GEAR TECHNOLOGY

The Journal of Gear Manufacturing

GRINDING

May/June 1997

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GEAR TECHNOLOGY

MAY/JUNE 1997 *The Journal of Gear Manufacturing*

FEATURES

11

DEPARTMENTS

60

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ABCs Management

Recently I had the pleasure of having dinner with Frank Sinatra, Jr. He was here in Chicago for a benefit concert for Roosevelt University (my wife is co-chairperson of the benefit). Our conversation ranged over a wide variety of subjects, including a small gem of an HBO television movie, "Truman" with Gary Sinise in the title role.

Sinatra expressed admiration for Truman's no-nonsense approach to leadership. From there our conversation moved on to the subject of leadership in general, and, while Sinatra dismissed his own conclusions with a modest, "What do I know? I'm just a thick-skulled musician," much of what he said struck a chord with me.

The leadership qualities he admired (and ones I admire as well) were simple: Truman's understanding of accountability—"The buck stops here"—and Ronald Reagan's clarity of vision. You may not have agreed with many of Reagan's policies, but you at least knew what they were.

These simple elements of leadership are often overlooked; or, what strikes me as a little sad and funny at the same time, about once every four or five years, some management "expert" dusts them off and brings them out as the latest insight that's going to save American competitiveness and turn your company into the next Microsoft and you into the next Bill Gates. Then he charges $49.95 a pop for a 300-page book explaining it all.

The fact is these basic leadership rules are so simple that anyone can understand them, and without 300 pages of explanation. No Harvard MBA or University of Chicago doctorate in economics is required.

Rule One is this: Have a clear understanding of where you want to go and how you intend to get there. Your basic goal should be so simple that it can be expressed in one or two sentences a grade school child can understand; for example, "to make a profit selling gears." Here at the magazine our goal is this: To be the *Gear Industry's Information Source*.

Getting your goal down to a couple of simple sentences requires some hard thinking and clearing away of all the clutter and buzzwords that can muddy *the water. But unless your goal is clear*, at least in your mind, all your other efforts may be wasted.

It's not enough to know where you're going. You have to tell your destination to the people you expect to follow you, such as your employees. This is the area in which Ronald Reagan shined. He told people where he was going and invited them along.

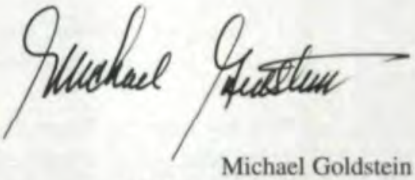
The days of managing by means of the mantra, "Trust me, I know what I'm doing," are over in business, if not in politics. The bright, hard-working, innovative employees we all want don't work well for managers who tell them that, and expecting them to do so is a waste of the valuable resource they represent. Outside the earshot of managers, employees call the trust-me approach the "mushroom school of management," (keep people in the dark and cover them with "fertilizer"), and they respond to such treatment with the contempt it deserves.

Rule Two in our Dinner-Table Course in Basic Management is the Harry Truman Rule: "The buck stops here." Somebody has to have the final responsibility for each piece of the project and for the overall project. That person has to be clearly identifiable to everyone involved. Correlatively, if a particular someone is accountable for the success or failure of the project, he or she has to be empowered to get the job done. You can't make people responsible for a job and then not give them the tools or the freedom to do it.

Neither of these rules is a piece of complicated, mystic wisdom. A bunch of reasonably intelligent people from a variety of backgrounds came up with them in the course of a dinner-table conversation. And yet, there are dozens, if not hundreds, of companies (not to mention our various government bodies) out there whose management teams don't *seem to "get it."* Cartoonist Scott Adams' Dilbert has become a new workplace hero, and Adams has become a millionaire by poking fun at them.

A recent issue of *Forbes* ran a feature about Bridgestone Tire's President Yoichiro Kaizaki. He came to Akron, OH, and turned around a company that had been hemorrhaging red ink with a basic strategy. His mission statement: Let's make a profit selling tires. His implementation: Remind each one of the division presidents of Harry Truman's dictum, "The buck stops here," by the simple expedient of linking their pay to their performance.

The implementation was not without pain, but Kaizaki kept his eye on his simple goal and on the Harry Truman Rule, and the company has begun its turnaround. It's a strategy that will work with any business, even making gears.



Michael Goldstein
Publisher & Editor-in-Chief

New Book For Gear Purchasers & Specifiers

Gears and Gear Manufacture, The Fundamentals *by Richard H. Ewert, Chapman & Hall, New York, 1997. ISBN 0-412-10611-6. $54.95.*

This book is written for those among us, with or without a technical background, who have an occasional need to use, purchase or specify gears. The author assumes an audience that is not made up of experienced gear designers, but of people who do need to have a basic understanding of the criteria used by the designer. The subjects covered include not only the gears themselves, but their manufacturing methods, the systems that contain them and the terms used to describe them.

The traditional approach to beginning a gear book is to start with a historical lesson, move on to the types of gears and then to the geometry of the involute curve. Ewert follows this same path, but does so by quoting and referencing several classic books on gearing. This has the two-fold effect of not only covering important material, but also exposing the reader to valuable sources for further study. In fact, throughout the book, the reader will find a liberal amount of material from Earle Buckingham, Darle Dudley and AGMA. The experienced individual might find this basic approach somewhat disappointing, but, remember, the book is directed to the beginner.

While Ewert has taken a traditional approach to beginning a gear book, he has added some material not always found in a basic volume. A chapter on noise gives the reader some idea of the complexity of this factor and the concepts used to deal with gear noise. This chapter quotes heavily from Buckingham and Dudley. A chapter on drafting practice is included, but it could have been much better if some discussion of gear data blocks had been included. One of the most interesting additions is the chapter on cost. Ewert suggests that those who feel they can produce gears better than their suppliers should read this chapter before ordering their hobbing machine. Other interesting additions throughout the book are the numerous definitions of various gear terms. While the AGMA nomenclature standard is cited as a reference, it is valuable to note that Ewert is also co-author of the *Encyclopedic Dictionary of Gears and Gearing*, published by McGraw-Hill.

The book, like most gear books, is peppered throughout with illustrations. Unfortunately, not all are of good quality. Some of the photos are dark, and some even appear to be photocopies of photographs. At least one of the line drawings is distorted as if copied out of a book near its binding. Two of the tables, consisting of numerous pages, are also copied from Buckingham. Buckingham's original book was printed in his own handwriting to eliminate any typesetting errors. The handwritten material has a unique appearance, but is not as easy to read as it should be. Given current typesetting technology, these tables could easily have been reproduced in a much more legible format. Some of the other tables are reproduced from out-of-date AGMA standards. To be fair, Ewert states this was done for simplicity. A basic book doesn't have to be cutting edge.

Despite the aforementioned faults, the book is a welcome library addition for anyone interested in gears. Those that are new to gearing or those who will have only an occasional exposure to gears will find this volume most useful. The book may also be a useful textbook for a manufacturing technician or an engineering student.

Robert W. Wasilewski
Design Engineering Manager,
Arrow Gear Company,
Downers Grove, IL

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CIRCLE 135

A Conversation With Darle Dudley

Gear Technology *consults with a master gear engineer.*

Nancy Bartels

For many years, when gear engineers have been confronted with tough problems either in the field or on the drawing board, one of the inevitable suggestions has been, "Ask Darle Dudley," or "Check the Dudley book." That's not surprising. With more than fifty years' experience in gear design and credits for five books (with translations in French, German, Spanish and Italian), numerous papers, lectures, and patents, and a worldwide reputation as a gear expert, Darle Dudley's position as one of the men to ask when dealing with knotty gear problems is unassailable.

Recently, Gear Technology *had some conversations with Dudley, not about specific gearing problems, but about "the evolution of the gear art" as he has seen it over the last half-century and where he sees the art and the industry moving as we enter a new century.*

What follows are excerpts from these conversations, ranging on topics from What Every Young Gear Engineer Needs to Know to Gears of the Future.

GT: What has been the most significant technical development in gear design and manufacturing of the last 50 years?

DD: Significant progress has been made in both design calculations for gears and in manufacturing methods. We now have calculations for gear ratings based on probability of failure and recognition of how the allowable stress for 10 billion cycles must be much lower than the allowable stress for 10 million cycles. These concepts of probability of failure and recognition of fatigue of metal over long periods of time were not used to any great extent prior to 1950.

The most significant manufacturing development has been the use of CBN (cubic boron nitride) for grinding. CBN grinding quite often results in closer control of gear accuracy and higher rates of production.

Darle Dudley

GT: Overall, would you say gear development has been evolutionary or revolutionary?

DD: I think gearing evolves. Historically, 10 to 40 years may pass from when a new idea is first heard of to when it becomes an established trade practice. For example, I and a man named Dr. H. Poritsky first published a paper in 1943 about the feasibility of making geometric calculations for any kind of gears meshing together with fully conjugate action. But the calculations involved were very hard to do until the computer came into wide-spread use about 1960. Even then the calculations were not applied to all kinds of gears until the 1980s. In 1994 I wrote the forward to Faydor Litvin's book, *Gear Geometry and Applied Theory*, which shows how to make calculations of tooth shapes for any kind of involute or noninvolute tooth form in any kind of spur, helical, bevel, worm, hypoid or Spiroid® gear in any meshing, cutting or grinding operation.

Areas that are developing quite rapidly now are powder metal and plastic gears and ausforming of hardened steel gears. I think the space program is going to continue to have a big influence on gear design technology.

GT: Speaking of the space program, you've been involved in the military development of gearing since World War II. How have military needs, like the various war efforts we've seen and the space program, affected the development of gear technology? Have the improvements made there entered the mainstream gear markets, and how has the industry as a whole benefitted from these military developments over time?

DD: I think the space program has been the most important thing to promote rapid advancement in gear technology—and in other kinds of technology as well. After 1957, when the Russian Sputnik was launched, this country was committed to a moon landing in ten years' time, and we weren't even sure at the time we could successfully get a rocket into orbit! The massive push from the government was a tremendous impetus to develop technology quickly.

For example, we found when designing gearing for the drives of rocket booster pumps, we needed gears that could carry loads almost twice as great as 1950s gear practice allowed and yet have a reliability against tooth breakage of 1000 to 1 instead of the customary 100 to 1. The kind of focus and effort needed to get that job done taught us a lot about building better gears. We did produce the super gears we needed, but the many failures we encountered along the way also taught us a good deal about ways to enhance gear load carrying capacity that we might not have learned otherwise—or at least not learned as quickly.

GT: The geopolitical situation has changed a lot since 1957, and government spending on things like the space program is being cut back drastically. How is that going to affect gear research and development?

DD: Gear research is an ongoing thing. Sometimes the government has a program going that requires and pays for substantial gear research, as with the space program. In the last 20 years, Japan and Germany have been the world leaders in gear research. We've benefitted from their work, but in many cases, we've had to pay for not doing the development. For example, General Electric invented Borazon®, but the Japanese developed the method for using it in gear grinding. Now we import Borazon gear grinding machines from Japan and Germany, and the key patents for them are held by the Japanese.

In the future, I'd like to see us develop a test machine that can get data on elastohydrodynamic (EHD) oil film thickness up to 1 billion cycles or more. Right now there are no machines that can get this data in any reasonable period of time. But if we don't do this important development work—for lack of funds, either from private sources or the government—I suspect that it will be done in some other country, and they will get the business benefit from it. We'll only benefit second-hand.

GT: What do you see as the next great development in gear technology?

DD: We're already into the study of EHD effects as a major factor in the rating of gears for service life of more than 10^8 cycles. Even though we lack laboratory test data at 10^9 cycles, field experience is teaching the gear trade how important it is to have an EHD oil film thickness that will separate the rubbing and rolling tooth surfaces when gears are expected to survive for 10^9 or even 10^{10} tooth contact cycles.

Looking ten years or more ahead, I think we're in for surprises in gear development. Generally, engineers have a hard time guessing what's coming next. Who would have thought in the 1940s that computers would become so clever and important?

GT: What is the one technological improvement you would like to see right now in gear design and manufacturing?

DD: I'd like to see more work done on worm gears, which are running on nonparallel, nonintersecting axes. At present it's running considerably behind development in parallel axis gearing of all sorts and bevel gearing on intersecting axes. I'd like to see the research done so that worm gear strength and worm gear surface durability could be calculated and understood as well as we can calculate and understand helical gear strength and surface durability.

GT: Where do you see the gear industry in 10 years? 15? 25?

DD: Gear technology has grown rapidly in the last 50 years. Noise and vibration are now very important things in power gearing. All kinds of new formulations for both metal and nonmetallic gears have come into production. There has also been an enormous growth in technical standards, rules and codes for making gears. The ways one can manufacture a gear have also multiplied.

This has created a situation rather like the one in law or accounting. It used to be that you could do your own taxes, and

DARLE DUDLEY

EDUCATION
BSME, Oregon State University, 1940

CAREER EXPERIENCE
1940–1978. Worked for General Electric, Mechanical Technology Inc. and Solar.

1978–present. Founded Dudley Engineering Co., a gear consulting firm working with companies involved in turbine, aerospace, mining and industrial production. In 1991, most of the assets of the company were transferred to Dudley Technical Group Inc. Dudley Engineering still does limited engineering consultation as a sole proprietorship.

PUBLICATIONS
- *Practical Gear Design*. McGraw-Hill, New York, 1954, (translated into French in 1958, German in 1961).
- *Gear Handbook*. McGraw-Hill, New York, 1972, (translated into Spanish and published in Mexico in 1973).
- *The Evolution of the Gear Art*, AGMA, 1969.
- *Handbook of Practical Gear Design*, McGraw-Hill, New York, 1984. (Reissued by Technomic Publishing Inc., Lancaster, PA, 1994, and translated into Italian, 1996.)
- *Dudley's Gear Handbook*, 2nd ed., Dennis Townsend, ed., McGraw-Hill, New York, 1992.

PATENTS
- Thrust Bearing (U.S. 2,659,635), November 17, 1953.
- Flexible Coupling with Torque-Limiting Means (U.S. 2,975,620), March 21, 1961 (with E. E. Shipley)

MEMBERSHIPS
- AGMA
- ASME
- ASME Gear Research Institute
- International Federation for the Theory of Machines and Mechanisms

Dudley was the chairman of the AGMA Aerospace Gearing Committee for 19 years. He was also first chairman and the founder of the Vehicle Gearing Committee. He was also the first chairman of the IFToMM Gear Technical Committee and chairman of the ASME Research Needs Task Force for Gearing. He still serves on the Advisory Board of the Gear Research Institute.

