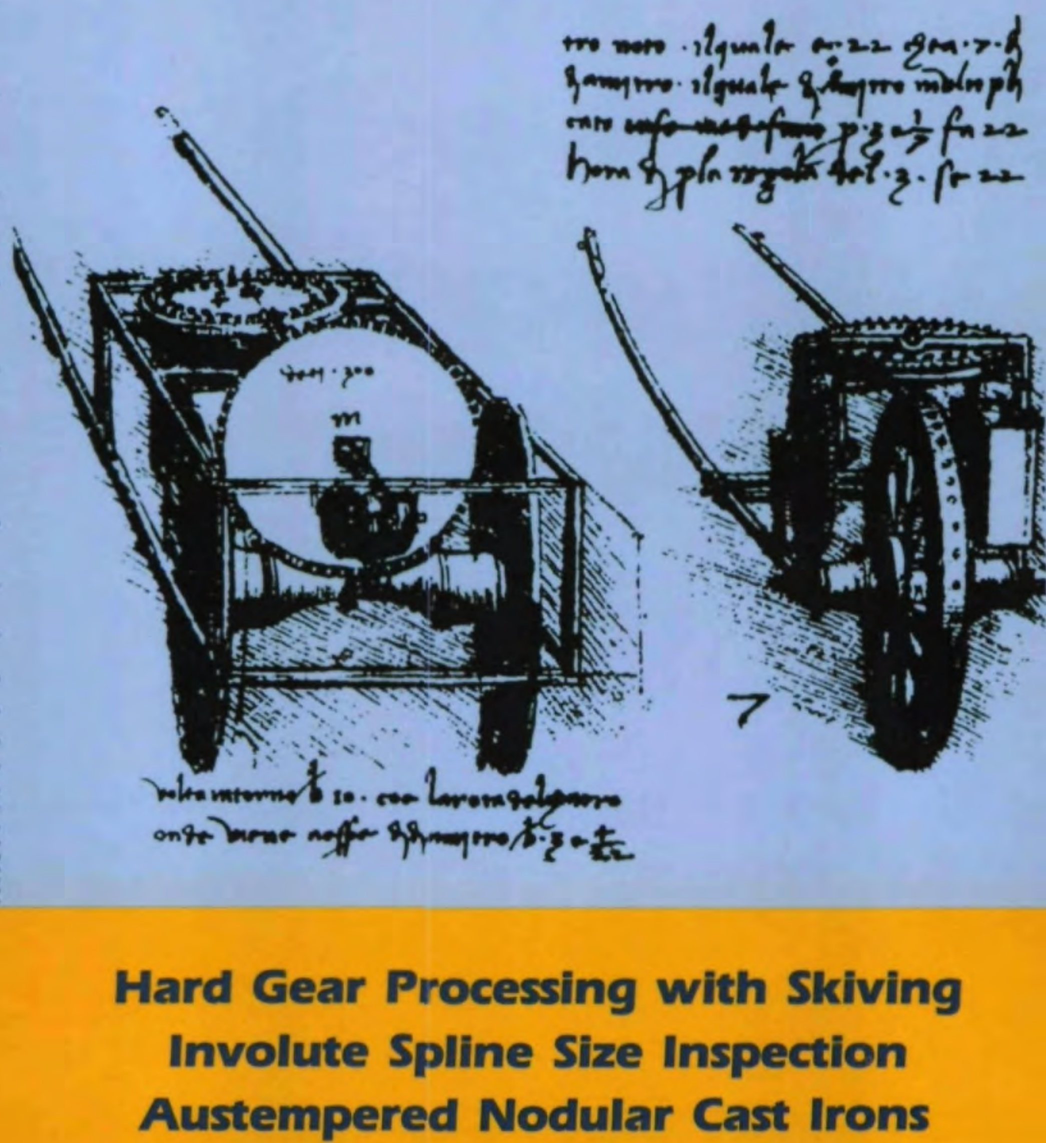
GEAR TECHNOLOGY

The Journal of Gear Manufacturing

MARCH/APRIL 1985



Hard Gear Processing with Skiving

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AMERICAN PFAUTER LIMITED

World-class gearmaking technology in hobbing • grinding • shaping • hard gear finishing • inspection • gear cells and systems

CIRCLE A-1 ON READER REPLY CARD

Can you answer these tough gear processing questions?

1. Is CNC hard finishing of high production gears less expensive than gear shaving?
2. How can you produce gears for grinding without pre-grind shaping or hobbing?
3. Is automatic tool and fixture changing economically justifiable?
4. How flexible are flexible gear manufacturing cells and systems?
5. Can you use a class B hob to finish an AGMA class 12 gear?

If you're not sure, make plans to attend the Gear Process Dynamics Clinic on May 19–21 or October 6–8, 1985. You'll learn how to apply the latest technology to your company's gear manufacturing and measuring problems.

What subjects are covered

- soft and hard gear dynamics
- achievable gear accuracies by machining method
- AGMA and DIN gear tooth element accuracy classifications
- gear noise sources and controls
- measuring methods and practices
- gear cutting/finishing machine kinematics
- multi-thread hobbing
- tool inspection methods
- CNC gear hobbing
- flexible gear manufacturing systems, automation and robotics
- carbide milling and hobbing small and large gears
- hard gear carbide finish skiving
- gear grinding systems
- CBN CNC controlled form grinding of gears and splines . . . and much more

Who should attend

The American Pfauter Gear Process Dynamics Clinic is a two-day intensive course on metal removal and measuring techniques for spur and helical gears. The clinic is structured for manufacturing and process management who have a basic understanding of gear geometry, nomenclature and some gear manufacturing or gear quality assurance experience. The clinic takes an in-depth look at modern methods, practices and hardware in gear manufacturing and measuring, including in-plant demonstrations at American Pfauter's Elk Grove Village plant.

What clinic graduates say

"The selection of material covered was excellent. The visual aids, handouts and actual demonstrations were very good."—Manufacturing Engineer

"Your bound edition of ***Gear Process Dynamics*** *is absolutely first class. Its mere existence sets American Pfauter apart from all competition."—Company President*

"The Gear Process Dynamics Clinic was the most thorough presentation of modern gear technology in the industry. I highly recommend it to everyone."—Shop Superintendent

How to register

The clinic will be held May 19–21 and October 6–8, 1985 at Indian Lakes Resort, Bloomingdale, IL. Please call **312-640-7500** early to reserve your place. To enhance the learning environment, clinic attendance will be strictly limited to 60 people on a first-come, first-served basis. Fee of $450 per person covers clinic and all materials, but *not* hotel accommodations. An acknowledgement letter with hotel and ground transportation information will be sent to all registrants 2 weeks before the clinic. Payment may be made by check or purchase order to: American Pfauter Ltd., 925 East Estes Avenue, Elk Grove Village, IL 60007.

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Hard skived, fully conjugate, spiral bevel gears at cut and lapped prices.

Hard finished gears by the Klingelnberg HPG-S process using BZN* coated blades, meet or exceed the quality of the more expensive ground spiral bevels.

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Whatever your spiral bevel gear needs may be, Klingelnberg can offer a more accurate and cost effective solution on gears to 80 inches in diameter.

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CIRCLE A-3 ON READER REPLY CARD

COVER

The Advanced Technology of
LEONARDO DA VINCI
1452-1519

Many of Leonardo's designs were improvements of existing ideas. His interest in accuracy in all things led him to investigate the measurement of surface distances. The machine on the right is his sketch of the Roman system of measuring the distance traveled by a wheel. The wheel was pushed like a wheelbarrow and as it moved, its projecting teeth meshed with the horizontal gear above. By a series of reducing gears, each one turning slower than the one before, a dial moved to show the distance the wheel had covered. With each revolution, a pebble would drop into the box. The number of pebbles was the measure of distance.

Leonardo simplified this hodometer and arranged it for use on a wagon. On his design on the left, the wagon wheel axle, rather than the wheel itself, would be the first step in the transmission. The gearing reduction is so large that the horizontal wheel turns only once for each mile covered.

GEAR TECHNOLOGY
The Journal of Gear Manufacturing

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DEPARTMENTS

March/April 1985 — Vol. 2, No. 2

SUBSCRIPTION INFORMATION: GEAR TECHNOLOGY is distributed free of charge to **qualified** individuals and firms in the gear manufacturing industry. To continue receiving your subscription, complete and mail the application card found elsewhere in this magazine. Subscription rates for nonqualified individuals and firms are: $30.00 in the United States, $50.00 for foreign countries. Back issues are $7.00 in the United States, $15.00 for foreign countries. Subscription requests to RANDALL PUBLISHING CO., INC., P.O. BOX 1426 Elk Grove, IL 60007.

MANUSCRIPTS: We are requesting technical papers of every sort from manufactured of gear making machinery and related equipment, universities, and engineers. Articles should be of an educational and training nature with general appeal to anyone having anything to do with the purchase of materials or machinery, or the design, manufacture, testing or processing of gears. Subjects sought are solutions to specific problems, explanations of new technology, techniques, designs, processes, and alternative manufacturing methods. These can range from the "How to ..." of gear cutting **(BACK TO BASICS)** to the most advanced technology. All manuscripts submitted will be carefully considered. However, the Publisher assumes no responsibility for the safety or return of manuscripts. Manuscripts must be accompanied by a self-addressed, self-stamped envelope, and be sent to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, P.O. Box 1426, Elk Grove, IL 60007.

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EDITORIAL

BEING FAIR IS A MATTER OF PERSPECTIVE

Photo by Jennifer Short

I recently attended a briefing, arranged by the White House, regarding the Treasury's tax simplification plan. A Treasury Undersecretary explained that their goal was to come up with a tax code that was "fair" to everyone. "For too long," he said, "the tax code has been unfairly favorable to capital intensive 'smokestack' industries" by giving tax credits and fast depreciation." This is most advantageous to companies which require large investments in themselves. To be "fair", they recommended that the Investments Tax Credit (ITC) be eliminated and the depreciation on capital equipment be stretched to seventeen years.

While this obviously satisfies the Treasury's need for "fairness", it is clear that they have not given consideration to the economic consequences of their plan. For example, they improperly try to equate the investment tax considerations for a fifty man law office with that of a fifty man CNC machine shop. In the real economic world, only one or two CNC machines might equal the entire investment of the law office. More importantly, the law firm only competes against other law firms, which are operating under the same investment rules. However, the machine shop owner must also compete with foreign shops whose governments encourage investments to modernize their industries.

There has been a direct parallel between the rate of investment in capital equipment and the availability of Investment Tax Credit. With machine tools having a life of twenty or more years, and investment decisions being projected over long periods of time, we are only now starting to see the positive results of the 1981 Accelerated Cost Recovery System (ACRS), which provided for accelerated depreciation of capital equipment. The 13th annual AMERICAN MACHINIST INVENTORY showed a marked increase in the percentage of less than 10 year old machine tools for the first time, except for World War II, in the 60 year history of the inventory. Productivity, also increasing, was up 4.7 percent in 1984, the biggest one-year gain since 1973.

It is economically imperative that we maintain the ability to manufacture high quality goods at low cost for our own consumption. It is better for this country that a General Motors has the tax incentives to invest five billion dollars in this country, for their Saturn Project, in order to ensure that every year, 500,000 more cars will be built in the U.S. rather than being imported. Doesn't it seem "fair" that General Motors will employ approximately 20,000 workers in their new plant rather than have their cars built in far-off lands?

The harm that will be caused by the elimination of ITC and ACRS goes far beyond our heavy industries. Our high technology industries, which have often been hailed as the best hope for shoring up the U.S. manufacturing base, are starting to be eroded by these same investment problems. 1985 will probably be the first year that the Japanese semiconductor industry invests more money in itself than the U.S. industry, although U.S. chipmakers still maintain a declining 56% to 38% share of world production. For our economic welfare, we must provide the economic incentives for our nation to reinvest in itself; otherwise, we will very shortly find that we have spent and consumed our heritage.

To compensate for the elimination of these investment tax incentives, the Treasury Department stated that taxes for all corporations will be reduced. It will, in reality, RAISE taxes for about ninety percent of the active corporations in the United States. According to the National Small Business Association, 90.1% of U.S. corporations have taxable income of less than $100,000. Those corporations will have their taxes INCREASED BY UP TO 120%. The 9.9% of the corporations having income of more than $100,000 will have their taxes DECREASED BY 28%.

For the near term, the administration is occupied with the deficit, but after that issue is settled, they will turn their attention to tax simplification. If the ITC and ACRS tax incentives are removed, our entire industry, our nation, will be severely and adversely affected. No matter what your job, whether employer or employee, manager or managed, your future is at stake. Now is the time to write your Congressmen and the President and tell them how important ITC and ACRS are to the viability and future of your business and our country.

Michael Goldstein

Editor/Publisher

TECHNICAL CALENDAR

March 11-14	SME — Flexible Manufacturing Systems Show Dallas, Texas
March 19-21	SME — Metalworking Coolants Boston, MA
March 26-27	SME — Buff, Brush & Polish Techniques Orlando, FL
March 28-29	SME — Unique Processes of Deburring Orlando, FL
April 2-3	SME — Production of Holes Itasca, IL
April 9-11	SME — Tool & Manufacturing Engineering Conference & Exposition Hartford, Connecticut
April 22-25	SME — Superabrasives '85 Rosemont, IL
May 7-8	SME — Machining Centers Detroit, MI
May 21-23	SME — Conventional & Wire EDM Chicago, IL
June 2-5	AGMA Annual Meeting The Homestead Hot Springs, VA

AGMA's 1985 Fall Technical Meeting will be held October 14-16, 1985 in San Francisco.

AGMA is soliciting papers for this year's meeting now, to allow time for careful preparation and review.

The schedule for submission and review of papers is:

Submission of abstracts to Headquarters	February 14, 1985.
First draft of paper to Headquarters	April 19, 1985.
Review complete	June 3, 1985.
Complete revision of draft and return to Headquarters	July 3, 1985.
Camera-ready copy to Headquarters	August 16, 1985.

For further information contact:
AGMA — Bob Brown (703) 525-1600
SME — (313) 271-1500

. . . AND FROM THE INDUSTRY

SEIREG ELECTED PRESIDENT GEAR RESEARCH INSTITUTE

The Gear Research Institute (GRI) reelected Dr. Ali Seireg to serve as President of this organization at their November meeting in Naperville, IL. Dr. Seireg, a Professor at the University of Wisconsin, is known around the world for his expertise in gear technology. He has published over 150 papers in the field. He is best known for his interest in computer utilization, vibrations and gear dynamics. Dr. Seireg is author of the book, **Mechanical Systems Analysis,** and has edited and contributed to other books and published on facets of automation, dynamic systems, friction, lubrication and wear, design optimization and biomedical engineering.

To serve with Dr. Seireg, all previous incumbents were reelected. They are Dr. Herbert Chen, Vice President; Mr. John Graham, Treasurer; Mr. Dale Breen, Secretary. At the same meeting, the following were elected to serve as trustees: Walter F. Craig, Morris E. Fine, John Graham, Philip R. Visser, Kenneth F. Packer and Dale Breen. Mr. Breen is also the director of GRI. GRI is a not-for-profit organization dedicated to supporting industry through the development of new, useful technologies. For further information on this organization, contact Dale Breen, GRI, N. Washington at E.W. Tollway, Box 353, Naperville, IL 60566. (312) 355-4200.

SPLINE GAUGES, LTD., ACQUIRED BY ACME-CLEVELAND

Spline Gauges, Limited, a leading manufacturer of master gears, spline and thread gauges in England, has been acquired by Acme-Cleveland Corporation, Cleveland, Ohio.

S.G.L. has the only gauge laboratory in England approved by British Calibration Service and National Physics Lab for calibration and certification of master gears and splines traceable to the United States Bureau of Standards.

Beginning March 1985, S.G.L. products will be marketed in this country through M & M Precision Systems of West Carrollton, Ohio (also an Acme-Cleveland owned company).

SME NAMES MARVIN F. DEVRIES PRESIDENT-ELECT FOR 1985-86

Dr. Marvin F. DeVries, Professor of the Mechanical Engineering Department, University of Wisconsin-Madison, is the 1985-86 President-Elect of the Society of Manufacturing Engineers (SME). Dr. DeVries will be installed at SME's 1985 International Manufacturing Engineering Conference and Exposition in Detroit, May 6-9.

An SME member since 1960, Dr. DeVries has served on numerous international administrative and technical committees. In addition to serving with SME, Dr. DeVries has been elected to three honorary societies and is listed in five Who's Who directories. He is a longtime member of the American Society of Mechanical Engineers, serving in several capacities.

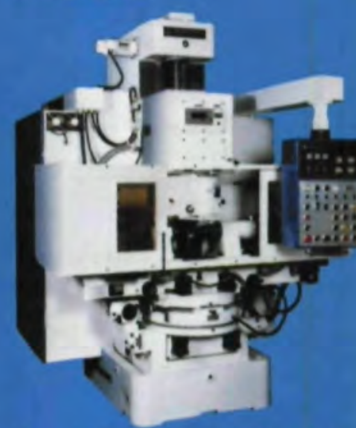
In 1983 he was selected as Director of the Master of Science degree program in Manufacturing Systems Engineering. In 1979 he was named to a Fulbright-Hayes lectureship and spent a year as Visiting Professor at the Cranfield Institute of Technology, England.

SME sponsors a broad spectrum of continuing education programs to benefit manufacturing engineers and technologists including Certification and the Manufacturing Engineering Education Foundation.

Koepfer Gear Hobbing Machine

Karatsu GSM-25 High Speed Gear Shaper

Kashifuji KH-150 NC Hobbing Machine



Kanzaki GSF-400X Gear Shaving Machine

Gear Makers Get More Equipment Choices at Cosa

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Fine Pitch Gear Hobbing
Koepfer Type 143, 153, 173

- High precision
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- Hydro copying device for crowning
- Universal automatic loading magazines
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- Pre-settable control panel, precision digital readout for setting cutter
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Gear Hobbing
Kashifuji KH-150 NC

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- NC control speeds set-up, stores data for up to 150 gears
- Quick-change hob system with auto clamping
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We also offer standard machines and others such as the KH-150 HD carbide hobber, KG-250 hob sharpener and KD-1 gear deburring/chamfering machine.

Gear Checking
Osaka Seimitsu GC-HP Series

- These models cover sizes from 1 mm to 2500 mm pitch diameter
- Full CNC control
- With options, will check all gear elements, including profile, lead, single flank and double flank rolling, pitch (spacing), size, eccentricity, and composite tooth action
- Several machines used in a factory may be controlled by a host computer to provide permanent record of the accuracy

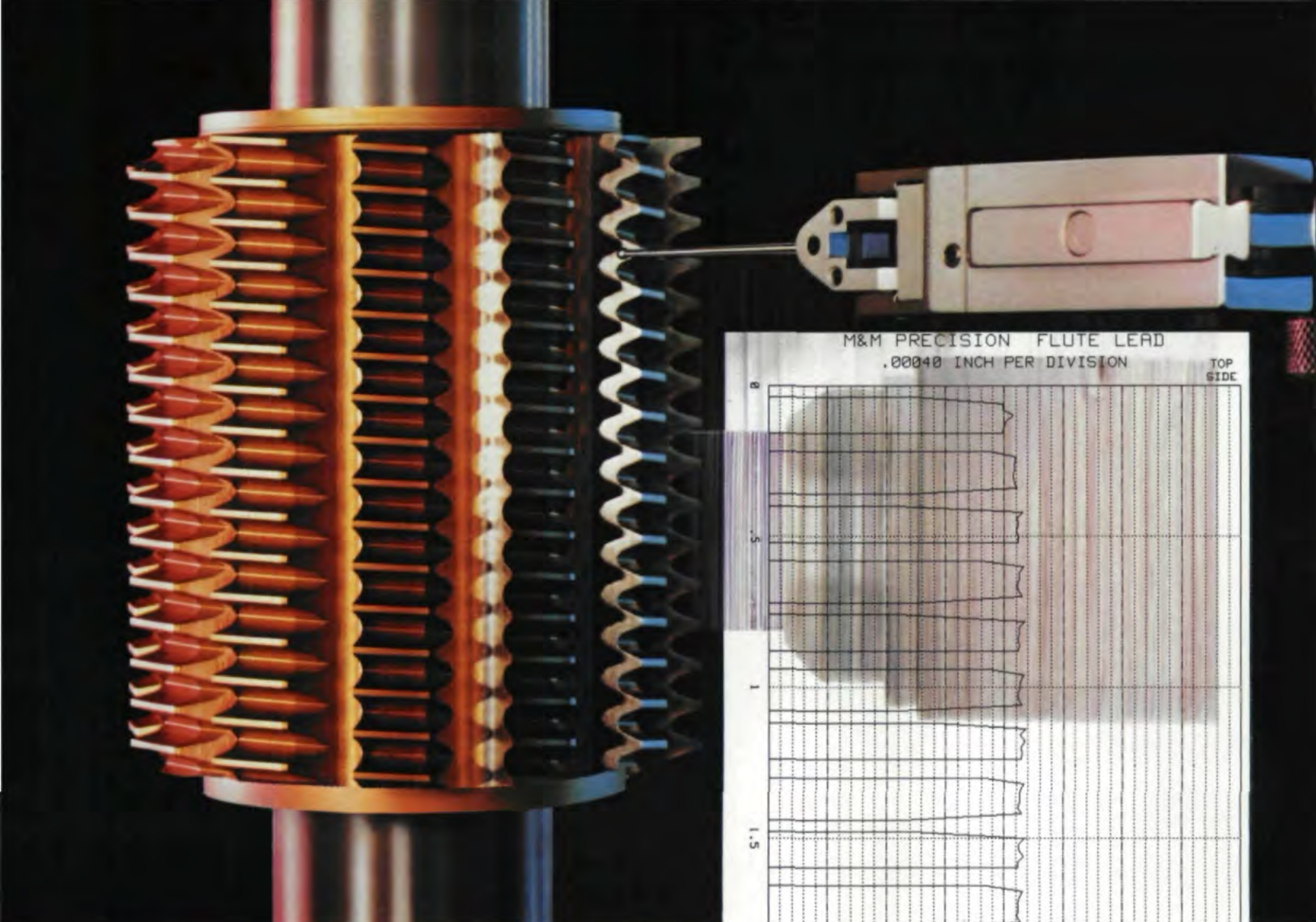
For further information, contact COSA CORPORATION, 17 Philips Parkway, Montvale, NJ 07645, (201) 391-0700.

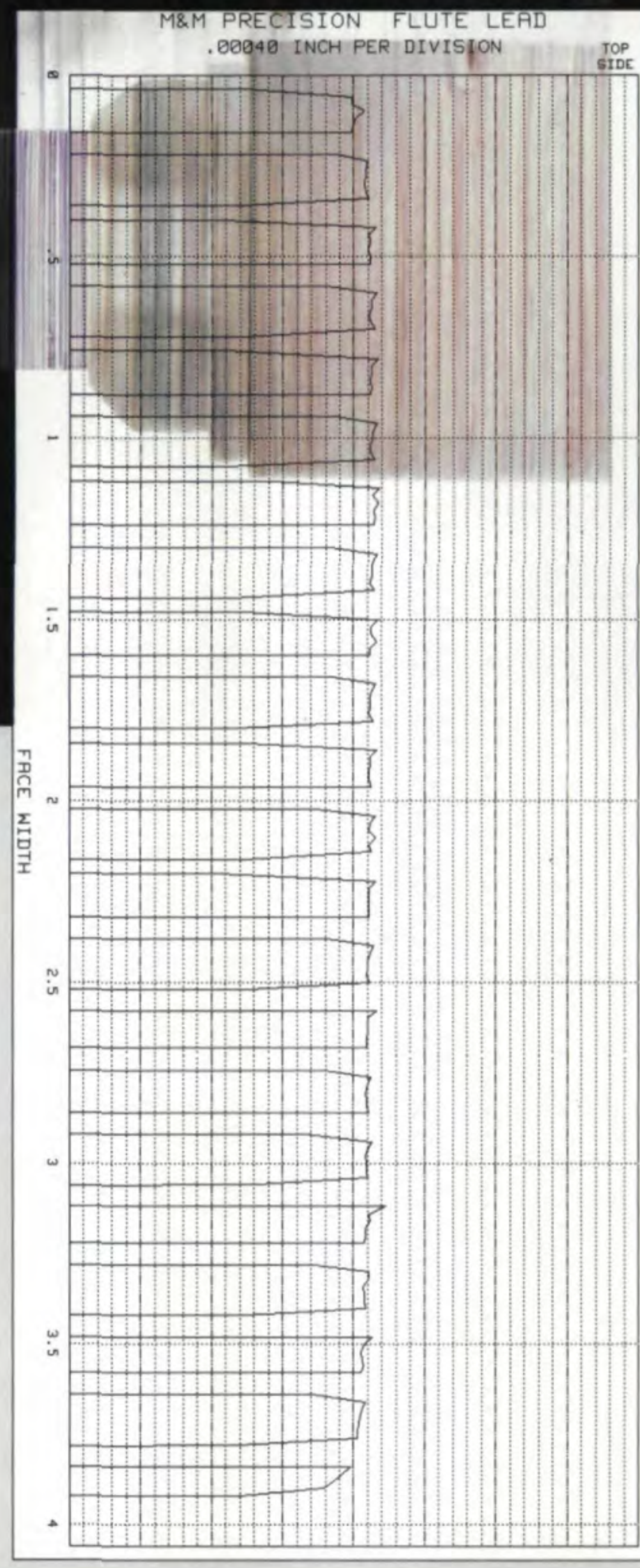
Osaka Seimitsu GC-HP Series CNC Gear Checking Machine

cosa

Gear Group

CIRCLE A-5 ON READER REPLY CARD





M&M PRECISION FLUTE LEAD
.00040 INCH PER DIVISION
TOP SIDE
FACE WIDTH
0
.5
1
1.5
2
2.5
3
3.5
4

Hard Gear Processing with Skiving Hobs

By
William E. Loy
Barber-Colman Co.
Rockford, Illinois

As we approach the problem of hard gear processing, it is well to take a look at the reason for discussing it at this time. In our present economic atmosphere throughout the world, more and more emphasis is being placed upon efficiency which is dictated by higher energy costs. We also see more regulations that encompass the personal environment for workers, which is being translated into more stringent requirements, as far as gear noise is concerned. As we see more activity in these areas, gear designers are being forced to consider the advantages of higher loads, lighter weights, and noise reductions.

