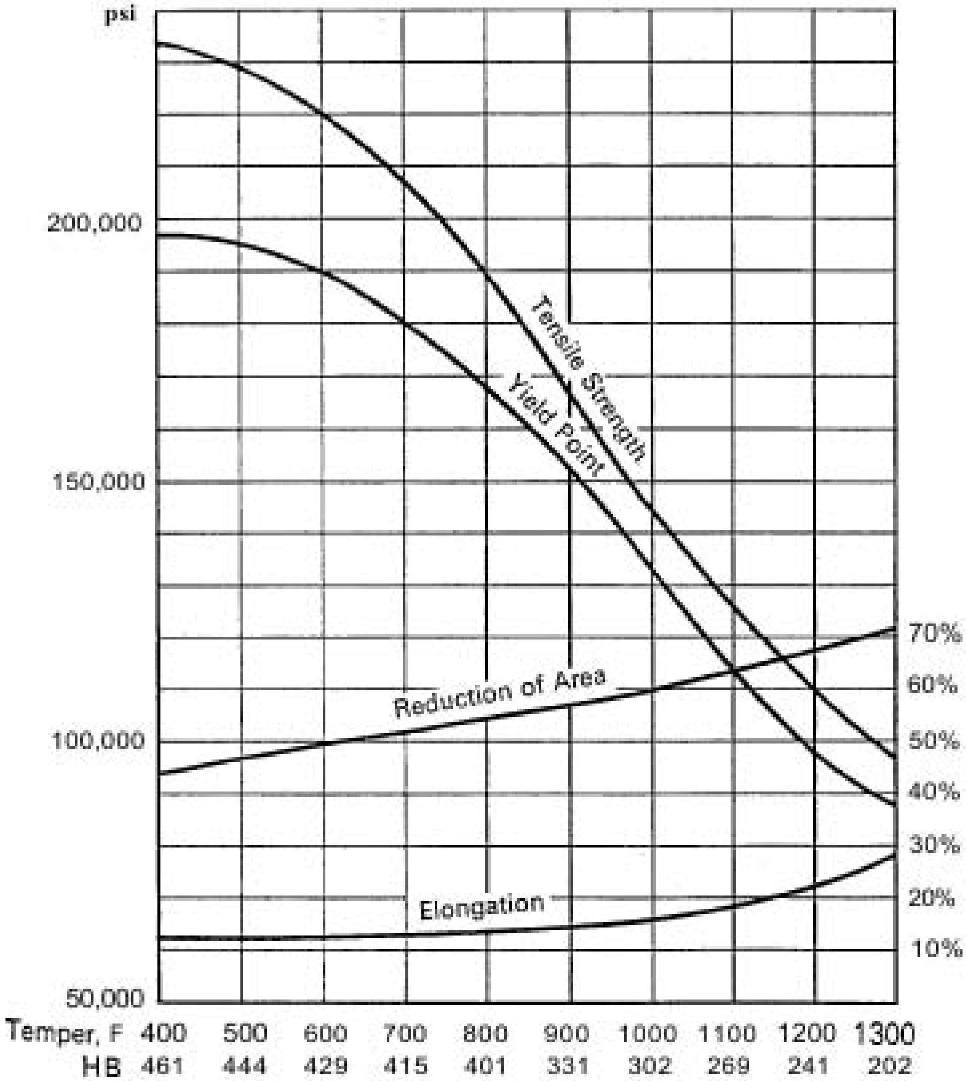


Table 4-6

Chemical Compositions of Alloy Steel Oil-Hardening Grades

SAE 4140,4340 and 4150:

Composition:

SAE 4140 *C* 0.38 to 0.43, Mn 0.75 to 1.0, Si 0.2to 0.35, Cr .8 to 1.1,Mo 0.15 to 0.25 percent

SAE 4340 C 0.38 to 0.43, Mn 0.6 to 0.8, Si 0.2 to 0.35, Ni 1.65 to 2.0, Cr 0.7 to 0.9, Mo 0.2 to 0.3 percent

SAE 4150 C 0.48 to 0.53, Mn 0.75 to 1.0, Si 0.2 to 0.35, Cr 0.8 to 1.1,Mo 0.15 to 0.25 percent

Annealing:

SAE 4140: Heat to 1500 degrees F, furnace cool to 1230 degrees F, cool in air.

SAE 4340: Heat to 1490 degrees F, furnace cool to 670 degrees F, cool in air.

SAE 4150: Heat to 1525 degrees F, furnace cool to 1190 degrees F, cool in air.

Normalizing treatment:

SAE 4140, **SAE** 4340, and **SAE** 4150:

Heat to 1600 degrees F, cool in air.

Maximum tensile strengths and achievable hardness:

Tensile strength

SAE 4140, 252,00 lb./sq. inch, 578 Brinell

SAE 4340, 293,00 lb./sq. inch, 555 Brinell

SAE 4150, 301,50 lb./sq. inch 578 Brinell

(For specific details, refer to Bethlehem Charts 4-5, 4-6, 4- 7 and 4-8.)

Alloy Carburizing Grades --SAE 4820, 4320, E 9310

Chemical Compositions:

SAE 4820. C 0.18 to 0.23, Mn 0.5 to 0.7, Si 0.2 to 0.35, Ni 3.25 to 3.75, Mo 0.2 *to* 0.3 percent

SAE 4320. C 0.17 to 0.22, Mn 0.45 to 0.63, Si 0.2 to 0.35, Ni 1.65 to 0.2,Cr 0.4 to 0.6, Mo 0.2 to 0.3 percent

SAE E 9310 C 0.08 to 0.13, Mn 0.45 to 0.65, Si 0.2 to 0.35, Ni 3. to 3.5, Cr 1. to 1.4, Mo 0.08 to 0.15 percent

Annealing: For all these steels, heat to 1550 degrees F, cool to 760 degrees F in the furnace, at the rate of 30 degrees F per hour, and air cool.

Normalizing:

SAE **4820.** Heat to **1580** degrees F and cool in air.

SAE **4320.** Heat to **1640** degrees F and cool in air.

SAE **9310.** Heat to **1630** degrees F and cool in air.

(For further technical details, refer to Bethlehem Tables 4-9, 4-10, 4-11, and 4-12.)

Nearest German, British, and French Equivalents to Direct Hardening SAE Steels

SAE	*British (En)*	*German (DIN)*	*French*
1063	**En 9K**	**DIN C6**	**C6**
1044	**En 8K**	**DIN C45**	**c45**
2034	En6K	DINC35	**c35**
4337		**DIN 37 Ni, Cr,** Mo, **7**	
4340		**DIN 4 Ni, Cr,** Mo 7	

Nearest Equivalents to SAE Case-Hardening Steels

SAE	*German (DIN)*
1015	**DIN CK15**

British and German Equivalents

British (En)	*German (DIN)*
EN 36	**DIN 14 Ni Cr 14**
EN 39	**DIN 14 Ni Cr 18**

Aluminum Gears

The following aluminum-based materials are mostly used for gears: 2024-T4, 7075-T4, 7075-T6, 6061-T4, 6061-T6. AL 2024-T4 is alloyed with **4.5** percent copper. **T4** is a solution heat-treatment specification and is followed by natural ageing at room temperature to a substantially stable condition. The ultimate strength achieved is approximately 68,000 lb./sq. inch, the yield strength is **47,000** lb./sq. inch, the hardness is **120** Brinell, and the shear strength is **41,000** lb./sq. inch.

However, the tensile strength varies with operating temperature. At **75** degrees F, the tensile strength is 68,000 lb./sq. inch, but at elevated temperatures it decreases considerably as follows: at 300 degrees F, **45,000** lb./sq. inch, at **400** degrees F, **27,000** lb./sq. inch, and at 700 degrees F, 5,500 lb./sq. inch.

Aluminum Rounds in **T-4** condition are generally supplied in diameters from 1/8 to 8 inches.

Oil-quenched 4340

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain
Ladle	.41	.67	.023	.018	.26	1.77	.78	.26	6-8

Critical Points, F: Ac_1 1350 Ac_3 1415 Ar_3 890 Ar_1 720 .

,Treatment: Normalized at 1600 F; reheated to 1475 F; quenched in agitated oil, .530-in. Round Treated ; .505-in. Round Tested. As-quenched HB 601.

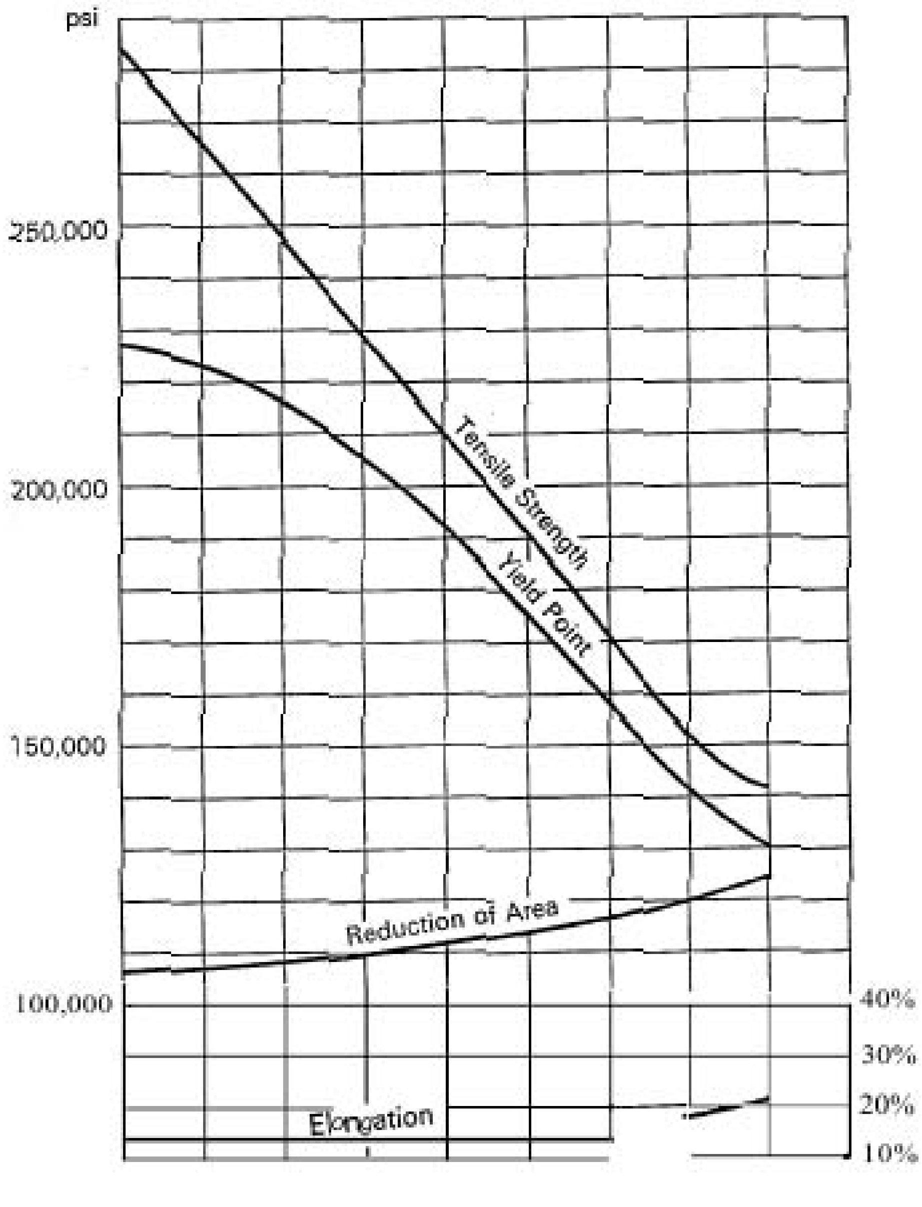


Table 4-7

Oil-quenched 4150

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	.50	.76	.015	.012	.21	.20	.95	.21	90% 7-8

Critical Points, F: Ac_1 1390 Ac_3 1450 Ar_3 1290 Ar_1 1245

Treatment: Normalized at 1600 F; reheated to 1525 F; quenched in agitated oil.
.530-in. Raund Treated; .505-in. Round Tested. As-quenched HB 656.

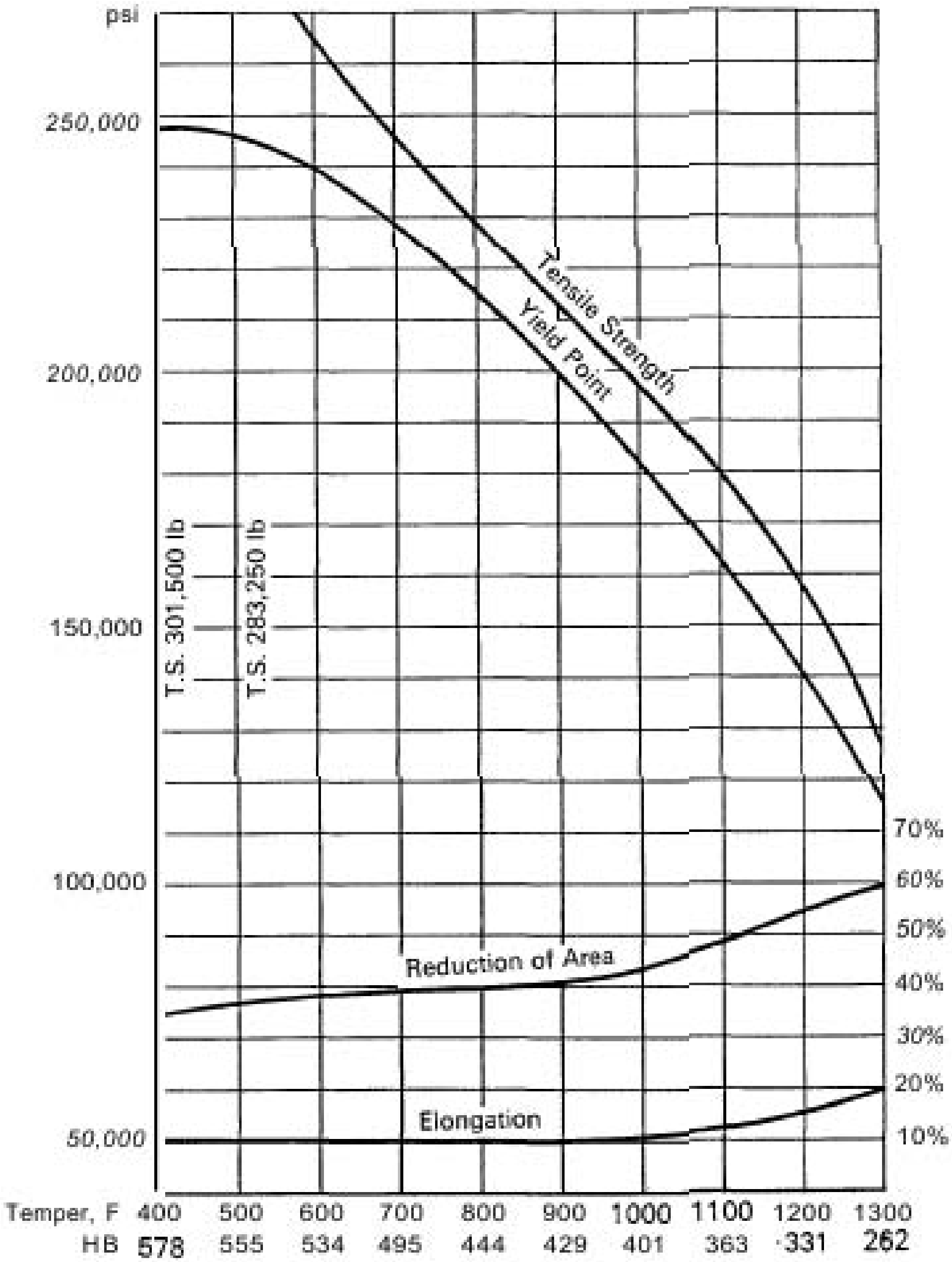


Table 4-8

4820

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	.21	.51	.021	.018	.21	3.49	.18	.24	6-8

Critical Points, F: Ac_1 1310 Ac_3 1440 Ar_3 1215 Ar_1 780

.565-in. Round Treated; .505-in. Round Tested

CASE		CORE PROPERTIES				
Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
Recommended Practice for Maximum Case Hardness						
Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil; 3) tempered at 300 F.						
60	.039	205,000	165,500	13.3	53.3	415
Single-quench and temper—for good case and core properties: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1475 F; 4) quenched in agitated oil; 5) tempered at 300 F.						
61	.047	207,500	167,000	13.8	52.2	415
Double-quench and temper—for maximum refinement of case and core. 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1500 F; 4) quenched in agitated oil; 5) reheated to 1450 F; 6) quenched in agitated oil; 7) tempered at 300 F.						
60	.047	204,500	165,500	13.8	52.4	415
Recommended Practice for Maximum Core Toughness						
Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil; 3) tempered at 450 F.						
56	.039	200,500	170,000	12.8	53.0	401
Single-quench and temper—for good case and core properties: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1475 F; 4) quenched in agitated oil; 5) tempered at 450 F.						
57.5	.047	205,000	184,500	13.0	53.3	415
Double-quench and temper—for maximum refinement of case and core: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1500 F; 4) quenched in agitated oil; 5) reheated to 1450 F; 6) quenched in agitated oil; 7) tempered at 450 F.						
56.5	.047	196,500	171,500.	13.0	53.4	401

Table 4-9

4320

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	.20	.59	.021	.018	.25	1.77	.47	.23	6-8

Critical Points, F: Ac_1 1350 Ac_3 1485 Ar_3 1330 Ar_1 840

.565-in. Round Treated; .505-in. Round Tested

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
Single-quench and temper—for good case and core properties: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1500 F; 4) quenched in agitated oil; 5) tempered at 300 F.						
62.5	.075	218,250	178,000	13.5	48.2	429
Double-quench and temper—for maximum refinement of case and core: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1500 F; 4) quenched in agitated oil; 5) reheated to 1425 F; 6) quenched in agitated oil; 7) tempered at 300 F.						
62	.075	151,750	97,000	19.5	49.4	302
Recommended Practice for Maximum Core Toughness						
Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil; 3) tempered at 450 F.						
58.5	.060	215,500	158,750	12.5	49.4	415
Single-quench and temper—for good case and core properties: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1500 F; 4) quenched in agitated oil; 5) tempered at 450 F.						
59	.075	211,500	173,000	12.5	50.9	415
Double-quench and temper—for maximum refinement of case and core: 1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1500 F; 4) quenched in agitated oil; 5) reheated to 1425 F; 6) quenched in agitated oil; 7) tempered at 450 F.						
59	.075	145,750	94,500	21.8	56.3	293

Table 4-10

E9310

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	11.	.53	.013	.014	.29	3.19	1.23	.11	5-7

Critical Points, F: Ac_1 1350 Ac_3 1480 Ar_3 1210 Ar_1 810

.565-in. Round Treated ; .505-in. Round Tested

CASE Hardness HRC	CASE Depth in.	CORE PROPERTIES Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB

Recommended Practice for Maximum Case Hardness

Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil; 3) tempered at 300 F

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
59.5	.039	179,500	144,000	15.3	59.1	375

Single-quench and temper—for good case and core properties:
1) Carburized at 1700 F for 8 hours ; 2) pot-cooled ; 3) reheated to 1450 F ; 4) quenched in agitated oil; 5) tempered at 300 F.

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
62	.047	173,000	135,000	15.5	60.0	363

Double-quench and temper—for maximum refinement of case and core:
1) Carburized at 1700 F for 8 hours ; 2) pot-cooled ; 3) reheated to 1475 F ; 4) quenched in agitated oil ; 5) reheated to 1425 F ; 6) quenched in agitated oil ; 7) tempered at 300 F.

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
60.5	.055	174,500	139,000	15.3	62.1	363

Recommended Practice for Maximum Core Toughness

Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil; 3) tempered at **450** F.

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
54.5	.039	178,000	146,500	15.0	59.7	363

Single-quench and temper—for good case and core properties:
1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1450 F; **4)** quenched in agitated oil ; 5) tempered at **450** F.

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
59.5	.047	168,000	137,500	15.5	60.0	341

Double-quench and temper—for maximum refinement of case and core:
1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1475 F; 4) quenched in agitated oil ; 5) reheated to 1425 F; 6) quenched in agitated oil ; **7)** tempered at **450** F.

Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
58	.055	169,500	138,000	14.8	61.8	352

Table 4-11

8620

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Ni	Cr	Mo	Grain Size
Ladle	.23	.81	.025	.016	.28	.56	.43	.19	90% 7-8 10% 4

Critical Points, F: Ac_1 1380 Ac_3 1520 Ar_3 1400 Ar_1 1200

.565-in. Round Treated ; .505-in. Round Tested

CASE		CORE PROPERTIES				
Hardness HRC	Depth in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB

Recommended Practice for Maximum Case Hardness

Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil; 3) tempered at 300 F.

63	.056	192,000	150,250	12.5	49.4	388

Single-quench and temper—for good case and core properties:
1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1550 F; 4) quenched in agitated oil ; 5) tempered at 300 F.

64	.075	188,500	149,750	11.5	51.6	388

Double-quench and temper—for maximum refinement of case and core:
1) Carburized at 1700 F for 8 hours; 2) pot-cooled ; 3) reheated to 1550 F ; 4) quenched in agitated oil ; 5) reheated to 1475 F ; 6) quenched in agitated oil ; 7) tempered at 300 F.

64	.070	133,000	83,000	20.0	56.8	269

Recommended Practice for Maximum Core Toughness

Direct quench from pot: 1) Carburized at 1700 F for 8 hours; 2) quenched in agitated oil ; 3) tempered at 450 F.

58	.050	181,250	134,250	12.8	50.6	352

Single-quench and temper—for good case and core properties:
1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1550 F; 4) quenched in agitated oil ; 5) tempered at 450 F.

61	.076	167,750	120,750	14.3	53.2	341

Double-quench and temper—for maximum refinement of case and core:
1) Carburized at 1700 F for 8 hours; 2) pot-cooled; 3) reheated to 1550 F; 4) quenched in agitated oil ; 5) reheated to 1475 F ; 6) quenched in agitated oil ; 7) tempered at 450 F.

61	.070	130,250	77,250	22.5	51.7	262

Table 4-12

The 7075 T6 alloy contains zinc and lesser amounts of magnesium, copper and chromium. The properties are similar to those of 2024 T4, but it is selected for its higher tensile strength. The ultimate tensile strength is approximately 83,000 lb./sq. inch, the yield strength is 73,000 lb./sq. inch, and the shear strength is 48,000 lb./sq. inch.

Increases in operating temperature with aluminum result in reductions in tensile strength, as with other materials. At 75 degrees F, tensile strength of a typical alloy is 83,00 lb./sq. inch, at 212 degrees F, tensile strength is 70,00 lb./sq. inch, at 300 degrees F, tensile strength is 31,000, at 400 degrees F, the tensile strength is 16,000 lb./sq. inch, and at 700 degrees F the tensile strength is 6,000 lb./sq. inch,

Alloy 6061-T6 contains magnesium 1 percent and silicon 0.6 percent. The tensile strength at 75 degrees F is approximately 42,000 lb./sq. inch, the yield strength is 37,000 lb./sq. inch, and the shear strength is 27,000 lb./sq. inch. At elevated operating temperatures the tensile strength falls considerably. At 212 degrees F, the tensile strength is 42,000 lb./sq. inch, at 300 degrees F it is 34,000 lb./sq. inch, at 400 degrees F it is 19,000 lb./sq. inch, and at 700 degrees F the tensile strength is 3,000 lb./sq. inch.

Precipitation-Hardening Stainless Steels

In aircraft and missiles, where parts must function without being oxidized, many gears are made from precipitation-hardening stainless steels such as 17-4 PH, PH 13-8, Mo, 15Cr-5 Ni. Commercially available materials to these specifications are generally supplied in solution treated condition A.

On heat treatment at temperatures not exceeding 1200 degrees F, the material becomes harder, depending on the heating temperature. Generally, the material is heated in the furnace (preferably in a neutral atmosphere), and held for 4 hours, then cooled in air.

The following are the maximum tensile strengths and hardnesses that can be achieved with PH steels:

PH 17-4, tensile strength	235,00 lb./sq. inch, hardness	49 Rockwell C.
PH 13-8 Mo, tensile strength	235,00 lb./sq. inch, hardness	48 Rockwell C.
15 Cr, 5 Ni, tensile strength	200,00 lb./sq. inch, hardness	44 Rockwell C.

The remarkable characteristic of these PH materials is that component size after heat treatment can be pre-determined because the metal shrinks in both diameter and length by specific amounts. Thus, to achieve the final size specified on the drawing, a gear can be cut oversize by a specific calculated amount (depending upon the contraction rate). After heat treatment the size will be exactly as called for on the blueprint.

PH materials should never be used in solution heat-treated condition called 'A,' because in that condition the material is susceptible to stress corrosion cracking. Solution heat-treatment of PH 13-8 Mo is achieved by heating to 1900 degrees F and cooling rapidly to room temperature. Typical mechanical properties of PH 13-8 Mo and 15 Cr-5 Ni are reproduced here from the Carpenter stainless steel catalog. (Refer to Table 5-1.).

It is important for the manufacturing engineer to know that once the precipitation hardness of 44 Rockwell has been achieved by hardening at 900 degrees F (as with 15 Cr-5 Ni), special procedures are needed to modify this hardness. For instance, if it becomes necessary to reduce the hardness to 34 Rockwell, the component must first be hardened by heating to a temperature of 1100 degrees F, holding that temperature for 4 hours and then air cooling to room temperature. However, if the part has already been heat-treated at 1100 degrees F and a hardness of 44 Rockwell is required, the part must first be solution heat-treated and then precipitation hardened to a specific hardness using Table 4-13 as a guide.

Precipitation Hardness and Tensile Strengths of 17-4 PH

Condition	*Ultimate Tensile Strength*
H 900	198 KSI
H 950	182 KSI
H 1000	186 KSI
H 1050	142 KSI
H 1100	157 KSI

(KSI means thousands of pounds per square inch)

15 Cr-5 Ni Contraction Rate

Condition	*Inch per Inch*
H 950	0.0004 to 0.0006
H 1150	0.0008 to 0.001

PH 13-8 Mo Contraction Rate

Condition	*Inch per Inch*
H 950	0.0004 to 0.0006
H 1000	0.0004 to 0.0006
H 1050	0.0005 to 0.0008
H 1100	0.0008 to .0012

Copper Plating of Gears for Processing

Carburization and hardness is required mostly in the gear tooth area, the remainder of a gear does not need to be carburized. One way to mask the area not needing added carbon is to finish-turn the gear, then copper plate the whole blank with **0.0003** inch maximum plating thickness. The teeth are then cut, leaving a grinding allowance, and the workpiece is then carburized and hardened. The copper platting can then be stripped away before the hardened teeth are finish ground to size.

Nital Etch for Detecting Grinding Cracks

During the grinding of gear teeth, the heat generated may result in the development of hair line cracks. Burning marks often become visible on the teeth, and ground gears are therefore subjected to a Nital etch to detect cracks. The Nital etch process requires the parts to be cleaned to remove grease and oil, usually by immersing the parts for 4 to **5** minutes in denatured alcohol containing **5** percent by volume of concentrated hydrochloric acid.

The parts are then cleaned in water, then rinsed in alcohol, and again immersed for **35** to **4** minutes in denatured alcohol containing **3** percent nitric acid. The parts are then immersed again in the hydrochloric acid solution described earlier and then neutralized in an alkaline solution. Any localized dark area or white areas on gear teeth are indications of overheating and such parts should be rejected.

After the Nital etch, the parts can either be tumbled, honed, or polished to remove remaining Nital etch stains. Nital etching is necessary for aircraft and missile gears that are subjected to grinding operations.

Chapter 5

PROCESSING OF GEAR PARTS

This chapter discusses processing of six typical gears. The parts selected are either spur gears or gears with splines. With a knowledge of the technique of processing these gears it will be found that processing of bevel gears, and worms and worm wheels will be similar.

Part PHD-1

Referring to Figure **5-1**, the first thing to decide when making a component is the raw material size and the condition in which it is to be procured. The final hardness of this part is to be **46** to 50 Rockwell **C**, but for ease in machining, the material to be purchased should be in the annealed condition.

The largest finished diameter on the print is the **0.1336** inch diameter. All steel is supplied in two basic forms: hot rolled and cold rolled. Since the size is so small, the obvious choice is cold-rolled material. The nearest higher size in the inch system is **9/64** inch or **0.1406** **(3.571** mm.). The difference in diameter between **0.1406** and the finished diameter of **0.1336** inch is approximately 0.007 inch, which requires a radial material removal of approximately **0.0035** inch. Any material, whether hot rolled or cold rolled, always has some surface defects (more so in hot rolled); so the obvious selection **of 9/64 (.1406)** is not suitable for this application. The next available commercial size is **5/32** inch **(0.156** inch). If this size is selected it will give **0.156 – 0.137 ÷ 2** = 0.019/2 = **0.0095** inch depth of surface removal.

The drawing calls for the part to be heat treated, during which hairline surface cracks can develop, so it is recommended that the next higher size than **5/32,** which is **11/64** inch **(0.172)** be used. This choice will give us 0.172 – 0.137 ÷ 2 = 0.035/2 = 0.017 inch of radial material removal. The 11/64-inch size material may not be easily available (unless mill quantity is ordered), so the recommendation is to use 3/16-inch diameter cold-rolled material for this part.

Economic aspects of the cost of manufacturing must also be considered. Stainless steel material costs more than ordinary steel. Allowing too great a machining allowance increases the cost of both raw material and machining. At the same time, the machining allowance has to be sufficient to ensure that there is no possibility of surface defects.

Drilling of the 3/64-inch diameter hole will have to be done with the material in the annealed condition because drilling a small hole in material with a Rockwell C hardness of 46-50 is very difficult. At this hardness, the only other practical way of providing this hole is by electrical discharge machining, which is a comparatively costly operation. Another critical feature of the part is the two narrow undercut grooves which will have to be machined with the material in the annealed condition.

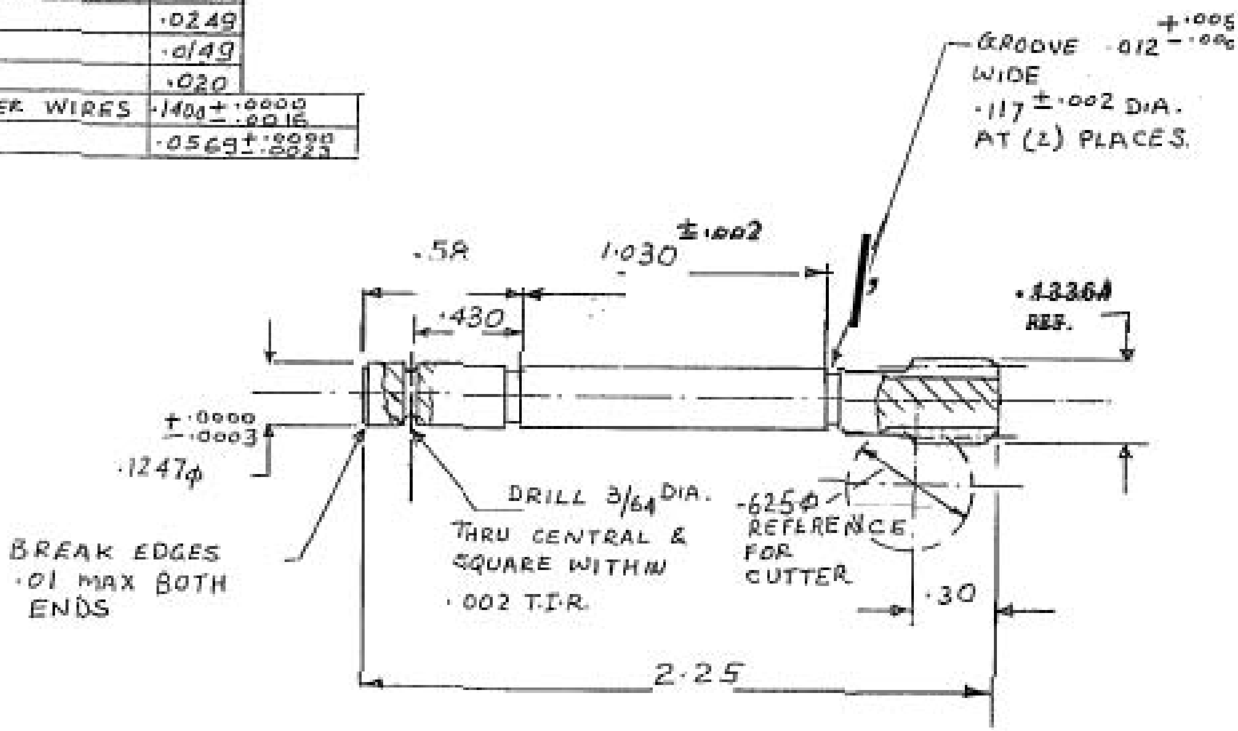
Whether the turning operation is to be performed with the material in the annealed condition will depend on the number of parts to be produced. If the lot quantity is higher than 500, and thousands of the parts are to be made often, and if the shop has Swiss-type automatics (preferably CNC), the cost of the turning operations will be a minimum. To suit the Swiss-type automatics, the material will have to be centerless ground. In these machines, the tools are stationary, and the chuck or spindle moves axially.

Thus, on a Swiss-type automatic, rough or finish turning, facing, centering, two undercuts, one drilling operation, and cutting-off, can be done in one cycle as shown in sketch A of SK-PHD-1 (Refer to Figure 5-2).

If the quantity to be processed is one or two, the very first operation will be sawing (or milling) the bar to the length of 2.25 inches, plus the machining allowance on each end of the bar. The cut length will have to be 2.25 + 0.12 = 2.37 or 2-3/8 inches (using 0.12 inch as the machining allowance). However, if the quantity in a lot is 100 or more, the bar length will have to be in multiples of 2-3/8 inch, plus the width of the cutting-off tool. It will be advantageous to order the material in lengths of 10 or 12 feet.

Depending upon what turning equipment is available in a particular shop, the bars might have to be cut or milled in shorter lengths. On CNC turning machines, with bars over 6 feet in length, due to con-

SPUR GEAR DATA		
REFERENCE DATA	PITCH DIA. +.000 −.000	.1042
	OUTSIDE DIA. +.000 −.002	.134
	DIAMETERAL PITCH	96
	NUMBER OF TEETH	10
	PRESSURE ANGLE	20°
CUTTING DATA	CLASS OF GEAR AGMA#	10
	TOTAL COMPOSITE ERROR	.001
	TOOTH TO TOOTH COMP. ERROR	.0007
	WHOLE DEPTH	.0249
	ADDENDUM	.0149
	WIRE SIZE	.020
	MEASUREMENT OVER WIRES	.1408 +.0000 −.0016
	TEST RADIUS	.0569 +.0000 −.0023



NOTES:-

1. MATERIAL ST. STEEL 440C
2. HEAT TREAT TO 46-50 R'c'.
3. CENTERS PERMISSIBLE BOTH ENDS.

GEAR, PINION	
PART NO#	PHD-1

Figure 5-1

tinuous rotation of the head-stock, the noise and vibration created by the bar feeding mechanism will be so high that a maximum length of 4 feet may be preferred. With Swiss-type automatics, which use centerless ground material, because of the higher speeds required, the length may have to be restricted to 6 feet.

Another point to be noted is that no gear grinding machines are available to grind the teeth of this small pinion. After the turning operation in the annealed condition, the part will have to be heat-treated to 46-50 Rockwell *C*. Finish hobbing can then be done using either a solid carbide or cobalt hob with titanium nitride coating.

It should also be noted that this part is very slender, so that, after the turning operations and during heat treatment, there will be considerable distortion. Sufficient grinding allowance must therefore be provided during the turning stage to take care of this distortion.

With gear and pinion shafts, centering with Bell-type center drills (as illustrated in sketch **C**, Figure **5-2)**, is recommended (instead of the plain type of center drill), to prevent any burr on the end face in the centering area from coming into contact with the tailstock center. In some turning operations, the operators first center-drill the face, then face the part to length, thus leaving a burr. Unless this burr is removed, it will cause an inaccurate gear profile.

Hobbing and grinding is often done between centers, and any such center must be clear of center hole burrs. The Bell-type center-drilled hole should not produce problems with a burr. In this instance, since the maximum turned diameter of the part is 0.131 inch, the Bell-type center drill cannot be used. The Bell-type center drill can be used for shaft sizes over 0.150 inch.

At the turning stage, the operator machining the part will have to be careful to finish face the adjoining gear (facing the adjoining 0.1316-inch diameter) first, and then center drilling. Smoothing the center-drilled hole can be accomplished by allowing an idle cycle to turn the spindle through 10 to 20 extra revolutions.

