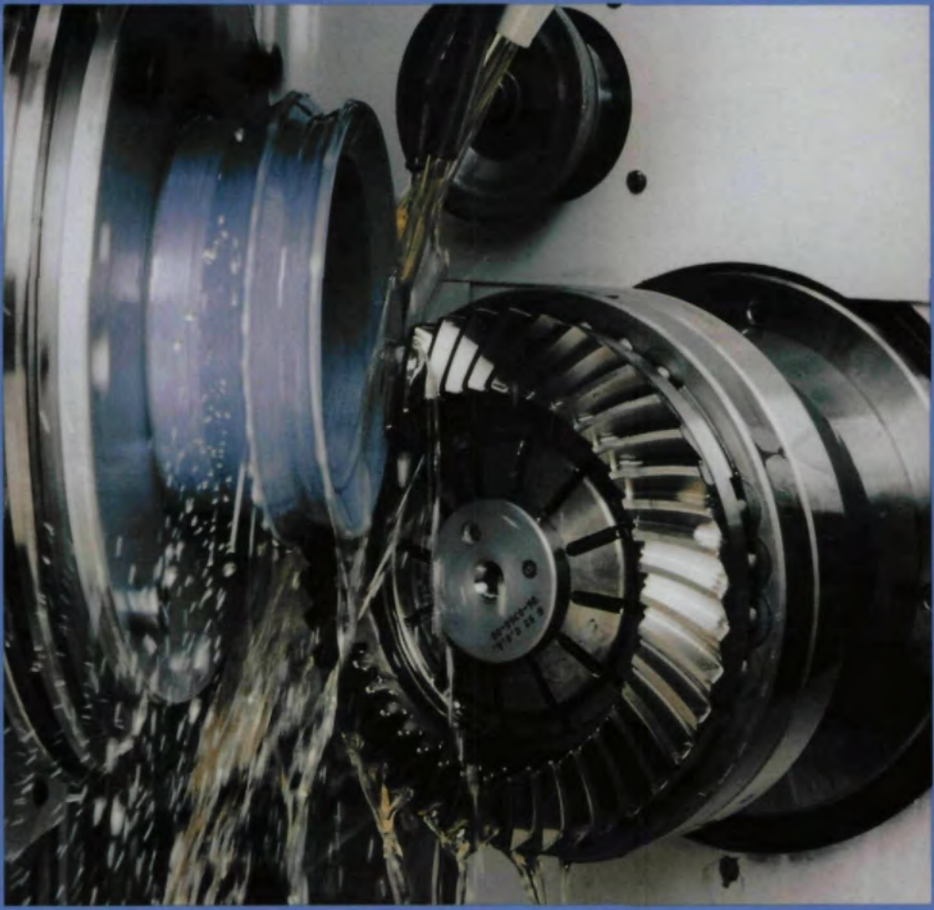
GEAR TECHNOLOGY

THE JOURNAL OF GEAR MANUFACTURING

JANUARY / FEBRUARY 1994



GEAR FINISHING

GRIND SMALL CONE ANGLE BEVEL GEARS ON CYLINDRICAL MACHINES

HELICAL GEAR BEARING CONTACT AND
REDUCED VIBRATION THROUGH CNC GRINDING

WHAT'S NEW IN CNC GEAR SHAPING?

THE HOBBING PROCESS AND MULTI-THREAD HOBS

American Pfauter's New CNC Vertical Hobbing Machine...

Now you can afford the gear hobber you've always wanted!

It's a Pfauter...in stock and available today with these outstanding *features...all standard!*

- ☑ **GE FANUC Series 15 CNC**, with universal-menu programming to fully automate setup
- ☑ **FANUC Digital AC servo drives on all 5 axes**, as well as FANUC microprocessor-controlled hob spindle drive system
- ☑ **Worktable with two-start double worm and worm gear drive**
- ☑ **Hob head with tangential slide**, including hydro-mechanical clamping/unclamping of hob head swivel
- ☑ **Quick-change hob arbor clamping**, including hydro-mechanical clamping attachment for outboard bearing support
- ☑ **Small footprint design**, including attached-tank hydraulic and recirculating lube system
- ☑ **Built and supported by American Pfauter**, conveniently located in Rockford, Illinois U.S.A.

...And much more!

For the gear hobber you've always wanted, call (815) 282-3000

AMERICAN PFAUTER
Limited Partnership

1351 Windsor Road
Loves Park, IL 61132-2698 U.S.A.

Phone: 815-282-3000
Telefax: 815-282-3075

CIRCLE A-1 on READER REPLY CARD

Simply revolutionary...

Pfauter-Maag Cutting Tools Introduces... Opti-Gash™ Hobs

In response to industry's demands for higher production and accuracies, and as a result of the successful introduction of our Wafer concept for throw-away tools, PMCT has developed the Opti-Gash™ hob.

This hob, designed for a specific production application, optimizes the hob design for maximum benefits in productivity and generated gear geometry.

Until now, most hobs have been designed with the minimum number of gashes to produce a required gear tooth geometry coupled with the maximum number of available resharpenings.

Today's high costs of operation demand higher production rates of greater accuracy gears on fewer, more expensive machines. The Opti-Gash hob has been developed to meet these demanding and conflicting requirements.

Our engineers designed this hob around a specific chip load and created a tool having an optimum number of gashes at a diameter and length to suit the machine capability and part requirement.

The result is a hob which will produce a high degree of form accuracy – and a machine cutting load generating low-spindle torques – producing as a consequence the highest possible lead and index accuracy.

The low chip-load, high-quality tool steel and coatings, along with efficient cutting geometry result in higher cutting rates and many more pieces per sharpening than with conventional solid or segmental hobs.

The resulting reduction in machine change-over time, resharpening and recoating costs more than compensates for the reduced number of available sharpenings.

Accuracy? The Opti-Gash is available in all accuracy classes – better than AA DIN or AGMA standards if required. For a specific proposal on an Opti-Gash hob for your application, send full part and machine data to your local representative or contact the PMCT sales engineer for your area.

Pfauter-Maag Cutting Tools
Limited Partnership

1351 Windsor Road, P.O. Box 2950, Loves Park, IL 61132-2950 USA
Telephone 815-877-8900 • FAX 815-877-0264

CIRCLE A-2 on READER REPLY CARD

Gear down your process control costs

Affordable analysis

The new PC-based QC 1000 gear inspection system performs fast, repeatable and highly accurate index, lead and profile tests on internal and external spur and helical gears and splines. And it does all this so economically that even a small shop now can replace several manual gear checkers with a powerful, easy-to-use CNC gear inspection system.

Full 4-axis value

Unlike some competitors' 3-axis systems, the QC 1000 offers real value with full 4-axis CNC capability that handles work pieces up to 15″ long and 9″ in diameter.

Learn more now

Phone 513/859-8273 or Fax 513/859-4452. And find out how easily you can reduce your gear manufacturing costs.

M&M PRECISION SYSTEMS Corporation

AN ACME-CLEVELAND COMPANY

CIRCLE A-3 on READER REPLY CARD

CONTENTS

JANUARY/FEBRUARY, 1994

Cover photo courtesy of The Gleason Works, Rochester, NY.

FEATURES

SPECIAL FEATURES

DEPARTMENTS

HIGH NOON

★ western collectables ★

BOUGHT & SOLD

FINE COWBOY ARTIFACTS

bridles ★ buckles ★ horsehair
bits ★ books ★ belts ★ bolos
chaps ★ spurs ★ saddles

APPRAISALS

9929 Venice Blvd.
Los Angeles, CA 90034

(310) 202-9010 BY APPOINTMENT
FAX (310) 202-1340

CIRCLE A-5 on READER REPLY CARD

Announcing Our New Line of Precision Hobs

PRODUCES FASTER-RUNNING, QUIETER, ACCURATE GEARS.

Precision hobs with a superb surface finish are the result of new production methods now in place at Star Cutter. Hardened hobs are finished by skiving or grinding, depending on hob geometry. The vast majority are skived, providing additional regrind life. The EDM process has been discontinued.

Our new hobs give longer tool life and consistently produce higher quality gears. They accept titanium nitride and other advanced coatings.

CONTACT US FOR DETAILS.

Since 1927
Star
STARCUT SALES, INC.
23461 Industrial Park Drive
Farmington Hills, MI 48335
313/474-8200 FAX 313/474-9518

We are manufacturers and suppliers of hobs, form-relieved cutters, pressure-coolant reamers, gun drills, tool holders, coatings, and machine tools. We also provide application engineering.

CIRCLE A-7 on READER REPLY CARD

GEAR TECHNOLOGY

EDITORIAL

Publisher & Editor-in-Chief
Michael Goldstein

Associate Publisher & Managing Editor
Peg Short

Senior Editor **Nancy Bartels**

Copy Editor **Don Story**

Technical Editors
Robert Errichello
William L. Janninck
Don McVittie
Robert E. Smith

ART

Art Director **Jean Sykes**

Art Director **Jennifer Goland**

MARKETING

Advertising Sales Manager **Patricia Flam**

Advertising Sales Coordinator
Jean Marie Mangan

CIRCULATION

Administrative Coordinator
Deborah Donigian

Circulation Assistant
Mary Gabrys

RANDALL PUBLISHING STAFF

President **Michael Goldstein**

Vice President **Richard Goldstein**

Vice President/General Manager **Peg Short**

Controller **Patrick Nash**

Accounting **Laura Kinnane**

Art Consultant **Marsha Goldstein**

RANDALL PUBLISHING, INC.

1425 Lunt Avenue
P.O. Box 1426
Elk Grove Village, IL 60007
(708) 437-6604 Phone
(708) 437-6618 Fax

VOL. 11, NO. 1

GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published bimonthly by Randall Publishing, Inc., 1425 Lunt Avenue, P.O. Box 1426, Elk Grove Village, IL 60007. Subscription rates are: $40.00 in the U.S.; $50.00 in Canada; $55.00 in all other countries. Second-Class postage paid at Arlington Heights, IL, and at additional mailing office.

Randall Publishing makes every effort to ensure that the processes described in *Gear Technology* conform to sound engineering practice. The Publisher cannot be held responsible or liable for injuries sustained or any direct or indirect, special, consequential, or other damages of any kind or nature whatsoever resulting from following the procedures described.

Randall Publishing is not responsible for the content of, claims made, or opinions expressed in advertisements or other printed matter in the publication.

Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1425 Lunt Avenue, P.O. Box 1426, Elk Grove Village, IL, 60007.

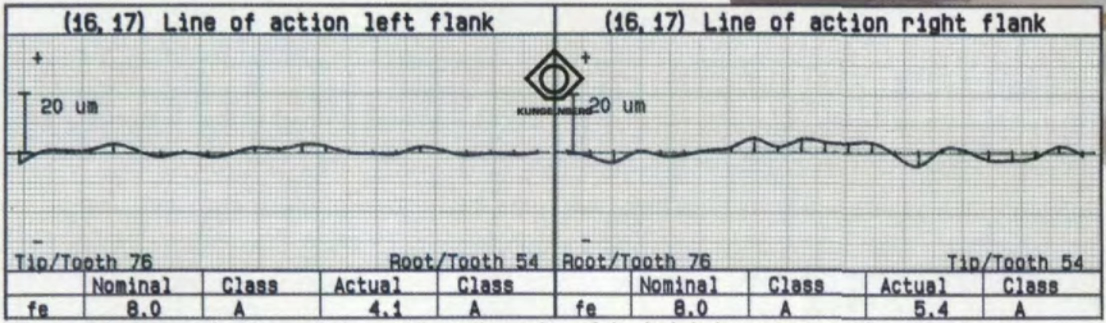
©Contents copyrighted by RANDALL PUBLISHING, INC., 1994. Articles appearing in GEAR TECHNOLOGY may not be reproduced in whole or in part without the express permission of the publisher or the author.

When Gear Quality is extremely critical...

ACTION

speaks louder than words.

Check our Line of Action*



	Nominal	Class	Actual	Class		Nominal	Class	Actual	Class
fe	8.0	A	4.1	A	fe	8.0	A	5.4	A

*Line of Action testing insures that each cutting edge of the hob is in proper position relative to lead, flank form and rotational accuracy of the hob.

Meeting A or AA quality requirements is easier said than done. That's why each FHUSA hob is guaranteed – every tooth is in proper position to generate the desired gear profile.

When gear quality is critically important, **Line of Action** can assure success.

Insist on FHUSA hobs that are inspected and verified to meet your requirements. ALL FHUSA hobs are ...and can.

Once you've checked our **Line of Action** you've taken the first step...and best step towards a better bottom line...too!

GMI

PO Box 31038
Independence, OH 44131
Phone (216) 642-0230
FAX (216) 642-0231

CIRCLE A-6 on READER REPLY CARD

FHUSA

Reduce generative gear grinding wheel dressing time with Normac's CNC Threaded Wheel Trueing System

This new system is based on replacing the existing diamond disc with a vitrified CBN wheel. The system includes the Normac Wheel Profiling Center, software for calculating the required form, and a special dresser unit to replace the existing dresser on the grinding machine. The form is profiled on the CBN wheel on the Profiling Center, and is then mounted on the dressing unit on the machine. The entire form is dressed into the grinding wheel in one operation, including both flanks, root radius, and modifications. Because the software accurately generates the proper form, the need for trial and error test grinding is eliminated, dramatically reducing setup time.

Call (313) 349-2644 today for more information or to arrange a demonstration.

NORMAC
INCORPORATED

CIRCLE A-14 on READER REPLY CARD

PERFORMANCE, EXPERTISE, QUALITY

WHEN YOU NEED INTRICATE DESIGNS AND METICULOUS CRAFTSMANSHIP, RELY ON FAIRLANE GEAR, INC.

NEW MACHINES JUST PURCHASED
- KAPP CNC HARD FINISHER
- AMERICAN PFAUTER CNC HOB

WE OFFER:
- Gear Noise Reduction Program
- Expert Technical Assistance
- Gear Cutting in a Wide Range of Sizes, Types & Quantities
- Prototype & Emergency Repair / Rebuild Service

Quality gears up to AGMA 15, MIL-1-45208A, MIL-STD-45662

SIZE RANGE -Smaller than an inch to 48"

TYPES:
Spur - Internal & External
Helical - Internal & External
Worms, Worm Gears
Serrations - Shafts
Splines - Internal & Extermal
Sprockets - Clusters
Segments - Spindles
Ratchets - Gear Boxes

COMMITTMENT TO QUALITY
Reishauer Ground Gears
M & M Precision Gear Checker
Kapp CBN Hard Finished Gears
American Pfauter CNC Hob
Coordinate Measurement Machine

Fully implemented SPC, and data communications capabilities.

For the ultimate in quality gears, call or send inquiries to:

Fairlane Gear, Inc.

P. O. Box 409 A
Plymouth, MI 48170
Phone (313) 459-2440
(800) 837-1773
Fax (313) 459-2941

CIRCLE A-10 on READER REPLY CARD

Random Thoughts for the New Year....

Another year has passed and, because of the short term ups and downs of the economy, it's still hard to judge whether we are in an appreciably different place than we were a year ago. The economy doesn't seem to be worse than it was, but it also doesn't seem to be a whole lot better.

The gear business seems to share this oddly ambivalent condition. According to my colleagues, a lot of gears are being cut in this country and cutting tool sales are at record levels, but no one is making much money. Competitive pressures are forcing companies to cut gears at little or no profit.

Machine tool manufacturers face a similar struggle: They too are under pressure to lower prices, but they are also faced with the added difficulty of low overall volume. Add to that the closing of nearly a dozen gear plants in 1993, probably some kind of dubious record, and it's hard to be optimistic. The fact is, the end of the Cold War defense boom and the recession have hit the gear industry hard.

Yet business does seem to be getting a bit better, even though the skeptics point out that what we may be seeing here is similar to the blips we experienced in 1991-1992, when companies rushed to replace their low inventories near the end of the year, and once that was done, the little boomlet petered out. It's hard to know which interpretation of the facts is the right one.

Capitalism has always been a Darwinian affair. Only the strongest and the fittest survive. While not trying to minimize the devastating effect of lost jobs and the breakup of long-established organizations, the fact is that the survivors of this shakeout are emerging stronger and more efficient and are learning new strategies to survive in the new business environment.

For one thing, there is a new appreciation of the fact that our competitors are not just the people next door, but those all over the globe, and that in order to match them, every element of our businesses, from plant maintenance to product packaging, has to be rethought.

Among the positive signs of this rethinking is a growing awareness that every resource in a business, including its people, has to be used to its fullest. In the most progressive companies, the old "us/them" paradigm of labor/management relations is giving way to the understanding that there is no "them," only a "we" who have to work together if all are to survive. As Benjamin Franklin put it in a far different, but no less serious context, "We must all hang together now, or most assuredly we shall all hang separately."

PUBLISHER'S PAGE

"We" in the gear industry also includes our customers, and again, our most progressive companies are working hard at understanding the needs of customers and meeting them in creative ways. One example of this is the aggressive marketing strategy on the part of some of our major machine tool builders. Believing that if you get the price down, the buyers will come, these companies are offering non-option, lower-priced CNC machines. Many features that in the past would have cost extra are now

TITIVILLUS* STRIKES *GEAR TECHNOLOGY*!

An error appeared in the article, "The European Rack Shift Coefficient 'X' for Americans" (July/August, 1993). Equation 1 on page 35 of that article should read as follows:

$$\Sigma x = \frac{z_1 + z_2}{2} \cdot \frac{\text{inv}\,\alpha_{wt} - \text{inv}\,\alpha_t}{\tan \alpha_n}$$

Our thanks to Mr. Ed teRaa of the University of Waterloo, Waterloo, Ontario, for being more alert than we were. We regret any inconvenience this error may have caused.

*Titivillus is the patron demon of medieval scribes and modern copy editors. He creates distractions, breaks our concentration and causes embarrassing errors. Apparently neither medieval scribes nor modern copy editors deserve patron saints.

NOW YOU HAVE A CHOICE...
and it's made in AMERICA!

A/W Systems Co. announces that it is now a manufacturing source of spiral gear roughing and finishing cutters and bodies.

We also can remanufacture most spiral cutter bodies and can manufacture *new* spiral bodies in diameters of 5" through 9" at present.

A/W can also supply roughing and finishing cutters, hardware and replacement parts for most 5"– 9" diameter bodies.

Whether it's manufacturing or remanufacturing, consider us as an alternative source for replacement parts and hardware as well as bodies and cutters. You'll be in for a pleasant surprise.

A/W Systems CO.

612 Harrison • Royal Oak, Michigan 48067
Telephone (313) 544-3852 • FAX (313) 589-1690

CIRCLE A-8 on READER REPLY CARD

part of the package, but the price is still within the range of the smaller job shops.

This marketing strategy addresses the peculiar paradox that developed under the old price structure. Previously, the only companies that could afford the newest CNC machines were the volume users, such as automotive manufacturers, who used the machines to make thousands and thousands of identical gears, thus bypassing one of the big advantages of CNC machines: their quick-change flexibility. The companies that could make the most of this feature couldn't afford them. This aggressive pricing strategy should put the machines into the price range of the companies — those that cut small batches of many different gears — that can use the machines to their greatest advantage. This is a benefit, not only for the machine manufacturers, but for the job shops, who can now begin to sell themselves in niche markets and to customers who before were simply out of their reach.

No change comes without pain, and where the economy is going to be in a year, given the volatile global economic environment, is anybody's guess. The one thing I do know is that we cannot stop our struggle to change and adapt to the new environment. As one pundit put it, "Business is like riding a bicycle; you have to keep moving or you fall down."

Michael Goldstein

Michael Goldstein,
Editor-in-Chief

over 35 years experience in gears and gear equipment

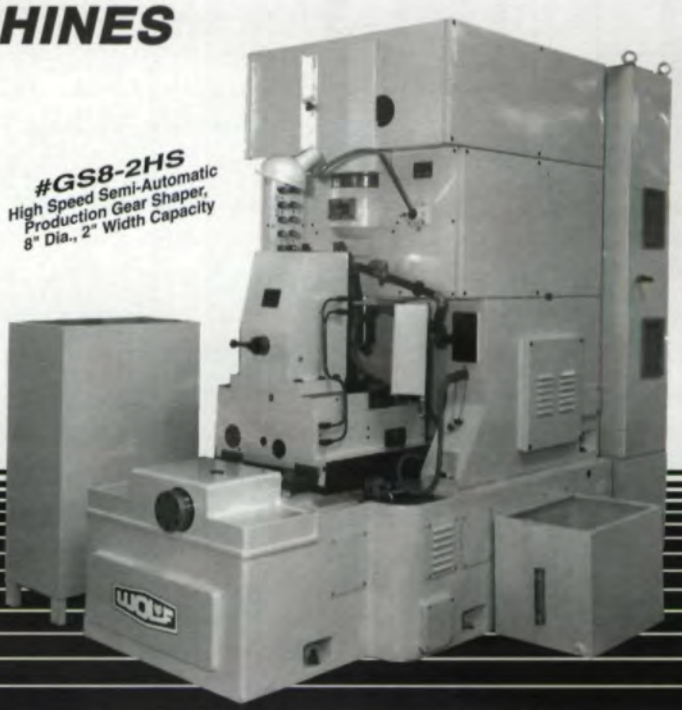
...always ahead of the pack!

WOLF GEAR MACHINES

SALES & SERVICE

Many Models and Sizes to choose from:

- ✔ Gear Shapers
- ✔ Gear Hobbers
- ✔ Gear Shavers
- ✔ Gear Honers
- ✔ Gear Grinders
- ✔ Hob Sharpeners
- ✔ Inspection Equipment



#GS8-2HS
High Speed Semi-Automatic Production Gear Shaper, 8" Dia., 2" Width Capacity

NATIONAL DISTRIBUTOR:
BASIC INCORPORATED GROUP
Telephone: (213) 933-0311
Fax: (213) 933-7487
P.O. Box 36276, Los Angeles, CA 90036

EASTERN REPRESENTATIVE:
SPECK GEAR SERVICES, INC.
Phone: (708) 213-8340 • Fax: (708) 213-8341
P.O. Box 88177, Carol Stream, IL 60188-0177

CIRCLE A-9 on READER REPLY CARD

ADVERTISER INDEX

	Reader Service No.	Page Number
A/W Systems	8	8
American Metal Treating Co.	20	48
American Pfauter L. P.	1	IFC
Basic Incorporated Group	9	9
Bourn & Koch Machine Tool Co.	18	47
Dessau Diamond Tool	13	13
Diamond Black	15	15
Eltech, Inc.	21	48
Fairlane Gear, Inc.	10	6
GMI-Fhusa	6	5
High Noon	5	4
M & M Precision Systems	3, 19	2, IBC
MTM König	17	47
National Broach and Machine Co.	4	BC
Niagara Gear Corp.	16	46
Normac, Inc.	14	6
Parker Industries, Inc.	12	13
Pfauter-Maag Cutting Tools L. P.	2	1
Profile Engineering, Inc.	24	48
Pro-Gear Co.	23	48
Starcut Sales, Inc.	7	4
Strathmore Machine Tool Co.	22	48
Yieh Chen Co., Ltd.	11	12

CALENDAR

JANUARY 10-14
TWI, Inc., Vibration Analysis, Alignment and Balancing Workshop. Uptime/Hane Industrial Training Facility, Milwaukee, WI. Workshop for mechanics, maintenance personnel and operators. Covers diagnosis, measurement, and other vibration, alignment and balancing basics. For more information, contact Uptime, Inc., (812) 234-0007 or fax (812) 232-3978.

JANUARY 23-26
American Society of Mechanical Engineers 17th Annual Energy Sources Technology Conference & Exhibition. Clarion Hotel, New Orleans, LA. Papers and presentations on drilling and emerging energy technologies, energy and environmental management, fossil fuel combustion, hydrocarbon processing, internal combustion engines, materials and design, and more. For more information call ASME Petroleum Division, (214) 746-4901 or fax (214) 746-4902.

FEBRUARY 21-24
Center for Industrial Heat Treating Processes, University of Cincinnati, Heat Treating Workshops, Clarion International at O'Hare, Chicago. **February 21-22, Applied Induction Heat Treating Workshop,** covering fundamentals including electromagnetic induction, equipment and power supplies, metallurgy, coil design, quenching, quality control and troubleshooting, and **Quenching Processes, Part Distortion and Residual Stress Analysis in Heat Treating**, covering importance of distorion and stresses, control of distorion and stress in quenching, gas carburizing and carboni-triding, straightening distorted parts, and controlling distortion. **February 23-24, Applied Gas Carburizing in Heat Treatment**, covering fundamentals of gas carburizing process, furnaces and atmosphere control, instrumentation, pre- and post-heat treatimg, quality controll and part distortion, and **Applied Metallurgy for Heat Treating Industries**, which covers material selection, characterization, measurement of mechanical properties, solidification, corrosion and more. For more information, contact Dr. A. H. Soni (513) 556-2710 or fax (513) 556-3390.

MARCH 3-5
AGMA 1994 Annual Meeting, Marriott Marco Island Resort, Marco Island, FL. The theme of the meeting will be "Perspective On World Class Manufacturing." Jerry Flaherty, Group President of Caterpillar, will be the keynote speaker. Note: This meeting is **two months earlier** than previous meetings. For more information, contact AGMA at (703) 684-0211 or fax (703) 684-0242.

MAY 9-10
Penn State University National Center for Advanced Gear Manufacturing Technologies Advanced Gear Manufacturing Symposium. Penn State University, State College, PA. Speakers from government, academia and industry discussing current gear manufacturing technology and research. For more information, contact Greg Johnson at (814) 865-8207.