The strength and wear resistance in gear teeth may be increased by hardening the tooth and roof fillet surfaces, thereby, making it possible to reduce gear size and increase transmitted load and speed. When going in this direction, there are normally three basic hardening processes that are used to obtain the strength and wear resistance needed in the gear teeth. This is through hardened alloy gears, case hardened gears, and carburized and hardened gears. In all instances, one is faced with either trying to predict the distortions that are to be expected in the hardening process, or to do something to the gears after the hardening process is completed. While it is possible to predict hardened distortions with some degree of succcess where you have large quantities of smaller gears, such a prediction process does not lend itself to larger gears, as they are usually produced in smaller quantities, where some additional work must be done on the gears after hardening.

When discussing skiving by the hobbing process, questions invariably arise as to the meaning of the word "skiving". The origin of the word, as described in Webster's unabridged dictionary, was applied to smoothing hides and removing flesh without gouging or cutting the surface of the hide. To quote Webster, skiving is "to slice, pare, to cut off in thin layers or pieces, shave, to form a smooth joint." This basically leads us to the derivation of the term skiving, and as it applies to skiving hobs, is attributed to the cutting geometry which enables one to cut hardened materials with a thin curled chip and produce a smooth finish.

AUTHOR:

MR. WILLIAM E. LOY *is manager of special products at Barber-Colman Company, Machines and Tools Division. He is a 25 year member of the Society of Manufacturing Engineers and was a member of the AGMA Vehicle Gearing Committee.*

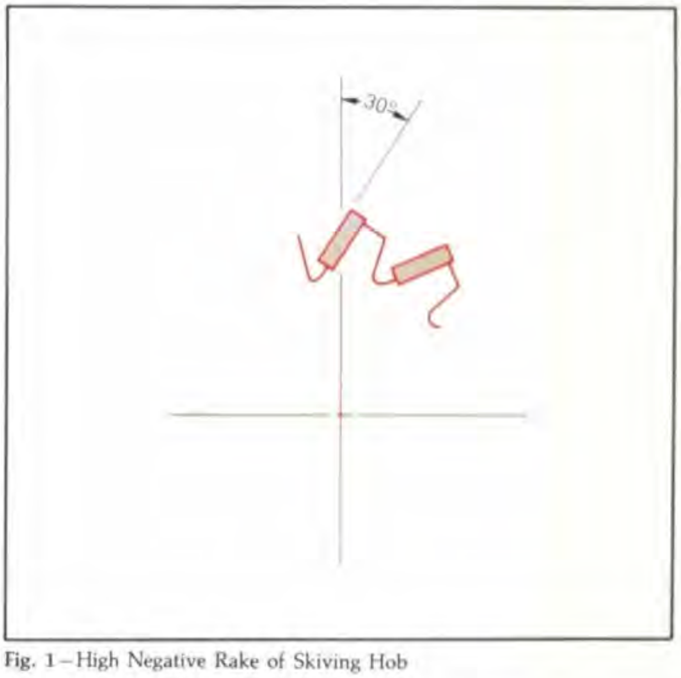


Fig. 1—High Negative Rake of Skiving Hob

One of the first questions asked about finished gears by the skiving hob process is, are the gears too hard? Normally within the range of the hardening processes being used, such is not the case, as the application of the skiving hob can satisfactorily be applied in the range of Rockwell C hardness 40 through 65. It is important to consider that this is a new technology of finish or semi-finishing hardened gears, and the economics of the process should not be compared to hobbing of gears in the soft condition, but rather to the other alternative which is gear grinding. As more distortion is present in the gears, the economics become more and more favorable to the skiving process. The skiving hob is to be used in a manner which allows the hob to cut only on the involute profile of the gear without cutting in the root fillet area of the gear. It is possible to cut the hardened gears in this manner because of a combination of the carbide used and the high negative rake in the hobs (See Fig. 1).

The high negative rake, which imparts a shear cut cutting geometry to the hob, lessens the cutting resistance and shock and decreases vibration. The spiral formation of chips typically insures a very smooth cutting operation. In Fig. 2, we are showing the comparison of the cutting action of a normal hob with zero degree rake and one with 30° negative rake which is the degree of negative rake normally applied to skiving hobs. (On very coarse pitch hobs, 1-1/4 DP and coarser, a negative rake of 25° is utilized.)

In reviewing Fig. 2, note that the cutting edge of the hob moves in an oblique line starts hobbing at the base cutting edge thus producing curled chips. Figs. 3, 4 and 5 show chips produced at various feed rates utilizing a 2-1/2 DP hob.

Why should one be concerned about the hob design and this new technology? It all resolves itself into one simple statement. "To remain competitive." To do this one must avail themselves of all new technology, and in so doing reduce part cost.

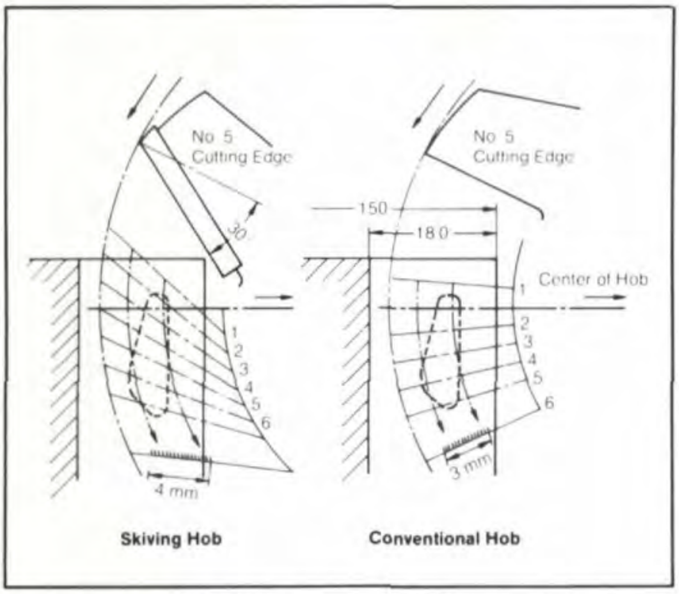


Fig. 2 – Function of the Side Cutting Edge in Hobbing for the Finish

Fig. 3 – .047" Feed/Revolution

Fig. 4 – .063" Feed/Revolution

Fig. 5 – .103" Feed/Revolution

Application of Hobs

The application of the skiving hobs should be applied as a pre-grind operation or as a finishing operation on carburized or through-hardened gears. Most of the applications are on through-hardened gears 54 to 58 Rockwell C and in carburized and hardened gears 58 to 63 Rockwell C. It is possible to satisfactorily cut gears with a hardness as high as Rockwell C 65. The composition of the material in the gear blank does not have as much bearing on the feeds and speeds to be utilized as does the hardness itself.

Gear Blank Preparation

The application of skiving hobs requires adequate preparation of the gear prior to skiving. When the gear is soft and cut to the proper pre-skive tooth form, it is one that is developed by a protuberance type hob. This is a hob that will adequately undercut the flank of the tooth at the gear root radius to insure that the skiving hob cuts on the involute portion of the tooth and not in the root. Normally such a pre-skiving protuberance hob will have a hob addendum of 1.250" or 1.350" ÷ D.P. *while the skiving hob has an addendum of* 1.15708" ÷ D.P. (See Fig. 6).

There is an alternative method which can be used, which for purposes of discussion, shall be identified as the "pressure angle increment" method. This employs a hob with a pressure angle that is slightly less than the finished specified pressure angle. Extra depth is required and care must be taken to insure that the hob tip radius on the skiving hob is large enough to accommodate the stock left at the last point of contact. Normally such a "pressure angle increment" hob has an addendum of 1.350" ÷ D.P. while the skiving hob has an addendum of 1.15708" ÷ D.P. (See Fig. 6A).

To obtain desired accuracies, the gear blank should be finished after hardening to insure that the locating face and the running bore or shaft are concentric one with the other.

Suggested Feeds and Speeds

As in any type of cutting operation, there are a multitude

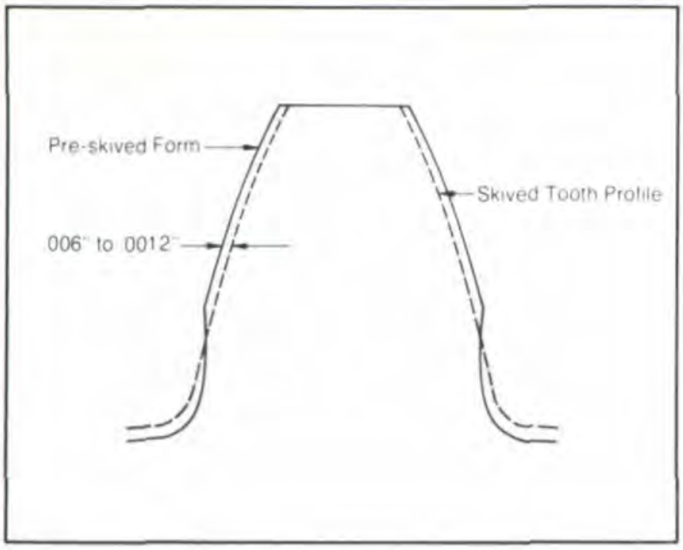


Fig. 6 – Protuberance Pre-skived Hob

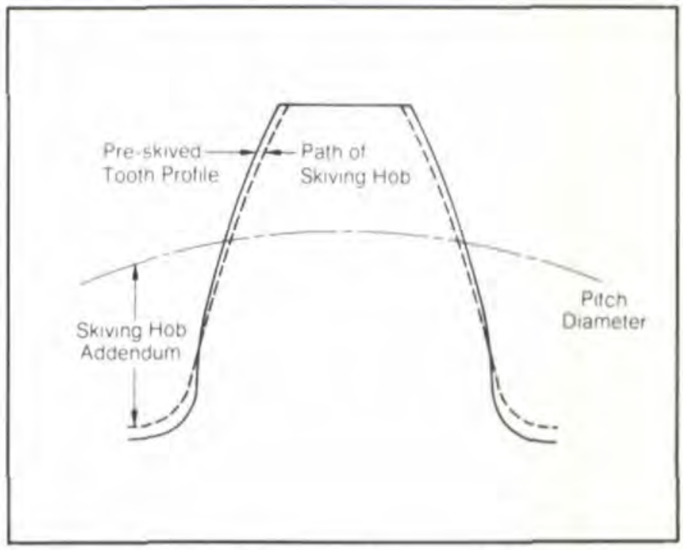


Fig. 6A – Pressure Angle Increment Hob

of factors which must be considered when establishing feeds and speeds so that one might optimize the operation as much as possible. The essential factors to consider are: rigidity of the machine, finish and accuracy requirements in the gear, gear blank preparation, work holding fixture, and condition of the machine to be used.

Table 1. Suggested Speed Ranges

Rockwell C Hardness	Surface Feet Per Minute
40-42	365-450
43-45	300-400
46-48	230-380
49-52	190-365
53-56	165-295
57-59	150-265
60-62	135-230
63-65	130-190

Table 1 lists speed ranges (surface feet per minute) depending upon hardness. The broad range of speeds for various hardnesses, is simply due to the various applications and requirements.

When the skiving hob was initially introduced, the normal surface feet per minute was about 150 in the Rockwell C 62 range. Laboratory testing has indicated that higher speeds are desirable when machine and cutting conditions warrant the same. This conclusion, reached under laboratory conditions, is being born out in the actual use on a commercial basis. Also, for the best life from the hobs, a heavier feed rate, rather than a lower feed rate should be used. This is, of course, dependent upon the accuracy and finish requirements that will serve to constraint the feed rate. Table 2 and Table 3 show the results of laboratory testing on the feeds and speeds.

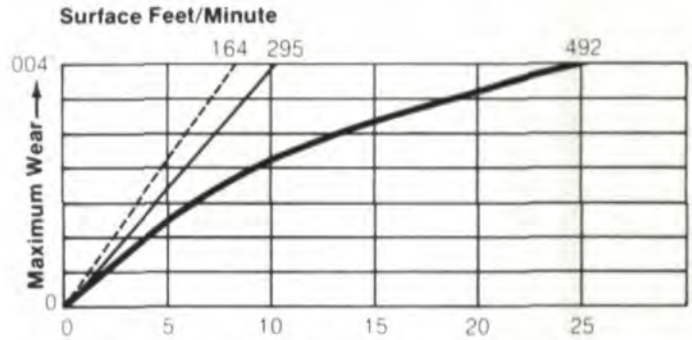


Table 2. Effect of Speed on Hob Life

Hob = 8 module (3.17 D.P.), R.H., 9 gashes, 20° P.A., 30° negative rake

Gear = 17 teeth, diameter 5.9", 1.968" face width, 55 Rc.

Feed Per Revolution = .236", wear land = .005"

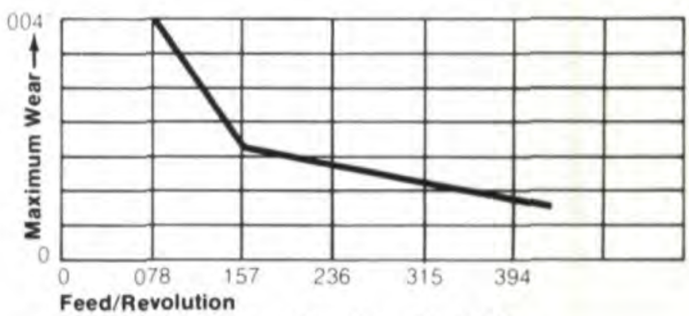


Table 3. Effect of Feed on Hob Life

Hob = 8 module (3.17 D.P.), R.H., 9 gashes, 20° P.A., 30° negative rake

Gear = 17 teeth, diameter 5.9", 1.968" face width, 55 Rc.

Cutting Speed = 328 SFM

Feed Rates

The suggested feed rates per revolution of the gear are as follows:

Table 4. Feed Rates

Pitch Range	Feed Rates IN/REV	
	Roughing	Finishing
2 DP & Coarser	.120-.160	.080-.120
2-1/4 DP & Finer	.080-.140	.060-.100

In application, it is essential to remove the same amount of stock from each flank of the gear tooth. This requires centering a hob tooth in the gear space, which can be done manually. In a production operation, a fixture to center the gear teeth, after the first gear has been set into the hob, would be helpful to the hobbing machine operator.

The maximum amount of stock that is normally recommended to be removed in one cut is as follows:

Table 5. Stock Removal

Pitch Range	Stock Removal on Tooth Thickness IN
1-1/4 DP	.016-.024
1-1/2-2 DP	.012-.020
2-1/4 DP & Finer	.012-.016

Equipment

Any heavy-duty hobbing machine in good condition can be utilized for skiving. However, one should bear in mind not to overtax the machines; that is, do not go to the limit of the coarsest diametral pitch for which the machine is rated. There are two critical areas of any hobbing machine when it comes to the skiving operation. The first is the amount of backlash between the index worm wheel and the index worm. This should be maintained to the manufacturer's minimum tolerance. The hob spindle should be of the anti-friction type and should have no axial run-out in it. Among the popular machines which can be utilized for skiving are Barber-Colman, Liebherr, Module, Pfauter, and Shibaura.

Maintenance of Hobs

Resharpening of the hobs should take place where the wear of the hob has reached about .008" on the wear flank of the hob. The resharpening should be performed utilizing a cup-type diamond grinding wheel on a precision hob sharpening machine with high rigidity. This should be done using a wet grinding method to achieve the best possible surface quality on the cutting face of the hob. The axis of the grinding wheel should be offset about 10 minutes, so that the cup-type wheel is cutting only on its edge. A resin bonded diamond wheel with a mesh of 220 to 230 is recommended. A light hand lapping of the cutting edge (if done without influencing tooth profile accuracy) does help to prevent some chipping. This is especially important if one is cutting without coolant. A controlled edge honing operation may be beneficial. In all cases, the sharpening machine must have the capability of a large offset, the amount of which can be determined by the following formula:

$$\frac{\text{Hob O.D.}}{2} \times \text{Sine of the rake angle}$$

Economics

There are more items to consider than merely tool cost when reviewing the economics of this technology. The real criteria is the actual cost of gears. Example #1 shows a saving in skiving prior to a grinding operation. The other examples which will be given are finish skive examples and are being done in lieu of grinding.

One small part of the equation is an estimated life of the skiving hob. A "rule of thumb" estimate can be obtained by utilizing the factor of 165 lineal feet per position of the hob. This would be calculated first of all by establishing the generating length of the hob which is the working depth of the hob divided by the tangent of the pressure angle. This would be subtracted from the rest of the active face of the hob and shift, determined by 1/4 of the circular pitch minus 1, to be sure that you would always have sufficient generating length on the last position and/or to compensate for any slight errors in the positioning of hob which might occur. This would then translate itself into the number of pieces expected per sharpening of the hob, and the following is an example of the calculation of one such item:

Gear Data	Hob Data
4 D.P.	5.906 O.D.
20° P.A.	4.527 length
4-5/8" face width	3.740 active face
Spur* 17 teeth	2-1/2 bore

$$\text{Generating Length} = \frac{\text{Working Depth}}{\tan \text{P.A.}}$$

$$\text{G.L.} = \frac{.500}{\tan 20^\circ \text{ P.A.}} = 1.374''$$

$$\frac{17 \times 4.625}{12} = 6.55 \text{ lineal feet per gear}$$

$$\frac{165}{6.55} = 25 \text{ pcs. per position/per sharpening}$$

$$3.740 - 1.374 = 2.366''$$

$$\text{N.C.P.} = .7854''$$

$$\frac{2.366}{.7854} = 3.01 \times 4 = 12 \text{ shifts} - 1 = 11 + \text{initial position} = 12 \text{ positions}$$

$$12 \times 25 = 300 \text{ gears per sharpening} \times 20 \text{ sharpenings} = 6{,}000 \text{ pcs/life hob}$$

*If helical, divide face width by cosine of the helix angle.

Coolants

The normal high viscosity type coolants, used for cutting soft gears with high speed steel hobs, will simply not work.

The high viscosity film between the carbide hob and the work will tend to make the skiving hob slip or scuff, thus crushing the cutting edges and leading to severe cratering and chipping of the cutting edges. The gears should, therefore, be cut completely dry or by utilizing a special low viscosity cutting fluid, which was designed especially for skiving hobs. This cutting fluid has organic molybdenum as its active ingredient. When utilizing this oil, it is important that previous cutting oils be drained and the machine completely flushed with a solvent before the addition of the new cutting oil. If the machine is not cleaned in this manner, there will be residue that interacts with the new cutting oil which will cause stickiness and gumminess throughout the machine.

Through the utilization of this special cutting oil, skiving hob life is extended, thus providing for economical hobbing with the skiving hob.

The following are some examples of actual production runs utilizing skiving hobs.

Examples

EXAMPLE 1
(Skiving prior to grinding)

Gear Data

Diametral pitch	6
Pressure angle	20°
Number of teeth	129
Face width	2-1/2"
Hardness	Rc58-62
Helix angle	15°

Application Data

Finishing stock on tooth thickness	.011"
Hob RPM	200
Surface ft/min	309
Feed/rev	.100"
Climb hobbed machine — Pfauter	P630

Results

Skive hobbed	= 31 min.
Finish ground	= 40 min.
Total hard processing time	= 71 min.
Previous grinding method	= 240 min.
Savings per gear	= 169 min.
Average hob wear	.006"
Estimated life of hob	1230 gears

Economic Justification

$35.00 hour × (169 min. ÷ 60)	= $ 98.58
Less tool cost/gear	= 3.02
Less sharpening cost/gear	= 1.00
	$ 94.56
Total savings 1230 × 94.56	= $116,308

EXAMPLE 2
(Finish Skiving)

Gear Data

Diametral pitch	8
Pressure angle	14-1/2°
Number of teeth	29
Helix angle — R.H.	27° 16'
Face width	1.250"
Hardness	Rc54-57

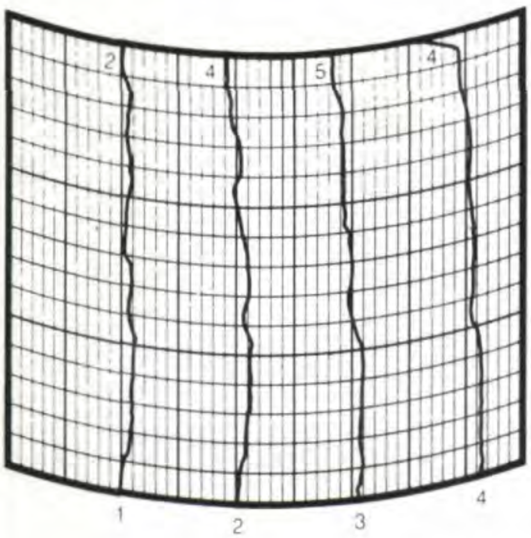
Application Data

Hob RPM	162
SFM	250
Feed/rev	.080"
Conventional hobbed machine — Barber-Colman	16-15
Cycle time	4.12 min

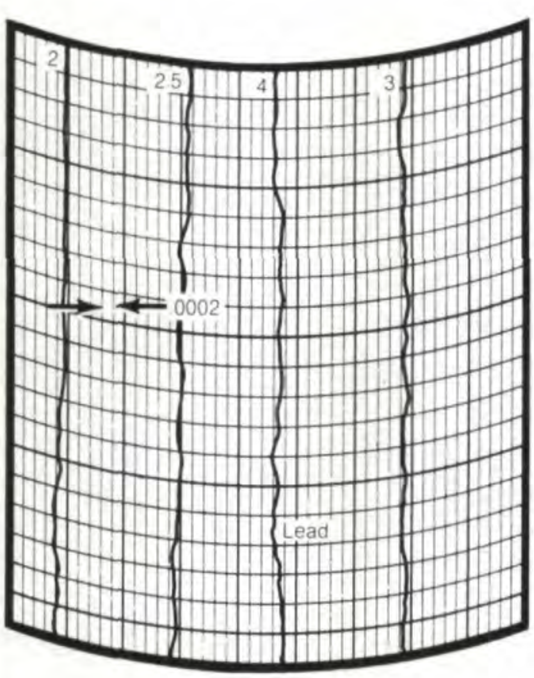
Results

Accuracy AGMA Class 12

(continued on next page)



Example 2 – Involute Charts



Example 2 – Lead Charts

EXAMPLE 3

Gear Data

Diametral pitch	4
Pressure angle	20°
Number of spur teeth	100
Face width	4″
Hardness	Rc53-56

Application Data

Hob RPM	78
SFM	120
Feed/rev	.067″
Finishing stock on tooth thickness	.010″

Results

Finish smooth
Bearing pattern excellent (75% bearing required)

EXAMPLE 4

Gear Data

Diametral pitch	2.54
Pressure angle	25°
Number of spur teeth	70
Face width	4-5/8″
Hardness	Rc62

Application Data

Hob RPM	92
SFM	180
Feed/rev	.103″
Conventional hobbed machine — Barber-Colman	40-15
Cycle time	40 min.

Results (See Example 4 Charts)

(continued on page 33)

Involute Spline Size Inspection

by
William L. Janninck & John C. Nielsen
ITW Illitron
Illinois Tool Works Inc.

Abstract

This article describes a new technique for the size determination of external involute splines, by using a span measuring method. It provides application performance information demonstrating how this method and its measurements correlate with the traditional spline ring gage sizing method.