Thus, the sequence of operations for this part is:

1. Saw or mill bar to either 4 or 6 feet length depending upon whether the machine to be used is a regular CNC Swiss-type automatic.
2. Turn the part on the Swiss automatic to dimensions in sketch (Fig. 5-2).
3. Face to length of 2.250 inch and center drill.
4. Heat-treat part to 46-50 Rockwell **C**, preferably heating in a neutral atmosphere to avoid oxidation and scale formation.

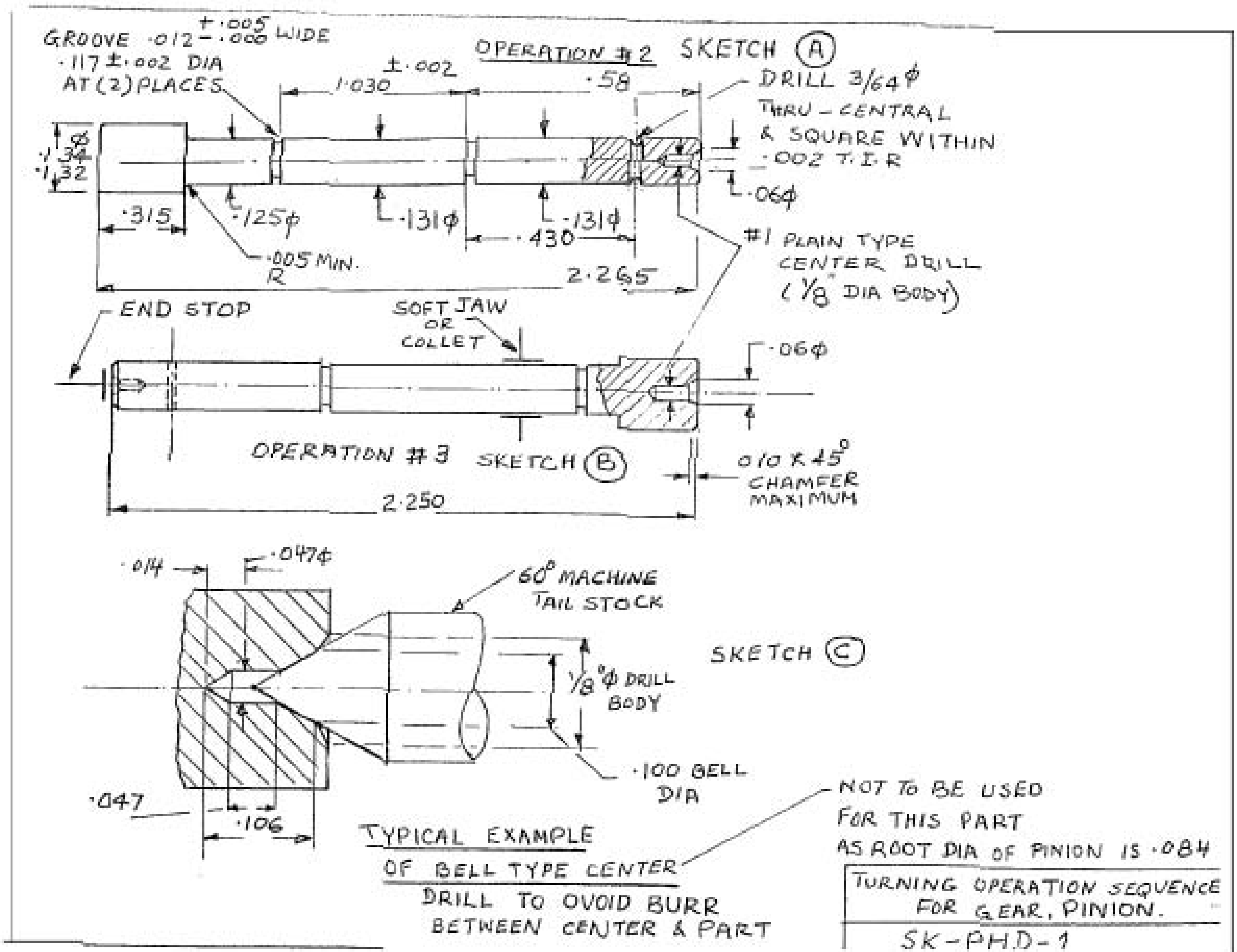

GROOVE .012 +.005 −.000 WIDE
.117 ±.002 DIA
AT (2) PLACES
OPERATION #2
SKETCH (A)
±.002
1.030
.58
DRILL 3/64 ϕ
THRU – CENTRAL
& SQUARE WITHIN
.002 T.I.R
ϕ .134 .132
.06ϕ
.315
.125ϕ
.131ϕ
.131ϕ
.430
.005 MIN. R
2.265
#1 PLAIN TYPE
CENTER DRILL
(1/8" DIA BODY)
END STOP
SOFT JAW
OR
COLLET
.06ϕ
OPERATION #3
SKETCH (B)
.010 X 45°
CHAMFER
MAXIMUM
2.250
.014
.047ϕ
60° MACHINE
TAIL STOCK
SKETCH (C)
1/8 ϕ DRILL
BODY
.100 BELL
DIA
.047
.106
TYPICAL EXAMPLE
OF BELL TYPE CENTER
DRILL TO OVOID BURR
BETWEEN CENTER & PART
NOT TO BE USED
FOR THIS PART
AS ROOT DIA OF PINION IS .084
TURNING OPERATION SEQUENCE
FOR GEAR, PINION.
SK-PHD-1

Figure 5-2

5. Between centers, using a driver, grind 0.1247-inch diameter and 0.1336-inch diameter in two settings.
6. Finish hob teeth using 96 dp, 5/8-inch diameter, carbide or cobalt hob.
7. Use measurement over wires to check teeth. 0.1400 + 0.0000, – 0.0016 inch
8. Deburr teeth manually, removing any left-over burrs on tooth flanks. Use of a magnifying glass or eye-loupe will be necessary.
9. Check tooth to tooth composite error (TTCE), and total composite error (TCE), and test radius of each gear individually on Fellows type gear checker or some other similar machine. These checks are more reliable than measurement over wires. Types of machines for testing the radius will be covered in a later chapter.
10. Check for cracks with M.P.I. (Magnetic Particle Inspection).
11. Inspect and check all dimensions.
12. Passivate as explained in earlier chapters.
13. Identify part by tag. Care is needed with the location of identification markings. One way of identifying is by etch ing. The etching cannot be done on ground diameters or bearing journals. Often the designer specifies specific areas for identification marks. In absence of any drawing nota tion, common sense must be used. Identifying the part by tag is an easy method.
14. Place parts in stock bin.

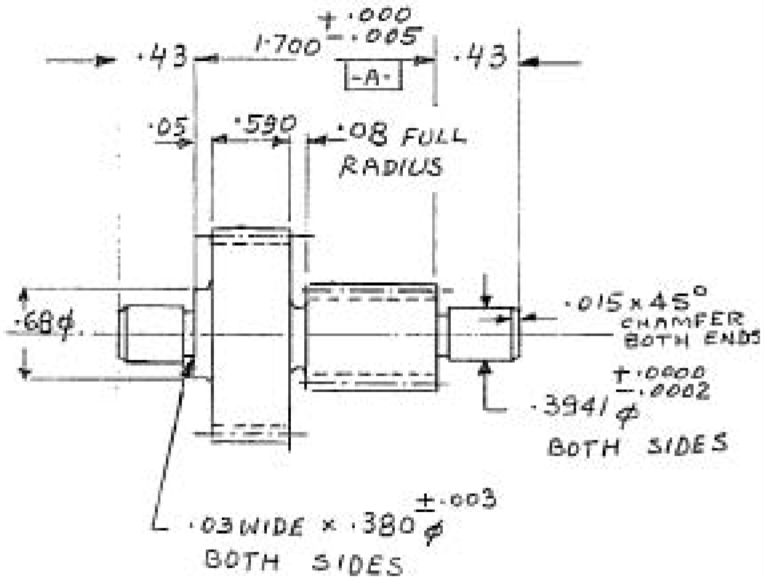
Part PHD-2

Referring to Fig. 5-3, the 13-8 PH-Mo (Precipitation Hardening Material) specified on the print is one of the most costly, but most stable materials in the corrosion resistant group. One advantage of this material is that shrinkage in gear dimensions, which depends on the specific temperature at which it is being hardened, can be predicted accurately. This material can also be heat-treated to a higher tensile strength than most of the other commonly available 17-4 PH and 15-5 PH materials.

Typical chemical analysis of PH 13-8 Mo, in percentage, as given by Carpenter Technology, is as follows: carbon 0.05 maximum, manganese 0.10 maximum, phosphorous 0.01 maximum, sulfur 0.008

SPUR GEAR DATA (ENLARG. ADDENDUM)		
REFERENCE DATA	PITCH DIA	·7000
	OUTSIDE DIA +·000 −·003	1·763
	DIAMETERAL PITCH	20
	NUMBER OF TEETH	32
	PRESSURE ANGLE	25°
	CLASS OF GEAR AGMA #	10
CUTTING DATA	TOTAL COMPOSITE ERROR	·001
	TOOTH TO TOOTH COMP. ERROR	·0005
	WHOLE DEPTH	·112
	ADDENDUM	·0315
	WIRE SIZE	·0864
	MEASUREMENT OVER WIRES	1·7853 +·000 −·003
	TEST RADIUS ·8320 +·000	−·0023

PINION DATA (ENLARGENED ADDENDUM)		
REFERENCE DATA	PITCH DIA (REF) STD.	·5000
	OUTSIDE DIA +·000 −·003	·647
	DIAMETRAL PITCH	20
	NUMBER OF TEETH	10
	PRESSURE ANGLE	25°
	CLASS OF GEAR AGMA #	10
CUTTING DATA	T·C·E	·001
	T·T·C·E	·0007
	WHOLE DEPTH	·112
	ADDENDUM	·0735
	MEASUREMENT OVER ·096 DIA WIRES	·6790 +·000 −·002
	TEST RADIUS ·2742 +·000	0 −·0025



NOTES:–

1. MATERIAL PRECIPITATION HARDENING 13-8 MO
2. HARDNESS 43-45 R'C'
3. CENTERS PERMISSIBLE

GEAR AND PINION	
PART NO#	PHD-2

Figure 5-8

maximum, silicon 0.10 maximum, chromium 12.25 to 13.25, nickel 7.50 to 8.50, aluminum 0.9 to 1.35. molybdenum 2.00 to 2.5, nitrogen 0.01 maximum.

Material from the mills is normally supplied in solution annealed condition (called Condition A). Because of its excellent corrosion resistance properties, this material is widely used in aircraft and missile actuators. However, care should be taken not to use the part in condition A, condition A material must necessarily be heat treated to a specific hardness. Condition A is reached by heating mill material to 1900 degrees F and then rapidly cooling to room temperature. The material can be hardened by heat-treating solution-treated material to a temperature of 900 to 1150 degrees F for one to four hours, depending upon specific hardness required, and then air cooling.

Table 5-1, supplied by Carpenter Technology, gives hardness values for different hardness temperatures. The author has personally heat-treated many components in accordance with instructions in the table and found hardness to be exactly as the table states. The hardness desired on the part is 43 to 45 Rockwell C, so table condition H 1025 will be ideal for the job being considered. In other words, if the part is gradually heated to 1025 degrees F and held at this temperature for 4 hours, then air-cooled, the hardness of the part will be 43 to 45 Rockwell C.

It will be observed from the Table that the maximum hardness of 47 Rockwell C is achieved in condition H 950, giving an ultimate tensile strength of 225,000 lb./sq. inch. Somewhat cheaper 15-5 PH material in condition H900 will give 44 Rockwell C and 200,000 lb./sq. inch ultimate tensile strength. Another peculiarity of PH (precipitation hardening) materials is that the contraction after heat-treatment is on both diameter and length.

For 13-8 PH, the contraction rate, as specified by Carpenter Technology, is as follows:

Condition

H 950	0.0004 to 0.0006 inch/inch
H 1000	0.0004 to 0.0006 inch/inch
H 1050	0.0005 to 0.0008 inch/inch
H 1100	0.0008 to 0.0012 inch/inch

For 15-5 PH, the contraction rate is:

H 900	0.0004 to 0.0006 inch/inch
H 1150	0.0008 to 0.0010 inch/inch

Condition	Ultimate Tensile Strength		Yield Strength 0.2 %		% Elongation in 2" (50.8 mm)	% Reduction of Area	Hardness Rockwell C	Impact Charpy V-Notch		Modulus of Elasticity	
	ksi	MPa	ksi	MPa				ft-lb	J	ksi	MPa
RH950	235,	1620	215	1482			48	20	27	—	—
H950	225	1551	210	1448			47	30	41	28,600	197 200
H1000	215	1482	205	1413			45	40	54	32,000	220 600
H1050	190.	1310	180	1241			43	60	81	30,800	212 400
H1100	160	1103	150	1034	18	60	36	100	136	28,600	197 200
H1150	145	1000	105	724		63	33	—	—	33,300	229 600
H1150M	130	896	85	586	22	70	28	120	163	25,000	172 400

TYPICAL MECHANICAL PROPERTIES: 15Cr - 5Ni

Typical Mechanical Properties — Longitudinal Direction, Intermediate Location

Condition	Ultimate Tensile Strength		Yield Strength 0.2%		% Elongation in 2" (50.8 mm)	% Reduction of Area	Hardness		Impact Charpy V-Notch		Modulus of Elasticity'			
											In Tension		In Torsion	
	ksi	MPa	ksi	MPa			Rockwell C	Brinell	ft-lb	J	ksi	MPa	ksi	MPa
H900	200	1379	185*	1276	14	50	44	420	15	20	28,500	196 600	11,200	77 270
H925	190	1310	175	1207	14	54	42	409	25	34	—	—	—	—
H1025	170	1172	165	1138	15	56	38	352	35	48	—	—	11,000	75 900
H1075	165	1138	150	1034	16	58	36	341	40	54	—	—	10,000	69 000
H1100	150	1034	135	931	17	5u	34	332	45	61	—	—	—	—
H1150	145	1000	125	862	19	60	33	311	50	68	—	—	10,000	69 000
H1150M	125	862	85	586	22	68	27	277	100	138	—	—	—	—

'The modulus of elasticity of 15Cr-5Ni Alloy at elevated temperature can be conveniently expressed as a percent of the room temperature values as follows:

72°F (22°C) — 100.0%	400°F (204°C) — 94.7%
100°F (38°C) — 99.6%	500°F (260°C) — 93.0%
200°F (93°C) — 97.8%	600°F (316°C) — 91.4%
300°F (149°C) — 96.3%	

*Compressive yield strength for Condition H900 is 178 ksi (1228 MPa)

Table 5-1

Part PH D-2 is required to be heat-treated to H 1025 condition, so its probable contraction rate will be 0.0006 inch/inch. Thus, if a blank is turned in both linear and diametrical dimensions to a size 1.0006 times the blueprint dimensions, after heat treatment at a temperature of 1025 degrees F, the size will turn out to be exactly as given on the print.

One major factor in deciding processing of this part is the requirement for AGMA Quality number 10. Although a gear of 32 teeth, 20 dp can be hobbed in the 43-45 Rockwell C hardness condition, using either a carbide hob or a cobalt titanium nitride coated hob, the teeth on a pinion with 10 teeth, and 20 dp cannot be hobbed and will have to be shaped. Generally, on a production scale, shaping is limited to 38 Rockwell C. Therefore, it is recommended that after the turning operations, the pinion should be finish hobbed in the annealed condition. The pinion will have to be cut oversize by the calculated contraction rate for the finished hardness specified on the print. After shaping, the pinion part will be heat-treated to final requirements

Factors Determining Bar Size

The outside diameter of the gear is 1.763 inches and the nearest fractional size of common stock is 1-49/64 (1.765) inches. If 1-25/32-Ø(1.781-) inch diameter material is selected, the material removal during turning will be (1.781 – 1.763) ÷ 2 = 0.009 inch, which is too low. The next size of 1-51/64 (1.797) inch will give (1.797 – 1.763) ÷ 2 = 0.017 inch machining allowance radially.

Most of this material is stocked in increments of 1/32 inch, so it is better to select 1-13/16 inch diameter material, which will give ample margin to guard against any surface defects. The sequence of operations will then be as follows:

1. Saw off 1-13/16-inch diameter bar to approximately 4-feet length. This short length is chosen for two reasons; to make it easier to handle and load the bar, and to reduce whiplash and vibration at the cutting point, which will be far less than if a long bar is used, an important aspect with close tolerances on the turned parts.
2. Turn one side on the CNC lathe to dimensions given in drawing SK-PHD-2 (Fig. 5-4). It will be noticed that extra material has been left on the 0.3941-inch bearing journal dimension because it will be subjected to two grinding operations: pre-grinding in the annealed condition and finish grinding after heat-treatment.

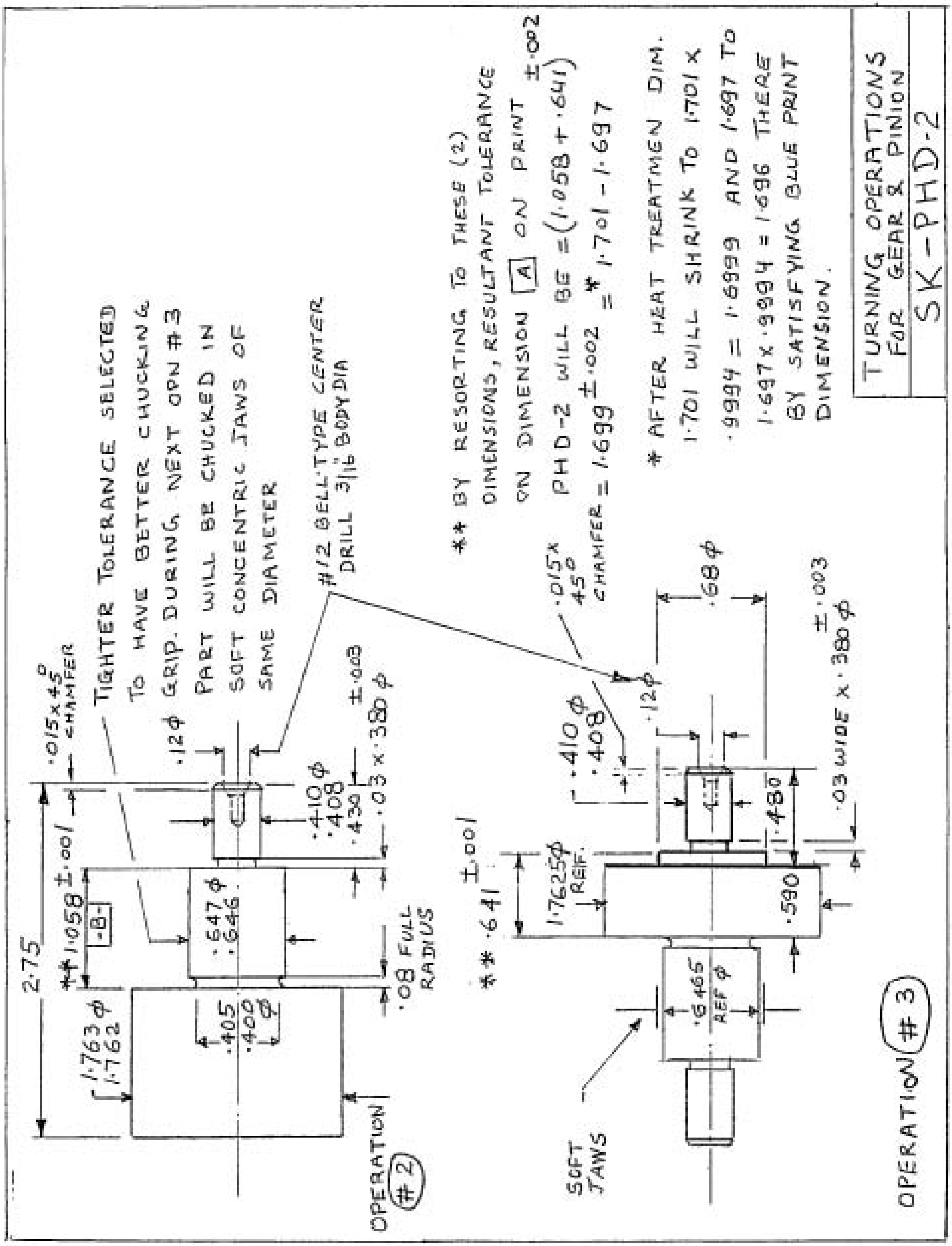

TURNING OPERATIONS FOR GEAR & PINION
SK-PHD-2
** BY RESORTING TO THESE (2) DIMENSIONS, RESULTANT TOLERANCE ON DIMENSION A ON PRINT PHD-2 WILL BE = (1.058 + .641) ±.002
CHAMFER = 1.699 ±.002 = * 1.701 - 1.697
* AFTER HEAT TREATMEN DIM. 1.701 WILL SHRINK TO 1.701 x .9994 = 1.6999 AND 1.697 TO 1.697 x .9994 = 1.696 THERE BY SATISFYING BLUE PRINT DIMENSION.
TIGHTER TOLERANCE SELECTED TO HAVE BETTER CHUCKING GRIP. DURING NEXT OPN #3 PART WILL BE CHUCKED IN SOFT CONCENTRIC JAWS OF SAME DIAMETER
#12 BELL TYPE CENTER DRILL 3/16 BODY DIA
OPERATION #2
OPERATION #3
SOFT JAWS
2.75
** 1.058 ±.001
-B-
1.763 ϕ
1.762
.647 ϕ
.646
.405
.400
.12 ϕ
.015 x 45° CHAMFER
.410 ϕ
.408
.430
.03 x .380 ϕ ±.003
.08 FULL RADIUS
** .641 ±.001
1.7625 ϕ REF.
.590
.6465 REF ϕ
.68 ϕ
1.480
.03 WIDE x .380 ϕ ±.003
.015 x 45° CHAMFER

Figure 5-4

Note that, although the outside diameter on the print is 1.760-1.763 inches, dimensions of 1.763-1.762 inches have been select ed on the gear (and 0.646-0.647 inch on the pinion). After the heat treatment, the 1.762-1.763-inches dimension will shrink to 1.762 x (1-0.0006) inches, and 1.763 x (1-.0006) inches; i.e., 1.7609and 1.7619 inches, which are within the blueprint dimensions.

3. Turn the second side on the CNC lathe to dimensions in SK-PHD-2 (Fig. 5-2). The tolerance on the 0.646-0.647-inch diame ter has purposely been kept narrow, and during this operation, the part is held in accurately-bored soft jaws resulting in better concentricity and grip.
4. Pre-grind the 0.408-0.410-inch turned diameter on one side to 0.405-0.406 inch. (This dimension is approximately 13/32 inch and is selected so that the part can be held tightly in a 13/32-inch collet during the hobbing operation).
5. Pre-grind the 0.408-0.410-inch diameter on the other side to 0.405-.406 inch diameter.
6. With the part held between centers, and using a driving dog, finish shape the 10 teeth of the pinion to 0.6745 - 0.6765 inch measured over pins. (This dimension takes into consideration the shrinkage that will take place after heat-treatment). Check the part by means of a test radius on a gear-checking machine similar to Fellows number four.
7. De-burr the pinion and check TCE. and TTCE. De-burring is best carried out using either a magnified eye-loupe or with the aid of a magnified illuminated lens, removing any stuck, hairy chips.
8. Heat-treat in either a vacuum or an inert atmosphere at 1025 degrees F, holding for 4 hours and then cooling at room temperature. This sequence should result in a hardness of 43-45 Rockwell C, which condition is known as H1025.
9. Chucking on one side on the pre-ground 0.405-0.406- inch diameter, and using a 60-degree center on the other side, finish hob the 32 teeth gear as shown on the print.
10. De-burr the 32 teeth, checking TCE and TTCE, and test the radius.
11. Grind the bearing journal to the 0.3939-0.3941-inch dimension.
12. Grind the bearing journal on the other side to the 0.3939-0.3941-inch diameter.
13. Perform final inspection to the print.

14. Apply passivation treatment.
15. Apply identification tag.
16. Place in stock.

Part PHD-3

Figure 5-5 shows a part that is more complex than the two simple parts discussed previously and it also requires to be carburized. Examining the print, the first thing that will occur to a manufacturing engineer is the possible distortion that will result from carburization. The part has a very thin cross section so will require a quenching fixture to prevent distortion. Design of this fixture will be a major exercise. Without a quenching fixture, the part will be greatly distorted and will become oval in shape. If subsequently ground to size, such a part will not have a uniform depth of case and may not clean up well in grinding.

If there were no distortion, the objective would be to carburize to a depth of (0.025 + 0.045) ÷ 2 = 0.035 inch. Generally 0.005 inch of thickness is removed during grinding, and would leave a minimum of 0.040 inch carburized thickness. The ovality, therefore, should not be more than 0.040 minus 0.005 inch (grinding thickness) minus 0.025 inch (minimum carburized thickness) = 0.010 inch.

The problem becomes complicated however, because the inner spline teeth required are not going to be ground. Grinding will be used only on the outside teeth. The fixture therefore must be designed in such a way that the distortion does not become more than 0.005 inch, especially because measurement over wires has a total tolerance of 0.006 inch on the splines.

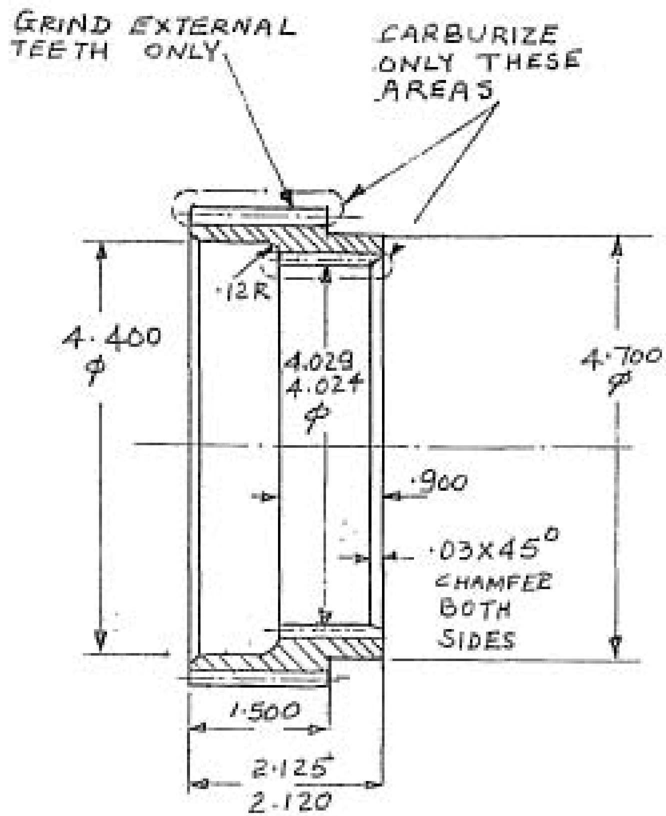
Raw Material Considerations

1. If the yearly requirement is high, forging will be recommended. The forging must be normalized at 1725 degrees F, held at this temperature for 2 hours in an endothermic atmosphere, and air-cooled in a chamber to room temperature (refer to Fig. 5-6 Sketch A).

If the part is to be produced from cold-rolled solid bar, and if an Eldorado type gun-drilling machine is available in the shop, the best approach is to saw off a **4** foot length from a 5-inch diameter bar in the annealed condition and have the piece drilled to 3.96 inches diameter as in Sketch B. If no gun-drilling machine is available in the plant, the bar should be sent to an outside vendor who can gun-drill

GEAR DATA	
NUMBER OF TEETH	45
D.P	9/11
PRESSURE ANGLE	20°
BASE CIRCLE DIA	4.6895
MAX. TIP DIA	4.827
ADDENDUM	.0909
CORRECTED ADDENDUM	.0924
WHOLE DEPTH	.2045
ROOT FILLET RADIUS	.015-.025
CIRCULAR PITCH	.3291
THEORITICAL CHORDIAL THICK.	.1745
CHORDAL THICKNESS MIN	.1685
CHORDAL THICKNESS MAX	.1705

SPLINE DATA	
NUMBER OF TEETH	50
D.P	12/14
PRESSURE ANGLE	20°
THEORITICAL CHORDAL SPACE	.1309
WHOLE DEPTH	.1607
ROOT DIA	4.365 — 4.345
THEORITICAL PITCH DIA	4.1667
WIRE SIZE	.140
MEASUREMENT BETWEEN WIRES	3.9805 3.9745
ROOT RADIUS	.025
INVOLUTE FORM MUST BE TRUE WITHIN 4.300 MIN	



MATERIAL STEEL-E93K
HARDNESS 'A' 81-85
CORE HARDNESS 30-40
DEPTH OF CASE R'C'
.025-.045

GEARED COUPLING
PHD-3

Figure 5-5

the internal diameter to 3.96 or 3-31/32 inches diameter. (Refer to Sketch C). Before sawing to the exact length it may be advisable to ask the vendor what is the maximum length capacity of the available gun-drilling machine.

1. Whichever method is selected, the aim should be to rough turn the part as shown in Sketch D. To avoid any development of cracks during subsequent operations, normalizing of the rough blank is recommended.
2. Normalize by heating the work to 1725 degrees F and holding it for two hours, then cooling in an endothermic atmosphere to room temperature.
3. Sand blast to remove heat treatment scale.
4. Turn on a CNC lathe to dimensions in SK-PHD-3, sheet 2 of 3 (Fig. 5-7) on one end, referring to operation number 5.
5. Turn on a CNC lathe on the second end to dimension in SK-PHD-3 sheet 3 of 3 (Fig. 5-7) (refer to operation number 6).
6. Copper plate 0.0003 inch thick all over. The purpose of copper plating is to prevent carbon entering certain surfaces, which are not to be carburized, so that they remain soft..
7. Turn to remove copper plate from areas to be hardened, as shown on Sketch SK-PHD sheet 2 of 3 in two settings
8. Hob outside teeth leaving a 0.005-inch grinding allowance on each flank. Center the part on a bushing having 4.387-4.388 inches outside diameter.
9. De-burr the gear teeth.
10. Shape the inside teeth to the finished dimensions shown in the print (PHD-3).
11. De-burr inside the teeth.
12. Carburize at 1700 degrees F to 0.035-0.045 inch thickness. Furnace-cool to 1500 degrees F, then cool in air to room temperature.
13. Sub-critically anneal at 1150 degrees F for two hours in air.
14. Harden at 1500 degrees F for one hour in an endothermic atmosphere. Quench in oil at 1300 degrees F, using quenching fixture shown in Fig. 5-8. Freeze at –120 degrees F for one hour; thaw to room temperature. Temper at 300 degrees F for four hours in air.
15. Clean the! part.
16. Strip the remaining copper plate electrolytically.
17. Parallel surface-grind one side on Blanchard surface grinding machine to 2.127-2.128 inch dimension.

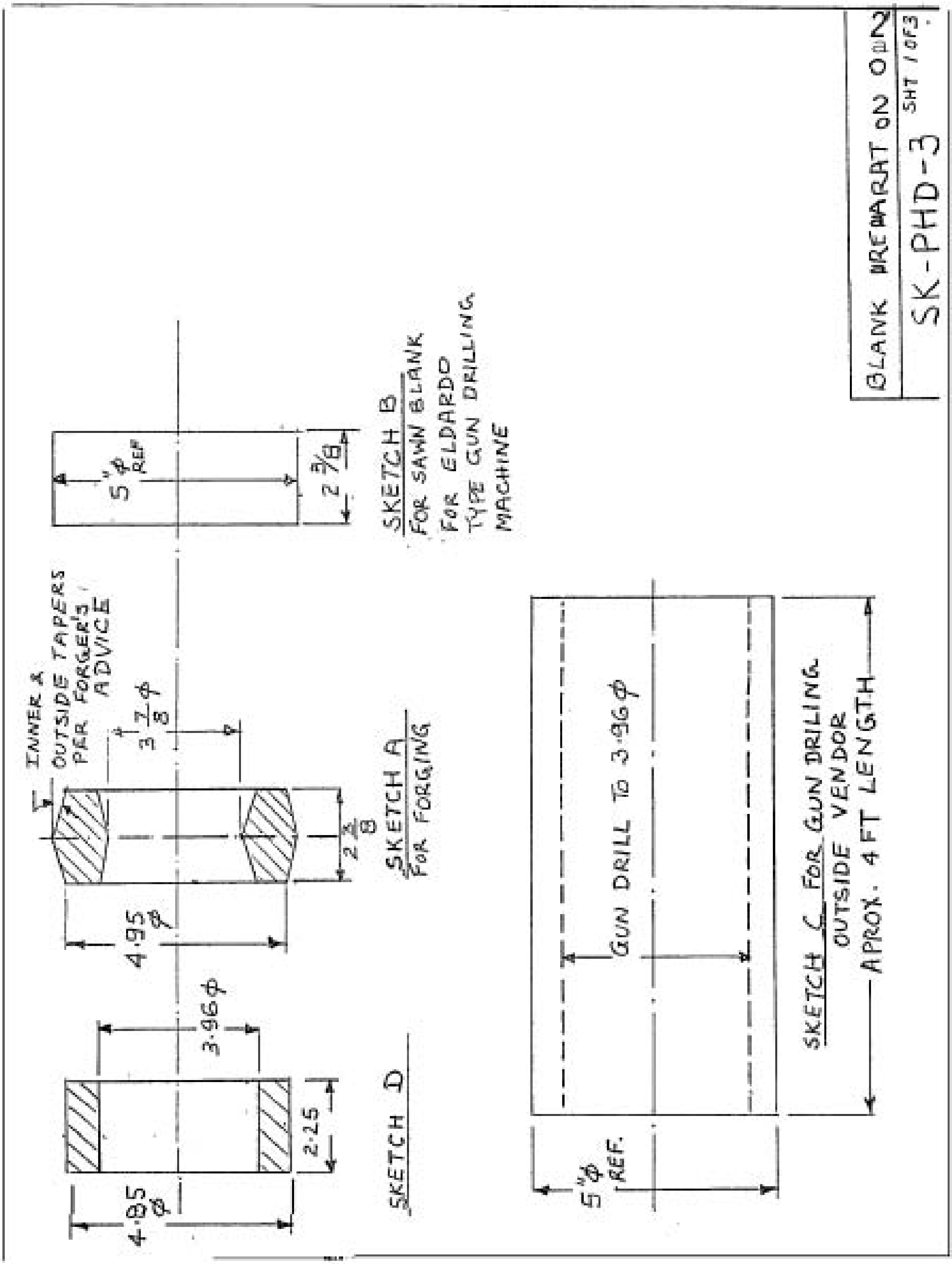

BLANK PREPARATION ON OWN
SK-PHD-3
SHT 1 OF 3
SKETCH B
FOR SAWN BLANK
FOR ELDARDO
TYPE GUN DRILLING
MACHINE
SKETCH A
FOR FORGING
INNER & OUTSIDE TAPERS PER FORGER'S ADVICE
SKETCH D
SKETCH C FOR GUN DRILING
OUTSIDE VENDOR
APROX. 4 FT LENGTH
GUN DRILL TO 3.96 Φ
5" Φ REF.
4.95 Φ
4.85 Φ
3.96 Φ
2.25