CALL FOR PAPERS
The Gear Research Institute is planning an international conference on Induction Hardened Gears and Precision Components to be held in Indianapolis, IN, on **May 15-17, 1995**. The conference will cover materials processing, quality assurance and engineering performance of induction hardened gears and precision components. The Institute is looking for papers on the following topics: distortion control, case depth (optimization and control), cost factors, quenching and quenchants, materials selection, pretreatment (microstructure control), principles of coil design, bending fatigue, scoring, contact fatigue, influence of carbon and alloy content, machinability, residual stress, environmental impact and extreme applications. For more information contact Sharon Schaefers at GRI, (708) 241-0660, or fax (708) 241-0662.

GEAR SCHOOLS AND WORKSHOP

AGMA has announced the dates for its 1994 Training School for Gear Manufacturing sessions. The dates are **Jan. 10-14, Mar. 7-11, May 16-20, Sept. 12-16 and Nov. 14-18.** All sessions will be held at Daley College in Chicago, IL. The 1994 curriculum is designed to teach novice operators — those with less than one year's experience — how to maximize the output from the machines they operate. The sessions are also useful for sales engineer training, new employee orientation and refresher courses for veteran operators. Contact AGMA at (703) 684-0211 for a registration packet or more information.

The Falk Corporation, Milwaukee, WI, offers a series of four-day workshops dedicated to the theory, operation and maintenance of speed reducers and flexible shaft couplings. It covers installation, alignment, maintenance and failure analysis procedures. Contact Ron Nimmers at The Falk Corporation, (800) 852-3255, or by fax at (414) 937-4359 for the 1994 workshop schedule.

Cutting Down On Labor Costs

"Pay-for-Performance" can cut costs and increase productivity. Is it right for you?

Woodruff Imberman

What can be done about the rising cost of labor? Mr. Robert Reich, U.S. Secretary of Labor, has already indicated the administration's intention of pushing the minimum wage from $4.25 to $4.50 per hour and indexing it for inflation. That means that every jiggle in the inflation chart will push the minimum wage higher.

But of course, boosting the minimum wage does not merely raise the wage rate at the bottom. In order to maintain skill differentials, every wage level above the minimum would have to move up also. This is what employees will expect, and presumably the only ways to avoid that outcome are to freeze wage levels or raise productivity. The Germans have recently chosen the first alternative; i.e., freezing wage rates and benefits. Some American companies, such as Frigidaire, have chosen the second alternative — raising productivity by installing pay-for-performance wage systems. It may be of interest to discuss both of these alternatives.

Germany's Solution

In September, 1993, Germany's metal fabricating and heavy industries association cancelled a wage agreement for the first time in their history. According to the *Wall Street Journal*, "the announcement by the Gesamtmetall employers' association caused a stir because it broke precedent."

Reached through collective bargaining, Gesamtmetall's labor agreements cover wages, training programs, vacation days and the "vacation money" paid to workers to help fund their holidays. The contracts cover Germany's automotive, metal, electrical, electronics and machinery industries.

MANAGEMENT MATTERS

Germany's generous wages and benefits and flagging productivity have made German labor costs the highest in the world — 25% higher than in the U.S. and about a third higher than in Japan. In western Germany, manufacturing workers receive an average of $26.89 an hour, of which benefits account for $12.47. Blue chip companies such as Daimler-Benz AG and Thyssen AG have been shedding tens of thousands of jobs, idling capacity or shifting production to other countries as higher costs cripple their ability to compete at home and abroad. Hans Peter Stihl, president of the German Chamber of Industry and Trade, said that unions must realize that unrealistic wage demands will force companies to cut even more jobs.

Managing a business today is hard work. Let Management Matters lend a hand. Tell us what management matters interest you. Write to us at P. O. Box 1426, Elk Grove, IL 60009, or call our staff at (708) 437-6604.

Dr. Woodruff Imberman

is a principal in the management consulting firm of Imberman and DeForest, with offices in Evanston, IL, Los Angeles and Boston.

SIX STAR GEAR
(JIS O, DIN 4, AGMA 12)
We specialize to produce precision gears

- Machine Tool Gears
- Auto & Motorcycle Gears
- Agricultural Tractors
- Printing & Textile Machine Gears
- Pump Gears
- Gear Reducers
- We can make strictly according to customer's samples or blueprints.

Manufacturer & Exporter
SIXSTAR
YIEH CHEN CO., LTD.
No. 333, Lin Sheng Rd., Chang Hua City,
Taiwan, R. O. C.
Tel: 886-4-7627747, 7628550 Fax: 886-4-7620213
P. O. Box 538 Chang Hua, Taiwan, R. O. C.

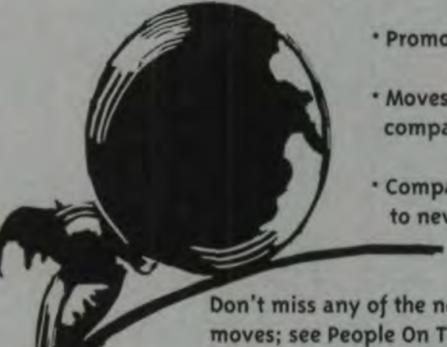
CIRCLE A-11 on READER REPLY CARD

NEW • NEW • NEW • NEW • NEW

ALL THE RIGHT MOVES

Introducing our newest column: People On The Move.

Beginning with this issue, we will be reporting on



- Promotions
- Moves to new companies
- Company moves to new locations

Don't miss any of the new moves; see People On The Move. If you have a move of your own you'd like to report, call us at 800-451-8166 or fax us at :

708-437-6618

U.S. Experience

In the U.S., we have seen a slow but steady rise in labor cost. "The government has made the cost more expensive," according to Richard Vedder and Lowell Gallaway, professors of economics at Ohio University. "The only way to raise the real wage rate is through productivity growth," both professors maintained at a conference in Washington in July, 1993.

"In Europe, wages are high, on top of which governments have imposed a laundry list of costs on employers. Consequently, unemployment rates in Europe now average about 12% and are as high as 24% in Spain. Surely, we want to avoid having the U.S. government imposing any more labor costs on U.S. employers," the professors said.

How has the U.S. government contributed to increased labor costs? According to Professors Vedder and Gallaway, "By raising the minimum wage, by such legislation as the Davis-Bacon Act (which mandates prevailing union wages to be paid on federal construction projects), by the Fair Labor Standards Act, the National Labor Relations Act, and because of programs such as public assistance and unemployment compensation, which pay people to sit and wait until they can find jobs with a higher level of compensation."

Japan offers an exception, says Steve Hanke, professor of applied economics at Johns Hopkins University, who spoke at the same Washington conference. "In Japan, wages are very flexible, with about two-thirds of compensation fixed and a third in the form of bonuses that can be varied," Hanke said. "Such wage flexibility gives Japan a current unemployment rate of 2.5% and long employee tenure."

Right now, the United States occupies an intermediate position, with wages more fixed than in Japan, but with fewer costly regulations than in Europe. If administration officials try to preserve high wage rates while putting new regulations and taxes on business, "we could be in for some bad times on the unemployment front," was Hanke's conclusion.

A Way Out?

Japan's wage practices have suggested a course for many U.S. businesses. About 2,200 American employers have instituted a pay-for-performance system called "gainsharing," which provides basic wage rates, plus bonuses for the achievement of higher levels of productivity and quality.

Speaking recently at an industrial symposium on how to achieve improvement in productivity and quality, David S. Hoyte, executive vice president (operations) of Frigidaire pointed out that *lasting* boosts in productivity and quality are not achieved by adding new equipment or tinkering with the manufacturing process. According to Hoyte,

"In building a team dedicated to total quality, problems must be viewed as buried treasure, to be unearthed by a workforce motivated to improve the process and the product. Equipment cannot do it. Only workforce corrective action can do it, and here we must recognize the role of gainsharing, which is really a pay-for-performance system. With such a system, people become willing to make problems visible and work toward their elimination and improvement. Gainsharing leads the whole organization to develop a fundamental understanding that the cooperative process creates great results. Such results are not a chance occurrence; they flow only from systematic efforts. We have seen it at Frigidaire, at the GM-Toyota joint venture in Fremont, CA, and elsewhere. Gainsharing has become accepted as the preferred method for raising the sights of an organization and developing its confidence that exceptionally high standards can be achieved."

Hoyte concluded: "The domestic home appliance industry is an American success story that attests to the use of such pay-for-performance wage systems. Over 84% of the major appliances sold in America are made in America. Excellence in design and productivity has contributed greatly to that success."

Whether the current federal administration will succeed in raising the minimum wage rate to $4.50 and indexing it for inflation remains to be seen. After all, Congress has proven to be a rather stubborn body and may balk at this boost in labor cost.

But Congress has nothing to do with companies trying pay-for-performance systems on their own. Some 2,200 companies now use some variety of such gainsharing programs with varied success. Gainsharing need not be

> **With a pay-for-performance system, people become willing to make problems visible and work toward their elimination and come to understand that the cooperative process creates positive results.**


QUICK QUALITY!

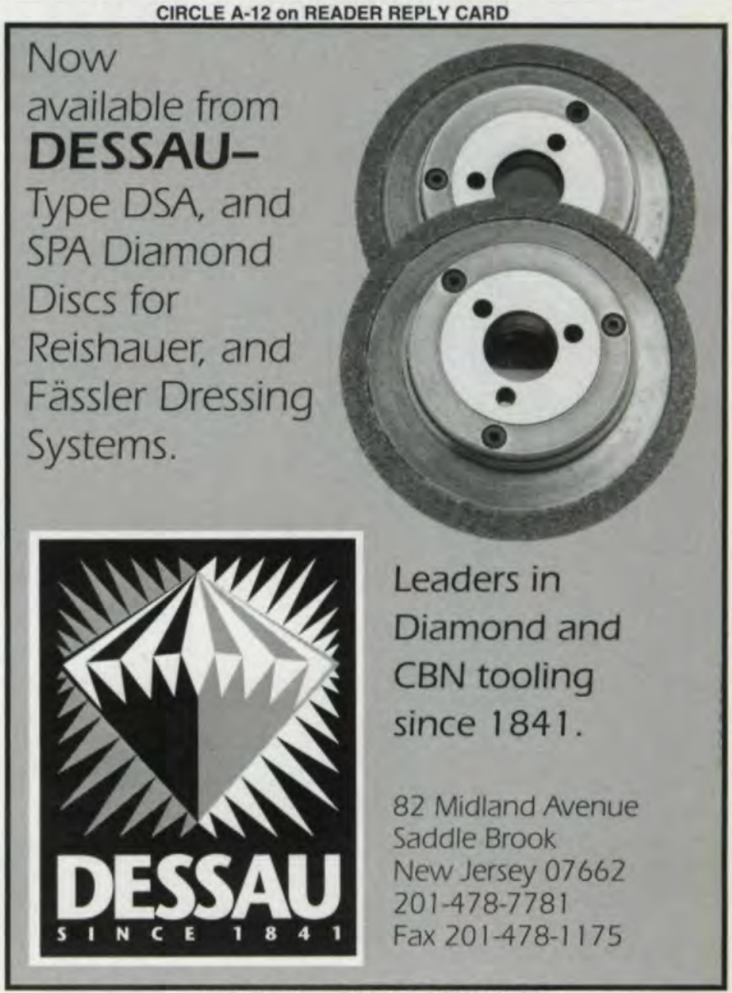
MASTER GEARS SPUR AND HELICAL

"Quick" because our delivery time from specifications to finished product is usually about six weeks. "Quality" because each one is certified to be on spec. We are also expert at refurbishing worn or damaged master gears (for example, for the automotive industry). And, every gear we deliver is precision ground and backed by a Parker test certificate. Call or fax for more information.

PARKER

PARKER INDUSTRIES INC.
1650 Sycamore Ave.,
Bohemia, NY 11716
Phone: 516-567-1000
Fax: 516-567-1355

CIRCLE A-12 on READER REPLY CARD


Now available from **DESSAU–** Type DSA, and SPA Diamond Discs for Reishauer, and Fässler Dressing Systems.

DESSAU
SINCE 1841

Leaders in Diamond and CBN tooling since 1841.

82 Midland Avenue
Saddle Brook
New Jersey 07662
201-478-7781
Fax 201-478-1175

CIRCLE A-13 on READER REPLY CARD

FILL IN THE BLANKS

Complete your *Gear Technology* library now.

Single issues and complete yearly sets of back issues are available now. Don't miss this opportunity to fill in the missing issues in your gear information library.

Single issues mailed to

U.S. Addresses — $9.00 Canadian Addresses — $10.00 Other Addresses — $16.00

Special price on complete yearly sets

	U.S. Address	Canadian Address	Other Address
1984 (3 issues)	$20.00	$22.50	$36.00
1985, 86, 87, 88, 90, 91, 92, 93 (6 issues)	$40.00	$45.00	$72.00
1989 (5 issues – no Mar/Apr)	$35.00	$40.00	$67.00

Fill out the order form below to get your back issues now.

Send me the following individual back issues:

____

____

____

Send me the following complete sets:

☐1984 ☐1985 ☐1986 ☐1987 ☐1988

☐1989 ☐1990 ☐1991 ☐1992 ☐1993

My check for $ ______________ is enclosed

☐Charge my VISA/MC/AMEX card
No. ________________________

Expiration Date _______ / _______

Signature ________________________

Send to the following address

Name ________________________

Address ________________________

City ______________ State __________

Country ______________ Postal Code __________

Mail completed form and payment to

Gear Technology
P. O. Box 1426
Elk Grove Village, IL 60009

limited to productivity and quality. It can also lead to improvements in on-time deliveries, can speed up work-in-progress, cut down on the accumulation of inventory, lead to savings in use of gas/electric energy, and so on.

Two Conditions for Success

Successful gainsharing programs require at least two programs:

1. A careful study of a company's wage and quality records for the past two years, so as to provide a benchmark to gauge current improvements.

2. Careful indoctrination of the entire workforce — middle managers, supervisors, engineers, technical employees and hourly workers — as to what is expected of them under gainsharing and the rewards they may anticipate.

There is no halting the rise in labor cost, even though a company may be non-union. Non-union companies are not isolated from the industrial world; they are affected by union wage rates in various industries. And they will certainly be affected by any federal legislation.

The only salvation is to work ardently to boost internal productivity and quality, thereby cutting unit costs. Prayer alone will not do it; nor will exhortation succeed for long. What is required is a systematic effort to improve workforce cooperation on new ways of doing things. The payoff can be great and lasting, provided the systematic effort is done carefully with some guidance. ■

Pay-for-performance can lead to improved productivity and quality and to improvements in on-time deliveries, work-in-progress, inventory control, and lead to savings in utility and maintenance bills.

*Note: Readers interested in gainsharing should refer to the following articles: "Gains Through Gainsharing," (*Area Development, *May, 1990), "Boosting Plant Performance with Gainsharing," (*Business Horizons, *Indiana University, Nov./Dec., 1992), and finally, "All You Ever Wanted to Know about Gainsharing," (*Target Magazine, *Association for Manufacturing Excellence, May/June, 1993).*

PEOPLE ON THE MOVE

Surface Combustion, Inc.

Maumee, OH. Surface Combustion, Inc. has announced the reassignment of three staff members to consolidate and facilitate the transmission of information between key functional areas in the organization.

Richard L. Nolte is now Product Manager in the Special Heat Treat Group with responsibility for project development, proposal/contract execution and project management.

Richard A. Huber will hold the position of Rebuild/Retrofit Contract Proposal Engineer, responsible for estimating and proposal preparation and contract management.

Nicholas J. Orzechowski is now a Proposal Engineer in the Non-Ferrous Product Area, estimation and development of proposals covering equipment and control systems for the nonferrous industry.

Diamond Black Technologies

Conover, NC. **John Chapin** has joined Diamond Black Technologies, Inc., as the new National Sales & Marketing Manager. Mr. Chapin brings many years' experience in sales, marketing and business to his new post.

Janco Products, Inc.

Mishawaka, IN. **Kim Burch** has been named Sales Assistant with responsibilities for inside sales and customer service. Janco Products, Inc., is a manufacturer of fiberglass reinforced plastics composites for electrical, medical, marine and other applications.

Do you have news of employee promotions, transfers or relocations you would like to share? Send your news release to Gear Technology, *People on the Move, P. O. Box 1426, Elk Grove Village, IL 60009, or fax it to our offices at (708) 437-6618. Note: Stories must be received by* ***the tenth of the month two months prior to the issue date*** *to appear in a particular issue. For example, if you want your story to appear in the March/April issue, it must be in our offices by January 10. Items reaching us past our deadline date will appear in the next issue.*

✎ PENCIL US IN . . .

If your company or organization is planning an educational or trade show event that you think would be of interest to our readers, announce it in our Technical Calendar. Notices need to be in our hands by the 10th of the month two months prior to the issue date in which you wish your announcement to appear. Mail your announcement to:

Technical Calendar
Gear Technology
P.O. Box 1426
Elk Grove Village, IL 60009
or fax us at (708) 437-6618.

DIAMOND BLACK
TECHNOLOGIES, INC.

DIAMOND BLACK COATING™

HOW CAN DIAMOND BLACK SOLVE YOUR WARRANTY COSTS

- Applied at LOW TEMPERATURE under 250F
- 95 Rc HARDNESS
- UNIFORMITY (2 Micron thickness +/- 5%) Surface replication w/no build up
- AMORPHOUS Structure (submicron wear particles)
- US & Foreign patented
- HIGH ADHESION (will not transfer)
- LUBRICANT RETENTION (strong wicking action)
- TEMPERATURE RESISTANCE (2282F)
- CHEMICAL RESISTANCE (not affected by lubricants)

Diamond Black™ coated gears have provided 7 times the gear life vs. uncoated!

100 SOMERSET DRIVE
Conover, NC 28613
(800) 368-9968
Fax (704) 322-4636

DISTRICT OFFICES:
Fenton, Grand Rapids & Livonia, MI
Milwaukee, WI, Muncie IN & NY, NY
Pomfret, CT & San Jose, CA
Cleveland & Toledo, OH

Member of: SME Society of Manufacturing Engineers

CIRCLE A-15 on READER REPLY CARD

Innovative CNC Gear Shaping

John Lange
American Pfauter Limited Partnership,
Loves Park, IL

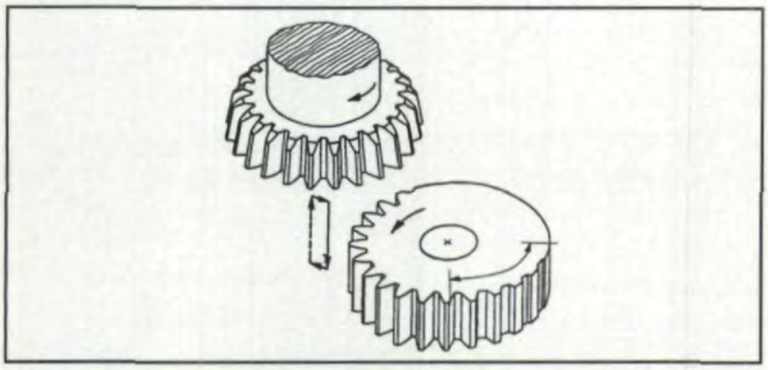


Fig. 1 — Working principle of shaping a spur gear.

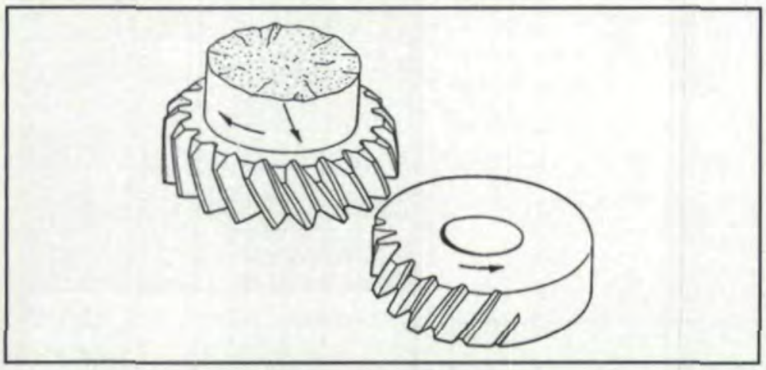


Fig. 2 — Working principle of shaping a helical gear.

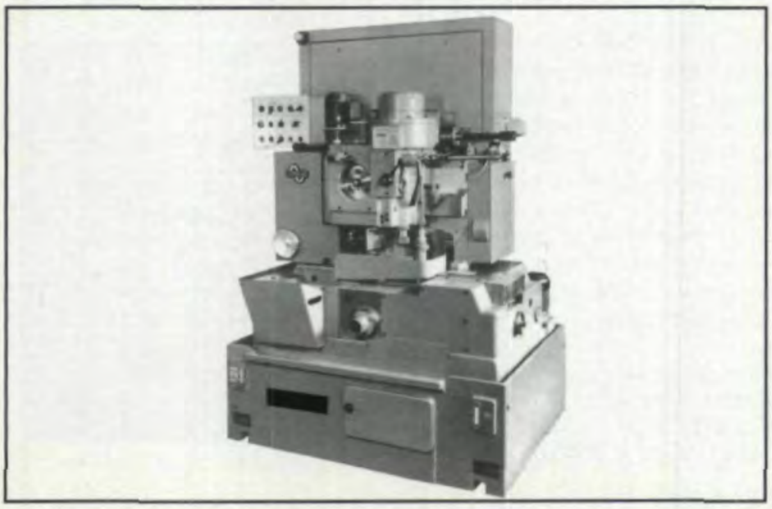


Fig. 3 — "Old style" gear shaper — work table back-off system.

Introduction

The Shaping Process — A Quick Review of the Working Principle. In the shaping process, cutter and workpiece represent a drive with parallel axes rotating in mesh (generating motion) according to the number of teeth in both cutter and workpiece (Fig. 1), while the cutter reciprocates for the metal removal action (cutting motion).

When shaping helical gears, an additional spiral motion is introduced to the cutter by the helical guide (Fig. 2). During the return stroke (relief stroke) the cutter is moved away from the workpiece to prevent flank contact or back-off motion.

These motions are basic functions of the shaping process. Efficient and flexible processing of small lot sizes requires additional automatically controlled functions and operations which will be discussed later.

Shaping methods. Any cutting action which a machine tool performs is based on a relative motion between tool and work. With gear shapers this relative motion is always the cutter stroke motion which is, depending on the application and shape of the cutter, complemented by the generating motion and radial infeed. In principle, three methods of shaping gears from a combination of these motions can be considered.

Conventional vs. CNC Machine Concept

"Old Style" vs. "Modern". "Old style" pinion cutter-type gear shaping machines changed very little from their conception in the early 1900s. They were bridge-type cutter head machines, with a table relieving system to clear the cutter from the workpiece on the return, nonproductive stroke of the cutter spindle (Figs. 3-5). The "modern shapers," introduced in 1969, went to a cutter spindle relieving action instead of the table relieving movement on the older style machines. Furthermore, the cutter spindle (and its moving housing) were mounted into a robust column (Figs. 6-8).

Modern machines are at least two times heavier than old style machines of equal diameter capacity. They are also two to three times more productive than the old style machines. This increase in productivity is directly attributed to the following:

1. Rigidity in the machine because of cutter spindle relief stroking drive train. This is a much smaller and constant mass to move than the larger mass of the table on the old style machine. That mass also varied, depending on the size and weight of the gear being cut and the fixture.

2. Stroking rates in the range of 1,000 to 2,000 strokes per minute made possible by a cutter spindle relieving mechanism and hydrostatically mounted cutter spindle bearing and guides.

3. Larger cutting spindle diameters with proportionally increased horsepower of the main drive motor; for example, a 20" maximum diameter capacity modern machine may have a 3.93" diameter cutter spindle and a 22 horsepower, stroke drive motor, while an old style machine may have a cutter spindle diameter of 3.34" and a 5.7 horsepower motor driving the entire machine, i.e., the cutter spindle stroking and the rotary and radial feed change gears (Fig. 5). Note: Maximum DP rating on this size machine went from 5 DP for the old style machine to 3 DP for the modern machine.

4. Increase in overall weight of the machine by a factor of two to three times. For example, a 6" maximum diameter capacity modern machine weighs 17,000 lbs; the old style machine, 4,900 lbs. This extra weight helps to absorb the higher cutting forces and reduces vibration.

"Modern" Spindle Relief Type Gear Shaper with Change Gear Drive Train "First Generation". Figs. 7 and 8 illustrate the drive train of a modern conventional gear shaping machine with independent drives, i.e., AC main drive motor for stroke drive, AC servo drive motor for rotary feed and rotary power traverse and, finally, AC servo drive motor for radial infeed and radial power traverse. Notice that rotary feed and required rotational timing of the workpiece and cutter are handled by an index change gear drive train. Up until the 1980s and despite the introduction of CNC controls, the uniformity of the generating motions for rotary movement was maintained

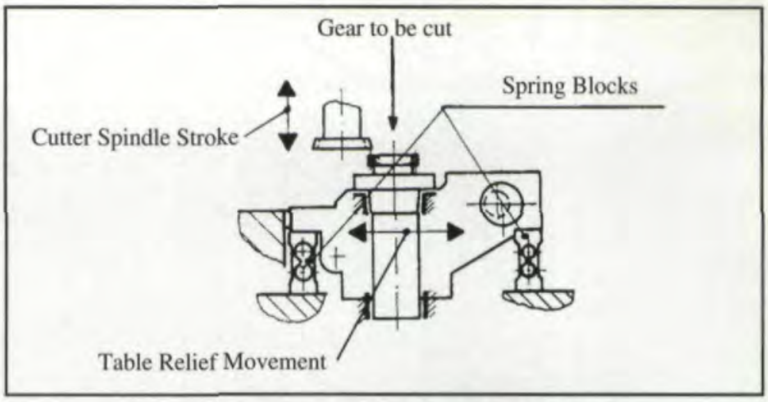


Fig. 4 — "Old style" gear shaper — work table back-off system.