Involute splines provide a positive rotational coupling between a shaft with external teeth and related mating member with internal spline teeth. Their use permits ease of assembly or disassembly for replacement or servicing, and permits fixed or sliding connections. Other uses permit compact assembly of parts, or by use of standardized fittings, the intercoupling of motors with gear boxes or other loads.

Since there is no rolling action between the mating members, as there is between meshing gears, all of the spline teeth are expected to fit together. Although various internal and external fits are available, the final goal of involute splines is to achieve a self centering condition with full contact bearing. The result of this would be equalized load sharing and stress on all the teeth.

Various manufacturing induced errors diminish this ideal equalized condition up to the point where a spline may fail to properly engage its mating member. Some typical factors which affect proper mating are: tooth thickness, space width, index errors, profile variations, lead variation and out of roundness. Among the manufacturing processes the one most difficult to deal with is heat treating. It is particularly troublesome if the part is slender, thin walled or tubular, because distortion becomes extremely likely and also probably irregular.

To screen out parts which will not mate properly or not mate at all, it is necessary to inspect the product prior to the assembly operation. A very common way of doing this is by the use of solid tool steel gages. For external splines, the gages are internal toothed rings called "GO" and "NO GO". (See Fig. 1).

The "GO" ring is a composite gage having a full complement of teeth and is used to inspect maximum material conditions, minimizing the chance of fit interference. In other words, if the part fits the "GO" gage, there is a high probability of assembling with its mate later. The "GO" gage cannot measure the looseness or size of the part being gaged. It can only reject those parts that will not enter the "GO" gage.

The "NO GO" gage does not have a full compliment of teeth, but rather only two diametrically opposed groups of teeth. It is used to inspect minimum material conditions, thereby, governing the maximum looseness. If the spline part is thin walled, or tubular, or heat treated, it is desirable to try the "NO GO" gage in at least two places 90 degrees apart. An oval part, for example, may enter the "NO GO" gage at the low point, but not the high. Ovality reduces the chances of getting the full use of all the teeth in the final assembly. At this point a few definitions would be in order. (See Fig. 2).

Profile Variation: Deviation from specified involute profile normal to the flank surface with zero established at the pitch line. Positive errors reduce clearance or increase interference. Negative errors increase clearance and reduce contact area.

Index Variation: The difference between the actual and true spacing of any two teeth, adjacent or not.

Effective Tooth Thickness: The space width of a perfect mating internal spline for a fit without looseness or interference.

Actual Tooth Thickness: The actual measured tooth thickness on the pitch line which is equivalent to the effective tooth thickness, less width allowance for profile and index errors.

The "GO" composite spline gage is used to inspect the effective tooth thickness down to the form diameter. These gages must be very precise, since they are used as the perfect mating member, and any tolerances allowed would steal from the part tolerance.

The "NO GO" sector ring gage containing opposing sectors of about two teeth is used to check the minimum actual tooth thickness.

Using these gages requires a degree of manual dexterity. The "GO" gage needs to be tried in only one angular position, but some skill is required to start the

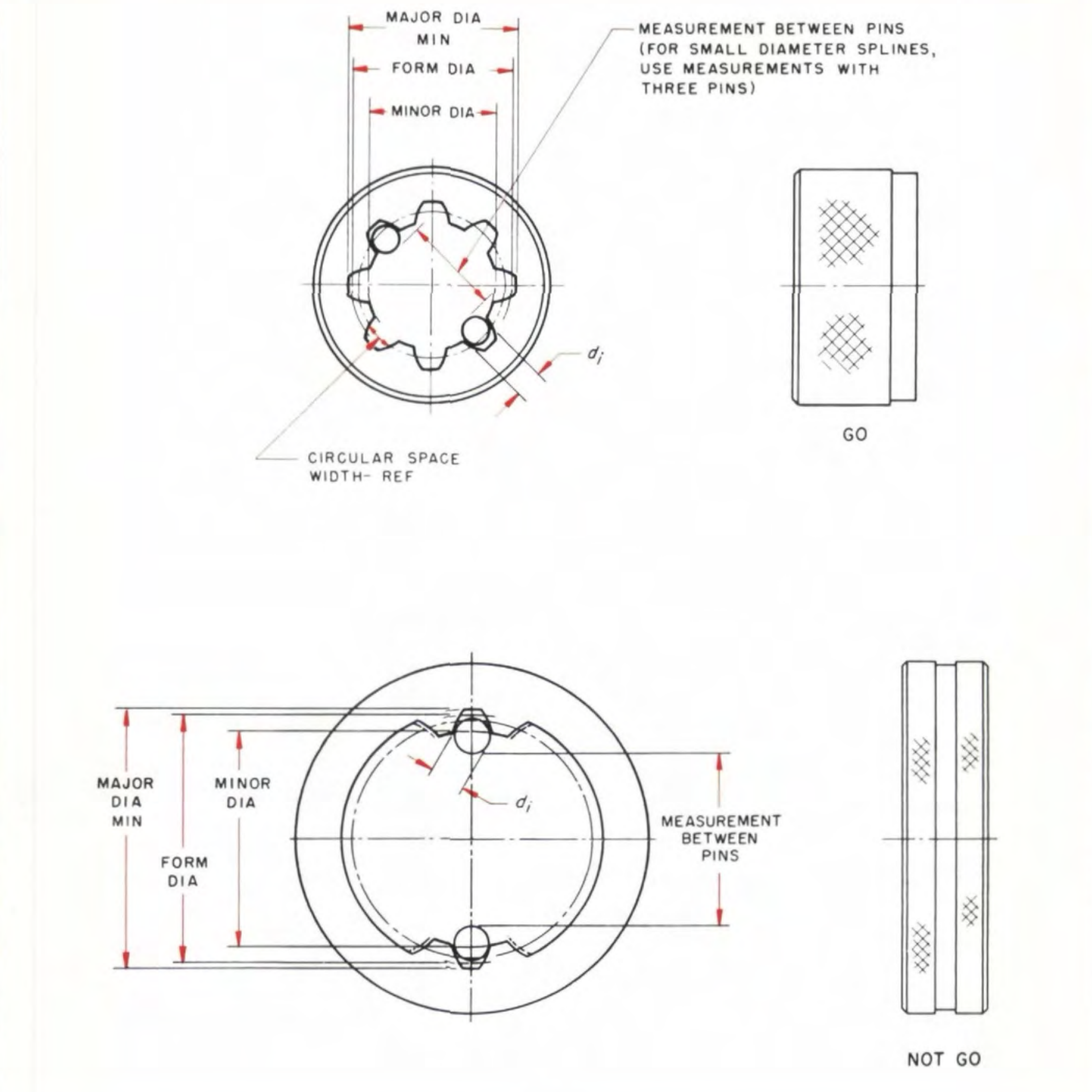
AUTHORS:

MR. W. L. JANNINCK *is Technical Manager for the ITW-Illitron Division of Illinois Tool Works Inc. He has been involved in the design and application of many types of metal cutting tools specializing in the area of tooling and gaging for the manufacture of gears, splines and sprockets of both generating and forming types. He was Chief Engineer and Manager of Product Engineering from 1979 through 1984 for the Illinois Eclipse Division. He has served on various committees of the AGMA and MCTI and is Chairman of the AGMA Cutting Tool Committee. He also served on the SAE-ANSI Involute Spline Committee and the ASME-ANSI Committee on Power Transmission Chains and Sprockets. He has written several articles on tooling subjects and has spoken at various SAE, SME, ASQC and AGMA meetings. He was educated at Northwestern University.*

MR. JOHN C. NIELSEN *has been a staff member of the ITW corporate machine development group for 10 years. Subsequently he became supervisor of the group. He has been responsible for the design or project management of a wide variety of equipment relating to new product entry or productivity improvement for fastener, cutting tool and capacitor manufacture and underwater cable handling. He currently specializes in inspection instrument development.*

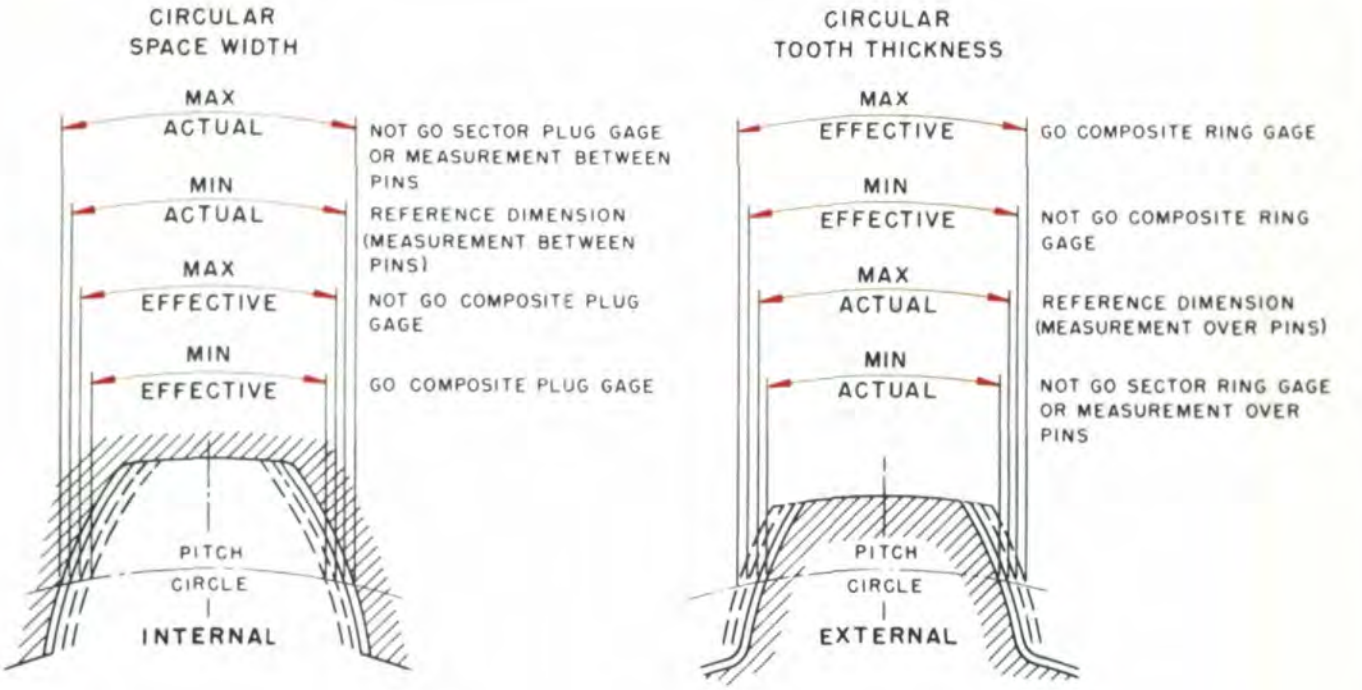
Prior to ITW, his design experience was in the development of new business machines for Bell & Howell — Ditto and electronic countermeasures equipment for Northrop (Hallicrafters).

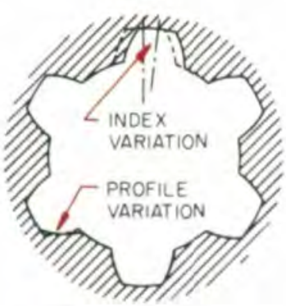
He holds a Bachelor of Science degree in Mechanical Engineering from Purdue University and is a member of the American Society of Mechanical Engineers.



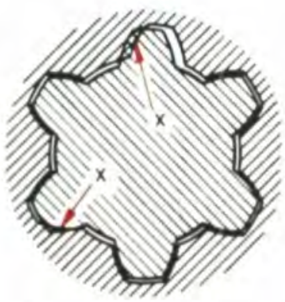
MAJOR DIA
MIN
FORM DIA
MINOR DIA
MEASUREMENT BETWEEN PINS
(FOR SMALL DIAMETER SPLINES,
USE MEASUREMENTS WITH
THREE PINS)
d_i
CIRCULAR SPACE
WIDTH- REF
GO
MAJOR
DIA
MIN
MINOR
DIA
FORM
DIA
d_i
MEASUREMENT
BETWEEN
PINS
NOT GO

Fig. 1

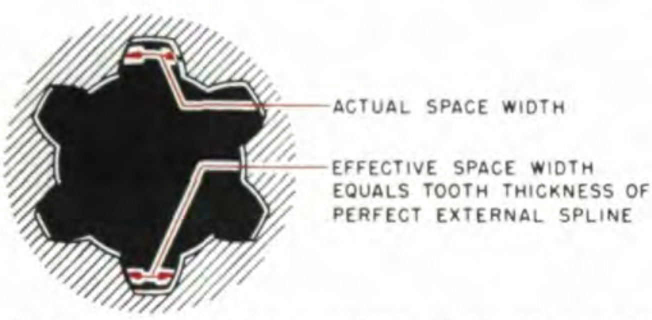




EACH SPACE IS BASIC WIDTH.

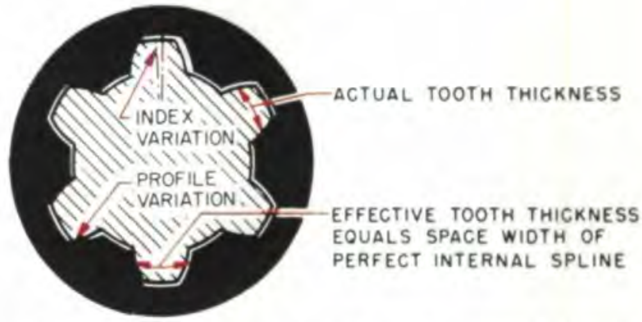


THE PERFECT EXTERNAL SPLINE WITH BASIC TOOTH THICKNESS INTERFERES AT X.



THE PERFECT EXTERNAL SPLINE FITS IN ANY POSITION, IF ALL SPACES ARE WIDENED BY THE AMOUNT OF THE INTERFERENCE.

EFFECT OF VARIATIONS ON INTERNAL SPLINE



THE PERFECT INTERNAL SPLINE FITS IN ANY POSITION, IF ALL TEETH OF THE EXTERNAL ARE NARROWED BY THE AMOUNT OF THE INTERFERENCE.

EFFECT OF VARIATIONS ON EXTERNAL SPLINE

Fig. 2

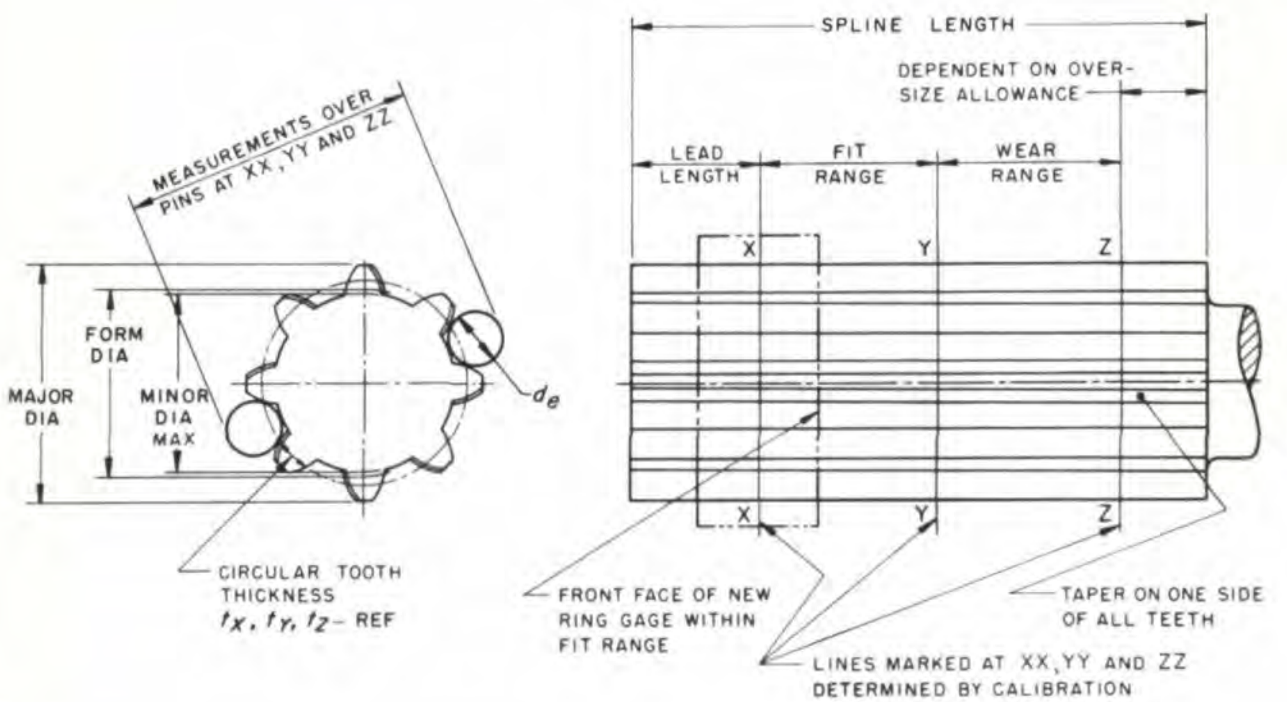


Fig. 3

spline into the gage, especially when the fit between part and gage is close. If the spline won't enter fully, it is classed as an oversize reject. The "NO GO", because of its limited teeth and usual non entry situation, is more difficult to apply. Along with the difficulty in use, industry standards for this check are not consistent for either the number of places, which constitute a reject, nor for the force required to attain engagement. It is obvious that the use of "GO" and "NO GO" gages is tedious and labor and skill intensive.

Another element necessary to consider is gage wear. Allowances are made for this in making a new gage. Periodically active gages must be monitored for size. This can be done with measurement between pins, but usually a tapered master plug is used. (See Fig. 3). Etched lines along the plug indicate the fit or wear range. *This means splines accepted by a* worn gage may be rejected by a new one.

Ring gage tolerances are planned to absorb no more than 25% of the product tolerance. In practice, by way of a sampling of actual gages in active use, it was found that the measured accuracy of "GO" gages can absorb a higher percentage.

For many years, the span or block measurement system for sizing involute gears and splines has been used. It is a simple procedure using a micrometer and reads over a group of teeth. (See Fig.4). It is independent from the outside diameter variations or runout. A normal line to any tangent on an involute will lie in a plane tangent to the base cylinder. Therefore, two parallel span flanges will contact opposing tooth profiles similar to the measurement of a cylinder. This means the micrometer can be rocked, reading from base diameter to tip for a constant reading, in either direction. As in measuring a cylinder, the check is independent of runout.

A dynamic means for span measurement has been developed to duplicate the principle of a flange micrometer on block measurement. *This requires a support for* the piece part on its journals in a roller cradle or between centers. The work piece is approached by a rotating spindle which is pivoted for access. The spindle carries a pair of helical checking discs which engage the work piece over an appropriate span of teeth as shown in Fig. 5. One disc is fixed axially on the drive spindle and is keyed to rotate the spline on its axis. The second disc is also keyed to the drive spindle, but is free to slide axially on the spindle. The sliding disc is directed by a spring to close over the span of spline teeth. As the work piece is rotated through one full revolution, the axial movement of the second disc senses the variation in spans progressively tooth by tooth. A displacement transducer records the axial movement of the sensing disc and provides a continuous signal, which includes a succession of span readings equal to the number of teeth in the part.

The number of teeth in the span for 30 degree PA splines falls in approximately a 60 degree sector, or for a 40 tooth part the span is 7 teeth. In the check of this part, 40, 7 tooth span readings *will* occur.

The output of the displacement transducer may be displayed on an oscilloscope, recorded on a strip chart or made to trigger indicator lights. (See Fig. 6). This shows a strip chart trace for span measurement of a typical spline. Each

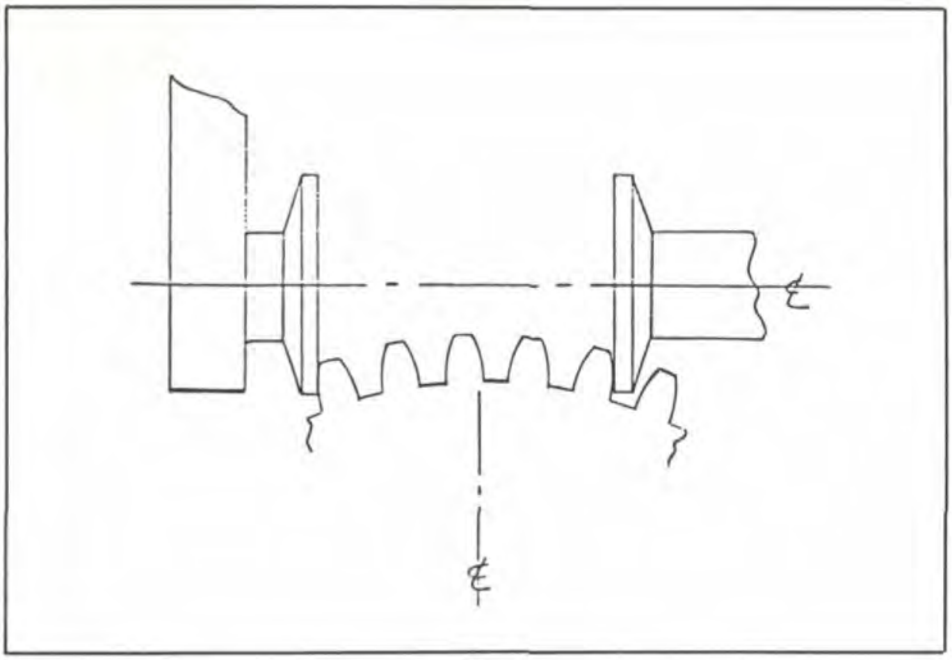


Fig. 4

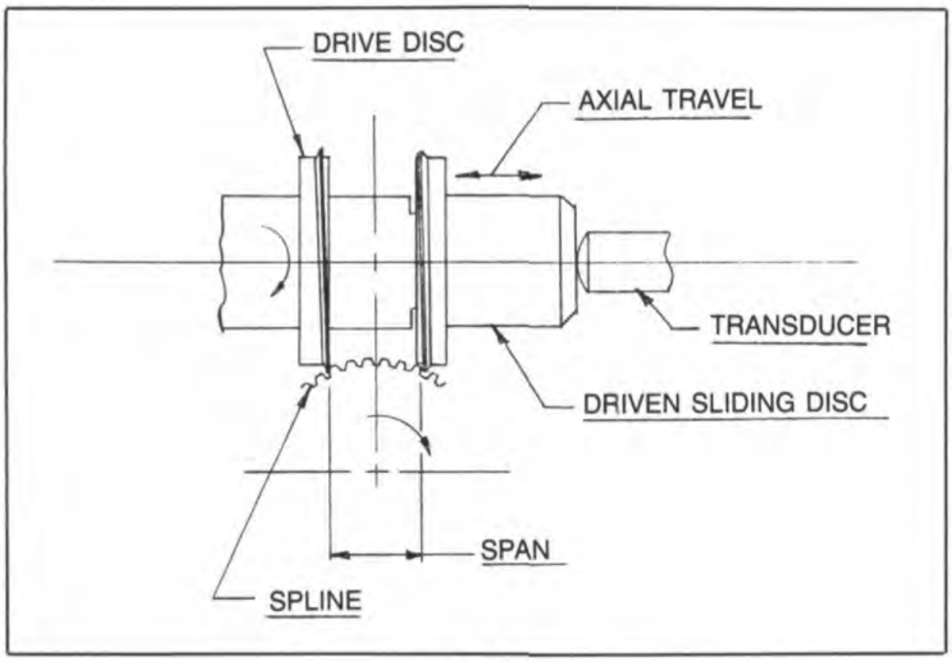


Fig. 5

amplitude excursion from one peak to the next represents one span measurement. The 45 teeth in the spline are represented by 45 peak to peak span *measurements over 8 teeth. One revolution* of the part is obvious as the cycle repeats again after 45 peaks. The sinusoidal record for this particular spline is an indication of piece part ovality caused by heat treat distortion of a thin walled, tubular part.

To relate the span measurement signal to the "GO" – "NO GO" acceptance limits, the following paramaters have been established. To determine an over*size condition, the maximum span* reading plus the span variation in one revolution of the part are compared to established preset limits. For determination of an undersized spline the maximum span is compared to an established lower limit. In addition, span variation

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is compared to an established limit. The size category determination, that is comparision of the measured span to limits is accomplished in an electronic logic package accompanying the mechanical inspection unit. The package incorporates digital displays of the greatest span measured and span variation as well as indicator lights which classify the inspected spline as OVERSIZE, GOOD, or UNDERSIZE. Setting masters are used to calibrate the instrument.

In the development of this span measurement, three specific production splined shafts were studied thoroughly. (See Fig. 7). They were: turbine shaft, sun gear shaft and oil pump shaft. The turbine and oil pump were rack rolled, the sun shaft was broached.

With the assistance of an independent quality laboratory, samples of the three production shafts and their ring gages for inspection were accurately measured for various elements. The results of some of the most important measured piece part elements are shown in TABLE I. The results of corresponding measurements made on the "GO" composite ring gages for these piece parts are shown in TABLE II.