Figure 5-6

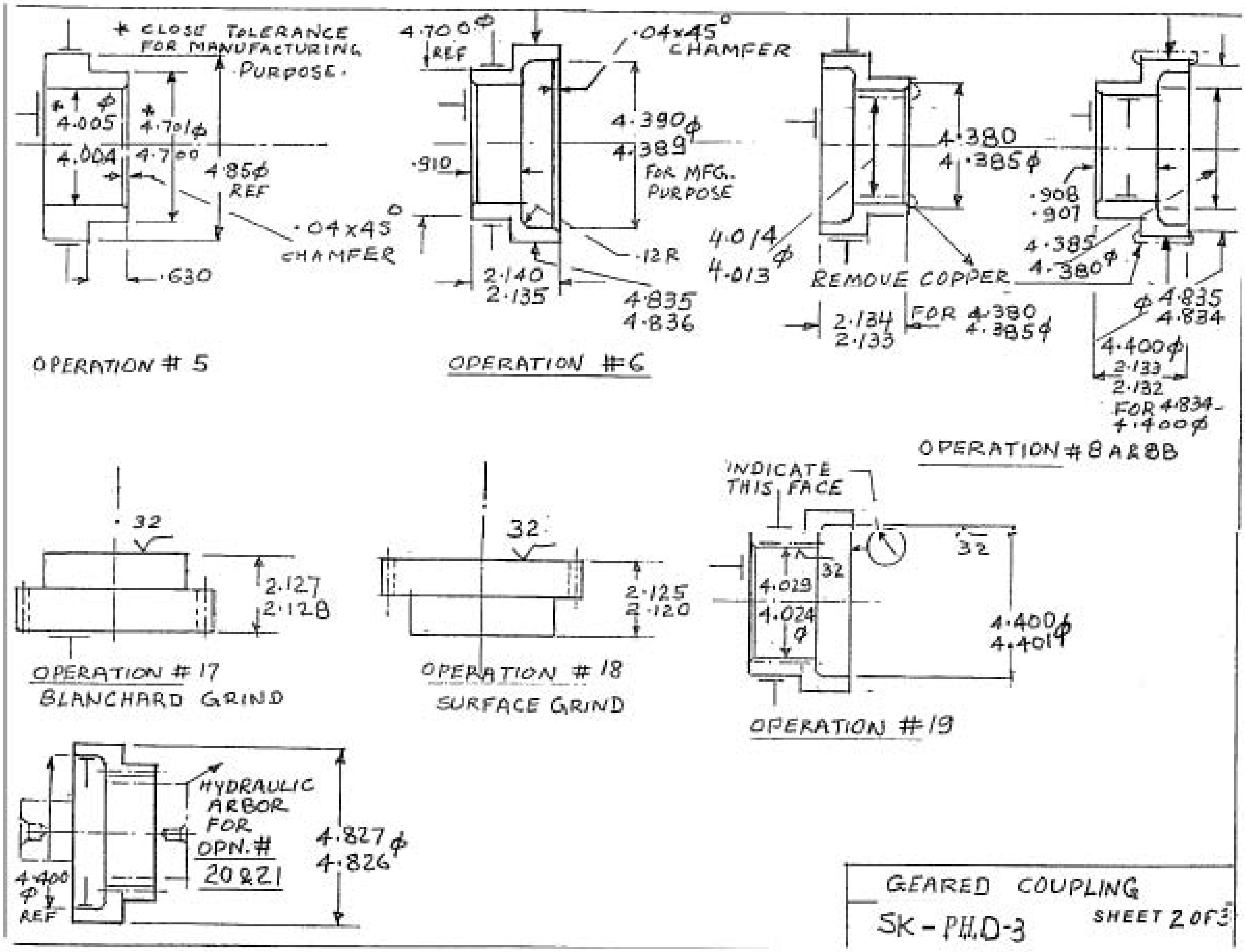

* CLOSE TOLERANCE FOR MANUFACTURING PURPOSE.
OPERATION # 5
OPERATION #6
.04x45° CHAMFER
4.390φ 4.389 FOR MFG. PURPOSE
REMOVE COPPER
OPERATION #8 A&8B
OPERATION #17 BLANCHARD GRIND
OPERATION #18 SURFACE GRIND
INDICATE THIS FACE
OPERATION #19
HYDRAULIC ARBOR FOR OPN.# 20&21
GEARED COUPLING
SK-PH.D-3
SHEET 2 OF 3

Figure 5-7

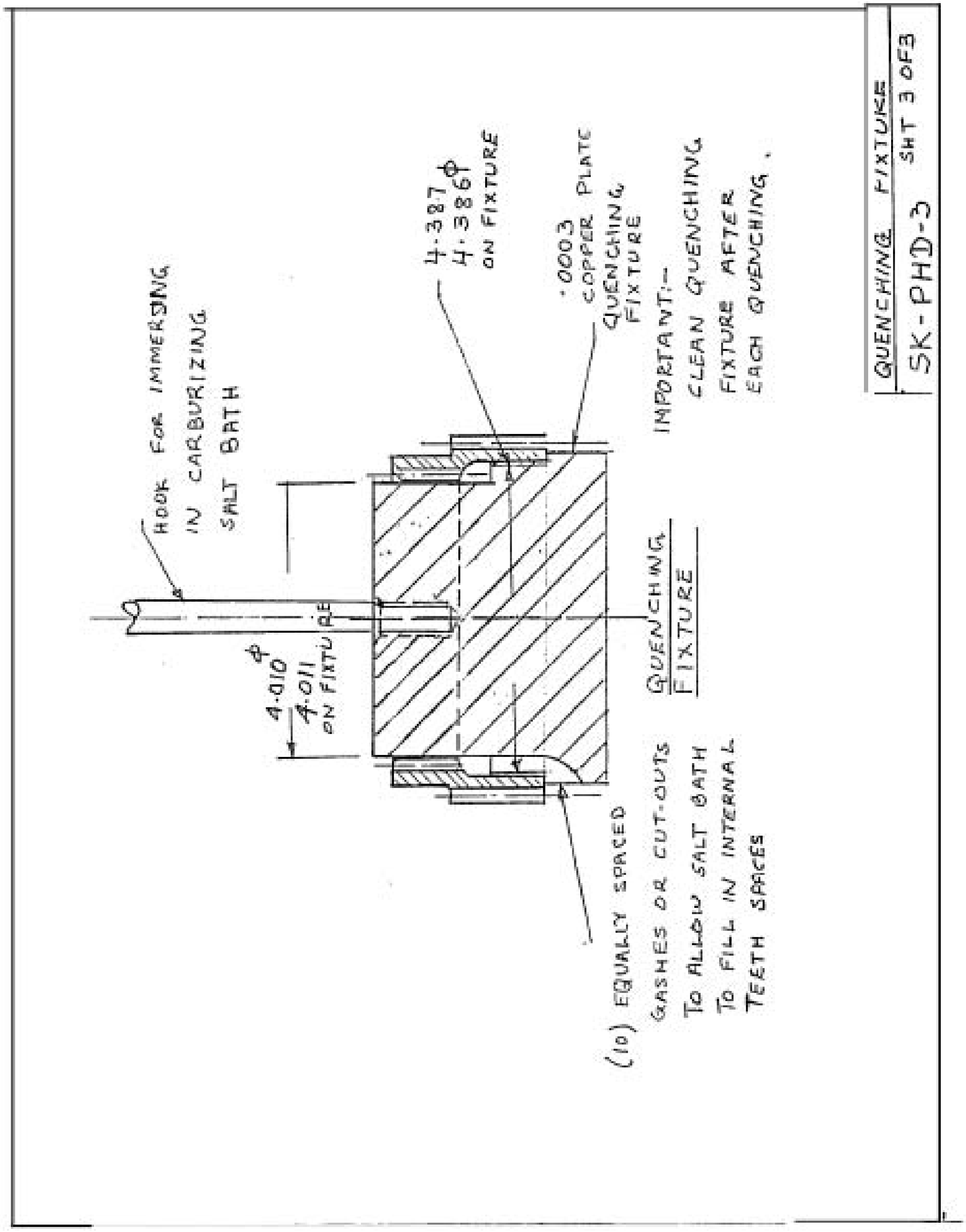

HOOK FOR IMMERSING
IN CARBURIZING
SALT BATH
4.387
4.386 ⌀
ON FIXTURE
.0003
COPPER PLATE
QUENCHING
FIXTURE
IMPORTANT:-
CLEAN QUENCHING
FIXTURE AFTER
EACH QUENCHING.
4.010 ⌀
4.011
ON FIXTURE
QUENCHING
FIXTURE
(10) EQUALLY SPACED
GASHES OR CUT-OUTS
TO ALLOW SALT BATH
TO FILL IN INTERNAL
TEETH SPACES
QUENCHING FIXTURE
SK-PHD-3
SHT 3 OF3

Figure 5-8

18. Surface-grind the other side to the 2.120-2.125 inch dimension.
19. Chucking on the 4.700-inch diameter, and truing with a dial indicator on the ground face, grind the internal diameter and the 4.400-inch diameter.
20. Chucking on the 4.400-inch diameter with a hydraulic arbor, grind the outside to the 4.826-4.827 inch diameter.
21. Using the hydraulic arbor used on the previous operation, grind the external teeth; check TCE and TTCE.
22. Nital etch to reveal any grinding cracks (the Nital etch process was explained in Chapter 4).
23. Inspect for all dimensional and other requirements.
24. Apply rust preventive compound.
25. Apply identification tags.
26. Transfer to stock.

Part PHD-4

Made from 13-8 PH Mo. material (Refer Fig. 5-9), this part is simple to process. The difficult part is machining the 0.750-0.751-inch diameter counter bore which is required to be concentric with the two bearing diameters A and B. The bore also needs to be machined at a hardness of 43-45 Rockwell C.

The ideal material for this part is an investment casting that has been heat-treated to 43-45 Rockwell C, and is made with a hollow core. However, the batch quantity for such a part is often so small that solid bar material is the only choice. This discussion will cover processing of the part from a solid bar.

The AGMA Quality number of the gear on the part is 10 and the hardness is 43-45 Rockwell C, so to minimize the cost, cutting of the teeth should be done after heat-treatment, using either a carbide or a cobalt hob with a titanium nitride coating. For 20 dp in this size of gear, grinding is an alternate method of cutting the teeth. If this method is used, oversized hobbing will be done in the solution annealed condition. The material required is expensive and chances of surface defects are low, so use of 3-3/8-inch diameter solid bar is recommended.

The sequence of operations is:

1. Saw off bar to the length of 4.73-4.75 inches
2. Rough turn one end to the dimensions shown in Fig. 5-10, sheet 1 of 2., operation number 02. Note that the tolerance of 0.002 inch on the 2-inch diameter is imposed so that the part may be held tightly in soft-bored jaws during the next operation.

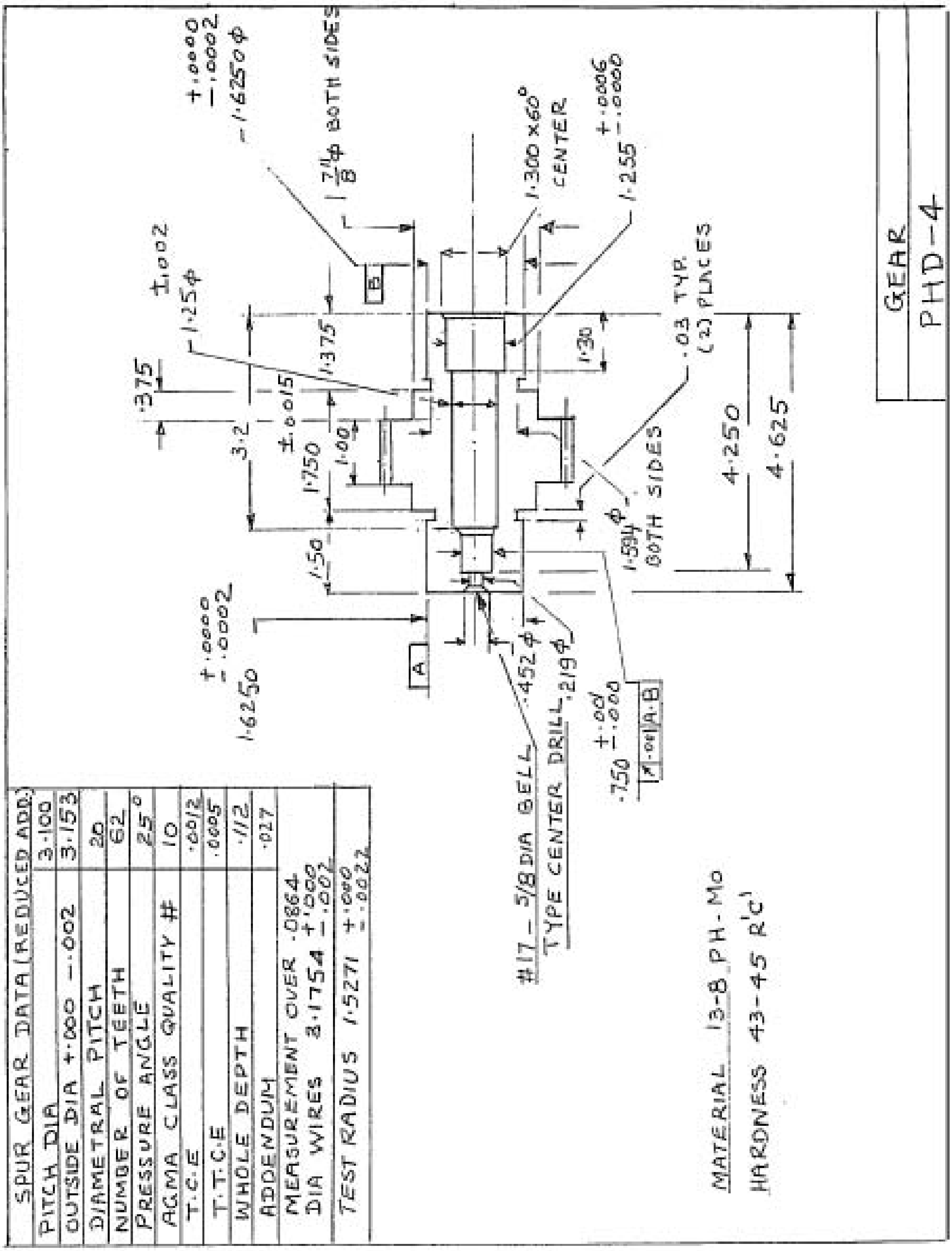

SPUR GEAR DATA (REDUCED ADD.)
PITCH DIA 3.100
OUTSIDE DIA +.000 −.002 3.153
DIAMETRAL PITCH 20
NUMBER OF TEETH 62
PRESSURE ANGLE 25°
AGMA CLASS QUALITY # 10
T.C.E .0012
T.T.C.E .0005
WHOLE DEPTH .112
ADDENDUM .027
MEASUREMENT OVER .0864 DIA WIRES 3.1754 +.000 −.002
TEST RADIUS 1.5271 +.000 −.0022
#17 — 5/8 DIA BELL TYPE CENTER DRILL
MATERIAL 13-8 PH-Mo
HARDNESS 43-45 Rc
GEAR
PHD-4
1 7/8 Φ BOTH SIDES
1.300 x 60° CENTER
1.6250 Φ +.0000 −.0002
1.255 +.0006 −.0000
1.25 Φ ±.002
.375
3.2
1.375
1.750 ±.0015
1.00
1.30
1.50
.03 TYP. (2) PLACES
4.250
4.625
1.594 Φ BOTH SIDES
1.6250 +.0000 −.0002
.452 Φ
.219 Φ
.750 +.001 −.000
A
B

Figure 5-9

Otherwise, there is no need for tight tolerances. The operation should be done on a CNC machine.

3. Rough turn second end using a CNC machine. Refer to sketch for operation number 03 on sheet 1 of 2.
4. Gun-drill to 0.718 inch diameter, to a depth of 4.24 inches, preferably using an Eldorado or similar gun drilling machine. Refer to sketch for operation number 04, sheet 1 of 2.
5. Precipitation harden blank to 43-45 Rockwell C by heating to 1025 degrees F, holding at that temperature for 4 hours and then air-cooling. Refer to sketch number 05, sheet 1 of 2.
6. Chucking on 2.000-inch diameter with soft-bored jaws, turn on a CNC machine. Refer to sketch for operation number 6. The 0.745-inch C bore is very deep, so the 1.2478-1.2480-inch diameter will need to be programmed first, then a special cobalt end mill will have to be used to machine the 4.250-inch full depth. (Refer to sketch number 06, sheet 1 of 2.) The lengths 1.375 and 1.750 inches have purposely been kept to tighter tolerances so that the 1.750-inch dimension on Fig. 5-9 (Part PHD-4) is maintained to ± 0.0015 inch.
7. Finish turn on the CNC lathe as specified in operation number 07, sheet 2 of 2, SK-PHD-4. Close tolerances have been kept purposely on the 4.625, 1.500 and 1.875-inch dimensions to achieve a ± 0.0015-inch tolerance on the 1.750-inch dimension mentioned in sketch number 6.
8. Pre-grind the bearing journal on one side to 1.633 inch, as shown in sketch number 08 on sheet 2 of 2.
9. Pre-grind the bearing journal on the other side to 1.633 inch size.
10. Using Borematic machine and diamond-tipped boring tools (mounted on special boring bar with adjustable diamond tips) bore in one setting in accordance with sketch number 010, sheet 2 of 2.
11. Finish hob, de-burr, and check TTCE and TCE on each piece. This operation can be done by the operator on previously hobbed parts while hobbing is being performed on the next part.
12. Using centers and dog, grind the bearing journal on one side.
13. Grind the bearing journal on the other side.
14. Inspect part.
15. Apply passivation treatment.
16. Apply identification tags.
17. Place in stock.

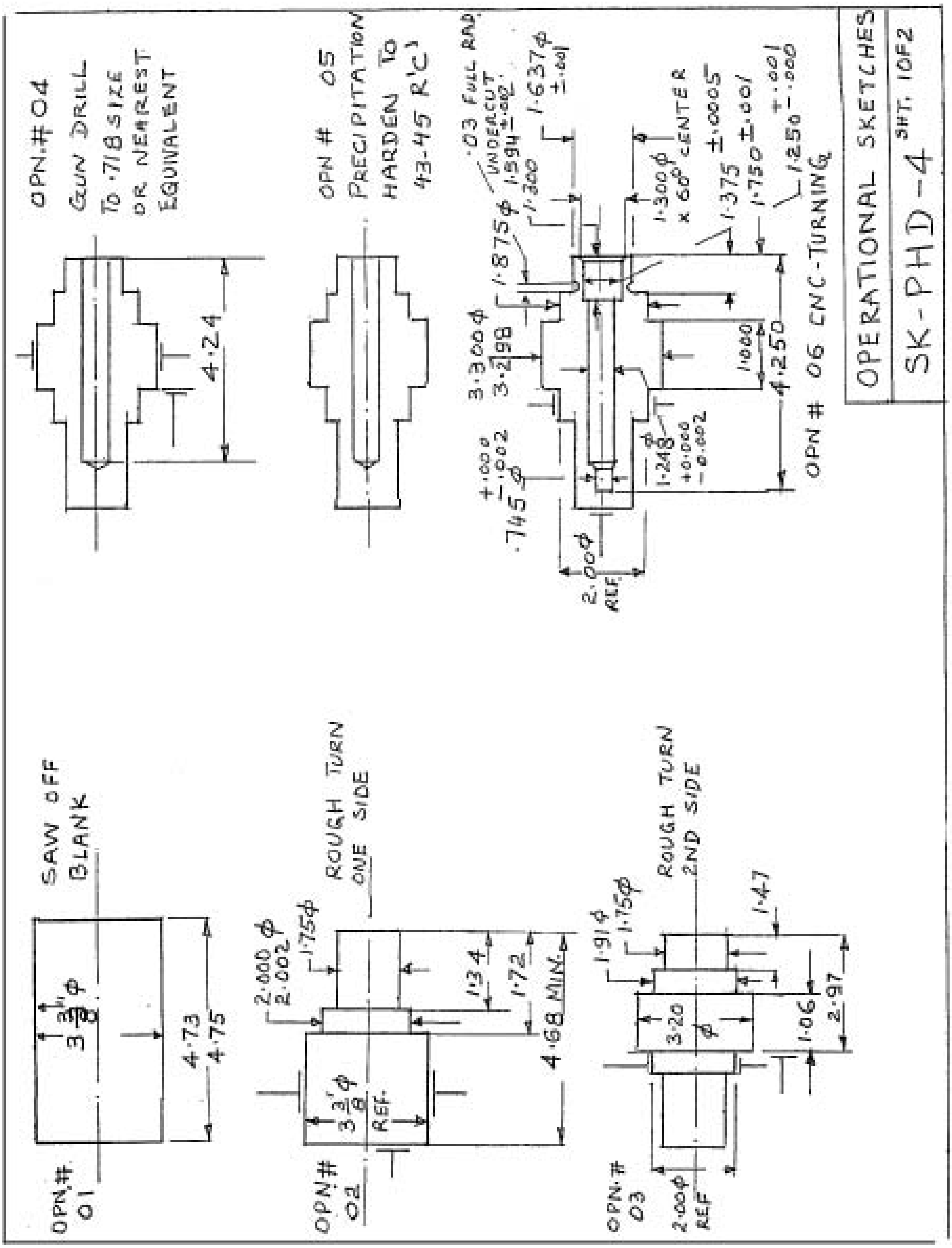

OPERATIONAL SKETCHES
SK-PHD-4 SHT. 1 OF 2
OPN.# 01
SAW OFF BLANK
3 3/8 φ
4.73
4.75
OPN.# 02
ROUGH TURN ONE SIDE
2.000 φ
2.002
1.75φ
1.34
1.72
4.68 MIN.
3 3/8 φ REF.
OPN.# 03
ROUGH TURN 2ND SIDE
1.91φ
1.75φ
1.47
3.20 φ
1.06
2.97
2.00φ REF
OPN.# 04
GUN DRILL TO .718 SIZE OR NEAREST EQUIVALENT
4.24
OPN # 05
PRECIPITATION HARDEN TO 43-45 R'C'
OPN # 06 CNC-TURNING
.03 FULL RAD.
UNDERCUT
1.637φ
±.001
1.875φ
1.300φ x 60° CENTER
1.375 ±.0005
1.750 ±.001
1.250 +.001 -.000
3.300φ
3.298
1.000
4.250
.745φ
1.248
+0.000
-0.002
2.00φ REF.

Figure 5-10

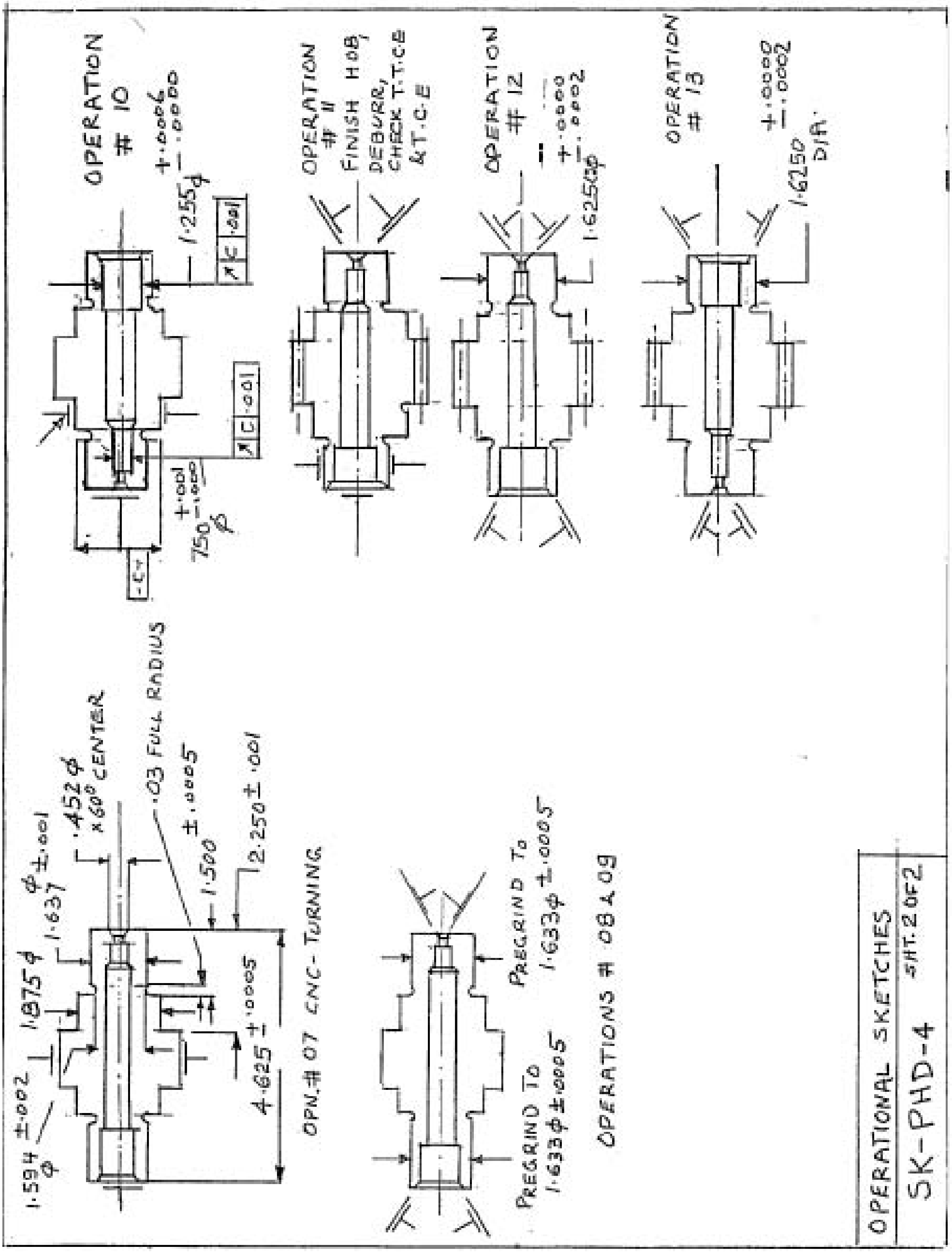

OPN. # 07 CNC- TURNING
OPERATIONS # 08 & 09
OPERATION # 10
OPERATION # 11
FINISH HOB,
DEBURR,
CHECK T.T.C.E
& T.C.E
OPERATION # 12
OPERATION # 13
OPERATIONAL SKETCHES
SK-PHD-4
SHT. 2 OF 2

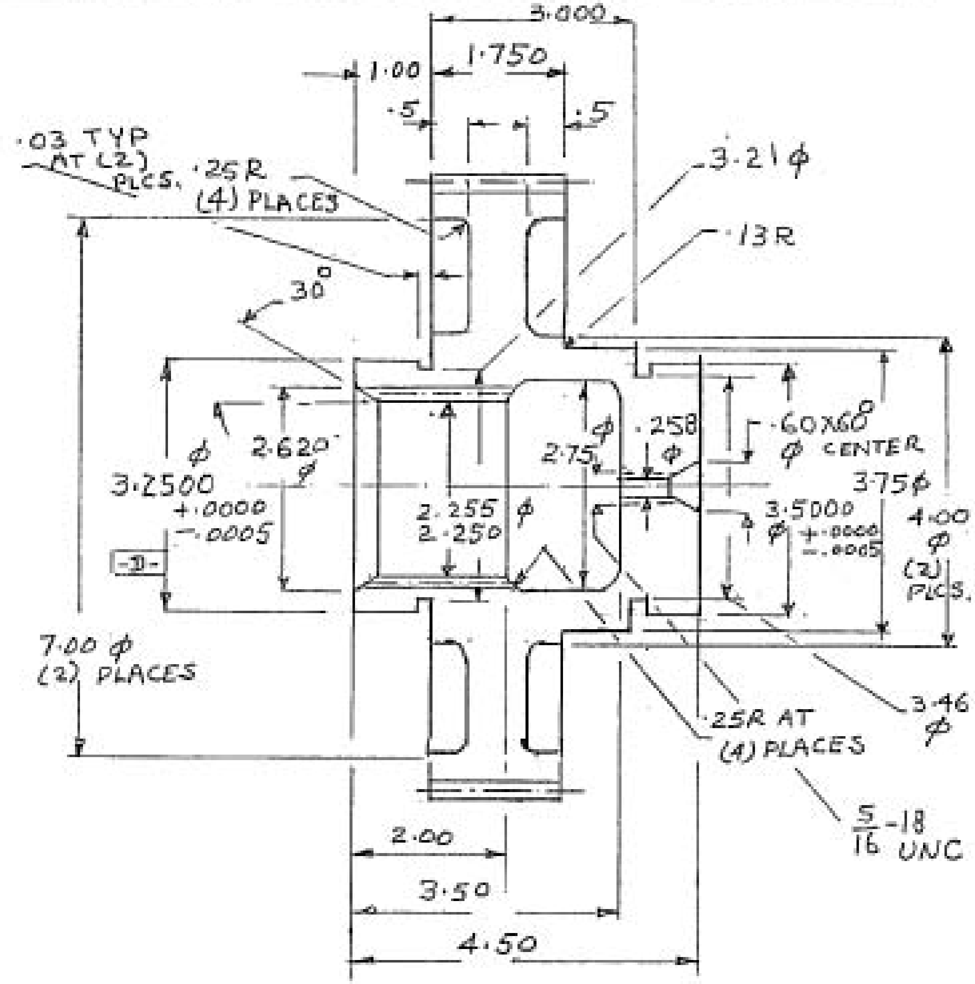
Figure 6-11

Note: Special attention has been paid to tolerance limits on linear dimensions during operations numbers 06 and 07. The overall length of the part is 4.620-4.630 inch, but for manufacturing purposes, to achieve the length of 1.7485-1.7515 inch, tolerances on the 4.625, 1.500, and 1.375-inch, dimensions have been kept to ± 0.0005 inch. Thus the cumulative dimension for 1.750 ± 0.0015 = 4.625 ± 0.0005 − 1.375 ± 0.0005 − 1.500 ± 0.0005 inch.

Part PHD-5

The outside diameter of the part shown in the sketch in SK-PHD-5 in Fig. 5-12, is 8.097 inch. Cold rolled steel of 5-1/4 inches diameter, to specification 9310, in the annealed condition is appropriate for its manufacture. The sequence of operations is as follows:

1. Cut (preferably with a circular saw) blanks of 4-11/16 inch width, which will give a machining allowance of approximately 0.094 inch per side. Reciprocating saws generally do not cut square, so a liberal allowance of 0.094 inch is recommended.
2. Chucking on the 5-1/4-inch diameter, rough turn on a CNC machine to dimensions on the sketch in SK-PHD-5 (Fig. 5-12). Here, the 3.799-3.800-inch diameter has been provided with a 0.001-inch tolerance because, for the next operation, the part will be chucked on this diameter.
3. Chucking on the 3.800-inch diameter, rough turn to dimensions in sketch number 03. The inner recessed 2.75-inch diameter clearance area will be finished here so that it does not have to be machined again in subsequent operations.
4. Stress relieve at 1500 degrees F, furnace cool to 760 degrees F, and cool in air.
5. Sand blast to remove scale.
6. Finish turn on one side to drawing dimensions, leaving grinding allowance on outside diameter; internal diameter of spline, and bearing journals. This operation is preferably done on a CNC machine.
7. CNC turn to dimensions in sketch number 07.
8. Copper plate all over 0.0003 inch thick.
9. Hob outside teeth leaving 0.005-inch grinding allowance on each flank.
10. De-burr outside of gear portion near end faces.



INTERNAL SPLINE DATA	
NUMBER OF TEETH	28
DIA. PITCH	12/24
PRESSURE ANGLE	30°
MAJOR DIA	2.4963
FORM DIA MIN	2.4214
PITCH DIA REF.	2.333
FILLET ROOT SIDE FIT	

NOTES

1. MATERIAL 9310 STEEL
2. CARBURIZE GEAR TEETH, DEEP FREEZE & TEMPER PART.
3. DO NOT CARBURIZE TOP LANDS OR END FACES OF GEAR TEETH.
   SURFACE HARDNESS ON 30N SCALE 77-81
   CORE HARDNESS 34-44 R'c)
   DEPTH OF HARDNESS .024-.034
4. M.P.I & NITAL ETCH ESSENTIAL

CARBURIZED GEAR

PHD-5

Figure 5-12

11. Shape internal spline teeth leaving 0.005-inch grinding allowance on each flank.
12. De-burr faces of spline teeth.
13. Carburize part at 1700 degrees F to 0.035 ± 0.005 inch depth of carbon. Furnace cool to 1500 degrees F, and air-cool to room temperature.
14. Sub-critically anneal at 1150 degrees F for two hours in air.
15. Harden at 1500 degrees F for one hour in an endothermic atmosphere, quenching in oil.
16. Freeze at minus 120 degrees F for one hour. Thaw at room temperature.
17. Temper at 300 degrees F for four hours in air.
18. Remove copper plate electrolytically.
19. Blanchard-grind both sides removing approx.0.005 inch from each side.
20. Chuck on 3.270-inch diameter, true ground face, grind gear outside diameter to 8.090-8.097 -inch diameter and grind 3.2500-inch diameter.
21. Chucking on 3.2500-inc diameter, grind 3.5000-inch diameter.
22. Chucking on 3.500-inch diameter, grind internal diameter to 2.254-2.255 inch for manufacturing purposes.
23. Locating part on internal spline ground diameter (preferably on a hydraulic arbor) grind gear teeth.
24. Chucking on 3.500-inch ground diameter, grind internal spline teeth using formed Borazon grinding wheel.
25. Check spline dimensions.
26. Nital etch.
27. Inspect all dimensions.
28. Apply rust preventive.
29. Apply identification tag.
30. Place in stock.

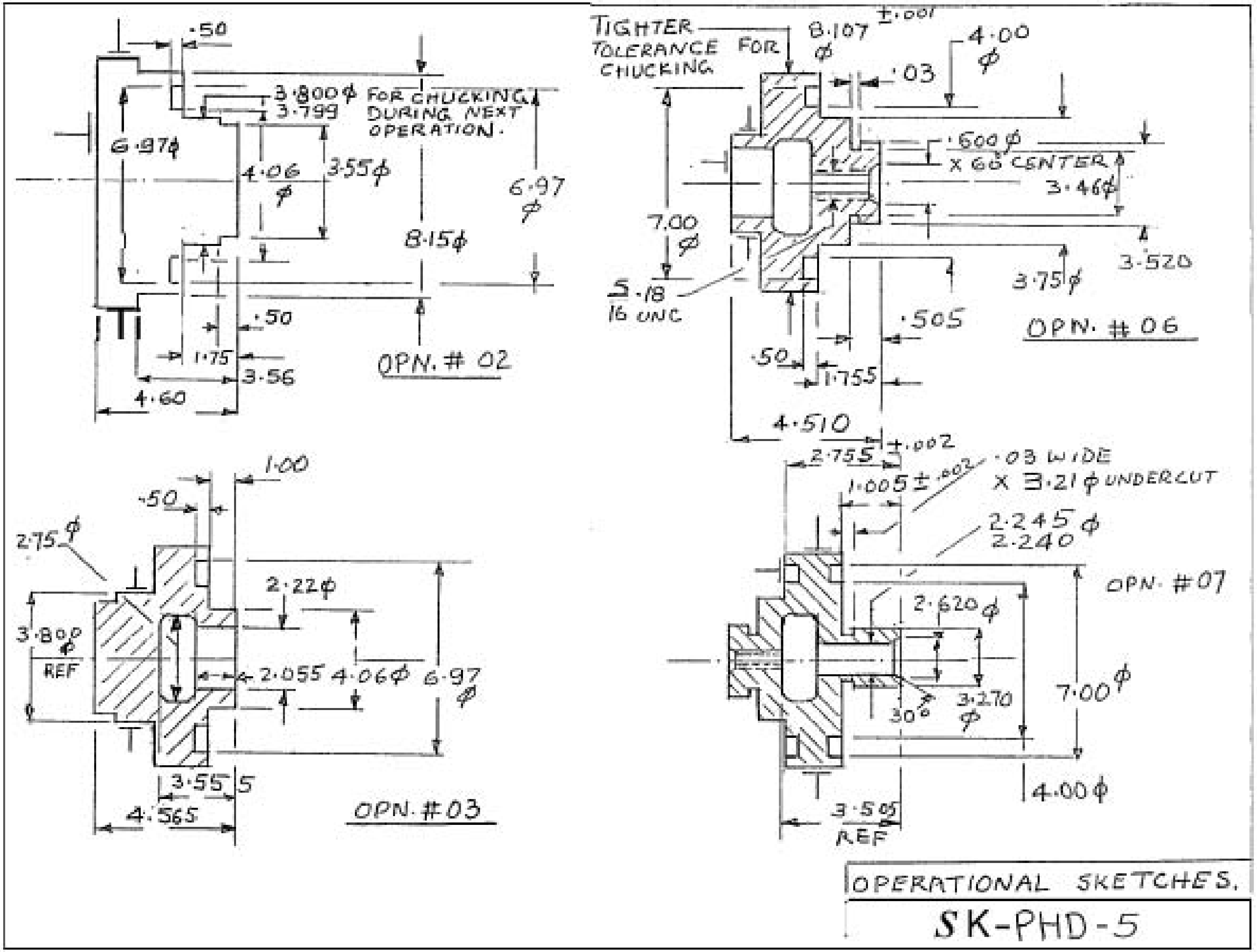

3.800 ϕ 3.799 FOR CHUCKING DURING NEXT OPERATION.
6.97 ϕ
4.06 ϕ
3.55 ϕ
8.15 ϕ
6.97 ϕ
.50
1.75
3.56
4.60
OPN. # 02
TIGHTER TOLERANCE FOR CHUCKING
8.107 ϕ ±.001
4.00 ϕ
.03
.600 ϕ X 60 CENTER
3.46 ϕ
7.00 ϕ
3.520
3.75 ϕ
5/16-18 UNC
.505
.50
1.755
4.510
OPN. # 06
1.00
.50
2.75 ϕ
2.22 ϕ
3.800 ϕ REF
2.055
4.06 ϕ
6.97 ϕ
3.555
4.565
OPN. # 03
2.755 ±.002
.03 WIDE X 3.21 ϕ UNDERCUT
1.005 ±.002
2.245 ϕ 2.240
OPN. # 07
2.620 ϕ
3.270 ϕ
30°
7.00 ϕ
4.00 ϕ
3.505 REF
OPERATIONAL SKETCHES.
SK-PHD-5

Figure 5-18

Part PHO-6

SK-PHD-6, shown in Fig. 5-14, gives major dimensions of a forging, from which Part PHD-6 can be produced. If the forging has not been normalized, apply the following heat-treatment procedure:

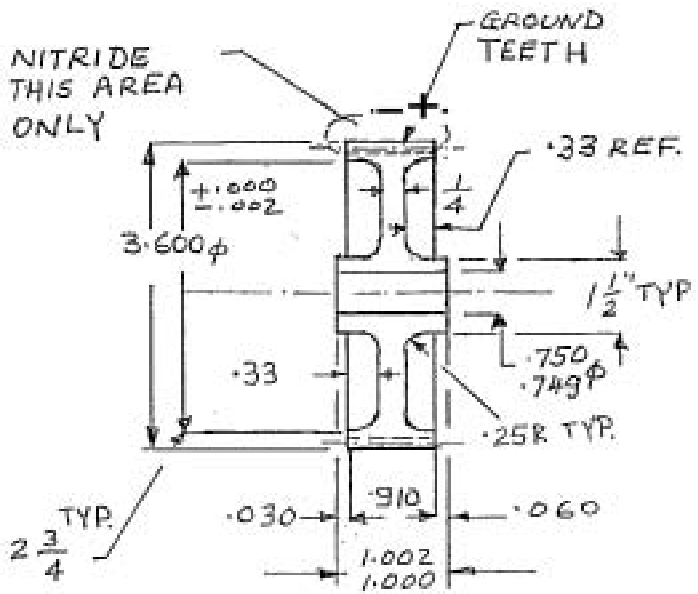
1. Normalize at 1600-1650 degrees F.
2. Cool to 1225 degrees F.
3. Equalize at 1225 degrees F for minimum of 12 hours.
4. Cool in furnace to 1150 degrees F.
5. Remove from furnace and air cool.
6. Hardness expected, 187-229 Brinnell.