AWARDS
- Honorary lifetime member of AGMA.
- Edward P. Connell Award (1958) for outstanding service to the gearing industry and authoritative writing in the field.
- Golden Gear Award (1966) from *Power Transmission Design* for outstanding contributions to the gear art during the last 50 years.
- Medaille D'Argent (1977) from the French Institute of Gears & Gear Transmissions.
- Worcester Reed Warner Medal (1979) from ASME for engineering contributions to gearing.
- Honorary member of Verein Deutscher Ingenieure (VDI), the association of German Engineers.
- Medaille D'Or (1986) from the French Institute of Gears & Gear Transmissions.
- Ernst Blickle Award (1994) from SEW-Eurodrive-Siftung, Bruchsal, Germany.

generally an honest man didn't ever need a lawyer. Now professional people need a tax accountant to work out their income taxes, and you don't dare enter into a contract without having a lawyer check it to make sure the words are right. The same thing is happening in gearing. Now it's very hard for the average business person or engineer to keep up technically. I think in the next decades we will see a great increase in the need to hire outside gear consultants.

For the same reason, I think we're going to see an increase in standardization for gear products. Just like you don't need to hire a consultant to buy a 100-watt light bulb, you won't need to hire a consultant to help you buy simple gear drives for simple gear jobs because standardized items will be available everywhere.

GT: We've been hearing much about the problem of young engineers coming to work very knowledgeable about computers and general engineering, but lacking much of the knowledge they need to design gears. Do you see this as a problem, and, if so, what should be done about it?

DD: I think this has become a serious problem in the last 15 or so years. The young engineers coming up have very little experience in the intricacies of gear manufacturing or the problems encountered when putting gears into service. A good gear tooth design may fail for all kinds of peripheral reasons: Inadequate bolting of the gear casing, failure of oil seals, improper or inadequate lubrication, contamination in the oil system . . . A gear designer needs a broad education in a variety of things like machinery installation, machinery maintenance and servicing, noise and vibration measurement, instrumentation and trade standards.

A young engineer interested in gearing needs to start with a basic knowledge of machine design. Then you need to know about metallurgy, heat treating procedures, the proper choice of metals for various applications, even the effect the environment will have on performance. A gear assembly doesn't perform the same way in the Arctic as it does in the Tropics or in the American desert as it does in Western Europe. All of these considerations need to go into gear design. It's not enough to be able to plug in formulas from a computer program.

GT: Where does a young person get this kind of training?

DD: A lot of it will have to come with on-the-job training. Ideally I would have beginning gear engineers spend a couple of years working with or in a gear manufacturing shop and with field service people in a large company where failed equipment is being repaired or replaced. Then I'd have them regularly attend meetings of AGMA and ASME where technical papers on gearing subjects are presented and discussed. I would also send them to listen in on standards committee meetings so they can hear the debates and see what goes into determining gear standards.

In the meantime, I think companies would be well advised to have experienced gear consultants take a look at new designs for new projects. Even the largest companies in the automotive and electric power industries can no longer afford to keep a staff of engineers who are fully up to speed on the newest advances in gear engineering. In the cutbacks of the last few years, many of those senior engineers who had the most knowledge and the broadest experience have been given early retirement.

GT: Throughout your career, you have been very active in AGMA. What changes have you seen in this organization over the years?

DD: AGMA is becoming a world organization. Probably at some time in the future, it will change its name to AGMA International, just like the American Society for Metals did a few years ago. It's a cliché, but we really are living in a global village. The role and mission of all trade organizations now is to work toward international development and cooperation.

For example, right now AGMA is heavily involved in work with ISO to reconcile differences between ISO and AGMA gear rating standards. Eventually we'll get to the point where the ISO and AGMA standards will be fully compatible with one another.

GT: You've spent more than 50 years in gear engineering and during that time have racked up a significant list of achievements. What work are you the proudest of?

DD: One of the most important things to me was the 19 years I was chairman of the AGMA Aerospace Gear Committee. We made great progress, starting out from some very conflicting viewpoints and arriving at standards for the very demanding gearing required for the Mercury, Gemini and Apollo space programs.

I think the other area that's significant is my writing. In 1954 McGraw-Hill persuaded me to write a book, *Practical Gear Design*, which was very well received by the technical community. It's been translated into French and German and was on the market for over 30 years. Now a second edition of my *Gear Handbook* has just been translated into Italian.

Writing technical books is not very rewarding financially, but in terms of building relationships with people in the business, the rewards have been significant. Your viewpoint on technical questions gets known worldwide. Other engineers are anxious to talk with you and discuss in depth the latest technical and business developments. On that score, I've been very pleased with my writing career. ○

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It takes more than Machines.

It takes more than Wheels.

It takes

Kish Method for Determination of Hunting Mesh

Jules Kish

When designing a gear set, engineers usually want the teeth of the gear (*Ng*) and the pinion (*Np*) in a "hunting" mesh. Such a mesh or combination is defined as one in which the pinion and the gear do not have any common divisor by a prime number. If a mesh is "hunting," then the pinion must make *Np* x *Ng* revolutions before the same pinion tooth meshes with the same gear space. It is often easy to determine if a mesh is hunting by first determining if both the pinion and the gear teeth are divisible by 2, 3, 5, 7, etc. (prime numbers). However, in this age of computerization, how does one program the computer to check for hunting teeth? A simple algorithm is shown below.

Kish Method

(1) Designate the larger number of teeth on the pinion or gear as *Nmax*.

(2) Designate the smaller number of teeth as *Nmin*.

(3) Find the integer part of the fractional remainder of *Nmax/Nmin* as follows:

$$Nremain = \left(\frac{Nmax}{Nmin} - \text{integer part of } \frac{Nmax}{Nmin}\right) Nmin$$

(4) If *Nremain* = 1, the mesh is hunting.
If *Nremain* = 0, the mesh is not hunting.
If *Nremain* > 1, then:
Set *Nmax* = *Nmin*,
Set *Nmin* = *Nremain*,
Go back to Step (3) and repeat until *Nremain* = 1 or 0.

As an example, consider the following:

Example #1	*Example #2*
$Np = 28, Ng = 91$	$Np = 29, Ng = 91$
$Nmin = 28$	$Nmin = 29$
$Nmax = 91$	$Nmax = 91$
$Nremain = \left(\frac{91}{28} - 3\right) 28 = 7$	$Nremain = \left(\frac{91}{29} - 3\right) 29 = 4$
$Nmin = 7$	$Nmin = 4$
$Nmax = 28$	$Nmax = 29$
$Nremain = \left(\frac{28}{7} - 4\right) 7 = 0$	$Nremain = \left(\frac{29}{4} - 7\right) 4 = 1$
Therefore, the mesh is not hunting.	**Therefore, the mesh is hunting.**

The Kish method is easily programmed, and checks for hunting teeth can be performed in the computer. The method works for any tooth combination. As seen above, each time a new *Nmax* and *Nmin* are set, the fractional remainder becomes smaller until finally the remainder is either 1 or 0.

Jules Kish *has nearly 35 years of experience working on the design and development of transmissions for Sikorsky Aircraft Corporation. He holds a MSME from Yale University.*

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Profile Grinding Gears From The Solid . . . Is It Practical?

Brian W. Cluff

Planetary Gear Set Data

Planet gear: Double helical, 28° HA, 37 teeth, 5.5 DP, 25° PA, 2.350 FW.

Ring gear: Double helical, 28° HA, 117 teeth, 5.5 DP, 25° PA, 2.350 FW.

Sun Gear: Double helical, 28° HA, 43 teeth, 5.5 DP, 25° PA, 2.590 FW.

Sun Gear Internal Spline: Spur, 48 teeth, 7.5 DP, 14.5° PA, 2.750 FW.

Ring Gear External Spline: Spur, 200 teeth, 7.5 DP, 22.5° PA, .5450 FW.

	Grinding Time From Solid in Soft State	Grinding Time After Heat Treatment
Planet Gear	330 min.	41 min.
Ring Gear	980 min.	156 min.
Sun Gear	380 min.	68 min.
Sun Gear Internal Spline	130 min.	82 min.
Ring Gear External Spline	80 min	22 min.

Fig. 1 — Planetary gear set, ground from the solid, using non-dressable CBN plated wheels.

Fig. 2 — Pfauter CNC profile grinding machine with internal grinding arm and 58 mm diameter CBN-plated grinding wheel for grinding 117-tooth, internal double helical gear described in Fig. 1.

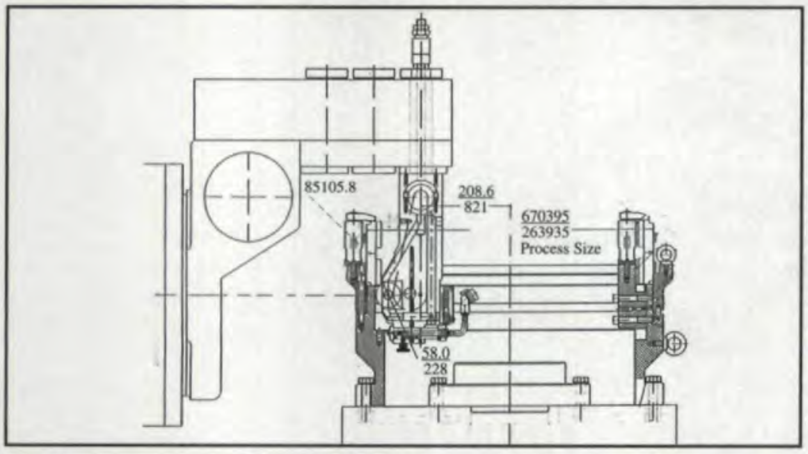

Fig. 3 — Layout of internal grinding setup for 117-tooth, internal double helical gear. Note the location of the grinding arm position on the grinding head. There are three possible positions to mount the arm, depending on the workpiece geometry.

It isn't for everyone, but . . .

Within the installed base of modern CNC gear profile grinding machines (approximately 542 machines worldwide), grinding from the solid isn't frequent, but a growing number of gear profile grinder users are applying it successfully using CBN-plated wheels.

One U.S. East Coast manufacturer of large gears disposed of 22 older wet and dry, single-index generating grinders (Höflers, Niles, and Maags) and replaced them with two new 100" CNC-controlled Pfauter profile grinders, which use plated, single-layer, nondressable CBN wheels. Part of the throughput increase enjoyed by this manufacturer came from processing all through-hardened parts by grinding from the solid.

Gears have been ground from the solid, either in the soft or hardened condition, for a variety of applications for over ten years. Most of these applications were developed through the efforts of Kapp, a manufacturer of CBN-plated wheels and CNC profile grinding machines up to 500 mm capacity, and of Pfauter, a manufacturer of CBN-plated wheels and CNC profile grinding machines up to 4000 mm or larger.

In Figs. 1–4, a double helical planetary set with 28° helix angle, 2.35" face width, 5.4978 DP and 25° PA gear elements was ground completely from the solid in the soft state, then finished on the same machine in the hardened state. In the mid-1980s, grinding from the solid was already a production process for the 9.6 DP, internal helical shown in Fig. 5. The internal/external set of high helix angle gears shown in Fig. 6 were ground from the solid in the soft state before finishing in the hardened state. In the aircraft industry a variety of gear forms, threads and splines have been ground from the solid since 1985, using non-dressable CBN-plated wheels.

What's The Appeal?

Gear profile grinding, particularly with plated CBN wheels on modern CNC form grinding machines, is about 30 times faster than Maag dry grinding, about 10-12 times faster than index generating grinding, competitive with threaded wheel grinding and on some medium pitch through-hardened gears, 2.5 times faster than hobbing and finish grinding.

The additional ability of the larger (above 400 mm) profile grinding machines to measure and document the stock envelope to be removed before grinding and to measure and evaluate the finished ground gear on the machine has significantly increased the productivity and efficiency of large grinders. On one-meter and larger profile gear grinders, the integrated measuring system feature can mean that the grinder enjoys 3-4 times more actual grinding hours than machines without the feature. This additional productivity depends on local plant off-machine measuring practices, queue times and re-setup times.

Some users state (and have closely held data to back up their statements) that the quality and the grinding signature of profile grinding with CBN-plated wheels provides them with the best performing, smoothest running, longest lived gears of all the grinding processes. One manufacturer of transmissions says profile grinding with CBN-plated wheels allows him to warranty the transmission longer than transmissions ground by other processes.

Some users who finish near-net forged gears have found the process of CBN-plated wheel profile grinding capable of removing large near-net stock envelopes faster than the two-step pregrind hobbing and finish grinding process. Fig. 7 shows a dual wheel setup for finishing a 3.5 DP gear with 4.0 mm of stock per flank in a single revolution of the gear.

When it comes down to purchasing an additional pregrind hobbing or shaping machine, many manufacturers who presently use modern CNC profile grinding machines are giving the alternative process of grinding from the solid a second look—particularly if it means saving on the purchase of capital equipment and the elimination of steps in the process which require additional direct labor.

Why Profile Grinding Instead of Generating Grinding?

Form grinding is a single index process where the grinding wheel has the form of the tooth space, or tooth flanks, and grinds the space in one operating step before indexing to the next tooth space. If single-layer, CBN-plated wheels are used, the profile is fixed on the wheel. If dressable media wheels are used, the profile is dressed onto and maintained on the wheel during the grinding cycle.

For large gears (800 mm and above in diameter), traditional index generating grinding is a single indexing, single flank generating process where the flank of the grinding wheel has only point contact on the flank of the workpiece tooth. To produce the final tooth profile, the grinding wheel must make several grinding strokes per tooth flank to create the enveloping cut which generates the profile.

Profile grinding efficiently creates a full line contact with the desired workpiece flank(s), providing

1. Higher metal removal rates than index generating grinding;

2. Simpler motion kinematics than index generating grinding;

3. A workpiece-dedicated wheel profile, repeatable from setup to setup.

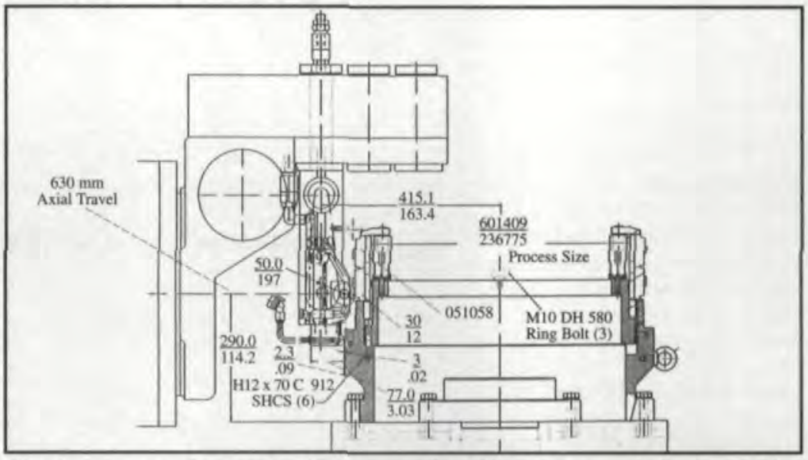

Fig. 4 — Layout of external grinding setup for 200-tooth, external ring gear spline shown in Fig. 1. Note the location of the grinding arm position on the grinding head relative to Fig. 3. The arm has been rotated for external grinding. The internal spur and helical grinding head can be used, with properly designed arms, for doing both internal and external work.