The tabular information indicates the variability within the parts and the gages. From the data it can be seen that a large portion of the fit tolerance was used by the ring gage itself. In the case of the oil pump shaft, the accuracy of the production piece parts was as good or better than the inspection ring gage.

A correlation study of span measurement to determine spline size, using ring gages, for the 40 tooth turbine shaft is shown in Fig. 8. It reveals a rather good correlation, and in this case, the gray area is only a few tenth thousandths inches wide.

The span measurement system provides a measurement for size determination; whereas, the ring gages give a somewhat subjective size determination. In practice, it has been found that from the measurement resulting from the span system, ring gage fit predictions can be made.

Splines determined to be "GOOD" by the span system, and new, unworn ring gages may be "REJECT", as determined by worn, but still within tolerance ring gages. This disparity can be troublesome to a supplier of splines and a user of

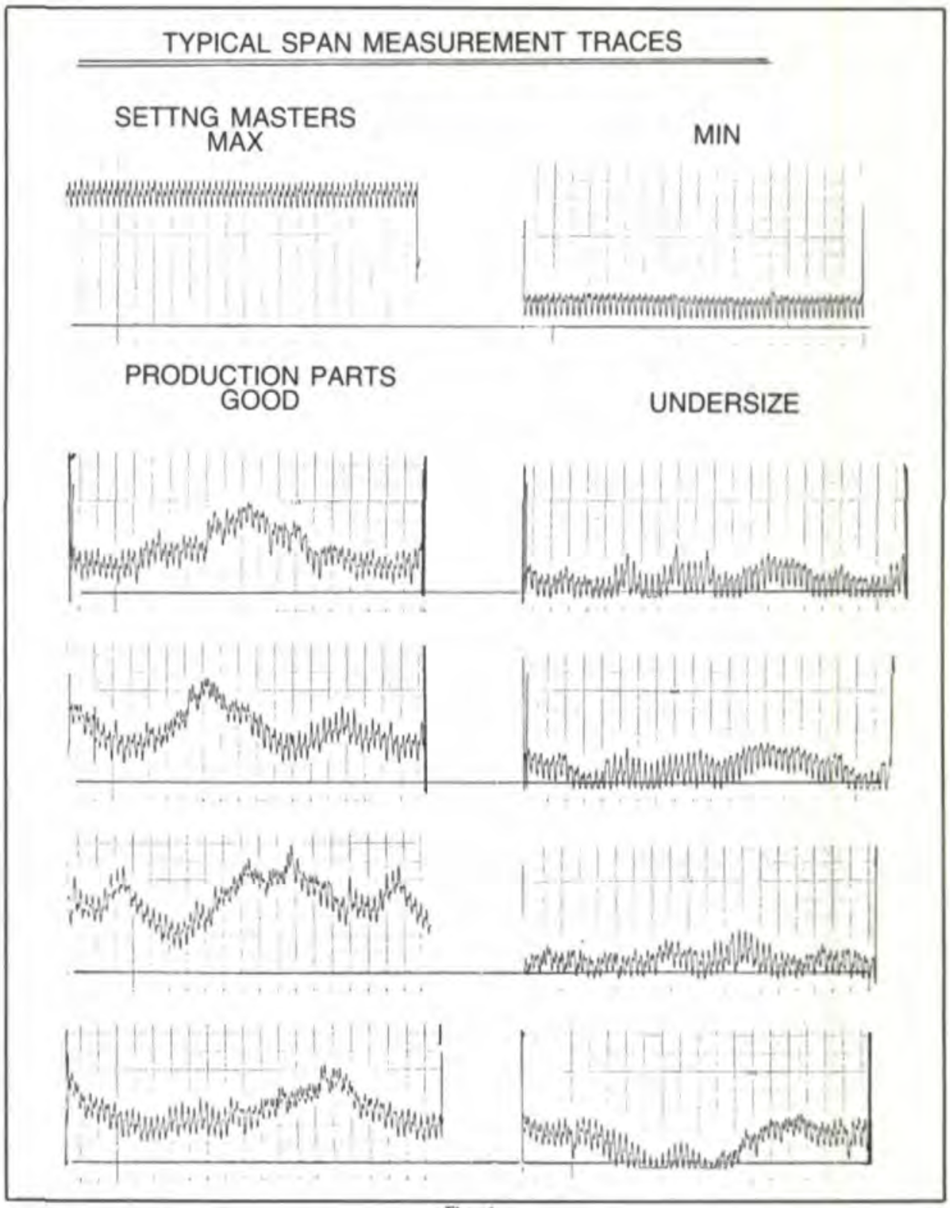

Fig. 6

TABLE 1
Measurement of Splined Product

Element Range in inches	Turbine	Sun	Oil Pump
1) Total Index Variation	.001 – .0029	.0036 – .01158	.000810 – .001670
2) Pitch Variation	.00034 – .00087	.00074 – .00190	.000290 – .000830
3) Spacing Variation	.00032 – .00111	.00063 – .00197	.000300 – .001090

TABLE 2
Measurement of Ring Gages
("GO" Composites)

Element Range in inches	Turbine	Sun	Oil Pump
1) Total Index Variation	.00136 – .00162	.00175 – .00215	.00155 – .00165
2) Pitch Variation	.00021 – .00025	.00075 – .00100	.00037 – .00040
3) Spacing Variation	.00024 – .00037	.00143 – .00176	.00029 – .00038

splines both checking parts with ring gages, but one using a worn set and one using a new set. The span system precludes this possibility.

Further application of the span measurement system to a broader range of products will eventually determine the limit of this process. In the future, ring gages may be merely a periodic check of size correlation much as tapered plug gages are a periodic check of ring gages for wear today.

Portions of this paper have been presented at the Fall 1984 Technical Conferences for AGMA & SME.

E-2 ON READER REPLY CARD

Fig. 7

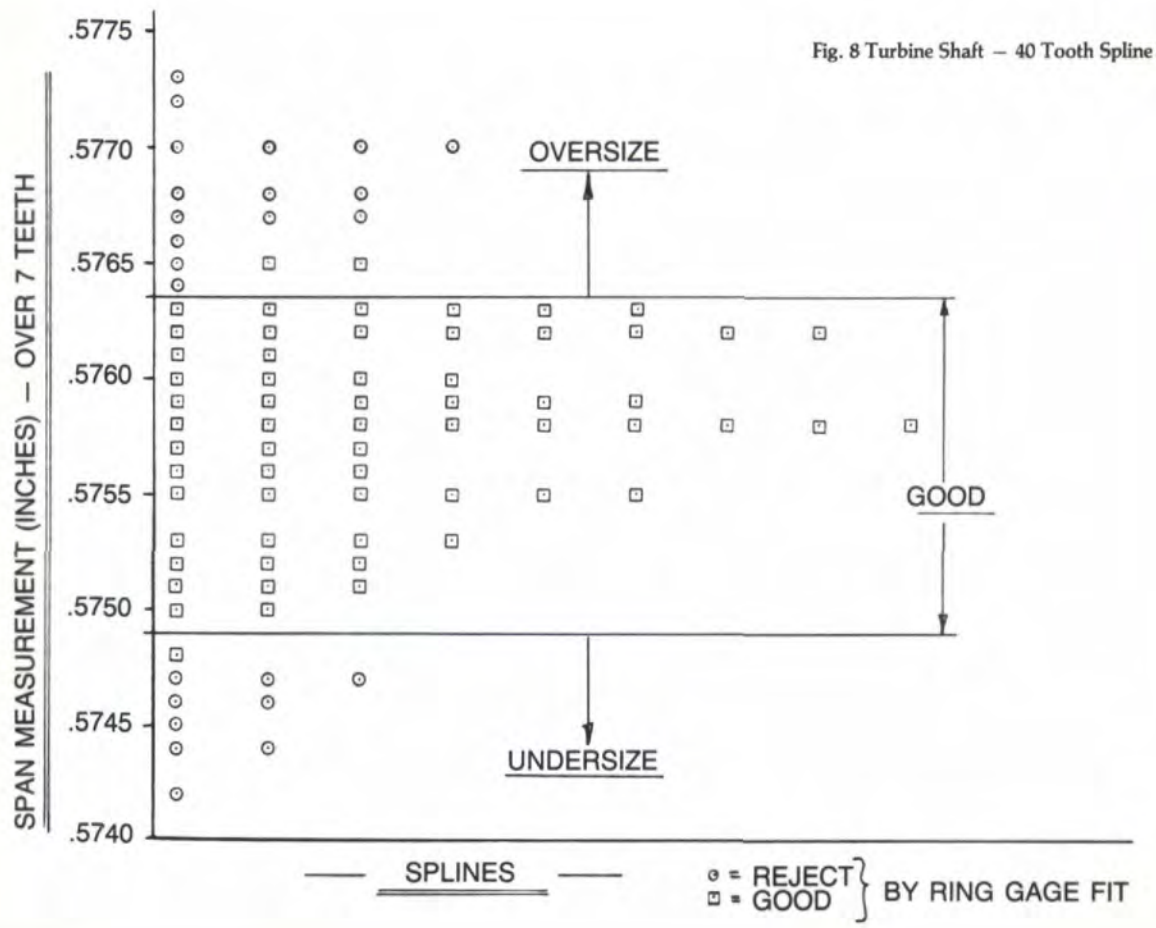

Fig. 8 Turbine Shaft — 40 Tooth Spline Correlation

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•Higher speeds
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— modifying tooling (hobs or shaving cutters) to correct for distortion . . .

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To accomplish this, the tool flank and the work gear flank being machined are positively guided in such a way that the workpiece and tool are rigidly linked during machining with the tool performing a plunge-feed motion for stock removal. All right-hand flanks are finished first. The machine then reverses and finishes left-hand flanks. This single-flank contact means no broken-out tool teeth due to workpiece defects and permits correction or "redesign" of the workpiece gear during finishing.

The tool, either Borazon® or ceramic, is conditioned and profiled for the work gear geometry and desired stock removal by using a coated dressing master. Dressing takes no longer than the time required to finish one workpiece and each dressing removes a minimal amount of material from the tool surfaces.

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The hard finishing process gives the widest range of applications of all post-hardening gear finishing methods. Adjacent shoulders or collars rarely pose serious problems.

This illustration shows the tool finishing the work-piece gear and the external master gears engaged to control the operation.

Other advantages of the process:

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- Definitely no grinding burns.
- Tool marks run diagonally to gear diameter.
- Permits machining of gear teeth adjacent to shoulders.
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Shaving Cutter Grinding Machines
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Austempered Nodular Cast Irons

by
Jay F. Janowak
Climax Molybdenum
&
Robert Q. Barr
Communications Plus, Inc.

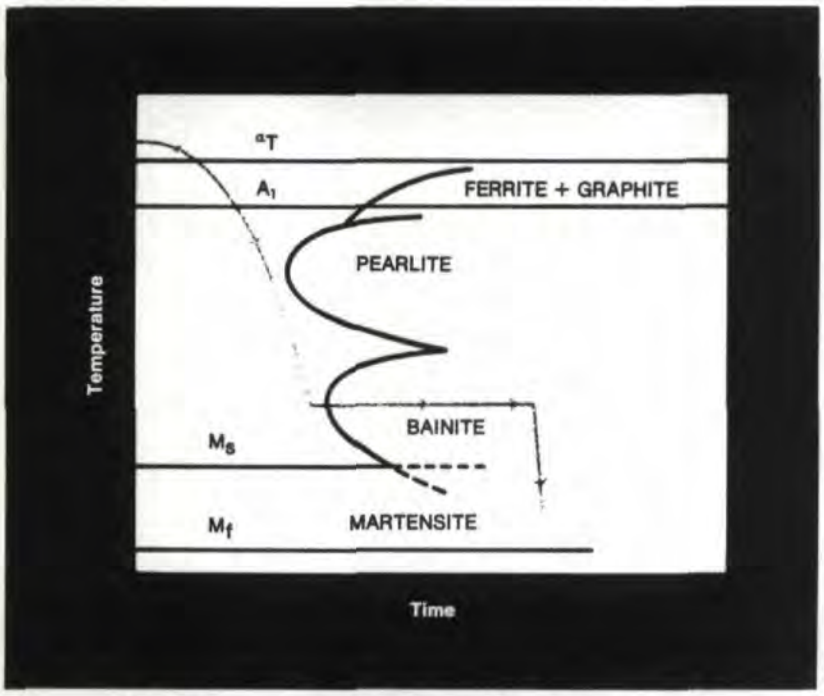

Fig. 1 – Representation of Austempering Heat Treatment (– –) Imposed on Hypothetical Nodular Iron CCT Diagram

Austempering heat treatments (austenitizing followed by rapid cooling to the tempering temperature) have been applied to nodular irons on an experimental basis for a number of years, but commercial interest in the process has only recently come to the surface. Research in the seventies in Europe, Japan and the United States has shown that austempering is capable of producing irons with strengths over 1000 MPa (145 ksi), ductilities in the order of 10% and toughness levels approaching those of ferritic nodular irons.[1-5]

Austempering as a treatment for alloy steels was discovered in the 1930's as a result of work on the subcritical transformation of austenite. The principal advantages are (1) good control of the transformation process and (2) freedom from residual stress, distortion and cracking associated with rapid cooling from the austenitizing temperature to room temperature.

In steels, austempering results in a bainitic structure consisting of acicular ferrite with carbide needles. In irons, however, the high silicon content suppresses precipitation of the carbide phase, and a lamellar structure of acidular ferrite and high carbon austenite is produced. Fig. 1 schematically represents the austempering treatment superimposed on a hypothetical nodular iron transformation diagram. Rapid cooling from the austenitizing temperature is necessary to avoid precipitation of ferrite or pearlite. Unalloyed irons must be severely quenched in oil or water, but alloying that moves the ferrite and pearlite regions to longer times allows parts to be cooled at lower rates as, for example, in salt baths or forced air systems. Thus alloying is a necessity as section size increases or when distortion and cracking from rapid cooling rates cannot be tolerated. Approximate alloy contents required to avoid pearlite formation on cooling nodular irons to the austempering temperature have been proposed as follows:[4]

Section	Alloy Content*	
mm(in.)	Salt Quench	Forced Air
8 (0.3)	None	0.3% Mo
10 (0.4)	None	0.35% Mo + 1% Cu or 0.48% Mo
25 (1)	0.3% Mo.	0.3% Mo + 1% Ni or 0.3% Mo + 1.5% Cu
37 (1.5)	0.35% Mo. + 1% Cu or 0.5% Mo	0.5% Mo + 2% Ni or 0.7% Mo + 1% Cu or 1% Mo + 0.6% Ni
50 (2)	–	0.5% Mo + 2.3% Ni

*Alloy content required in typical nodular base irons containing 3.4–3.8% C, 2.0–2.6% Si, 0.1–0.4% Mn

Molybdenum is technically necessary as an alloying element in austempered irons in heavy sections, and it is cost effective in light sections because it permits the use of lower cooling rates and/or bulk heat treating of parts.

To further pursue the effects of alloying, it should be recognized that silicon, an element used to control carbides, has a negative effect on hardenability, and it segregates to the solid during solidification resulting in a gradient in the direction of lower levels in the intercellular material. Nickel can be added to compensate for the hardenability loss due to silicon, but the nickel content must be

AUTHORS:

MR. J. JANOWAK *is currently Manager of Foundry Development at Climax Molybdenum Co. He holds a B.S. and an M.S. in Metallurgical Engineering from the University of Wisconsin. Mr. Janowak is a frequent speaker and author of numerous papers on cast iron technology relating to cost reduction and product improvement. Currently he is Chairman of AFS High Temperature Iron Committee 5F, Chairman of the steering committee for AFS research program on austempered ductile iron, and he is a member of AFS, SAE, ASM, D.I.S., STIM, and AIME. Prior to working at Climax, he was with GM in various positions relating to the Implementation of Ductile Iron technology for Cost reduction.*

MR. ROBERT BARR, *President of Communications Plus, Inc. was formerly director of technical information at Climax Molybdenum Company. He is a graduate of the University of Michigan with a degree in metallurgical engineering. In addition to doing metallurgical research for Climax, he also worked for NASA.*

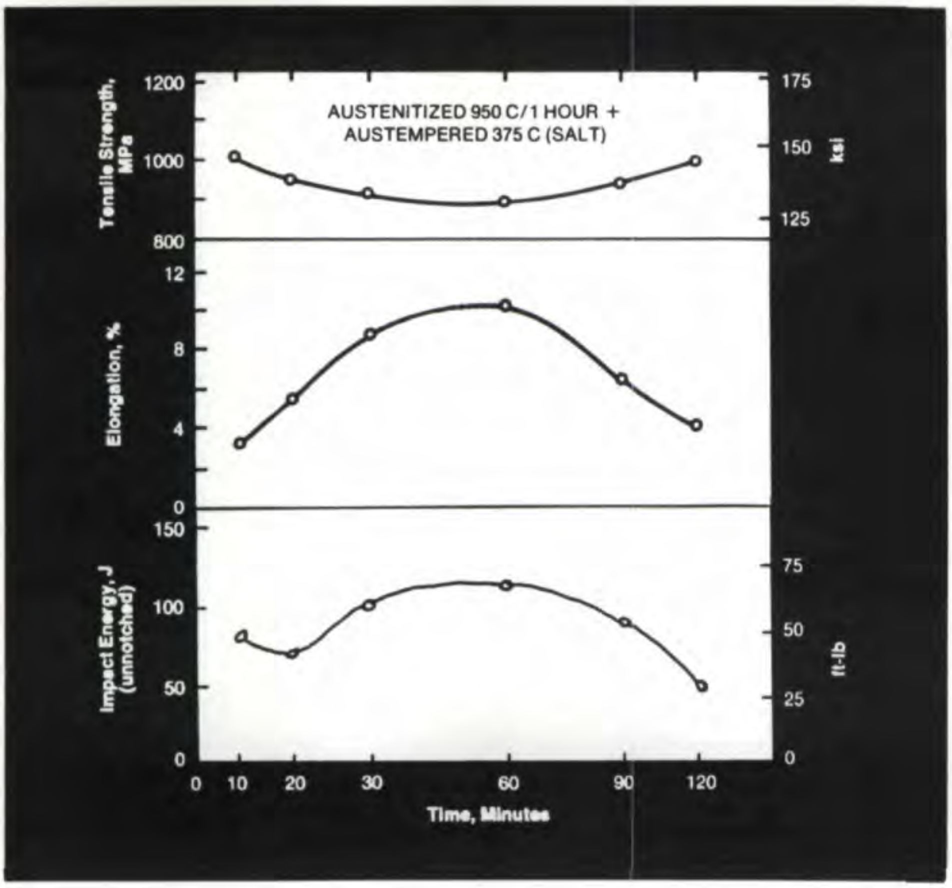

Fig. 2 – Influence of Austempering Time on the Mechanical Properties of Unalloyed Nodular Iron

point of microstructure and mechanical properties. Too short a holding time results in the formation of martensite on quenching to room temperature, and extended holding can result in carbide precipitation depending on the alloy content (hence stability) of the austenite. Consequently optimum toughness is achieved by holding times sufficiently long to suppress martensite, but not so long that carbide precipitation occurs.

Fig. 2 shows that ductility and toughness of unalloyed austempered irons decrease at longer holding times because of carbide precipitation and decreasing austenite content.

As shown in Fig. 3, austempering can be described as a two-stage reaction. In the first, austenite decomposes to acicular ferrite and carbon-enriched austenite. In the second, austenite further decomposes to ferrite and carbide. Most alloying elements have been shown to retard austenite decomposition, and, therefore, reduce sensitivity to austempering time.

The interesting properties of austempered nodular irons, particularly high toughness and wear resistance, result from the austenite content. The nature

limited because of its stabilizing effect on austenite. Molybdenum is effective in austempered nodular irons because (1) it retards pearlite formation while allowing the acicular ferrite transformation to proceed, (2) it segregates in an opposite manner to nickel, thereby, providing a better balanced microhardenability without promoting massive intercellular cementite, and (3) it does not delay intermediate transformations, thereby, keeping austempering times reasonable.

Typically, austempering treatments for nodular iron components consist of quenching from the austenitizing temperature to a tempering temperature in the 175 to 425 C (300 to 800 F) range, holding at that temperature for a predetermined time, then cooling to room temperature. Tempering at the high end of the range, above about 370 C (700 F), produces a coarse structure of acicular ferrite in austenite. At lower tempering temperatures, structures are finer and resemble typical upper bainites with lath formations containing alternate platelets of ferrite and austenite.

Holding time at the austempering temperature is important from the stand-

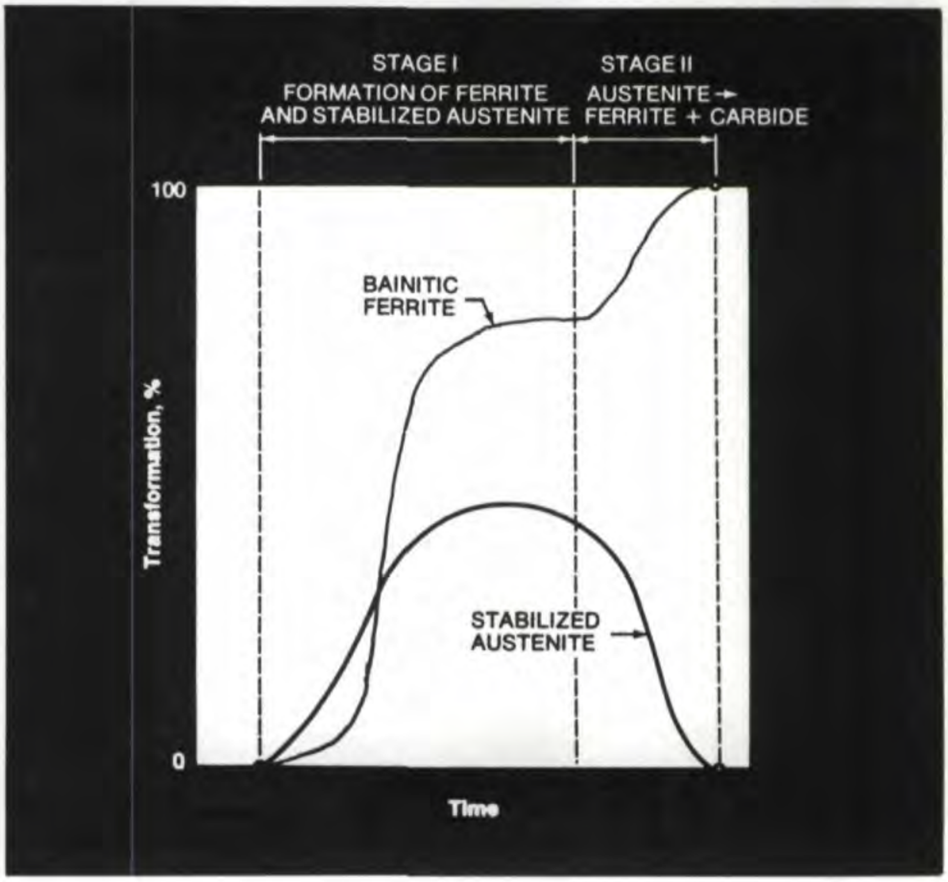

Fig. 3 – Transformation of Austenite During Austempering

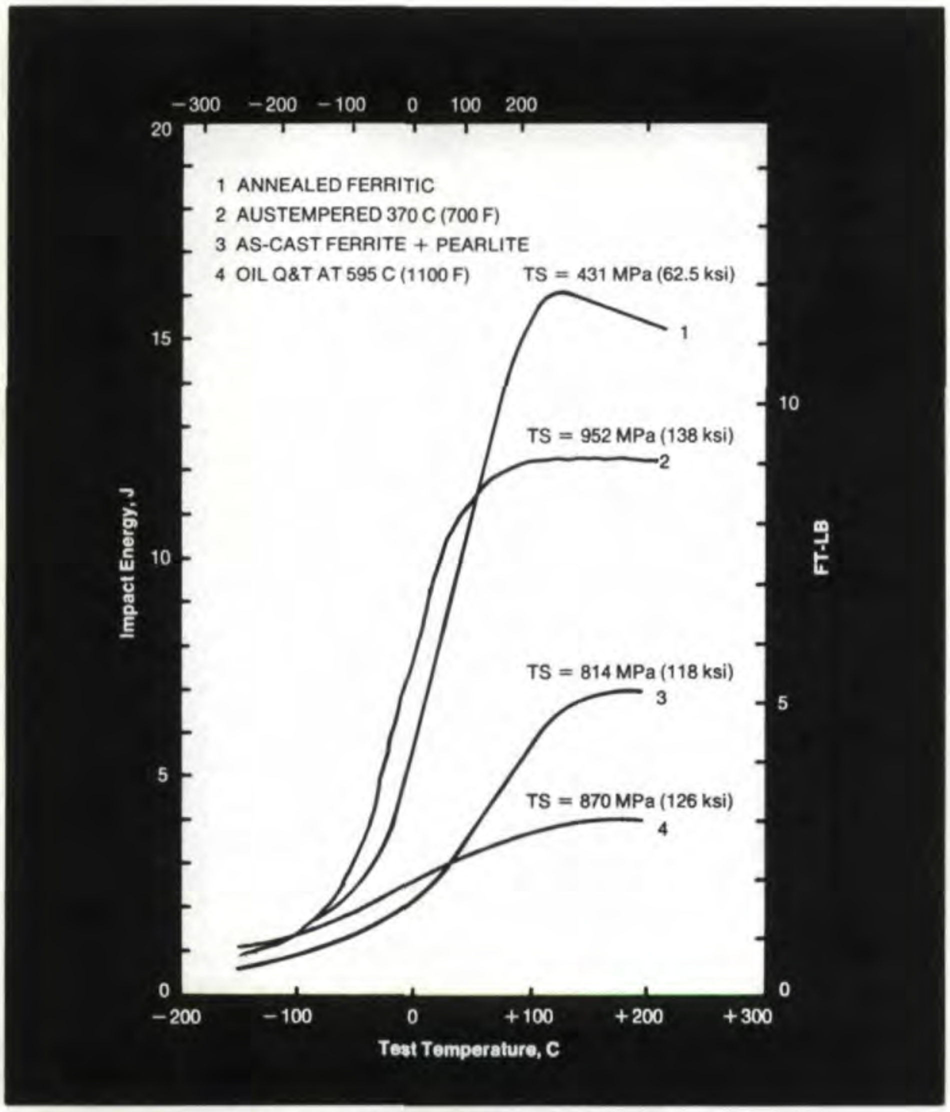

Fig. 4—Impact Properties of Indicated Nodular Irons

of the austenite is markedly influenced by its carbon content. For example, work hardening rate, resistance to stress-induced martensite transformation, low temperature structural stability and toughness are considered dependent on the carbon content of the austenite, which, in turn, is controlled by the austenitizing conditions and also influenced by chemistry.