The sequence of manufacturing operations to produce this part is:

1. Rough turn one side on CNC machine.
2. Chucking on previous partially-turned, 3.63-inch-diameter, turn second side.
3. Stress relieve at 950-1150 degrees F, holding at this temperature for two hours, and air cool.
4. Harden at 1500-1550 degrees F, quench in oil and then in air. Temper at 1025 degrees F for minimum of 2 hours.
5. Finish turn per sketch, using CNC lathe.
6. Finish turn on second side.
7. Copper plate 0.0003 inch thick all over.
8. Hob teeth leaving 0.005-inch grinding allowance on flanks.
9. Grind teeth to AGMA Quality number 14 using hydrauli- arbor.
10. Nitride at 975 degrees F for 48 hours.
11. Remove copper electrolytically.
12. Inspect all dimensions.
13. Place in stock.

GEAR DATA

VU
DI
A



NOTES

1. MATERIAL 4340 FORGING
NORMALIZED AT 1600-1650°F
2. NITRIDE TEETH ONLY.
CASE HARDNESS R'C' 45 MIN.
CORE HARDNESS 32-36
CASE DEPTH .012-.018
GEAR FACES & REST OF BLANK
TO HAVE 32-36 R'C'

NITRIDED GEAR
PHD-6

Figure 5-14

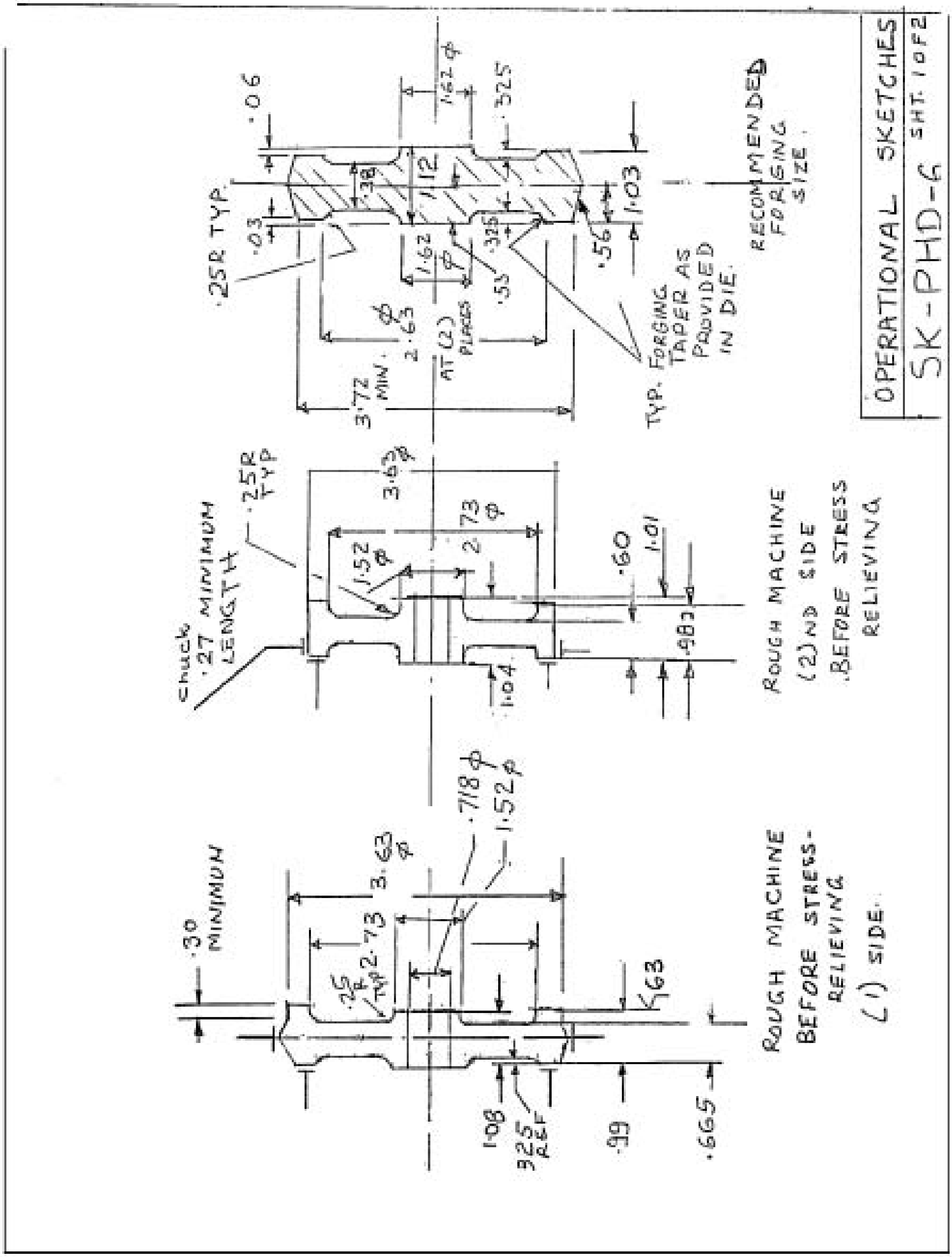

OPERATIONAL SKETCHES
SK-PHD-6
SHT. 1 OF 2
RECOMMENDED FORGING SIZE
TYP. FORGING TAPER AS PROVIDED IN DIE
ROUGH MACHINE (2)ND SIDE BEFORE STRESS RELIEVING
ROUGH MACHINE BEFORE STRESS-RELIEVING (1) SIDE
.27 MINIMUM LENGTH
.30 MINIMUM

Figure 5-15

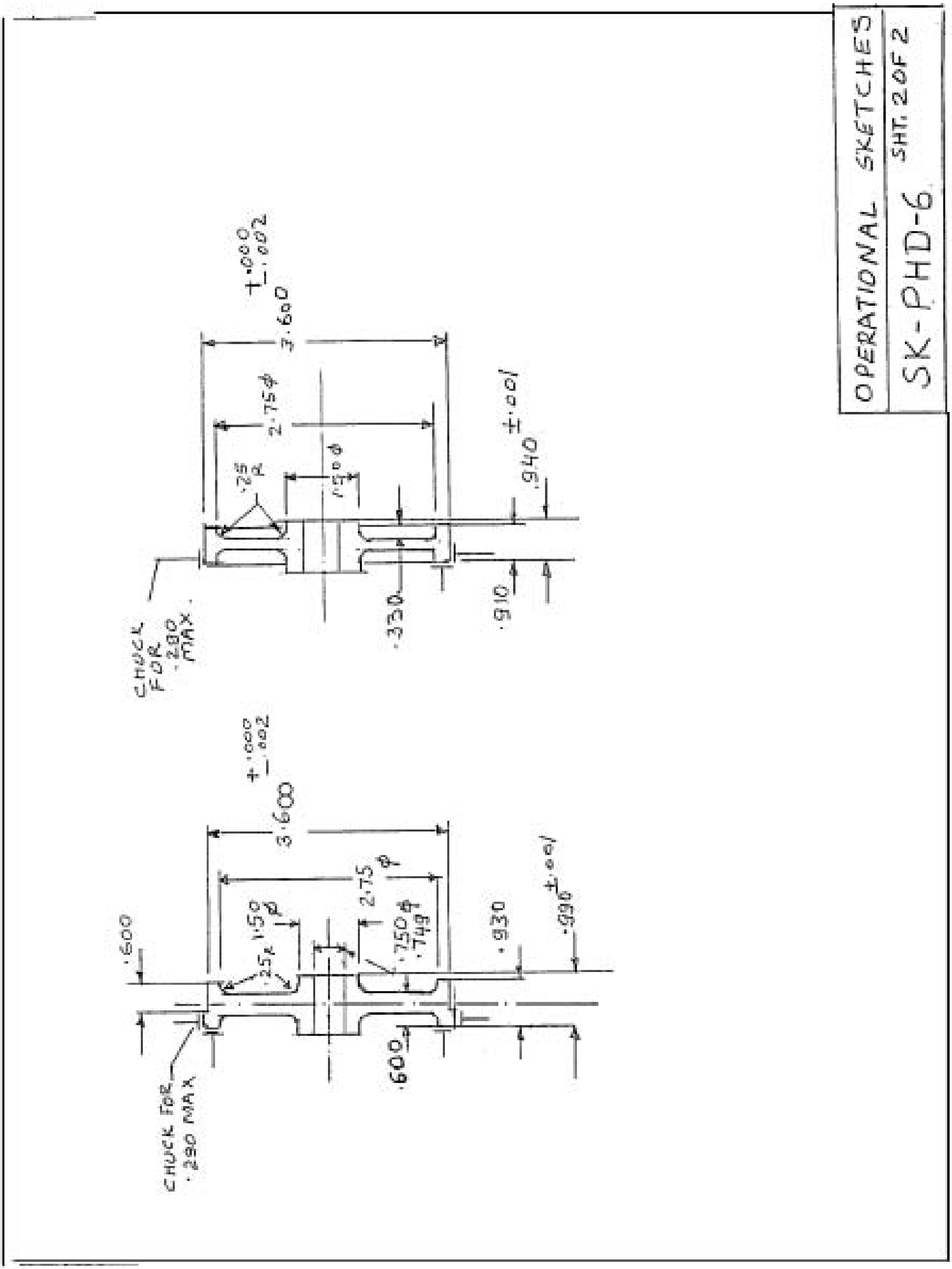

OPERATIONAL SKETCHES
SK-PHD-6
SHT. 2 OF 2
CHUCK FOR .280 MAX.
CHUCK FOR .290 MAX

Figure 5-16

Chapter 6

CHECKING OF GEAR SIZE

In the USA, gear size is measured by means of precision-ground wires placed in diametrically-opposite tooth spaces of a particular gear. For measuring gears with odd numbers of teeth, the wires are placed in the space next to the nearest diametrically opposite tooth as shown in Fig. 6-1.

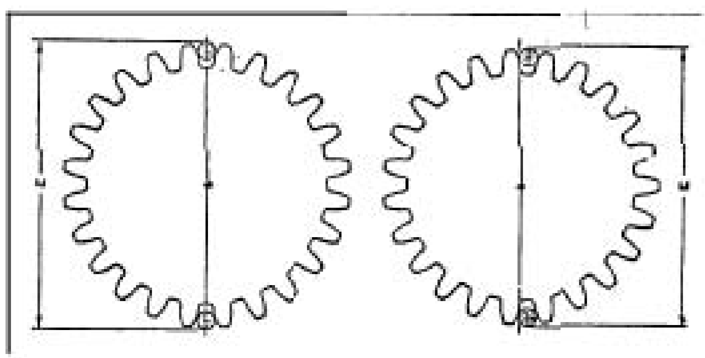


Figure 6-1 Checking of grear size

Gear Measurement System

The majority of gear engineers and shop personnel in the **USA** use the Van Keuren gear measuring system, which was first published in **1937.** This system is fully explained in Van Keuren's Handbook number **37**, titled Precision Measuring Tools, published by the Van Keuren **Company, 176** Waltham Street, Watertown, MA 02172.

For normal standard gears, the wire size for a specific dp is selected from Table numbers 7 and 8, which are reproduced in Chapter 2 as Table **2-3).**

The measurements over wires can be calculated by:

1. Calculating manually as in Table 6-6.
2. Writing a calculation program for a computer.
3. Purchasing a commercially available gear calculation program like the GCP2 available from Ash Gear & Supply Co. A description of this program is given in Table 6-1.
4. In Tables 6-3 and 6-4, for 14-1/2- and 20-degree pressure angles, Van Keuren Co. has tabulated measurements over wires for odd and even numbers of teeth. The measurements are for standard gears only. In these tables it is assumed that the gear tooth thickness is equal to half the normal circular pitch. Figures in the tables are to be divided by the diametral pitch. In practice, gear teeth are always thinned by some amount so that the gears have some backlash, (i.e., they do not run tight). The amount of thinning has to be multiplied by a factor **K** given in Table 6-5.

- **Reduction in Measurement = K x amount by which teeth are thin**
- **Increase in Measurement = K x amount by which teeth are thick**
- **The K factor is also useful when measurements are made over wires for finish-hobbed teeth for shaving and grinding. Shaving and grinding allowances must be made when special bobbing tools are ordered.**

Span Measurements

For span measurements in the inch system, refer to sheets G-21, G-22 and G-23 of Ash Gear Co.'s Catalog number 2000. Disc type micrometers will give better accuracy than a vernier caliper.

GEAR CALCULATION PROGRAM

7 POWERFUL PROGRAMS IN ONE:

- INTERNAL - EXTERNAL - SPUR AND HELICAL GEARS
WORM GEARS - RACK AND WORMS
STRAIGHT SIDED AND INVOLUTE SPLINES

CALCULATES ALL YOUR GEAR DATA

Using your existing tooling, program will calculate the root produced when tooth thickness is achieved

GCP 2

Calculates both operating & generating data on normal & transverse planes

Lets you change wire size

Calculates T.I.F. and roll angles

Matches by Base Pitch

Calculates land at major

GCP 2

Span measurements

Involute of pressure angles (both operating and generating)

Point width of tool for racks, worms and straight sided splines

GCP 2

Base tooth thickness

Simulates two gears in tight mesh, internal, external spur or helical

Apex of gear

Operating pitch and pressure angles

Helix angle at any diameter

Even checks for "Trimming" of teeth on internals gears

Table 6-1

over-pin measurements for even numbers of teeth

(All measurements are in inches)

No. of Teeth	14½°	20°	No. of Teeth	14½°	20°	No. of Teeth	14½°	20°
6	8.2846	8.3032	66	68.4933	68.4369	126	128.5198	128.4493
8	10.3160	10.3271	68	70.4948	70.4376	128	130.5203	130.4496
10	12.3399	12.3445	70	72.4963	72.4383	130	132.5208	132.4498
12	14.3590	14.3578	72	74.4977	74.4390	132	134.5213	134.4500
14	16.3746	16.3683	74	76.4990	76.4396	134	136.5217	136.4502
16	18.3877	18.3768	76	78.5002	78.4402	136	138.5221	138.4504
18	20.3989	20.3840	78	80.5014	80.4408	138	140.5226	140.4506
20	22.4087	22.3900	80	82.5026	82.4413	140	142.5230	142.4508
22	24.4172	24.3952	82	84.5037	84.4418	142	144.5234	144.4510
24	26.4247	26.3997	84	86.5047	86.4423	144	146.5238	146.4512
26	28.4314	28.4036	86	88.5057	88.4428	146	148.5242	148.4513
28	30.4374	30.4071	88	90.5067	90.4433	148	150.5246	150.4515
30	32.4429	32.4102	90	92.5076	92.4437	150	152.5250	152.4516
32	34.4478	34.4130	92	94.5085	94.4441	152	154.5254	154.4518
34	36.4523	36.4155	94	96.5094	96.4445	154	156.5257	156.4520
36	38.4565	38.4178	96	98.5102	98.4449	156	158.5261	158.4521
38	40.4603	40.4198	98	100.5110	100.4453	158	160.5264	160.4523
40	42.4638	42.4217	100	102.5118	102.4456	160	162.5267	162.4524
42	44.4671	44.4234	102	104.5125	104.4460	162	164.5270	164.4526
44	46.4701	46.4250	104	106.5132	106.4463	164	166.5273	166.4527
46	48.4729	48.4265	106	108.5139	108.4466	166	168.5276	168.4528
48	50.4756	50.4279	108	110.5146	110.4469	168	170.5279	170.4529
50	52.4781	52.4292	110	112.5152	112.4472	170	172.5282	172.4531
52	54.4804	54.4304	112	114.5159	114.4475	180	182.5297	182.4537
54	56.4826	56.4315	114	116.5165	116.4478	190	192.5310	192.4542
56	58.4847	58.4325	116	118.5171	118.4481	200	202.5321	202.4548
58	60.4866	60.4335	118	120.5177	120.4484	300	302.5395	302.4579
60	62.4884	62.4344	120	122.5182	122.4486	400	402.5434	402.4596
62	64.4902	64.4352	122	124.5188	124.4489	500	502.5458	502.4606
64	66.4918	66.4361	124	126.5193	126.4491	∞	(N+2).5558	(N+2).4646

Courtesy of The Van Keuren Company

For pitches other than 1 DP, divide by the desired diametral pitch.

All measurements are based on $\frac{1.728''}{DP}$ diameter pins.

Table 6-2

over-pin measurements for even numbers of teeth

(All measurements are in inches)

No. of Teeth	14½°	20°	No. of Teeth	14½°	20°	No. of Teeth	14½°	20°
6	8.2846	8.3032	66	68.4933	68.4369	126	128.5198	128.4493
8	10.3160	10.3271	68	70.4948	70.4376	128	130.5203	130.4496
10	12.3399	12.3445	70	72.4963	72.4383	130	132.5208	132.4498
12	14.3590	14.3578	72	74.4977	74.4390	132	134.5213	134.4500
14	16.3746	16.3683	74	76.4990	76.4396	134	136.5217	136.4502
16	18.3877	18.3768	76	78.5002	78.4402	136	138.5221	138.4504
18	20.3989	20.3840	78	80.5014	80.4408	138	140.5226	140.4506
20	22.4087	22.3900	80	82.5026	82.4413	140	142.5230	142.4508
22	24.4172	24.3952	82	84.5037	84.4418	142	144.5234	144.4510
24	26.4247	26.3997	84	86.5047	86.4423	144	146.5238	146.4512
26	28.4314	28.4036	86	88.5057	88.4428	146	148.5242	148.4513
28	30.4374	30.4071	88	90.5067	90.4433	148	150.5246	150.4515
30	32.4429	32.4102	90	92.5076	92.4437	150	152.5250	152.4516
32	34.4478	34.4130	92	94.5085	94.4441	152	154.5254	154.4518
34	36.4523	36.4155	94	96.5094	96.4445	154	156.5257	156.4520
36	38.4565	38.4178	96	98.5102	98.4449	156	158.5261	158.4521
38	40.4603	40.4198	98	100.5110	100.4453	158	160.5264	160.4523
40	42.4638	42.4217	100	102.5118	102.4456	160	162.5267	162.4524
42	44.4671	44.4234	102	104.5125	104.4460	162	164.5270	164.4526
44	46.4701	46.4250	104	106.5132	106.4463	164	166.5273	166.4527
46	48.4729	48.4265	106	108.5139	108.4466	166	168.5276	168.4528
48	50.4756	50.4279	108	110.5146	110.4469	168	170.5279	170.4529
50	52.4781	52.4292	110	112.5152	112.4472	170	172.5282	172.4531
52	54.4804	54.4304	112	114.5159	114.4475	180	182.5297	182.4537
54	56.4826	56.4315	114	116.5165	116.4478	190	192.5310	192.4542
56	58.4847	58.4325	116	118.5171	118.4481	200	202.5321	202.4548
58	60.4866	60.4335	118	120.5177	120.4484	300	302.5395	302.4579
60	62.4884	62.4344	120	122.5182	122.4486	400	402.5434	402.4596
62	64.4902	64.4352	122	124.5188	124.4489	500	502.5458	502.4606
64	66.4918	66.4361	124	126.5193	126.4491	∞	(N+2).5558	(N+2).4646

Courtesy of The Van Keuren Company

For pitches other than 1 DP, divide by the desired diametral pitch.

All measurements are based on $\frac{1.728''}{DP}$ diameter pins.

Table 6-3

over-pin measurements for odd numbers of teeth

(All measurements are in inches)

No. of Teeth	14½°	20°	No. of Teeth	14½°	20°	No. of Teeth	14½°	20°
5	6.9936	7.0153	65	67.4734	67.4173	125	127.5096	127.4392
7	9.1116	9.1260	67	69.4755	69.4186	127	129.5103	129.4396
9	11.1829	11.1905	69	71.4775	71.4198	129	131.5109	131.4400
11	13.2317	13.2332	71	73.4795	73.4210	131	133.5115	133.4404
13	15.2677	15.2639	73	75.4813	75.4221	133	135.5121	135.4408
15	17.2957	17.2871	75	77.4830	77.4232	135	137.5127	137.4411
17	19.3182	19.3053	77	79.4847	79.4242	137	139.5133	139.4414
19	21.3368	21.3200	79	81.4863	81.4252	139	141.5139	141.4418
21	23.3524	23.3321	81	83.4877	83.4262	141	143.5144	143.4421
23	25.3658	25.3423	83	85.4892	85.4271	143	145.5149	145.4424
25	27.3774	27.3511	85	87.4906	87.4279	145	147.5154	147.4427
27	29.3876	29.3586	87	89.4919	89.4287	147	149.5159	149.4430
29	31.3966	31.3652	89	91.4932	91.4295	149	151.5164	151.4433
31	33.4047	33.3710	91	93.4944	93.4303	151	153.5169	153.4435
33	35.4119	35.3761	93	95.4956	95.4310	153	155.51'14	155.4438
35	37.4185	37.3807	95	97.4967	97.4317	155	157.5179	157.4440
37	39.4245	39.3849	97	99.4978	99.4323	157	159.5183	159.4443
39	41.4299	41.3886	99	101.4988	101.4329	159	161.5188	161.4445
41	43.4348	43.3920	101	103.4998	103.4335	161	163.5192	163.4448
43	45.4394	45.3951	103	105.5008	105.4341	163	165.5196	165.4450
45	47.4437	47.3980	105	107.5017	107.4346	165	167.5200	167.4453
47	49.4477	49.4007	107	109.5026	109.4352	167	169.5204	169.4455
49	51.4514	51.4031	109	111.5035	111.4357	169	171.5208	171.4457
51	53.4547	53.4053	111	113.5044	113.4362	171	173.5212	173.4459
53	55.4579	55.4074	113	115.5052	115.4367	181	183.5230	183.4469
55	57.4609	57.4093	115	117.5060	117.4372	191	193.5246	193.4478
57	59.4637	59.4111	117	119.5068	119.4376	201	203.5260	203.4487
59	61.4664	61.4128	119	121.5075	121.4380	301	303.5355	303.4538
61	63.4689	63.4144	121	123.5082	123.4384	401	403.5404	403.4565
63	65.4712	65.4159	123	125.5089	125.4388	501	503.5433	503.4581

Courtesy of The Van Keuren Company

For pitches other than 1 DP, divide by the desired diametral pitch.

All measurements are based on $\frac{1.728''}{DP}$-diameter pins.

Table 6-4

change factors (K)

N even, $K = \frac{\cos \phi_t}{\sin \phi_w}$ N odd, $K = \frac{\cos \phi_t}{\sin \phi_w} \cos \frac{90^\circ}{N}$

No. Teeth	14½°	20°	No. Teeth	14½°	20°
5	1.90	1.67	37	3.08	2.43
6	2.09	1.83	38	3.10	2.44
7	2.11	1.84	39	3.11	2.45
8	2.24	1.94	40	3.12	2.45
9	2.27	1.95	41	3.13	2.46
10	2.36	2.01	42	3.14	2.46
11	2.39	2.03	43	3.15	2.47
12	2.47	2.09	44	3.17	2.47
13	2.49	2.10	45	3.18	2.48
14	2.55	2.14	46	3.19	2.48
15	2.58	2.15	47	3.20	2.49
16	2.63	2.19	48	3.21	2.49
17	2.65	2.20	49	3.21	2.50
18	2.70	2.23	50	3.22	2.50
19	2.72	2.25	60	3.30	2.54
20	2.76	2.26	70	3.36	2.56
21	2.78	2.28	80	3.41	2.58
22	2.81	2.29	90	3.45	2.60
23	2.83	2.30	100	3.48	2.61
24	2.86	2.32	110	3.51	2.62
25	2.88	2.33	120	3.54	2.63
26	2.90	2.34	130	3.56	2.64
27	2.92	2.35	140	3.58	2.65
28	2.94	2.36	150	3.59	2.65
29	2.96	2.37	160	3.61	2.66
30	2.98	2.38	170	3.62	2.66
31	2.99	2.39	180	3.63	2.67
32	3.01	2.40	190	3.64	2.67
33	3.03	2.41	200	3.65	2.68
34	3.04	2.41	300	3.72	2.70
35	3.06	2.42	400	3.75	2.71
36	3.07	2.43	500	3.78	2.72

K factors are approximate and are satisfactory only for small changes in tooth thickness.

Table 6-5

PROCEDURE FOR COMPUTING MEASUREMENT OVER PINS FOR EXTERNAL SPUR & HELICAL GEARS

Measurement of spur or helical gears over Pins is an essential part of gear inspection. It determines the exact tooth thickness of a gear. The computation of a Pin measurement is based on the pin, or wire as it is sometimes called, contacting the active tooth profile within the immediate vicinity of the pitch line.

The Pin Diameter for 1 NDP is 1.728 in. It is the accepted constant for standard external gears. All other Measuring Pin diameters (Symbol G) can be derived by simply dividing this constant by the required normal diametral pitch.

The formulas given here for computing the Measurement over Pins (Me or Mo) can be used for external spur and helical gears of any pressure angle and are further simplified by the proper use of the format shown in Figure 2.

For helical gears, the helix angle must be either known or computed prior to the determination of the Measurement over Pins. To compute the correct helix angle (ψ), the following formula is used:

$$\cos\psi = \frac{N_p + N_g}{2 \times P_n \times C}$$

As most gear sets require backlash to avoid a tight mesh and provide free rotation, it is necessary to thin the tooth thickness by an amount shown in Figure 1. This data is necessary for Steps 36 through 38 of format in Figure 2.

With the above information available, we are now ready to compute the Measurement over Pins.

$$\text{Inv}\,\phi_w = \frac{T}{D} + \frac{G}{Db} + \text{Inv}\,\phi - \frac{\pi}{N}$$

$$D_w = \frac{Db}{\cos\phi_w}$$

$$Me = D_w + G$$

$$Mo = D_w \times \cos\frac{90^\circ}{N} + G$$

Using a 35-tooth/72-tooth, 10 normal diametral pitch combination as an example, the procedure would be as shown in Figure 2.

LEGEND

- N_p = Number of Teeth in Pinion
- N_g = Number of Teeth in Gear
- P_n = Normal Diametral Pitch
- C = Center Distance
- D = Pitch Diameter
- ψ = Helix Angle
- Db = Base Diameter
- D_w = Diameter to Center of Wires
- ϕ_n = Normal Pressure Angle
- ϕ = Transverse Pressure Angle at D
- ϕ_w = Transverse Pressure Angle at D_w
- inv ϕ = Involute of ϕ
- inv ϕ_w = Involute of ϕ_w
- G = Diameter of Measuring Pin
- Me = Measurement over Pins external even number of teeth
- Mo = Measurement over Pins external odd number of teeth.
- T = Transverse Circular Tooth Thickness.

Recommended Minimum Total Backlash

NORMAL D. P.	TOTAL BACKLASH	NORMAL D. P.	TOTAL BACKLASH
1	.025-.040	5	.006-.009
1.5	.018-.027	6	.005-.008
2	.014-.020	7	.004-.007
2.5	.011-.016	8 & 9	.004-.006
3	.009-.014	10-13	.003-.005
4	.007-.011	14-32	.002-.004

FIGURE 1

			Pinion	Gear
1	HELIX ANGLE	ψ	13° 24' 43"	
2	COSINE (1)	$\cos\psi$	.9727275	
3	TANGENT (1)	$\tan\psi$	.2384537	
4	NORMAL DIAMETRAL PITCH	P_n	10	
5	TRANSVERSE PITCH (4) × (2)	P	9.7272754	
6	NUMBER OF TEETH	N	35	72
7	PITCH DIAMETER $\frac{(6)}{(5)}$	D	3.5981298	7.4018672
8	LEAD $\frac{3.1415926 \times (7)}{(3)}$	L	47.4067935	97.5184339
9	NORMAL PRESSURE ANGLE	ϕ_n	20°	
10	TANGENT (9)	$\tan\phi_n$	.3639702	
11	$\frac{(10)}{(2)}$	$\tan\phi$	.3741748	
12	TRANSVERSE PRESSURE ANGLE (11)°	ϕ	20° 30' 52"	
13	COSINE (12)	$\cos\phi$	.9365833	
14	BASE DIAMETER (7) x (13)	Db	3.3699504	6.9321696
15	BASE RADIUS .5 x (14)	Dbr	1.6849752	3.4660848
16	(12) IN DECIMAL DEGREES	ϕ	20.51411	
17	INVOLUTE (See Inv. Tables)	inv ϕ	.0161274	
18	TRANSVERSE TOOTH THICKNESS $\frac{1.5708}{(5)}$	T	.1614840	
19	$\frac{3.1415926}{(6)}$	$\frac{\pi}{N}$	.0897597	.0436332
20	PIN DIAMETER $\frac{1.728}{(4)}$	G	.1728	
21	SINE (9)	$\sin\phi_n$	.3420201	
22	SINE (12)	$\sin\phi$	.3504135	
23	COSINE BASE HELIX $\frac{(21)}{(22)}$	$\cos\psi b$	.9737636	
24	$\frac{(20)}{(23)}$ IMAGINARY PIN DIA.	G'	.1774557	
25	$\frac{(18)}{(7)}$	$\frac{T}{D}$	.0448797	.0218166
26	$\frac{(24)}{(14)}$	$\frac{G'}{Db}$	.0525395	.0255400
27	(25) + (26) + (17) − (19)	inv ϕ_w	.0237871	.0198508
28	(27) IN DEGREES (See Inv. Tables)	ϕ_w	23° 14' 10"	21° 55' 43"
29	COSINE (28)	$\cos\phi_w$	.9188087	.9276499
30	SINE (28)	$\sin\phi_w$	.3945211	.3734311
31	$\frac{(14)}{(29)}$ DIM TO CTR OF PINS	Dw-even	3.6674367	7.4731527
32	COS $\frac{90°}{(6)}$ (Odd only)	$\cos\frac{90°}{N}$	.9989931	—
33	(31) x (32) (Odd only)	Dw-odd	3.6637239	—
34	M $\frac{\text{EVEN}}{\text{ODD}}$ (33) + (20)	Me / Mo	3.8365	7.6460
35	CHANGE FACTOR "K" $\frac{(19)}{(30)}$	K	2.174	2.508
36	NORMAL TOTAL BACKLASH BETWEEN MATES		MIN .003 — MAX .005	
37	$\frac{(35) \times \frac{1}{2}(36\ min)}{(2)}$	ΔM	.0037	.0037
38	$\frac{(35) \times \frac{1}{2}(36\ min)}{(2)}$	ΔM	.0061	.0061
39	M max (34) — (37)		3.8328	7.6421
40	M min (34) — (38)		[illegible]	[illegible]

FIGURE 2

Table 6-6

Chapter 7

AGMA QUALITY NUMBERS

Most of the gear design engineers in the **USA** specify an **AGMA** Quality Number on the print.

AGMA Quality tolerances on run-out, Total Composite Error (TCE) and Tooth to Tooth Composite Error (TTCE) are given in Tables 7-1, 7-2 and **7-3**, and the concepts of TCE and TTCE. are further appropriately described in Table 7-4.

Gleason has published a very practical method of machining methods for different **AGMA** and DIN (Deutsche Industrie Normen) standards. Table 7-5 can be used as a guide. The gear quality often depends upon the condition of the tool.