Fig. 5 — Pfauter CNC profile grinding machine with internal arm and single layer, non-dressable CBN wheel grinding a 124-tooth, 9.6 DP, 2.650 FW internal helical gear from the solid in 75 minutes.

Fig. 6 — High helix angle internal and external gears ground from the solid with single layer, non-dressable CBN plated wheels.

Brian W. Cluff
is Vice President at American Pfauter Limited Partnership, Loves Park, IL.

Fig. 7 — Near-net forged gear with 4.0 mm stock per flank, 43 teeth, 3.5 DP, 20° PA, 5.0" FW, being finished ground in the soft state using a dual set of CBN-plated grinding wheels. Time to complete, 21 minutes. One CBN wheel roughs the stock while the finer grit CBN wheel finishes the tooth. This same part can be finish ground from a pregrind hobbed state in 10 minutes (.15 mm stock per flank), but the combined pregrind hobbing and finish grinding process consumes 38 minutes of machine time, plus part handling and duplicate tooling.

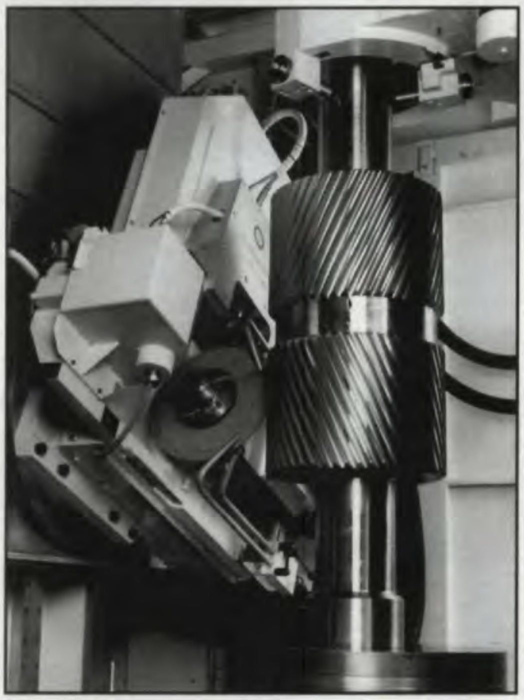

Fig. 8 — CNC 2-axis integrated dressing unit on a Pfauter 1600 mm profile grinding machine.

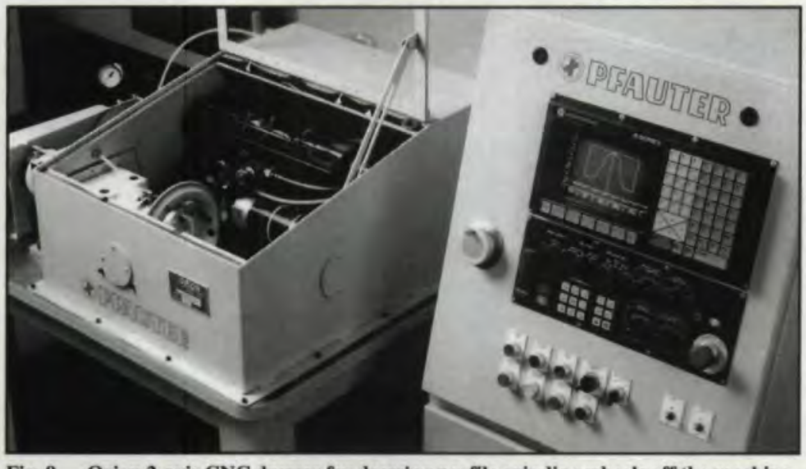

Fig. 9 — Orion 2-axis CNC dresser for dressing profile grinding wheels off the machine. Used commonly with dressable CBN media and SG media.

Modern CNC profile grinding machines for gears offer a variety of practical shop solutions for increasing productivity, reducing work in progress, increasing the number of inventory turns, reducing scrap and direct labor and improving overall quality. Many of the available CNC profile grinding machines offer

1. Integrated dressing units capable of dressing any of the available wheel media using diamond dressing wheels (see Fig. 8);

2. Stand-alone dressing units for dressing seeded gel (SG) wheels and CBN-dressable wheels off the machine (Fig. 9);

3. The capability of using any commercially available CBN-plated wheel;

4. Integrated stock envelope measuring and documentation (Fig. 10);

5. Final finished gear measuring and evaluation;

6. Internal and external gear and form grinding capability;

7. Grinding from the solid capability.

Profile grinding on modern CNC machines with the latest grinding media and techniques have elevated gear grinding to a new performance level. The gear industry worldwide, in general, has been slow to recognize the capabilities of this old, but very new method of processing gears. The installed base of new profile grinding machines has elevated the competitive level of play in the gear industry, and companies wishing to remain competitive are no longer ignoring the profile grinding process.

Why the Reluctance?

There is a worldwide gear manufacturing paradigm block when considering finish grinding gears 500 mm or larger. This paradigm is often expressed by repeating the following general misconceptions:

1. Gear grinding is too slow and expensive.

2. Because it is slow, grinding puts a bottleneck in production.

3. It requires comparably sized, expensive, stand-alone analytical gear inspection equipment.

4. It's inefficient. The grinder sits idle while the workpiece gets inspected.

5. It's labor intensive, requiring a high skill level among operators.

But the fact is, four key developments in grinding media, process technique, integrated measurement and software development have made profile grinding of gears of all sizes extremely efficient.

Grinding media. The pioneering efforts of the Kapp Company of Coburg, Germany, using CBN replatable, non-dressable profile grinding wheels have made profile grinding a productive, precise,

Fig. 10 — Integrated measuring probe on a Pfauter 1200 mm profile grinding machine grinding head. The probe is used to establish the angular position of the gear relative to the stock envelope condition on the workpiece and to inspect the finish ground gear.

Fig. 11 — View of Pfauter-Winter CBN-plated wheels. The profile incorporated into the base body is defined by a CAD system which takes into consideration the quality of the profile to be achieved on the workpiece and the thickness of the layer of CBN crystal.

Fig. 12 — Microphotography of a CBN-plated form wheel showing the nickel bonded CBN crystals and the degree of exposure of the CBN for cutting. Photo courtesy of Kapp.

Fig. 13 — Magnified view of chips produced by CBN micromachining. Photo courtesy of Kapp.

Fig. 14 — Magnified view of chips produced by an aluminum oxide wheel. Photo courtesy of Kapp.

repeatable and economic process for finishing gears.

Process technique. What is unique about the Kapp process is that it uses a non-dressable, but replatable CBN wheel (Fig. 11). The wheel body is made from thermally stable ball bearing steel ground to a geometrically precise form on a 2-axis CBN grinder and then plated electrolytically with a single, uniform, preselected size CBN crystal layer. The bonding medium for the CBN is nickel. Roughly half the CBN particles are exposed for cutting (Fig. 12). No bond clearing is necessary. No wheel dressing is necessary. Wheel bodies can be stripped and replated indefinitely.

CBN, known by its trade name of Borazon®, has been applied to many types of grinding. As applied by Kapp, CBN is a micromachining process more akin to milling than grinding. The nickel bonded particles on the Kapp form wheel are like the cutting edges of microscopic milling cutter inserts. When magnified, chips produced by CBN form micromachining with a Kapp wheel look like milling cutter chips with a characteristic comma shape (Fig. 13). These chips dramatically differ from those produced by aluminum oxide wheel grinding, where the chips are non-uniform (Fig. 14). Single-layer CBN wheels are 3,000–4,000 times more wear resistant than aluminum oxide wheels.

CBN is free cutting. It does not cause burning, since the heat goes into the chip. The thermal conductivity of CBN compared to aluminum oxide is 46 to 1. Using CBN, about 4% of the heat generated goes into the workpiece. With aluminum oxide wheels, about 63% of the heat goes into the workpiece. The temperature of the chips as produced by CBN is typically 500–550°. Chip temperature as produced by aluminum oxide wheels is typically 800-950°. Several users have reported that it leaves significantly lower residual stresses than does vitrified wheel grinding.

Because the form of the profile to be ground is in the wheel, even after dozens of replatings, gear accuracies from lot size to lot size are significantly more repeatable than by dressable methods.

Integrated measurement. The integration of measuring into the gear grinding machine was inevitable. As CNC was applied to large, highly stable machine platforms for grinding applications, and with the accuracies demanded of grinding, it became apparent that the controls, axes resolutions and repeatabilities, feedback methods, machine kinematics and even some of the hardware was identical or very similar to the same devices used on stand-alone gear inspection equipment. It was logical to inspect on the machine because in large gear grinding, inspection and re-setup, which are often done 3 or 4 times, represent a large percentage of the time to produce the finished gear.

Software. Sophisticated software is now available that can align the heat treated teeth of the gear (including distortions) for uniform stock removal; measure and document the minimum and maximum amount of stock for removal; align, grind and measure double helicals in a single setup with precise apex alignment; determine cost-effective use of media though a combination of wheel inventory management programs and tool life programs; predetermine the grinding time based on wheel media and grinding method and store grinding programs on desktop or laptop computers. These programs have eliminated the variables that lead to cost overruns on large gear grinding. For example, the integrated measuring system feature for aligning the gear teeth allows the operator to measure before grinding several selectable teeth around the gear along the lead to determine the mean amount of stock and the minimum and the maximum amounts of stock. A screen display (see Fig. 15) shows the operator whether or not he will be able to grind the gear relative to the input size tolerance over pins dimension; that is to "clean up" to that pin dimension before he even starts to grind. Similarly, on double helicals, depending on the grinding stock left, the operator can determine before the start of grinding whether or not the apex lies within the allowed tolerance band for cleanup.

What these improvements have led to is a growing number of large gear producers who are applying the profile grinding method using:

a. Single layer, replatable CBN wheels roughing and finishing soft or hardened gears.

b. Single layer, replatable CBN wheels roughing and finishing soft and through-hardened gears from the solid.

c. Full form wheels for grinding full forms for better tooth strength.

d. CBN-plated grinding wheels for recurring small lot production and dressable wheels for low lot production.

e. Wheel saver programs to control wheel inventory and maximize wheel usage

f. Media selection programs to select the lowest cost option for production lot sizes on an annual basis. (See Fig. 16).

g. Special software for measuring before grinding to angularly position the gear to remove uniform stock.

h. Special software to determine apex alignment on double helical gears based on measured stock envelope.

The combination of these developments in a single profile grinding machine creates a powerful machine tool, compared to older processes and machines, that helps companies process high quality gears profitably, keep their competitive edge and achieve the advantages of innovation. ○

References:

Cluff, Brian W. *Gear Process Dynamics*. 1992, Chapter 13, pp. 219-221.

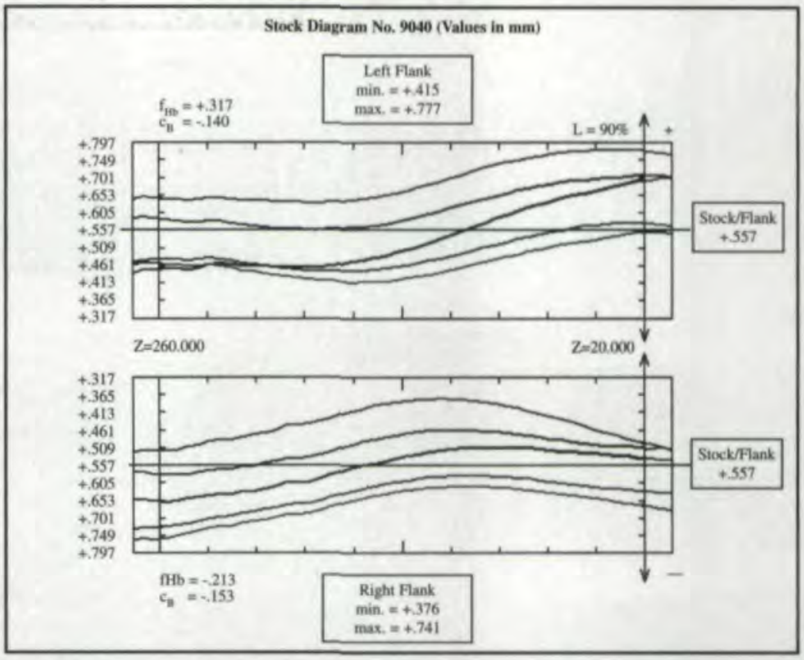

Fig. 15 — Graphic of the control screen display which an operator sees after measuring 5 leads, right and left flanks, on a heat treated, distorted workpiece to be finish ground. After the 5 leads on right and left flanks have been measured automatically, the angular position of the workpiece is positioned to a "best fit" condition relative to the desired finish size dimension and the stock envelope. The display shows the mean amount of stock (.557 mm in the example). The minimum amount of stock is displayed for each flank to verify that the part can be "cleaned up" all the way around the gear. The maximum amount of stock is displayed to allow the operator to select the most cost-effective grinding method. This prevents damage to the workpiece and to the grinding wheel.

COST ANALYSIS OF GRINDING A 3 DP GEAR, SPUR, 80 TEETH, 6" FACE WIDTH

Hourly Rate		$120.00			
INPUT DATA IN CELLS COLORED					
Itemized Grinding Input		*Plated CBN*	*SG*	*AL Oxide*	*Vitrified CBN*
Wheel Cost	CBN Rgh+Fin	$6,000	$800	$300	$6,000
Dressing Disc Cost			$4,000	$4,000	$4,000
Setup Time of Dresser (min)			30	30	30
Setup Cost of Dresser			$60	$60	$60
Roughing Time Wheel Profile (min)			30	30	30
Roughing Cost Wheel Profile			$60	$60	$60
Finish Dressing Time of Wheel (min)			90	60	120
Finish Dressing Cost			$180	$120	$240
Inspection Time for 1st Pc (min)		120	120	120	120
Inspection Cost for 1st Pc		$240	$240	$240	$240
Redress Time for Final Dress			60	60	60
Redress Cost for Final Dress			$120	$120	$120
Inspection Time for Final Dress			60	60	60
Inspection Cost for Final Dress			$120	$120	$120
Machine Cycle Time for Dressing			18	12	0
Machine Cycle Cost for Dressing			$36	$24	$0
Parts/Wheel		50	10	2	1,500
Wheel Cost/Part		$120	$80	$150	$4
Parts/Dresser Disc			200	500	150
Dressing Disc Cost/Part			$4	$1	$40
Grinding Pc Cost per Lot Quantity					
	1	$6,240	$1,620	$1,045	$6,880
	25	$250	$230	$555	$314
Part Setup Time (min)		120	120	120	120
Machine Grind Time (min)		90	110	120	110
Machine Grind Costs (+ Setup)		$420	$460	$480	$460
Dress + Grinding Pc Costs/Quantity					
	1	$6,660	$2,080	$1,525	$7,340
	25	$670	$690	$1,035	$774
Note: Dresser Cost should be an average of new plus relap costs.					

Fig. 16 — Printout example of the wheel media selection decision matrix software. The software establishes the wheel cost/workpiece, the grinding cost/workpiece and total cost/workpiece based on the lot size of the gears to be processed.