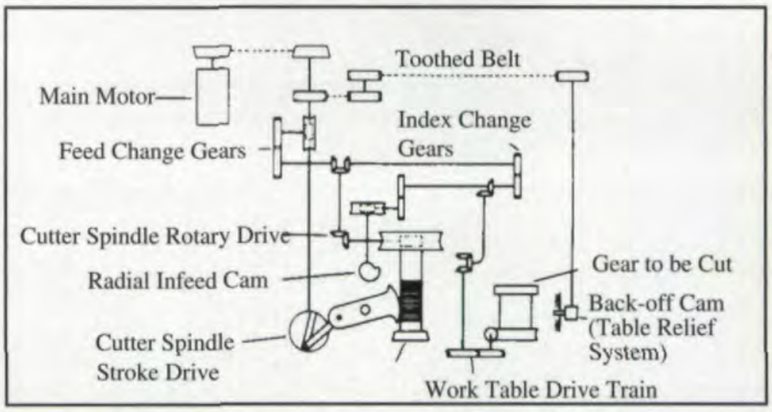
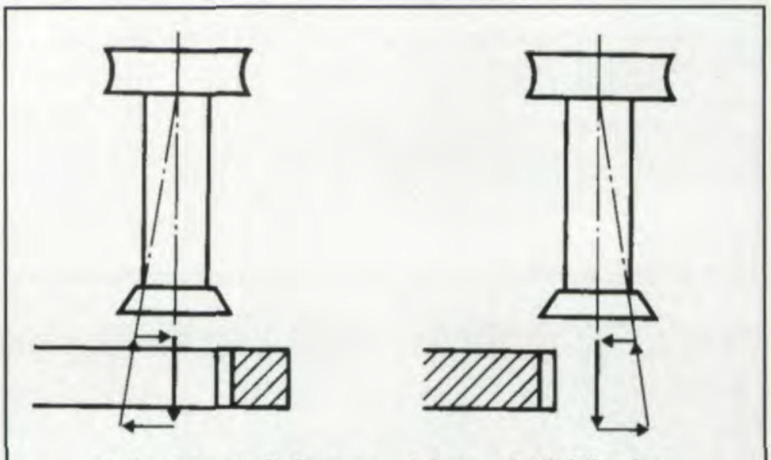


Fig. 5 — "Old Style" table relief machines with numerous drive trains necessitated by having a *single drive motor.*



- Adjustment of relief amount and change of relief direction.
- Relief amount setting adapted to the application.
- Change in relief direction in external/internal machining.

Fig. 6 — "Modern" spindle relief type gear shaper with change gear drive train ("first generation").

John Lange
is a product manager at American Pfauter Limited Partnership. He is currently Chairman of the AGMA Gear Manufacturing Committee and is the author of numerous papers and a contributor to the SAE Gear Design, Manufacturing and Inspection Manual.

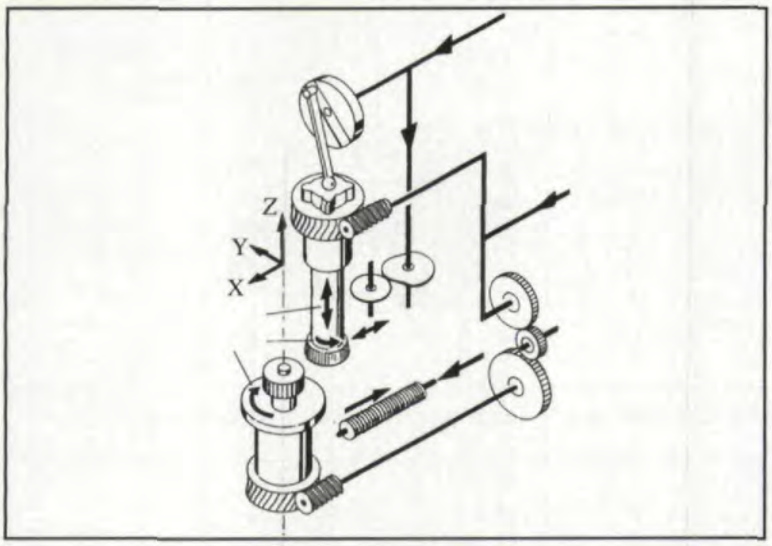


Fig. 7 — Mechanical link between cutter and work on a mechanical gear shaper.

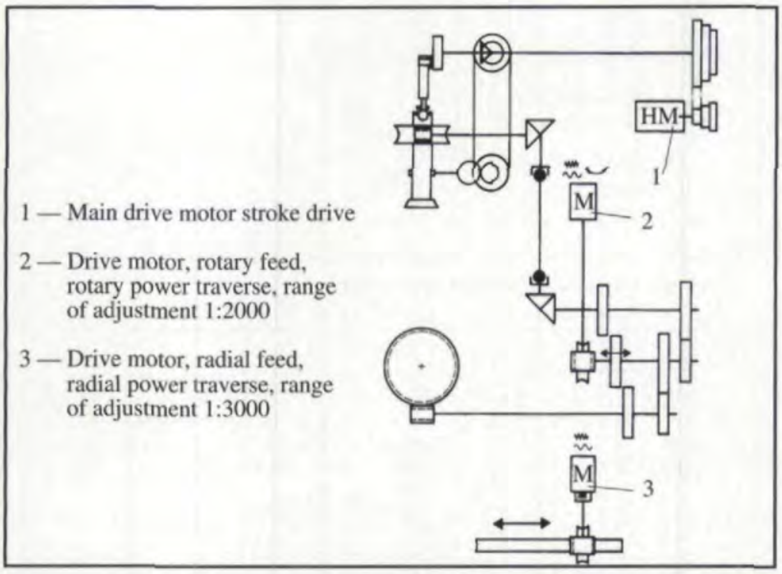


Fig. 8 — Three separate motors for stroke, rotary and radial movement.

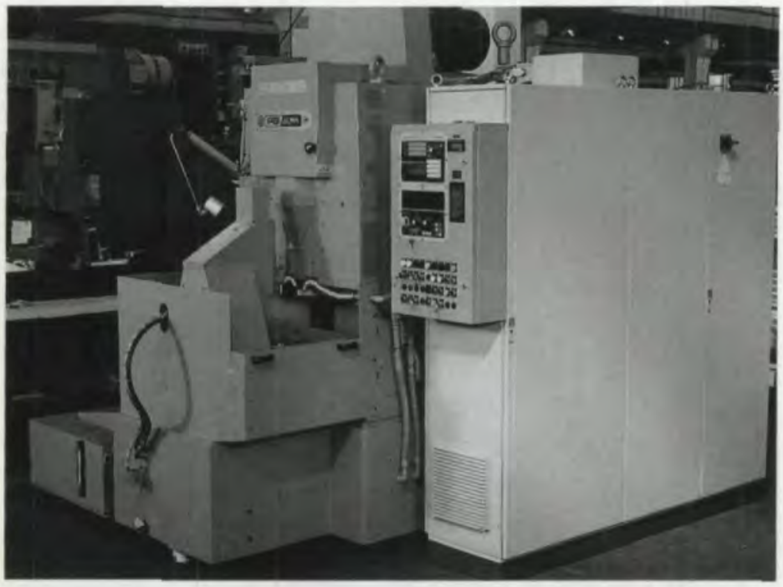


Fig. 9 — A conventional gear shaping machine with a maximum diameter capacity 7" and 2" face widths, stroking rates up to 1,800 strokes per minute.

almost solely by a mechanical drive train providing a positive link between these movements. The transmission ratio was varied by change gears.

CNC Development. Fig. 9 shows a non-CNC modern spindle relief gear shaping machine. Fig. 10 is the same machine, but with CNC control. There is little difference in the outer appearance other than the operator controls, however, the internal machine kinematics are quite different. CNC refers not only to programming of feeds and speeds, but more important, to the elimination of index change gear drive trains. In reality, little benefit can be realized by using a CNC control only to program feeds and speeds.

CNC Shaper "Electronic Gear Box". A "full" CNC gear shaping machine does not contain index change gear drive trains. The required index ratio and the timing relationship between the "C" axis cutter spindle and the "D" axis work table is controlled by CNC, i.e., the so-called electronic gear box. The same controller is used to specify the X axis radial infeed rates and the cutter spindle stroking rates per minute. Figs. 11 and 12 illustrate a five axis gear shaping machine. In addition to the X, C and D axes, we also see the Z axis, which is a vertical positioning of a given stroke length. "L" is a stroke length setting.

Flexibility and New Machine Design Concept

A Flexible Shaper. A gear shaping machine with a two-inch stroke has a very limited vertical height position (distance above the work table) in which that two-inch stroke can occur — normally only three inches or less. Because of this, the machine needs to be supplied with a riser block (a spacer mounted between the bed of the machine and the column) to elevate the maximum stroke height to the same level as the tallest part to be cut. Consequently, shorter parts must be raised up in a special fixture to this predetermined height. Obviously, riser blocks and built-up fixtures reduce the desired rigidity of the machine, and in turn, accuracy of the cut part and tool life. The cost for fixturing elements increases proportionately.

Quite frequently, shapers are used for cutting one gear in a cluster of gears, because one or two elements in the cluster must be shaped, i.e., cutter run-through clearance is restricted. In addition to the shaped gear in the cluster, it would be advantageous to shape another gear in the cluster in the same setup. However, because of the different number of teeth, the required index ratios, and the fixed index change gear drive trains, this was not possible with the older style and first generation spindle relief machines. Also, the location of the second gear on the shaft made it difficult to reach, even with stacked cutters, i.e., two cutters mounted to the cutter spindle.

In the 1960s the cutting tool was not the limiting factor in the cutting process. Lightweight "old style" machines with numerous gear drive trains, slow stroking rates and general lack of rigidity made the machine, not the tool, the limiting factor. In the early 1970s, the modern first generation spindle relief shapers using conventional M-2 tool steels found the tool, not the machine, the limiting factor. In the late 1970s and early 1980s, with the advent of powdered metal ASP 30 and 60 titanium-nitrided coated cutters, we found, in many cases, the machine to be the limiting factor once again. New infeed techniques had to be developed to realize the full potential of these new tools.

The "second generation" of the spindle relief machines added a CNC controller, which eliminated index change gear drive trains. These machine advances dealt with the previously mentioned limitations through the design features shown in Figs. 13 and 14.

The machine is fitted with a vertical adjustable cutter head slide (Z axis) (Fig. 13) which allows vertical positioning of the entire head. In most cases, riser blocks and specially elevated work fixtures are not necessary. For example, this 2.35" stroke length machine has an axial displacement of the cutter head slide (stroking position) of 6.7". Using NC techniques, the positioning of the cutter head slide is accurate to within a tolerance of .0008".

The C and D axes, which required rotary movement (index ratio) of the cutter spindle and rotary movement of the work table respectively, are controlled by CNC with rotary encoders. There are no index change gears in the machine. The resolution of the rotary encoders is 3.6 arc seconds. This design

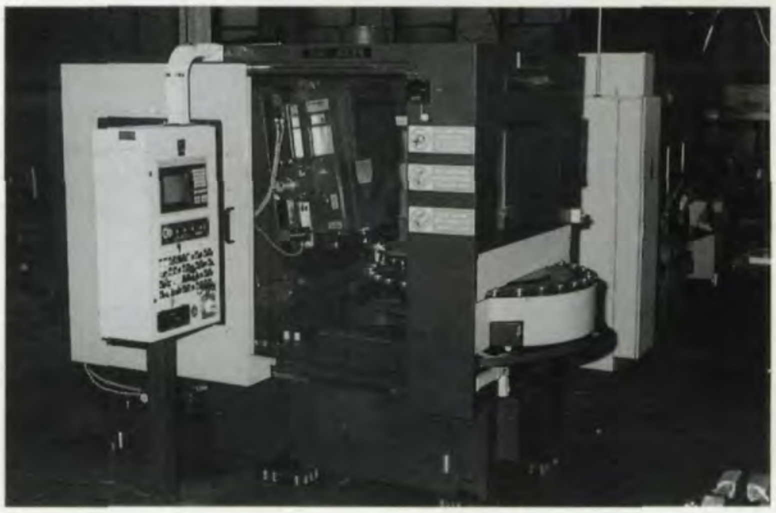


Fig. 10 — CNC gear shaper. Note the use of spring mount shock absorbers and tilt column for root taper cutting capability.

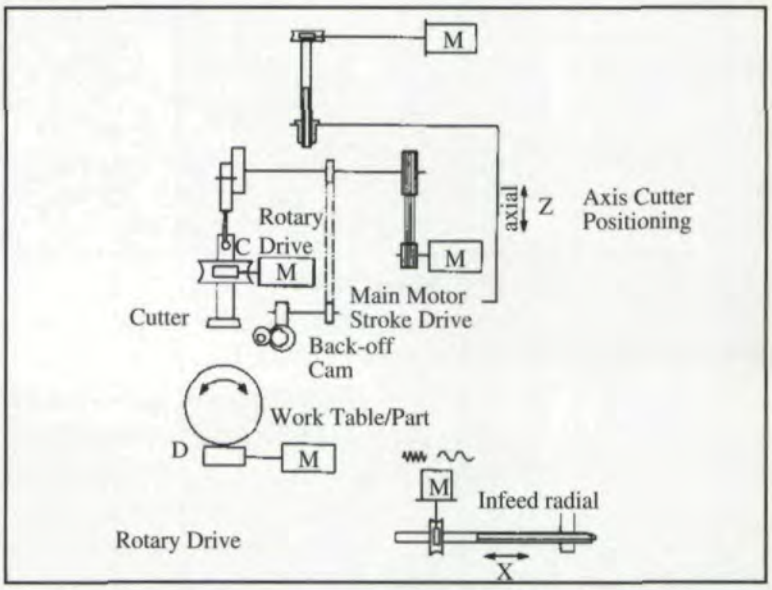


Fig. 11 — Kinematic drawing of drive train for a 4-axes CNC shaper. The servo drive motors (M) for X, D and C are AC brushless type for low maintenance. They also must have a wide speed range ratio, i.e., rotary axes C and D 1:4800 and X radial axis 1:1800 ratio.

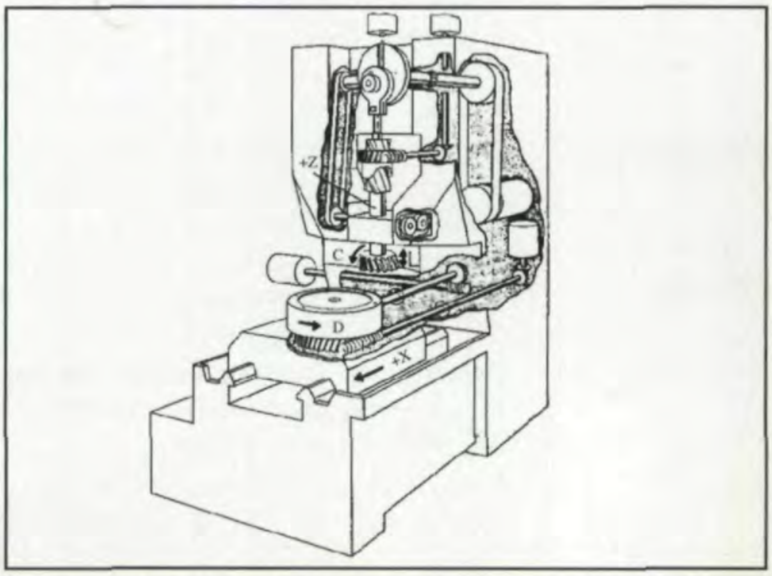


Fig. 12 — 5-axes CNC gear shaper.

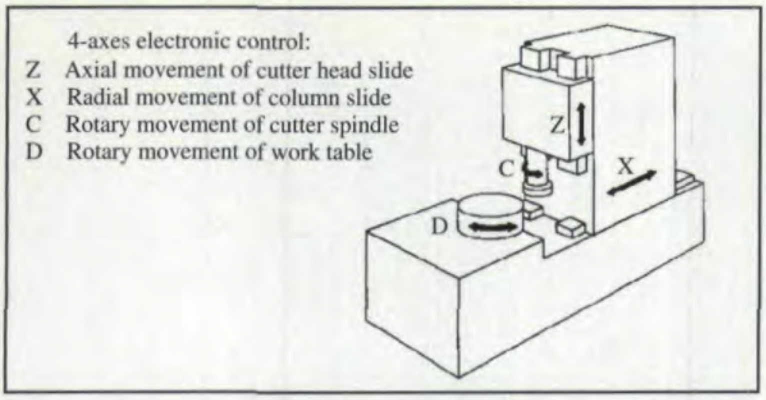


Fig. 13 — Cutter Head Slide CNC Shaper

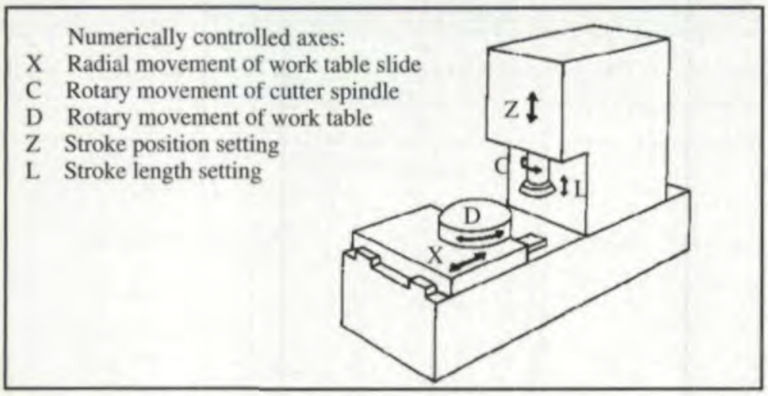


Fig. 14 — Conventional CNC Shaper

feature makes it possible to cut two or more cluster gears having different index ratios in a single setup. Depending on the gear data of the cluster gear, it might be necessary to use stack-mounted cutters. The lead of both cutters must be the same. A CNC guide has not yet been developed, but experimental work is being done in this area.

Example 1 in the appendix shows two external gear clusters being shaped in a single setup. CNC shapers are also perfectly capable of cutting components having both internal gears (or splines) and external gears in a single setup.

Frequently, cluster gears have a timing requirement between a tooth on a gear in the cluster in relation to another tooth on a second gear in the cluster. The use of a CNC control system makes it possible to meet these demanding requirements. This example illustrates such an alignment requirement. This automotive transmission component requires a tooth alignment accuracy between the two gears of .0008". The part has been cut on a CNC shaper, as illustrated in Fig. 13, achieving an alignment accuracy of .0004". This accuracy will be maintained in a production environment.

Down-and-up shaping of a component is made possible with CNC. The part configuration illustrated by Example 2 in the appendix dictates that both the upper and the lower gear be shaped. To do this part in a single setup, down-and-up shaping is required. The upper gear of the component has an outer diameter larger than the root diameter of the lower gear. The teeth of the upper gear must also be aligned to the lower gear. That alignment can be easily obtained, because the part is cut in a single setup using keyed cutters. The relation of the cutter spindle backoff and cutting stroke direction is controlled by the CNC unit. When cutting the upper gear, the cutter relief occurs on the upward, non-productive stroke. In the case of the lower gear, the cutter relief action occurs in the downward stroke.

Innovative Design — An 8-Axes FMS-Ready Machine. Since the advent of CNC gear shaping machines in the early 1980s, hundreds have been sold worldwide. These machines, with their four and five axes, revolutionized gear shaping production in job shops and small batch production by increasing productivity by four to five times compared to older shapers. Even in mass production installations we have seen an increase in productivity of two to three times due to CNC cutting feed techniques and quick cutter changes.

However, these machines were not flexible manufacturing systems (FMS) or cell "ready." To meet this requirement, three additional axes and auto tool and pallet fixture loaders were needed. This was a real challenge for the builders of CNC shapers and their CNC control manufacturers, as the machine now has eight axes. Also, to be totally free of constraints, the Z axis stroke positioning range had to be as large as practically possible to accommodate various part configurations. Fig. 15 illustrates such a machine. Note the additional three axes:

O axis — quick return stroke; especially useful for gears with large face width;

A axis — the direction of the cutter spindle relief; internal versus external gears; and

B axis — a column tilt for cutting root tapered teeth.

Combining this machine capability with a pallet fixture and a 12-station tool loader results in a CNC gear shaping machine well suited for FMS installation. The flexibility of the large stroke positioning range (15.75") is equally important to special industries such as aircraft engine manufacturers and heavy construction equipment builders.

Feed Techniques to Match High Tech Machines

Optimizing the Generating Method. Four types of infeed can be distinguished (X, C and D axes):

1. Radial feed with rotary motion. (Fig. 16a). This is a traditional method, with radial infeed of cutter or workpiece to final depth with rotary motion of both cutter and workpiece. A comparatively short spiral length pattern, depending on the selection of the approximate feed rate (generating feed up to 1.0 mm (.04")/double stroke and radial feed of .02-.04 mm (.0008-.0016")/double stroke), results.

2. Radial feed without rotary motion. (Fig. 16b). Also a traditional approach, this method is recommended for:

a. Shaping internal teeth in order to avoid return stroke marks by the tool on workpieces with difficult tooth geometry;

b. Reducing feed times; and

c. Producing form cut profiles (single tooth indexing method).

Radial infeed is to final depth without rotary motion of workpiece and tool. It is used primarily to prevent collision when shaping internal gears and to save time by applying higher infeed rates (approximately .05-.10 mm (.002-.004")/double stroke), and meet special requirements.

3. Spiral method with constant radial feed. (Fig. 16c). This is used on a modern machine, but not necessarily one equipped with CNC. The chip volume increases with increasing cutting depth of the tool and

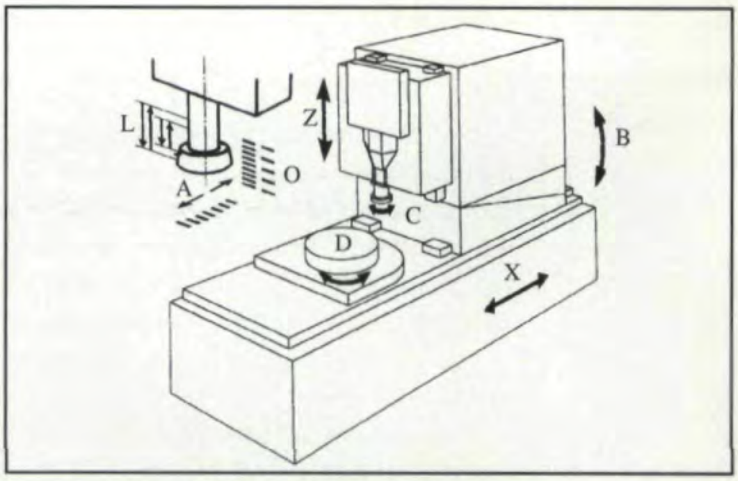


Fig. 15 — 8-axes CNC gear shaping machine.

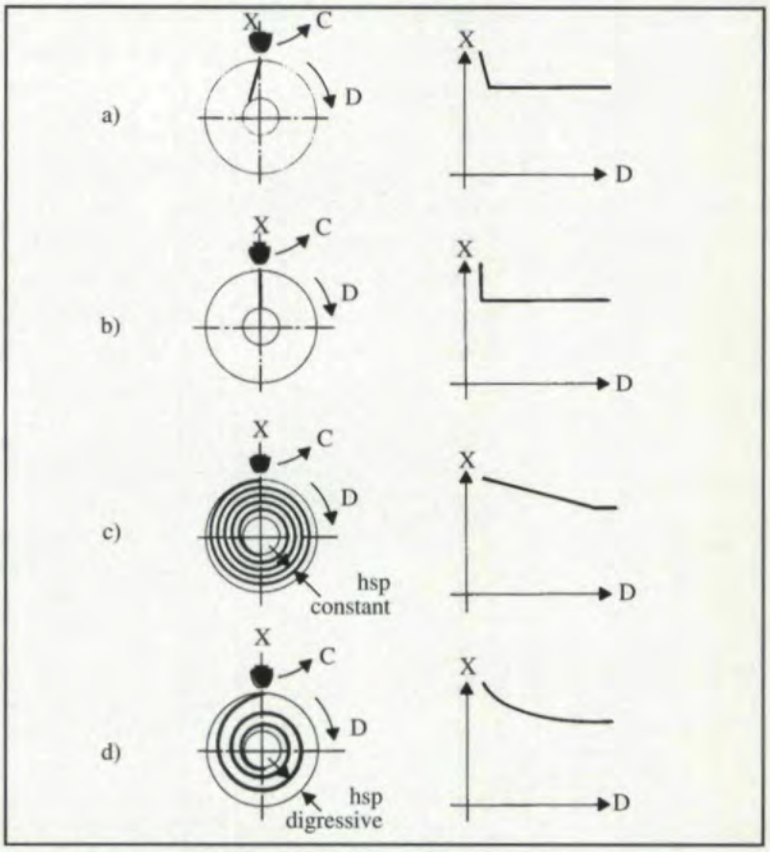


Fig. 16a — Radial feed with rotary motion.
Fig. 16b — Radial feed without rotary motion.
Fig. 16c — Spiral method with constant radial feed.
Fig. 16d — Spiral method with digressive radial feed.

Table 1 — Summary of cutting methods.

Method	Description	Types of Cutters
Generating	— Infeed without generating — Infeed with generating — Spiral infeed with either constant or variable radial feed	— disk-type cutters — hub-type cutters — shank cutter
Index generating	— Like generating, but no full work revolutions at constant feed (segment gears, special profiles which can be generated)	— cutter types as — segment cutter — single tooth form cutter
Single indexing	— No generating motion of workpiece during stroke action	— form cutter (primarily single tooth cutter)

uniform radial feed. This amounts to continuously increasing loads on the machine and the tools until the depth of the tooth is reached. Continuous uniform radial infeed is to final depth over several work revolutions. The desired large spiral length pattern results from appropriate feed rate combinations, depending on gear parameters (generating feeds up to 10 mm (.40")/double stroke and radial feeds of approximately .002-.030 mm (.000080-.0012")/double stroke).