COARSE- PITCH GEAR TOLERANCES

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	RUNOUT TOLERANCE – PITCH DIAMETER (INCHES)										PITCH TOLERANCE – PITCH DIAMETER (INCHES)									
		3/4	1 1/2	3	6	12	25	50	100	200	400	3/4	1-1/2	3	6	12	25	50	100	200	400
3	1/2					788.2	938.6	1106.9	1305.5	1539.6	1815.7										
	1				477.8	563.5	671.1	791.4	933.4	1100.8	1298.1										
	2			289.7	341.6	402.9	479.8	565.9	667.4	787.1	928.2										
	4			207.1	244.3	288.1	343.1	404.6	477.2	562.7	663.7										
	8			148.1	174.7	206.0	245.3	289.3	341.2	402.4	474.5										
4	1/2					563.0	670.4	790.7	932.5	1099.7	1297.0										
	1				341.3	402.5	479.3	565.3	666.7	786.3	927.3										
	2			206.9	244.0	287.8	342.7	404.2	476.7	562.2	663.0										
	4			147.9	174.5	205.8	245.0	289.0	340.8	102.0	474.1										
	8			105.8	124.8	147.1	175.2	206.6	243.7	287.4	338.9										
5	1/2					402.1	478.9	564.8	666.1	785.5	926.4										
	1				243.8	287.5	342.4	403.8	476.2	561.6	662.4										
	2			147.8	174.3	205.6	244.8	288.7	340.5	401.6	473.6										
	4		89.6	105.7	124.6	147.0	175.0	206.4	243.5	287.1	338.6										
	8		64.1	75.6	89.1	105.1	125.1	147.6	174.1	205.3	242.1										
6	1/2					287.2	342.1	403.4	475.8	561.1	661.7					38.4	43.7	49.4	55.9	63.2	71.4
	1				174.1	205.4	244.6	288.4	340.2	401.2	473.1				29.1	32.9	37.4	42.3	47.8	54.1	61.1
	2			105.6	124.5	146.8	174.9	206.2	243.2	286.8	338.3			22.0	24.8	28.1	32.0	36.2	41.0	46.3	52.3
	4		64.0	75.5	89.0	105.0	125.0	147.4	173.9	205.1	241.9		16.7	18.9	21.3	24.1	27.4	31.0	35.1	39.6	44.8
	8	38.8	45.8	54.0	63.6	75.1	89.4	105.4	124.3	146.6	172.9	12.6	14.3	16.1	18.2	20.6	23.5	26.6	30.0	33.9	38.4
	12	31.9	37.6	44.4	52.3	61.7	73.5	86.6	102.2	120.5	142.1	11.5	13.0	14.7	16.7	18.8	21.5	24.3	27.4	31.0	35.0
	20	24.9	29.4	34.6	40.8	48.2	57.4	67.7	79.8	94.1	111.0	10.3	11.6	13.1	14.9	16.8	19.1	21.6	24.5	27.6	31.3
7	1/2					205.2	244.3	288.1	339.8	400.8	472.7					27.0	30.8	34.8	39.3	44.5	50.3
	1				124.4	146.7	174.7	206.0	243.0	286.6	337.9				20.6	23.1	26.4	29.8	33.7	38.1	43.1
	2			75.4	88.9	104.9	124.9	147.3	173.7	204.9	241.6			15.5	17.5	19.8	22.6	25.5	28.8	32.6	36.9
	4		45.7	53.9	63.6	75.0	89.3	105.3	124.2	146.5	172.8		11.7	13.3	15.0	17.9	19.3	21.8	24.7	29.9	31.6
	8	27.7	32.7	38.5	45.5	53.6	63.9	75.3	88.8	104.7	123.5	8.9	10.1	11.4	12.9	14.6	16.5	18.7	21.1	23.9	27.0
	12	22.8	26.9	31.7	37.4	44.1	52.5	61.9	73.0	86.1	101.5	8.1	9.2	10.4	11.7	13.3	15.1	17.1	19.3	21.8	24.7
	20	17.8	21.0	24.7	29.2	34.4	41.0	48.3	57.0	67.2	79.3	7.2	8.2	9.3	10.5	11.8	13.5	15.2	17.2	19.6	22.0

Table 7-1

AGMA QUA CHAR

AGMA Quality Numbers

COARSE- PITCH GEAR TOLERANCES (CONTINUED)

Table 7-2

AGMA QUALITY CHART

AGMA Quality Numbers

RUNOUT TOLERANCE — PITCH DIAMETER (INCHES)

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	3/4	1-1/2	3	6	12	25	50	100	200	400
8	1/2					146.5	174.2	205.8	242.7	286.3	337.8
	1				88.8	104.6	124.6	147.2	173.6	204.7	241.4
	2			53.9	63.5	74.9	88.2	106.2	124.1	146.3	172.6
	4		32.7	38.5	45.4	53.6	63.6	75.2	88.7	104.6	123.4
	8	19.6	23.3	27.5	32.5	38.3	45.6	53.8	63.4	74.8	88.2
	12	16.3	19.2	22.6	26.7	31.5	37.5	44.2	52.1	61.5	72.5
	20	12.7	15.0	17.5	20.8	24.6	29.3	34.6	40.7	48.0	56.6
9	1/2					104.7	124.7	147.0	173.4	204.5	241.2
	1				63.5	74.8	89.1	105.1	124.0	146.2	172.4
	2			38.5	45.4	53.5	63.7	75.2	88.6	104.5	123.3
	4		23.3	27.5	32.4	38.3	45.6	53.7	63.4	74.7	88.1
	8	14.6	16.7	19.7	23.2	27.4	32.5	38.4	45.3	53.4	63.0
	12	11.6	13.7	16.2	19.1	22.5	26.8	31.6	37.2	43.9	51.8
	20	9.1	10.7	12.6	14.9	17.6	20.9	24.7	29.1	34.3	40.4
10	1/2					74.8	89.0	105.0	123.8	146.1	172.3
	1				45.3	53.5	63.7	75.1	88.5	104.4	123.2
	2			27.5	32.4	38.2	45.5	53.7	63.3	74.7	88.1
	4		16.7	19.6	23.2	27.3	32.5	38.4	45.3	53.4	63.0
	8	10.1	11.9	14.0	16.6	19.5	23.3	27.4	32.4	38.2	45.0
	12	8.3	9.8	11.5	13.6	16.1	19.1	22.6	26.6	31.4	37.0
	20	6.5	7.6	9.0	10.6	12.5	14.9	17.6	20.8	24.5	28.9
11	1/2					53.4	63.6	75.0	88.5	104.3	123.0
	1				32.4	38.2	45.5	53.6	63.2	74.6	88.0
	2			19.6	23.1	27.3	32.5	38.3	45.2	53.3	62.8
	4		11.9	14.0	16.6	19.5	23.2	27.4	32.3	38.1	45.0
	8	7.2	8.5	10.0	11.8	14.0	16.6	19.6	23.1	27.3	32.2
	12	5.9	7.0	8.2	9.7	11.5	13.7	16.1	19.0	22.4	26.4
	20	4.6	5.5	6.4	7.6	9.0	10.7	12.6	14.8	17.5	20.6

PITCH TOLERANCE — PITCH DIAMETER (INCHES)

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	3/4	1-1/2	3	6	12	25	50	100	200	400
8	1/2					19.5	21.7	24.5	27.7	31.3	35.4
	1				14.4	16.3	18.6	21.0	23.7	26.8	30.3
	2			10.9	12.3	14.0	15.9	18.0	20.3	23.0	26.0
	4		8.3	9.5	10.6	11.9	13.6	15.4	17.4	19.7	22.2
	8	6.3	7.1	8.0	9.0	10.2	11.7	13.2	14.9	16.8	19.0
	12	5.7	6.5	7.3	8.3	9.3	10.6	12.0	13.6	15.4	17.4
	20	5.1	5.8	6.5	7.4	8.3	9.5	10.7	12.1	13.7	15.5
9	1/2					13.4	15.3	17.3	19.5	22.1	24.9
	1				10.2	11.5	13.1	14.8	16.7	18.9	21.4
	2			7.7	8.7	9.8	11.2	12.7	14.3	16.2	18.3
	4		5.8	6.6	7.4	8.4	9.6	10.8	12.2	13.8	15.7
	8	4.4	5.0	5.6	6.4	7.2	8.2	9.3	10.5	11.9	13.4
	12	4.0	4.6	5.1	5.8	6.6	7.5	8.5	9.6	10.8	12.2
	20	3.6	4.1	4.6	5.2	5.9	6.7	7.6	8.5	9.7	10.9
10	1/2					9.6	10.8	12.3	13.7	15.6	17.6
	1				7.2	8.1	9.2	10.4	11.9	13.3	15.0
	2			5.4	6.1	6.9	7.9	8.9	10.1	11.4	12.9
	4		4.1	4.6	5.2	5.9	6.7	7.6	8.6	9.8	11.0
	8	3.1	3.5	4.0	4.5	5.1	5.8	6.5	7.4	8.3	9.4
	12	2.8	3.2	3.6	4.1	4.6	5.3	6.0	6.7	7.6	8.5
	20	2.5	2.9	3.2	3.7	4.1	4.7	5.3	6.0	6.8	7.7
11	1/2					6.8	7.6	8.6	9.7	10.9	12.4
	1				5.2	5.7	6.5	7.3	8.3	9.4	10.6
	2			3.9	4.3	4.9	5.6	6.3	7.1	8.0	9.1
	4		2.9	3.3	3.7	4.2	4.8	5.4	6.1	6.9	7.8
	8	2.2	2.5	2.8	3.2	3.6	4.1	4.6	5.2	5.9	6.6
	12	2.0	2.3	2.6	2.9	3.3	3.7	4.2	4.7	5.4	6.1
	20	1.8	2.0	2.3	2.6	2.9	3.3	3.7	4.2	4.8	5.4

PROFILE TOLERANCE — PITCH DIAMETER (INCHES)

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	3/4	1-1/2	3	6	12	25	50	100	200	400
8	1/2					42.8	47.7	53.1	59.1	65.7	73.1
	1				28.3	31.5	35.3	39.3	43.7	48.6	54.1
	2			18.8	21.0	23.3	26.1	29.0	32.3	36.0	40.0
	4		12.5	13.9	15.5	17.2	19.3	21.5	23.9	26.6	29.6
	8	8.3	9.3	10.3	11.5	12.8	14.3	15.9	17.7	19.7	21.9
	12	7.0	7.8	8.6	9.6	10.7	12.0	13.3	14.8	16.5	18.4
	20	5.6	6.2	6.9	7.7	8.6	9.6	10.7	11.9	13.2	14.7
9	1/2					30.4	34.1	37.9	42.2	46.9	52.2
	1				20.2	22.5	25.2	28.1	31.2	34.7	38.6
	2			13.5	15.0	16.7	18.6	20.7	23.1	25.7	28.6
	4		8.9	10.0	11.1	12.3	13.8	15.3	17.1	19.0	21.1
	8	5.9	6.6	7.4	8.2	9.1	10.2	11.4	12.6	14.1	15.6
	12	5.0	5.6	6.2	6.9	7.8	8.6	9.5	10.6	11.8	13.1
	20	4.0	4.4	4.9	5.5	6.1	6.8	7.6	8.5	9.4	10.5
10	1/2					21.7	24.1	27.1	30.1	33.5	37.3
	1				14.5	16.1	18.0	20.0	22.3	24.8	27.6
	2			9.6	10.7	11.9	13.3	14.8	16.5	18.3	20.4
	4		6.4	7.1	7.9	8.8	9.9	11.0	12.2	13.6	15.1
	8	4.2	4.7	5.3	5.9	6.5	7.3	8.1	9.0	10.0	11.2
	12	3.6	4.0	4.4	4.9	5.5	6.1	6.8	7.6	8.4	9.4
	20	2.9	3.2	3.5	3.9	4.4	4.9	5.4	6.1	6.7	7.5
11	1/2					15.5	17.4	19.3	21.5	24.0	26.7
	1				10.3	11.5	12.9	14.3	15.9	17.7	19.7
	2			6.9	7.6	8.5	9.5	10.6	11.8	13.1	14.6
	4		4.6	5.1	5.6	6.3	7.0	7.8	8.7	9.7	10.8
	8	3.0	3.4	3.8	4.2	4.6	5.2	5.8	6.4	7.2	8.0
	12	2.5	2.8	3.1	3.5	3.9	4.4	4.9	5.4	6.0	6.7
	20	2.0	2.3	2.5	2.8	3.1	3.5	3.9	4.3	4.8	5.4

LEAD TOLERANCE — FACE WIDTH (INCHES)

AGMA QUALITY NUMBER	1 AND LESS	2	3	4	5
8	5	8	11	13	16
9	4	7	9	11	13
10	3	5	7	9	10
11	3	4	6	7	8

COARSE- PITCH GEAR TOLERANCES (CONTINUED)

Table 7-3

AGMA QUALITY CHART

AGMA Quality Numbers

RUNOUT TOLERANCE — PITCH DIAMETER (INCHES)

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	3/4	1-1/2	3	6	12	25	50	100	200	400
12	1/2					38.1	45.4	53.6	63.2	74.5	87.9
	1				23.1	27.3	32.5	38.3	45.2	53.3	62.8
	2			14.0	16.5	19.5	23.2	27.4	32.3	38.1	44.9
	4		8.5	10.0	11.8	13.9	16.6	19.6	23.1	27.2	32.1
	8	5.2	6.1	7.2	8.5	10.0	11.9	14.0	16.5	19.5	23.0
	12	4.2	5.0	5.9	6.9	8.2	9.8	11.5	13.6	16.0	18.9
	20	3.3	3.9	4.6	5.4	6.4	7.6	9.0	10.6	12.5	14.7
13	1/2					27.2	32.4	38.3	45.1	53.2	62.8
	1				16.5	19.5	23.2	27.4	32.3	38.1	44.9
	2			10.0	11.8	13.9	16.6	19.6	23.1	27.2	32.1
	4		6.1	7.2	8.4	10.0	11.9	14.0	16.5	19.5	22.9
	8	3.7	4.3	5.1	6.0	7.1	8.5	10.0	11.8	13.9	16.4
	12	3.0	3.6	4.2	5.0	5.9	7.0	8.2	9.7	11.4	13.5
	20	2.4	2.9	3.3	3.9	4.6	5.4	6.4	7.6	8.8	10.5
14	1/2					19.5	23.2	27.3	32.2	38.0	44.8
	1				11.8	13.9	16.6	19.5	23.0	27.2	32.1
	2			7.2	8.4	9.9	11.8	14.0	16.5	19.4	22.9
	4		4.3	5.1	6.0	7.1	8.5	10.0	11.8	13.9	16.4
	8	2.6	3.1	3.7	4.3	5.1	6.1	7.1	8.4	9.9	11.7
	12	2.2	2.5	3.0	3.5	4.2	5.0	5.9	6.9	8.2	9.6
	20	1.7	2.0	2.3	2.8	3.3	3.9	4.6	5.4	6.4	7.5
15	1/2					13.9	16.6	19.5	23.0	27.2	32.0
	1				8.4	9.9	11.8	14.0	16.5	19.4	22.9
	2			5.1	6.0	7.1	8.5	10.0	11.8	13.9	16.4
	4		3.1	3.7	4.3	5.1	6.1	7.1	8.4	9.9	11.7
	8	1.8	2.2	2.6	3.1	3.6	4.3	5.1	6.0	7.1	8.4
	12	1.5	1.8	2.1	2.5	3.0	3.6	4.2	4.9	5.8	6.9
	20	1.2	1.4	1.7	2.0	2.3	2.8	3.3	3.9	4.6	5.4

PITCH TOLERANCE — PITCH DIAMETER (INCHES)

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	3/4	1-1/2	3	6	12	25	50	100	200	400
12	1/2					4.7	5.3	6.0	6.8	7.7	8.7
	1				3.5	4.0	4.6	5.2	5.8	6.6	7.5
	2			2.7	3.0	3.4	3.9	4.4	5.0	5.6	6.4
	4		2.0	2.3	2.6	2.9	3.3	3.8	4.3	4.8	5.5
	8	1.5	1.7	2.0	2.2	2.5	2.9	3.2	3.7	4.1	4.7
	12	1.4	1.6	1.8	2.0	2.3	2.6	3.0	3.3	3.8	4.3
	20	1.3	1.4	1.6	1.8	2.0	2.3	2.6	3.0	3.4	3.8
13	1/2					3.3	3.8	4.2	4.8	5.4	6.1
	1				2.5	2.8	3.2	3.6	4.1	4.6	5.2
	2			1.9	2.1	2.4	2.8	3.1	3.5	4.0	4.5
	4		1.4	1.6	1.8	2.1	2.4	2.7	3.0	3.4	3.8
	8	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.6	2.9	3.3
	12	1.0	1.1	1.3	1.4	1.6	1.8	2.1	2.4	2.7	3.0
	20	0.9	1.0	1.1	1.3	1.4	1.6	1.8	2.1	2.4	2.7
14	1/2					2.3	2.6	3.0	3.4	3.8	4.3
	1				1.8	2.0	2.3	2.6	2.9	3.3	3.7
	2			1.3	1.5	1.7	1.9	2.2	2.5	2.8	3.2
	4		1.0	1.1	1.3	1.6	1.7	1.9	2.1	2.4	2.7
	8	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.8	2.1	2.3
	12	0.7	0.8	0.9	1.0	1.1	1.3	1.5	1.7	1.9	2.1
	20	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.5	1.7	1.9
15	1/2					1.6	1.9	2.1	2.4	2.7	3.0
	1				1.2	1.4	1.6	1.8	2.0	2.3	2.6
	2			0.9	1.1	1.2	1.4	1.5	1.7	2.0	2.2
	4		0.7	0.8	0.9	1.0	1.2	1.3	1.5	1.7	1.9
	8	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6
	12	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.5
	20	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.2	1.3

PROFILE TOLERANCE — PITCH DIAMETER (INCHES)

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	3/4	1-1/2	3	6	12	25	50	100	200	400
12	1/2					11.1	12.4	13.8	15.4	17.1	19.0
	1				7.4	8.2	9.2	10.2	11.4	12.7	14.1
	2			4.9	5.5	6.1	6.8	7.6	8.4	9.4	10.4
	4		3.3	3.6	4.0	4.5	5.0	5.6	6.2	6.9	7.7
	8	2.2	2.4	2.7	3.0	3.3	3.7	4.1	4.6	5.1	5.7
	12	1.8	2.0	2.2	2.5	2.8	3.1	3.5	3.9	4.3	4.8
	20	1.5	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.4	3.8
13	1/2					7.9	8.8	9.9	11.0	12.2	13.6
	1				5.3	5.9	6.6	7.3	8.1	9.0	10.1
	2			3.5	3.9	4.3	4.9	5.4	6.0	6.7	7.6
	4		2.3	2.6	2.9	3.2	3.6	4.0	4.4	4.9	5.5
	8	1.6	1.7	1.9	2.1	2.4	2.7	3.0	3.3	3.7	4.1
	12	1.3	1.4	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.4
	20	1.0	1.2	1.3	1.4	1.6	1.8	2.0	2.2	2.5	2.7
14	1/2					5.7	6.3	7.1	7.8	8.7	9.7
	1				3.8	4.2	4.7	5.2	5.8	6.5	7.2
	2			2.5	2.8	3.1	3.5	3.9	4.3	4.8	5.3
	4		1.7	1.9	2.1	2.3	2.6	2.9	3.2	3.5	3.9
	8	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.6	2.9
	12	0.9	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.4
	20	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.8	2.0
15	1/2					4.0	4.5	5.0	5.6	6.2	6.9
	1				2.7	3.0	3.3	3.7	4.1	4.6	5.1
	2			1.8	2.0	2.2	2.5	2.8	3.1	3.4	3.8
	4		1.2	1.3	1.5	1.6	1.8	2.0	2.3	2.5	2.8
	8	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.1
	12	0.7	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.7
	20	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.3	1.4

LEAD TOLERANCE — FACE WIDTH (INCHES)

AGMA QUALITY NUMBER	1 AND LESS	2	3	4	5
12	2	3	5	6	7
13	2	3	4	4	5
14	1	2	3	4	4
15	1	2	2	3	3

TOLERANCE GUIDE

The composite action of a gear is the variation in center distance when the gear is rolled in tight mesh (double flank contact) with its mate or a master gear of known accuracy.

The composite gear accuracy, or sum total of gear tooth accuracies, is measured by means of a total composite checking machine. This machine magnifies and charts the actual composite action of the inspected gear with its reference mate. See chart below.

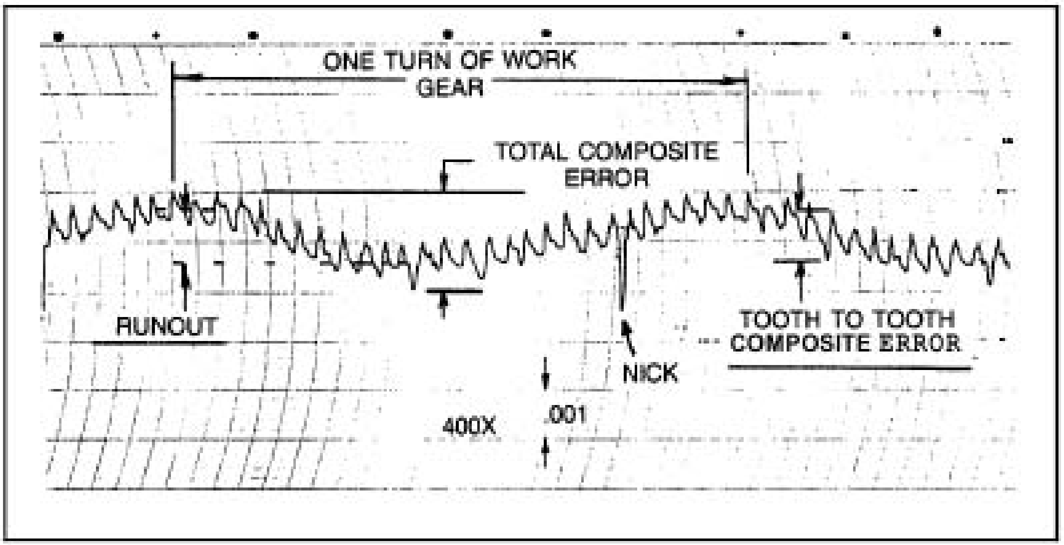
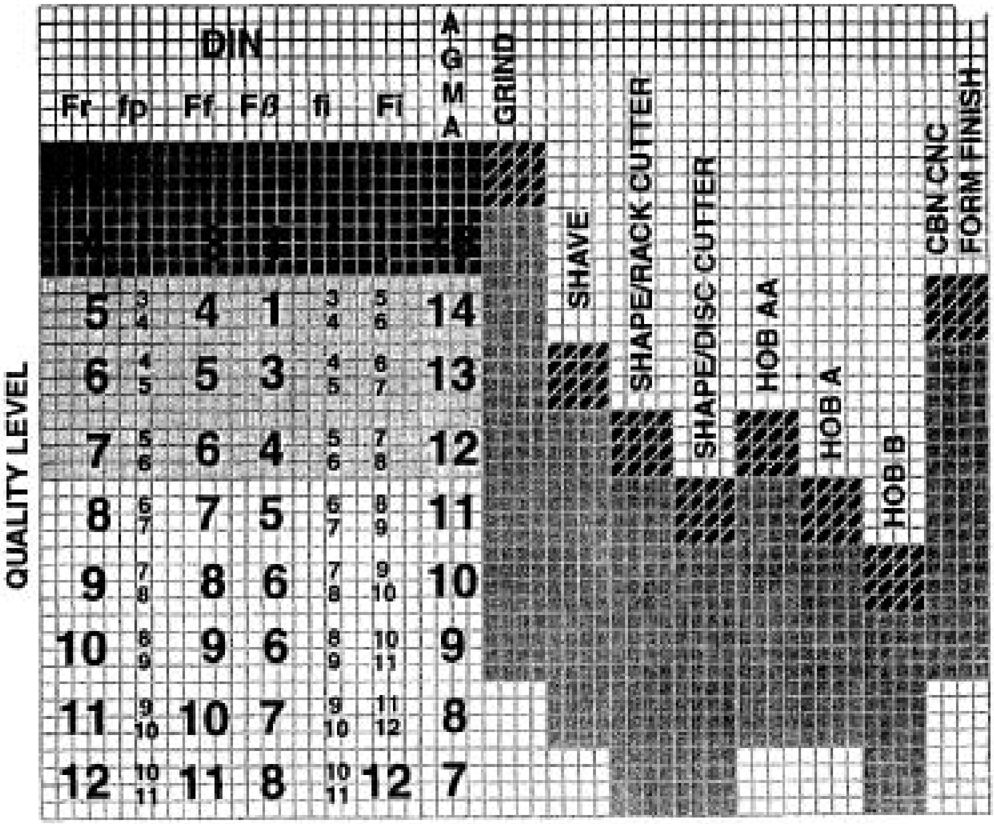


Table 7-4 Explanation of T.C.E. and T.T.C.E.

ACHIEVABLE GEAR QUALITIES
BY MACHINING METHOD



Fr = Runout
fp = Pitch variation
Ff = Profile
Fß = Lead
fi = Tooth-to-tooth composite
Fi = Total composite

Possible only under special conditions (hatched)

SOURCE COMPARISONS: DIN 3962 (1974) and AGMA 390.03

NOTE: SEE THE ACTUAL STANDARDS FOR EXACT COMPARISONS

Courtesy of Gleason Pfauter Hurth.

Table 7-5

Chapter 8

PRODUCIBILITY

The cost of manufacturing is related to the tolerances specified on the part. Designers are rightfully determined to keep tight tolerances on certain dimensions, and it is ultimately the designer who has the full concept of the design and function of the part. Many designers however, are not much interested in the cost of manufacturing, and some of them do not have sufficient practical experience in the machine shop field.

During the design stage, manufacturing and producibility engineers can recommend both design and tolerance changes on parts and submit them to the designer for consideration. Design changes to improve producibility should preferably be decided as part of a group effort between the manufacturing engineer, the designer, and the chief of design engineering.

Figures 8-1 thru 8-6 (titled P-PHD-1 through P-PHD-6) relate to parts PHD-1 thru PHD-6, listed in Chapter **4.** Figures 8-1 thru 8-6, however, are here modified by the letters in the balloons, which correspond to a recommendation specified under each part.

Producibility of Part P-PHD-1

The print in Figure 8-1, for part number P-PHD-1, carries letters that have been added to indicate various aspects that bear comment. For the dimension **A,** the drawing specifies that center holes are permissible, but the part shown cannot be fabricated without center holes. Center holes are essential for use in grinding the 0.1247 + 0.0000 – 0.0003-inch diameter marked ***G.***

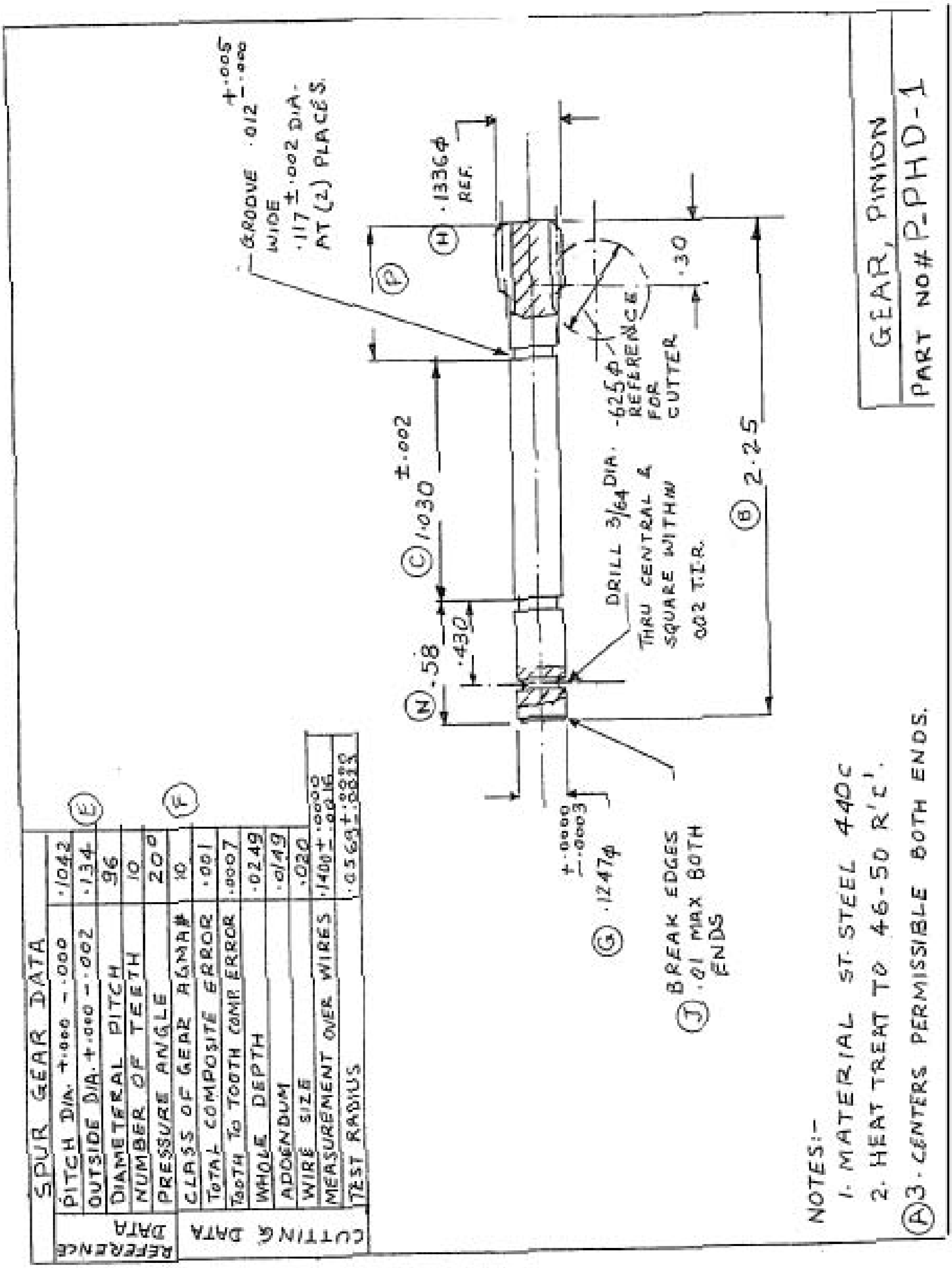

SPUR GEAR DATA
REFERENCE DATA
PITCH DIA. +.000 -.000 ·1042
OUTSIDE DIA. +.000 -.002 ·134
DIAMETERAL PITCH 96
NUMBER OF TEETH 10
PRESSURE ANGLE 20°
CUTTING DATA
CLASS OF GEAR AGMA# 10
TOTAL COMPOSITE ERROR ·001
TOOTH TO TOOTH COMP. ERROR ·0007
WHOLE DEPTH ·0249
ADDENDUM ·0149
WIRE SIZE ·020
MEASUREMENT OVER WIRES ·1400 +.0000 -.0016
TEST RADIUS ·0569 +.0010 -.0013
GROOVE ·012 +.005 -.000 WIDE ·117 ± ·002 DIA. AT (2) PLACES.
·1336 Ø REF.
·30
·625 Ø REFERENCE FOR CUTTER
1·030 ±·002
DRILL 3/64 DIA. THRU CENTRAL & SQUARE WITHIN ·002 T.I.R.
2·25
·58
·430
·1247 Ø +·0000 -·0003
BREAK EDGES ·01 MAX BOTH ENDS
NOTES:-
1. MATERIAL ST. STEEL 440C
2. HEAT TREAT TO 46-50 R'c'.
3. CENTERS PERMISSIBLE BOTH ENDS.
GEAR, PINION
PART NO# P-PHD-1

Fig. 8-1

The outside diameter H, of the part is 0.1336 inch and the diameter at the root is calculated by (.1336-2 x .0249) inch (whole depth) = 0.084 inch. The correct choice for the center holes in this part is a number 1,60-degree, center drill, with 0.06-inch maximum diameter. Thus, in Note 3, a maximum diameter of 0.06 inch be specified.

For the dimension marked B, unless specific tolerances on dimensions are called for, the generally assumed tolerances in the **USA**, based on the number of decimal places, are as follows:

X.XX ± .010 inch, and X.XXX ± .005 inch

Designers who prepare drawings in CAD programs often get into the habit of specifying 1/4 as 0.250. If a dimension on part P-PHD-1 is specified as 2-1/4 inch, the assumed tolerance will be ± 1/64 (0.016 inch).

The overall length of a part often is not a critical dimension and as such should have tolerances that are as liberal as possible. In the example, the tolerance off 0.010 inch is adequate. If this component has to fit in a tight spot, it could given a dimension of 2.250 inch.

Dimensions N, P & B

The dimension 0.58 inch marked N on the print in Figure 1 should be deleted, and a dimension marked P should be inserted as 0.640 ± 0.003 inch. The reason for such a tight tolerance here is that the overall length of the part has a tolerance of ± 0.010 inch. Dimension N therefore, will become :

$$2.25 \pm .010 - .640 \pm .003 - 1.030 \pm .002 = 0.58 \pm .015 \text{ inch}$$

If dimension B was 2.250 inch, the resultant dimension N will be as shown below, which satisfies the blueprint dimension:

$$2.250 \pm 0.005 - 0.640 \pm 0.003 - 1.030 \pm 0.002 = 0.58 \pm 0.010 \text{ inch}$$

To summarize, from the point of view of producibility, dimension B should be 2.250 inch, dimension **P** should be 0.640 ± 0.003 inch, and dimension N (0.58) should be called as Reference.

Dimension F

AGMA quality is an important factor in determining the choice of process to be used. If the **AGMA** quality number is 5, the part can be fabricated by powder metallurgy.

AGMA numbers 7 and 8 can be achieved by hobbing on any machine. However, **AGMA** number 10, which is especially associated with small, fine-pitched gears, requires a precision gear-hobbing machine like the Swiss Mikron 102 Series. Therefore, the designer must carefully weigh whether a higher **AGMA** quality number is necessary.

Dimension J

It is a mistake to specify a 0.01-inch chamfer because application of the standard tolerance off 0.010 inch may leave a sharp corner. It should therefore be changed to 0.010 inch.

Producibility of Part P-PHD-2

Dimension A

For the part P-PHD-2, shown in Figure 8-2, a tolerance of 0.39395 ± 0.00015 inch is recommended on dimension **A.** It is possible to grind this bearing journal within a tolerance of 0.0002 inch, but to avoid high rejection rates, a 0.0003-inch total tolerance is recommended for mass-produced items.

Dimension B

With the outside diameter of dimension **A** at 0.3941 inch, and the groove dimension B in Fig. 8-2 at 0.380 inch, the radial depth = (0.3941 – 0.380)/2 = 0.007 inch. Standard carbide grooving-tool inserts are supplied in widths of 1/32 inch with a 0.005-inch corner radius; so our dimension B has been specified appropriately.

Because of the possibility of stress concentrations and the dangers of fatigue failure with some components, the designer may specify the 0.03 inch width as a full radius. The neck diameter will, therefore, decrease considerably.

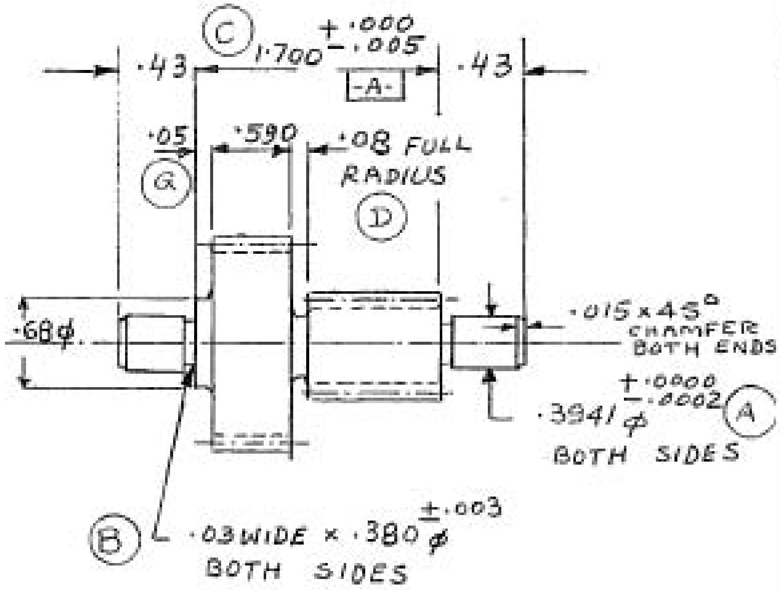
Dimension C

It is up to the designer to check the stress. The total tolerance on linear dimensions should preferably not be less than 0.002 inch. On hardened material, a linear tolerance of 0.001 inch can be held by a grinding operation on the collar. Here, the designer will specify a total tolerance of 0.005 inch, which is even better and more economical.

SPUR GEAR DATA (ENLARG. ADDENDUM)			
REFERENCE DATA	PITCH DIA	·7000	
	OUTSIDE DIA +·000 −·003	1·763	
	DIAMETERAL PITCH	20°	
	NUMBER OF TEETH	32	
	PRESSURE ANGLE	25°	
	CLASS OF GEAR AGMA #	10	
CUTTING DATA	TOTAL COMPOSITE ERROR	·001	
	TOOTH TO TOOTH COMP. ERROR	·0005	
	WHOLE DEPTH	·112	
	ADDENDUM	·0315	
	WIRE SIZE	·0864	
	MEASUREMENT OVER WIRES	1·7853	+·000 −·003
	TEST RADIUS ·8320 +·000	−·0023	

(F)

PINION DATA (ENLARGENED ADDENDUM)			
REFERENCE DATA	PITCH DIA (REF) STD.	·5000	
	OUTSIDE DIA +·000 −·003	·647	
	DIAMETRAL PITCH	20	
	NUMBER OF TEETH	10	
	PRESSURE ANGLE	25°	
	CLASS OF GEAR AGMA #	10	
CUTTING DATA	T·C·E	·001	
	T·T·C·E	·0007	
	WHOLE DEPTH	·112	
	ADDENDUM	·0735	
	MEASUREMENT OVER ·096 DIA WIRES	·6790	+·000 −·002
	TEST RADIUS ·2742 +·000	0 −·0025	



NOTES:–

① MATERIAL PRECIPITATION HARDENING 13-8 MO

② HARDNESS 43-45 R'C'

(H) ③ CENTERS PERMISSIBLE

GEAR AND PINION
PART NO # P-PHD-2

Figure 8-2

Dimension D

In shaping the pinion, the preferred clearance for the chips is either 0.094 or 0.109 inch. Here, the designer wants a greater pinion length and has, therefore, specified 0.08 inch. A full radius will add strength to the component. An 0.08-inch groove can be easily machined with a 2-mm carbide insert (0.0787 inch width).

Dimension F

A tolerance of 0.003 inch is very practical here. At the final turning stage, if the outside diameter is turned to 1.762 – 1.763 inch diameter, the part will shrink to the size of 0.9993 x 1.763 – 0.9993 x 1.762 inch after heat treatment. The size will then become 1.7607 - 1.7617 (assuming a 1– 0.9993 = 0.0007-inch per inch contraction rate). The part will thus be within the drawing limit.

Dimension G

Before deciding on the tolerance for dimension G (here given as 0.05 inch), it is necessary to calculate the resulting dimension G, which is carried out as follows:

$1.6975 \pm 0.0025 - 0.05 \pm 0.010 - 0.590 \pm 0.005 - 0.08 \pm 0.010$, giving 0.9775 ± 0.0275 inch.

No designer would choose such a wide tolerance on the pinion length. However, iff 0.001 inch were allocated as the tolerance on a 0.05-inch dimension and dimension D was 0.080 inch, the resultant gear length would be:

$1.6975 \pm 0.0025 - 0.05 \pm 0.001 - 0.590 \pm 0.005 - 0.08 \pm 0.005 = 0.9775 \pm 0.0135$ inch

To summarize:

Dimension D should be 0.080 inch full radius, and dimension G should be 0.050 ± 0.001

Dimension H

It is better for the designer to specify the size of the center, because otherwise the manufacturing engineer may select a larger size center drill, thereby weakening the bearing area. A better solution is to specify a 3/16-inch diameter, Bell-type 60-degree center drill with a 0.120-inch Bell mouth diameter.