Fig. 4 shows impact transition temperature curves for nodular irons in four different conditions. The austempered iron, Curve 2, has by far the best combination of tensile strength, transition temperature and upper shelf energy.

In applications requiring good wear resistance, service-induced work hardening of the austenite is the key to successful uses of austempered nodular irons.

Austempered nodular irons are being used or are being comtemplated for use in a number of applications formerly thought of as being in the exclusive province of wrought steels. Further, the interesting combinations of properties that can be achieved plus the inherent part-to-part uniformity that is possible are certain to increase the uses of these materials.

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Tolerance for Overload Stress

by
D. E. Diesburg
AMAX Materials Research
Ann Arbor, MI

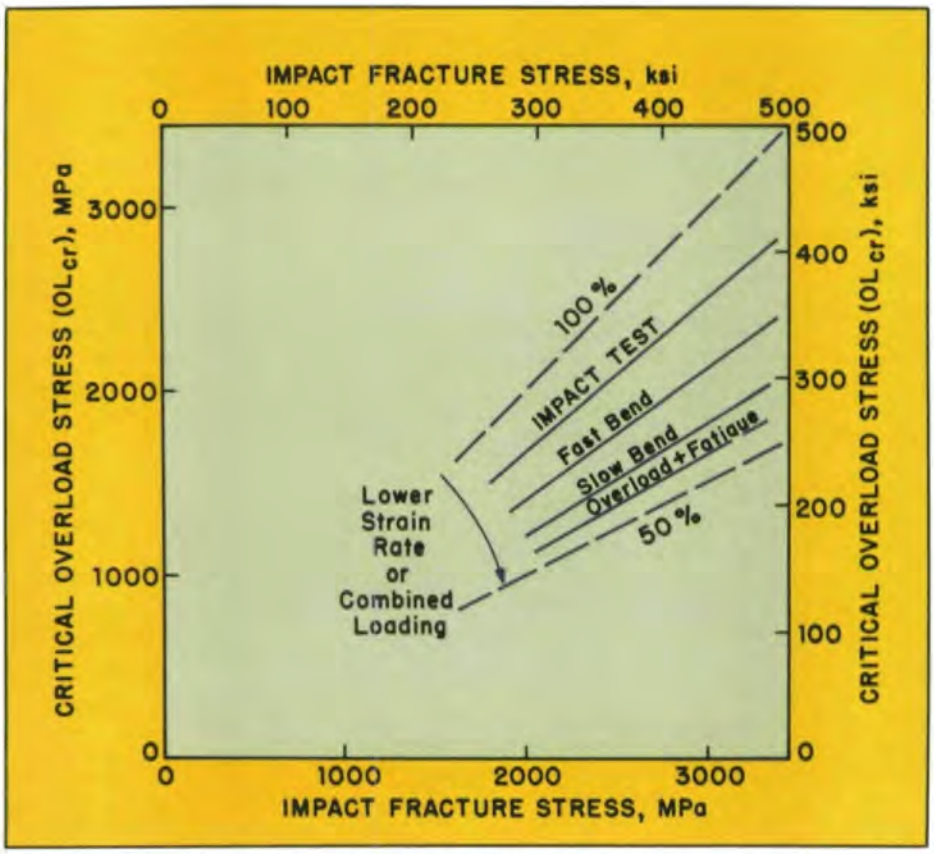

Fig. 1 – Critical Overload Stress Obtained with Various Testing Conditions Compared with Impact Fracture Stress

The performance of carburized components can be improved simply by changing the alloy content of the steel. This fact is particularly useful when a manufacturer becomes tied into a specifically designed assembly and suddenly realizes that some component within the assembly exhibits a higher than desired frequency of failure. Eliminating the problem at this stage by simply changing the steel grade would be a far more economical solution than initiating a change in design. However, the data base available for the selection of an improved grade of carburizing steel does not always make the proper choice of a new grade crystal clear.

There have been several examples in the last few years where the basis for selecting an improved grade of carburizing steel was a parameter defined[1,2,3] as the impact fracture strength of the steel. In most of these situations, the failures were thought to be fatigue related, thus making an alloy steel selection based on an impact property seem inappropriate. However, recent research has shown a connection between fatigue related failure and impact fracture strength.[4] It turns out that all carburized cases have a critical value of stress which cannot be exceeded without causing irreversible damage that, in turn, can result in premature fatigue failure. The failure itself may appear to be fatigue related when, in fact, the initiation event was actually caused by an overload.

Attempts to measure the critical

AUTHOR:

MR. DANIEL E. DIESBURG *is Research Supervisor, at Amax Materials Research Division, Ann Arbor, Michigan. Dr. Diesburg received his BS and PhD from Iowa State University and his MS from Michigan Technological University. At Amax he has served as senior research metallurgist and then staff metallurgist conducting research on carburizing and other low-alloy steels. He is a member of the Metallurgical Society of AIME and the Gear Research Institute, (GRI).*

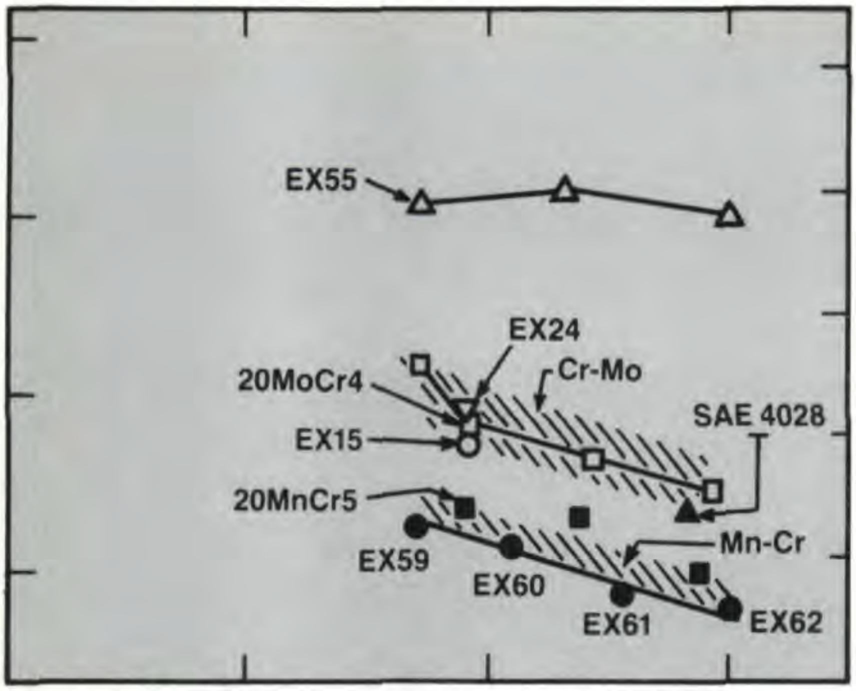

Fig. 2 – Impact Fracture Strength of Various Carburized Steels Plotted Versus Carbon Content of the Core (Reference 4)

overload (OL_{cr}) fracture stress of carburized cases have revealed that this property is strain rate sensitive and also exhibits a damage accumulation effect such that the OL_{cr} value is dependent on the number of fatigue cycles the steel has experienced before the overload stress is applied. The most straightforward method of measuring OL_{cr} is to slowly apply the load until crack initiation is detected.[4] Such a measurement of fracture resistance provides only a relative measure of the steel's ability to resist overload stresses, and it must be realized that fatigue exposure prior to overloading lowers the measured value of OL_{cr}, as can be seen in Fig. 1 where OL_{cr} is correlated with impact fracture strength. Fig. 1 also illustrates the strain rate sensitivity of OL_{cr}, showing increasing values with increasing strain rate. A carburzied case is more likely to initiate an overload crack, if the maximum load is reached with a slow strain rate, than if the same load is applied in impact. Fig. 1 indicates a consistent correlation. Although different for each strain rate, between OL_{cr} and the impact fracture strength. Steels having a high impact fracture strength will also exhibit a high OL_{cr}; therefore, impact fracture strength provides a good relative measure of the steel's ability to tolerate overload stresses during fatigue.

The overload stresses that cause damage are generally above the fatigue limit of the carburized case. Such stresses are not expected to occur, but have been observed to develop for several reasons such as gear misalignment, an object being trapped between gear teeth, higher than expected stress concentration resulting from poor machining or gouging, high stresses encountered during drag start accelerations, and finally, mechanical phenomena such as torsional excitation amplitude stresses that exceed the critical. Regardless of the source, it takes only one application of stress exceeding the critical value to result in premature fatigue failure.

The more commonly used low alloy carburizing steels have OL_{cr} stress values only slightly above the fatigue limit. This fact makes failure analysis difficult. In these situations, a transgranular crack initiation site, usually corresponding to a pure fatigue initiation as discussed previously,[5] is not likely to exist because the OL_{cr} stress, the stress necessary for intergranular fracture, is low and easily exceeded. An example of a steel having a low OL_{cr} value is SAE 4027, and the intergranular nature of the fatigue surface of this steel has been documented.[6] In steels having OL_{cr} stress values significantly above the fatigue limit, the fatigue crack initiation sites are transgranular, thus making failure analysis much easier; i.e., a pure fatigue crack initiation site is transgranular and an overload crack initiation site is intergranular.[5] The remedial action required to correct the situation remains the same for all intergranular crack initiation sites: Change to a grade of steel having a high impact fracture strength.

The magnitude of differences in impact fracture strength to be expected among carburizing steels can be seen in Figs. 2, 3, and 4. SAE 8620 is a commonly used automotive steel, and it can be seen that there are several grades of steel having higher impact fracture strengths such as SAE 4620 + Mo, SAE 4320, EX32, SAE 4817, and EX55. There are also grades of steel having less impact fracture strength than SAE 8620 such as EX59, EX60, EX61, 20MnCr5, and SAE 4028.

The conclusion can be made that, if a given grade of carburizing steel is exhibiting a higher than desired frequency of failure and the fracture appearance of the crack initiation sites are intergranular, the problem can be corrected simply by up-grading to a steel with a higher impact fracture strength. If the crack initiation site is transgranular (excluding microvoid coalescence sometimes observed to occur with single impact fractures), it may be possible to correct the problem simply by shot peening or polishing the surface. An alloy steel change will not generally correct a *pure* fatigue problem unless low fatigue limits were encountered through severe surface oxidation and subsequent alloy depletion of the matrix at the carburized surface.[3]

Parameters other than alloy content such as surface carbon (surface hardness and retained austinite), core carbon (core hardness) and case depth can change the impact fracture strength. The above discussion of relative impact fracture strength presupposes: 1 – that the steels being used have adequate hardenability for the section size and quench, 2 – that the surface carbon results in adequate case hardness, and 3 – that the case depth is sufficient to avoid subsurface crack initiation. The magnitude of change in impact fracture strength, resulting from case depth differences and minor variations in surface carbon and retained austenite, are on the order of that exhibited by changing the core carbon shown in Fig. 2.

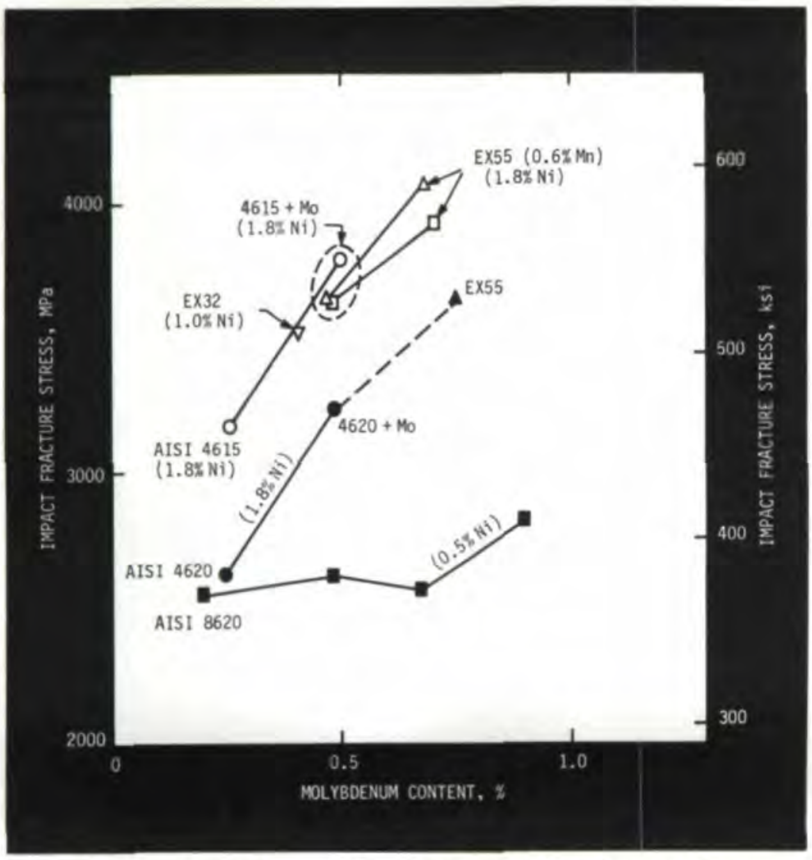

Fig. 3 – (Above) Impact Fracture Stress of Carburized Steels Containing Various Combinations of Molybdenum and Nickel. Open data points are for vacuum-melted heats; solid data points are for air-melted heats. (Reference 3)

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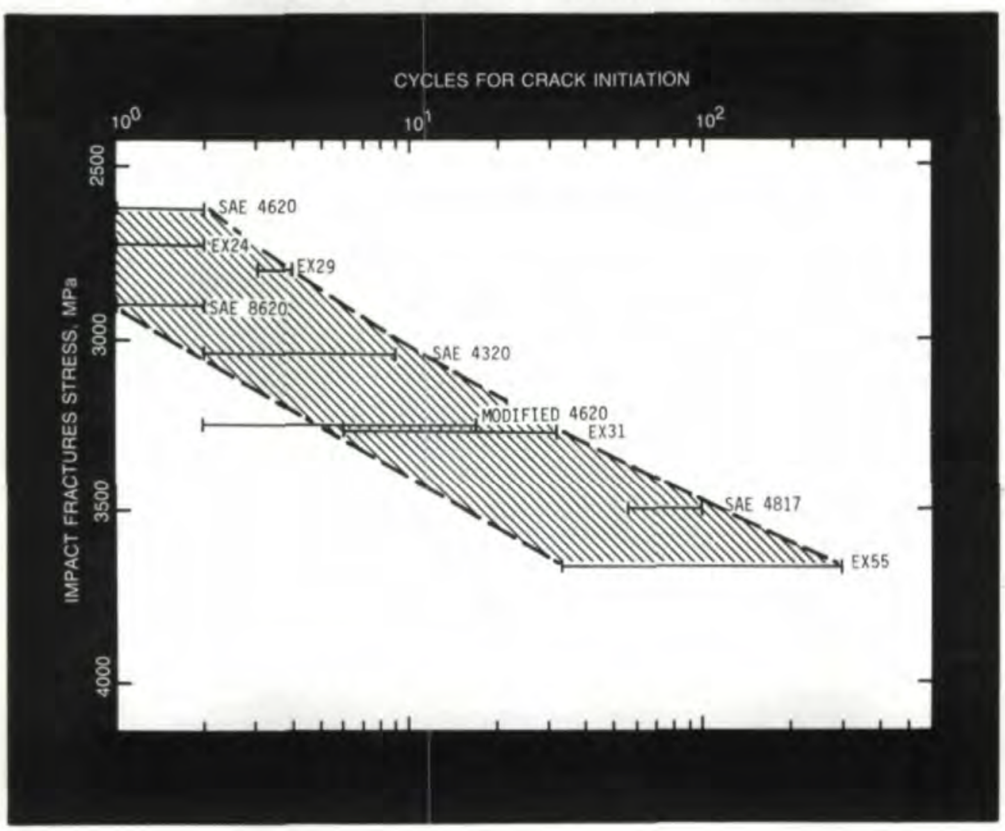
Fig. 4 (Below) – Relationship Between Impact Fracture Stress and the Number of Impacts Required for Crack Initiation Under Repeated Impacts at an Energy Level of 4.0 J (35 in.-lb) (Reference 2)



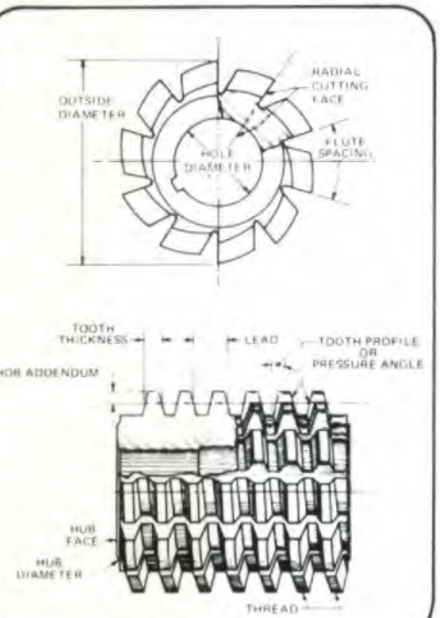
Tooth Forms for Hobs

by
Starcut Sales, Inc.
Farmington Hills, Michigan

The gear hobbing process is a generating type of production operation. For this reason, the form of the hob tooth is always different from the form of the tooth that it produces. For example, an involute form of gear tooth is produced by a hob having angular straight sides. A straight-sided spline tooth is produced by a hob having a curved tooth shape. The amount of fillet radius that a hob will produce is normally different from the radius on the tip of the hob.

It is not necessary for users of hobs to be students of hob generation or to delve deeply into the complexities of such studies. They can specify on the drawing what is desired on a particular gear, spline or special tooth form, and the hob manufacturer can develop the tool.

The following illustrations of hob teeth and produced forms are given to aid hob users in understanding the basic relationships between hob and produced part.



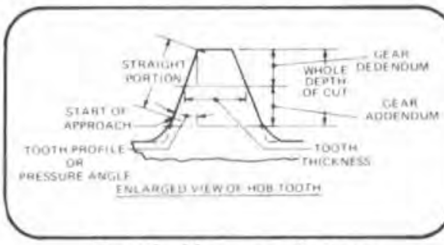
Hob Nomenclature

The conventional method of hobbing a gear is to have the root of the hob clear the outside diameter of the gear blank. This is called a non-topping hob.

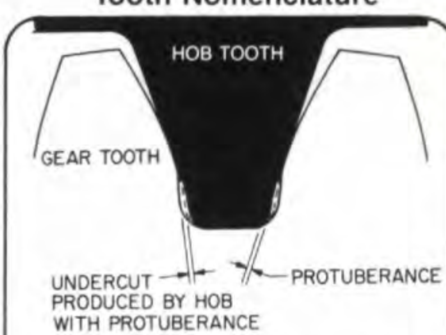
Non-Topping

Topping hobs cut the outside diameter of the gear blank at the same time that the gear tooth is generated. This provides a gear blank with the outside diameter concentric with the gear teeth.

Topping



Tooth Nomenclature

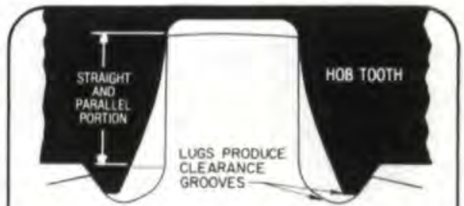


When hobbing operations are followed by gear shaving operations, it is extremely important that the tip of the shaving cutter does not dig into the gear tooth fillet and leave a 'shaving step'. This can be avoided by a protuberance-type hob with projections on the tip of the teeth. These protuberances actually undercut the gear tooth profile in such a manner that the shaving operation can produce a blended fillet profile. The protuberance depth must be carefully calculated so that the active profile of the tooth is not destroyed in the bottom portion of the gear teeth.

Protuberance Type

A hob can be designed to chamfer the outside corners of the gear teeth at the same time that the teeth are generated. These chamfers are extremely beneficial in avoiding handling nicks that interfere with correct tooth action. Called semi-topping hobs, it is extremely important that none of the chamfer goes down far enough to interfere with tooth action. (No. of teeth in contact).

Semi-Topping

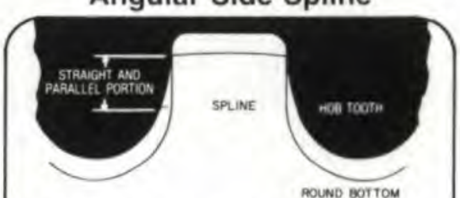


Proper fit of straight-sided spline members is achieved by hobbing a clearance groove in the area where the straight side meets the minor diameter of the spline. Small projections can be provided on the corners of the hob teeth to provide a blended clearance groove.

Straight Side Clearance Groove

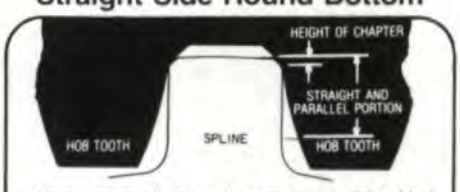
Angular-sided splines are produced with hobs having curved tooth forms. The true angular side is produced at only one depth of cut. Feeding in a hob of this type to reduce tooth thickness has the detrimental effect of distorting the tooth form.

Angular Side Spline



Straight-sided splines have maximum strength when a full-fillet design is utilized. Such full fillets (round-bottoms) can be simply reproduced by the hobbing tool. The fillet on the tool differs from that of the produced fillet on the spline.

Straight Side Round Bottom

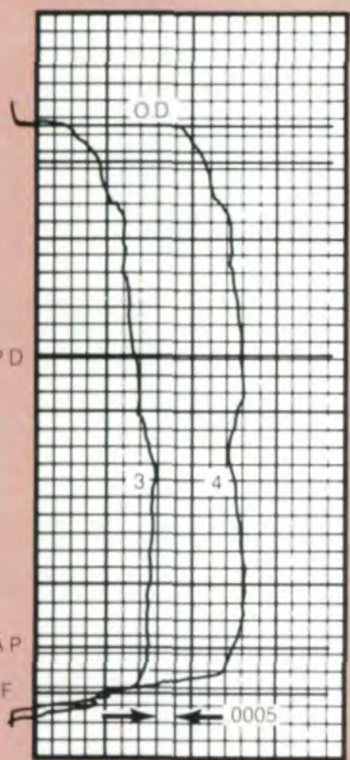


A semi-topping hob can be used on straight-sided splines to produce a chamfer on the outside corners of the spline teeth.