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AGMA TRAINING PROGRAMS

May 8–9. Gear Failure Analysis. This two-day seminar will be taught by Bob Errichello and held at the Sacajewa Inn, Three Forks, MT.

The AGMA Training School for Gear Manufacturing is held at Daley College, Chicago, IL. This one-week course is designed for employees with a least six months' experience in setup or machine operation, and it covers setup, gear inspection, gear calculations and basic gearing principles. The curriculum includes both classroom and hands-on training in hobbing, shaping and inspection. The remaining sessions for 1997 are scheduled for **June 16–20, Sept. 22–26 and Nov. 17–21**.

The Hob Sharpening Workshop is also held at Daley College. It is a two-day course with both classroom and hands-on training in hob sharpening basics, grinding and wheel dressing, setup, inspection and sharpening helical flute hobs. Remaining classes for 1997 are scheduled for **June 26–27 and Aug. 7–8**. For more information, contact Susan Fentress at AGMA. Phone 703-684-0211 or fax 703-684-0242.

SME EDUCATIONAL EVENTS

May 6, Fundamentals of Honing, Troy, MI. **May 21**, Modern Grinding Technology, Springfield, MA. **May 12**, Preliminary Gear Design Development Course: Where Do You Begin? Taught by Ray Drago; **May 13–14** Advanced Gear Processing and Manufacturing Conference. Indianapolis, IN. **June 3**, International Advanced Gear Processing and Manufacturing, Indianapolis, IN. These popular courses on gear manufacturing and design subjects fill up early, so register now. Phone SME at 313-271-1500 or fax 313-240-8254.

OTHER EVENTS

May 14–16. Microcomputer Applications in Parallel Axis Gear Design & Analysis. University of Wisconsin Milwaukee Center for Continuing Engineering Education. This course provides a framework for engineers and others who specify, use or design gears to learn how to solve parallel axis gear design and analysis problems with microcomputers. Instructor: Ray Drago. Call Valerie Jordan at 414-227-3167 or 800-638-1828. Information about the Center is also available at *www.uwm.edu/Dept/CCEE.*

June 16–19. M/cad Expo '97. Pennsylvania Convention Center, Philadelphia, PA. This conference will feature 27 three-hour tutorials and seven seminars and panel discussions on CAD/CAM/CAE solutions for mechanical engineering, design, collaborative engineering, solid modeling, rapid prototyping and product data management. Contact Pat Smith at A/E/C Systems International, Inc. 415 Eagleview Blvd, #106, Exton, PA 19341-1153. Phone 800-451-1196, fax 610-458-7171 or go to *http://www.aecsystems.com* for information on the Internet.

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- ❑ Gear Reducers
- ❑ Gearmotors
- ❑ Helical Gears
- ❑ Herringbone (Chevron) Gears
- ❑ Hypoid Gears & Spiral Bevel Gears
- ❑ Internal Gears
- ❑ Master Gears
- ❑ Pinions
- ❑ Powder Metal Gears
- ❑ Racks
- ❑ Ratchets
- ❑ Ring Gears
- ❑ Rotors
- ❑ Segment Gears
- ❑ Serrations
- ❑ Speed Reducers
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Eddy Current Examination of Gear Systems

This nondestructive testing method can save time and labor.

Christopher E. Collins

Nondestructive examination (NDE) of ferrous and nonferrous materials has long proved an effective maintenance and anomaly characterization tool for many industries. Recent research has expanded its applicability to include the inspection of large, open gear drives. Difficulties inherent in other NDE methods make them time-consuming and labor-intensive. They also present the user with the environmental problem of the disposal of used oil. The eddy current method addresses these problems.

Nondestructive examination is the inspection of an object or material in a manner that does not impair its future usefulness. The form, fit and function of the test piece or material are not damaged by the examination. Standard NDE techniques currently available for detection of surface flaws in gear systems include dye penetrants, magnetic particle examination and specialized ultrasonic procedures. A list of the five major NDE field techniques and a brief description of each method is found in Table 1.

The magnetic particle examination method is commonly used to detect surface flaws in the tooth roots in gear systems. This technique, while simple to perform, is very complex because of the number of variables that must be considered. Does the inspector use wet or dry media? Visible or fluorescent magnetic particles? Is proper lighting available for the technique being used? Is the test material completely clean (lubricant free)—an absolute necessity in the magnetic particle and dye penetrant methods?

Eddy Current Testing Principles

Eddy current examination is based on the process of electromagnetic induction. Alternating current flowing through a coil produces a magnetic field (primary magnetic field). If a conductive test piece is placed in close proximity to the coil, the changing magnetic field induces a current in the test piece. The induced electromagnetic field provides for eddy current flow.

The flow of eddy currents depends on numerous variables related to test piece properties and the electronic characteristics of the test equipment. As eddy currents flow, they generate their own magnetic field (secondary

Table 1 — The Five Major Nondestructive Examination Techniques

Ultrasonic Examination. Most ultrasonic testing concentrates on the interior of the component. The most common method is to use a transducer to send ultrasonic vibrations through the test object. The transducer converts electrical signals, sent from an oscilloscope, into ultrasonic vibrations. Interior defects show up in the sound waves reflected back to the transducer. The transducer converts the sound energy back to an electrical signal for display on the oscilloscope. Examining a weld or component can be quick and economical, but the skill of the inspector, coupled with the expense of his training and equipment, is a limiting factor.

Eddy Current Examination. Eddy current testing uses an alternating magnetic field to induce small electric currents in the component being examined. These currents are affected by surface or slightly sub-surface abnormalities in the components. Defect indications appear on the instrument CRT. Eddy current testing is limited to conductive materials. Care must be taken to avoid false indications due to part geometry or permeability variations (ferromagnetic materials).

Magnetic Particle Examination. The magnetic particle examination technique detects surface and slightly sub-surface indications. While providing a magnetizing force over a test area of the component, the inspector sprays a suspension of colorized iron filings (either dry or wet fluorescent) within the magnetized area. The iron filings align themselves along the artificial magnetic field created by any defects. The process is simple to use and some methods do not require extensive training. The test surface should be completely cleaned before applying the magnetic particles. Many components require demagnification after testing.

Liquid Penetrant Examination. Penetrants detect surface flaws by permeating cracks or pores. A small amount of penetrant is applied to a test area. After a specified "dwell time" has elapsed, the penetrant is removed from the surface. A blotter-like developer is applied over the test surface. The developer draws excess penetrant from the defects. The penetrant is either a color that contrasts strongly against the component background, or it is fluorescent. Although simple to use, penetrants can miss defects if the surface is not adequately cleaned or the flaw is obstructed with smeared metal.

Radiographic Examination. Radiography employs X-rays or gamma rays to penetrate the test object. It displays a permanent picture of the test object's interior on radiographic film. Radiographic limitations include the need for adequate component geometry, strict security of the test area and time to develop and interpret the test film. Radiographic examiners require extensive training.

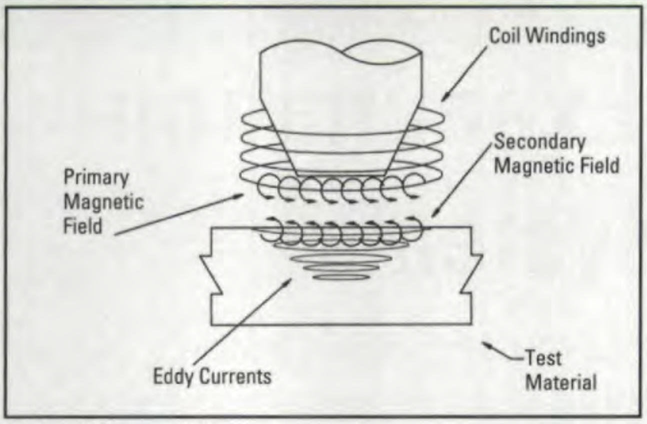


Fig. 1 — Eddy current flow.

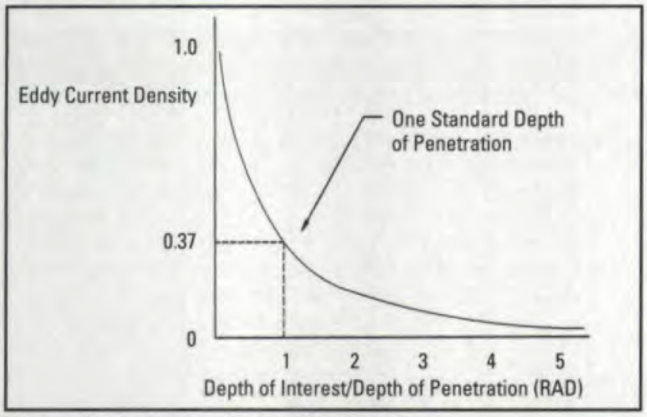


Fig. 2 — Depth of penetration of eddy current flow.

Table 2 — Eddy Current Examination Formulas

One standard depth of penetration in inches: $\delta = 1.98 \sqrt{[\rho/(f^*\mu_r)]}$

where: ρ = resistivity in micro-ohm-centimenters ($\mu\Omega$cm)
f = test frequency in Hertz (Hz)
μ_r = magnetic permeability relative to air (dimensionless)

For non-ferromagnetic materials, magnetic permeability is constant ($\mu_r = 1$),

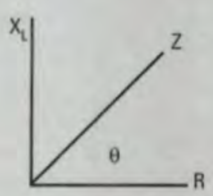
therefore: $\delta = 1.98 \sqrt{(\rho/f)}$

Phase Diagram Construction:

Inductive reactance (Imaginary component) in ohms:
$X_L = 2\pi^* f^* L$

where: f = test frequency in Hertz (Hz)
L = coil inductance in Henrys (H)

R = Resistance in ohms (real component)



Initial coil impedance: $Z = \sqrt{(X_L)^2 + (R)^2}$

Phase lag: θ = arctan (X_L/R)

magnetic field), which opposes the primary magnetic field (See Fig. 1).

Distortions in the secondary magnetic field created by surface or sub-surface flaws change the impedance of the coil. The eddy current test equipment senses these differences and displays the changes on an oscilloscope CRT, strip chart or other display recording device. Electrical conductivity differences between flaws (cracks) and the homogeneous area of the test piece allow the inspector to utilize the eddy current equipment for flaw detection.

Nonferromagnetics

Eddy current examination of nonferromagnetic materials is common. Alloys of aluminum, titanium, copper and nickel are inspected regularly in aerospace, power generation, chemical and petrochemical applications. Good candidates for eddy current testing include aircraft components and steam generator/chiller tubes. Eddy current examination is also used for alloy sorting, hardness testing, corrosion detection and coating thickness evaluation.

Magnetic permeability of nonferromagnetic materials is assumed to be constant, allowing one to accurately perform phase analysis calculations. These calculations allow the technician to accurately determine inspection parameters such as coil impedance, phase angle and eddy current penetration depth. The eddy current probe's test frequency, the magnetic permeability of the test material and its electrical conductivity values are characteristics affecting the density of the eddy currents throughout the test part. Eddy currents are more dense near the test coil.

This concentration of eddy currents at the test piece surface is defined as the "skin effect." As the eddy currents are generated in the test specimen, the current density decreases exponentially. One standard depth of penetration is defined as the depth at which the eddy currents entering the test piece are reduced to approximately 37% of those at the surface (Fig. 2). The formula for one standard depth of penetration is

$$\delta = 1.98 \sqrt{[\rho/(f^*\mu_r)]}$$

For air and nonmagnetic materials the magnetic permeability is constant (see Table 2). Therefore,

$$\delta = 1.98 \sqrt{(\rho/f)}.$$

Inductive reactance is the opposition, independent of resistance, of a coil to the flow of alternating current. By using the formula for inductive reactance (assuming the reactive component is imaginary), $X_L = 2\pi^*f^*L$, and the given resistance for the test piece (assuming the resistive component is real), a phase diagram, such as the one shown in Table 2, can be constructed.

From the phase diagram (impedance graph), the coil's initial impedance and phase lag can be calculated.

$$Z = \sqrt{(X_L)^2 + (R)^2}$$

$$\theta = \text{Arctan}\ (X_L/R)$$

The difference in eddy current densities from the surface to the interior of the test material is known as phase lag. After performing these calculations, the inspector can be aware of all of the parameters and can

accurately perform the examination on nonferromagnetic materials. Knowing the exact location of the eddy currents is crucial when performing an examination on steam generator/chiller tubes.

Ferromagnetics

Ferromagnetic materials have long been considered "off limits" to eddy current examination because of random magnetic permeability changes. These permeability variances in ferromagnetic materials make ordinary phase analysis difficult unless the material is magnetically saturated. Without saturation, permeability variances could create signals that mask discontinuity signals.

Magnetization theory states that permeability can be made relatively constant by saturating the material with an independent magnetizing force. If the test piece is completely saturated, magnetic permeability can be considered constant. This would allow for phase analysis calculations and an accurate eddy current examination. The inability to completely saturate large ferromagnetic components and then demagnetize them after the examination is a major reason why eddy current examination technologies have not been aggressively utilized for ferromagnetic materials—especially for field applications in the gear industry.

Eddy current examination of ferrous materials is also known as magneto-inductive testing. This type of NDE uses the induced electric current as the source of the magnetic field. For the gear examination procedure, only the induced currents at or near the surface are interpreted.

Electromagnetic techniques are most sensitive to the test material variables nearest the test coil due to the "skin effect." The "skin effect" is the product of the mutual interaction of the eddy currents, the selected test frequency, the test material's electrical conductivity and its magnetic permeability. Changes in coil impedance created by surface (and slightly sub-surface) flaws in the vicinity of the eddy current probe are detected and displayed on the eddy current CRT. Unlike the case with tubing applications, where interior defects are scrutinized, little attention is devoted to internal discontinuities. Magnetic permeability variances are still a difficulty, but they are dramatically reduced by the effective utilization of the "skin effect" phenomenon. Since the inspection is magneto-inductive (the magnetic field is derived from induced electrical current), no residual magnetic fields remain once the examination is completed.

Development

During the late 1980s, Steven W. Pogue, an NDE lab manager, developed the eddy current gear examination system to inspect large diameter, open lubricant gears. These gears were in service on large capacity draglines and stripping shovels in the surface mining industry. Mine personnel wanted to establish a quantitative NDE technique without sacrificing production. Magnetic particle examination of large gear systems was not feasible. Removal of high-tack open gear lubricant for the sake of an inspection was a chore not readily undertaken by maintenance workers.

Because of the history of the nature and type of actual gear tooth failures, the tooth root area along the entire face width of each tooth and both side edges became the target area for the inspection. Upper flank, pitch point and upper face areas of each tooth were not focused on because of difficulties with wear (pitting, spalling and metal push). Because eddy current technology senses homogeneous changes in the test material near the probe, indications produced by tooth wear conditions would be too numerous to interpret.