Producibility of Part P-PHD-3

Part number P-PHD-3 is shown in Figure 8-3. The tolerances on the dimensions marked A, B, and C, are all appropriate. For the 0.12-inch radius, the manufacturing engineer can select a boring tool with a 1/8 (0.125) inch radius and still be within tolerance. Nothing comes in contact with dimension B, so the ± 0.005-inch tolerance is correct. During carburizing, the part will become oval. With the use of the quenching fixture, the important dimensions will most probably be held within the tolerance of ± 0.005 inch.

Producibility of Part PHD-4

Specifying a width of 0.03 inch for dimension F on part **PHD-4** in Figure 8-4, can be interpreted as likely to produce an undercut with sharp edges. Sharp edges or undercuts are potential sources of stress concentration, that may result in fatigue cracks, aand should be avoided.

The designer has specified a ± 0.005-inch tolerance on the undercut size, so the approximate depth from the basic 1.6250-inch size must be reached by the undercut tool. 1.625 – 1.594 = 0.031 ÷ 2 = 0.015 inch

The obvious choice therefore is either a full radius or a groove with a 0.005-inch corner radius. The author prefers to specify 0.005- to 0.010-inch corner radii. If a 0.005-inch corner radius is specified, with a general tolerance off 0.005 inch, an insert with zero corner radius may be used.

Specifying 0.375 ± 0.002 inch for dimension G, will result in the gear face length being as calculated below, which is well within the drawing print tolerance:

$$1.750 \pm 0.0015 - 0.375 \pm 0.002 - \mathbf{0.375} \pm 0.002 = 1.000 \pm 0.0055$$

inch

Dimension J

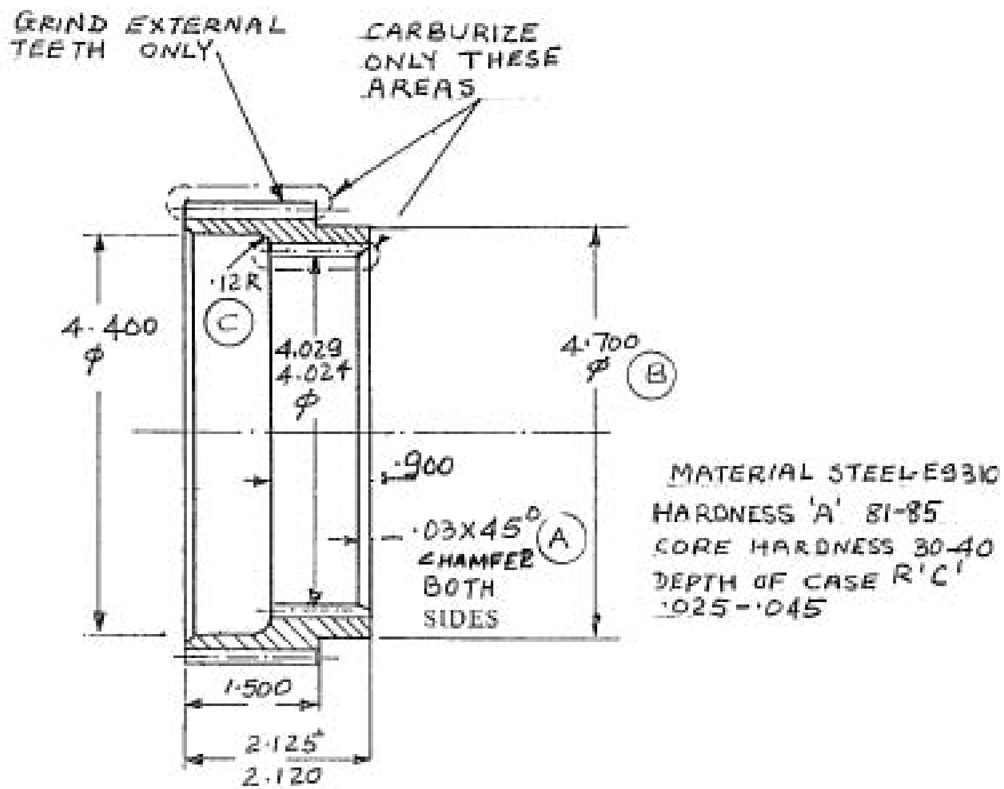
The dimension J of 1.245 ± 0.005 inch, with ± 0.010 inch tolerance, as if the dimension were 1.25 inch, is recommended. The maximum size can thus be 1.260 inch. Grinding of the internal diameter of 1.255 inch is possible only if dimension J is less than 1.255 inch.

Dimensions K, L, and M

On certain dimensions it is advisable to specify surface finishes. Recommended surface finishes, for example, are:

GEAR DATA	
NUMBER OF TEETH	45
D.P	9/11
PRESSURE ANGLE	20°
BASE CIRCLE DIA	4.6895
MAX. TIP DIA	4.827
ADDENDUM	.0909
CORRECTED ADDENDUM	.0924
WHOLE DEPTH	.2045
ROOT FILLET RADIUS	.015-.025
CIRCULAR PITCH	.3291
THEORITICAL CHORDIAL THICK.	.1745
CHORDAL THICKNESS MIN	.1685
CHORDAL THICKNESS MAX	.1705

SPLINE DATA	
NUMBER OF TEETH	50
D.P	12/14
PRESSURE ANGLE	20°
THEORITICAL CHORDAL SPACE	.1309
WHOLE DEPTH	.1607
ROOT DIA	4.365 — 4.345
THEORITICAL PITCH DIA	4.1667
WIRE SIZE	.140
MEASUREMENT BETWEEN WIRES	3.9805 3.9745
ROOT RADIUS	.025
INVOLUTE FORM MUST BE TRUE WITHIN 4.300 MIN	



GEARED COUPLING
P-PHD-3

Figure 8-3

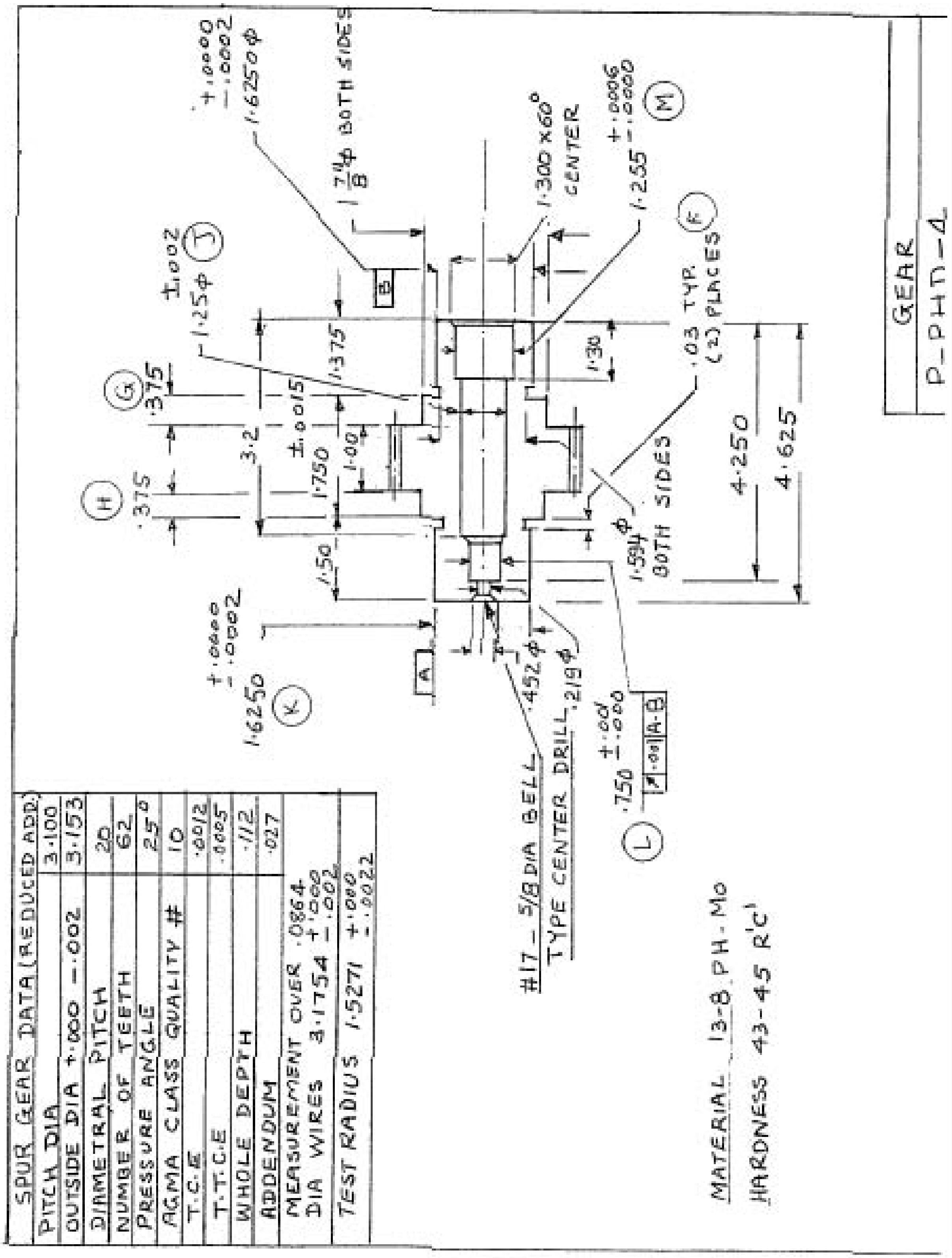

SPUR GEAR DATA (REDUCED ADD.)
PITCH DIA 3.100
OUTSIDE DIA +.000 −.002 3.153
DIAMETRAL PITCH 20
NUMBER OF TEETH 62
PRESSURE ANGLE 25°
AGMA CLASS QUALITY # 10
T.C.E .0012
T.T.C.E .0005
WHOLE DEPTH .112
ADDENDUM .027
MEASUREMENT OVER .0864 DIA WIRES 3.1754 +.000 −.002
TEST RADIUS 1.5271 +.000 −.0022
MATERIAL 13-8 PH-Mo
HARDNESS 43-45 Rc
#17 – 5/8 DIA BELL TYPE CENTER DRILL
BOTH SIDES
CENTER
4.250
4.625
GEAR
P-PHD-4

Figure 8-4

Dimension M	32 micro-inch rms
Dimension K	32 micro-inch rms
Dimension L	63 micro-inch rms

Dimension L (for the 0.750-inch internal diameter) means the bore is very deep, and it will be very difficult to grind. Chucking on the 1.6250-inch ground diameter with a soft-jaw chuck, and using a carbide-shank tool holder (to dampen vibration and reduce chatter marks) will make it possible to achieve the required 0.001-inch concentricity as well as the 0.001-inch total tolerance.

To summarize:

Dimension F should be specified as 0.015-inch, full-radius, as typical at two places.

Dimension G should be specified as ± 0.002 inch.

Dimensions K, L, and M should have surface finishes specified.

Producibility of Part P-PHD-5

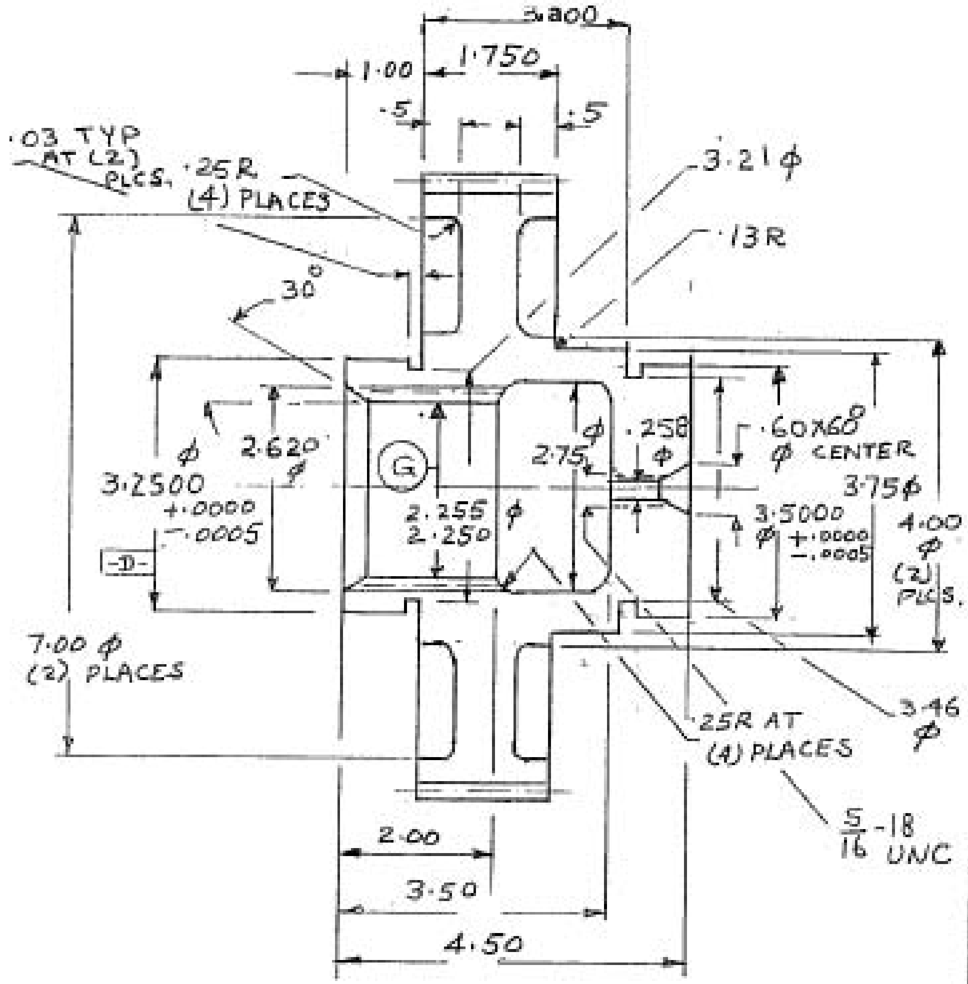
Part P-PHD-5, shown in Fig. 8-5 is an example of proper design, except that a note needs to be added to the 2.255 to 2.250-inch inside diameter marked G, stating that it is to be concentric with diameter D within 0.001 inch.

Producibility of Part P-PHD-6

The AGMA Quality for part P-PHD-6, shown in Fig. 8-6 is 14, so it is essential to have a closer tolerance on dimension G, for the 0.749 to 0.750-inch diameter bore of ± 0.0001 inch. The preferred tolerance on this bore size should be 0.7498 to 0.7500 inch.

If, for any reason, the designer wants a 0.749-0.750 dimension here, it will be essential to use a precision hydraulic expanding arbor while grinding the external teeth.

INTERNAL SPLINE DATA	
NUMBER OF TEETH	28
DIA. PITCH	12/24
PRESSURE ANGLE	30°
MAJOR DIA	2.4963
FORM DIA MIN	2.4214
PITCH DIA REF.	2.333
FILLET ROOT SIDE FIT	



NOTES

1. MATERIAL 9310 STEEL
2. CARBURIZE GEAR TEETH, DEEP FREEZE & TEMPER PART.
3. DO NOT CARBURIZE TOP LANDS OR END FACES OF GEAR TEETH.
   SURFACE HARDNESS ON 30N SCALE 77-81
   CORE HARDNESS 34-44 R'C)
   DEPTH OF HARDNESS .024-.034
4. M.P.I & NITAL ETCH ESSENTIAL

CARBURIZED GEAR
P-PHD-5

Figure 8-5

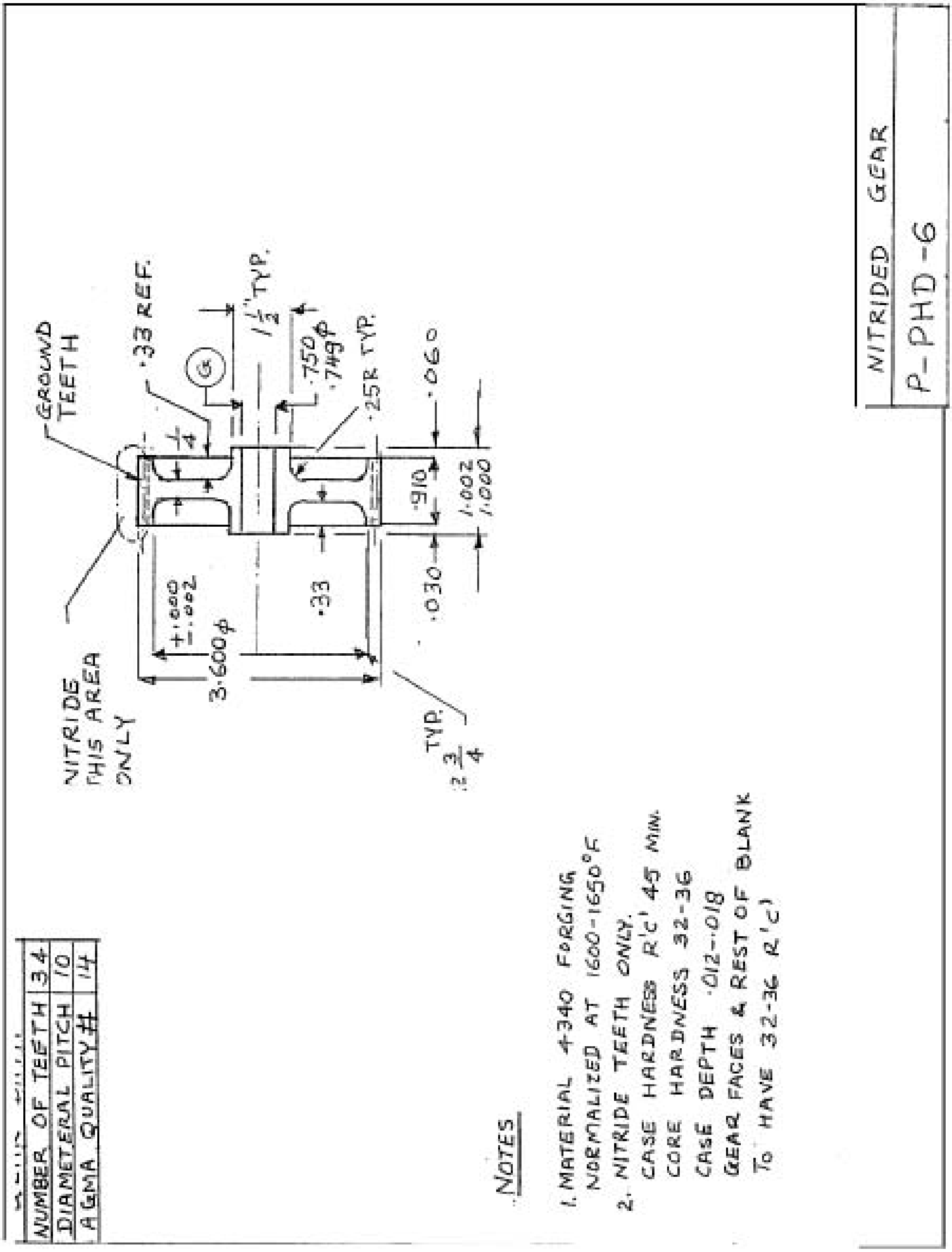

NUMBER OF TEETH 34
DIAMETERAL PITCH 10
AGMA QUALITY # 14
NOTES
1. MATERIAL 4340 FORGING
NORMALIZED AT 1600-1650°F
2. NITRIDE TEETH ONLY.
CASE HARDNESS R'C' 45 MIN.
CORE HARDNESS 32-36
CASE DEPTH .012-.018
GEAR FACES & REST OF BLANK
TO HAVE 32-36 R'C'
NITRIDED GEAR
P-PHD-6
GROUND TEETH
.33 REF.
1 1/2" TYP.
.25R TYP.
NITRIDE THIS AREA ONLY
3.600φ
.33
.030
.060
.910
1.002
1.000
TYP.

Figure 8-6

Chapter 9

FINISHES ON GEARS

Aluminum Gears

The materials most commonly used for gears in the aluminum series are AL 2024-T4, 7075-T6, 6061-T4 and 6061-T6. These aluminum gears are mostly used in aircraft actuators and instrument gearboxes. There are basically two types of finishes: chemical filming, and anodizing.

Chemical Filming

Chemical filming provides the maximum possible protection against corrosion. Surfaces with this treatment can be left unpainted or painted on all areas except the gear teeth and the bores. Chemical filming does not change the size of the gear.

For protection against corrosion, when low electrical resistance is required, chemical film in accordance with MIL-C-5541 Class 3, or No. 7.3.3 of MIL-STD-171 may be specified. However, for protection against corrosion of surfaces that are to be painted, chemical film to MIL-C-5541 Class 1A, may be preferred.

Anodized Gears

Anodized aluminum coatings are thicker than chemical films, generally being between 0.00005 and 0.0003 inch in thickness, whereas sulfuric acid coating thickness is generally 0.00005 to 0.001 inch. The finished thickness on a surface will be half that specified above. Because of its shallow thickness, a chromic acid type finish is generally specified for tapped and blind holes.

MIL-A-8625 Type 1, C1.1 specification is a clear type, whereas Class 2 is a black finish. There is also a hard-anodized coating identified as MIL-A-8625, Type III C1.l, in which the thickness is generally 0.002 ± 0.0002 inch.

Stainless Steel Gears

All stainless steel gears, whether hardened or unhardened, must necessarily be passivated. Passivation improves corrosion resistance by removing surface iron particles and aids in formation of a passive oxide film, and it does not change the gear size. In the USA, passivation is covered by ASTM A 380 and the conventional drawing call out is number 5-4-1 of MIL-STD-171 for surfaces to be unpainted and number 5-5-1 for surfaces to be painted.

Finishes on Steel Gears

Black Oxide

Black oxide is a decorative finish and is not corrosion-resistant. In the USA, black oxide is classified under MIL-C-13924 Class 1. This finish does not result in any increase in dimensions. Stainless steels can also be black oxided, but they are generally passivated first and then black oxided to MIL-(3-13924 Class **3.** Again, there is no increase in dimensions.

Other Finishes

Gear teeth and flanks are best left unplated. However, there are certain finishes like electroless nickel plating with a minimum 0.0002 inch thickness, titanium nitride coatings, dry lubricant films based on molybdenum sulfide (MOS2), and amorphous carbon with tungsten carbide inclusions, all of which can be applied to gear teeth and flank. The majority of electro-deposited coatings, including hard chromium plating, except those mentioned above, deposit a thicker coating at the outer tip of the gears.

Figure 9-1 Corner effect electroplated materials like chromium plating.

Hard Chromium Plating

Hard chromium plating is capable of achieving hardnesses up to 70 Rockwell C, but the coating will adhere only if the surface to be coated is of a very rough nature (preferably 250 micro-inches rms). Plating will go deep into ridges. Sufficient build up of hard chromium must be applied to ensure that, after grinding of the teeth, a minimum coating thickness of 0.004 inch is retained. The hardness of electroless nickel plating can be varied to suit blueprint requirements.

All the finishes mentioned have advantages if plating covers the entire part and the part is not masked. Masking is a very costly operation and is achieved by application of a number of epoxy coatings, followed by removal of the coatings after plating. Masking, that is, applying and removing epoxy, is a manual operation, so a major part of the cost in plating goes for masking. All over plating has the disadvantage of decreasing the size of bores and increasing the size of bearing diameters.

It is better to select stainless steel or precipitation type heat treatable materials than to use semi-masked gears involving electroless nickel plating or titanium nitride coatings.

Amorphous carbon with tungsten carbide inclusions (referred to as WC/C coating) is a physical vapor deposition process, and is a good method of applying a coating. Bores of cluster gears, or single gears, will need to be plugged during coating processes to avoid deposits.

One of the processes called Balinit C, has the following characteristics:

Coefficient of friction	0.1 to 0.2 (versus 0.6 to 0.7 for steel)
Hardness	1000 Hv 0.05
Coating thickness	1 to **4** úm. (40 to 158 micro-inch)
Coating temperature	480 degrees F

Worms used with wormwheels, and cluster gears in the motorcycle industry, especially those used for racing (in addition to case-hardening by carburization) are good candidates for WC/C coatings.

On some gears, a phosphate compound coating is recommended to prevent galling action. Parts to be processed must have a hardness greater than **55** Rockwell C in any area that is ground before coating. Parts must be suitably stress-relieved between grinding and coating.

Electro-deposited Cadmium Plating

Cadmium Plating is classified as follows:

Class 1	0.0005 inch thick
Class 2	0.0003 inch thick
Class 3	0.0002 inch thick
Type I	as plated
Type II	with supplementary chromate treatment
Type III	with phosphate treatment

Chapter 10

USEFUL TABLES

The tables in this Chapter contain information useful for processing gears. The information is summarized below.

Tables 10-1, 10-2 and 10-3

These tables list stainless steels produced throughout the world, with equivalent BS (British Standard), DIN (German) AISI, AFNOR (French), UNI (Italian), and SIS (Swedish) numbers.

The tables have been condensed and are reproduced from U ISAA-CENTRO, Milano.

Tables 10-4 through 10-14

These tables are taken from catalogs of American steel suppliers. In the USA, drawings often call out a commercial name or one of the AISI, AMS, ASTM, Military, or Federal Specification numbers. Data is included from a catalog of Aeromet Inc. of Englewood, which is no longer in business. Of specific importance is data on the shapes in which a particular type of steel is available. This firm has been aquired by a specialty steel and forge company.

Table 10-15

This table gives equivalent surface finish symbols used in countries that employ the metric system of measurements. The equivalent American Standards are identified.

Table 10-16

This decimal chart has been used by the author for selection of the nearest correct size of commercially available material in the USA.

Table 10-17, 10-18, and 10-19

Table 10-17 is a hardness chart. Table 10-18 has been compiled for figuring centers so that the programmer need not calculate the value for Z every time. Instead, Z can be taken from the table.

Table 10-20

This recommended stock removal table is reproduced from the Tool & Manufacturing Engineers Handbook.

Table 10-1 Comparable Sr. steel standards of different countries.

UNI (Italia)	AISI (USA)	AFNOR (Francia)	BS (Gran Bretagna)	DIN (Repubblica Federale Tedesca) designazione secondo DIN 17006	DIN Werkstoff Nummer secondo DIN 17007 tabella 2	SIS (Svezia)
X 15 CN 1707 UNI 4047	301	Z 12 CN 18-8	970 opp. 1449 1554 opp. 2056 } En 58A	X 12 CrNi 17 7	1.4310	23 30 23 31
X 15 CN 1808 UNI 4047	302	Z 12 CN 18-8 Z 12 CN 18-16	970 opp. 1449 1554 opp. 2056 } En 58A	X 12 CrNi 18 8	1.4300	23 30 23 31
	302 B					
X 15 CNF 1808 UNI 4047 (2)	303 (1)	Z 10 CNF 18-10 (2)		X 12 CrNiS 18 8 (2)	1.4305 (2)	23 4[illegible]
	303 Se					
X 8 CN 1910 UNI 4047 X 6 CN 1911 UNI 4047	304	Z 6 CN 18-10	970 opp. 1449 1554 opp. 2056 } En 58E	X 5 CrNi 18 9	1.4301	23 3[illegible]
X 3 CN 1911 UNI 4047	304 L	Z 3 CN 18-10	1501 opp. 1506 801C	X 2 CrNi 18 9	1.4306	23 52
X 12 CN 1811 UNI 4047	305	Z 12 CN 18-10				23 33
	308					
X 20 CN 2412 UNI 4047	309	Z 15 CNS 25-13		X 15 CrNiS 20 12 (3)	1.4828 (3)	
	309 S	Z 10 CNS 25-13				
X 25 CN 2520 UNI 4047	310	Z 15 CNS 25-20	1453 A11	X 15 CrNiSi 25 20	1.4841	23 61
X 8 CN 2520 UNI 4047	310 S	Z 10 CNS 25-20		X 12 CrNi 25 21	1.4845	23 69
				X 15 CrNiSi 25 20	1.4841	
X 8 CND 1712 UNI 4047	316	Z 6 CND 18-12	970 opp. 1449 1554 opp. 2056 } En 58J (5) 1507 opp. 1508 845 (10) 3014 Grade 6 (10)	X 5 CrNiMo 18 10 X 5 CrNiMo 18 12	1.4401 1.4436	23 43
	316 L	Z 3 CND 18-12		X 2 CrNiMo 18 10 X 2 CrNiMo 18 12	1.4404 1.4435	23 53
		Z 8 CNDT 18-12	1501 845Ti	X 10 CrNiMoTi 18 10 X 10 CrNiMoTi 18 12	1.4571 1.4573	23 44
		Z 8 CNDNb 18-12	1453 A12Nb	X 10 CrNiMoNb 18 10 X 10 CrNiMoNb 18 12	1.4580 1.4583	23 45
	317		1501 846			
	(11)	Z 3 CND 18-12 (3)		X 2 CrNiMo 18 12 (3)	1.4435 (3)	

UNI (Italia)	AISI (USA)	AFNOR (Francia)	BS (Gran Bretagna)	DIN (Repubblica Federale Tedesca) designazione secondo DIN 17006	DIN Werkstoff Nummer secondo DIN 17007 tabella 2	SIS (Svezia)
			970 opp. 1449 / 1554 opp. 2056 } En 58J (*)			
X 8 CNT 1810 UNI 4047	321	Z 10 CNT 18-10	970 opp. 1449 / 1554 opp. 2056 } En 58C (*) / 1507 opp. 1508 821 (*)	X 10 CrNiTi 18 9	1.4541	23 37
	(*)					
X 8 CNNb 1811 UNI 4047	347	Z 10 CNNb 18-10	970 opp. 1449 / 1554 opp. 2056 } En 58G (*)	X 10 CrNiNb 18 9	1.4550	23 38
	348		970 opp. 1449 / 1554 opp. 2056 } En 58B (*)			
X 15 C 13 UNI 4047	403	Z 12 C 13	970 opp. 1449 / 1554 opp. 2056 } En 56A (*)	X 7 Cr 13 / X 10 Cr 13 / X 15 Cr 13	1.4000 / 1.4006 / 1.4024	23 03 (*)
X 8 CA 13 UNI 4047	405	Z 6 C 13 (*)	1501 713	X 7 CrAl 13	1.4002	
X 12 CA 12 UNI 4047				X 10 CrAl 13	1.4722	
X 15 C 13 UNI 4047	410	Z 6 C 13 / Z 12 C 13	970 opp. 1449 / 1554 opp. 2056 } En 56A / En 56B (*)	X 7 Cr 13 / X 10 Cr 13 / X 15 Cr 13	1.4000 / 1.4006 / 1.4024	23 02
	(*)		970 En 56A (*)			
	414					
X 15 CF 13 UNI 4047	416 (1)	Z 12 CF 13 (2)	970 En 56AM (2)			
	416 Se					
X 20 C 13 UNI 4047	420	Z 20 C 13	970 opp. 1449 / 1554 opp. 2056 } En 56C (*)	X 20 Cr 13	1.4021	23 03
X 32 C 13 UNI 4047	420	Z 30 C 13	970 opp. 1449 / 1554 opp. 2056 En 56D (*)			23 04
X 40 C 14 UNI 4047	420					
				X 7 Cr 14	1.4001	
X 12 C 17 UNI 4047	430	Z 8 C 17	970 opp. 1449 En 60 (12)	X 8 Cr 17	1.4016	23 20
				X 8 CrTi 17	1.4510	

Table 10-2

Table 10-8

UNI (Italia)	AISI (USA)	(Francia)	(Gran Bretagna)	designazione secondo DIN 17006	Nummer secondo DIN 17007 tabella 2	(Svezia)
	430 F (1)	Z 10 CF 17 (12)		X 12 CrMoS 17 (14)	1.4104 (14)	
	430 FSe					
X 16 CN 19 UNI 4047			970 opp. 1449 / 1554 opp. 2056 } En 57 (12)	X 22 CrNi 17	1.4057	23 21 (16)
X 20 CN 16 UNI 4047	431	Z 15 CN 16-2	970 opp. 1449 / 1554 opp. 2056 } En 57 (12)	X 22 CrNi 17	1.4057	23 21 (16)
				X 6 CrMo 17	1.4113	
	440 A					
	440 B					
	440 C					
	442	Z 12 C 18				
X 12 CA 23 UNI 4047				X 10 CrAl 24	1.4762	
X 25 C 26 UNI 4047	446	Z 15 C 27				23 22
X 80 CSN 20 UNI 3992		Z 70 CSN 22-02	970 En 59	X 80 CrMoSi 20	1.4747	
X 45 CNW 1909 UNI 3992			970 En 55 (13)	X 45 CrNiW 18 9	1.4873	
X 50 CNW 1414 UNI 3992		Z 45 CNWS 15-14				

SHAPES — PARTIAL LISTING OF SPECIFICATIONS

*ASME SAME AS ASTM WITH PREFIX "S" USED

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM	MILITARY	FEDERAL
A-286	X	X	X	X	X	X	X	X		X	660	5525 5731 5732 5734 5735 5736 5737 5804 5805	A453 A461 A638		
300-M (4340 MOD)	X		X	X				X		X		6416 6417 6419		S-8844 S-83135	
AM-350	X				X	X	X	X		X	633	5546 5548 5554 5745 5774 5775		S-8840	S-763
AM-355	X				X	X	X			X	634	5547 5549 5594 5743 5744 5780 5781	A461 A565	S-8840	S-763
Almar 362	X									X		5739 5740	A564	S-46123	
Custom 450												5763	A564		
Custom 455	X				X	X	X	X		X		5578 5617 5672 5860	A313 A564		
U-500	X									X	684	5751 5753	A567 A637		
W-545	X				X	X	X			X	665	5543 5741	A453		
S-590	X				X	X	X			X		5533 5770			
U-700	X									X	687				
S-816	X				X	X	X			X	671	5534 5765	A461 A639		
D-979	X				X	X	X			X	664	5509 5746			
Astroloy	X				•					X					
Carpenter #10	X									X	384		A493		
Carpenter #20Cb3	X				X	X	X	X	X	X			B462 B463 B464 B468 B471 B472 B472 B474 B475		
Carpenter #49	X				X	X				X				N-14411 N-22840	
AL 47-50	X				X	X				X				N-14411 N-22840	
Chromalloy	X				X	X	X			X	604				

Table 10-4

SHAPES **PARTIAL LISTING OF SPECIFICATIONS**

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM	MILITARY	FEDERAL
													*ASME SAME AS ASTM WITH PREFIX "S" USED		
Columbium (Niobium)	X		X	X	X	X		X				7850			
Columbium 10W-2.5ZR	X			X	X	X						7851 7855			
Discalloy	X									X	662	5733	A453 A461 A638		
Elgiloy	X			X	X					X				C-45662	
Greek Ascoloy	X	X	X	X	X	X	X	X		X	615	5508 5616 5817	A565 A565		
Hastelloy "B"	X		X	X	X	X	X	X					B295 A296 B304 B333 B335 A494		
Hastelloy "C"	X		X	X	X	X	X	X	X	X		5530 5750	B296 B304 B334 B336 A494 A567		
Hastelloy "C-276"	X		X	X	X	X	X	X	X	X			B574 B575		
Hastelloy "N"	X				X	X				X		5607	B366 B434 B573		
Hastelloy "W"	X									X		5755 5786 5787			
Hastelloy "X"	X	X	X	X	X	X	X	X		X	680	5536 5507 5508 5754 5798 5799	A567 B336 B435 B572		
Heavy Metal (Tungsten Base)	X		X	X								7725		T-21014	
High Expansion	X	X										5624 5625			
Hipernik	X				X	X								N-14411 N-22840	
Hipernom					X	X								N-14411	
HyMu80	X				X	X								N-14411	
Incoloy 800	X			X	X	X	X	X		X		5766	B163 B336 B407 B408 B409 B514 B515 B564		
Incoloy 801 (T)	X				X	X	X			X		5552 5742			
Incoloy 802	X		X	X			X	X							
Incoloy 825	X		X	X	X	X	X	X	X	X			B163 B425 B424 B423		
Incoloy 901	X									X	681 682	5660 5661			
Incoloy 902 (Ni-Span-C)	X			X	X							5221			
Inconel 600	X		X	X	X	X	X	X	X	X		5540 5580 5665 5683 5687	B163 B166 B167 B168	N-6710 N-6840 N-15721 N-22986 N-22987 N-23228 N-23229 T-7840 T-22945 T-23227	W-390