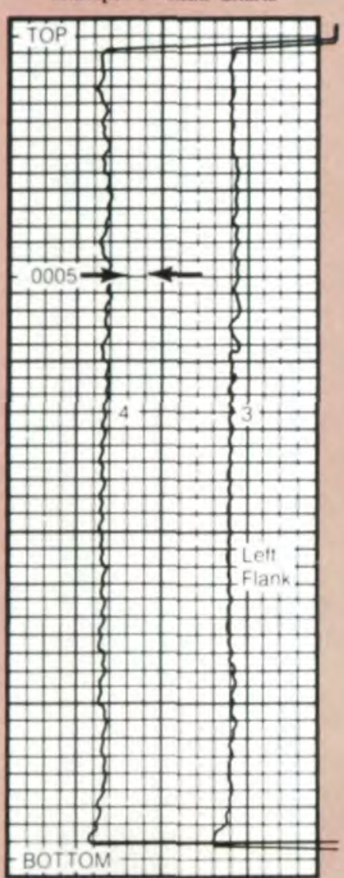
Semi-Topping Flat Root

HARD GEAR . . .
(continued from page 15)

Example 4 – Involute Charts



Example 4 – Lead Charts



The worth of any new technology can be best determined by its acceptance in the marketplace. It is apparent that by having the skiving hob available, more and more uses are being found for this bridge between the extremely accurate ground gears, and those that had previously been ground only because there was no way to correct distortions, even though an AGMA class 8 to 10 gear would be acceptable. The technology has thus advanced from one of being essentially a "pre-grind technology" to one that now encompasses also "finishing of hard gears by skiving".

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BACK TO BASICS . . .

Gear Grinding Techniques Parallel Axes Gears

by
John M. Lange
Miller Associates, Inc.

The fundamental purpose of gear grinding is to consistently and economically produce "hard" or "soft" gear tooth elements within the accuracy required by the gear functions. These gear elements include tooth profile, tooth spacing, lead or parallelism, axial profile, pitch line runout, surface finish, root fillet profile, and other gear geometry which contribute to the performance of a gear train.

The strength and wear resistance of gear teeth may be increased by hardening the tooth and root surface. Hardened gear teeth make it feasible to reduce the gear size and increase the transmitted load and speed. This is highly desirable from the standpoint of economy as well as the product efficiency. However, distortions occur during the hardending process which can be corrected only by abrasive machining or grinding.

AUTHOR:

MR. JOHN M. LANGE *is the Vice President of Miller Associates Inc., the United States Agent for Maag Gear Wheel Co. Ltd., Zurich, Switzerland. Mr. Lange joined Miller Associates in 1969 after graduating from Carthage College in Kenosha, WI with a BA in Business. His gear training began through enrolling in an apprentice program at Maag's plant in Zurich in 1971, and has continued ever since through his exposure to the Gear Technology of hundreds of customers nationwide. Mr. Lange has presented papers at SME's Gear Processing Manufacturing Seminars and AGMA's Gear Manufacturing Semposiums. He is presently active in AGMA as a member of the Gear Manufacturing Committee and the Chairman of the Metric Resource and Advisory Committee.*

Ground Unhardened Gears

Low hardness or "soft" gears in the range of Rockwell C 25 to 40 are usually cut by a gear shaper, Shear-speed, or hobber, and then finish shaved to obtain a relatively high degree of accuracy, i.e. AGMA 10-11 (American Gear Manufacturers Association quality no.). In some applications, it may be more economical to grind the "soft" teeth in the solid gear blank or bar stock, especially in the range of 16 diametral pitch and finer.

High Alloy Gears Ground From Solid

The high temperature high alloy gears and splines afford an excellent area in which the economics of abrasive machining of gear teeth may be realized. It has been demonstrated that a 16/32 DP internal spline, which required 12 hours to shaper cut in a very high nickel-chrome alloy, could be form ground from the solid in approximately 4 hours. In addition to the time saved, a more accurate spline was produced at considerably less cost.

Medium Hardness Ground Gears

Through-hardened alloy gears in the range of Rockwell C 45 to 55 are usually cut, hardened and then finish ground or honed as required to obtain specified accuracy and surface finish. Although gears harder than Rockwell C 40 are not usually cut, it is possible to shaper cut through hardened gears up to about Rockwell C 50. This procedure is very costly due to rapid cutter wear and should be restricted to those applications where grinding after hardening is not possible.

Gas turbine manufacturers employ abrasive machining to effect considerable savings in the manufacture of splines and keyed through-hardened spacer rings. The solid through-hardened ring blanks are stacked on an arbor, then the splines, keyways and peripheral grooves are form ground from the solid. These rings were formerly made by cutting in the soft-blank, heat treating and then finish grinding individually. Form grinding from the solid blanks after hardening effected savings in excess of 50% of the original cost.

Case Hardened Ground Gears

Case hardened gears are usually employed in high speed and high load units which require maximum durability and reliability as well as high power performance. Aircraft, missile systems, truck and automotive transmissions, marine speed reducers, gas turbine gearing, farm and off-the-road equipment, and machining tools are typical of durable reliable high performance case hardened gear applications.

Gear tooth and root surfaces may be hardened locally by carburizing, nitriding, induction hardening, (and a number of shallow surface hardening methods which improve resistance to wear, but not the bending strength of fatigue life at the critical root fillet section.)

Carburized And Hardened Ground Gears

Due to their high impact and bending load capacity and their good wear resistant properties, carburized and hardened gears are the most widely used case hardened gears, where rugged high performance is required. Gears may be hardened all over, or masked off during carburizing to prevent hardening of the hub, web, and rim areas. Carburized gear blanks are frequently copper plated all-over prior to cutting the teeth and finish machining those surfaces to be hardened, such as functional bearing or mounting surfaces. The gear is then heated above the critical temperature, approximately 1700°F. in a carbon pack, salt bath or a carbon atmosphere, and held for the time required for the exposed machined surfaces to absorb carbon to the desired depth. The carburized case depth may vary from 0.010 to 0.020 inch for 20 diametral pitch gears, up to 0.025 to 0.035 inch depth for 12 diametral pitch, and 0.075 to 0.100 inch depth for gears of 2 diametral pitch and coarser.

A carburized gear may be hardened by quenching directly from the carburizing furnace, or it may be slow cooled in a protective atmosphere, then reheated in a protective atmosphere and quenched for grain refinement and case hardening. The case will quench out at about Rockwell C 63 to 65 and is then tempered to Rockwell C 58 or 60 to 63 before finish grinding or honing. Since about 85% of the distortion takes place during carburizing, it is sometimes advantageous to temper the carburized gear below Rockwell C 40, then finish shave prior to hardening. This procedure may make it possible to hone for surface finish only, or minimize the necessary grinding stock.

Most automotive transmission gears are small and of simple design, which makes it possible to shave them prior to carburizing and hardending. They only require honing to correct minor heat treat distortions. Unlike grinding, honing is not a metal removing process and should be used only to improve surface finish and correct very minor thermal distortions. Honing will also remove handling nicks and burrs.

Other high speed high performance gears are cut, carburized, hardened, and finish ground. The grinding stock should not exceed 0.005 to 0.007 inch for case depths up to 0.025 to 0.035 inch and 0.010 inch in the 0.075 to 0.100 inch depth range.

In order to minimize the grinding stock removal, the nominal pitch circle of the gear can be indicated after hardending and used to locate the centers, the bore, or the operating journals which will determine the gear axis during additional operations including gear tooth grinding. Since the pitch circle, distored in carburize and hardening, may be difficult to define, a proof circle near the root diameter, and a reference face perpendicular to the axis, should be provided to facilitate optimizing the concentricity and squareness of the gear teeth before finish grinding. Another popular approach is to use a pitch line chuck with either three or six pins to re-establish the center line in relation to the pitch circle.

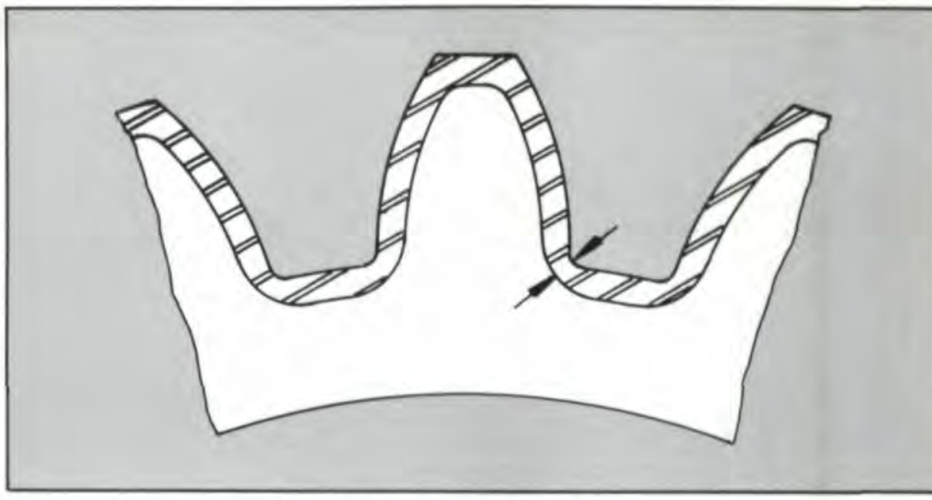


Fig. 1A – Shallow case depth in root fillets.

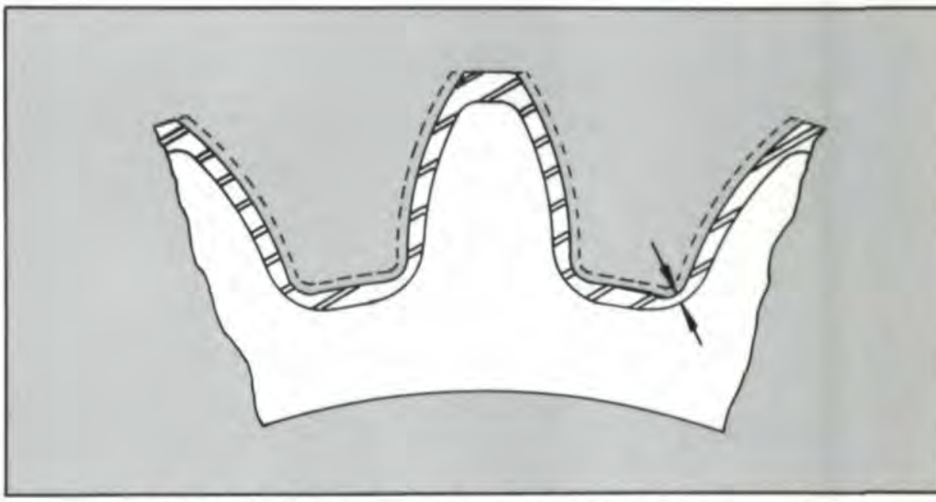


Fig. 1B – Excessive case removal in root fillet reduces bending strength.

It is absolutely essential that excessive case removal in the root fillet be avoided. Fig. 1(A) illustrates the shallow case which occurs in a sharp root fillet as a result of the small entrance area in the fillet during carburizing. View 1(B) shows the resulting removal of most of the case hardened fillet during grinding. Note the thinness of the hardened section at the root fillet of the gear tooth which will fail in bending fatigue due to insufficient case depth in this critical area. Sharp root fillets or steps should be avoided whenever possible, especially on case hardened gears.

Fig. 2(A) illustrates schematically a protuberance-cut full-fillet gear tooth and shows that the tendency towards a lean case in the fillet is greatly reduced. View 2(B) shows that adequate case depth remains after grinding in the root and fillet of a carburized protuberance-cut full-fillet gear.

Fig. 3(A) and 3(B) illustrate a protuberance cut and a full fillet after grinding only the tooth profiles. These roots remain unground, fully hardened and,

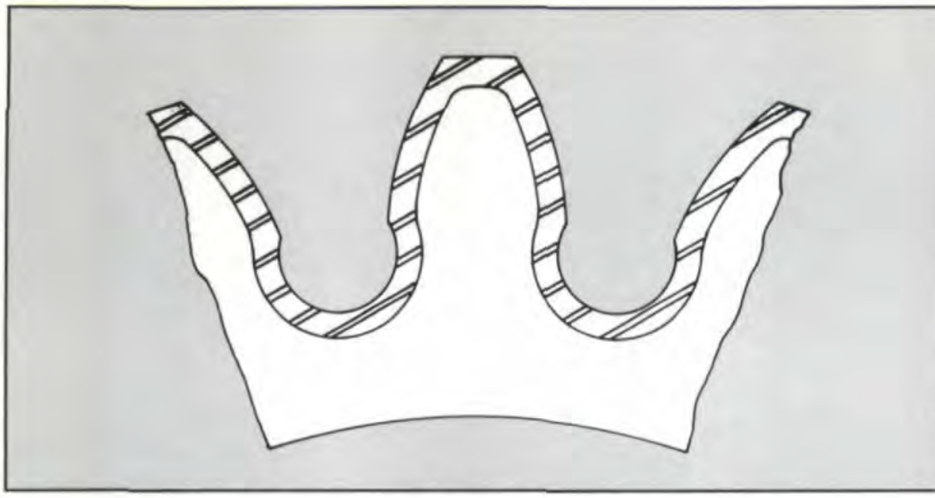


Fig. 2A – Protuberance cut full fillet improves case depth in fillet.

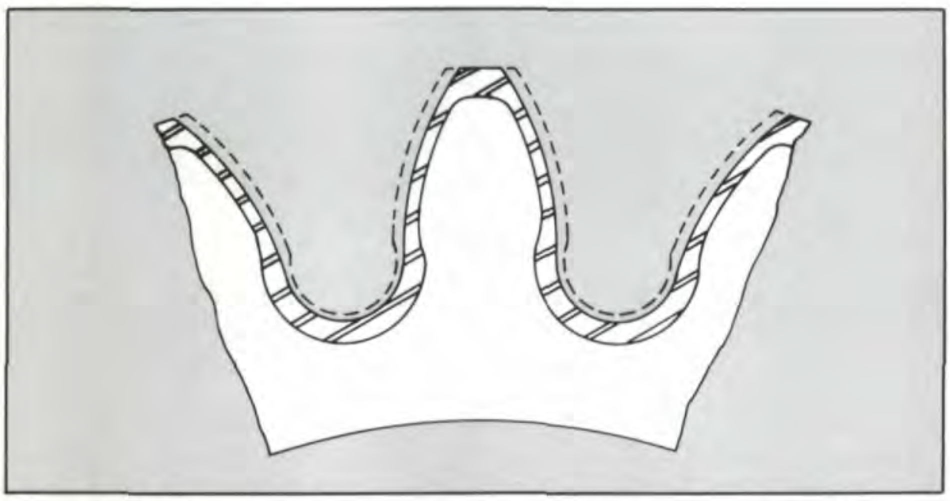


Fig. 2B – Ground protuberance cut fillet showing sufficient case in ground root fillet.

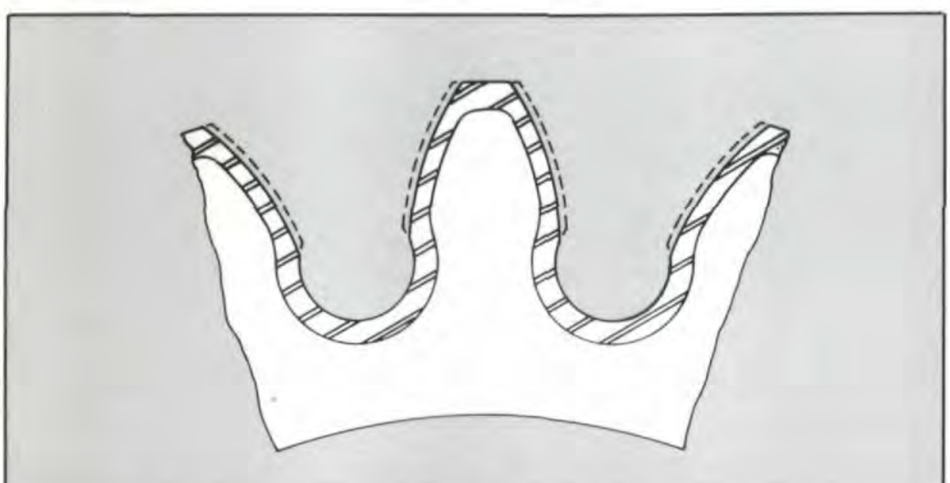


Fig. 3A – Ground tooth profile with unground protuberance cut full fillet root.

therefore, at maxiumum strength. However, care must be taken to remove all residual heat treat scale from the root and fillet. If not removed, the scale may act as a stress riser, or flake off in operation and abrade the tooth and bearing surfaces. Scale may be removed by grit blasting the gear teeth and fillet surfaces prior to finish grinding the tooth profiles. Grit blasting may be followed by shot-peening the tooth and fillet surfaces before finish grinding of the tooth profile, only.

Nitrided Case Hardened and Ground Gears

Nitriding steels contain nitride-forming elements such as aluminum, chromium, molybdenum, vanadium or tungsten which combine with atomic nitrogen (N) when heated from 925°F to 1100°F in an atmosphere of dissociated ammonia. The nitriding cycle requires 25 to 48 hours to produce a 0.015 to 0.022 inch deep case, which is very hard – Rockwell 15N 90 to 93 – and highly resistant to wear. The hardness of the relatively thin case drops off rapidly leaving a hard surface which is not well suited for application where impact loadings will be encountered.

Since nitriding is done at a temperature below the critical, heat treat distortions are minimum. In many cases, grinding after nitriding would not be necessary except to insure removal of the "white layer" from the tooth and fillet surfaces. The white layer is a brittle, weak, over-rich nitride which forms during nitriding and ranges in thickness from 0.005 to 0.003 inch depending upon the nitride cycle used.

Nitrided gears are processed to take maximum advantage of the small thermal distortions. The gear blanks are normalized at 1800°F, annealed, rough machined, quenced from 1725°F, tempered for core properties, finish machined and gear teeth finish cut or shaved prior to nitriding. After nitriding, the grinding stock removal should be limited to 0.003", and extra care should be taken to avoid excessive case removal in the root fillets.

Gear Grinding Methods

The two basic methods used to grind gear and spline teeth are the form grinding method and the generating method.

Form grinding employs a disc-type grinding wheel, contoured by diamond dressing tools to grind the complete gear tooth space profile. This type of grinding is illustrated in Fig. 4. There are several different generating methods as shown in Figs. 5, 6 and 7. Each of the generating methods is identified in the industry by the name of the manufacturer who originally developed the particular method. All of the generating methods

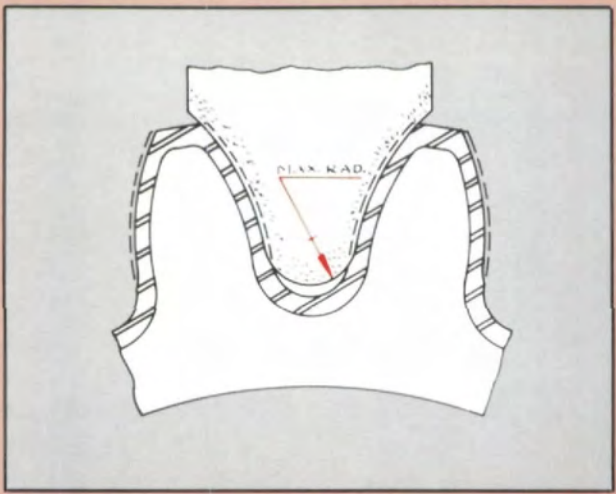


Fig. 3B – Ground tooth profile with unground full fillet root.

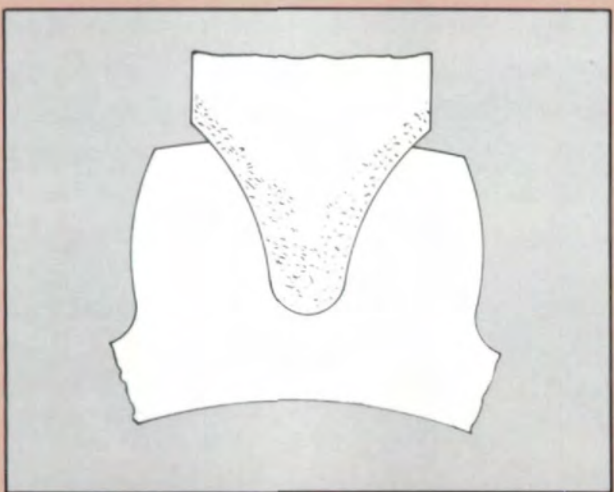


Fig. 4 – Formed-wheel gear grinding method.

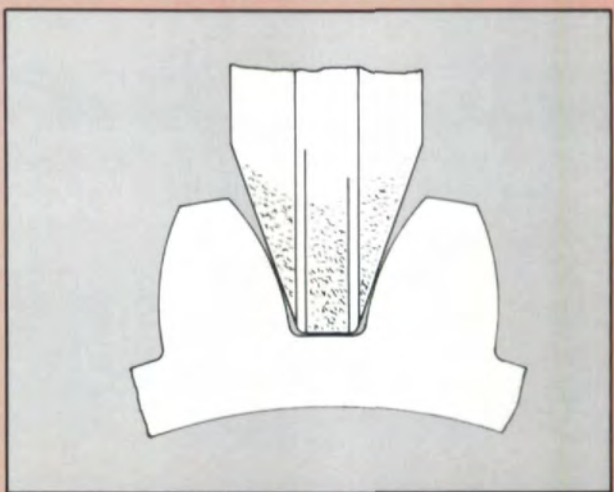


Fig. 5 – Conical wheel gear grinding method.

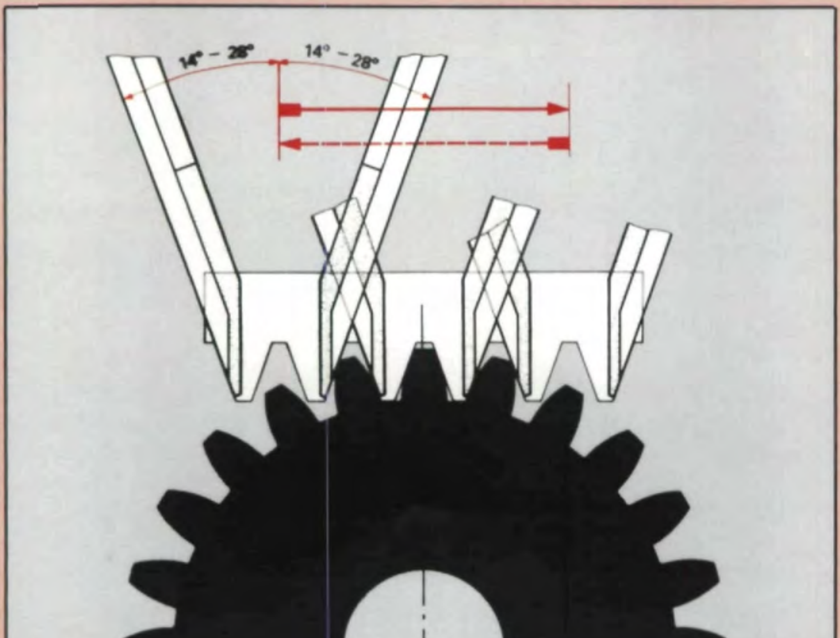


Fig. 6 – Saucer-shaped wheel gear grinding method.

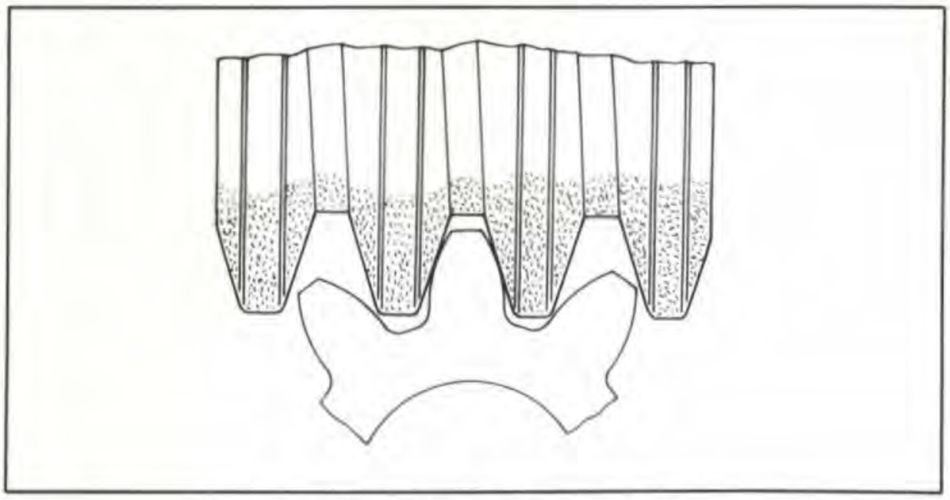


Fig. 7 – Threaded wheel gear grinding method.