In early 1989, improvement in the design of probes allowed them to retain their required sensitivity and be usable in spite of up to .25" of lubrication on the gears. Research and development progressed at local mines, and by the fall of 1989 the system was ready for use.

The eddy current gear examination system for large gears consists of a portable eddy current machine, proprietary scanning probes, various cables, scrapers, cleaner (solvent for initial cleaning and nonchlorinated for final cleaning) and protective clothing. A portable magnetic particle yoke and wet or dry magnetic particles are recommended for flaw verification. This "double sorting" is a common practice in nondestructive examination.

Eddy Current Examination

The procedure begins by removing compacted lubrication from the tooth roots using a root scraper that closely conforms to twice the fillet radius of the gear teeth. Lubrication is also scraped from the face width side edges. The teeth are numbered for documentation and repeatability. If possible, stationary reference points are used for reporting. Then, if they are accessible, the side edges of the teeth are scanned. They are also inspected for flaws extending from tooth roots. It is advisable to follow the contour of the tooth when scanning.

Two types of failure modes exist when fatigue cracks are detected in gear tooth roots. The most common mode attempts to split the gear band. Crack propagation in a tooth-to-tooth pattern (shearing teeth from the band) has also been regularly documented. Following the tooth contour will detect either failure mode.

Once the side edges have been inspected, the tooth root inspection follows. The process begins by selecting the proper size root scan probe. It is important to choose a probe diameter that closely matches the fillet radius of the gear teeth. If the proper size probe is not available, multiple passes through the tooth root, paying close attention to the flank/root junction areas of each tooth, are recommended.

The scanning takes place by moving the probe at a controlled pace throughout the entire face width of the root being scanned (see Fig. 3). If the remaining lubricant in the roots is very tacky, commercial lubricant is applied in the roots to help move the probe. At least two passes through the root are made to insure proper coverage. If no indications (electronic signals that point to

Fig. 3 — An NDE technician uses a probe with a proprietary design to perform an eddy current examination (tooth root scan) of a large grinding mill ring gear.

Fig. 4 — Tooth root cracks (shown in red and circled in white) documented in the roots of two adjacent teeth. Cracks were detected with eddy current testing and double sorted with dry magnetic particle examination (red color). Note undisturbed lubrication condition in the tooth roots of gear teeth that passed the eddy current examination.

Fig. 5 — An NDE technician performs a side face scan of a small gear. An indication signal is displayed on the eddy current instrument (triggering the need for further evaluation; i.e., "double sorting").

the existence of flaws) appear on the eddy current instrument, the inspection proceeds to the next tooth root. The examination ends when all accessible tooth roots have been inspected.

When a phase shift indication appears on the eddy current instrument CRT (see Fig. 4), the inspection is halted for indication evaluation. The defect area is pinpointed using communication between the technician running the probe and the technician interpreting the instrument. The precise area is cleaned using solvents and scanned again. If the indication disappears, the inspection continues.

The disappearing indication phenomenon is usually caused by metal flake compacted in the remaining lubrication. The eddy current instrument senses a change in magnetic permeability created by the metal flake and produces an indication signal. If the indication remains after reexamination, further evaluation is necessary. The suspected area is cleaned using a commercial, nonchlorinated cleaner, and a magnetic particle examination is performed. Indication areas are documented (see Fig. 5). Shear (transverse) wave ultrasonics can sometimes determine the depth of the flaw at the client's request. The defect depth evaluation usually takes place after the eddy current examination is completed.

Practical Examinations

Much initial work in eddy current testing was done on mining equipment. Large open gearing applications (swing racking or bull gears and their corresponding drive pinions, for example) were targeted. Flaws ranging from minor scratches and pits to severe cracks were detected.

In early 1992, the steel and aluminum rolling mill industries began to adopt eddy current techniques. Covers were removed from oil-bathed gearboxes, exposing multiple gears for examination. Indications of flaws have been found in the tooth roots of large bull gears and double-helical, high-speed pinions. Eddy current tests have also been performed in roughing and finishing mill stands, shear drive boxes and vertical edger assemblies. Grinding mill (ball, rod, autogenous and semi-autogenous) and rotary kiln ring gears (spur design) are very similar to the gears found in the mining industry. These are the applications for which the eddy current gear examination system was designed. Findings from these inspections parallel those from other industries.

The Time It Takes

Gear inspection time is directly proportional to the number of indications encountered, depending heavily on the time it takes to clean suspected areas and perform the magnetic particle examination. The inspection pace is very rapid on gears that are in good condition. A large ring gear (four segments, open lubrication, 38' outer diameter, 26.5" face width, and 448 teeth) in service on a semi-autogenous mill was completely examined in eight hours, including time for cleaning all equipment. No significant indications of flaws were detected.

In another case, during one eight-hour shift, a mill

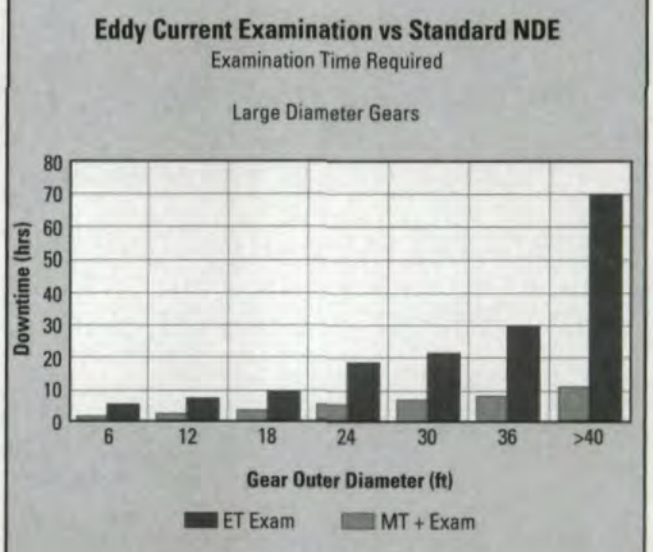
was taken offline, one cover was removed, the gear was inspected (with little help from maintenance personnel) and the cover reinstalled.

Obviously, when flaws are detected, the process takes longer. For example, the inspection of a ring gear installed on a medium size mining shovel (one-piece construction, open lubrication, 19' outer diameter, 13.5" face width and 154 teeth) took approximately 10 hours. But 73 tooth roots contained cracks. Flaw sizes ranged from 0.125" to 8" in length (see Fig. 5).

Conclusion

Based on increased downtime, labor, safety and environmental concerns, standard magnetic particle and/or dye penetrant examinations are usually not completed on large gearing applications to the extent recommended by the manufacturer. By performing an eddy current examination, engineering and maintenance personnel can be aware of potential problems quickly (usually within eight to ten hours). An enormous amount of man-hour savings, coupled with increased production, can be achieved by implementing the eddy current examination technique as shown in Fig. 6.

Upon comparison of nondestructive examination methods (covering the same precise area), eddy current techniques are far superior to magnetic particle and/or dye penetrant methods. The main argument for this is the fact



MT+ = time involved for magnetic particle/dye penetrant examination (standard NDE) and pre-clean time.

All values are based on field experience and maintenance information.

Assumptions: Gears are in good condition (no metal flake in roots and/or severe wear).
Few flaws detected per method.
Adequate assistance from maintenance personnel (gear movement/cover removal).

Fig. 6 — Comparison of required time for eddy current examination and standard NDE.

that the potential for human error is greater using the magnetic particle and/or dye penetrant techniques. Less reliance on component cleaning, lighting conditions and eyesight make eddy current testing the more dependable examination method. Because of the localized scan design of the eddy current system and the wide coverage areas (tooth faces) of the other methods, accurate examination method comparisons could not be completed for an entire gear.

For production and maintenance planning staffs with adequate resources, the new eddy current and standard NDE methods work well together. An effective use of eddy current and magnetic particle examination technologies provides for excellent preventive maintenance. An eddy current examination on an annual basis will pinpoint potentially harmful discontinuities at the earliest point in time. A 100% tooth profile magnetic particle/dye penetrant examination should be performed at five-year intervals to check for tooth wear and profile flaws.

Because of demands for increased production and the downtime required to perform standard NDE techniques, gear examinations are frequently performed inadequately or not at all. For maintenance and engineering personnel worried about the downtime needed for a gear inspection, the eddy current gear examination system quickly eliminates doubts whether a potentially harmful condition exists in a particular gearing application. ○

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CNC Gear Grinding Methods

Which technique is best for your application?

Dennis Richmond

Grinding in one form or another has been used for more than 50 years to correct distortions in gears caused by the high temperatures and quenching techniques associated with hardening. Grinding improves the lead, involute and spacing characteristics. This makes the gear capable of carrying the high loads and running at the high pitch line velocities required by today's most demanding applications. Gears that must meet or exceed the accuracy requirements specified by AGMA Quality 10–11 or DIN Class 6–7 must be ground or hard finished after heat treatment.

Few manufacturers have been successful at developing a machine that is without some compromise. As a result of the enormous challenge of trying to design one machine that fits all needs, the various manufacturers apparently have decided that specializing their products to target specific market niches is more efficient; therefore, over the past three decades, machine tool manufacturers have engineered their gear grinders specifically to be very efficient grinding certain types of parts. The remainder of this article is a survey of the various types of grinding processes available today.

Single Index Form Grinders

Although most of today's modern machine tools are quite good at grinding external spur and helical gears, very few manufacturers have been successful at incorporating the ability to handle internal gears without major compromises. Today, one of the only ways to efficiently grind internal gears is the single-index method with a dressable vitrified wheel or a bonded CBN-plated wheel. A plated wheel maintains its form well; however, its high purchase price and dedication to a single part result in a high perishable cost. A vitrified dressable wheel offers greater flexibility and is much less expensive, but is more susceptible to process variables that can lead to gear geometry errors.

Single index form grinding is the easiest gear grinding process to understand. It is a "what you see is what you get" process. The form required on the workpiece is identical to the form or shape put into the grinding wheel. Gear teeth, or more accurately, gear space is ground one tooth at a time. The gear is indexed to correspond to the number of teeth on the workpiece. In machines under 400 mm capacity, the part to be ground is normally mounted between centers in a horizontal space. These machines have tables that reciprocate under a stationary wheel spindle. The wheel spindle is mounted to a vertical column supported by a feed device, which raises and lowers the wheel spindle to realize the center distance and facilitate wheel dressing (see Fig. 1).

Older machines use templates and a copy device to transfer the form onto a vitrified wheel. Newer machines use either steel body plated wheels that include the desired form or dressable wheels that are profiled through the machine control.

This process derives its appeal primarily from its simplicity and flexibility. Wheels can easily be made from aluminum oxide for either internal forms or external shapes (Fig. 2).

The operator has little to do with putting the form onto the wheel; therefore, the process demands fewer operator skills. For the past decade, machine builders have offered grinders that use superabrasives, such as cubic boron nitride (CBN), which are plated directly to a steel wheel body or made as a vitrified bonded wheel that can be dressed to the desired form. The user can expect to achieve profile tolerances of .0002" or less. Nickel is the bonding agent that holds the CBN crystal to the steel wheel (Fig. 3).

The crystal is sifted to the desired size prior to the plating process so that a final lapping operation is not required. This allows the crystal to remain sharp and extends its useful life, permitting more parts to be ground between replating operations. To further optimize wheel life, roughing wheels and additional machine axes are used. A machine configured to mount more than one wheel can rough and finish the gear in the same pass, resulting in a higher productivity and extended wheel life. A high-volume/high-pressure coolant delivery system permits the removal of large amounts of stock while reducing or minimizing the risk of burning or cracking from excessive heat during grinding.