4. Spiral method with digressive radial feed. (Fig. 16d). This is the newest technology and is only possible with CNC. Here, a decreasing rate of radial feed keeps the chip volume during the feeding process almost constant. The result is improved tool life and improved surface quality of the tooth flanks. In this method, travel is dependent on digressive feedrate pattern. The high requirements for proper control can fully realized only with CNC.

Cutting Forces and Torque Based on Feed Techniques. The controlled infeed of the spiral infeed method over as many as possible work revolutions is primarily used. Comparison tests with traditional infeed methods with or without generating at equal time for roughing show that the individual cutting edge is exposed to substantially reduced main cutting forces and torques (Fig. 17). This occurs because of better and more uniform chip formation, better chip flow and less chip deformation (Fig. 18). The desired effects are less cutter flank contact, less danger of rubbing on the return stroke, reduced temperature build-up at the cutting edge and less tendency for edge build-up.

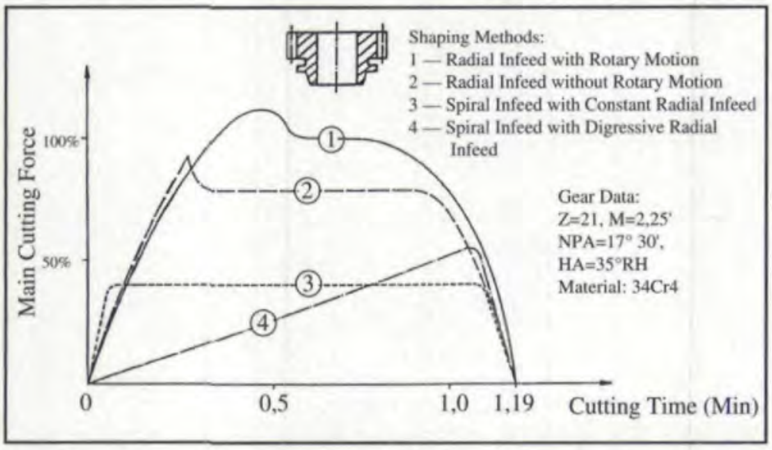


Fig. 17 — Main cutting force diagram roughing by the four infeed methods.

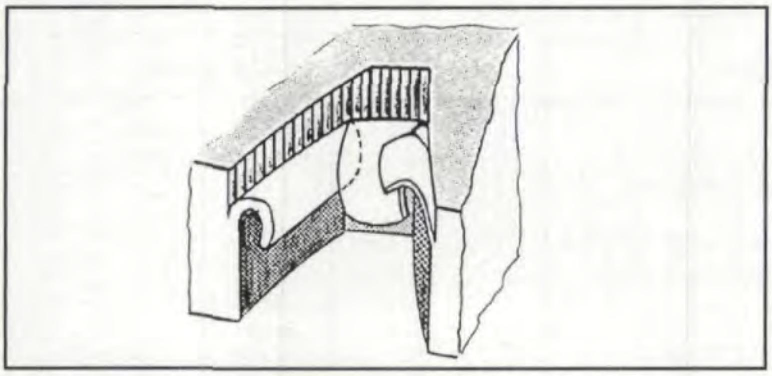


Fig. 18 — Chip formation, spiral digressive infeed method.

Spiral Digressive Infeed Cutting Technique. Applying the digressive infeed substantially increases the productive efficiency of gear shaping, assures short cutting times and provides effective tool utilization coupled with high accuracy. The process is applied to roughing operations with subsequent shaving, fine rolling, honing or grinding and to finish cutting operations such as are shown in Fig. 19, where both higher feed marks and enveloping cut formation, as with coupling gears, are acceptable or even desirable because of the improved lubrication effect (oil pockets). Key features of this infeed technique are:

1. Controlled Chip Removal

a. The spiral type infeed pattern is according to section.

b. Cutting data, such as numbers of strokes, generating feed, radial feed and cutting depth, are determined by computer control.

c. The bases for determining cutting data are the geometrical parameters of workpiece, tool, machine, material specifications and values obtained from trials.

2. High Speed Finish Shaping

a. This improves surface quality, particularly the formation of enveloping cuts for the desired subsequent operation.

b. This also yields extremely short finishing times as a result of the high generating feed rate, which can be up to fifteen times the rate of conventional finishing feeds, depending on the gear parameters.

3. Spring Cuts Without Infeed For Improving Quality

a. Typical tooth deviations (e.g., errors reproduced as a result of inaccuracies built into the cutter or as a result of improper cutter mounting) are averaged out.

b. The number of spring cuts depends on the relation of the number of teeth between cutter and workpiece and on the required gear quality.

Gears shaped by the digressive technique are comparable to hobbed gears in both surface and enveloping cut patterns. The same comparison applies to checking the gear, particularly to chart evaluations and to subsequent finish operations.

Actual production results have shown that selecting a machinable workpiece material and using TiN-coated cutters (especially face-coated) can have a positive effect on the surface quality of gears produced by the digressive technique.

This is not to say that one must always look for the easiest material to cut. For example, if an 8620 material is cut at a high rate (finishing at a surface cutting speed of 300 fpm), a 200 Brinell hardness would be preferable to the softer 150-160 Brinell. The softer material will tear and chip-weld to the flanks of the cutting, especially if the cutter's face is not TiN coated. This tearing and chip-welding will lower the obtainable AGMA finish-cut accuracy from a 10 to a 7 or 8.

Besides higher chip removal rates and reduced cutter wear through the digressive infeed technique, a subsequent finishing operation has generally better results than roughing by conventional shaping infeed methods. This occurs because of reduced gear runout and spacing errors, smaller required stock envelope and reduced chip volume.

These New Technologies Affect Cutting Times. The new feed techniques go hand in hand with the technology advancements made in the hardware, i.e., machine and cutting tools. The pendulum of the shaper cutting process no

Fig. 19 — Feed marks and enveloping cut formation.

Table 2 — Past to present cutting time review.

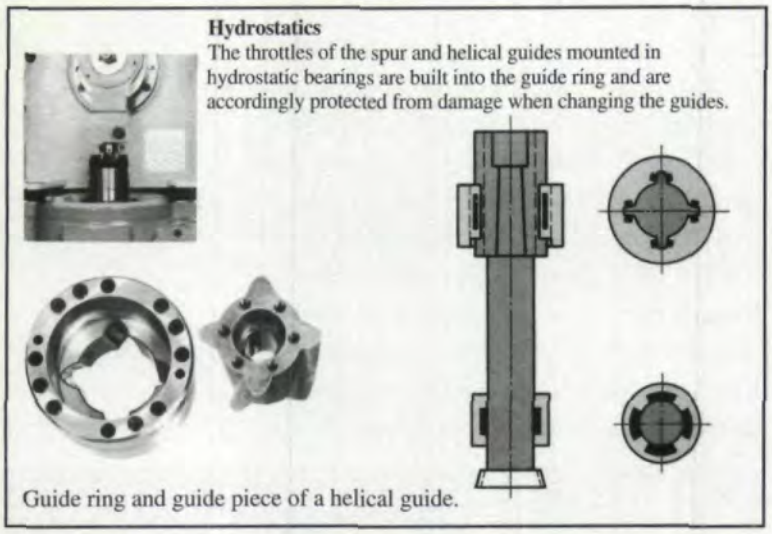
Gear Data	**Typical Automotive Gear**			**Typical Truck/Agricultural Gear**		
Diametral Pitch	12			5		
No. of Teeth	30			30		
Pitch Circle	2.88"			6.92"		
Pressure Angle	20°			20°		
Helix Angle	30°			30°		
Face Width	.8"			1.5"		
Material/Hardness	8620/220 BHN			8620/BHN		
Cutting Condition	Preshave			Preshave		
Quality AGMA	8/9			8/9		
Shaping Machine Data*	**Old**	**Modern**	**CNC**	**Old**	**Modern**	**CNC**
Infeed Method	Conv.	Conv.	Spiral Digress.	Conv.	Conv.	Spiral Digression
No. of Cuts	2	2	2 Feed Changes	3	3	3 Feed Changes
Strokes/Min.						
Cutting Speed, Ft./Min						160/99'
Roughing	335/115'	335/115'	360/121'	142/85'	150/92'	242/150'
Finishing	500/174'	670/232'	1000/360'	213/131'	150/92'	480/292'
Rotary Feed/Stroke						
Roughing	.0177"	.019"	.1007"	.0244"	.030"	.181"
Finishing	.0177"	.030"	.030"	.0244"	.030"	.072"
						.032"
Radial Infeed/Stroke	.0012"	.0012"	.020-.0008"	.0012"	.0012"	.020-.0008"
Roughing	.0004"	.0004"	.0002"	.0004"	.0004"	.0004"
Finishing						.0004"
Cycle Time, Minutes,						
Without Load & Unload	3.15	2.5	1.68	19.01	17.13	7.98
Pieces Per Sharpening						
Percentage	100%	190%	290%	100%	180%	340%

*Old — Table relief type machine (See Figs. 3-5).
Modern — Spindle relief type machine, but with change gears and independent drives (see Figs. 6-8).
CNC — Spindle relief type machine with large speed ranges and without change gears (see Figs. 11-12).

longer swings in favor of the cutting tool vs. the machine or vice-versa. Cutting tool and machine are equal limiting factors.

Advancing Technology for Mechanical Components

Hydrostatic Guides. Gear shaping machines require spur and/or helical (lead) guides. Helical gears require helical guides that introduce to the cutter spindle an additional rotary motion during the working stroke. These mechanical guides are still required, but in almost all cases, the cutter spindle and guide are mounted hydrostatically (Fig. 20). This is a necessity based on the high stroking rate capabilities of some machines, i.e., 2,050 strokes per minute. This can lead to cutting speeds for finishing up to 492 surface feet per minute. Of course, work is being done on CNC guides, but none are currently available for quality production at high stroking rates.



Hydrostatics
The throttles of the spur and helical guides mounted in hydrostatic bearings are built into the guide ring and are accordingly protected from damage when changing the guides.

Guide ring and guide piece of a helical guide.

Fig. 20 — Hydrostatic lubrication of a helical or spur guide and cutter spindle.

Another element which is not CNC on the machines is lead correction, i.e., crowning capability. *Involute modifications are produced by modifying the cutter tooth form,* but crowning is achieved by moving the cutter spindle as it traverses the face of the gear. This movement is created by modification of the "back-off cam," which is part of the relieving mechanism for cutter relief. Cutter relief is the process of moving the cutter away from the gear so it does not contact the gear on the non-cutting return stroke. Of course, this applies only to "modern" spindle relief shapers.

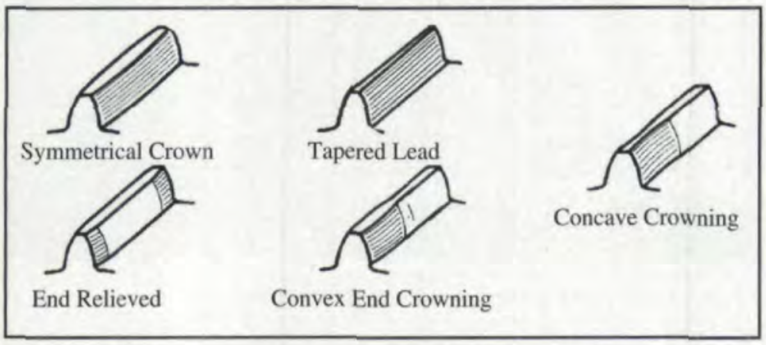


Fig. 21 — Types of longitudinal correction (lead correction) crowning, taper, etc.

Cutter Changing — Manual Quick Change and Fully Automatic Changes. See Figs 21-24 for illustrations of these features.

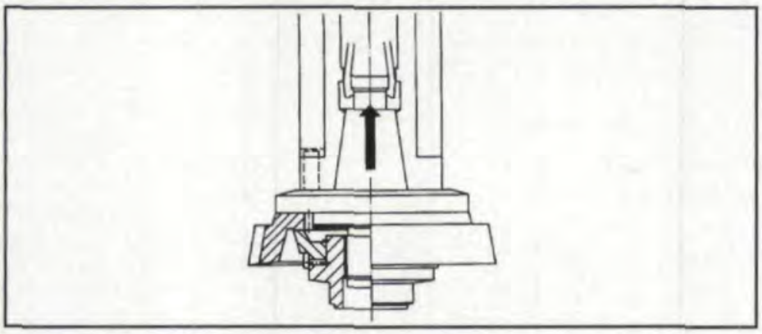


Fig. 22 — Automatic cutter clamping feature. The cutter and adapter are hydro-mechanically clamped into the cutter spindle.

Worm and Worm Wheel Designs for Backlash Control. When the gear shaping process is evaluated for geometric capabilities, the following **general statements** can be made.

1. Lead errors are minimal with modern hydrostatic machines, i.e., AGMA 11-12 is an achievable quality. The hydrostatic mounting of guide and spindle maintains this capability.

2. Profile results are closely tied to shaper cutter tolerances, but are also related to cutter coatings, cutter clearance and rake angles and sharpening errors.

3. Part pitch line runout errors can be directly related to cutter mounting errors

Fig. 23 — Cutter adapters are automatically clamped concentric to the cutter spindle to an accuracy of .0001-.0002". Two cutters are mounted for cluster gear cutting.

and/or fixturing errors.

A Summary of the Benefits That Can Be Realized from a CNC Shaper:

1. The operator set-up is simplified because:

a. The operator does not have to mount index change gear,

b. The operator does not have to set cutter spindle stroke length and position;

c. The operator does not have to set infeed cams or micrometer switches for depth of cut;

d. The operator does not have to set speeds and feeds, which can be loaded by punch tape or DNC or recalled from the CNC controller memory;

e. The operator does not have to change direction of cutter relieving for upcutting or internal gear cutting to external gear cutting;

f. With the appropriate cutter measuring equipment the operator does not have to cut a trial piece to verify correct infeed setting for an overpin dimension check, i.e., cut a part to size;

g. On some machines the spindle back-off direction does not need to be changed.

2. Cluster gears can be cut in a single setup because of the Z axis stroke position and the absence of index change gears. If the DP differs from gear to gear, stacked cutters are applied.

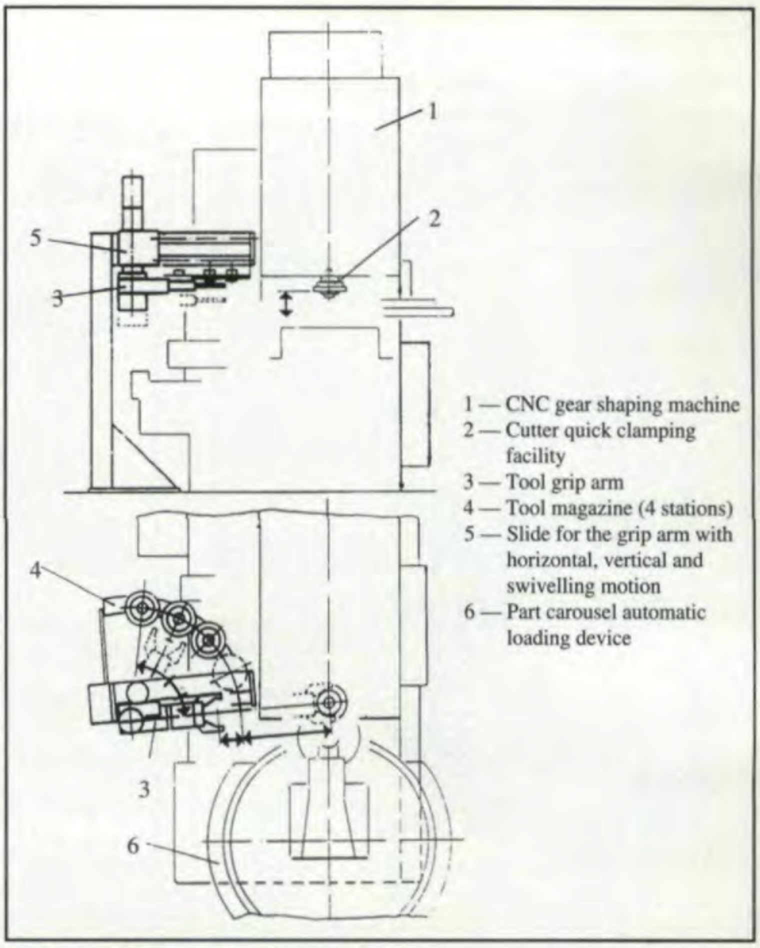
3. Cluster gears with tooth location requirements can be cut in a single setup. C and D axes are independently controlled.

4. Keyways, single tooth form or other forms can be cut by the plunge cutting technique, i.e., no C or D axes rotation except for single tooth indexing. The X axis radial infeed is the only feed component used with this technique.

5. An internal spline or gear and external gear may be cut on the same blank. This requires the Z axis stroke positioning feature and stacked cutters with C and D axes index ratio change.

6. Cutter change down-time is reduced. The cutter can be electronically measured off the machine and new tool offset data entered through the CNC control while the machine is in production. Axes used are Z stroke position and X axis for new infeed depth stopping position ("final size"). Of course, this is done to compensate for tool height and diameter change due to cutter sharpening or new set-up.

7. Zero set-up time is important in connection with just-in-time inventory and flexible manufacturing cells and systems. A setup of only a few minutes can be presently obtained on gear shaping machines if the guide does not have to be changed and additional support equipment is purchased with the machine, i.e., automatic fixture and cutter change equipment.



1 — CNC gear shaping machine
2 — Cutter quick clamping facility
3 — Tool grip arm
4 — Tool magazine (4 stations)
5 — Slide for the grip arm with horizontal, vertical and swivelling motion
6 — Part carousel automatic loading device

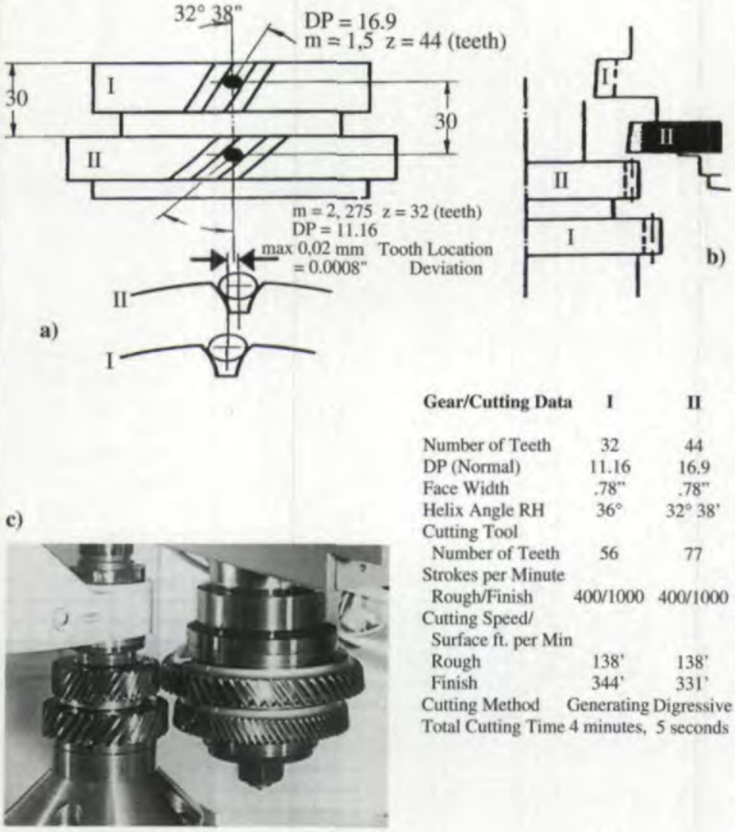
Fig. 24 — CNC gear shaping machine.

8. CNC gear shaping machines are more accurate than conventional shapers. X-axis infeed, feed per strokes and depth of cut (final size) are controlled by a linear electronic scale and AC servo drive. The accuracy of stopping at a preset infeed depth is plus or minus 40 microinches. Z-axis stroke length positioning is also controlled by a linear electronic scale to an accuracy of .0008". C and D axes are controlled individually by rotary encoders with a resolution of 3.6 arc seconds. These new shapers are capable of producing quality level AGMA 11 under production circumstances and optionally, AGMA 12.

9. The installation of a CNC gear shaping machine into a flexible manufacturing cell or system would dictate automatic tool changing capability.

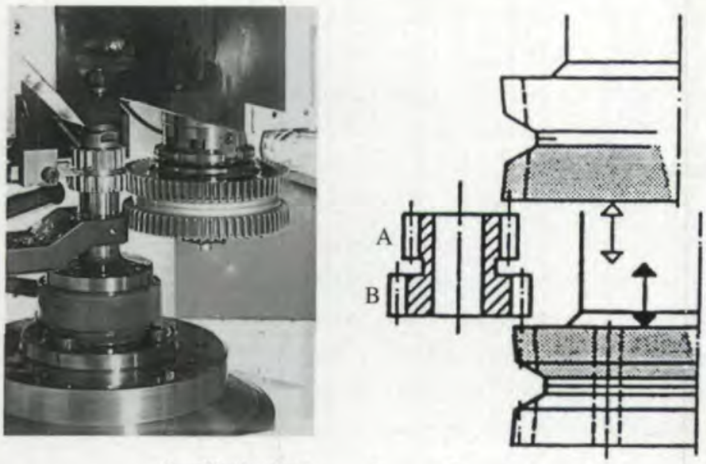
Appendix: CNC Shaping Applications — The Real World

Example 1. Cutting a Helical Gear Cluster with a Tooth Alignment Requirement in a Single Setup. Figs. 25 a, b and c show a helical cluster gear with a tooth location requirement. This is an automotive transmission component. Gear I and gear II have



Gear/Cutting Data	I	II
Number of Teeth	32	44
DP (Normal)	11.16	16.9
Face Width	.78"	.78"
Helix Angle RH	36°	32° 38'
Cutting Tool		
Number of Teeth	56	77
Strokes per Minute		
Rough/Finish	400/1000	400/1000
Cutting Speed/		
Surface ft. per Min		
Rough	138'	138'
Finish	344'	331'
Cutting Method	Generating	Digressive
Total Cutting Time	4 minutes, 5 seconds	

Fig. 25 — Helical cluster gear with a tooth location requirement.



Gear/Cutting Data	A	B
Number of Teeth	18	21
DP	10	10
Face Width	.70"	.61"
Material 8620	180-200 BHN	
Number of Teeth in Cutters	62	
Strokes Per Min./ Cutting Speed Surface Ft. Per Min.		
Roughing	700/167'	700/167'
Finishing	1050/249'	1250/295'
Cutting Method (Generating)	Down Digressive	Up Digressive
Total Cutting Time	1.2 min	

Fig. 26 — Cluster planetary pinion cutting down-and-up shaping in a single setup.

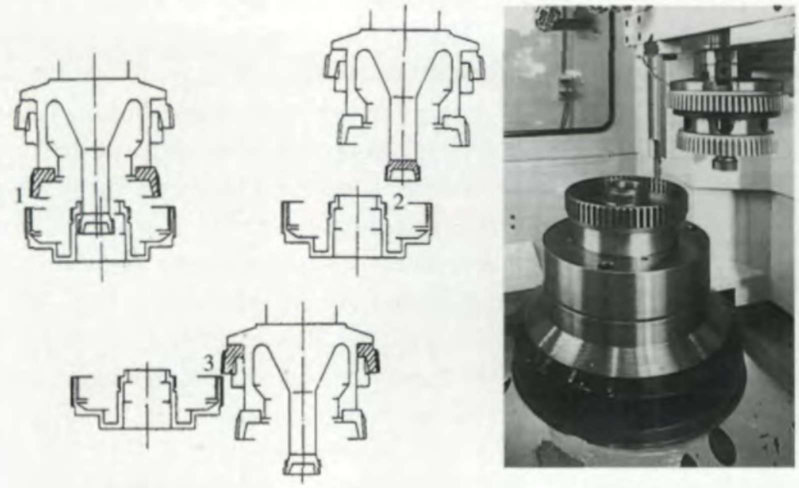
dissimilar helix angles, modules (diametral pitch) and number of teeth (Z). The required tooth location alignment accuracy is .0008". The part is cut on a CNC gear shaping machine to a preshave condition in a single setup. It is made of case-hardened material having a hardness at the time of cutting of about 190 BHN. Total cutting time for the component is 4 minutes, 5 seconds with an achieved alignment accuracy of .0004". The unusual condition here is that while there are two different helix angles, the lead of the cutters can be made the same and still retain the required helix angles by changing the diameter of the cutters. A single guide satisfies the lead requirement of both cutters.

Example 2 — Cluster Gear Cutting by the Down-and-Up Shaping Method in a Single Setup (Fig. 26). Note the back-to-back mounting of the cutters. When down-and-up cutting in a single setup, it is necessary to change the back-off direction, i.e., the relieving action of the cutter spindle. This is done automatically by the CNC controller during the repositioning of the cutters. Of course, when up-cutting, the pull stroke is a power stroke, not simply a return stroke, as when down-cutting.

Example 3 — Cutting of Three Gear Clusters with Three Cutters in a Single Setup. Three gear members (Fig. 27) are cut in a single setup. Two members have a tooth location requirement.

Example 4 — Cutting Gears by the Index Generating Method. "Index generating" implies alternating generating action between tool and workpiece at a given ratio with single indexing of workpiece and/or tool. This capability must be provided by the CNC control and requires that the electronic drive (i.e., the controlled motion between cutter and workpiece) can be temporarily opened and closed at any time and at any position without memory loss of travel increments.