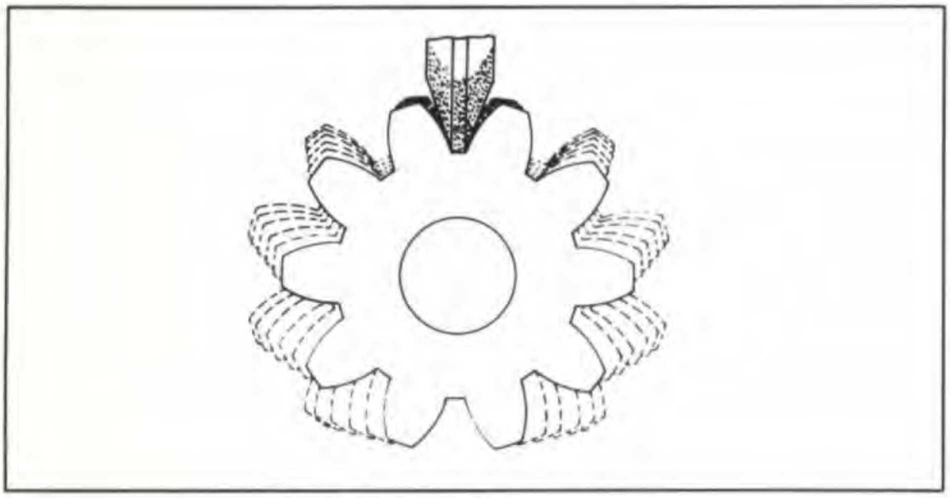


Fig. 8 – Involute tooth profile generation.

employ the straight profile rack generating principle illustrated in Fig. 8. While the straight profile rack grinding wheel and the gear reciprocate relative to each other, the gear simultaneously rolls on its pitch circle, in timed relation to the rack without slipping, thereby, generating the involute tooth profile.

Form Gear Grinders

Examples of brand names are National Broach Company, Liebherr, Kapp.

Form gear grinders are capable of grinding both external and internal spur and helical gears up to 36 inch diameter and larger. (See Figs. 9A and 9B) The machines have a capacity for diametral pitches from approximately 64 to 2. An automatic grinding cycle is provided which reduces the necessary reliance on operator skill and, at the same time, increases the accuracy of the gears ground on the production basis by insuring repeatability of the selected optimum grinding cycle. The gear to be ground is carried between centers in the index head and the tailstock. The index head, tailstock, and the dresser are mounted on the work table which reciprocates under the grinding wheel. The grinding wheel head is mounted on column ways and supported by a grinding feed mechanism which raises the grinding wheel after automatic dressing at finish size.

The two diamond tools which dress the grinding wheel are actuated by templates through reduction cams or pantographs. (Also see comments under CNC application.) The grinding wheel is dressed wtih sufficient accuracy to produce tooth profiles ground within a tolerance band of .0002 of an inch. Since the dresser is cam actuated, non-involute tooth forms such as cycloidal teeth, Wildhaber-Novikov gears, straight sided splines, and parallel sided splines, as well as half-round bearing grooves, can be produced with equal ease and accuracy. (See Fig. 10 form grinding wheel contour dresser).

The gear is indexed by accurately ground hardened index plates with the number of gashes corresponding to the number of teeth in the gear to be ground. (See Fig. 11) Gears are normally ground with a maximum tooth spacing variation between adjacent teeth of .0002 inch and a maximum variation on the gear .0006 of an inch. The lead produced is within .0001 of an inch per inch of facewidth.

The grinders are also equipped with crowning or axial modification devices. The vertical motion of the grinding wheel is superimposed on the grinding feed and produces a fully crowned tooth or end ease-off designed to prevent end loading of the teeth due to mounting support deflections under varying operating loads.

The automatic grinding cycle helps eliminate the hazard of surface tempering. However, additional insurance can be had and better finishes obtained by using a high grade, well filtered, sulphurized or chlorinated grinding oil. Oil mist extractors are suggested to eliminate contamination of oil misting the surrounding area.

Recommended grinding wheels are vitrified aluminum oxide wheels, 29A semi-friable or hard brittle universal 38A abrasive. The grain sizes vary from 46 to 80 for combined rough and finish grind. The hardness varies from H to J, and the structure from a medium 5 to 9. The grinding wheel range is (29A/38A) (46/80) (H/J) (5/9) V. These machines have been adapted to Borazon grind wheels as will be discussed later.

Saucer-Shaped Wheel Gear Grinder

Examples of Brand Names: (Maag and Hurth)

The generating gear grinding machine, shown in Fig. 12, employs two saucer shaped grinding wheels as shown in Fig. 6. Maag grinders are suitable for grinding external and internal spur and helical gears with various models having capacities up to 198 inches, and diametral pitch ranges varying from as fine as 25DP to as coarse as .63DP.

On a vertical type Maag grinder, the axis of the workpiece is vertical. The planes established by the rim of the

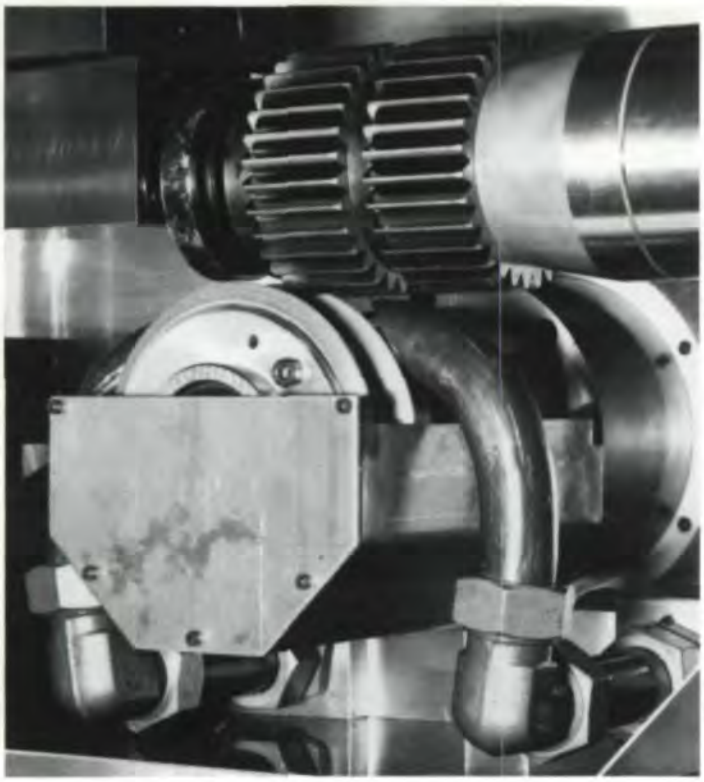


Fig. 9A – Form grinding on an external gear.

Fig. 9B – Form grinding on internal ring gear.

saucer-shaped grinding wheels represent the straight profile rack tooth on which the work gear rolls during the grinding cycle. The gear generating motion is produced by a rotary motion imparted through a change gear train driving the work table/work piece and a transatory motion of the workpiece with a lead screw change gear drive train. The gear, in effect, rolls across a single tooth rack with a tooth of the rack being replaced by reciprocating grinding wheels, i.e. one right and one left flank ground per a rolling pass.

The vertical column, which can be swivelled to the desired helix angle, supports the two separately powered grinding wheel heads. The grinding head slide can be adjusted vertically to accommodate different gear facewidths and gear locations. The individual grinding heads can be swivelled to the angle corresponding to the gear pressure angle. The grinding heads are also displaced laterally for various pitches.

Theoretically, the rim of the saucer-shaped grinding wheel contacts the tooth flanks at one or two points depending upon the angle settting of the wheels. The point generation method removes metal over a small area, generating less heat and, thereby, alleviating the need for grinding coolants or oils. Grinding dust is removed by a dust collector provided with the machine.

The horizontal Maag grinder also uses two saucer type wheels, but they are set at a zero degree grinding pressure angle. The generating principle can be likened to the basic mechanical construction of an involute, i.e. a circular disc with a string wrapped around it, and unwinding the taut string produces a series of tangents to the "base circle" producing an involute curve. Replace that base circle disc with a segment "rolling block" and steel bands for string, and you have the fundamental operating principle of a Maag horizontal grinder. (See Fig 13).

One of the most important factors about a Maag gear grinding machine is that the active face of the grinding wheel must stay in a set position. This is accomplished by a grinding wheel wear compensating device that senses as little as .000040" wear in the face of the active grinding wheel. Through a mechanical drive train, the grinding wheel is moved back into its correct position automatically.

In order to compensate for tooth beam deflections under varying loads, it is desirable to relieve the tooth profile at the tip and on the flanks. Profile and longitudinal modifications are achieved by a hydromechanical cam operated system or a CNC controlled unit which moves the grinding spindles laterally in timed relation with the generating stroke and axial feed slide. (Fig. 14A and B).

Helical gears require that an additional rotation be superimposed on the generating motion, the magnitude and direction of which is dependent upon the helix angle. On the horizontal machines, this is effected by a helical guide disc and sliding block arrangement which imparts a transverse motion to the tape support stand in proportion to the axial feed motion. The lateral movement of the tape stand is converted by the pitch block and tapes into additional rotary motion as required.

Both horizontal and vertical grinders are fitted with automatic infeed controls, indexing systems, wheel wear compensating units and diamond operated dressing devices for complete automatic operation.

Maag type grinders use vitrified bond type grinding wheels having a composition of aluminum oxide or silicone carbide. Grain sizes normally fall in the range of 46-80, depending upon diametral pitch, and also are in the soft ranges of F to I. Balancing of this type of grinding wheel is not that critical. Therefore, only a set of parallel bars and adjustable weights are used for balancing. It should be pointed out that Borazon grinding wheels are presently in use on Maag grinders for grinding of tool steel grade materials, i.e. shaving cutters and rolling dies. (See later comments regarding Borazon grinding).

Threaded-Wheel Gear Grinders

Examples: Reishauer and Okamoto

Reishauer and Okamoto gear grinders are fast precision machines employing a 3¾ inch diameter threaded grinding wheel as illustrated in Fig. 7. Operating principles of this type of grinder are illustrated in Fig. 15. A section of the threaded-wheel is an involute rack. These machines are designed for external spur or helical gears up to 28 inch diameter with helix angles up to 45°. Pitch and helix angle determine the maximum facewidth of helical gears. This type of grinder is capable of grinding DP's in the range of 3-48, depending on the size of the machine. The principle of the threaded-wheel generating grinder is the same as the gear hobbing machine. The gear is mounted vertically and moves axially in both directions during grinding

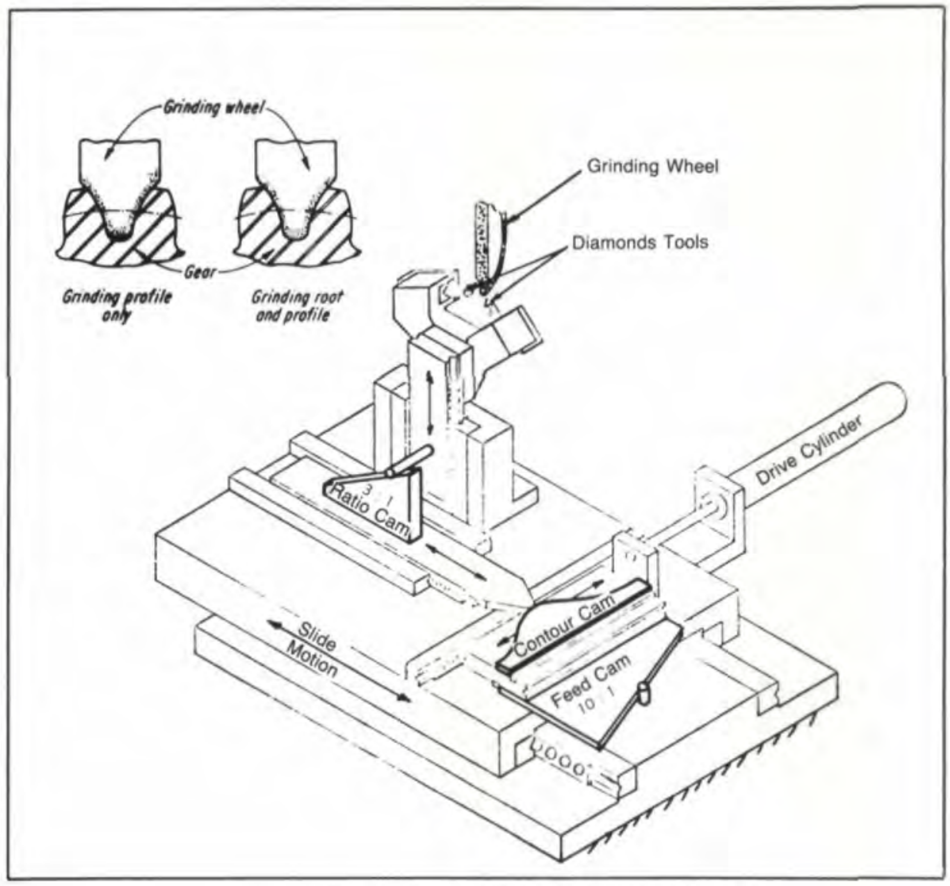


Fig. 10 – Form grinding wheel contour dressing.

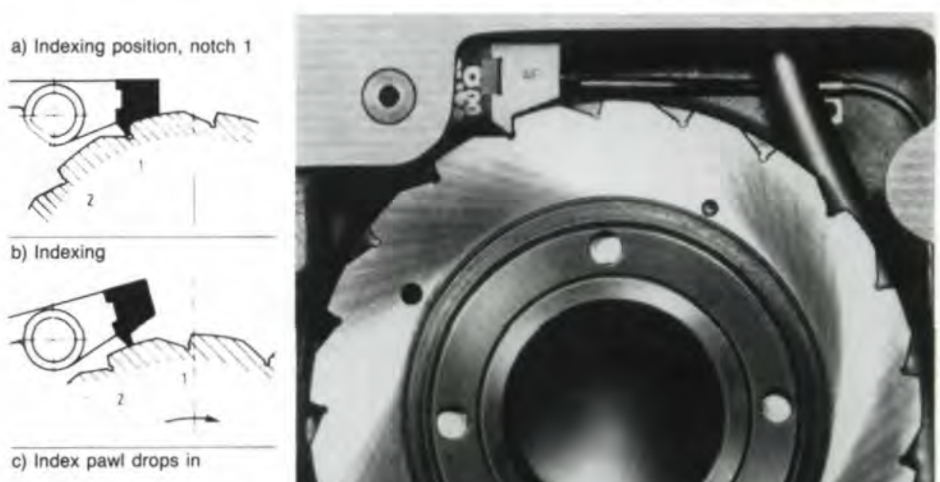


Fig. 11 – Mechanical indexing head (CNC indexing is also used).

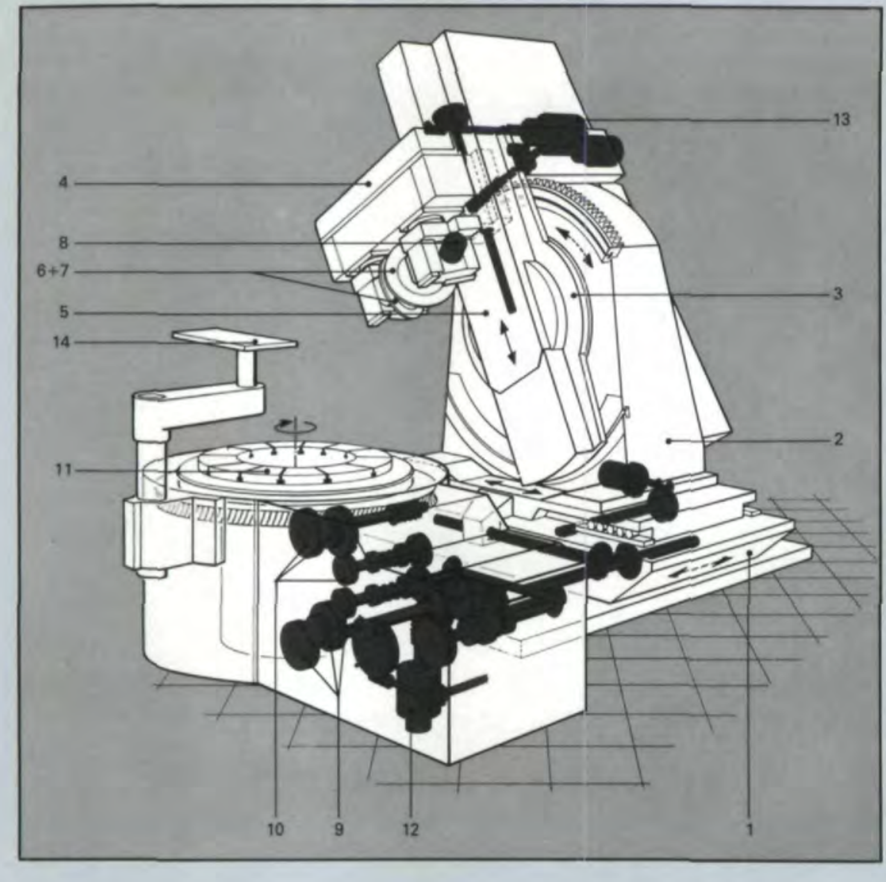


Fig. 12 – (Upper left) Kinematics of saucer – shaped wheel gear grinding machine, grinding wheels set to pressure angle of the gear.

1 column radial slide
2 column
3 swivel head (β)
4 crossbeam
5 ram
6 grinding wheel
7 grinding wheel
8 wheel head motor
9 module change gears
10 index change gears
11 work table with central hole
12 generating drive motor
13 ram drive reversing motor
14 hydraulically operated instrument table (for *ES-401 and ES-430 measuring systems)*

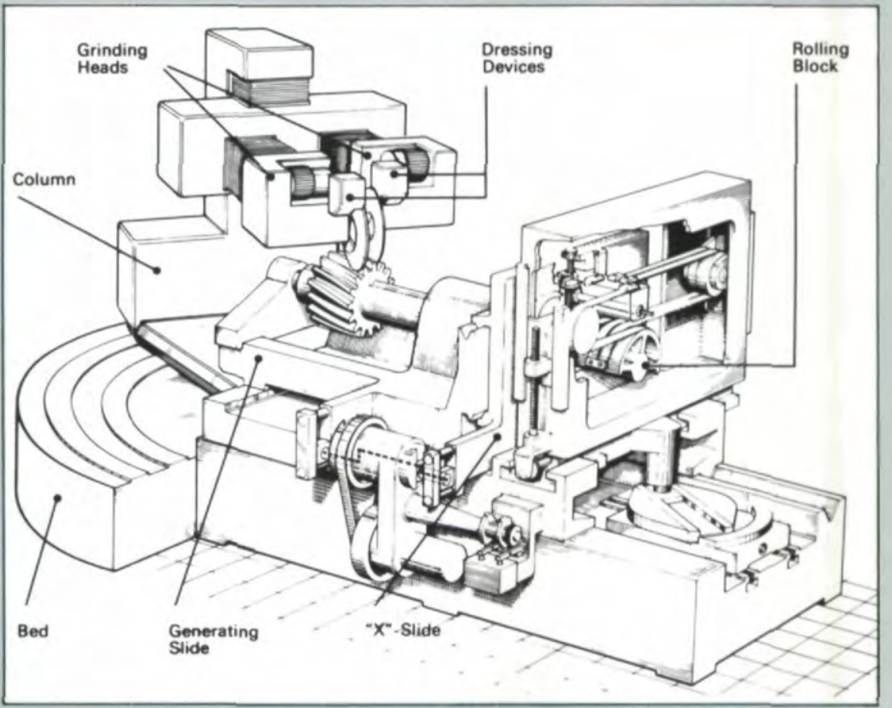


Fig. 13 – (Right) Kinematics of saucer-shaped wheel gear grinding machine.

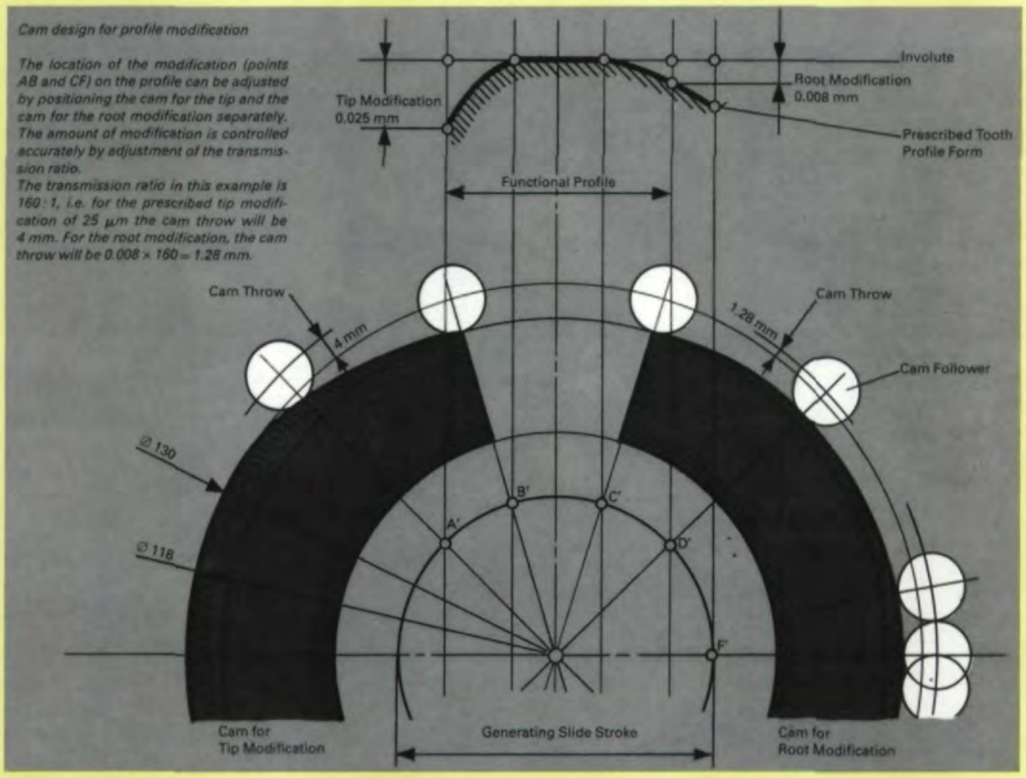


Fig. 14A – Correction cam for profile modification.

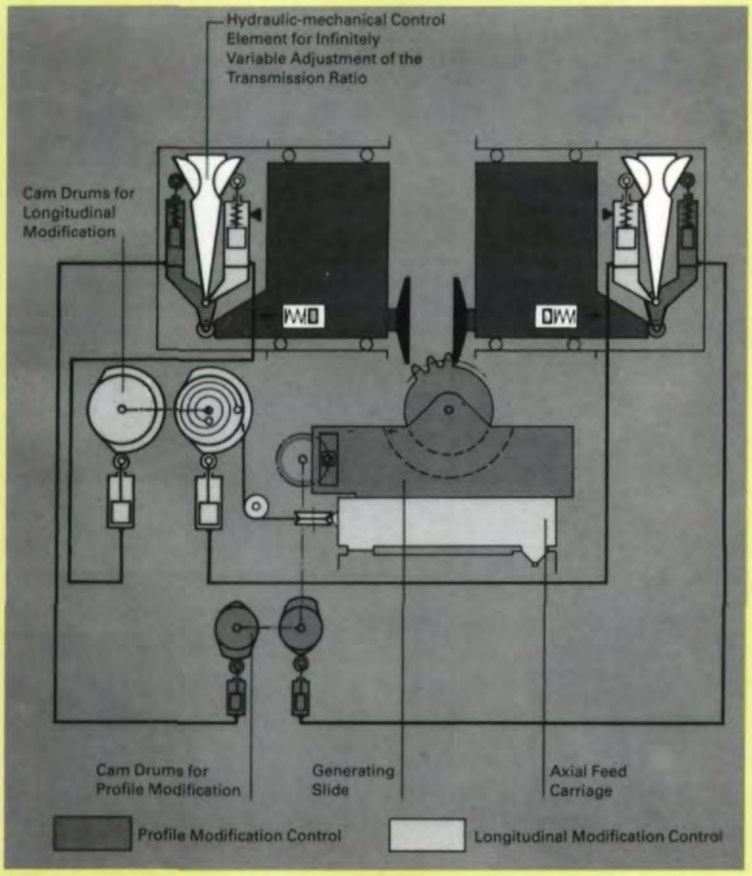
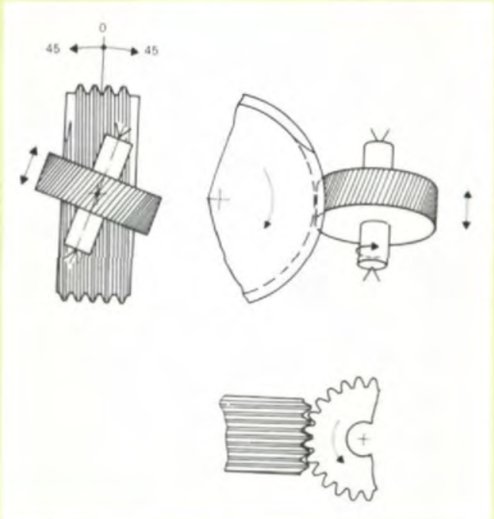
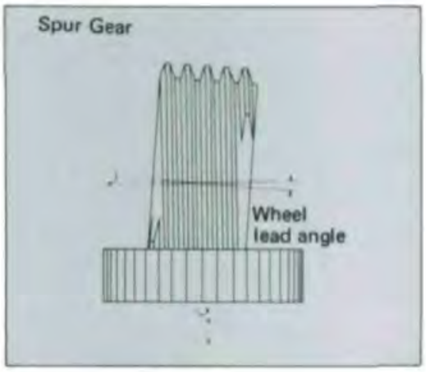


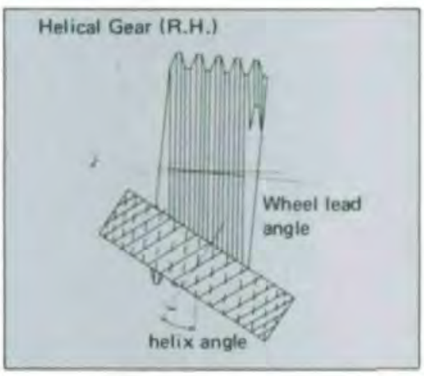
Fig. 14B – Kinematics of profile and longitudinal correction system.