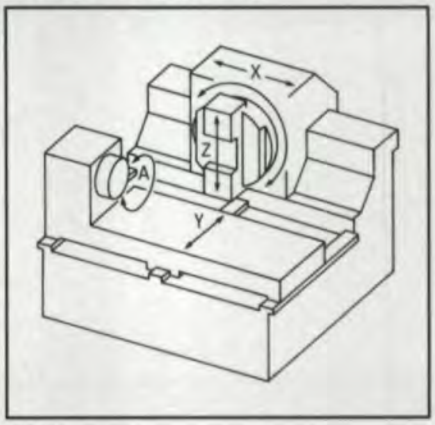

Fig. 1

Fig. 2

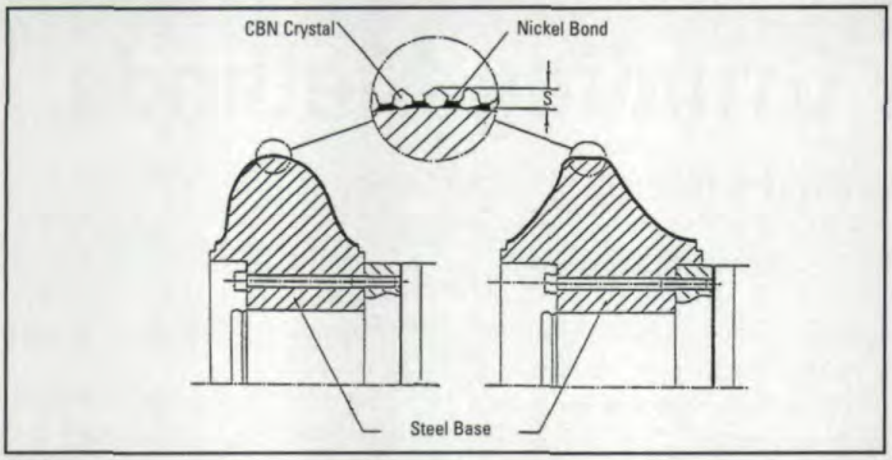

Fig. 3

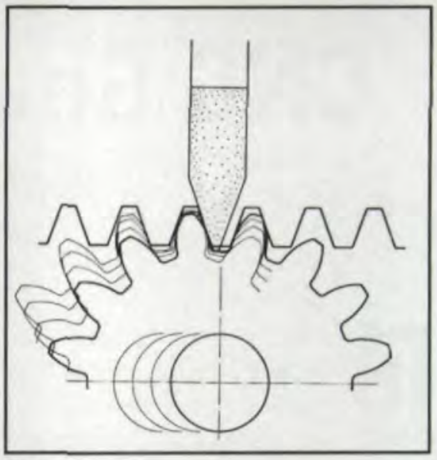

Fig. 4

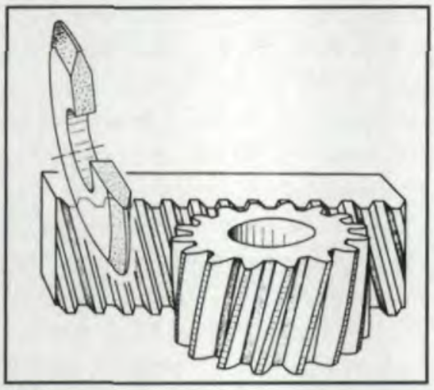

Fig. 5

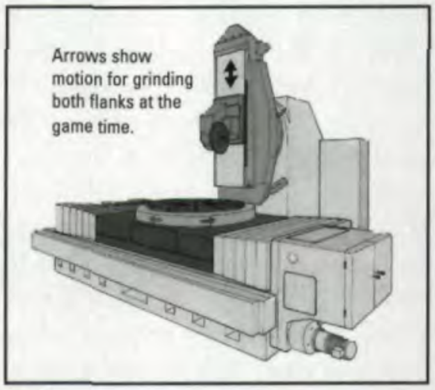

Fig. 6

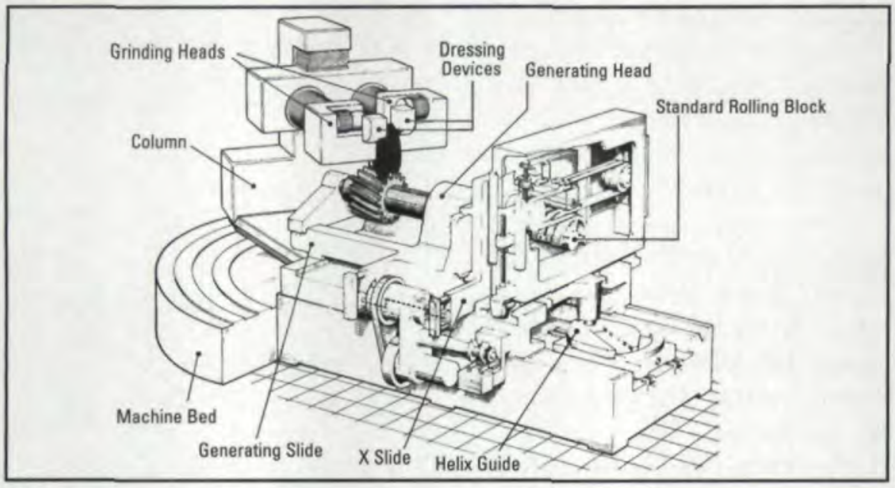

Fig. 7

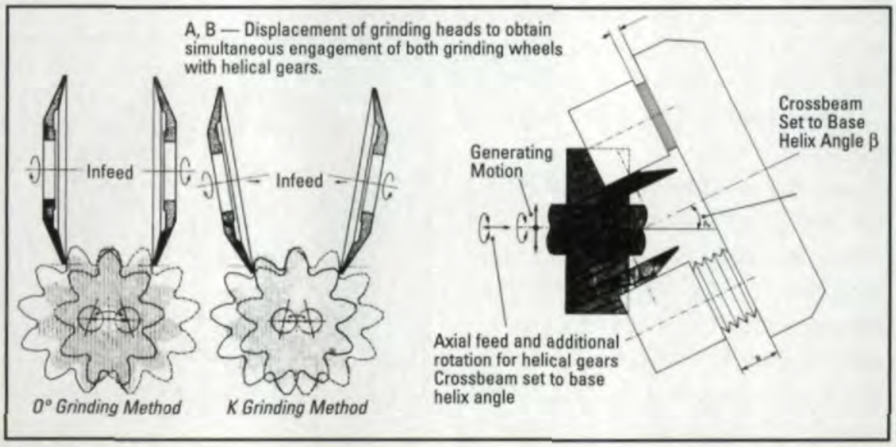

Fig. 8

Modifications to the lead such as *crowning, taper and end relief are simple* inputs to the control. Cams and templates are a thing of the past for the newer breed of machine. In many cases, internal gears or forms can be ground on the same machine with the addition of a suitable grinding arm.

Forms such as vane pumps, male and female compressor rotors, gerotors, worm ball screw tracks, root-type rotary pistons, gear hobs and constant velocity joints—any precise form that is evenly indexable—can be ground on a single index form grinder.

These machines are well-suited for small to medium gears and non-gear parts. They are capable of achieving the accuracies required for applications such as aircraft and aerospace gears, machine tools, screw compressor rotors, ball screw tracks, gerotors, internal gears, vane pumps, worms, constant velocity joints and automobile transmissions.

Single Wheel Generating Grinders

Several different styles of gear grinding *machines use the generating* method. As with other types of machining, the style sometimes takes on the name of the original manufacturer who developed the method. The Höfler or Niles method is sometimes referred to as "a single tooth rack process" method. It can best be described as one in which a rack or single ribbed wheel strokes parallel to the axis of the workpiece while at the same time traversing tangentially to the workpiece (Fig. 4).

In addition to these two motions, the workpiece rotates to simulate the rolling action required to generate the profile (Fig. 5).

The angle on the double-tapered wheel corresponds to the pressure angle of the gear. The generating path, or distance the wheel must travel, can be reduced by optimizing the wheel pressure angle, leading to shorter grinding times. Wheels can be made from either vitrified CBN or aluminum oxide. Automatic wheel balancing on the spindle has been incorporated into the newer machines, allowing them to achieve higher quality and better surface finish.

The latest grinders are capable of grinding both flanks in the same motion, resulting in a productivity advantage when double-flank grinding (Fig. 6).

During the grinding cycle infeed pass, the left and right flank of one tooth space is machined before the gear is indexed to the next tooth. The number of workpiece revolutions, typically two to four, will be determined by the grinding allowance on the flank of the gear.

Modifications to the lead and profile are easily realized by simple menu inputs to the control. Different modifications on left and right flanks are also possible when using the double-flank technique.

These machines are ideally suited for medium to large gears. The single wheel generating grinders are capable of achieving accuracies required for a variety of demanding applications such as large high speed marine transmissions, submarine drives, stationary turbines for power generation, machine tools, wind turbine generators, steel mills and large diesel engines.

Double Wheel Generating

This generating technique uses a pair of saucer-shaped wheels. Vertical and horizontal machines are built and dedicated to grinding gears and pinions respectively. The horizontal machines are equipped with devices to allow for lead modifications for pinions, while the vertical machines generally have no provisions for modifications, as they are primarily used for grinding large gears (Fig. 7).

Aluminum oxide wheels dressed with single point diamonds are the wheels of choice for this dry grinding process. The wheels on these machines act as a straight-sided rack that rolls past the gear during the grinding process. This motion generates the involute profile. The axes of the wheels can be set parallel to each other or at a 10° angle (Fig. 8).

The workpiece is reciprocated or "rocked" in the axial direction to provide the infeed motion as two flanks of different teeth are ground in one pass. At the end of the pass, the entire gear is indexed using mechanical index plates having the exact number of notches or a multiple of the teeth in the gear. Prime numbered gears require dedicated index plates. The depth of cut is determined by the infeed of the two grinding wheels toward each other.

When grinding spur gears, the axes of the grinding wheels are perpendicular to the axis of the gear. A simple motion to simulate the rolling of the gear on the rack represented by the wheels generates the involute. Steel bands attached to a stationary support on one end and a rolling block at the other produce the generating motion. The rolling block is generally the same diameter as the base circle of the gear; however, the newer style machine incorporates the use of a variable diameter rolling block. When grinding a helical gear, an additional motion must be imparted to the workpiece to compensate for the helix angle. A helical guide mechanism is used to accomplish this motion.

The contact point between the wheels and the tooth flanks is confined to a very small area at any given time. This explains why the productivity of the process is described in hours per gear rather than gears per hour. "Time consuming" and "slow" also describe this very accurate process. If productivity is the shortcoming of this process, its ability to grind point by point lead and profile modifications is a strength.

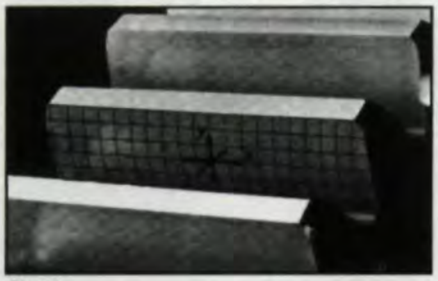

Fig. 9

The Maag is one of the only machines ever built to incorporate the point-by-point system for lead and involute modifications (Fig. 9). It has been said that the primary purpose for the design of this machine was to support the manufacture of Maag's own high-speed gearbox and transmission business and not necessarily as a commercial product. To summarize, the trade-off in productivity must be weighed against the advantage of flexibility.

These machines are best suited for small to medium lot size gears that require highly modified tooth forms. They are used in the following applications: gear rolling dies, shaving cutter sharpening, steel tooling, large marine transmissions, machine tools and high speed gearboxes.

Form Generating

Form generating is a unique process offered by a single manufacturer for high production grinding of helical automotive transmission gears. This process (see Fig. 10) was first introduced to the market in the mid 1980s. It is ideal for large volume, highly automated manufacturing environments. Because the feed motion for stock removal is rotary and not axial, cycle times can generally be stated as one second per tooth, regardless of the gear face width. Simply put, the wheel and the workpiece do not traverse past one another during the grinding cycle.

The aluminum oxide wheel has a globoid shape when viewed from the end (Fig. 11). This shape is dressed into the wheel with a diamond-plated gear with the desired profile and lead characteristics required by the product gear. The wheel is positioned above the dressing gear so that its axis is perpendicular to the lead or helix angle of the dressing gear. It is then plunged into the dressing gear and allowed to rotate in two directions, resulting in a thinning of the thread on the wheel. The thinning of the wheel is necessary so that rotary

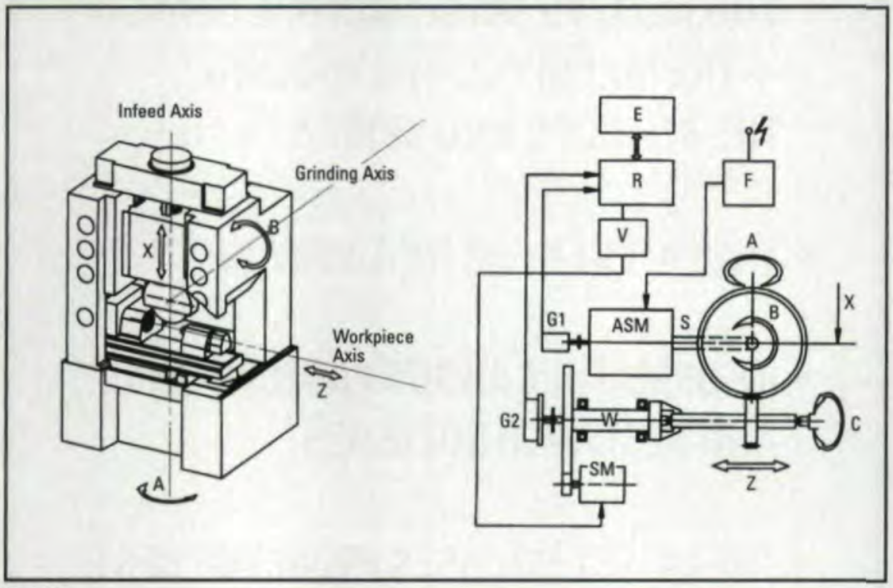

Fig. 10

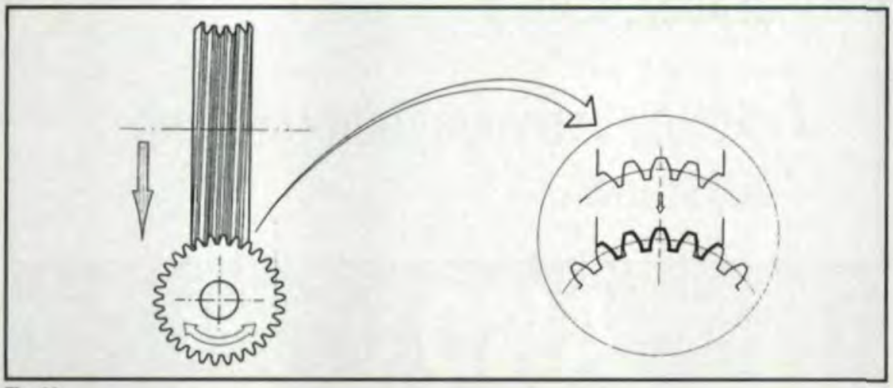

Fig. 11

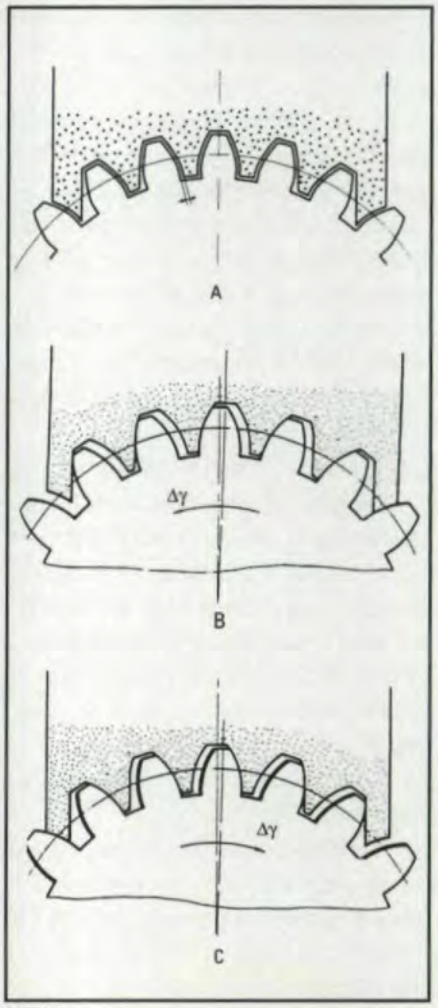

Fig. 12

feed can take place during the actual grinding. In this process, each side of the gear is ground separately.

The grinding sequence can be described as follows:

1. The workpiece is transferred into the machine with an auto loader, and a probe determines the optimum orientation considering the runout and stock conditions (Fig. 12a).

2. Rotary infeed begins, and the left flank is roughed and finished and allowed to spark out (Fig. 12b).

3. The workpiece is then electronically advanced so that the right flank comes into contact with the wheel (Fig. 12c).

4. Rotary feed begins, and the right flank is roughed, finished and allowed to spark out.

5. The workpiece is removed from the machine, and the next cycle can begin.

The profiling sequence can be described as follows (Fig. 13):

1. In the case of a shaft-type workpiece, the dressing gear is automatically loaded into the machine between centers.

2. The grinding wheel is plunged into the dressing gear.

3. Rotary feed is applied to the dressing gear, and the left and right flanks are sequentially dressed, allowing for a certain amount of dwell for both flanks.

4. The dressing gear is removed, and 15–30 gears are ground before the next dressing operation is necessary.

When grinding bore-type workpieces, the dressing gear is part of the work spindle and tooling and is mounted on the machine at all times. For shaft gears, the dressing gear is resident in the machine, but must be presented to the wheel in a separate sequence. This allows for slightly shorter dressing times.

This process is well suited to the manufacture of large-volume, automotive helical gears with annual quantities of approximately 200,000 gears per year of the same type.

Continuous Generating

This process is sometimes referred to as threaded wheel grinding and is by far the most wide-spread in use today. This technique has kinematics similar to those in hobbing (Fig. 14).