Table 10-5

SHAPES — PARTIAL LISTING OF SPECIFICATIONS

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM	MILITARY	FEDERAL
												*ASME SAME AS ASTM WITH PREFIX "S" USED			
Inconel 601	X	X			X	X	X			X		5717 5870			
Inconel 625	X		X	X	X	X	X	X		X		5599 5666 5837	B443 B444 B446		
Inconel 700	X									X					
Inconel 702	X		X	X	X	X	X	X		X		5550			
Inconel 706	X				X	X	X			X		5605 5606 5701 5702 5703			
Inconel 718	X		X	X	X	X	X	X		X		5589 5590 5596 5597 5662 5663 5664 5832	A637 A670	N-24469	
Inconel 722 (W)	X		X	X	X					X		5541 5714			
Inconel X-750	X		X	X	X	X	X	X		X	688	5542 5582 5598 5667 5668 5669 5670 5671 5698 5699 5778	A461 A637	N-7786 N-8550 N-24114 R-5031 S-21977 S-23192	W-562
Inconel X-751	X									X					
Invar 36	X		X	X	X	X	X	X	X	X				1-23011 S-16598	
Invar 36 FM	X	X	X	X	X			X		X				I-23011 S-16598	
42% Ni-Fe	X		X		X	X		X		X				1-23011	
46% Ni-Fe	X				X									1-23011	
49% Ni-Fe	X			X	X	X	X			X				1-23011 N-14411 N-22840	
52% Ni-Fe	X				X	X		X		X				I-23011	
Kovar	X				X	X	X	X		X		7726 7727 7728		I-23011	
Lapelloy	X									X	619		A565		
Maraging "250"	X									X		6512		S46850	
Maraging "300"	X									X		6514		S46850	
Maraging "350"	X									X					

Table 10-6

SHAPES — PARTIAL LISTING OF SPECIFICATIONS

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM	MILITARY	FEDERAL
												*ASME SAME AS ASTM WITH PREFIX "S" USED			
Molybdenum (Sintered/ArcCast)	X		X	X	X	X	X	X		X		7800 7801 7805 7806 7807			
Molybdenum +.5% Ti	X		X	X	X	X	X			X		7811 7813 7817			
Molybdenum TZM	X				X	X	X			X					
Moly Permalloy	X			X	X	X	X	X		X		7701 7702 7705		N-14411	
Mu Metal	X				X	X	X			X		7701 7702 7705		N-14411	
Hy-Mu-80	X			X	X	X	X	X		X		7701 7702 7705		N-14411	
MP35N (Multiphase)	X									X		5758 5844 5845			
Monel 400	X	X	X	X	X	X	X	X	X	X		4544 4574 457s 4875 4730 4731	8127 8163 8164 8165 8366 8395	N-894 N-24106 T-842 T-1368 T-23520	N-281
Monel R-405	X	X								X		4674	8164	N-694	N-281
Monel K-500	X	X	X	X	X	X	X	X	X	X		4676		F-23999 N-17506 W-4471	N-286
Monel 502	X		X	X	X	X	X	X	X	X		4677		N-17506	N-286
Nickel 200	X		X	X	X	X	X	X	X	X			8160 8161 8162 8163 8336 F175	N-19153 N-46025 N-46026	N-301
Nickel 201	X		X	X	X	X	X	X	X	X			8160 8161 8162 8163 8336		
Nickel 205	X			X	X	X	X	X		X		5555	F9	N-46025	
Nickel 270	X			X	X			X		X			F239		
T D Nickel	X				X	X				X					
Nichrome "V"	X			X	X							5676 5677 5682	8344 8446		
Nimonic 75	X				X	X				X					
Nimonic 80A	X					X				X			A637		
Nitralloy 135 MOD.	X							X		X		6470 6471 6472	A355	S-869 S-6709	
Pyromet X-15	X									X		5761			
Rene 41	X		X	X	X	X	X			X	683	5545 5712 5713 5800	A461		
Rhenium	X		X	X	X			X							

Table 10-7

SHAPES

PARTIAL LISTING OF SPECIFICATIONS

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM	MILITARY	FEDERAL
												*ASME SAME AS ASTM WITH PREFIX "S" USED			
Rhenium Alloys Molybdenum-Rhenium Tungsten-Rhenium	X		X	X	X			X							
Silicon Core "C"					X	X									
Super Invar	X				X	X	X			X					
Tantalum	X			X	X	X	X	X				7849			
Tantalum 10W	X			X	X	X	X					7847 7848			
Titanium (C.P.) A30 35A A40 50A A55 65A A70 75A 100A	X		X	X	X	X	X	X	X	X		4900 4901 4902 4921 4941 4942 4951	B265 B337 B338 B348 F-67	T-7993 T-9046 T-9047 T-12117	
Titanium 4A1-3Mo-1V	X				X	X	X			X		4912 4913		T-9046 T-9047	
Titanium 4A1-4Mn	X									X		4925		T-9047	
Titanium 5A1-2.5Sn	X		X	X	X	X	X			X		4909 4910 4924 4953 4966 4926	B265 B348 B-367	T-9046 T-9047 F-83142	
Titanium 6A1-2Sn-4Zr-2Mo	X			X	X	X	X			X		4975 4976		T-9046 T-9047	
Titanium 6A1-2Sn-4Zr-6Mo	X									X		4981			
Titanium 6A1-4V	X		X	X	X	X	X			X		4906 4907 4911 4928 4930 4954 4956 4965 4967	B265 B338 B367	T-9046 T-9047	
Titanium 6A1-6V-2Sn	X			X	X	X	X			X		4918 4970 4971 4978	B381	T-9046 T-9047 F-83142	
Titanium 7A1-4Mo	X			X						X		4970		T-9047	
Titanium 8Mn	X			X	X	X						4908		T-9046	
Titanium 8A1-1Mo-1V	X			X	X	X	X			X		4915 4916 4972 4973		T-9046 T-9047	
Titanium 13.5V-11Cr-3A1	X				X	X	X			X		4917		T-9046 T-9047	
TPA	X									X					
Tungsten	X		X	X	X	X	X			X		7899			
Tungsten Base- Heavy Metal	X		X	X						X		7725			

Table 10-8

SHAPES

PARTIAL LISTING OF SPECIFICATIONS

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	*ASME SAME AS ASTM WITH PREFIX "S" USED		MILITARY	FEDERAL
												AMS	*ASTM		
Tungsten-Moly 10% 15% 30% 40% 50%	X				X	X		X							
Tungsten-Thoria 1% 1.5% 2% 4%	X				X	X									
Vascojet 1000(H-11)	X		X	X	X	X	X			X		6437 6485 6487 6488	A681		T-570
Waspalloy	X		X	X	X	X	X	X		X	685	5544 5586 5704 5706 5707 5708 5709 5828	A461 A637		
Zirconium	X		X	X	X	X	X			X			B350		
Zircalloy No. 2	X		X	X						X			B350		
Zircalloy No. 4	X		X	X						X			B350		
201	X				X	X	X				201		A412 A429 A-666	S-17998	S-766
202	X				X	X	X			X	202		A314 A412 A429 A473 A-666		S-763 S-766
301 Sheet/Strip in All Tempers Annealed ¼H ½H ¾H FH	X				X	X	X			X	301	5517 5518 5519	A167 A177 A264 A314 A368 A666	S-5059 T-6695	S-682 S-763 S-766
302 Bars Available in Condition "B" Sheet/Strip in Various Tempers	X	X	X	X	X	X	X	X	X	X	302	5515 5516 5560 5565 5636 5637 5688	A167 A177 A217 A240 A264 A276 A296 A313 A314 A366 A473 A478 A479 A492 A493 A511 A580 A666	S-853 S-854 S-862 S-5059 S-7720 S-22216 S-46044 T-5677 W-6712	S-763 S-766 S-854 W-423
303 Bars Available in Condition "B"	X	X	X	X						X	303	5640	A194 A314 A320 A473 A581 A582	S-853 S-862 S-7720 W-52263	S-763 S-764
303-SE Bars Available in Condition "B"	X	X	X	X						X	303-SE	5640 5641 5738	A194 A314 A320 A473 A511 A581 A582	S-7720 W-52263	S-763 S-764
304 Bars Available in Condition "B"	X	X	X	X	X	X	X	X	X	X	304	5501 5513 5560 5565 5566 5567 5639 5697	A167 A177 A193 A213 A240 A249 A269 A270 A271 A276 A312 A313 A14 A320 A336 A358 A376 A409 A430 A473 A478 A479 A492 A493 A511 A580 A632 A666	F-20138 P-1144 S-853 S-854 S-862 S-4043 S-5059 S-7720 S-18170 S-18171 S-23195 S-23196 T-6845 T-8504 T-8506 T-16063 W-17481	S-763 S-766 W-423

Table 10-9

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM (*ASME SAME AS ASTM WITH PREFIX "S" USED)	MILITARY	FEDERAL
304-L	X	X	X	X	X	X	X	X	X	X	304-L	5511 5647	A167 A213 A240 A249 A269 A276 A312 A314 A473 A478 A479 A511 A580 A632	S-853 S-854 S-862 S-4043 S-18170 S-18171 S-22216 S-23195 S-23196 T-16063	S-763 S-766
305	X	X	X	X	X	X	X	X		X	305	5514 5685 5686	A167 A176 A240 A249 A276 A313 A314 A473 A478 A492 A493 A511 A580	W-3068 W-17481	S-423 S-763 S-766 W-409 W-423
309	X	X	X	X	X	X	X	X		X	309		A167 A249 A276 A312 A314 A358 A409 A473 A511 A580	E-19933 R-5031 S-862	S-763 S-766
309-S	X	X	X	X	X	X	X	X		X	309-S	5523 5574 5650	A167 A240 A276 A314 A473 A511 A580		S-763 S-766
310	X	X	X	X	X	X	X	X	X	X	310	5521 5572 5577 5651 5694 5695	A167 A182 A213 A249 A264 A276 A298 A312 A314 A336 A358 A409 A473 A511 A580 A632	E-19933 N-15721 R-5031 S-853 S-854 S-862 S-22216 W-17481	S-763 S-766 W-423
314	X	X	X	X	X	X	X			X	314	5522 5652	A276 A314 A473 A580		
316	X	X	X	X	X	X	X	X	X	X	316	5524 5573 5648 5690 5691	A167 A182 A193 A194 A213 A240 A249 A269 A276 A298 A312 A313 A314 A320 A336 A358 A376 A409 A430 A473 A478 A492 A580 F-55 F-56	E-16715 E-19933 S-854 S-862 S-1144 S-5059 S-7720 W-17481	S-763 S-766 W-423
316-L	X	X	X	X	X	X	X	X	X	X	316-L	5507 5653	A167 A182 A213 A240 A249 A269 A276 A298 A312 A314 A473 A478 A479 A511 A580 A632	E-19933 R-5031 S-862 S-7720	S-763 S-766
317	X	X	X	X	X	X	X	X	X	X	317		A167 A240 A249 A269 A276 A298 A312 A314 A409 A473 A478 A511 A580 A632	E-19933 S-862	S-763
317-L					X	X	X				317-L		A167 A240		

Table 10-10

SHAPES — PARTIAL LISTING OF SPECIFICATIONS

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	AISI	AMS	*ASTM	MILITARY	FEDERAL
												*ASME SAME AS ASTM WITH PREFIX "S" USED			
321	X	X	X	X	X	X	X	X	X	X	321	5510 5557 5559 5570 5576 5645 5689	A167 A182 A193 A194 A213 A240 A249 A254 A269 A271 A276 A312 A314 A320 A336 A358 A376 A409 A430 A473 A479 A493 A511 A580 A632	E-19933 P-1144 S-853 S-862 S-6721 S-22216 T-6721 T-6737 T-8606 T-8808	S-763 S-766
322	X									X					
329	X		X	X		X	X			X	329		A268 A511		
330	X				X	X	X		X	X	330	5592 5716	B511 B512 B535 B536 B546		
333	X					X	X			X		5593 5717			
347	X	X	X	X	X	X	X	X	X	X	347	5512 5556 5558 5571 5575 5646 5654 5674 5680 5681	A167 A182 A193 A213 A240 A249 A269 A271 A276 A312 A314 A320 A336 A358 A376 A409 A430 A473 A479 A493 A511 A580 A632	E-16715 E-19933 R-5031 S-853 S-862 S-6721 S-18063 S-18170 S-18171 S-23195 S-23196 T-6737 T-8606 T-8808 T-18286	S-763 S-766
348	X	X	X	X	X	X	X	X	X	X	348		A167 A182 A213 A240 A249 A269 A276 A312 A314 A358 A376 A409 A473 A479 A580 A632 A692	S-6721 S-18171 S-23195 S-23196	S-766
403	X		X	X	X	X	X	X		X	403 814	5611 5612	A176 A276 A314 A473 A511 A580	S-861 S-862	S-763
405	X		X	X	X	X	X	X		X	405	5628	A176 A240 A268 A276 A314 A473 A511 A580	S-861 S-862	S-763
409					X	X	X	X			409		A176 A268 A651		
410	X	X	X	X	X	X	X	X	X	X	410 814	5504 5505 5591 5612 5613 5776 5777 5821	4176 A182 A193 A240 A268 A276 A314 A336 4473 A493 A511 A579 A580	E-19933 S-854 S-861 S-862 W-17481	S-763 S-766 W-423
414	X		X	X				X		X	414	5615	A276 A314 A473 A511 A580	S-862	S-763

Table 10-11

TYPE	SHAPES: ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	PARTIAL LISTING OF SPECIFICATIONS: AISI	AMS	*ASME SAME AS ASTM WITH PREFIX "S" USED: 'ASTM	MILITARY'	FEDERAL
416	X	X	X	X			X			X	416	5610 5611	A193 A276 A314 A473 A581 A582	S-853 S-854 S-861 S-862 W-52263	S-763 S-764
416-SE	X	X	X	X						X	416SE	5610	A276 A314 A473 A581 A582	W-52263	S-763 S-764
420	X		X	X	X	X	X			X	420	5506 5621	A276 A314 A473 A580	S-853 S-862 S-8142 W-17481	S-763 S-764 S-766 w-409 w-423
420-F	X									X	420-F	5620	A276 A314 A473		S-764
422	X									X	422 616	5655	A437 A565 A579	S-861	
429	X				X	X	X	X		X	429		A176 A240 A268 A276 A314 A473 A493	S-763 S-766	
430	X	X	X	X	X	X	X	X		X	430	5503 5627	A176 A240 A263 A268 A276 A314 A314 A473 A493 A511 A580	S-853 S-854 S-862 W-17481	S-763 S-766 W-423
430-F	X	X	X	X						X	430-F	5620	A276 A314 A473 A581 A582	S-862 W-52263	S-763 S-764
431	X	X	X	X				X		X	431	5628	A276 A314 A473 A493 A579 A580	S-18732 S-86213	S-763
440-A	X	X	X	X				X		X	440-A	5631	A276 A314 A331 A473 A511 A580	S-862	S-763
440-B	X	X	X	X						X	440-B		A276 A314 A473 A580	S-862	S-763
440BM					X	X									
440-C	X	X	X	X			X			X	440-C 617	5618 5630	A276 A314 A473 A493 A580	S-862	S-763
440-F	X	X	X	X						X	440-F 617	5632		S-862	S-763
442					X	X	X				442		A176		S-763
446	X		X	X	X	X	X	X	X	X	446		A176 A268 A276 A314 A473 A511 A580	S-862 S-13336	S-766
501	X				X	X	X		X	X	501	5502 5602 5614	A182 A193 A314 A473 A357		
502	X				X	X	X	X		X	502	5466 5467	A213 A298 A314 A473		
D6AC	X		X	X		X	X	X		X		6431		S-8949	

Table 10-12

TYPE	SHAPES: ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING	PARTIAL LISTING OF SPECIFICATIONS: AISI	AMS	*ASTM	MILITARY	OTHERS AVAILABLE: FEDERAL	COMPANY
												*ASME SAME AS ASTM WITH PREFIX "S" USED				
H-11 (Vascojet 1000)	X		X	X	X	X	X			X	610	6437 6485 6487 6488	A681		T-570	HBO-160-001 MMS-260 EMS-642 PWA 726
Hy-Tuf	X			X						X		6418		S-7108		DMS-1841
4130	X	X	X	X		X	X	X	X	X	4130	6350 6351 6361 6362 6370 6371 6373	A274 A304 A322 A331 A372 A505 A519 A646	S-6758 S-16974 S-18729 T-6731 T-6736	S-624 S-626 S-627 S-629 S-671 T-825	B5F16 B5OR141
4140	X	X	X	X		X	X	X	X	X	4140	6376 6379 6381 6382 6390 6395	A193 A274 A304 A320 A322 A331 A434 A505 A519 A547 A646	S-5626 S-13049 S-16974	S-624 S-627 S-671	B5OR42
4330 MOD.	X		X	X						X		6411 6427	A292 A293	S-6699		BMS-7-27 BMS-7-122 EMS-96242 FMS-1012 GM-1010 CE-0906
4340	X	X	X	X	X	X	X	X	X	X	4340	6359 6414 6415	A274 A304 A320 A322 A331 A505 A519 A547 A646	S-5000 S-8699 S-8844 S-16974 S-21515	S-624 S-627 S-671	B5OR210 B5OT1041 B5OT1133 B5OTA306 BMS-7-28 DMS-1555 EMS-641 STM-05-502
4620	X									X	4620	6294	A274 A304 A322 A331 A505 A535	S-866 S-7493	S-624 S-671	
6150	X				X	X	X	X		X	6150	6448 6450 6455	A80 A231 A237 A274 A304 A322 A331	S-8503 S-16410 S-18731 S-20145 S-46033 W-22826	S-624 S-627 S-671 S-625 W-412	
8620	X							X		X	8620	6274 6276 6277	A274 A304 A322 A331	S-8690 S-16974	S-624 S-626 S-671	B5OR168
8740	X				X	X	X	X		X	8740	6322 6323 6325 6327 6358	A274 A304 A322 A331	S-6049	S-624 S-629 S-625	B5OR160
9310	X		X	X				X		X	9310	6260 6265 6267	A274 A304 A322 A331	S-7393	S-624	B5OR183 B5OA315
51100	X									X	51100	6443 6446 6449	A274 A295			
52100	X							X		X	52100	6440 6441 6444	A274 A295 A322 A505 A519 A535 A642	s-980 S-7420	S-624 S-771 S-778	B5OR173 PWA 723
A2	X		X	X				X		X	A2		A681		T-570	
D2	X		X	X				X		X	D2		A681		T-570	
D6	X		X	X						X	D6					
H11	X		X	X	X	X	X			X	610	6437 6485 6487 6488	A681		T-570	HBO-160-001 MMS-260 EMS-642 PWA 726

Table 10-13

SHAPES — PARTIAL LISTING OF SPECIFICATIONS

TYPE	ROUND	HEXAGON	SQUARE	FLAT	STRIP	SHEET	PLATE	TUBING	PIPE	FORGING		*ASME [illegible] ... PREFIX "S" USED			
											AISI	AMS	ASTM	MILITARY	FEDERAL
Alloy #25 (L-605)	X		X	X	X	X	X			X	670	5537 5759 5796 5797	F-90	R-5031 E-6844	
V-57	X									X	663				
N-155 (Multimet)	X	X	X	X	X	X	X	X		X	661	5531 5532 5585 5768 5769 5794 5795	A461 A567 A639	R-5031 E-6844	
PH 13-8 MO	X		X	X			X			X		5629 5840	A564		
15-5 PH	X	X	X	X			X			X		5658 5659	A564		
15-7 MO	X				X	X	X			X	632	5520 5657 5812 5813	A461 A564	S-8955	
16-25-6	X				X	X	X			X	650	5725 5727 5728	A457 A458 A477	S-16538	
17-4 PH	X	X	X	X	X	X	X	X		X	630	5604 5622 5643 5825 5827	A461 A564	C-24111 S-862 S-22216 S-81506	S-763
17-7 PH	X		X	X	X	X	X	X		X	631	5528 5529 5568 5644 5673 5824	A313 A461 A564	S-25043 W-46078	S-763 S-766
17-22(A)	X							X		X	601	6304	A193	S-11595	
17-22(AS)	X					X	X	X		X	602	6302 6385			
Haynes Alloy 188	X				X	X	X			X		5608 5772 5801			
19-9 DL	X				X	X	X	X		X	651	5526 5527 5579 5720 5721 5722	A453 A457 A458 A477	S-46042	
19-9 DX	X				X	X	X			X	652	5538 5539 5723 5724	A457 A458 A477		
21-6-9	X				X	X	X			X		5595 5656	A276 A580	T-8821	
22-4-9							X								
22-13-5	X									X		5764			
M-252					X	X				X	683	5551 5756 5757	A637		
Alloy R-235	X									X	686				

Table 10-14

METHOD OF INDICATING SURFACE TEXTURE ON DRAWINGS

Surface roughness values Ra — Metric in µm	Surface roughness values Ra — Inches in µ inch	Old Standard		New Standard		
50	2000	N12 ▽	▽ coarse	N12 ▽/	sight and 'feeler' comparison using surface patterns.	Roughness Test
25	1000	N11 ▽		N11 ▽/		
12.5	500	N10 ▽		N10 ▽/		
6.3	250	N9 ▽▽	▽▽ medium	N9 ▽/		
3.2	125	N8 ▽▽		N8 ▽/		
1.6	63	N7 ▽▽		N7 ▽/		
0.8	32	N6 ▽▽▽	▽▽▽ fine	N6 ▽/		
0.4	16	N5 ▽▽▽		N5 ▽/	with surface measuring instruments.	
0.2	8	N4 ▽▽▽		N4 ▽/		
0.1	4	N3 ▽▽▽▽	▽▽▽▽ very fine	N3 ▽/		
0.05	2	N2 ▽▽▽▽		N2 ▽/		
0.025	1	N1 ▽▽▽▽		N1 ▽/		

Table 10-16

DECIMAL CHART

FRACTIONAL INCHES CONVERTED TO
DECIMAL INCHES AND MILLIMETERS

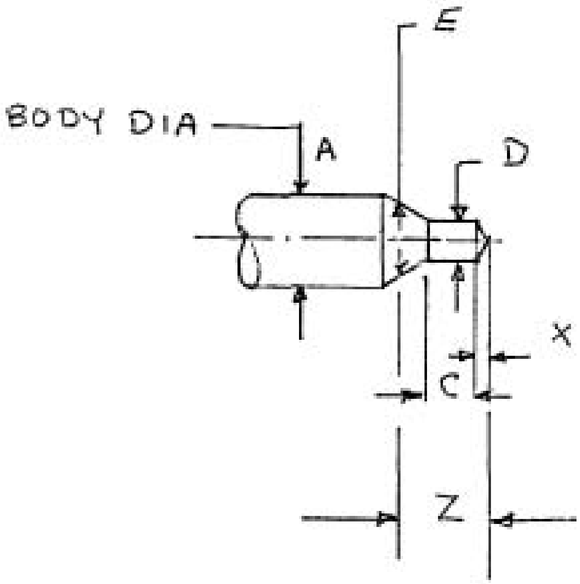
Fraction of Inch	Decimal of Inch	Decimal Millimeters	Fraction of Inch	Decimal of Inch	Decimal Millimeters
1/64	.015625	0.39688	33/64	.515625	13.09690
1/32	.03125	0.79375	17/32	.53125	13.49378
	.03937	1.			
3/64	.046875	1.19063	35/64	.546875	13.89065
				.55118	14.
1/16	.0625	1.58750	9/16	.5625	14.28753
5/64	.078125	1.98438	37/64	.578125	14.68440
	.07874	2.		.59055	15.
3/32	.09375	2.38125	19/32	.59375	15.08128
7/64	.109375	2.77813	39/64	.609375	15.47816
	.11811	3.			
1/8	.125	3.17501	5/8	.625	15.87503
				.62992	16.
9/64	.140625	3.57188	41/64	.640625	16.27191
5/32	.15625	3.96876	21/32	.65625	16.66878
	.15748	4.		.66929	17.
11/64	.171875	4.36563	43/64	.671875	17.06566
3/16	.1875	4.76251	11/16	.6875	17.46253
	.19685	5.			
13/64	.203125	5.15939	45/64	.703125	17.85941
				.70866	18.
7/32	.21875	5.55626	23/32	.71875	18.25629
15/64	.234375	5.95314	47/64	.734375	18.65316
	.23622	6.		.74803	19.
1/4	.25	6.35001	3/4	.75	19.05004
17/64	.265625	6.74689	49/64	.765625	19.44691
	.27559	7.			
9/32	.28125	7.14376	25/32	.78125	19.84379
				.7874	20.
19/64	.296875	7.54064	51/64	.796875	20.24067
5/16	.3125	7.93752	13/16	.8125	20.63754
	.31496	8.		.82677	21.
21/64	.328125	8.33439	53/64	.828125	21.03442
11/32	.34375	8.73127	27/32	.84375	21.43129
	.35433	9.			
23/64	.359375	9.12814	55/64	.859375	21.82817
				.86614	22.
3/8	.375	9.52502	7/8	.875	22.22504
25/64	.390625	9.92189	57/64	.890625	22.62192
	.3937	10.		.90551	23.
13/32	.40625	10.31877	29/32	.90625	23.01880
27/64	.421875	10.71565	59/64	.921875	23.41587
	.43307	11.			
7/16	.4375	11.11252	15/16	.9375	23.81255
				.94488	24.
29/64	.453125	11.50940	61/64	.953125	24.20942
15/32	.46875	11.90627	31/32	.96875	24.60630
	.47244	12.		.98425	25.
31/64	.484375	12.30315	63/64	.984375	25.00318
1/2	.5	12.70003	1	1.	25.40005
	.5118	13.			

Table 10-16

APPROXIMATIVE EQUIVALENT HARDNESS — CORRESPONDANCE APPROXIMATIVE DES DURETES

BRINELL		ROCKWELL						SHORE	TENSILE
		Standard Scale				Superficial Scale			
Indentation 3000 Kg. 10 mm. Carb. Ball	Hardness number	"A" 60 Kg.	"B" 1/16" Ball	"C" 150 Kg.	15-N "Scale"	"Scale"	"Scale"		
....	....	85.6	....	68.8	93.2				
....	....	85.3	....	67.5	93.0	84.0	74.8	..	
....	....	85.0	....	67.0	92.9	83.6	74.2	95	
....	....	84.7	....	66.4	92.7	83.1	73.6	93	
....	....	84.4	....	65.9	92.5	82.7	73.1	92	
2.25	745	84.1	....	65.3		82.2	72.2	91	
....	733	83.8	....	64.7		81.7	71.8	90	
....	722	83.4	....	64.0	91.8	81.1	71.0	88	
2.30	712	....	....	....	....	....	....	....	
....	710	83.0	....	63.3	91.5	....	70.2	87	
....	698	82.6	....	62.5	91.2				
....	684	82.2	....	61.8	91.0	79.1	68.6	....	
2.35	682	....	....	61.7	91.0	79.0	68.5	84	
....	670	81.8	....	61.0	90.7	78.4	67.7	83	....
....	656	81.3	....	60.1	90.3	77.6	66.7	....	....
2.40	653	81.2	....	60.0	90.2	77.5	66.5	81	....
....	647	81.1	....	59.7	90.1	77.2	66.2	....	....
....	638	80.8	....	59.2	89.8	76.8	65.7	80	329
....	630	80.6	....	58.8	89.7	76.4	65.3	....	324
2.45	627	80.5	....	58.7	89.6	76.3	65.1	79	323
2.50	....	80.0	....	58.1	89.2	76.2	64.5	78	318
....	601	79.8	....	58.0	89.0	75.1	64.0	77	309
....	....	79.6	....	57.3	89.0	75.1	63.5	76	300
2.55	578	79.1	....	56.0	88.4	73.9	62.1	75	297
2.60	558	78.8	....	55.6	88.1	73.5	61.6	74	293
....	555	78.4	....	54.7	87.8	[illegible]	[illegible]	73	285
2.65	....	78.0	....	54.0	87.5			72	279
....	534	77.8	....	53.5	87.2	71.6	59.2	71	274
2.70	519	77.1	....	52.5	86.7	70.7		70	263
....	514	76.9	....	52.1	86.5	70.3		69	261
2.75	502	76.7	....	51.6	86.3	69.9	56.9	68	259
....	495	76.5	....	51.1	86.0	69.6	56.2	67	254
....	485	76.3	....	51.0	85.9	69.4	56.1	66	253
2.80	477	75.9	....	50.3	85.6		55.2	65	247
....	467	75.6	....	49.6	85.3	68.2	54.5	64	243
2.85	461	75.1	....	48.8	84.9	67.4	53.5	....	237
....	452	74.9	....	48.5	84.7	67.2	53.2	63	235
2.90	444	74.3	....	47.2	84.1	66.0	51.7	62	226
....	438	74.2	....	46.1	84.0	65.8	51.5	61	225
2.95	429	73.4	....	45.7	83.4	64.6	49.9	60	217
3.00	415	72.8	....	44.5	82.8	63.5	48.4	59	210
3.05	401	72.0	....	43.1	82.0	62.3	46.9	58	202
3.10	388	71.4	....	41.8	81.4	61.1	45.3	56	195
3.15	375	70.6	....	40.4	80.6	59.9	43.6	55	188
3.20	363	70.0	....	39.1	80.0	58.7	42.0	54	102
3.25	352	69.3	(110.0)	37.9	79.3				
3.30	341	68.7	(109.5)	36.6	78.6	....	....	....	....
3.35	331	68.1	(108.5)	35.5	78.0	55.4	37.8	50	
3.40	321	67.5	(108.0)	34.3	77.3	54.3	36.4	48	166
3.45	311	66.9	(107.5)	33.1	76.7	53.3	34.4	46	160
3.50	302	66.3	(107.0)	32.1	76.1	52.2	33.8	45	150
3.55	293	65.7	(106.0)	31.0	75.5	51.2	32.4	44	145
3.60	285	65.3	(105.5)	29.9	75.0	50.3	31.2	43	141
3.65	277	64.6	(104.5)	28.8	74.4	49.4	29.9	41	137
3.70	269	64.1	(104.0)	27.6	73.7	48.3	28.5	40	133
3.75	262	63.6	102.0	26.6	73.1	47.3	27.3	39	129
3.80	255	63.0	101.0	25.4	72.5	46.2	26.0	38	126
3.85	248	62.5	100.5	24.2	71.7	45.1	24.5	37	122
3.90	241	61.8	100.0	22.8	70.9	43.9	22.8	36	118
3.95	235	61.4	99.0	21.7	70.3	42.9	21.5	35	115
4.00	229	60.8	98.2	20.5	69.7	41.9	20.1	34	111
4.05	223	....	97.3	....	....	....	....	....	....
4.10	217	....	96.4	....	....	....	....	33	105
4.20	207	....	94.6	....	....	....	....	32	100
4.30	197	....	92.8	....	....	....	....	31	95
4.40	187	....	90.7	....	....	....	....	29	90
4.50	179	....	89.0	....	....	....	....	21	87
4.60	170	....	86.8	....	....	....	....	26	83
4.70	163	....	85.0	....	....	....	....	25	79
4.80	156	....	82.9	....	....	....	....	24	76

Table 10-17



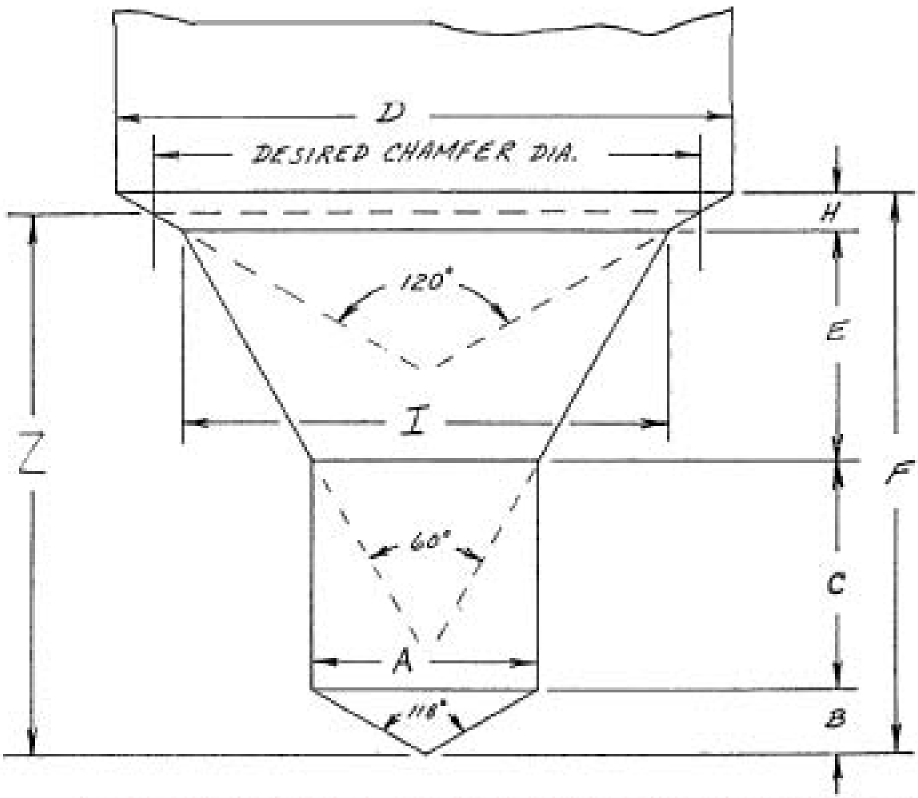
PLAIN CENTER DRILL DESIGNATION	DESIRED CENTER SIZE	DEPTH 'Z' FOR SPECIFIC 'E' SIZE	DRILL DIA.	DRILL LENGTH	BODY DIA.	POINT LENGTH
	E	Z	D	C	A	X
# 1	.06	.072	.047	.047	1/8	.014
# 1	.09	.098	.047	.047	1/8	.014
# 2	.12	.136	.078	.078	3/16	.022
# 2	.18	.187	.078	.078	3/16	.022
# 3	.20	.219	.109	.109	1/4	.032
# 6	.31	.363	.218	.218	1/2	.065
# 6	.40	.441	.218	.218	1/2	.065
AIRCRAFT SERIES	.04	.044	.025	.025	1/16	.007

Center Drill 'Z' Depth for programming on N/C & CNC Machines

Table 10-18

BELL TYPE CENTER DRILLS

$$Z = \left[\left(\frac{\text{DESIRED CHAMFER DIA.} - I}{2}\right) \div \tan 60^\circ\right] + B + C + E$$



SIZE	"A"	"B"	"C"	"D"	"E"	"F"	"H"	"I"	TYPICAL "Z"'S FOR GIVEN APPLICATIONS
#11	.047	.014	.047	.125	.046	.114	.007	.100	
#12	.063	.019	.063	.188	.075	.168	.011	.150	
#13	.094	.028	.094	.250	.092	.228	.014	.200	
#14	.109	.033	.109	.313	.122	.282	.018	.250	
#15	.156	.047	.156	.438	.168	.396	.025	.350	
#16	.188	.056	.188	.500	.184	.457	.029	.400	
#17	.219	.066	.219	.625	.243	.564	.036	.500	
#18	.250	.075	.250	.750	.303	.671	.043	.600	

Table 10-19

TABLE 1-36 Recommended Stock Removal for Hot-rolled or Cold-drawn Alloy-Steel Bars Subject to Magnetic-Particle Inspection

Hot-rolled size, in	Min stock removal from the surface,* in	Cold-drawn size, in
To 1/2, incl.	0.030	To 7/16, incl.
Over 1/2 to 3/4, incl.	0.045	Over 7/16 to 11/16, incl.
Over 3/4 to 1, incl.	0.060	Over 11/16 to 15/16, incl.
Over 1 to 1 1/2, incl.	0.075	Over 15/16 to 1 7/16, incl.
Over 1 1/2 to 2, incl.	0.090	Over 1 7/16 to 1 15/16, incl.
Over 2 to 2 1/2, incl.	0.125	Over 1 15/16 to 2 7/16, incl.
Over 2 1/2 to 3 1/2, incl.	0.156	Over 2 7/16 to 3 3/8, incl.
Over 3 1/2 to 4 1/2, incl.	0.187	Over 3 3/8 to 4 3/8, incl.
Over 4 1/2 to 6, incl.	0.250	
Over 6 to 7 1/2, incl.	0.312	
Over 7 1/2 to 9, incl.	0.375	
Over 9 to 10, incl.	0.437	

*For example, the minimum reduction in diameter of rounds is twice the minimum stock removal from the surface.

Table 10-20

Chapter 11

LIST OF USEFUL BOOKS

The list on the next page is reproduced with permission from the Ash Gear & Supply Co. (Catalog number 96).

The AGMA publication list (refer to Tables 11-1through 11-7), is of specific interest to Gear Engineers.For those who want to study specific gear subjects in detail, the attached bibliography will be helpful. Practical information in this book and in the Ash Gear Company's Catalog will enable Manufacturing Engineers to select the correct tools and to process gears with confidence.