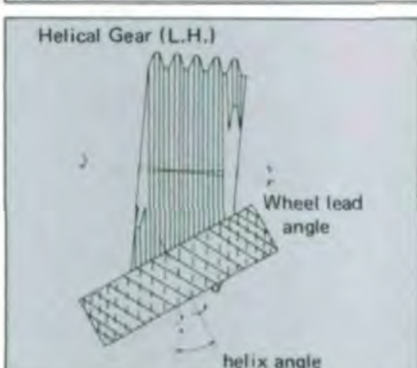
Fig. 15 – (Below) Operating principle of threaded-wheel gear grinder.



cycle. The grinding wheel is fed into the work at the end of each pass. The grinding feeds and speeds are automatically changed from rough to finish. A hydraulically actuated collet type clamping device can be disengaged to allow the workpiece to free wheel for exceptionally fine finishes. (See kinematic drawing, Fig. 16 for mechanical drive train machine).







Crush forming a new grinding wheel thread can be a relatively lengthy process, especially when it's done on the machine. Off machine dressing apparatus' are available that reduce this dressing cycle without interfering with grinding machine productivity. Furthermore, pre-formed wheels are available from the grinding machine manufacturer. Dressing a pre-crushed wheel requires only about 20 minutes. However, if profile modifications are required, it could take somewhat longer. A universal truing attachment can dress the wheel to produce involute profile or modifed tips and flanks to a type of diamond plated rolls mounted on motorized spindles available for dressing the grinding wheels. A single roll requires a very precise roll, and it dresses both sides of the grinding wheel at one time. The two roll methods have two diamond rolls mounted on independent spindles and makes it easier to adjust for diamond roll wear.

As the work passes axially through the grinding wheel, the gear rocks axially to produce crowning. The magnitude and location of the axial profile modification is controlled by cams mounted on the work slide. Generally, the best results are obtained with a good grinding oil and a vitrified aluminum oxide grinding wheel with a specification of 38A (150/180) (H/J) 9V.

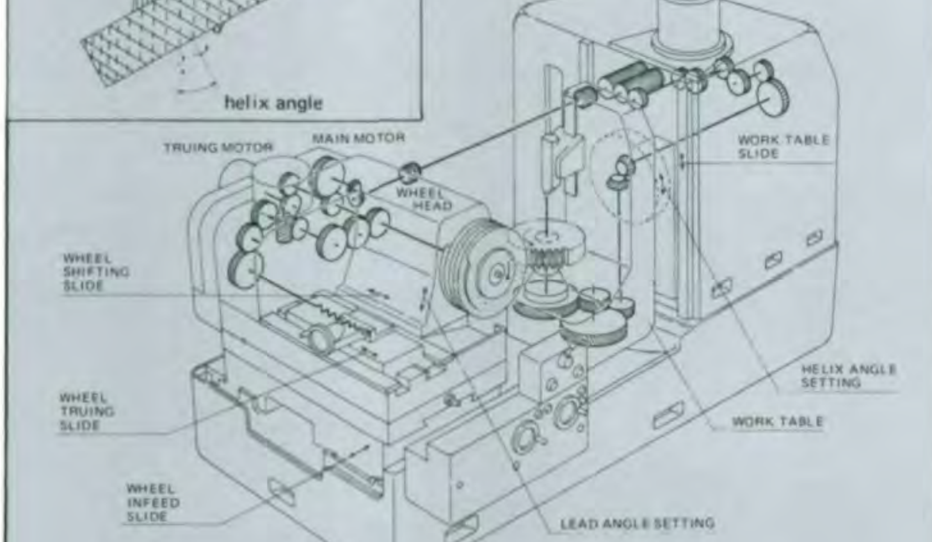


Fig. 16 – Kinematics of mechanical machine drive train.

Reishauer does have available an NC controlled machine that eliminates indexing change gear drives and other drive elements. Quicker set-up times are possible with this new machine and higher accuracies are claimed. (See kinematic drawing, Fig. 17)

Conical Wheel Gear Grinder

Example Brand Names: Pratt & Whitney which is no longer manufactured, Hofler and Niles

These grinders are available with maximum diameter capacity up to 137.8", diametral pitch ranges from .8 to 8.5, and helix angles up to 35°. The machines are capable of grinding external spur and helical gears only.

Fig. 5 shows the cross section of the conical grinding wheel as a straight profile rack tooth. The overhead grinding wheel head ram reciprocates rapidly as the work table feeds slowly back and forth at a right angle to the gear axis. The reciprocation of the ram is accomplished either via mechanical means or by a hydraulic piston. The generation of the tooth profile on this type of gear grinding machine is based on the principle of rolling a gear along a rack. The grinding wheel has a trapezoidal cross section corresponding to an individual rack tooth. The involute is produced by the rolling motion of the workpiece along a straight flank of the grinding wheel. For helical gears, the grinding wheel slide complete with grinding wheel, is swivelled to the helix angle of the workpiece. The machine produces the involute profile by grinding the tooth flanks along straight lines. These lines correspond to the contact line with the mating gear. The production of the involute profile requires the work table and its slide to carry out a positively controlled generating rolling movement, i.e. the linear and rotary motion must be synchronized. This synchronization is achieved by change gears. The right hand flank is ground while the work table moves in one direction, and the left hand flank is ground during movement in the return direction. The difference between the thickness of the grinding wheel and the width of the tooth space is compensated via two posi-

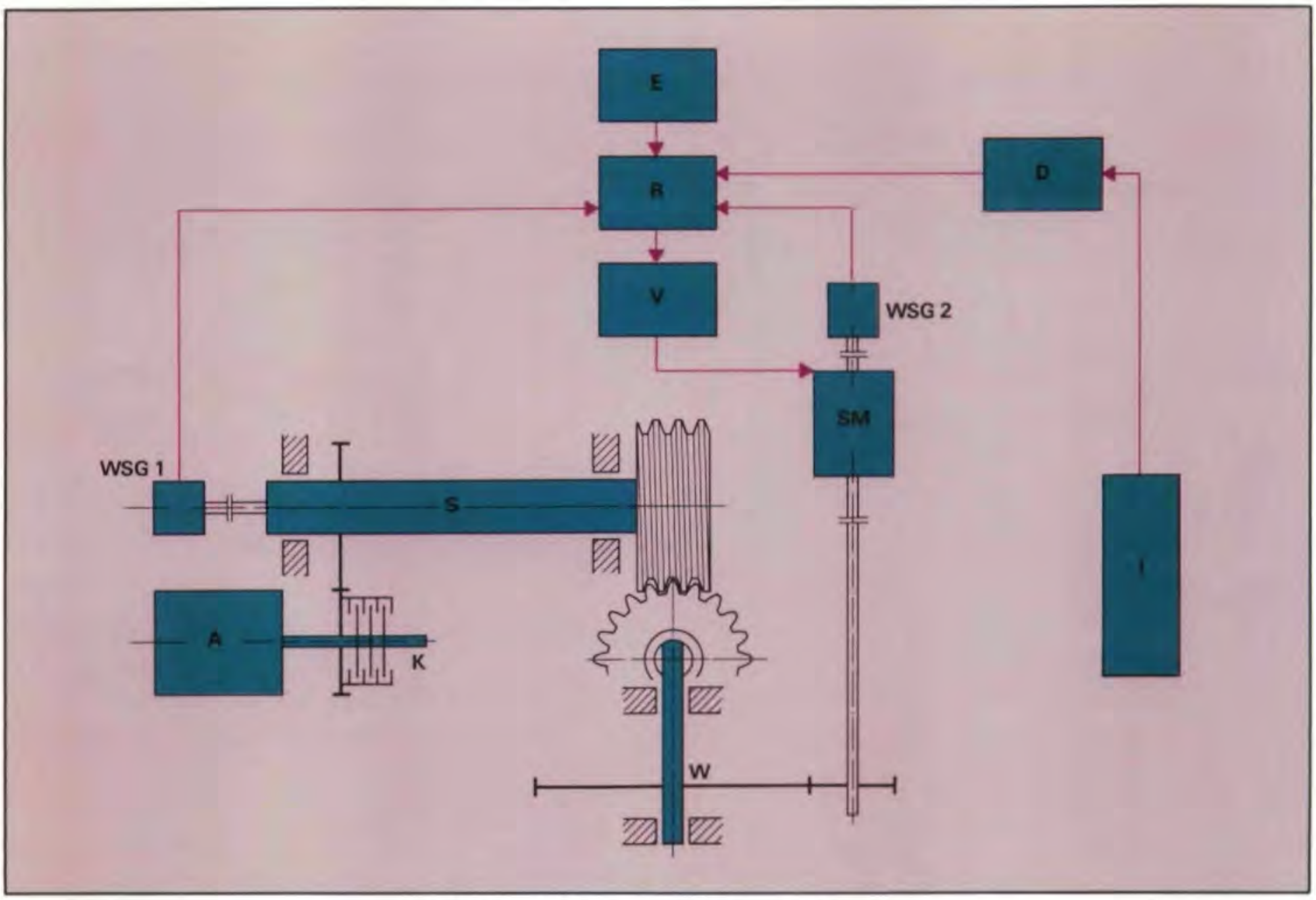


Fig. 17 – Threaded-wheel gear grinder electronic drive train.

tioning elements. The indexing process of the machine, i.e. the indexing motion of the workpiece from tooth to tooth, takes place automatically through a change gear drive using a spur gear differential. (See Fig. 18).

The grinding wheel is dressed or shaped by means of dressing diamonds located in a dressing unit mounted on the grinding carriage. There is a single diamond dressing the O.D. of the conical wheel, and two side diamonds are required to dress the flanks of the grinding wheel. These side diamonds are adjusted to the required angle by spindles with graduated positioning scales, i.e. set to the required pressure angle. During the dressing process, the grinding wheel and its dressing units are moved radially in relation to the workpiece, the dressing unit being fed at a 45° angle. This operating procedure is necessary so the grinding wheel diameters are automatically compensated to remain in the same radial relationship to the workpiece. (See Fig. 19).

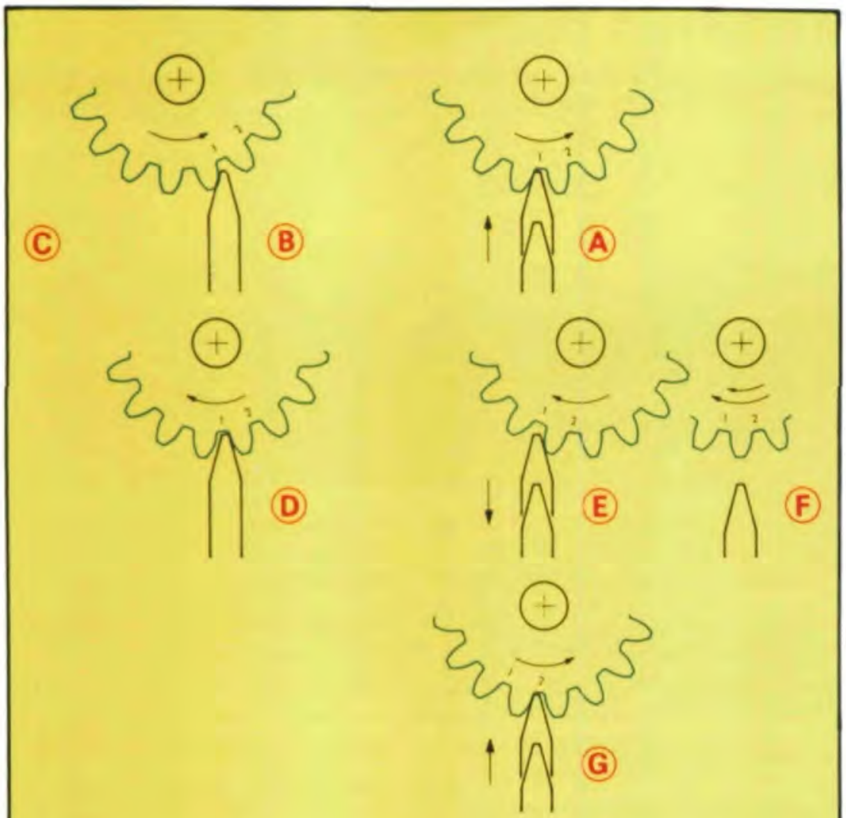
Fig. 20 illustrates how profile and longitudinal corrections are accomplished. For tip and root relief and the involute modifications, the grinding wheel is corrected by means of adjustable templates that alter the straight motion of the earlier mentioned side dressers. The rack tooth now contains the necessary tip and root relief corrections which are reproduced on the tooth profile during the grinding operation.

Longitudinal correction, crowning, is achieved during the stroke motion of the grinding slide with the tool slide following the adjustable template. The template device creates an addtional movement of the grinding wheels in a radial plane which results in a longitudinal correction. The amount of the correction depends on the form of the template and the magnification of the lever ratio. (See Fig. 20). Grinding wheel balancing, especially runout of the grinding wheel, is important in this grinding process. Some of the machines have built-in balancing devices.

As with any gear grinding machine, it is important that heat from the grinding process is not absorbed by the workpiece or the machine. Therefore, the hydraulics required for the machine drive and control is normally installed separately from the machine with a temperature control system. A considerable amount of heat is generated in this grinding process which normally dictates the need for a grinding oil coolant. Selection of the grinding oil is particularly important because the surface quality of the ground tooth is effected by the degree of purity of the oil. Both magnetic or continous band filter cleaning systems are needed to assure the coolant grinding oil remains clean. In most cases, an oil mist extractor is also required because of the unavoidable misting of the oil from the grinding operation.

CBN Grinding

Cubic Boron Nitride, also known under the trade name "Borazon" is the hardest material known to man, next to



(A) Grinding wheel is introduced into tooth space 1. Grinding of left hand flank.

(B) Grinding of left hand flank completed.

(C) Grinding action is changed over to right hand flank with compensation for flank clearance.

(D) Grinding of right hand flank begins.

(E) Grinding of right hand flank completed. Retraction of grinding wheel from tooth space 1. Indexing is initiated.

(F) Indexing whilst workslide is stationary.

(G) Reversal of feed motion, compensation for flank clearance, grinding wheel is introduced into tooth space 2. Grinding of left hand flank.

Fig. 18 – Generating process of a conical wheel gear grinder.

Fig. 19 – O.D. and side dressers for required pressure angle dressing.

a diamond. Its mechanical strength is more than double that of corundum. CBN also has the capacity to withstand thermic loads twice as high as that of a diamond. Furthermore, its cubic shape results in grains having a very pronounced cutting edge. All these features create an ideal condition for use as an abrasive in gear grinding. (See Fig. 21).

These attractive features can be looked at both positively and negatively. Dressing or forming the wheel can be very difficult because of the desirable abrasiveness of CBN. On the other hand, once the desired shape of the grinding wheel has been obtained, frequent dressing is not necessary, if not impossible. CBN grain size and bonding agent is as important as it is with conventional silicon carbide or aluminum oxide grinding wheels.

CBN grinding wheels can cost as much as 20-30 times more than conventional grinding wheels. This substantial difference in cost relates to the CBN raw material and the grinding wheel blank. Normally, a thin layer of CBN coating is applied to a steel wheel base. Of course, the wheel design relates to the grinding technique being used. This means that some grinding techniques can inherently benefit more than others from the use of CBN wheels. That benefit depends upon the increase in productivity in relation to the higher cost of the grinding wheel and the lot sizes.

CBN grinding has been effectively applied to the followed grinding techniques:

Form gear grinding, especially in the smaller diameter ranges, i.e. 12" and smaller, and finer pitches, i.e. 5 and up – a steel based wheel is formed to the required involute form and a thin layer of CBN is applied to the involute profile portion of the wheel. (See Fig. 22).

Saucer shaped wheel, as shown in Fig. 23 – CBN has been used quite extensively for the manufacture and sharpening of

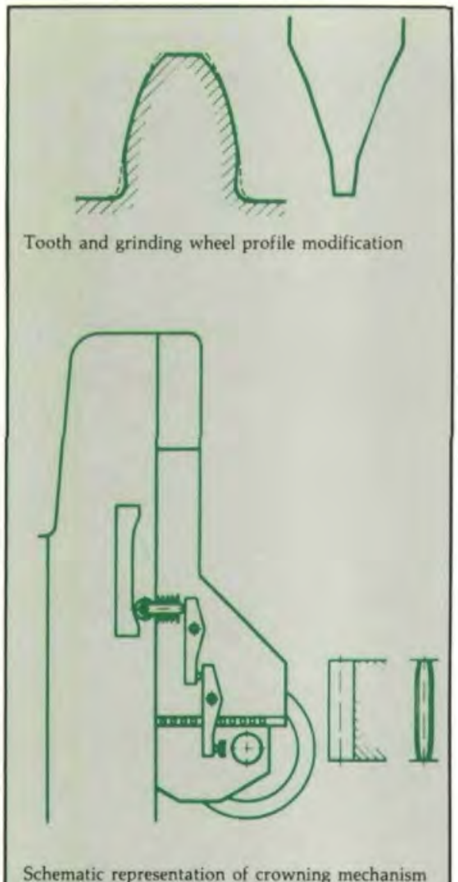


Fig. 20 – Profile dressing for correction, longitudinal correction (crowning) by radial movement of grinding wheel head with a template.

Fig. 21 – Cubic boron nitride grain.

rolling dies and for shaving cutters made of high speed steel. Recently, it has been applied to larger case hardened larger gears, i.e. 60" and coarser pitches, 2 DP.

Conical wheel gear grinders – CBN grinding is possible with this type of a machine and development work has been done in this area. The writer is not aware of any machine being used in production with CBN wheels.

Threaded-wheel gear grinders: Development work continues with these machines, as well as a variation of the threaded grinding wheel. However, rather than cylindrical, an hour glass designed wheel is used.

The Application of CNC (computer numerically controlled)

CNC has found its way into gear grinding machines only in the ast couple of years. One would associate CNC with gear grinding machines in several ways. First, as a controller used to set and monitor feeds and speeds. Second, in the case of a saucer type gear grinding machine, it is used to program profile and longitudinal modifications or, with a form gear grinder, control the profile dressers.

Fig. 24 illustrates the history of tooth modifications, while Fig. 25 shows topological modification which can only be accomplished through the use of a CNC controller.

The third application has been the elimination of change gear drive trains, as in the case of the threaded-wheel type grinding machine. (See Fig. 17) In the case of form grinding machines, it has eliminated tooth indexing plates. In either case, set-up changes and tooling costs have been substantially reduced. Undoubtedly, CNC controlled machines and in-process inspection equipment will lead to the installation of gear grinding machines in flexible manufacturing cells or systems.

Grinding Time Estimate

Estimating, Production Control, Manufacturing and other departments, frequently require estimates of the time required for a specific gear grinding opera-

Fig. 22 – A thin coating of CBN applied to a steel based wheel.

(Continued on page 48)

VIEWPOINT

Letters for this column should be addressed to Letters to the Editor, GEAR TECHNOLOGY, P.O. Box 1426, Elk Grove Village, IL 60007. Letters submitted to this column become the property of GEAR TECHNOLOGY. Names will be withheld upon request; however, no anonymous letters will be published. Opinions expressed by contributors are not necessarily those of the editor or publishing staff.

Dear Editor:

The cost of teaching salesmen the ins and outs of gearing has proven to be expensive. Your journal is just what we have been looking for. We found your article on lubrication analysis on gearing very interesting. More on the basics and more on lubrication would be appreciated.

William G. Lengenfelder, President
Modern Machine Works

Congratulations on your bold move in publishing a magazine devoted to gear manufacturing. In my opinion, this is something that has been needed for a long time, and I admire your courage and convictions in jumping into such a venture.

Both issues have been outstanding, and if future issues maintain the same high standard, I am absolutely certain everyone in the industry will benefit.

Keep up the good work, and we look forward to your continued success in the publication of this fine journal.

Robert Cragg, President
Earle Industries, Inc.

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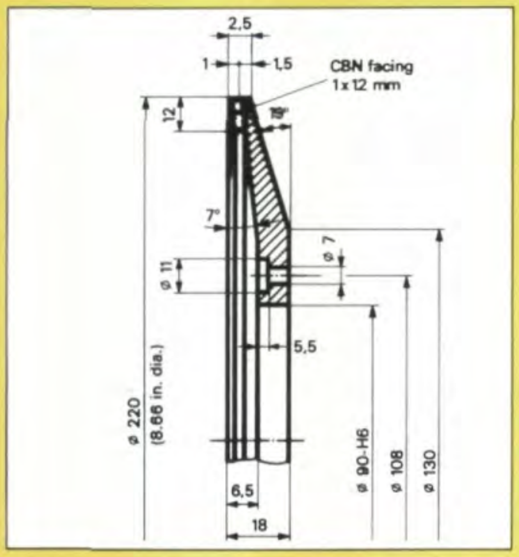

Fig. 23 – CBN saucer shaped wheel for shaving cutter sharpening.

Fig. 25 – NEW: Topological Modification variable modification"Z" of tooth profile across facewidth "X" as well as along profile "Y".

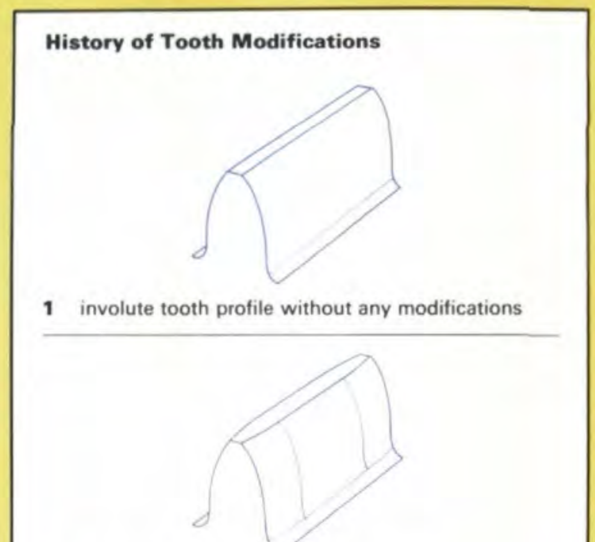

Fig. 24 – New topological modification variable modification "z" of tooth profile" across facewidth "x" as well as along profile "y".

tion. Many grinding machine manufacturers have published references that can assist a user in determining grinding times. Unfortunately, many of these references are old and no longer valid. Most manufacturers now have computer programs that will accurately calculate grinding times based on basic gear data input as well as grinding stock allowance per flank. However, production time estimates must be used with caution. Appreciable deviations from the estimated grinding times can occur because of gear blank quality, runout, grinding stock, grinding wheels used, tooling, loading fixtures, blank distortion due to the heat treating process, etc. Unfortunately, in quite a few cases, trial grinding is the only means possible to accurately determine grinding times.

A direct comparison of gear grinding cycle time with cycle time of other gear tooth finishing methods, such as finish cutting, shaving, honing and skiving, does not reflect the true relative cost of producing ground gears with the cost of producing quality unground gears. Gear grinding can effect substantial cost savings in cutting, perishable tools and inspection. Studies have shown that hardended and ground precision gears may cost less to produce than comparable unground gears.

THE UNBEATABLE GH400NC NOW APPEARING AT BENSENVILLE

Mitsubishi's full CNC Gear Hobbing Machine, GH400NC

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FEATURES

- Set-up time reduced to 1/10th compared to conventional type machines.
- Simple programming. Computer memory stores up to 100 different kinds of programs.
- Capable of tapered gear hobbing and crowning under CNC. No templates required.
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- Heavy duty construction and high power motor enables to generate gears up to module 10 (DP 2.5).
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Maximum workpiece diameter		400mm (40")
Maximum module		10 (DP 2.5)
Minimum number of teeth		6
Maximum number of teeth		120
Radial travel	X	250mm (10")
Axial travel	Z	300mm (12")
Hob shift	Y	150mm (6")
Hob head swivel angle	A	±45°
Maximum table rotation	C	27rpm
Hob speed range		80 ~ 350rpm

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MITSUBISHI HEAVY INDUSTRIES, LTD.

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