A threaded wheel similar to a gear hob without gashes is used as a cutting tool. The relationship of the workpiece and the wheel is described as follows:

$$\frac{\text{Wheel rpm}}{\text{no. of teeth}} \times \text{no. of starts.}$$

When grinding helical gears, the lead must be compensated for as it is in hobbing, through a mechanical or electronic differential. This differential imparts an additional rotary motion to the workpiece, allowing the wheel to traverse along the lead or helix angle of the part. The similarities do not stop here. The tool or grinding wheel is sensitive to the same constraints that affect a hob. As long as the diametral pitch or pressure angles are not changed, the same wheel can be used to grind a variety of workpieces, regardless of the helix angle or number of teeth. This is a major difference from the single index technique, which is affected by both helix angle and varying the number of teeth.

CNC Gear Grinding Techniques			
Method	**Manufacturer**	**Advantages**	**Disadvantages**
Single Index Form Grinders	Kapp National Broach Okamoto Klingelnberg	• Accurate control of form. • Ability to grind finer pitches from the solid. • No wheel dressing required. • Wheel can be stripped and replated. • Ability to grind roots and tips. • Ability to integrate on-machine inspection. • High stock removal rates. • Ability to grind noninvolute shapes. • Grinds internal gears.	• Dedicated steel wheel needed for each pitch, pressure angle and tooth number combination. • Form only correct once part is on size. • Steel wheels cannot be modified. • Expensive initial capital investment. • Potentially large inventory of wheels. • Horizontal workpiece axis.
Single Wheel Generating	Höfler; Niles	• Low perishable cost—wheels and diamond dressing tools. • Same wheel can be used for different pitches. • High achievable accuracy. • Fast setup. • Ability to integrate on-machine inspection equipment. • Coarse and fine pitches possible. • Vertical workpiece axis. • High stock removal per pass. • Machines available for large gears up to 157".	• Fast process, but not considered high production. • High initial capital costs. • Large floor space required. • Special foundations needed for some applications. • Cannot grind roots or ODs.
Double Wheel Generating	Maag method	• Very accurate. • Long machine tool life. • Can be inspected prior to complete grinding of gear. • Dry process makes washing unnecessary for inspection. • Point-by-point grinding reduces the tendency to burn. • Ideal for low volume production. • Low tooling costs.	• Cycle time quite long. • Expensive capital investment. • In gears with a large number of teeth a jump between the first and last tooth ground may be experienced.
Form Generating	Reishauer Type RZF	• Very short cycle times. • Low tooling costs. • Dedicated tooling—no development time needed. • Stable process with few variables.	• Process suitable only for helical gears. • Workpiece diameters up to 200 mm. • Large capital investment.
Continuous Generating	*Liebherr* Okamoto Gleason Reishauer	• *High productivity.* • Good process stability. • Very low perishable costs. • Lead and profile modifications made easily. • Easily automated process.	• *Unable to grind close to shoulders.* • No internal gear capability. • Large initial investment.

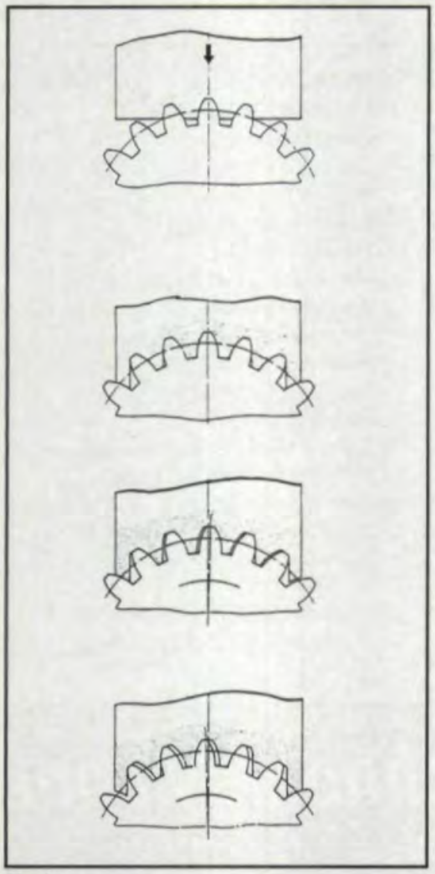

Fig. 13

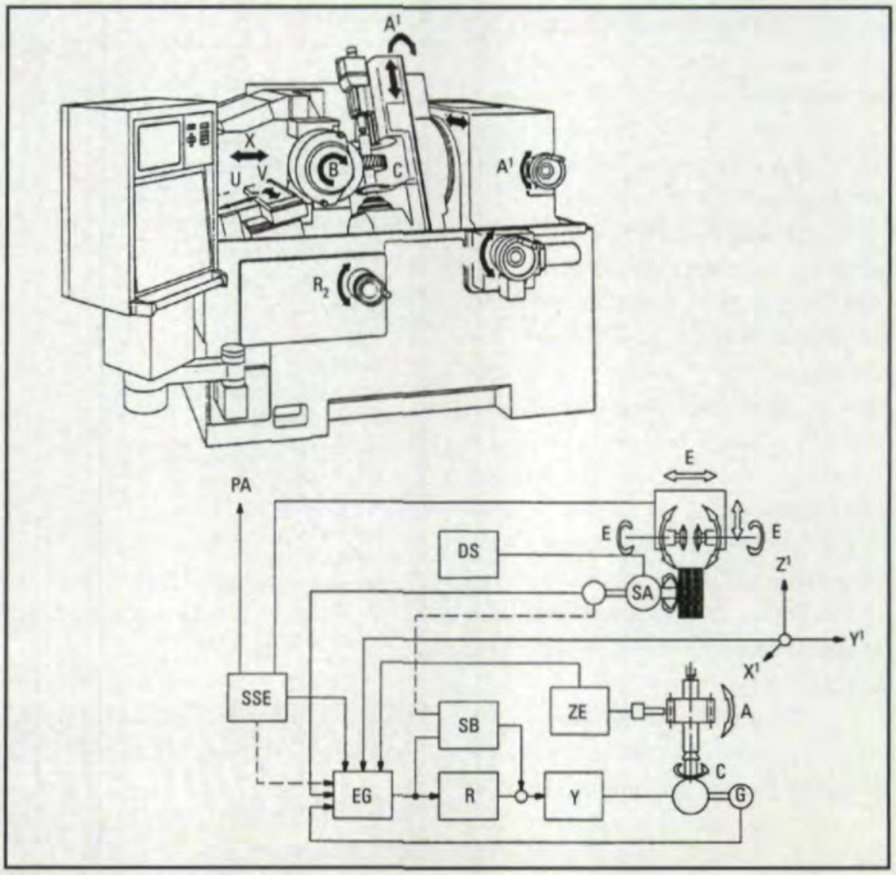

Fig. 14

The continuous generation technique is aptly named. The threaded wheel has a rack or straight-sided shape with the side angle corresponding to the pressure angle of the gear. This rack is in continuous contact with the gear during the grinding operation while the involute generation is occurring (Fig. 15).

In order to be able to accomplish this process, the wheel, unlike the hob, must run at speeds of 45 m/s or 8,800 sfm. The indexing system must have mechanical and electronic integrity many times that of its roughing brother, the hobber. To think that one could simply modify a modern hobber and turn it into a grinder is, however, to misunderstand the kinematics required.

In the past, complicated mechanical systems provided the movements required for index and differential motions of the machines. Today commercially available electronic gearboxes are used for these machine motions. In addition to the relatively simple motions described here, the newest machines incorporate "shift grinding," which is akin to creep feed grinding in the cylindrical grinding world. The workpiece is shifted tangentially as it is fed past the grinding wheel (Fig. 16).

This tangential movement is constantly exposing the workpiece to a fresh cutting edge of the wheel, which results in fewer passes (typically one roughing and one finishing) and significantly reduces the cycle time when compared to a conventional continuous generating grinder using the multi-pass process (Fig. 17).

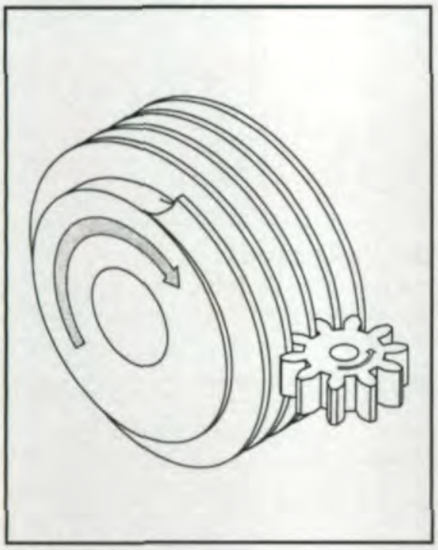

Fig. 15

Wheel technology and balancing maintenance have attempted to keep pace with machine tool advances. For most applications, the vitrified aluminum oxide wheel has been used with success. The newer breeds of machines have dictated that the wheels be "free cutting" to avoid burning. Wheels that have induced porosity and seeded gel achieve this goal. Wheels that change in size because of the constant need for redressing must be balanced in two planes. This is automatically done when the machine senses an out-of-balance condition. One machine tool manufacturer has developed a machine around a steel-bodied, threaded wheel plated with Borazon, making the dressing and the balancing operations obsolete. This makes modifications to the

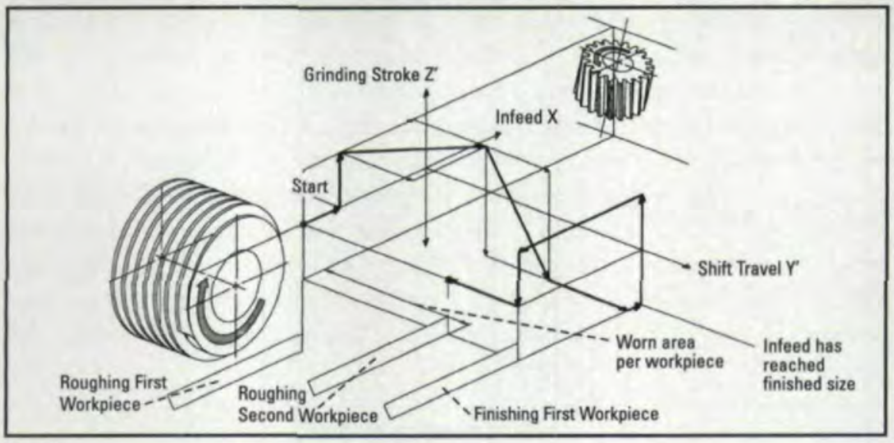

Fig. 16

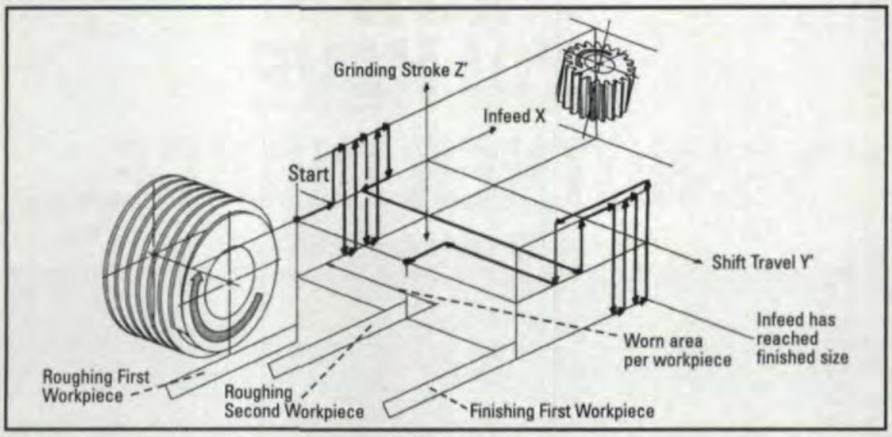

Fig. 17

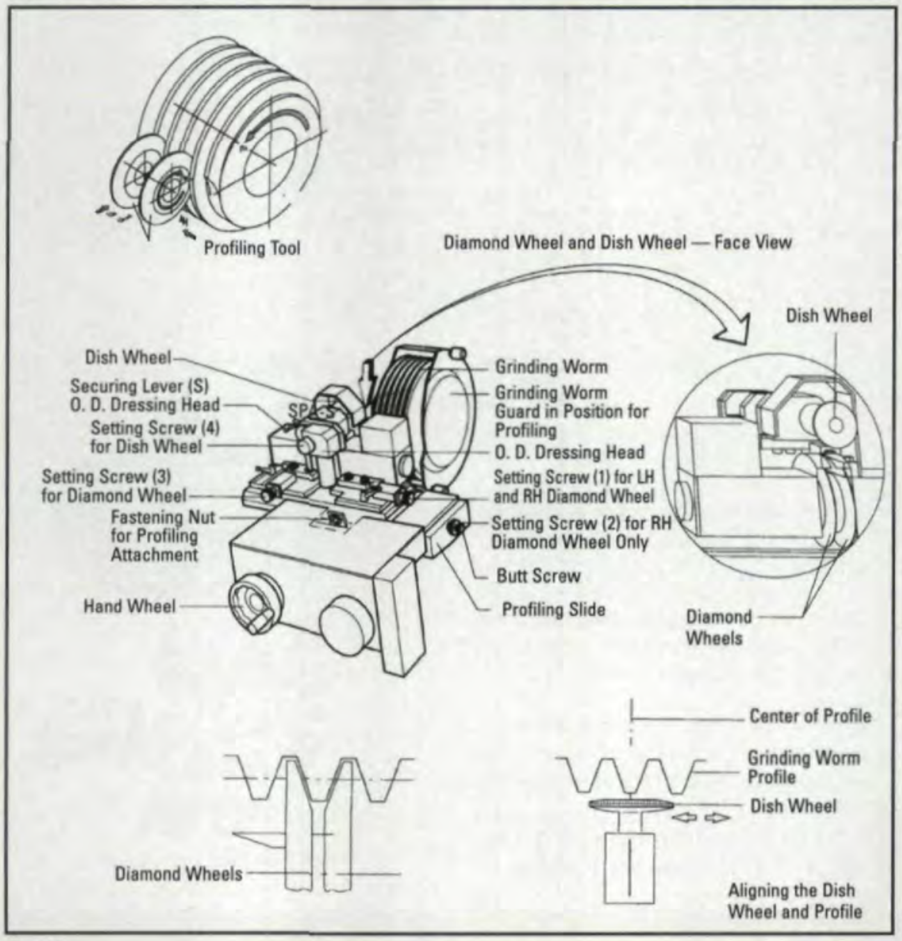

Fig. 18

wheel impossible without stripping the wheel of its coating and regrinding and replating the body. This compromise must be weighed against the productivity benefits.

Vitrified bonded wheels, regardless of their composition, must be dressed periodically to remain sharp and cut efficiently. This can be done in a number of ways, depending on the quantity of gears to be produced and the degree of flexibility required by the gear manufacturer (Fig. 18).

In the past it was difficult to automate these machines because the work spindle was in a different position after every cycle due to the part shifting across the face of the wheel. Microprocessors and modern machine controls makes this possible today.