Figs. 28 and 29 illustrate how this profile is produced. The pinion bore has straight-sided tooth profiles preventing the use of standard involute cutters. The profiles were broached in the past, but the many types of profiles resulted in exorbitant tool costs, and tool-related inaccuracies caused excessive pump noise levels. Precutting is done by single indexing



Gear/Cutting Data	1	2	3
Number of Teeth	60	70	64
DP	13.55	25.4	8.8
Face Width	.9"	1.1"	.47"
Material Cast Iron 200 BHN			
Number of Teeth in Cutters	56	42	68
Strokes Per Min./ Surface Ft. Per Min.			
Roughing	500/170'	500/170'	400/138'
Finishing	1100/374'	1100/374'	1100/374'
Gear Cutting Method	Generating Digressive		
Total Gear Cutting Time	4.25 minutes		

Fig. 27 — Planetary gear housing with three gearing elements being cut in a single setup (spurs).

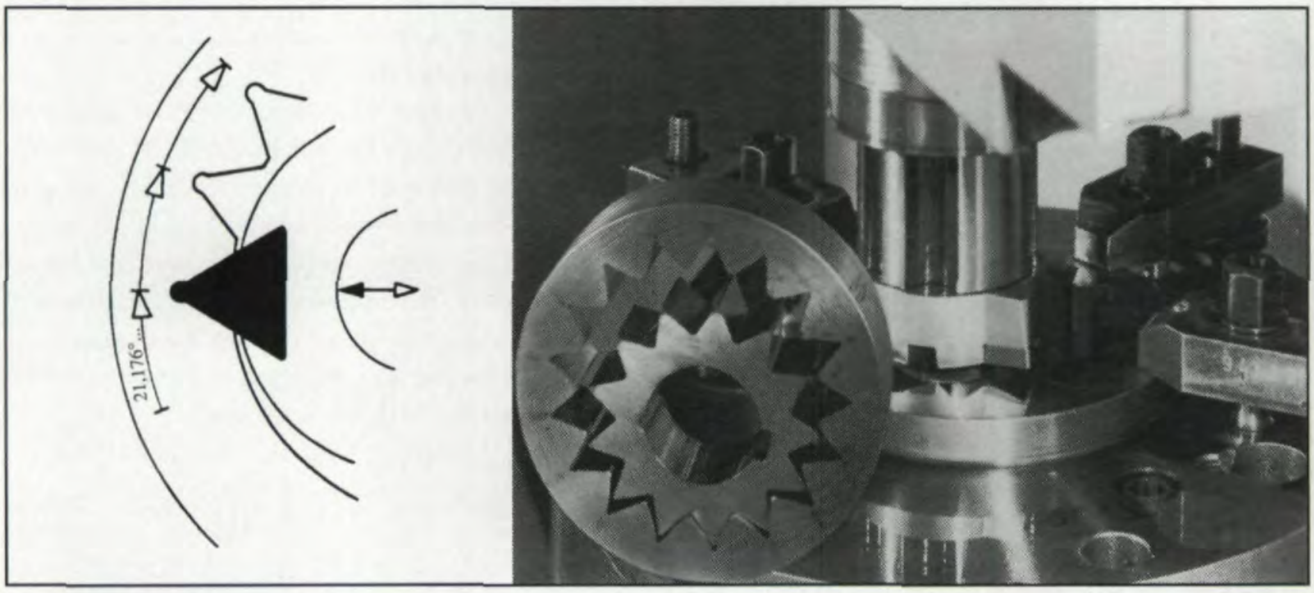
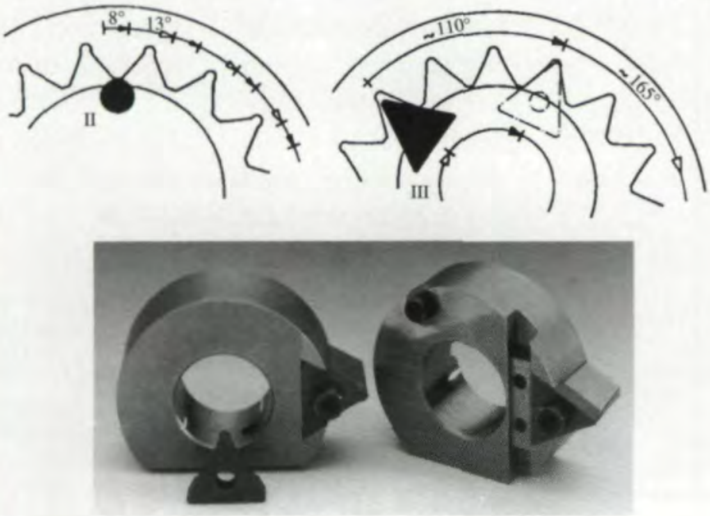


Fig. 28 — Preshaping the special internal profile of an oil pump gear by the single indexing method.

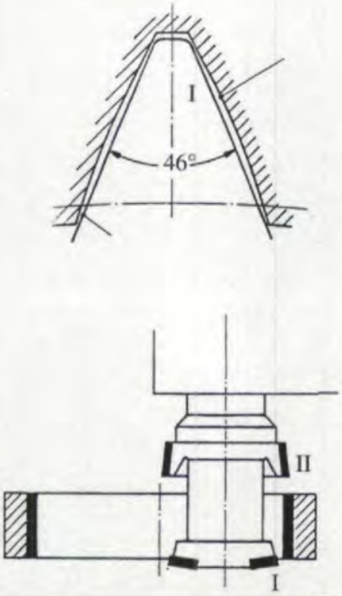


Gear/Cutting Data	Roughing	Tip Circle Shaping	Special Profile Finish Shaping
Number of Teeth/ Gaps	17	17	17
Profile Dimensions	.12" x .59" x .47"	.137"	.12" x .59" x .47"
Face Width		1.65"	
Cutting Tool		Indexable Carbide	
Strokes Per Min./ Surface Ft. Per Min.	350/173'	760/377'	Same
Cutting Method	Indexing	Indexing/Generating	
Cutting Time	2.5 Minutes	5.1 Minutes	

Fig. 29 — Finish-shaping the special internal profile of an oil gear by index generating.

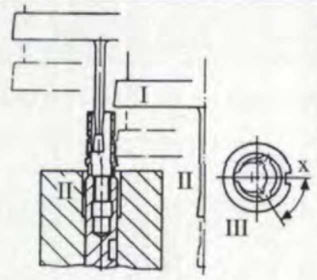
Table 3 — Finish Shaping Machining Sequence for a 17-Tooth Workpiece With a Single Tooth Cutter

Workpiece Revolutions \ Workpiece teeth	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	■													■			
2										■							
3						■											
4		■													■		
5											■						
6							■										
7			■													■	
8												■					
9								■									
10				■													■
11													■				
12									■								
13					■												



Gear/Cutting Data	Roughing	Finishing
Number of teeth/slots	60	60
DP	—	5
Profile dimensions	.08" x .43" x .41"	—
Face Width	2.36"	
Cutting Tool	Reversible carbide insert	Disc type
Strokes per Minute	450	450
Cutting Speed/ Surface Ft. per Minute	325'	325'
Cutting Method	Indexing	Generating
Total Cutting Time	17.5 minutes	

Fig. 30 — Roughing and finishing an internal gear with a disc cutter in a single setup.



Gear/Cutting Data	External I	Internal II
Number of Teeth/ Gaps	26	3
DP-slots	32 DP	Semi-Round .05" Radius
Face Widths	1.54"	.9"
Number of Teeth in Cutter	190	3
Strokes Per Minute/ Surface Feet Per Minute:		
Roughing	80/36'	
Finishing	160/75'	
Cutting Method	Generating	Indexing
Total Cutting Time	6.5 Minutes	

Fig. 31 — Cutting an external spline and internal recessed slots with a tooth location requirement in a single setup. This is an aircraft engine component!

with an indexable carbide cutter insert of special profile design.

Finish operations start by first machining the major diameter. The spaces are skipped by rapid traverse. The major diameter is used for locating and clamping the part for subsequent machine operations. The next step is finishing the tooth space for index generating with an indexable carbide cutter. Its profile exactly represents a tooth of the pump pinion. The space is generated over 110° and then indexed 165° in rapid traverse. The machining sequence of the tooth spaces are indicated in Table 3.

Example 5 — Carbide Form Cutting, Roughing and Generating Finishing with a Disc Cutter in a Single Setup. This internal gear is roughed with an indexable carbide cutter insert and finished with a standard disc type cutter (Fig. 30).

Example 6 — Profiles in Recessed Bores That Cannot Be Broached. Fig. 31 illustrates the cutting of an external spline and internal recessed slots with a tooth location requirement. By cutting this part in a single setup, the required position relationship between the oil grooves and the external gear is no problem. The part, a difficult aircraft material, is shaped in 6.5 min.

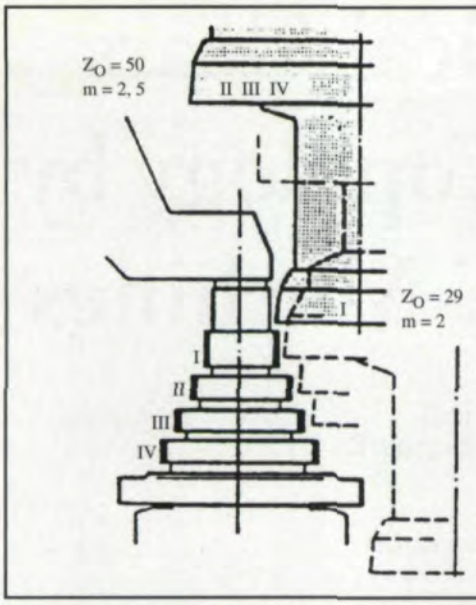
Example 7 — Finish-Shaping of a Countershaft in a Single Setup. Fig. 32 illustrates two cutters tandemly mounted cutting four gears in a single setup. Each gear is cut in an individual machine cycle. Of course, feeds and speeds are changed automatically between each cutting cycle. The parts are finish-cut. They were previously finished in a shaving operation.

Example 8 — Multiple Machining Operations in One Cycle. Figs. 33 and 34 demonstrate the flexibility of an 8-axes gear shaping machine. Note the deburring technique in Fig. 34, operations 2a, 3a and 4a. ■

Reference:

Dr. Klaus Felton, "Effective Gear Shaping Principles," presented at American Pfauter Gear Process Dynamics Clinic, Sept., 1987.

Acknowledgement: *Reprinted with permission of the American Gear Manufacturers Association. The opinions, statements and conclusions presented in this article are those of the Author and in no way represent the position or opinion of the AMERICAN GEAR MANUFACTURERS ASSOCIATION.*



Gear/Cutting Data	I	II	III	IV
Number of Teeth	12	13	17	21
DP	12.7	10.16	10.16	10.16
Face Width	.56"	.35"	.33"	.33"
Stroking Rates Per Minute				
Rough	700	800	800	800
Finish	1400	1400	1400	1400
Cutting Speed Surface Ft. Per Min.				
Rough	121'	141'	141'	141'
Finish	246'	246	246'	246'
Cutting Method	Generating Digressive			
Tool Cutting Time	2.46 minutes			

Fig. 32 — Finish-shaping of a countershaft in a single setup.

1 External Gear
m = 5, $Z_2 = 98$
CCP shaping with disc-type cutter

Quick return stroke

2 Internal Gear
m = 5 $Z_2 = 48$

CCP shaping with disc-type cutter

Without quick return stroke

3 Timed Triangular Grooves, Position-Oriented
Indexing method with
reversible carbide-tipped tool
(form tool)

4 Machining a Check Flange or Assembly Diameter
With Reversible HSS Tool

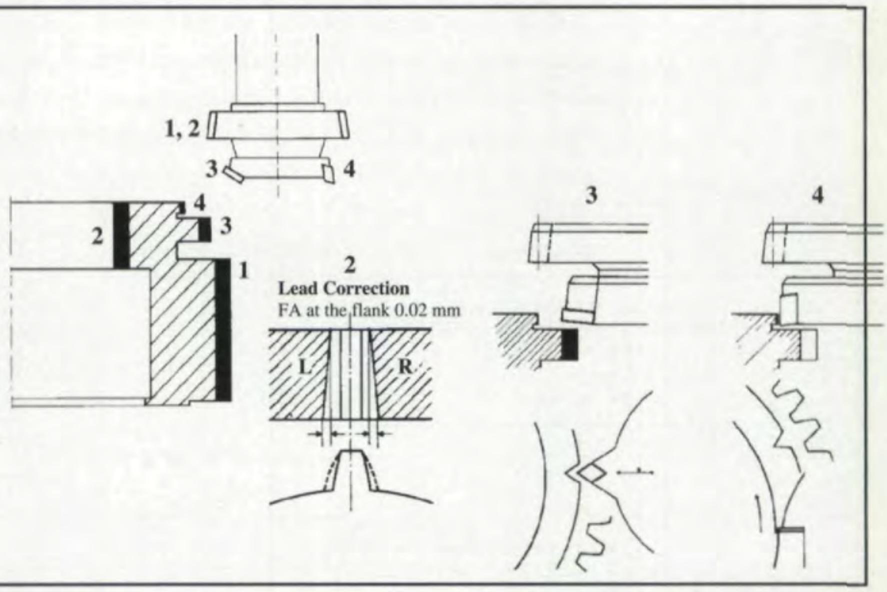
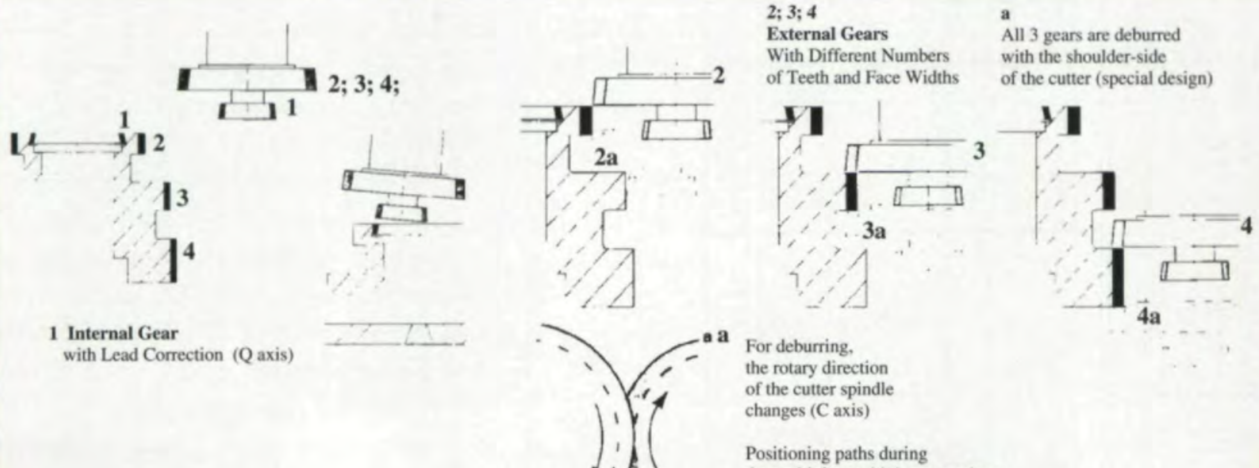


Fig. 33 — Four machining operations in one cycle.



2; 3; 4
External Gears
With Different Numbers
of Teeth and Face Widths

a
All 3 gears are deburred
with the shoulder-side
of the cutter (special design)

1 Internal Gear
with Lead Correction (Q axis)

For deburring,
the rotary direction
of the cutter spindle
changes (C axis)

Positioning paths during
the multiple machining operations:
Center distance (X axis) approx. -31 to + 230 mm
Stroke position (Z axis) approx. 285 mm

Fig. 34 — Seven machining operations in one cycle.

Generation of Helical Gears with New Surfaces Topology by Application of CNC Machines

F. L. Litvin, N. X. Chen & C. L. Hsiao
The University of Illinois at Chicago, Chicago, IL

R. F. Handschuh
NASA Lewis Research Center, Cleveland, OH

Abstract

Analysis of helical involute gears by tooth contact analysis shows that such gears are very sensitive to angular misalignment leading to edge contact and the potential for high vibration. A new topology of tooth surfaces of helical gears that enables a favorable bearing contact and a reduced level of vibration is described. Methods for grinding helical gears with the new topology are proposed. A TCA program simulating the meshing and contact of helical gears with the new topology has been developed. Numerical examples that illustrate the proposed ideas are discussed.

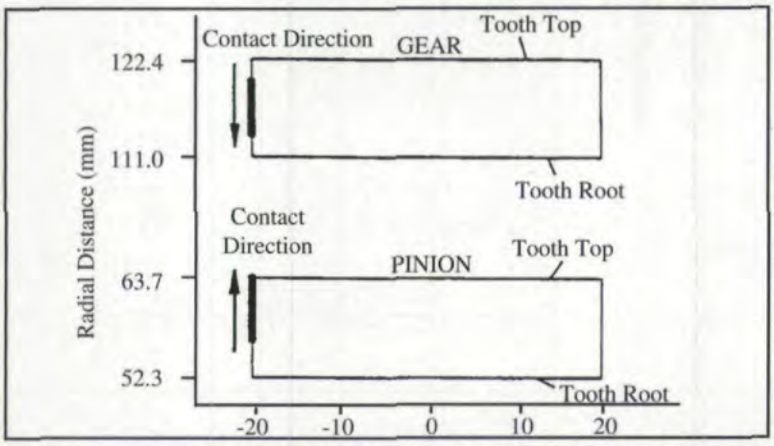


Fig. 1. Edge contact due to axis misalignment (crossing angle, $\Delta\gamma = 5$ arc-min).

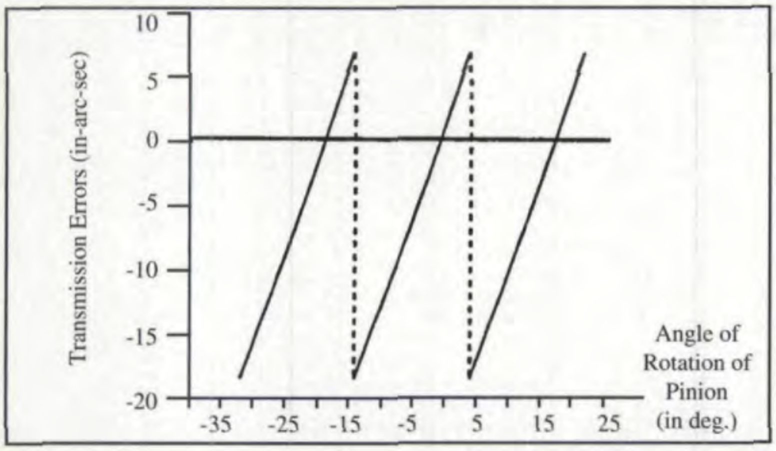


Fig. 2. Transmission errors of involute helical gears with axis misalignment (crossing angle, $\Delta\gamma = 5$ arc-min).

Introduction

Computations by tooth contact analysis (TCA) have shown that involute helical gears are sensitive to errors such as the crossing of gear axes (instead of being parallel) and lead errors. These errors shift the bearing contact to the edge and cause transmission errors of an undesirable shape (Figs. 1 and 2). The transfer of meshing of gears with such transmission errors is accomplished with a jerk, producing a high level of vibration and noise.

A new topology of tooth surfaces has been proposed (Refs. 1-3) that provides for a more favorable bearing contact and transmission error motion, even with misalignment present. The generation of the proposed gear tooth surfaces was based on the application of existing equipment for generation of helical gears that provided linear relations between the rotations and displacements of the tool and the gear being generated. The modified gear tooth surfaces proposed in Refs. 1 - 3 could be generated as Formate®-cut by a tool of large dimension or generated point by point if computer-controlled. These methods of generation have some difficulties for manufacturing, but they may be overcome by the new approach.

This new approach is based on the

application of CNC machines with five degrees of freedom that provide: (1) computer-controlled nonlinear functions that relate the motions of the tool and the gear being generated, (2) a varied plunge of the tool along the shortest center distance between the axes of the tool and the pinion and (3) a point contact of tooth surfaces that is spread over an elliptical area of controlled dimensions. This approach avoids edge contact and reduces the sensitivity of the gears to misalignment. The generation of gear tooth surfaces may be accomplished by form grinding.

The new form grinding method for helical gears provides: (1) a stabilized bearing contact, (2) better conditions of lubrication and (3) a predesigned parabolic function of transmission errors that is able to absorb an almost linear function of transmission errors caused by gear misalignment. It is expected that the new topology will eliminate edge contact and substantially reduce noise and vibrations.

The proposed form grinding requires the application of a computer numerical controlled (CNC) machine with five degrees of freedom, but only four require control by computer. Each tooth space is generated separately and indexing is required.

Bearing Contact and Transmission Errors of Misaligned Involute Helical Gears

The authors have developed a TCA program for conventional involute helical gears that permits the investigation of the impact of misalignment. Figs. 1 and 2 show that when the crossing angle $\Delta\gamma = -5$ arc-min, the contact is shifted to the edge, and the transmission errors have the shape shown in Fig. 2. Similar results are caused by the lead error $\Delta\beta_1 = -5$ arc-min.

The edge contact reduces the load capacity of the gears. The transmission errors of the type shown in Fig. 2 will inevitably cause premature failure, along with increased vibration and noise.

New Method for Grinding, Modified Topology

Pinion Form-Grinding. The form-grinding process for the pinion with the new topology is based on the following ideas:

1. Consider initially that both tooth sides of the pinion are conventional screw involute surfaces. Using the approach developed in Ref. 4, it is possible to determine the surfaces of a disk-shaped grinding tool that will generate the conventional screw involute surfaces. The tool performs the screw motion with respect to the pinion being generated.

2, The grinding wheel surface is modified in the axial section. The deviation of the modified tool surface from the conventional one is represented at the mean contact point by a parabolic function, which can be controlled to adapt to different applications. Both pinion tooth sides can be ground simultaneously. The surface of the pinion grinding wheel is a surface of revolution.

3. The modified grinding wheel must perform two motions with respect to the pinion: The conventional screw motion and an additional but varied translational motion along the shortest distance between the axes of the grinding wheel and the pinion. This translational motion, being deeper at the edges and less in the middle of the tooth width, prevents plunging of the grinding wheel into the space.

4. Using the methods developed in Ref. 4, it is possible to determine analytically the equations of the pinion generated as described above. These equations are necessary for the TCA that has to be applied for simulation of meshing and contact of helical gears with modified topology.

Gear Grinding. Consider that a conventional involute helical gear is in mesh with the pinion whose tooth surface is modified as described above. Such a gear train, if not misaligned, will transform rotation with negligible transmission errors. The bearing contact of gear tooth surfaces is localized, since the gear tooth surfaces are in point contact at every instant because of the pinion tooth surface described above.

The goal is to keep the surface point contact, but to provide a predesigned parabolic function of transmission errors. Such a function is able to absorb a linear discontinuous function of transmission errors caused by angular errors of misalignment. The goal above can be achieved by proper modification of the gear tooth surface based on the following considerations:

1. Consider that an imaginary rack-cutter is

Dr. Faydor L. Litvin
is Professor of Mechanical Engineering at UIC. He is the author of 250 publications and the holder of 22 patents.

Dr. N. X. Chen
earned his degree from Beijing University of Aeronautics & Astronautics and is a research associate and visiting lecturer at UIC.

Dr. C. L Hsiao
earned his doctorate from UIC and is presently a research associate at the university.

Dr. Robert F. Handschuh
is an aerospace engineer with NASA Lewis Research Center. He is the author of over 40 reports in the seal, gear and numerical methods areas.

simultaneously in mesh with the pinion and gear provided with conventional screw involute tooth surfaces. The pinion and the gear perform rotational motions, and the rack performs translational motions s_t described as follows:

$$s_t = r_1\phi_1 = r_2\phi_2 \qquad (1)$$

$$\phi_2 = \phi_1 \frac{N_1}{N_2} \qquad (2)$$

where r_1 and r_2 are the pinion-gear centrodes, and N_1 and N_2 are the tooth numbers.

Obviously, the transmission function $\phi_2(\phi_1)$ is a linear one, and the gears will be sensitive to angular errors of misalignment.

2. We may consider now that while the rack performs translational motion s_t, the pinion rotates through the angle $\phi_1 = \frac{s_t}{r_1}$, but the gear rotates through the angle

$$\phi_2 = \frac{s_t}{r_2} + \Delta\phi_2(\phi_1) \qquad (3)$$

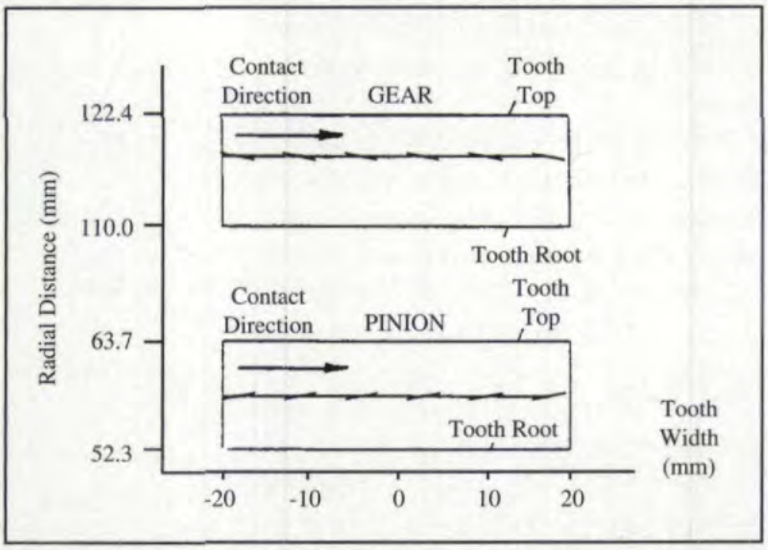


Fig. 3. Latitudinal contact path with shaft misalignment ($\Delta\gamma = -5'$).