List of Useful Books related to Gears

1. Trigonometry Tables and Involute Functions published by Illinois Tool Co.
2. Involutometry and Trigonometry By Dr. Eng Werner F. Vogel
3. Machinery's Handbook by Erik Oberg, Franklin D. Jones and others
4. Gear Handbook: Design, Manufacture and Application of Gears by D. W. Dudley
5. Handbook of Practical Gear Design by D. W. Dudley
6. Gear Design, Manufacturing & Inspection Manual ISBN 1-56091-006-2
7. Student's Shop Reference Book by Edward G. Hoffman
8. Metal Cutting Handbook by U.S. Cutting Tool Institute
9. Evolution of Gear Art by D. W. Dudley
10. Technical Shop Mathematics by John G. Anderson
11. Blueprint Reading Basics by Warren Hammer
12. Application of Metal Cutting Theory by Fryderyk E. Gorczya

13. Machine Shop Training Course by Franklin D. Jones
14. Machine Shop Practice by Karl H. Moltrecht
15. Manual of Gear Design by Earle Buckingham and Elliot Buckingham
16. Tables for Recess Action Gears by E. K. Buckingham
17. Metals Black Book Ferrous Edition ISBN 0-9696428-0-6
18. Geometry of Involute Gears by J. R. Colbourne
19. Handbook of Dimensional Measurement by Francis T. Farago
20. Design of Worm & Spiral Gears by Earle Buckingham and Henry H. Ryffel
21. Analytical Mechanics of Gears by Earle Buckingham (paperback)
22. Gear Handbook -Design and Calculations by Alec Stokes
23. Gear Design Simplified by Franklin D. Jones and Henry H. Ryffel
24. Basic Machining Reference Handbook by Arthur R. Meyers and Thomas Slattery
25. ISO 9000 Book by Quality Resources
26. Gear Geometry and Applied Theory by F .L. Litvin
27. Design Guide for Involute Splines by Robert W. Cedoz
28. Involute Splines and Inspection by the SAE and the ASME
29. Metric Module Involute Splines
30. AGMA Publications and Technical Papers

A.G.M.A. PUBLICATIONS (PARTIAL LIST)*

AG 110 **ANSI/AGMA 110.04.** *Nomenclature of Gear Tooth Failure Modes*, identifies and describes the classes of common gear failures, and illustrates degrees of deterioration. This will enable the user to distinguish between cause and effect, and assist in choosing a remedial course of action.
ISBN: 1-55589-001-6 Pages: 23

AG 115 **AGMA 115.01.** Reference Information - Basic Gear Geometry, illustrates important geometrical relationships with the intention of providing a sound basis for a thoroughly logical and comprehensive system of gear geometry.
ISBN: 1-55589-004-0 Pages: 25

AG 118 **AGMA 118.01.** *Information* Sheet - Gear Tooth Surface Texture for Aerospace Gearing (Surface Roughness, Waviness, *Form and Lay*), discusses surface texture of gear teeth and provides data on dimensions of roughness height waviness height and form height and definitions of roughness, waviness and form. The definitions are concerned with the conditions of the tooth surfaces, and are independent of the tooth surfaces, and are independent of the methods of measuring or the effects of the surface geometry on gear performance.
ISBN: 1-55589-006-7 Pages: 16

AG 120 **AGMA 120-01.** Gear-Cutting *Tools* Fine and Coarse-Pitch Hobs, provides specifications for nomenclature, dimensions, tolerances and inspection of coarse-and fine-pitch gear hobs.
ISBN: 1-5589-007-5 Pages: 32

AGMA 141-01. Plastics *Gearing-Molded, Machined, and Other Methods*, A Report on the State of the Art, aids those not fully familiar with plastic gearing. This paper enables one to become familiar with the methods of processing, the technical terms employed, and to learn in general how plastics gearing can be effectively use.
ISBN: 1-55589-008-3 Pages: 16 withdrawn

AGMA '170.01. Design Guide *for* Vehicle *Spur and Helical* Gears, is a guide to *the* design, fabrication, and inspection of vehicle spur and helical gears. It also covers the design of spur and helical gears used for power transmission on vehicles.
ISBN: 1-55589-009-1 Pages: 38 Replaced by 6002-B93

AG 201 **ANSI/AGMA 201.02.** Tooth Proportions for Coarse-Pitch Involute Spur Gears. Presents tooth proportion information required in designing spur gearing with 20 degree and 25 degree pressure angle full-depth tooth forms. The basic rack is used for specifying gear tooth proportions so that cutting tools can be designed to closely approximate this form regardless of the generating method used in manufacture.
ISBN:1-55589-010-5 Pages: 21

AG 203 **AGMA 203.03.** Fine-Pitch *On-Center Face* Gears *for 20* Degree *Involute Spur Pinions*, covers design of face-gear pairs in which: a) the axis of the gear and pinion intersect at an angle of 90 degrees, b) the gear is generated by means of a reciprocating pinion-shaped cutter having the same diametral pitch and pressure angle and is substantially the same size as the mating pinion and c) in which the pinion is made in accordance with AGMA Standard 270.05, Tooth Proportions for Fine-Pitch Involute Spur and Helical Gears.
ISBN: 1-55589-012-1 Pages: 23

AGMA 207.06. Tooth *Proportions* Fine-Pitch Involute *Spur and* Helical Gears, includes spur and helical gearing of 20 through 120 diametral pitch with tooth proportions of 20 degree pressure angle and having 7 or more teeth. Tooth proportions shown will also be found suitable in many instances for gear designs of finer than 120 diametral pitch.
ISBN: 1-55589-015-6 Pages: 20 Replaced by 1003-G93

AG 297 **AGMA 297.02.** Sound for Enclosed Helical, Herringbone and Spiral Bevel Gear Drives, describes a recommended method of acceptance testing and reporting of the sound pressure levels generated by a gear speed reducer or increaser. Other influences such as the prime mover, driven equipment, environment, mounting and system effects are discussed, An Appendix is included use in those instances where sound power levels are required.
ISBN: 1-55589-032-6 Pages: 27

AGMA 298.01. Sound for *Gearmotors* and In-Line Reducers *and* Increasers, was developed to provide improved communication between purchaser, gear manufacturer, and user in the areas of sound instrumentation, measurement and test procedures; as well as providing guidelines as to typical sound levels which can be expected from the applicable product.

Table 11-1

A.G.M.A. PUBLICATIONS (CONTINUED)

Because of the wide variation of system responses in various acoustical environments, this standard attempts to indicate certain areas where special considerations might be necessary and must be agreed upon between purchaser and gear manufacturer.
ISBN: 1-55589-033-4 Pages: 11 Replaced by 6025-C90

AG 299 AGMA 299.01. Gear Sound Manual: Section 1, Fundamentals of Sound and Related to Gears. Noise measurement and control on gear driven equipment is dependent upon the individual characteristics of the prime mover, gear unit, and driven machine–as well as their combined effects as a system in a particular acoustical environment. Because of the wide variation of gear driven systems and acoustical environments, this Manual attempts to indicate certain areas where special considerations might be necessary and must be agreed upon between purchaser and gear manufacturer when discussing gear sounds.
ISBN: 1-55589-034-2 Pages: 14

AGMA 341.02. Design of general Industrial Coarse-Pitch Cylindrical Wormgearing, covers the design of cylindrical worms and throated gears mounted with axes at a 90 degree angle and having axial pitches of 3/16 inch and larger.
ISBN: 1-55589-041-5 Pages: 10 Replaced by 6022-C93

AG 370 AGMA 370.01. Design Manual for Fine-Pitch Gearing, was compiled to provide a central source of information available on the design, manufacture and inspection of fine-pitch gearing. In various revisions of several other fine-pitch Standards, much design data previously shown have been omitted. The data omitted was considered to be of an informative nature which was not subject to standardization. Accordingly, this data, brought up to date, and additional data, is now presented in this Manual in the form of information sheets.
ISBN: 1-55589-044-X Pages: 120

ANSI/AGMA 374.04. Design for Fine-Pitch Wormgearing. Fine-pitch wormgearing is segregated from coarse-pitch wormgearing for a number of specific reasons that are described in this document.
ISBN: 1-55589-045-8 Pages: 30 withdrawn

AG 390 AGMA 390.03a. Handbook-Gear Classification. Materials and Measuring Methods for Bevel, Hypoid, Fine Pitch Wormgearing and Racks Only as Unassembled Gears, correlates gear quality levels with gear tooth tolerances. It provides information on gear measuring methods and practices. It provides guidance on specifying quality levels and materials and also contains information on tooth contact patterns and backlash.
ISBN: 1-55589-401-8 Pages: 68
(For Spur, Helical and Master Gears - see ANSI/AGMA 2000-A88)

AGMA 421.06. Practice for High Speed Helical and Herringbone Gear Units, includes design, lubrication and rating for helical and herringbone external tooth parallel shaft speed reducers or increasers. Units covered include those operating with pinion speeds of 3600 rpm and higher, or pitch line velocities of 5000 feet per minute and higher.
ISBN: 1-5589-049-0 Pages: 22 Replaced by 6011-G92

AG 422 AGMA 422.03. Practice for Helical and Herringbone Speed Reducers for Oilfield Pumping Units, is a method for rating the pitting resistance and bending strength of helical and herringbone gears for oilfield pumping unite reducers. Also included is a static torque rating and information on lubrication, shafting, and bolting.
ISBN: 1-55589-050-4 Pages: 44

AG 910 AGMA 910-C90. Formats for Fine-Pitch Gear Specification Data, consists of a series of printed forms for gear drawings that contain the appropriate data to be tabulated by the designer for the manufacturer. Included are definitions of the tabulated items. Contains blank, easily copied, preprinted forms.
Pages: 29

AG 1003 ANSI/AGMA 1003-G93. Tooth Proportions for Fine-Pitch Spur and Helical Gearing. This standard, a revision of AGMA 207.06, provides a system of enlarged pinions which use the involute form above 5 degrees of roll for 20 degree profile angle fine pitch gearing. Included are data on 14-1/2 and 25 degree profile angle systems. $55.00
Pages: 32

AG 1012 ANSI/AGMA 1012-F90. Gear Nomenclature. Definitions of Terms with Symbols. provides the agreed upon definitions and usage for terms, symbols and abbreviations used by the gear industry as well as terms commonly used in gear load rating. Terms have been incorporated from AGMA 112.05 and AGMA 116.01.
Pages: 64

Table 11-2

A.G.M.A. PUBLICATIONS (CONTINUED)

AG 2000 **AGMA 2000-A88.** (Partial Replacement of AGMA 390.03) Gear Classification and inspection Handbook - Tolerances and Measuring Methods for Unassembled Spur and Helical Gears (Including Metric Equivalents), correlates gear quality levels with gear tooth tolerances. It provides information on manufacturing procedures as well as master gears measuring methods and practices. Appendix material provides guidance on specifying levels and information on additional methods of gear inspection.
ISBN: 1-55589-495-X Pages: 128

AG 2001 ***AGMA 2001-B88.** (Revision of 218.01 1982) Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth. presents a comprehensive method for rating the pitting resistance and bending strength for spur and helical involute gear pairs. Detailed discussions of factors influencing gear survival and calculation methods are provided.
ISBN: 1-55589-502-6 Pages: 75

AG 2002 ***AGMA 2002-B88.** (Revision of 231.52) Tooth Thickness Specification and Measurement, presents procedures for determining tooth thickness measurements of external and internal cylindrical involute gearing. It includes equations and calculation procedures for the commonly used measuring methods. A specific tooth thickness measurement limit can be established from the design thickness or from another tooth thickness measurement.
ISBN: 1-55589-503-4 Pages: 47

AG 2004 **ANSI/AGMA 2004-B89.** Gear Materials and Heat Treatment Manual, provides information pertaining to engineering materials and material treatments used in gear manufacture. Topics include definitions, selection guidelines, heat treatment, quality control. life considerations and a bibliography. The material selection includes ferrous, nonferrous and nonmetallic materials. Wrought, cast, and fabricated gear blanks are considered. The heat treatment section includes data on through hardened, flame hardened, induction hardened, carburized, carbonitrided, and nitrided gears. Quenching, distortion, and shot peening are discussed. Quality control is discussed as related to gear blanks, process control, and metallurgical testing on the final products. Revision of AGMA 240.01.
Pages: 78

AG 2005 **ANSI/AGMA 2005-B88.** Design Manual for Bevel Gears, provides the standards for the design of straight bevel, zerol bevel, spiral bevel and hypoid gears along with information on fabrication. inspection and mounting. Topics include preliminary design parameters, blank design including standard taper, uniform depth, duplex taper and tilted root. Gleason. Klingelnberg and Oerlikon machine tools are covered. Also included are rating, strength. drawing format. inspection, materials, lubrication. mountings and assembly. Revision of AGMA 330.02. Also replaces AGMA 202.03, 208.03 and 209.04.
Pages: 115

AG 6002 **ANSI/AGMA 6002-B93.** Design Guide for Vehicle Spur and Helical Gears. This standard is a guide to design approaches for vehicle gear applications. This new standard addresses the selection of design considerations for the parallel axis gear sets required in vehicle drive lines. These include tooth and blank proportions, lubrication, profile and lead modification requirements, and gear tooth tolerances, update of AGMA 170.01. $60.00
Pages: 48

AG 6022 **ANSI/AGMA 6022-C93.** Design manual for cylindrical wormgearing. this design manual covers the design of fine and coarse pitch cylindrical wormgearing operating at right angles and primarily made as gear sets to be incoporated into other machines and mechanisims.
ISBN 1-55589-618-9 pages: 35

AG 6023 ***AGMA 6023-A88** (see AGMA 6123-A88 for metric version) AGMA Design Manual for Epicyclic Gear Drivers, is a design manual for drives employing epicyclic drives, nomenclature, application information and design guidelines with reference to other AGMA standards.
ISBN: 1-55589-604-2 Pages: 50

AG 6030 **ANSI/AGMA 6030-C87.** (Supercedes AGMA 342.02) Design of General Industrial Double-Enveloping Wormgears, provides design of Double-Enveloping wormgears mounted with axes at a 90 degree angle.
ISBN: 1-55589-493-3 Pages: 11

*A COMPLETE GUIDE TO PUBLICATIONS IS AVAILABLE UPON REQUEST FROM ASH GEAR OR DIRECT FROM AGMA IN ALEXANDER, VA.

Table 11-3

A.G.M.A. TECHNICAL PAPERS

AG 85-1 AGMA 85FTM1. Load Carrying Capacity of Bevel Gears According to DIN Standard
Authors: H. Winter-M. Paul
DIN-Standard (DIN 3991, Draft March 1985) for the calculation of the load capacity of bevel gears contains the calculation of tooth root strength, pitting and scuffing load resistance. The bevel gears are approximated by virtual cylindrical gears. The specific properties of bevel gears are considered by special influence factors. To check results obtained by the method with field experience, a number of comparative calculations have been performed. Results are compared with results obtained by the new AGMA calculation is conservative compared wih DIN method.
ISBN: 1-55589-094-6 Pages: 13

AG 85-2 AGMA 85FTM2. Bevel Gear Rating Using the New Standard-AGMA 2003-A86 (formely known as AGMA 2 19) Part I, General Gearing; Part II, Vehicle Gearing
Author: W. Coleman
Outlined is one method for determining the design torque, depending upon application and other available information used in selecting the preliminary gear size based on both pitting resistance and bending strength. The various torque values to be used in the calculations in the AGMA Standard 2003-A86 are defined. Included are graphs for selection of a preliminary gear size and a numerical example of calculations.
ISBN: 1-55589-095-4 Pages: 32

AG 85-3 AGMA 85FTM13. Identification of Gear Noise with Single Flank Composite Measurement
Author: R.E. Smith
This is a guide for the application of single flank composite inspection to the solution of gear noise problems. It includes a discussion of the relationship of transmission error to gear noise, housing dynamics, spectral analysis and how it is used in problem-solving situations. Several case histories are described.
ISBN: 1-55589-106-3 Pages: 20

AG 85-5 AGMA 85FTM15. Hardcutting-A competitive Process in High Quality Gear Production
Authors: R.P. Schwaighofer - A. Kaelin
the MAAG Hard Cutting process finishing of case-hardened gears and the range of its application, properties of the machine, tools, methods and cutting conditions are discussed. Practical results underline the quality and performance achieved by this process.
ISBN: 1-55589-098-9 Pages: 10

AG 86-1 AGMA 86FTM1. Describing Nonstandard Gears - an Alternative to the Rack Shift Coefficient
Author: Donald R. McVittie
The rack shift method of describing gears made with nonstandard addendum diameters (tip diameters) to nonstandard tooth thickness has serious limitations, since the nominal pitch of the cutting tool, required for the calculation of rack shift coefficient, may not be available to the designer, may vary with tool sharpening, or may be different for the gear's mate.
Detail calculations of rack shift coefficient are not standardized, so there is little agreement between analysis about the values of "x" for a given nonstandard gear. Two common methods to calculate rack shift coefficient are described in this paper.
ISBN: 1-55589-465-8 Pages: 23

AG 86-4 AGMA 86FTMA4. High Precision Gear Grinding
Author: Hagen Hofmann
Describes the large gear grinding machines operating under wet grinding conditions. Gears are ground to Navy standards in sizes up to 160 inches in diameter with all conceivable lead and profile modifications. A new dressing system is introduced. Integrated lead and profile measuring equipment for the in process inspection of gears on the grinding machine is presented.
ISBN: 1-55589-468-2 Pages: 8

AG 86-5 AGMA 86FTM5. The Interrelationship of Tooth Thickness Measurements as Evaluated by Various Measuring Techniques
Author: Paul M. Dean, Jr.
Tooth Thickness as established by measurements made by conventional gear measuring techniques: Over Pins, the Span Measurement, or with a Gear Tooth Vernier Caliper, does not always agree with the "Effective Tooth Thickness," (the value "seen" by the mating gear). Methods of adjusting the specified value of Measured Tooth Thickness to assure that the required value of Effective Tooth Thickness will not be exceeded are discussed.
ISBN: 1-55589-469-0 Pages: 12

Table 11-4

A.G.M.A. TECHNICAL PAPERS

AG 86-7 AGMA 86FTM7. *Complete* Checking Operation of Gear Hobs Using a Multi-Coordinate *Checking Center*
Author: Dipl.-Ing. Siegfried Franke - Dr.-Ing. Gert Goch-Dr. Ing. Franz Schubert
Coordinate checking instruments are particularly suitable for objective determination of deviations in form and position on component surfaces. A gear hob is used as an example to show a variety of checking possibilities, checking times, the output of results and the opportunities for checking operation sequence to be controlled by the operator.
ISBN: 1-55589-471-2 Pages: 16

AG 87-2 AGMA 87FTM2. The Geometric Design of Internal Gear Pairs
Author: John R. Colbourne
The Paper describes a procedure for the design of internal gear pairs, which is a generalized form of the long and short addendum system. The procedure includes checks for interference, tip interference, undercutting, tip interference during cutting, and rubbing during cutting.
ISBN: 1-55589-478-X Pages: 13

AG 87-4 AGMA 87FTM4. Gear Tooth profile *Determination* From *Arbitrary* Rack Geometry
Author: Sandeep M. Vijayakar-Biplab Sarkar - Donald R. Houser
A method is described for obtaining gear tooth profiles from geometry of the rack (or hob) used to generate it. This method works for arbitraly rack geometries, including the case when only a numerical description of the rack is available. Examples of a simple rack with protuberance and a hob with root chamfer are described. The application of this technique to the generation of boundary element models for the frictional contact analysis of gear pairs is also described.
ISBN: 1-55589-480-1 Pages: 13

AG 87-6 AGMA 87FTM6. The Relationship of Measured Gear Noise to Measured Gear Transnission Errors
Author: Robert E. Smith
This Paper deals with the instrumented testing of noise in the system and how to successfully relate the results back to the measured transmission errors in the gears. The difficulty in establishing the relationship of how to compare visually displayed sound analysis data to aural judgements of a human, and then relate the results back to measured transmission errors.
ISBN: 1-55589-482-8 Pages: 10

AG 87-7 AGMA 87FTM7. Crowned Spur Gears: *Optimal Geometry* and *Generation*
Author: Faydor L. Litvin - Jiao Zhang - Wei-Shing Chaing - John J. Coy - Robert F. Handschuh
A method to synthesize the pinion crowned surface that provides a localized bearing contact and a favorable type of transmission errors for misaligned gears is presented. A method for generating crowned surfaces by a surface of revolution (it slightly deviates from a regular cone surface) is proposed. Tooth Contact Analysis (TCA) programs for simulation of meshing and bearing contact for misaligned spur gears with the crowned pinions and graphic program for the display of the pinion crowned tooth surfaces in 3D space is discussed.
ISBN: 1-55589-483-6 Pages: 8

AG 87-13 AGMA 87FTM13. *A* Concept for Using Controlled *Shot Peening* Original Gear Design
Author: James Daly
With new materials, such as austempered ductile iron, dramatic increases in fatigue strength have been recorded. Peening can increase fatigue strength of case hardened carburized gears by 20 percent and increase the pitting fatigue resistance in the pitch line area by over 50 percent. Recent developments in the control of shot peening with the aid of a microprocessor afford the designer the opportunity to take credit for these improvements. The methods used in turbine engine components taking these improvements into design calculations are reviewed.
ISBN: 1-55589-489-5 Pages: 4

AG 87-14 AGMA 87FTM14. *Contact* Surface Topology *of Worm* Gear Tooth
Author: William L Janninck
An enveloping wormgear is generally evaluated by the contact pattern developed with a qualified worm. Patterns show the area of minimal separation between the worm and worm gear surfaces. The Actual form beyond the contact area is unknown. A mathematical modelling procedure is given to predict the initial contact pattern as well as the surface separation topology. Equations and procedures are presented to permit and analysis for any gear set and tool design parameters.
ISBN: 1-55589-490-9 Pages: 16

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Table 11-6

A.G.M.A. TECHNICAL PAPERS

AG 87-16 AGMA 87FTM16. New *Methods of Integrated Computerized* Design and *Manufacturing of High* Speed *Gearing*
Authors: Dr. -Ing. Manfred Hirt • Dr. -Ing. Toni Weiss
High-speed gearing is discussed using load capacity criteria and methods to analyze vibration and noise behavior. The calculation procedures are followed by application of CAD/CAM for drawings and numerically controlled manufacturing of gear units.
ISBN: 1-55589-492-5 Pages: 21

AG 91- 91FTMS1. The Element Stress Analysis of a Generic-Spur Gear Tooth. Author: E. A. Tennyson. The prediction of bending stresses in a gear tooth, resulting from an externally applied torque, requires special consideration when designing spur gear systems. The tooth geometry is such that excess risers exist which must be accounted for. In addition, variables affecting the exact load point on the tooth and the direction of the applied load are critical. An interactive preprocessor is developed which generates all the information, including a detailed tooth profile, necessary to perform a finite element bending stress analysis of the gear system. To validate the procedure, a test group of spur gears is identified and analyzed. The results are compared to those obtained via the American Gear Manufacturers Association (AGMA) standards. The comparison revealed the finite element stresses to be slightly more conservative than corresponding AGMA standard stresses. A generalized stress equation and geometry factor, based on the finite element approach, are also introduced. This paper is intended only as a proof of concept.
Pages: 9

AG 91-10 91FTM10. Dynamic Measurements of Gear Tooth Friction and Load. Authors: B. Rebbechi, F. Oswald, and D. Townsend. A program to experimentally and theoretically study fundamental mechanisms of gear dynamic behavior is being conducted at the NASA Lewis Research Center in support of a joint research program between NASA and the U. S. Army. This paper presents the results of dynamic tooth-fillet strain gage measurements from the NASA gear-noise rig, and it introduces a technique for using these measurements to separate the normal and tangential (friction) components of the load at the tooth contact.
Pages: 11

AG 91-15 91FTM15. Gear Hardness Technology. Authors: M. Broglie and D. Smith. As demands on the gear designer to make gearing that is smaller, lighter and more reliable increases so does the demand for better materials and hear treat processes. Proper hardness of a gear, both in the tooth and in the body is becoming increasingly critical since load carrying capacity is dependent on hardness. The scope of this paper is limited to the most common methods of heat treating steel gearing; however, there are many methods of heat treatment in wide use throughout the industry.
Pages: 12

AG 91-16 91FTM16. Contact Analysis of Gears Using a Combined Finite Element and Surface integral Method. Authors: S. M. Vijayakar and D. R. Houser. Describes a new method for solving the contact problem in gears. The method uses a combination of the finite element method and a surface integral form of the Bousinesq and Cerruti solutions. Numberical examples are presented for contacting hypoid, helical, and crossed axis helical gears.
Pages: 10

AG 92-7 92FTM7. Differences in the Local Stress of the Gear Tooth Root Based on Hobbing Cutters and Pinion Cutters. Authors: H. Linke and J. B. Homer. Differences in tooth root geometry are caused if a pinion shaped cutter is used in gear production instead of a hob. These differences also lead to a different stress concentration in the tooth root. Tooth root stresses are calculated with the Singularity Method for both production methods and their differences are discussed. The approximate calculation of stress concentration with the stress parameter (on 30' tangent) is proved to be applicable.
Pages: 10

AG92-8 92FTM8. The Role of Reliability for Bearing and Gears. Authors: C. Moyer. Details the experimental basis for the relationship between stress (load), life and reliability for bearings and gears considering the similarity and differences of their respective systems. The role of stress level and life scatter in terms of the Weibull distribution are addressed. The background and equations to calculated reliability factors. as included in both bearing and gear standards, are then developed.
Pages: 6

Table 11-6

A.G.M.A. TECHNICAL PAPERS AVAILABLE FROM ASH GEAR

AG 92-1 spur gear tooth design where each tooth has a thought hole made on its center line in a direction parallel to the gear axis. Static and dynamic analyses were carried out to study the effect of hole size and location. The studies indicate that for the same load contact stresses in a hollow-solid mesh are lower than that of a solid-solid mesh. Dynamic loads in a hollow-solid mesh are the same as that of a solid-solid mesh with the same damping.
Pages: 25

AG 97-3 97FTM3. High Efficiency Gear Hobbing. Authors: G. Ashcroft and B. Clull. Discusses the design advances of disposable gear cutting tools, specifically those which have produced the non-resharpenable Wafer hob, the application of the tools, and the benefits derived from applying these tools in gear manufacturing. The concurrent development of hobbing machines capable of efficiently applying these tool designs is also detailed.
Pages: 17

AG 119 P119. *Bibliography on the Measurement and Gaging of Gears*
Author: Bureau of Standards
ISBN: 1-55589-297-3 Date: 1943 Pages: 31

AG 238 P238. *Involute Gear Calculations Simplified*
Author A. H. Candee
ISBN: 1-55589-190-X Date: 1945 Pages: 7

AG 239 P239.01. *The Span System of Measuring Involute Gear Tooth Sire*
Author: J.E. Van Acker
ISBN: 1-55589-298-1 Date: 1954 Pages: 24

AG 240 P239.02. *A Precise Technique for Accurate Checking of Gear Dimensions*
Author: W.S. Tandler
ISBN: 1-55589-299-X Date: 1954 Pages: 10

AG 241 P239.04. *Over-Pin Measurement Tolerances for Various AGMA Classes of Fine-Pitch Gears*
Author: G.W. Michalec
ISBN: 1-55589-301-5 Date: 1957 Pages: 20

AG 255 P255. *The Design of Gear Teeth*
Author: F. Bohle
ISBN: 1-55589-456-9 Date: 1944 Pages: 19

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Table 11-7

Index

A

Addendum, 7, 10-11, 23
AGMA
    Standards, 7, 10-11, 46, 122, 131, 158
    publications, 199-205
    quality numbers, 153-158
Allowances,
    press fit, 85,
    shrink fits, 85
Aluminum gears, 103, 110
Approach, 17
ASA stub tooth system, 23
Ash Gear & Supply Co., 27, 32, 146
Automation, 82-84
Axial pitch, 16

B

Backlash, 7
Barber-Colman Co., 13, 28, 29
Bar stock sizes, 122
Base
    circle, 5
    diameter, 7
    pitch, 7
Bell-type center drills, 116, 195
Bevel gear
    cutting machines, 85
    machine manufacturers, 86
Bibliography, 197-205

C

Cam relief, 17
Carpenter Technology, 118-120
Case depth, 91
CBN (cubic boron nitride) wheels, 48-57
Checking gear sizes, 145-152
    tooth to tooth composite error (TTCE), 157
    total composite error (TTC), 157
Chemical compositions of gear steels, 102-103
Clearance, 7
    side, 17
Circular
    pitch, 10-11
    tooth thickness, 10-11
CNC gear cutting (ref), 28, 50-67
Copper plating for carburization, 112, 127
Cost of manufacturing, 159-170
Cutting gear teeth, methods for, 13-86

D

Dedendum, 7, 10-11, 23
Diametral pitch, (DP), 4, 5, 8, 10-11
Diameter
    outside, 16
    pitch, 16
    root, 16
DIN Standards, 46

F

Face width, 7
Fellows combination-pitch system, 24
Finish, 24
Fillet, 17, 20
Finishes on gears, 171-174
    aluminum gears, 171
        chemical films, 171
        anodizing, 171
    steel gears, 171
        amorphous carbon with tungsten carbide inclusions, 173
        black oxide, 172
        cadmium plating, 174
        electroless nickel, 172
        hard chromium plating, 173
    stainless steel, 171
Flute 16
    depth, 16
Friction, 1
Full fillet system, 10-11

G

Gear
    calculation program, 147
    finishing
        shaving, 20-23, 36-38, 47
    heat treatment, 87, 88
    grinding, 20
        CBN (cubic boron nitride) wheels, 48-57
        machine manufacturers, 46
        form grinding method, 38, 40
        generating method, 38
        threaded wheel method, 38, 44
        generating grinding, 39, 41
        wheels, 48-57
    hobbing, 45
        between centers, 27
        hard, or skiving, 47
        machines, 28
    machine collets, 27
        machine manufacturers, 29-31
    honing, 47
    lapping, 47
    ring gears, 27
    materials, 87
    milling, 31-32
    nomenclature, 5-9
    profile grinding, 39
    quality achievable by machining, 158
    shaping, 32-36
        machine manufacturers, 35-36
        shaving, 20-23, 36-38, 58-67

sizes, checking, 145-152
steels
for gears, 87-88
heat treatment
case hardening, 89
case depth, 91
flame hardening, 92
induction hardening, 93
liquid carburizing (salt bath), 90
normalizing, 88
pack carburizing, 89
nitriding, 91
teeth, methods for cutting, 13-86
teeth chamfer, 20
terminology, 4, 5
tolerance guide, 157
tooth profiles, 5
wire sizes and selection, 9
Gears,
bevel, 3
finishes on, 171-174
ground, 2
helical, 2
hobbed, 2
hypoid bevel, 47
spiral, 2
straight spur, 2
Grinding, 20
Nital etch for crack detection, 112, 131
machine manufacturers, 46
versus shaving and honing, 48
Gleason Works, The, 46, 86

H

Hardening
case, 88-90
flame, 92-93
induction, 93
machine manufacturers, 86
Hardness, 24
Heat treatment
annealing, 93-101
carburizing, 93-101
copper plating for carburizing, 112, 127
normalizing, 93-101
of gear materials, 87-112
of oil-hardening steels, 97-101
quenching fixtures, 125
Helix
angle, 18, 23
normal, 16
Hobbed gears, 1-2
Hobbing
between centers, 27
machines, 28
machine
collets, 27
machine manufacturers, 29-31
ring gears, 27
Hob
active length, 16
addendum, 17
bore size, 16, 27
dedendum, 17
definitions, 16
finishing, 20
flute, 16
length, 16
protuberance, 17, 19, 20
sizes, 27
Hobs, 13-24
classes of, 15
finishing, 15
pre-shave, 18
roughing, 27
semi-finishing, 18
semi-topping, 15
topping, 18
Honing, 47, 67
spheric, 67-80

I

Involute
circle, 20
curve, 5
profile, 14, 32

L

Lead, 16
angle, 16
Line
of action, 7
of centers, 7
Lug, 17

M

Magnetic particle inspection (ref), 118
Manufacturing
cost of 161-168
operations, 113-144
Measurement over wires, 5, 148-152
Measuring gears, 5, 145-152, 147
tooth to tooth composite error (TTCE), 157
total composite error (TTC), 157
Metal Cutting Tool Institute, 15, 16, 18, 21-22
Methods for cutting gear teeth, 13-86
Milling gear teeth, 31-32
Milling cutters, 31-32
Module, 4, 10-11

N

Nital etch, 112
Nitralloy, 92
Noise levels, 1
Nomenclature, 5-9
Normal
circular pitch, 17
diametral pitch, 21-22
helix, 16

pressure angle, 17, 23
tooth thickness, 17

O

Outside diameter, 7

P

Pfauter Co., 13, 28
Pitch
circle diameter, 4
diameter, 7, 8
diametral, 4, 8
point, 7
Precipitation hardening materials, 110-112.118.
120-121
Pre-shave hob tooth dimensions, 20-22
Press-fit allowances, 85
Pressure angle, 4, 5, 7-8,
Processing gears, 113-144
Producibility, 159
Profiles
hobbed, 19
shaved, 19
Protuberance, 17, 19, 20

Q

Quenching fixture, 130

R

Racks, 13, 15
Rack type cutters, 4, 32-33
Ramp, 17
Ratios, 4
Ring gears, 27
Root diameter, 7, 16

S

Shaping
gears, 32-36
tools, 32-36
Shaving gears, 20-23, 36-38
speeds, feeds and stock removal, 37
Shrink fit allowances, 85
Skiving, 47
Spheric honing, 67-80
Splines, 4
Spur gear tooth parts, 8
Steels
for gears, 87-88
heat treatment
case hardening, 89
case depth, 91
copper plating for carburizing, 112
flame hardening, 92
induction hardening, 93
liquid carburizing (salt bath), 90
normalizing, 88
pack carburizing, 89
nitriding, 91
stainless, 110-111
Stock sizes, 122
Stub tooth forms, 23

T

Tables, 175-196
decimal conversion, 192
Bell-type center drills, 195
center drill dimensions, 194
equivalent hardness scales, 193
material shapes, 180-190
stock removal recommendations, 196
surface textures, 191
world stainless steels, 177-179
Tooth
deburring machine manufacturers, 86
elements, 7
face, 16
profiles, 4
thickness at pitch diameter, 8
proportions for various gear systems, 10-11
Tooth to tooth composite error (TTCE), 157
Total composite error (TTC), 157
Types of gears, 1
Terminology, 4,

U

Undercut, 19

V

Van Keuren's handbook, 4, 6, 145

W

Wire
sizes, 9
selection, 9
Wires, measurement over, 5, 148-152
Whole
depth, 7, 10-11
depth of cut, 17
Working depth, 7
worms, 4
Worm wheels, 3

The ART of GEAR FABRICATION

Prem H. Daryani

This in-depth guidebook places emphasis on teaching beginners and advanced planners how to process gears, and will enable manufacturing engineers familiar with machine shop practice to be specialists in the gear manufacturing field. The first few chapters are devoted to common gear nomenclature and analysis of processing of six typical gears, including explanations of the logic and reasoning for every sequence of operation. Subsequent chapters thoroughly describe production, selection of materials, heat treatment, plating, methods of cutting, hobbing, shaping, and grinding.

Unique in content and broad in scope, *The Art of Gear Fabrication* provides beginners with sufficient information to independently process six typical gears step by step and presents model numbers, capacity, and addresses of gear machinery manufacturers and suppliers at the end of each process description. It also offers gear designers practical and useful hints on reducing fabricating costs. And it contains useful tables from commercial catalogs, including cross-references of different U.S. standards and American stainless steel materials with equivalent German, British, French, and Italian materials.

Additionally, it is essential for manufacturing and design engineers to have sufficient knowledge of various heat treatments and their related cost. Though it is a specialty, the author describes this subject in as easy-to-understand manner as possible. Gear designers and entry-level manufacturing and processing engineers in the machine shop field will find this reference extremely helpful and valuable.

ABOUT THE AUTHOR With extensive manufacturing experience worldwide, Prem H. Daryani most recently held senior manufacturing engineer positions at B.F. Goodrich Aerospace, Sier-Bath Gear Co., Thomas & Betts, and Sikorsky Aircraft. In addition to designing, fabricating, and installing the first aluminum rod-rolling mill in India, he oversaw the manufacture of India's first battery-driven forklift truck and 60-ton crane for lifting locomotives. Mr. Daryani was also employed in the German machine tool industry and at a hydraulic turbine manufacturing company in Sweden. He holds a B.E. in Mechanical Engineering from the University of Bombay, India and is presently working as a consultant.

TABLE OF CONTENTS Types of Gears and Processing of Gears. Gear Nomenclature. Methods for Cutting Gear Teeth. Gear Materials and Their Heat Treatment. Processing of Gear Parts. Checking of Gear Size. AGMA Quality Numbers. Producibility. Finishes on Gears. Useful Tables. List of Useful Books. Index.

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