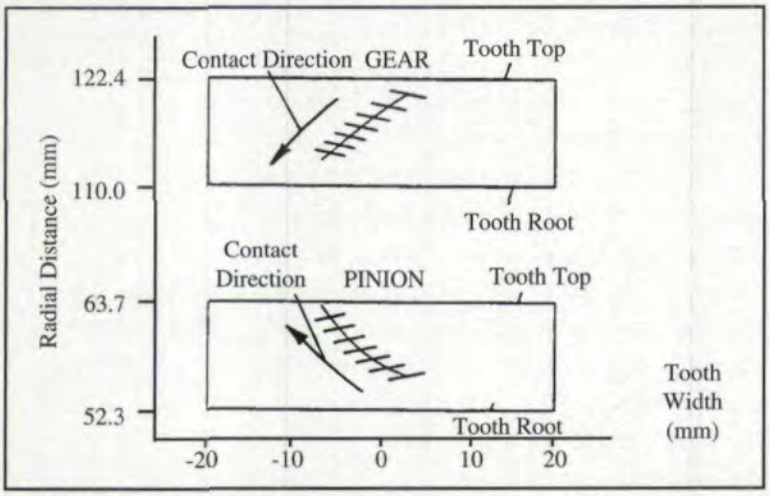


Fig. 4. Longitudinal contact path with shaft misalignment ($\Delta\gamma = 2'$).

where

$$\Delta\phi_2(\phi_1) = a\phi_1^2, \quad -\frac{\pi}{N_1} \le \phi_1 \le \frac{\pi}{N_1} \qquad (4)$$

is a parabolic function of the period of cycle of meshing determined as $\phi_1 = \frac{2\pi}{N_1}$.

Obviously, the transmission function of the pinion and gear generated as described above is determined as

$$\phi_2(\phi_1) = \phi_1 \frac{N_1}{N_2} + a\phi_1^2 \qquad (5)$$

where $a\phi_1^2$ is the predesigned parabolic function of transmission errors.

3. The nonlinear transmission function (Ref. 5) exists even in the case when the gear train is aligned. The advantage of such a function is the ability to absorb a linear but discontinuous function $b\phi_1$ ($0 \le \phi_1 \le \frac{2\pi}{N_1}$) that is caused by gear misalignment. This is based on the fact (Refs. 1 and 5) that the sum of functions represented as

$$\Delta\phi_2(\phi_1) = a\phi_1^2 + b\phi_1 \qquad (6)$$

can be transformed into the parabolic function

$$\Delta\phi_2(\phi_1^*) = a(\phi_1^*)^2 \qquad (7)$$

Parabolic functions ($a\phi_1^2$) and ($a(\phi_1^*)^2$) have the same slope. Transformation of function (6) into function (7) is equivalent to coordinate transformation when the coordinate system (ϕ_2, ϕ_1) is translated keeping the orientation of coordinates axes.

4. We have assumed above that the pinion tooth surface is a conventional involute screw surface Σ_1. In reality, the pinion tooth surface Σ_1^* is a modified one as mentioned above. However, a synthesized function of transmission errors of the parabolic type exists in the case of modification of the pinion tooth surface as well. This is based on the fact that surfaces Σ_1 and Σ_1^* are in tangency at the mean point and only slightly deviate along the helix on Σ_1 that passes through the mean point.

5. These methods of modification of tooth surfaces Σ_1 and Σ_2 enable one to localize the bearing contact of Σ_1 and Σ_2 and provide a predesigned parabolic type of transmission error to absorb the undesired linear function

caused by gear misalignment.

6. There are other methods for grinding the modified gear tooth surface besides the form-grinding method proposed here. The generation can also be achieved by either a grinding plane or by a grinding worm. However, a nonlinear function that relates the motions of the grinding wheel and the gear being generated is required for both alternative cases.

TCA for Helical Gears with New Topology

A TCA computer program to simulate the meshing and contact of the gears with the new topology has been developed.

The computations have been performed for a drive with the following design parameters: $N_1 = 20$, $N_2 = 40$, $P_n = 0.19685 \frac{1}{\text{mm}}$, $\alpha_n = 20^\circ$, $\beta_p = 30^\circ$, and tooth face width $F_w = 40.64$ mm.

Two types of path of contact can be provided as shown in Figs. 3 and 4. These can be obtained controlling the modification of the topology of pinion-gear tooth surfaces in the longitudinal and profile directions.

The influence of the crossing angle $\Delta\gamma$ is shown for the above data in Fig. 5.

The results of the investigation show that the almost linear function of transmission errors caused by misalignment of conventional involute helical surfaces (shown in Fig. 5) is indeed absorbed by the parabolic type of transmission errors for the modified surfaces (see Fig. 6).

The major axis of the contact ellipse, under an assumed light load, has been determined as shown in Figs. 3 and 4. The undesirable displacement of the path of contact to the bottom and the top of the gear tooth can be controlled by the modification of the surface of the grinding wheel for the pinion generation.

Conclusion

The conclusions of this study are as follows:

1. A TCA program for simulation of meshing and contact of conventional involute helical gears has been developed. This program has shown that such gears are very sensitive to angular misalignment, and high vibration is inevitable.

2. A new topology of helical gear tooth surfaces has been developed. Methods for grinding tooth surfaces have been developed. The bearing contact of gears with the proposed topology is localized and the transmission errors are reduced.

3. The TCA program for helical gears with the new topology has been developed. The influence of crossing angle on the location of the path of contact and on the transmission errors has been investigated. ■

References

1. Litvin, F.L. et al. "Topology of Modified Helical Gears." *Surface Topology*, March, 1989, pp. 41-58.
2. Litvin, F.L. et al. "Topology of Modified Helical Gears." NASA TM 102 134, April, 1989.
3. Litvin, F.L. and J. Zhang. "Topology of Modified Helical Gears and Tooth Contact Analysis (TCA) Program." NASA CR 4224, April, 1989.
4. Litvin, F.L. *Theory of Gearing*. NASA Reference Publication 1212, 1989.
5. Litvin, F.L. "Theory of Gearing and Application." Chapter 1 of *Dudley's Gear Handbook*, D.P. Townsend, ed., Second Ed., New York, McGraw-Hill, 1991, pp. 1.1-1.43.

Acknowledgement: *This article was originally presented at the AIAA/SAE/ASME/ASEE 29th Joint Propulsion Conference and Exhibit, June 28-30, 1993, Monterey, CA. Copyright © AIAA 1993. Reprinted with permission.*

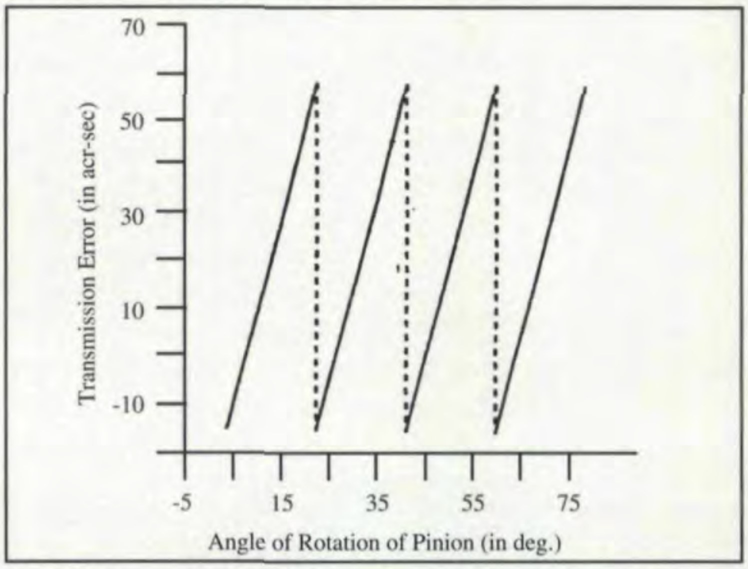


Fig. 5. Influence of misalignment on transmission errors ($\Delta\gamma$ = -5').

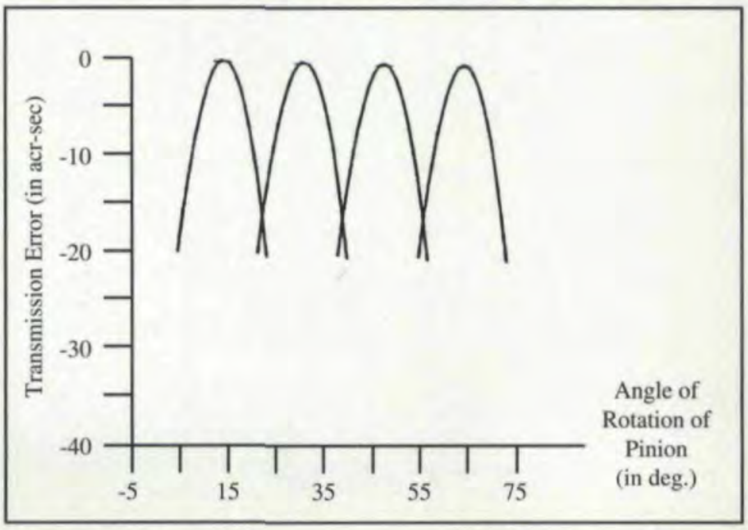


Fig. 6. Influence of misalignment on transmission errors ($\Delta\gamma$ = -5').

Grinding Bevel Gears on Cylindrical Gear Grinding Machines

Werner Kiess
Höfler Maschinenbau GmbH, Ettlingen, Germany

Power train designs which employ gears with cone angles of approximately 2° to 5° have become quite common. It is difficult, if not impossible, to grind these gears on conventional bevel gear grinding machines. Cylindrical gear grinding machines are better suited for this task. This article will provide an overview of this option and briefly introduce four grinding variation possibilities.

DIN 868 defines bevel gears as gears whose reference surface, circular cone and axes have a common point of intersection. Gears with a very small cone also have a common axial intersecting plane.

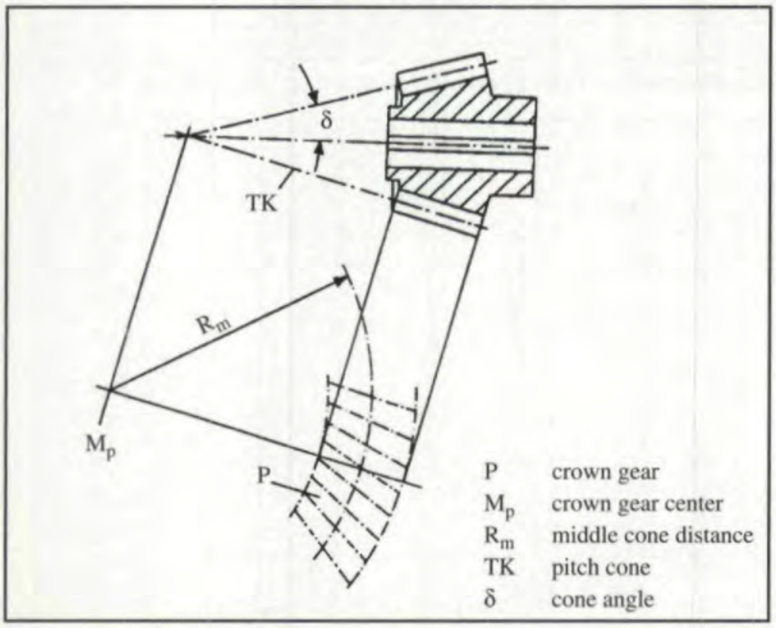


Fig. 1 — The relationship of the cone angle to middle cone distance.

Of course, gears without a common axis intersecting plane exist. The axes of these so-called hypoid gears cross each other somewhere in space. The name is derived from the mating of two exact hyperboloids, so even gears with extremely small cone angles are, by definition, bevel gears.

Gear box manufacturers (Refs. 1-3) increasingly turn to cylindrical gear grinding machines to grind spur and helical bevel gears with small cone angles. Most of these gears have cone angles of approximately $\delta = 5°$. The reason for this is that there are currently no bevel gear grinding machines on the market that can grind spur and helical bevel gears. Even if there were, it would be impossible to grind bevel gears with small cone angles as described above because of the extremely long middle cone distance R_m (middle radius of the crown gear, Fig. 1). This can reach lengths up to two meters and even more. R_m is one of the setting axes on a conventional bevel gear grinding machine, but such high numerical values lie outside the operating range of these machines. Therefore, it is appropriate to move the grinding of such gears to cylindrical gear grinding machines. The cone distance is of no significance on these machines, and the grinding wheel is moved along the cone envelope.

There are four principal solutions for solving this problem (see Fig. 2):

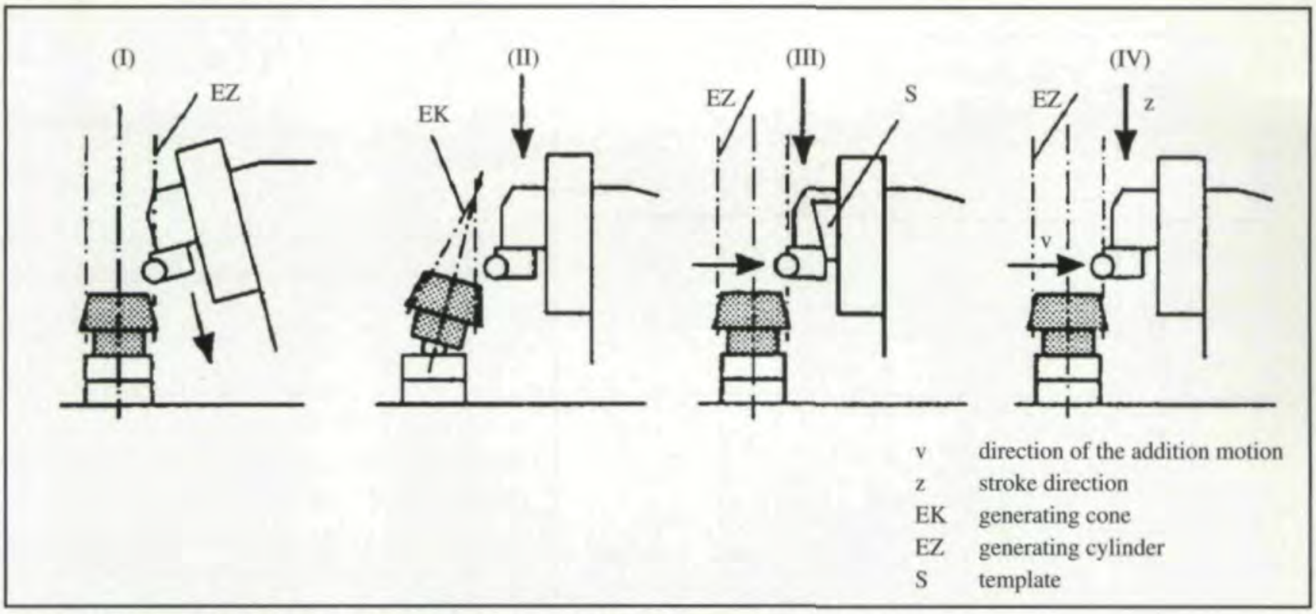


Fig. 2 — Four possibilities for grinding bevel gears on a cylindrical gear grinding machine.

I. The gear grinding machine is inclined to the workpiece's cone angle.

II. The bevel gear axis is inclined to its own cone angle. When this solution is used, a kinematic error automatically occurs because the workpiece's generating motion is produced by the machine table. However, this error can be calculated in advance and can be eliminated through numerically controlled machine table correction movements.

III. A template, which corresponds to the workpiece cone angle δ, is mounted on the grinding slide carrier. The resulting additional grinding wheel motion perpendicular to the stroke is produced by a tracing system which translates the template form into the stroke movement. This is the same process that is used to crown a cylindrical gear tooth.

IV. Numerically controlled actuator driven tool slides eliminate the necessity of the template described in Solution III above. The numerical controls take over the task of coordinating the additional forward or perpendicular tool motion.

How do these solutions differ from one another? When grinding cylindrical gears, the double stroke and generating speed must be coordinated with the stroke length and other variables. For Solutions I and II, this coordination is the same as for cylindrical gears. However, the double stroke speed must be reduced by about 20-40% in comparison to the cylindrical gear case for Solutions III and IV. The reason for this is the additional grinding wheel motion, perpendicular to the "normal" stroke motion. As the cone angle decreases, the time loss in comparison to cylindrical gear grinding decreases as well.

For this reason, Solution IV is the preferred variation for bevel gears with cone angles of δ ≤ 5°. Solution II is preferred for cone angles of more than 5°. To achieve the desired precision, it is easier to realize a slower, rather than a faster motion with help of numerical controls. Solutions I and III can be considered outdated because of the additional necessity of mechanical modifications.

However, one other consideration plays an important role in grinding bevel gears on cylindrical gear grinders: The principal difference in how the involute is created in each of the above described examples. In Solutions I, III and IV, the generating pitch cylinder is used as a basis for generation. Its diameter remains constant throughout the face width of the gear. In connection with the grinding wheel, the base cylinder also remains constant. Consequently, bevel gears ground in this manner can be viewed as a stack of cylindrical gears with displaced profiles and infinitely small face widths. The profile displacement is not constant, but changes infinitely along the tooth face width. That means that all these infinitely thin cylindrical gear plates use the same involute as the tooth flank. Only the utilized section wanders (Fig. 3).

Involutes produced in this manner are

Dr.-Ing. Werner Kiess

is the head of the quality assurance department at Höfler Maschinenbau GmbH, Ettlingen, Germany. Prior to his work at Höfler, Dr. Kiess worked in the gear manufacturing department of the Machine Tool Research Center in Chemnitz, Germany.

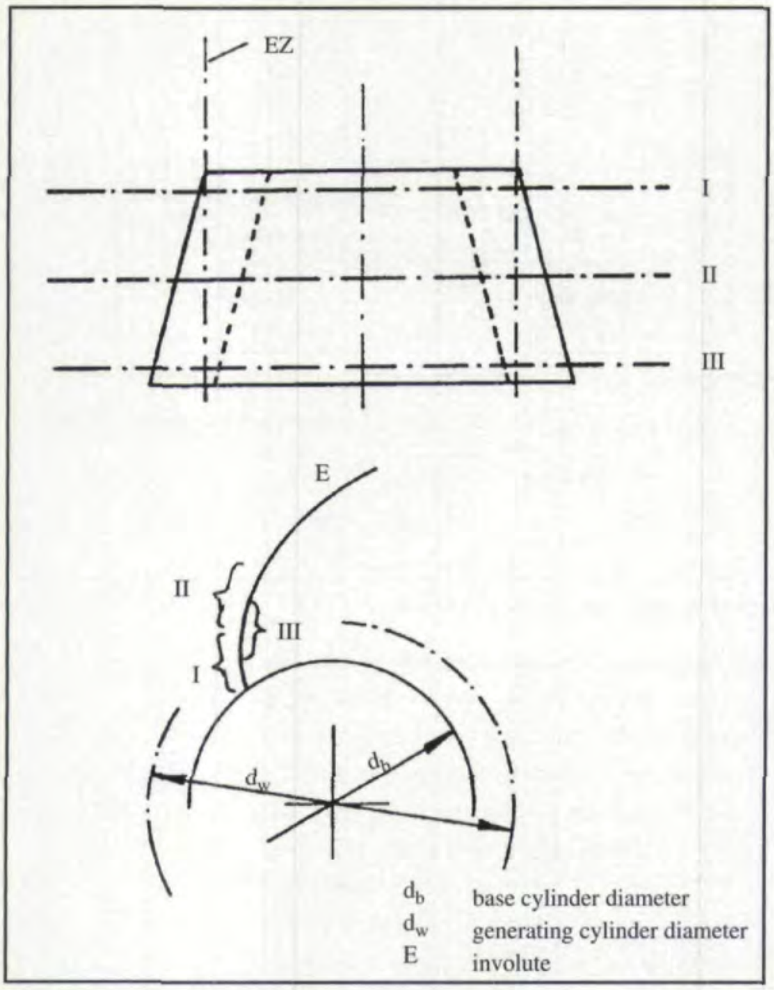


Fig. 3 — Profile displacement by bevel gear grinding.

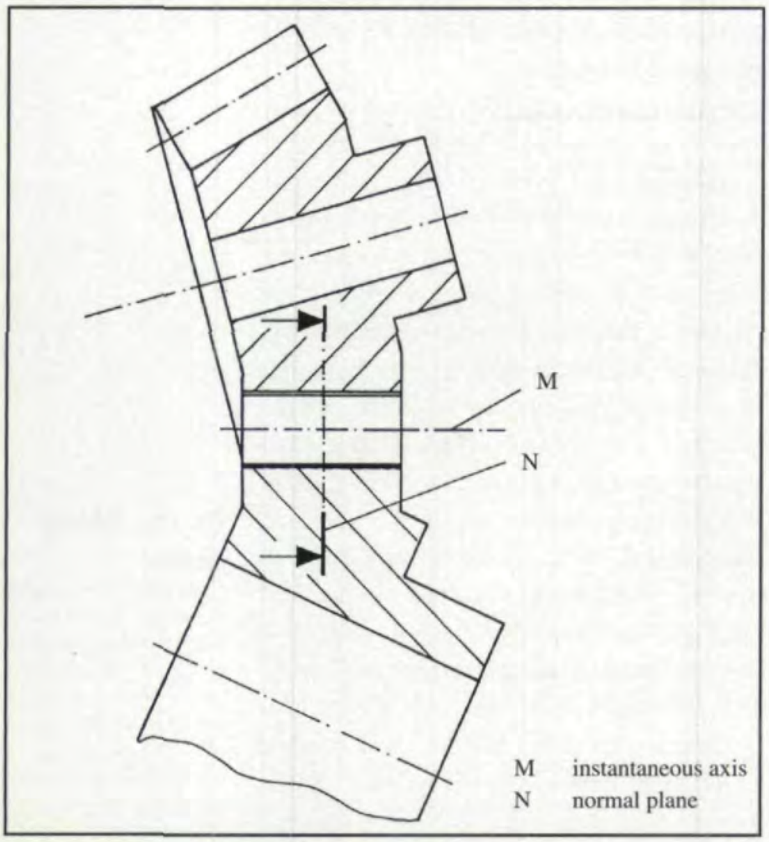


Fig. 4 — Common surface line of mated bevel gears.

present in the transverse section because of the utilized generating cylinder. But when two bevel gears are paired, the common surface line is simultaneously the instantaneous axis M (Fig. 4). In the plane in which the instantaneous axis is in a vertical position (perpendicular plane N), no involute flank rolls with another. At best, the involutes are distorted.

Contrary to this, involutes are created when rolled with the generating pitch bevel in the perpendicular plane on which the instantaneous axis is in a vertical position. Solution II is the best suited example for bevel gears with cone angles $\delta > 5°$ or geometrically exact bevel gears. When creating the involute with the generating pitch cone, the crown gear is the reference element for the layout as well as the production of the tooth system.

A considerable number of spur and helical bevel gears have been ground on Nova CNC cylindrical gear grinding machines using Solution IV. The direction of the pointed end of the cone (up or down) was not important. Gear body geometry and/or the available mounting fixture were the determining factors. In each case, bevel gears with cone angles from 2° to 5° achieved quality levels of (IV) and (III) in accordance with DIN 3962. ■

References:

1. Firmenschrift der Zahnradfabrik Friedrichshafen AG. *Diesel & Gas Turbine Catalog 57* (1992). Friedrichshafen, 1992.

2. Rothenhäusler (Zahnradfabrik Friedrichshafen AF): "Getriebe für schnelle und unkonventionelle Schiffe." TU Hamburg-Harburg, 14. bis 16. October, 1992.

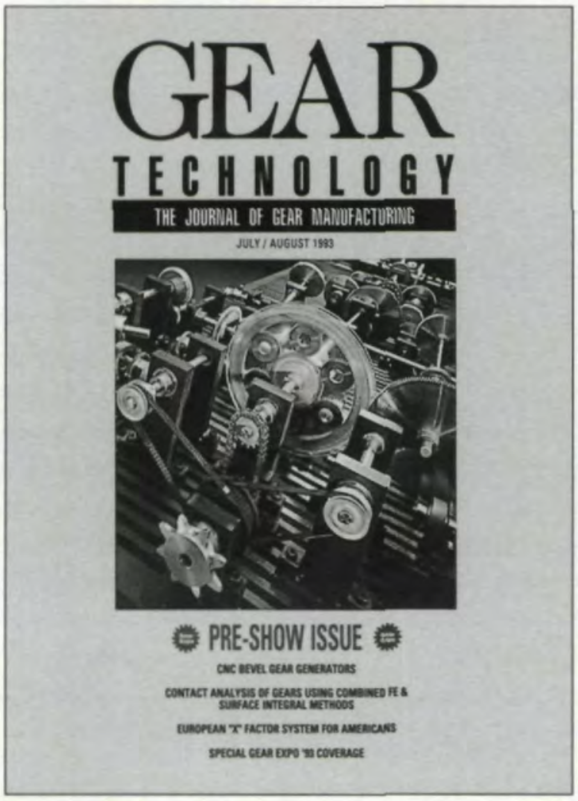
3. Beam, A.B. "Beveloid Gearing." *Machine Design*, December, 1954.

Acknowledgements:

All illustrations courtesy of Höfler, Ettlingen, Germany. This article first appeared in German in Werkstatt und Betrieb *126 (1993) 7, pp. 409-410. It also appeared in* European Production Engineering, *Sept, 1993. Reproduced with permission.*

THE GEAR MARKET IS GLOBAL.

Shouldn't Your Ad Campaigns Be Too?



GEAR

TECHNOLOGY

THE JOURNAL OF GEAR MANUFACTURING

JULY / AUGUST 1993

PRE-SHOW ISSUE

CNC BEVEL GEAR GENERATORS

CONTACT ANALYSIS OF GEARS USING COMBINED FE & SURFACE INTEGRAL METHODS

EUROPEAN "X" FACTOR SYSTEM FOR AMERICANS

SPECIAL GEAR EXPO '93 COVERAGE

Today's markets don't stop at the border. If your advertising does, you're missing a lot of potential customers.

Gear Technology **reaches potential buyers in 65 countries.**

Bring the gear buying world to your doorstep.
Advertise in *Gear Technology*.

CALL 1-800-451-8166 TO FIND OUT HOW.

GEAR FUNDAMENTALS

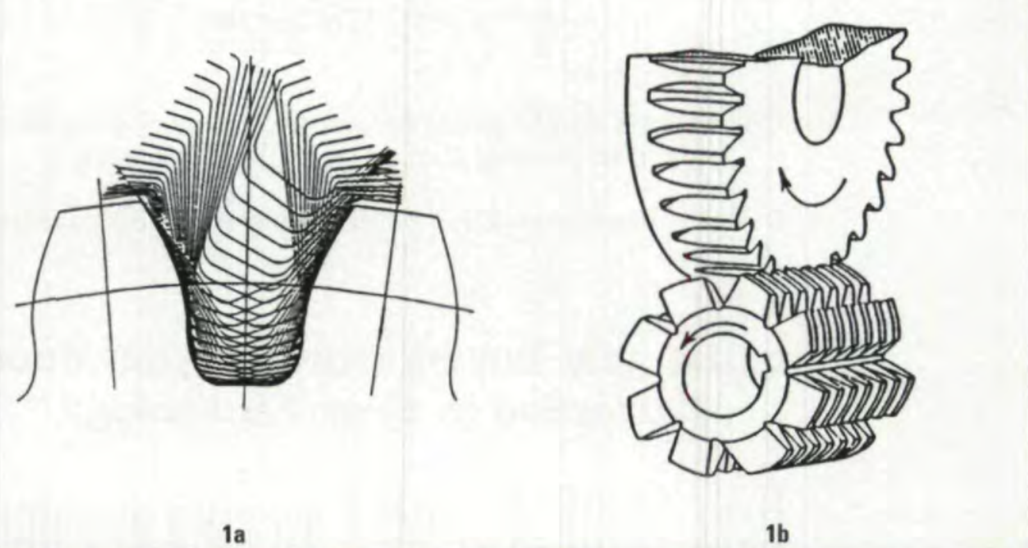
The Gear Hobbing Process

Dennis Gimpert
Koepfer America Limited Partnership,
South Elgin, IL

Gear hobbing is a generating process. The term *generating* refers to the fact that the gear tooth form cut is *not* the conjugate form of the cutting tool, the hob. During hobbing both the hob and the workpiece rotate in a continuous rotational relationship. During this rotation, the hob is typically fed axially with all the teeth being gradually formed as the tool traverses the work face (see Fig. 1a).

For a spur gear being cut with a single start hob, the workpiece will advance one tooth for each revolution of the cutter. When hobbing a twenty-tooth gear, the hob will rotate twenty times, while the workpiece will rotate once. The profile is formed by the equally spaced cutting edges around the hob, each taking successive cuts on the workpiece, with the workpiece in a slightly different position for each cut (see Fig. 1b). Several cutting edges of the tool will be cutting at the same time.

The hob is basically a worm with gashes cut axially across it to produce these cutting edges. Each cutting tooth is also relieved radially to provide chip clearance behind the cutting edge. This also allows the hob face to be sharpened and still maintain the original tooth shape. The final profile of the tooth is created by a number of flats blending together. The number of flats corresponds to the number of cutting gashes which pass the workpiece tooth during a single rotation. Thus, the greater the number of gashes in the hob, the greater the number of flats along the



1a

1b

Fig. 1 a & b

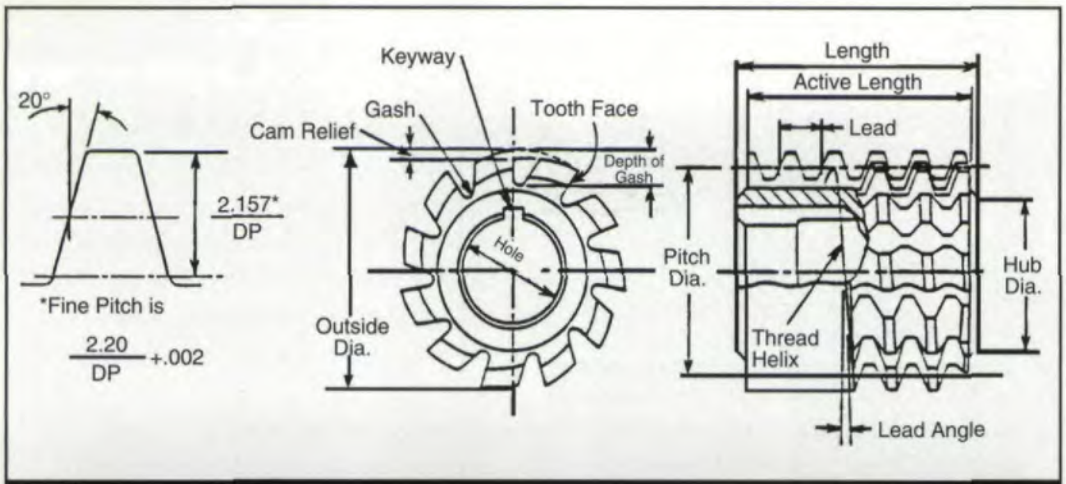


Fig. 2

profile which improves the "smoothness" of the tooth profile.

The Cutter

Hobbing is a generating process, and the hob will not cut the same shape as the cutting tool form. An unmodified involute gear tooth is produced by a hob with straight-sided cutting edges. Involute gear cutting is the largest application of hobbing (Fig. 2). In contrast, a straight-sided spline tooth is produced by a hob with curved cutting edges (see Fig. 3).

Cutter Modifications

It is possible to design the shape of a cutting tool to produce modified tooth forms. These are done for various reasons. The hob tooth root can be designed to cut the outside diameter of the gear tooth. With this "topping" hob, the tooth involute and the outside diameter of the blank will be hobbed in one operation (Fig. 4). This may eliminate finish turning of the gear blank, reducing machine operations.

The outside diameter of the gear will be concentric with the operating pitch diameter of the gear. This will provide a locating surface for subsequent operations and a method of measuring size.

Sharp corners between the tooth flank and outside diameter can be eliminated with a "semi-topping" or "tip chamfering" hob (see Fig. 5). With proper design such a hob may also correct the problem of gear tooth bending under load.

Gears which will be finished by a subsequent operation, such as skiving, shaving or grinding, may require clearance in the gear tooth fillet area for the finishing tool. This can be cut using a "protuberance" hob, which will

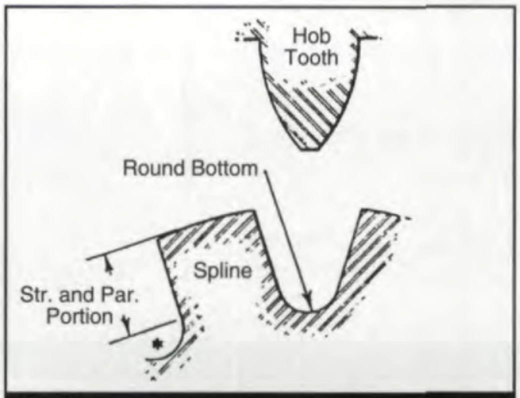


Fig. 3

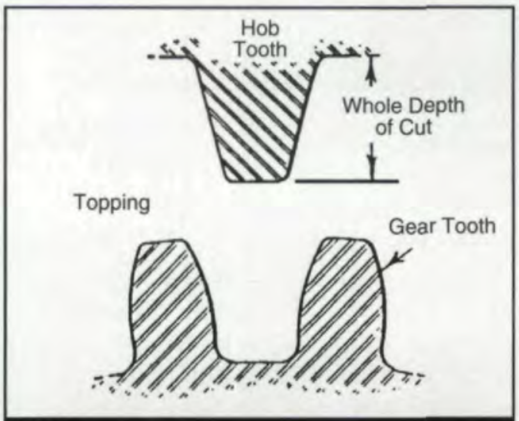


Fig. 4

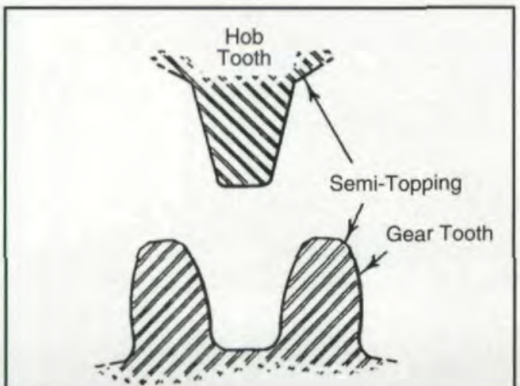


Fig. 5

Dennis Gimpert
is the president of Koepfer America Limited Partnership in South Elgin, IL. He is the author of several articles on gearing subjects.

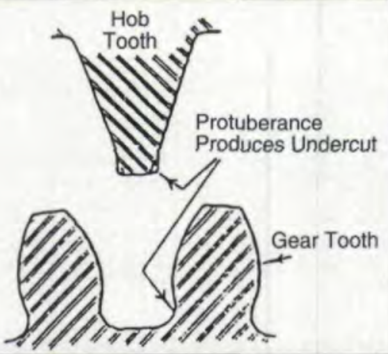


Fig. 6

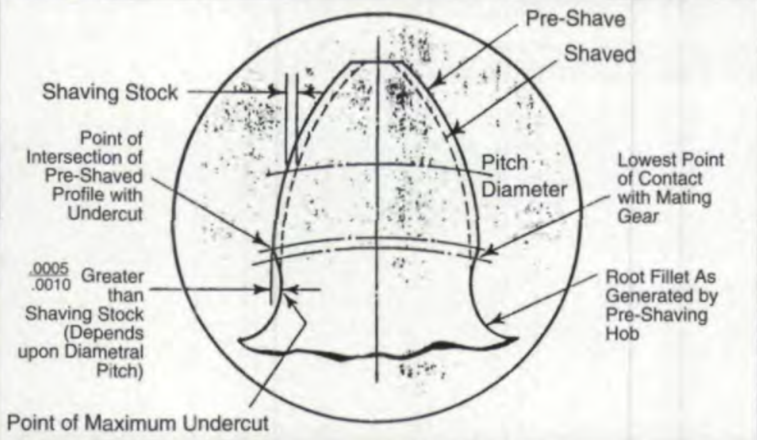


Fig. 7

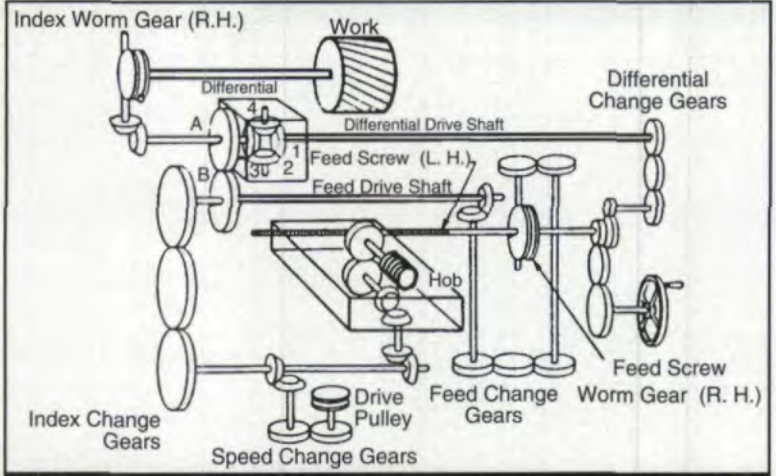
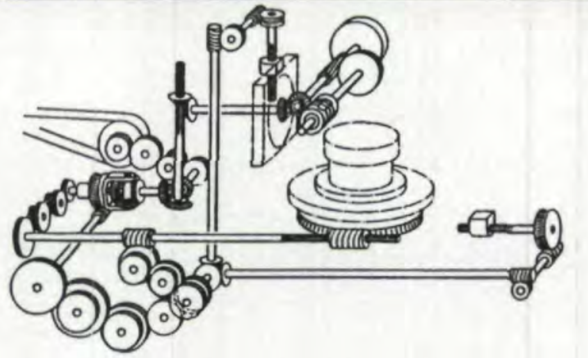


Fig. 8



Mechanical Vertical Hobbing Machine

Fig. 9

produce undercut (see Fig. 6). The protuberance hob is designed to provide a uniform stock for the finishing tool and to provide a blend between the hobbed root area and the finished flank. Caution: On any modified cutter, we are changing the correct rack shape. Thus, the tool may cut only a certain range of gear teeth numbers correctly (Fig. 7).

The Gear Hobbing Machine

A gear hobbing machine consists of five common elements:

- A work spindle to rotate the work.
- A hob spindle to rotate the hob.
- A means of rotating the work spindle and hob spindle with a constant of ratio, depending on the number of teeth in the workpiece and the number of threads in the hob.
- A *means of traversing the cutting tool* across the face of the work in the direction of the work axis for spur and helical gears.
- A means of adjusting the center distance of the work and the hobs for different size workpieces. Figs. 8-10 show schematics for three typical hobbing machines.

Hobbing Feed

During hobbing, the cutting tool can be fed in a manner similar to a milling machine; both conventional and climb hobbing are used (see Fig. 11). A general rule of thumb is that climb hobbing yields better tool life, and conventional hobbing yields a better finish. In all cases, the cutting force should be directed against the work spindle, never against the tailstock.

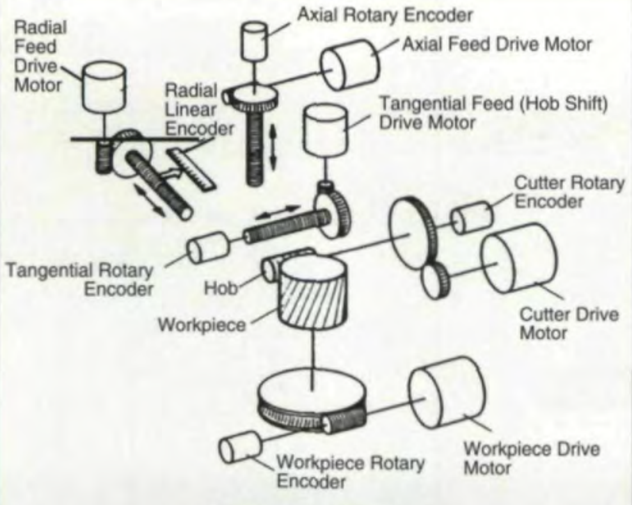
The directions of feed on a hobbing machine correspond to the work axis. Thus, three feeds are possible — axial, radial and tangential (Figs. 12a, b, c).

It is also possible to combine more than one axis of feed sequentially or simultaneously during the machine cycle. A radial feed approach followed by axial feed across the face is very typical in fine pitch gear work or on a workpiece where an open axial approach is not possible (Fig. 13).

Axial and tangential feed are used simultaneously for several purposes on very large, coarse pitch, wide-faced gears. The tangential feed presents a sharp portion of the tool as the axial feed cuts across the gear face (Fig. 14).

Taper root splines are cut with simultaneous axial and tangential feed (Fig. 15).

A "jump" or "skip" cycle is used to cut mul-



CNC Hobbing Machine

Fig. 10

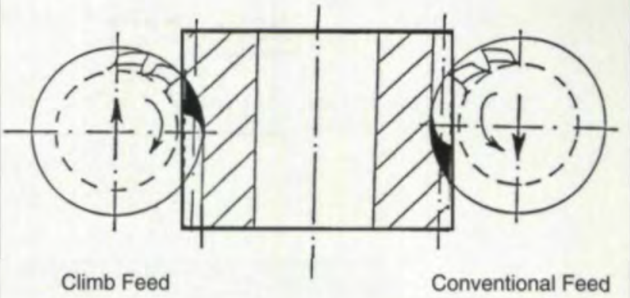
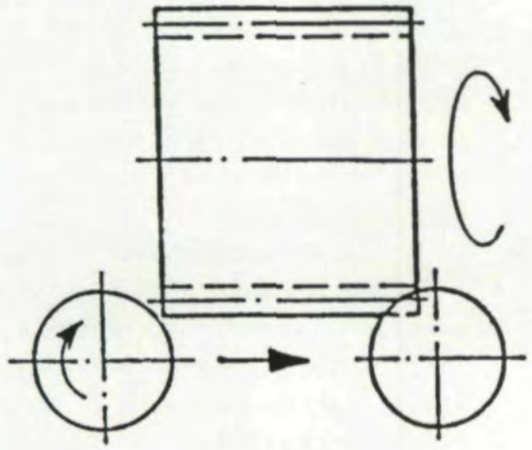
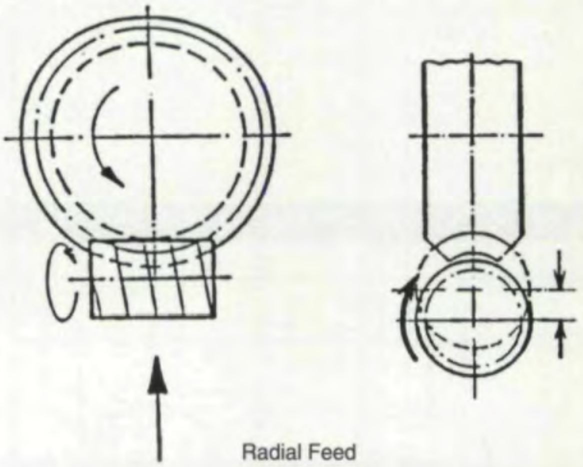


Fig. 11



Axial Feed
Conventional

Fig. 12a

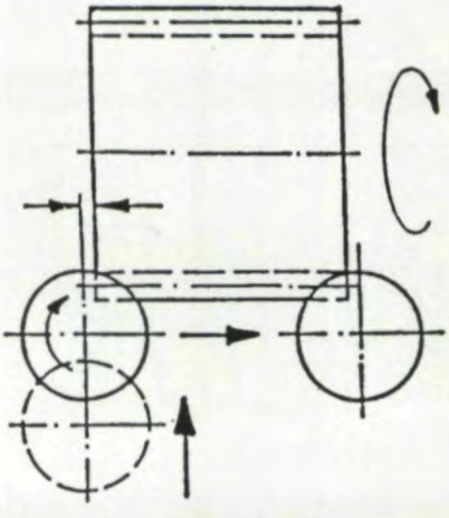


Radial Feed

Fig. 12b

Tangential Feed Used for Worm Wheel Generation

Fig. 12c



Radial Feed Approach with Axial Feed

Fig. 13

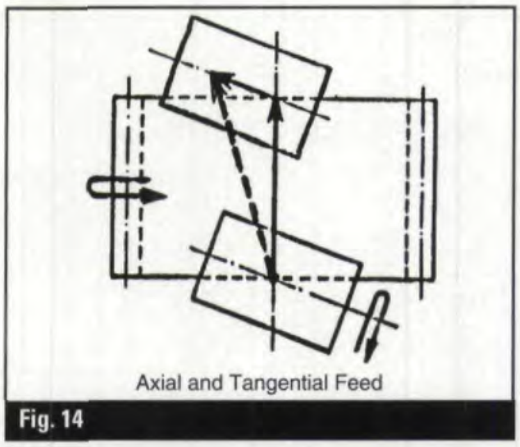


Fig. 14

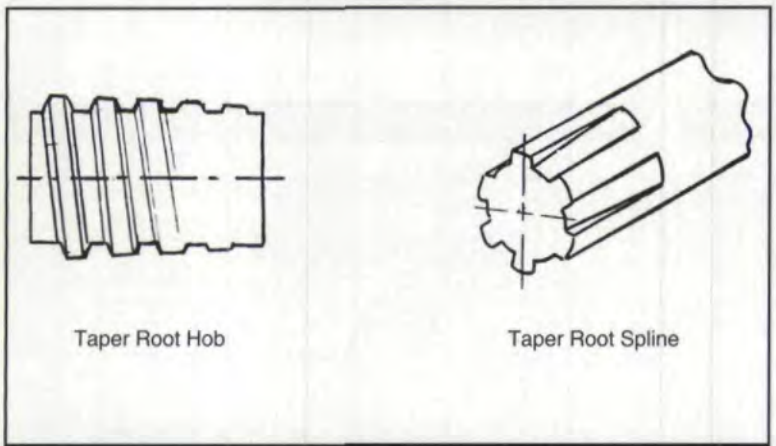


Fig. 15

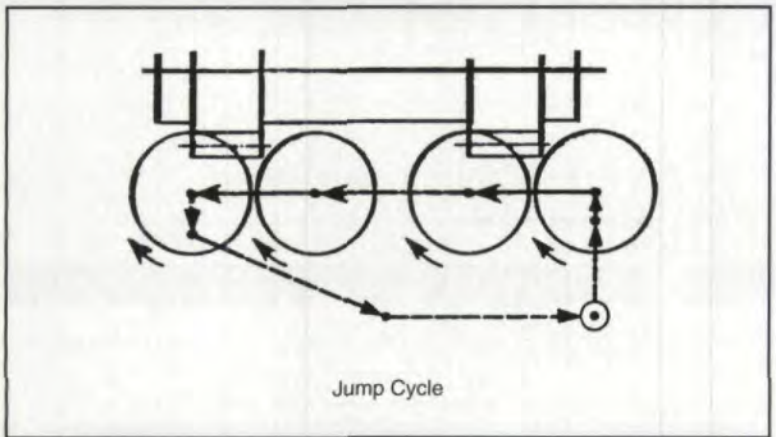


Fig. 16

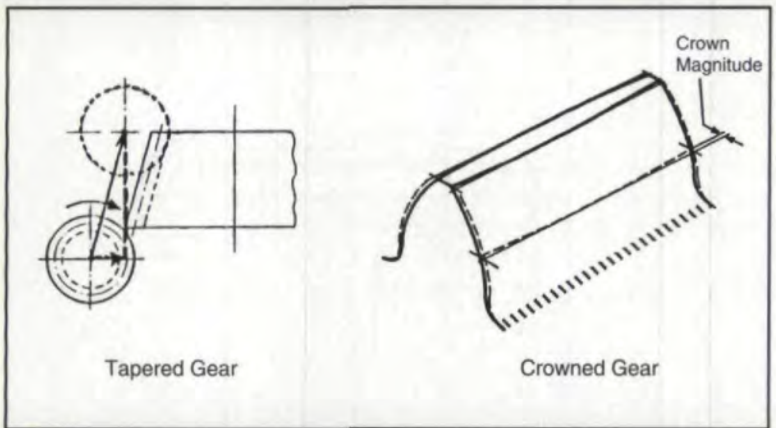


Fig. 17

tiple gear elements on a single part. This may be required for gear tooth alignment or simple cutting efficiency (See Fig. 16).

Tapered gears or crowned gears are produced with simultaneous radial and axial feed (Fig. 17).

At the beginning of the hobbing machine cycle, the cutter will not be generating the full depth of the gear tooth form. Only a small cut is made by each tooth in the hob gradually feeding into the part. This is known as the "approach" portion of the hobbing cycle. It is possible to utilize a different feed rate during this approach length with a reduction in cycle time (Fig. 18).

During the hobbing of some gears or splines, the cutter will not feed completely through the workpiece face. This is known as a "blind" cut. To complete all of the teeth evenly around the circumference of the gear, "dwell" is utilized. During dwell the hob and workpiece continue to rotate in a timed relationship for one or two more work revolutions, but without feed (Fig. 19).

Multiple Start Hobs

The hob is a series of racks positioned around the circumference of a cylindrical tool. Each successive rack is shifted axially to create a worm, typically a single thread. Thus, for each revolution of a single start hob, the gear must advance one tooth space (see Fig. 20). This is accomplished by the hobbing machine kinematic indexing system.

At this point, it is important to understand what causes the cutting marks on a hobbed gear. The marks axially across the face of the gear will correspond directly with the axial feed per work revolution of the tool. The marks positioned across the profile of the gear will correspond directly with the number of gashes or flutes on the hob (Fig. 21). Normally it is not possible to see the generating flats along the profile of the material.

It is possible to increase the speed of the hobbing operation by utilizing a hob with more than one thread. For example, if the hob has two threads, the gear must advance two tooth spaces for each revolution of that hob. This will double the speed of the work and double the production, all other factors being equal (Fig. 22). With four threads in the hob, four teeth on the part will index with every revolution of the cutter. However, there are factors that limit or prevent the use of multiple starts hobs for *all* cases.

The Hob

As more and more threads are designed into the tool, the lead of the thread will increase. Normally, a thread lead angle of 2-6° will be acceptable. Beyond six degrees, the left and right side of the cutting tooth will be loaded unequally, which will cause poor tool life. To compensate for this problem, the diameter of the tool can be increased slightly, but with a reduction in RPM to maintain the same SFM. Alternatively, the gash of the hob can be made helical to position the cutting tooth perpendicular to the cutting action.

To calculate the thread angle of a hob, use the following formula:

$$\text{Tan } \alpha = \frac{\text{Threads in Hob}}{\text{DP x Hob Diameter}}$$

Example:

$$\text{Tan } \alpha = \frac{1}{20 \times 2}$$

$$\text{Tan } \alpha = .025$$

$$\alpha = 1^\circ\ 25'\ 56''$$

Another problem with multiple thread hobs is the number of effective gashes generating the profile. Again, all factors being equal, a two-start hob with twelve gashes will generate the gear profile with six of the gashes versus a single-start hob with twelve gashes.

The Hobbing Machine

As the number of threads in the tool increases, the work will index faster. This means that the work spindle of the hobbing machine must be able to rotate at higher speeds. On workpieces with high numbers of teeth, the machine speed is not a problem, but for gears with a low number of teeth, the hobbing machine must be designed correctly.

Several machine design solutions are used. For traditional worms and worm wheel work spindle drives, a multiple-start worm and worm wheel can be used. Four, eight and more thread worms are common. Another approach is to utilize a helical gear index system. Both systems work effectively in providing a mod-

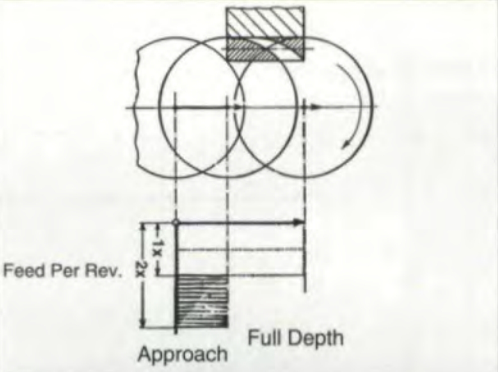


Fig. 18

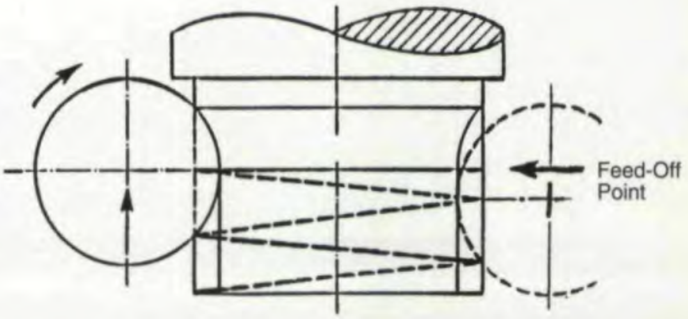


Fig. 19

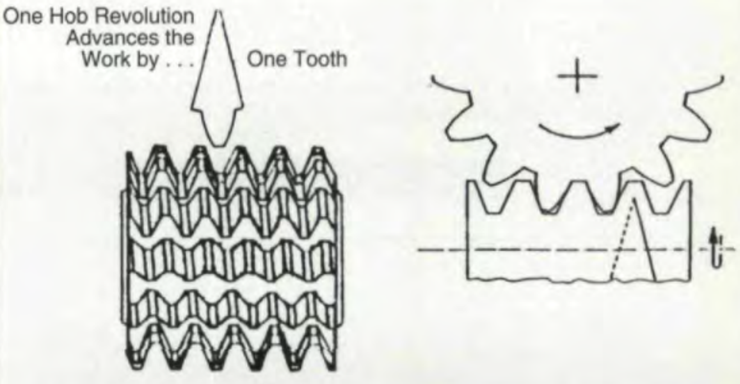


Fig. 20

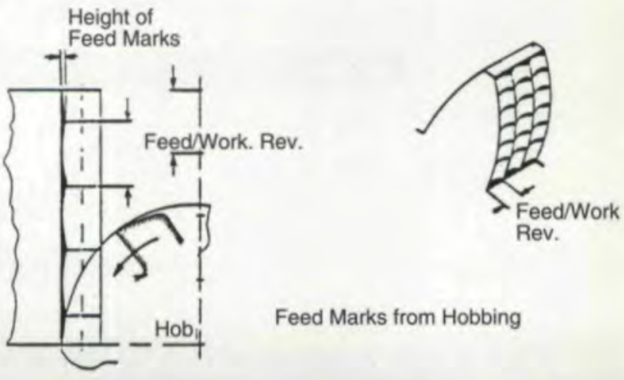


Fig. 21

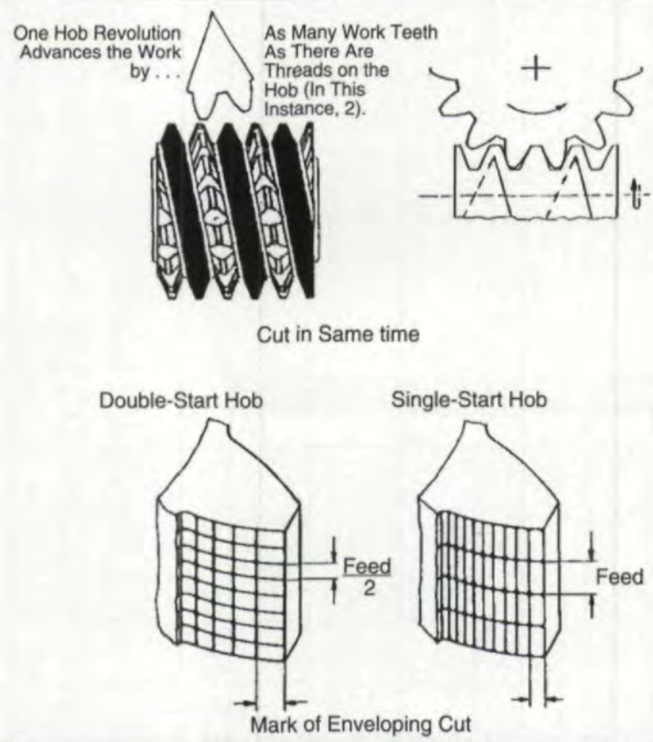
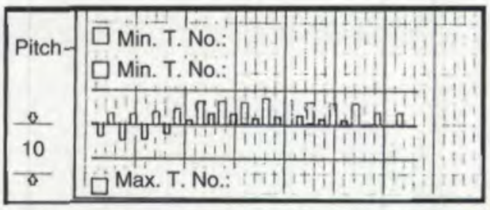
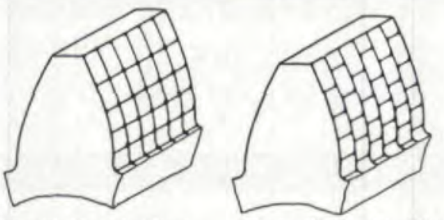


Fig. 22



Tooth Spacing Inspection Chart Showing Hob Error from Even Ratio

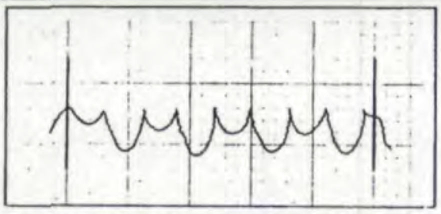
Fig. 23



Cut with Double-Start Hob
Even Ratio

Cut with Double-Start Hob
Hunting Ratio

Fig. 24



Lead Inspection Chart Showing Hob Error from Hunting Ratio

Fig. 25

ern high-speed hobbing machine.

Another consideration for the hobbing machine is the cutting capacity. As multiple-start hobs are used, the metal removal rate increases. If a subsequent finishing operation is used, such as shaving, rolling or grinding, it is practical to use much higher feed rates than used in finish hobbing. These feed rates can approach the maximum cutting capacity of a machine. Although the actual horsepower used in the hobbing operation is a small percentage of that used to drive the machine itself, the "effective" power of the machine must be considered. This effective power includes horsepower, rigidity, fixturing, maintenance, condition, etc.

Thread Spacing Errors

The multi-start hob will have manufacturing errors between the threads: in other words, the threads will *not* be in the correct position. This thread spacing error may or may not have an influence on the gear cut.

There are three possible conditions between the number of teeth in the part and the number of threads in the hob. First, an even ratio, such as a 2-start hob cutter and a 22-tooth gear (see Fig 20). In this case, one thread will cut the even teeth, and one thread will cut the odd teeth. Thus, *all* of the thread-to-thread error will be seen in the tooth-to-tooth spacing, but not in the lead inspection (see Fig. 23).

The second condition occurs when certain threads of the hob will cut certain teeth, such as a 4-start hob cutting the same 22-tooth gear (Fig. 24a).

The final condition occurs when all threads cut all the teeth. This is the most ideal condition, as the thread-to-thread errors become distributed among all the gear teeth and "cancel" each other out. This is known as a hunting ratio (See Fig. 24b). This occurs when a 4-start hob cuts a 21-tooth gear. The thread-to-thread hob spacing errors are not seen in the tooth-to-tooth spacing, but will be seen in the lead inspection (Fig. 25).

It is possible to purchase cutting tools with improved thread-to-thread spacing. ■

Acknowledgement: *Reprinted with permission of the American Gear Manufacturers Association. The opinions, statements and conclusions presented in this article are those of the Author and in no way represent the position or opinion of the AMERICAN GEAR MANUFACTURERS ASSOCIATION.*

Cutting Worm Gears with Standard Gear Hobs

William L. Janninck

We make a lot of single–start worm and worm gear sets, and it always seems as though we're buying another special hob. We also do a lot of spur gear cutting, and the spur gear hobs and the worm gear hobs look alike, so we wonder why we cannot use the standard hobs for cutting worm gears too. Can we do this?

Bill Janninck replies: Yes, you can. We will explain how in a moment, but we would suggest you first look into the catalog worm gear hobs carried in stock and try to use them as well as your own supply of worm gear hobs whenever possible.

Since the hand of the worm and the hand of the hob must be the same, you have a better chance of finding a stock hob for a right-handed application, because more right-handed stock hobs are available.

There are some differences between worm gear hobs and spur gear hobs which must be taken into consideration when using a spur gear hob to cut a worm gear.

Single–start worms, as well as those with multiple starts, can be of right- or left-hand configuration. Since it is imperative that the hand of the worm and the hand of the hob be the same, the chances of finding a stock hob are better for right-handed applications because there are many more right-handed standard stock hobs available than left-handed ones.

Worm gear designers traditionally have used standardized axial pitch dimensions for both the worm and gear, usually using fractional inches. The worm may have, for example, 1/2" or .5000 axial pitch, and the mating gear, for the typical right angle or 90° axis angle, will have a .5000 transverse circular pitch. This does make it easier to establish gear and worm specifications, including center distance, but there is no reason that the design cannot start with specifications located in the normal plane and based on the normal diametral pitch or normal circular pitch. A 10DP gear hob, for example,

SHOP FLOOR

Address your gearing questions to our panel of experts. Write to them care of Shop Floor, Gear Technology, P. O. Box 1426, Elk Grove Village, IL 60009, or call our editorial staff at (708) 437-6604.

William L. Janninck
is a gear and tool design consultant. He worked in gear manufacturing for 45 years, 40 of them with Illinois Tools — ITW, Inc., and is the author of numerous articles on gear-related topics.

GROUND
GEARS

BY NIAGARA

When quality and time are critical.

Ground gears with the quality you demand for close-tolerance applications plus the turnaround you expect from conventional manufacturing.

Unheard of?

Then you've never heard of Niagara Gear.

We use the latest grinding wheel technologies and all electronic Reishauer gear grinders to reduce cycle times without sacrificing quality.

Our ground spur and helical gears:

- Result in less scrap and inspection time to reduce costs and production delays
- Meet your most demanding requirements for higher loads, faster speeds and quieter operation
- Never sacrifice quality and are manufactured to AGMA Class 15 with crowning

More than 80% of our customers are Fortune 500 companies. Let us quote on your next ground gear requirement and you'll see why.

FAX: (716) 874-9003
941 Military Road • Buffalo, NY 14217
TEL: (716) 874-3131

NIAGARA
GEAR CORPORATION
GROUND GEAR SPECIALISTS

CIRCLE A-16 on READER REPLY CARD

When a stock hob is used as the basis for your design, you must develop worm specs based on the hob dimensions and complete the rest of the design based on the worm.

has a normal circular pitch of .31416, and the design would have to be developed around this normal plane data, a different approach from the usual procedure.

In a traditional design, the worm and gear set are fully specified with gear ratio, lead angle and worm and gear dimensions. Then a hob is procured to suit the worm specifications. When an in-hand stock gear hob is used as the basis, you must develop worm specifications based on the hob dimensions and then complete the rest of the design based on that worm.

A sample case might offer the best explanation. A standard 2-3/4" diameter gear hob would be marked:

10NDP 20NPA 1-RH LA 2° 16'
.2157 WD

The normal circular pitch NCP = π/NDP = .31416. The actual outside diameter of the hob measured is 2.730. The hob pitch diameter would be 2.730 - 2 x .1157 = 2.499. (.1157 is the standard hob addendum for .2157 whole depth.)

The suggested hob diameter oversize between the worm and hob, which will give about 30% gear face contact, is 0.10 x .31416 (NCP) + .050 and is .081. Worm pitch diameter is then set at 2.499 - .081 = 2.418, and the worm outside diameter is 2.418 + 2 x .100 = 2.618. (.100 is the standard addendum for .2157WD). The sine of the worm lead angle is NCP/(2.418 x π), so the worm lead angle = 2°, 22'. The worm lead and axial pitch are NCP/(cosine worm lead angle) = .3144. The worm normal pressure angle is the same as the hob and is 20°. The worm thread thickness at the pitch line is one half of the normal circular pitch, minus some allowance for backlash. The whole depth of the worm is as marked on the hob and is .2157. This provides enough data so that a worm can be made that is suitable to the above gear hob.

As with a regular worm gear hob, this hob can be used to cut any number of teeth on the gear from 16 up, without causing natural undercut. In our sample case, if we need a 40-tooth worm gear, its pitch diameter is (40 x .3144)/π = 4.003. The throat diameter would be 4.003 + 2 x .100 = 4.203. The center distance would be the sum of worm and gear pitch radii — in this case, 3.210.

If the center distance for the set must match some existing or preset dimension, it may be possible to spread or close the dimension and then cut the worm gear oversize or undersize to suit. There is no simple formula to calculate how much to allow, but on our 40-tooth example the center distance could be varied approximately ± .157 x NCP; that is, from 3.161 to 3.259.

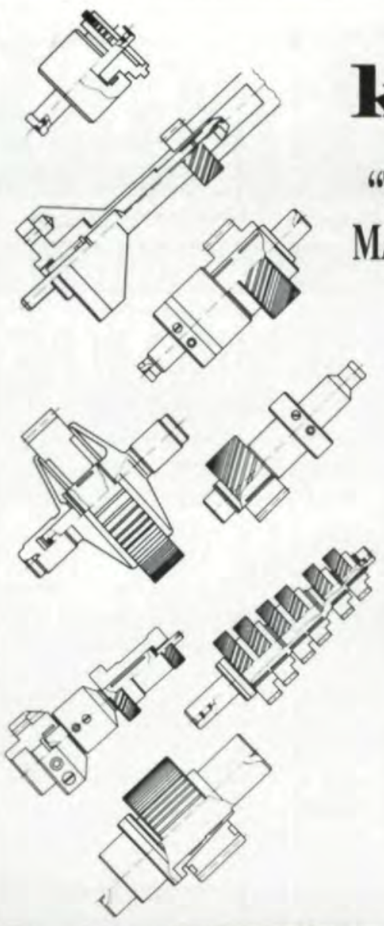
There is some further flexibility in the amount the center distance can be altered, and for our 40-tooth gear, if the centers are closed by .314 x NCP, the worm gear pitch diameter will coincide with the gear throat diameter, resulting in what the trade calls an all-recess-action worm gear set. Unless you are familiar with this design of worm gearing, going to this extreme is not recommended.

Another detail to be resolved is that most all worm gear hobs are made in a topping configuration so the throat radius is swept out or machined during the tooth hobbing operation. Most spur gear hobs are non-topping, meaning that they do not cut or touch the gear outside diameter. In preparing a gear blank then, the throat diameter and the sweep radius will have to be machined as a turning operation.

We have had success using this procedure in a number of situations. One case was with the replacement of a gear set on an emergency basis for an important section of a production machine. The steel worm was salvageable, but the bronze gear was completely worn away, resulting in tooth breakage. The worm gear had a long lead time for an original equipment replacement, the machine was foreign–built and the gear set was dimensioned in metrics. A common replacement set, including both worm and gear, were made using an available stock gear hob, meeting the required ratio and center distance. ■

SHOP FLOOR

Most spur gear hobs do not cut the gear outside diameter; therefore, when preparing a worm gear using such a hob, the throat diameter and the sweep radius will have to be machined as a turning operation.



königdorn®

"THE FIRST NAME" IN GEAR MACHINE & TESTING ARBORS

- PROVEN QUALITY
- SHORT DELIVERY TIME
- SERVICE IN THE U. S.
- DESIGN FOR ACCURACY AND PERFORMANCE
- COMPETITIVE PRICE

mtm KÖNIG

Main-Tauber- Maschinenbau GmbH
Am Stammholz
D-97877 Wertheim
Germany
Phone: 01149/9342/876-14
Fax: 01149/9342/876-25

CIRCLE A-17 on READER REPLY CARD

Bourn & Koch CBN Form Grinder

CNC 900 VG

Compare features
- Polymer concrete base-column-tailstock
- Anti-friction way system
- Gearless table drive
- Unique environmental control
- Industries most powerful conversational programming
- Design for accuracy, performance and the operator

For all your gear manufacturing requirements, whether it be new or remanufactured, retrofitted or rebuilt Barber-Colman gear equipment, Bourn & Koch can offer you the "Best Fit Solution."

bourn & koch machine tool co.
Purchaser of the Barber-Colman Machine Tool Division
2500 Kishwaukee St.
Rockford, IL 61104
815/965-4013 Fax 815/965-0019

CIRCLE A-18 on READER REPLY CARD

CLASSIFIEDS

SERVICE

Contour Induction Hardening Specialists

Spur, helical and bevel gears

Our gear hardening equipment includes 3 NATCO submerged process machines and 4 AJAX CNC-controlled gear scanning machines. We can also tool to meet any production need. Write for a free brochure.

American Metal Treating Company
1043 East 62nd Street
Cleveland, OH 44103
(216) 431-4492
Fax: (216) 431-1508

CIRCLE A-20 on READER REPLY CARD

KLINGELNBERG

HOB SHARPENERS

- Remanufacturing/Rebuilding
- Programmable Control Retrofits
- Updated Hydraulic Systems
- Field Service Repairs

GEAR INSPECTION EQUIPMENT

- Calibration/Certification
- Field Service Repairs

PRODUCTION HOB SHARPENING

ELTECH Inc.
9841 York Alpha Drive
N. Royalton, OH 44133
Phone: (216) 582-8195
Fax: (216) 582-8226

CIRCLE A-21 on READER REPLY CARD

Forst

- Hard broaching gears up to Rock-C-58-62
- High-speed broaching up to 120 f.p.m.
- Automatic broach sharpening

Strathmore Machine Tool Company
176 East Main Street
Westborough, MA 01581-1706
Tel: (508) 898-9490
Fax: (508) 898-9495

CIRCLE A-22 on READER REPLY CARD

GEAR TOOTH GRINDING SERVICES

- Cost effective gear tooth grinding specialists
- Gear manufacturers are our only customers
- Prototype and production quantities
- Capacity to 27.5" P.D., 3.5 D. P.
- Able to match delivery to your requirements
- All service to AGMA standards with Certified Gear Inspection Equipment

PRO-GEAR COMPANY, INC.

23 Dick Road Depew, NY 14043
Phone (716) 684-3811
Fax (716) 684-7717

CIRCLE A-23 on READER REPLY CARD

FELLOWS GEAR MEASURING

REMANUFACTURING SPECIALIST

INVOLUTE • LEAD • INDEX • COMPOSITE

EXPERT PRECISION REBUILDING
New Design Updates
100% Satisfaction Guaranteed

COMPLETE FIELD SERVICE
Calibration and Certification Contracts
Recorder Updates and Retrofits
Major Field Repairs
Parts and Supplies

Gear Composite Computer Analysing System Available with Rebuilds on Fellows Model #4FPRL Gear Composite Redliners.

Profile Engineering, Inc.
100 River Street
Springfield, VT 05156
(802) 885-9176
FAX (802) 885-3745

CIRCLE A-24 on READER REPLY CARD

REPS WANTED

REPS WANTED

Sales representatives wanted for major gear machine tool (parallel axis, as well as bevel gear) and cutting tool importer. Various areas are open in the United States, Mexico and Canada.

We are looking for professional organizations or individuals with gear and sales experience. Highly motivated sales background necessary.

GEAR PEOPLE ONLY NEED APPLY!!

Please apply in writing with:
- C/V — resume, if individual.
- Brochures and relevant information, if company.

Box OT
P. O. Box 1426
Gear Technology
Elk Grove Village, IL 60009

To Advertise in this section of GEAR TECHNOLOGY call 708-437-6604.

Rates: Line Classified — $37.50 per line. 8 lines per inch. $300 minimum. Classified Display — per inch (3" min.): **1X** — $170, **3X** — $160, **6X** — $150. Type will be set to advertiser's layout, or *Gear Technology* will set type at no extra charge.
Payment: Full payment must accompany classified ads. Send check or Visa/MasterCard/American Express number and expiration date to: *Gear Technology*, P. O. Box 1426, Elk Grove Village, IL 60009.
Agency Commission: No agency commission on classifieds. **Materials Deadline:** Ads must be received by the 25th of the month, two months prior to publication. **Acceptance:** Publisher reserves the right to accept or reject classified advertisements at his discretion.

HELP WANTED

PLANT SUPERINTENDENT: $50,000. 300 Hourly.
ENGINEERING MANAGER: $60,000. Enclosed Gear Boxes. Supervise 4 in Design of Helical, Spur and Parallel Gears.
SALES ENGINEER; $55,000. Gear Boxes
QUALITY ENGINEER: $40,000.
Contact: Ann Hunsucker, Excel Associates, P. O. Box 520 Cordova, TN 38088 or call (901) 757-9600 or Fax (901) 754-2896.

ADVERTORIAL

NEW PC-BASED CNC GEAR INSPECTION SYSTEM HAS FULL 4-AXIS CAPABILITY

The PC-based QC 1000 CNC gear inspection system from M&M Precision Systems Corporation can do the work of several manual units by performing fast, repeatable and highly accurate index, lead and profile tests of internal and external spur and helical gears and splines.

This affordable and easily installed system is the only one in its price range to offer full 4-axis CNC gear inspection capability on work pieces up to 15″ long and 9″ in diameter, weighing up to 50 pounds.

Other significant features of the QC 1000 include AGMA or DIN analysis, 0-90° helix angle, up to 7″ face width and diametral pitch of 4 to 64. It focuses on applications for gear manufacturers and job shops who need the accuracy and information of a full 4-axis, generative, analytical gear inspection system, but whose budgets require a simple, low cost alternative.

An Acme-Cleveland company, M&M sells more universal CNC gear inspection systems in the United States than all its competitors combined. Since developing the world's first CNC controlled analytical gear inspection system in 1975, the company has created a complete line of operator-friendly systems featuring fully automatic test routines, plus modular inspection and analysis software programs that have made M&M systems the accepted industry standard throughout the U.S.

Founded in 1951 as a die, fixture and gage manufacturer, M&M first became nationally known as a major source for rotary and linear positioning systems in 1969. Originally it was M&M's precision motion products that led gear manufacturers to approach the company with their gear inspection requirements. The positioning systems product line is still a major part of M&M's business today and contributes to ongoing improvements in their gear inspection capabilities.

Other M&M products include master gears, spline gages and double-flank gear roll testers, as well as system upgrade packages for both manual and direct computer controlled coordinate measuring machines. 1984's acquisition of Spline Gauges, Ltd. of Birmingham, UK added functional gear and spline gage testing products.

The Soft Mic.® CMM system upgrade package is a universal PC-based retrofit product for manual CMMs. This DCC/DMIS product provides users of outdated automatic and joy-stick operated CMMs with a new DMIS-based operating software package in a 3- or optional 4-axis servo controller.

M&M products serve industries such as aerospace, agricultural, appliances, automotive, machine tool, military and off-highway vehicles throughout the world, aided by facilities in England, France and Germany.

QC 1000 is an affordable gear inspection system

New system has full 4-axis CNC capability

M&M PRECISION SYSTEMS Corporation

"THE METROLOGY AND MOTION PEOPLE"

M&M Precision Systems Corporation
World Headquarters
300 Progress Road
West Carrollton, OH 45449
Phone: (513) 859-8273
Fax: (513) 859-4452

Contacts:

James Helton, President

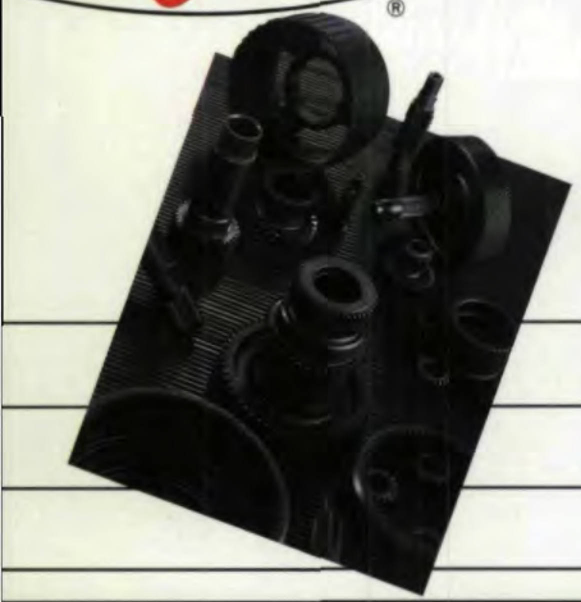
Douglas Beerck, Marketing Manager
Metrology and Motion Systems

Walter Lake, Sales Manager
Gear Metrology Systems

Brian Slone, Sales Manager
Functional Gear Testing Products

CIRCLE A-19 on READER REPLY CARD

RED RING
PRECISION ENGINEERED
HOBS & SHAPER CUTTERS



Here's your full-line
gear cutting source...
with the Red Ring quality you expect!

National Broach, an industry leader in contributions to gear manufacturing technology, now offers a broad line of precision-engineered hobs and shaper cutters.

Hobs, in a wide range of designs:
- Fine and coarse pitch hobs with single or multiple threads
- Available in a variety of coatings, or uncoated
- Worm gear hobs, spline hobs, sprocket hobs, inserted blade-type hobs
- Extra-long, small diameter or sharpenable integral arbor hobs, in any combination
- Optimized design hobs, utilizing conventional and powdered materials
- Completely finish-ground in AA, A and B quality ranges

Shaper cutters ... a full line:
- Fine and coarse pitch
- Spur and helical
- Available uncoated and in a variety of coatings
- Variety of high-performance steels

As with our quality-award-winning finishing tools, Red Ring hobs and shaper cutters from National Broach are backed by our commitment to total customer support.

National Broach & Machine Co.

GEARING THE WORLD FOR TOMORROW

An industry leader in gear-making machines and tools.

CIRCLE A-4 on READER REPLY CARD