These machines are well-suited for original equipment manufacturers as well as job shops. Productivity and flexibility standards are set today by the machines capable of using the continuous generating process. These machines can be found in the following industries: aircraft and aerospace, machine tools, printing press manufacturers, automotive truck and tractor, marine transmissions, wind turbine generators and high-speed industrial gearboxes. ⭘

Acknowledgement: *This article is based on a paper presented at the 1995 SME Advanced Gear Processing Clinic, Sept. 19–21, 1995, Chicago, IL.*

Dennis Richmond
is vice president of Reishauer Corporation, Elgin, IL, manufacturers of precision gear grinding machinery.

CIRCLE 182

CIRCLE 125

BRAD FOOTE GEAR WORKS PURCHASED

The assets of Brad Foote Gear Works, Inc., of Cicero, IL, have been purchased by J. Cameron Drecoll, Dennis Palmer and Pat Rosmonowski. The three men were all formerly with Foote Jones/ Illinois Gear.

Established in 1924, Brad Foote specializes in the design, manufacture and assembly of large, coarse pitch gears and gear drives for industrial applications. The company has two manufacturing facilities, one in Cicero and one in Pittsburgh, PA, and employs 150 people.

Revenues last year totaled approximately $20 million. The Cicero facility was the first U.S. gear manufacturing plant to receive ISO 9000 certification in early 1993 and has continued to be registered with Lloyd's Register Quality Assurance Ltd.

AGMA RELEASES NEW STANDARD

AGMA has announced the release of its standard, "Specification for Measurement of Linear Vibration on Gear Units" (ANSI/AGMA 6000-B96) This standard provides comprehensive methods for the measurement of linear vibration, the instruments to use and the test procedures to follow. It also presents the recommended discrete vibration limits for acceptance testing. Also included is an appendix regarding the ISO vibration rating curves from ISO 8579-2 "Acceptance Code for Gears—Part 2: Determination of Mechanical Vibrations of Gear Units During Acceptance Testing."

AGMA has also released the information sheet, "Load Classification and Service Factors For Flexible Couplings," AGMA 922-A-96.

Copies of the standard and the information sheet are available from Global Engineering Documents.

AGMA CHOOSES NEW BOARD MEMBERS & OFFICERS

Eleven gear industry leaders were appointed to the AGMA Board of Directors during the group's annual meeting in Tucson, AZ, in March.

David L. George of the Falk Corporation is chairman. Samuel R. Haines II of Gear Motions is senior vice president, and Bipin N. Doshi of Schafer Gear Works and Andert Manufacturing will serve as treasurer. Frank J. Posinski of Cincinnati Gear Company is chairman emeritus. Arlin Perry of the Dorris Company will serve as vice president, technical division, and Michael J. Drahuschak of the Russellville Division of Amarillo Gear Go. as vice president, administrative division.

New board members are Charles A. Brannen, Overton Gear, William M. Lechler, Sumitomo Machinery of America, Julian Sabados, Rapid Gear, Michael E. Short, Gear Products, Inc. and Mike Wheeler, LM Gear Company.

Continuing board members are Roger Pennycook of Boston Gear, Samuel D. Pierson of ABA-PGT Inc., Douglas V. Smith of P. T. Lufkin Indonesia, Dan Thurman of Caterpillar Inc., Gottfried H. Versock, Flender Corp., Robert R. Wallis of Rexnord and Frederic M. Young of Forest City Gear.

NCADT HOLDS AUSFORM FINISHING TECHNOLOGY DEMO

On April 8, the National Center for Advanced Drivetrain Technologies at Penn State University held an end-of-project demonstration and ausform finishing workshop. Details of the ausform finishing process were outlined and the world's first production-capable, double-die ausforming machine was demonstrated for key people from both business and the military.

INFAC/BELL HELICOPTER IN GRINDING EXPERIMENT

INFAC (The Instrumented Factory for Gears), Bell Helicopter and Texas A&M University are involved in an experimental grinding project that investigates the thermal damage (burn) in carburized and hardened precision gear materials. The result of the project will be a predictive model that facilitates the monitoring and control of grinding burn in precision gear manufacturing.

The findings will be made available to the aerospace and machined component industries.

Updates on the progress of the experiments are available from INFAC at 312-567-4264.

SLIGHT MODERATION IN MACHINE TOOL INDUSTRY GROWTH PREDICTED

Real domestic purchases (inflation adjusted) of combined metal cutting and metal forming equipment rose by an estimated 1.2% in 1996 to nearly $8.5 billion, marking the fourth consecutive year of growth, according to The CIT Group/Industrial Financing's *Fifth Annual Machine Tools Outlook—1997–1999*. However, consistent with the cyclical nature of the industry, growth in real purchases of machine tools is expected to ease somewhat through 1999.

According to the forecast, real purchases will retreat 8.2% in 1997, 1.5% in 1998 and 2.1% in 1999. According to Thomas A. Hanemann, assistant vice president of Economic Research at CIT, the relative stability of the industry is attributable largely to the overall health of the U.S. economy and the U.S. machine tool builders' ability to continue to distinguish themselves in the global marketplace while cutting unit costs and increasing productivity. The primary impeding factor to the strength of the U.S. machine tool industry through the outlook period is the probability of intensified price competition from foreign machine tool builders in the domestic marketplace and the resulting net increase in import penetration.

"Machine tool builders should not allow the 1995 and 1996 booms in the business to leave them complacent and even more vulnerable to losing market share to their foreign counterparts," says Hanemann. ○

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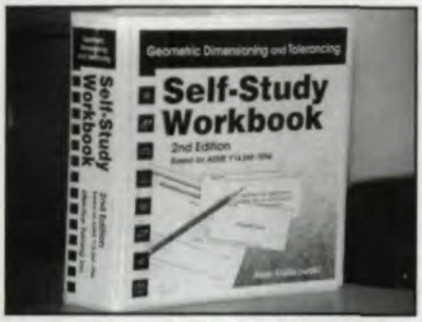
Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown. Send your new product releases to: *Gear Technology*, 1401 Lunt Avenue, Elk Grove Village, IL 60007, Fax: 847-437-6618.

Corrosion Resistant Gage Pins

Corrosion resistant coatings are now available on all gaging products from Meyer Gage. The electroless nickel coating is a unique nickel phosphorus alloy which exhibits good wear properties and excellent corrosion resistance. Coating thickness can be held to within .00005" even over complex shapes. Coating meets salt spray testing (ASTM) 1000 hours.

Circle 301



Geometric Tolerancing Workbook

Effective Training, Inc. has released the second edition of the *Geometric Dimensioning & Tolerancing Self-Study Workbook* by Alex Krulikowski. Using the ASME Y14.5M-1994 dimensions standard as its basis, the workbook has been revised, expanded and updated to reflect the changes in the field of geometric tolerancing. The book is useful to both the beginning student and the seasoned professional. The 30 lessons each contain graphics, study cards and self-tests that allow students to proceed at their own pace. After the course is completed, the book can serve as a reference tool.

Circle 302

UV Inspection Lamp

Spectronics Corp. has announced major design improvement to their BIB-150P ultraviolet inspection lamp. The company bills the products as the highest intensity self-ballasted UV lamp on the market. It has a new dent-proof and impact-resistant polymer housing and an ergonomically designed, stay-cool contoured handle. The lamp produces a nominal steady-state 365 nm intensity of 4,500 μW/cm^2 at 15" (38 cm) and meets mil specs for FPI and MPI. The lamp has as total weight of 3.25 lbs (1.5 kg), and its bulbs have and average rated life of 5000 hours. It is UL listed, CE and CSA approved.

Circle 303

TEC-14 Optical Comparator

Springfield, VT. J & L Metrology introduces the TEC-14 optical comparator with 0.00005" resolution, patented telecentric optics and a base price near $10,000. PC-based full automation is an available option. The standard machine package includes standard travels of 12" x 6" (305 x 152 mm) and a table surface of 5" x 20" (127 x 508 mm). Flat images true to size are produced at all magnifications from 5X to 100X. The TEC-14 has a standard 14" (355 mm) ground glass screen lit by tungsten halogen profile projection and surface illumination, and 360° chart rotation with DRO. Options include powered travels, geometric computation digital readout, automatic edge sensing and full automation.

Circle 304

Pfauter Introduces New Small Gear and Form Grinding Machines

Rockford, IL. American Pfauter, L.P. has introduced two new small CNC gear and form grinding machines to complement its line of larger gear grinders. The company says both of these machines are "highly affordable."

The P200G and P400G, with 200 mm and 400 mm capacities respectively offer all of the features and benefits of larger Pfauter machines in a small, compact package. The grinding heads and spindles are capable of using any commercially available single-layer plated CBN grinding wheels. The P400G can be equipped with an optional grinding head and spindle with a 2-axis CNC dressing unit for job shop environments.

The machines also have inductive sensor systems, CNC controls with Windows-based dialogue menus, optional machine-integrated, arbor-loading automation.

Circle 305

Compensating Face Spacer for Hobbing

Brookfield, WI. Euro-Tech announces the availability of a new hob spacer with a compensating face surface. The spacer's swivelling face eliminates the hob twist, bow, and bend that occur when tightening the hob nut against uneven spacer or hob faces. These can be used as a replacement for or in conjunction with existing spacers. They are available in all sizes.

Circle 306

Heavy Duty Vertical Rotary Surface Grinder

S & S Machinery Corp introduces the new ELIGIN 38 vertical rotary surface grinder. The company says that new features permit high speed precision grinding at a lower cost per part. The machine has ample power for rapid stock removal and rigidity for precision, and its advanced design and construction assures greater accuracy, extreme flatness and fine finish. It has an infinitely variable table rotating speed, full magnetic force and infinitely variable chucking, a meter for measuring magnetic forces, demagnetization and a meter for measuring work load on the main motor.

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Glendale, CA. Gloves In A Bottle is a lotion which provides a one-way barrier which helps prevent most irritants and toxins from penetrating the skin, while allowing the skin to breathe and perspire naturally and increasing natural moisturizer retention. According to the company, the lotion provides protection from a wide range of irritants including grease, solvents, thinners, paint, herbicides and pesticides, industrial detergents and disinfectants, epoxies and glues, cement and lime, gasoline and diesel and most other chemicals. It is said to be virtually undetectable within 3 to 4 minutes of application and will not affect dexterity or the sense of touch.

Circle 308

Adjustable Pitch Diameter Inspection Gage

The Measurement Systems Division of Moore Products Co. has introduced an adjustable pitch diameter inspection gage for checking the overball or over-pin characteristics of gears and splines either in the lab or on the production floor. The gage accommodates most external and internal gears and splines.

Standard equipment includes the pitch diameter inspection gage, one set of ball/pin anvils, a part-holding stand, the digital readout, the Data Gage 873 measuring system and a workbench with storage drawer. Options include center assembly, printer and interface with a LAN.

The gage can inspect external gear diameters from 0" to 8", internal gear diameters from 2.5" to 8" and overall gage dimensions to 30" long x 18" wide x 11" high.

Circle 309

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Gear Technology's bimonthly aberration — gear trivia, humor, weirdness and oddments for the edification and amusement of our readers. Contributions are welcome.

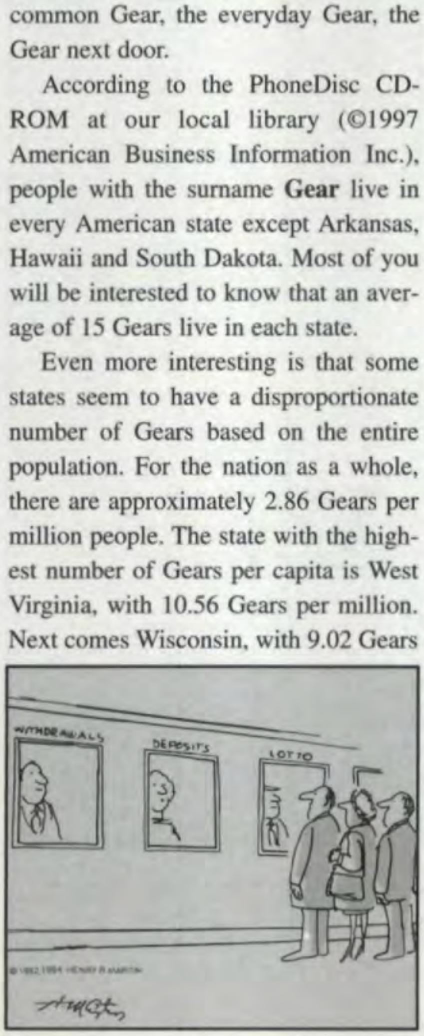
When you need totally useless information about gears, you can turn with confidence to the pages of Addendum, where we scour the globe for the obscure, the unusual and the ridiculous (the latter being our forte).

Where the Gears Are

In past issues we've brought you valuable information on famous or semi-famous people who have been named Gear (see past issues of Addendum for biographical sketches of John Henry Gear, Luella Gear and Dale Dudley Gear). But in the spirit of equality and in the interests of fairness, we thought we'd give you a portrait of the common Gear, the everyday Gear, the Gear next door.

According to the PhoneDisc CD-ROM at our local library (©1997 American Business Information Inc.), people with the surname **Gear** live in every American state except Arkansas, Hawaii and South Dakota. Most of you will be interested to know that an average of 15 Gears live in each state.

Even more interesting is that some states seem to have a disproportionate number of Gears based on the entire population. For the nation as a whole, there are approximately 2.86 Gears per million people. The state with the highest number of Gears per capita is West Virginia, with 10.56 Gears per million. Next comes Wisconsin, with 9.02 Gears per million, Massachusetts, with 8.85 Gears per million and Washington, with 6.85 Gears per million.



We hope you are beginning to see a pattern here. We're not entirely sure what it means, but the evidence is clear. From this highly scientific study, we conclude that there is a greater tendency for a person named Gear to live in the North. There also seems to be a correlation between people named Gear and states beginning with the letter W.

That's It, We're Moving!

In our cross-country travels in search of people named Gear, the Addendum staff also has come across a number of streets named Gear.

For example, there is Gear Road in Rochester, NH, Gearing Road in Monongahela, PA, Gearing Avenue in Pittsburgh, PA, Gear Avenue in Nashville, TN, and Gearing Street in Goose Creek, SC. We're pretty sure there are additional streets, roads, avenues and boulevards named Gear out there. We're counting on you to find them for us.

Until then, we are pleased to announce that the Addendum team is opening branch offices on Gear Road in Rochester, NH and Gearing Street in Goose Creek, SC (as soon as the right properties become available).

It Was Too Much To Hope For

We regret to report that we were unable to find anyone named Gear living on a street named Gear. We'll keep looking.

Martha Stewart Is In The Building

Is your office looking tacky, tacky, tacky with all those back issues of *Gear Technology* strewn about? Have you despaired of ever finding the perfect storage solution for them: the one that keeps them neat, tidy, in order and out of the way until needed? Well, your search is over.

TOP TEN STATES FOR PEOPLE NAMED GEAR

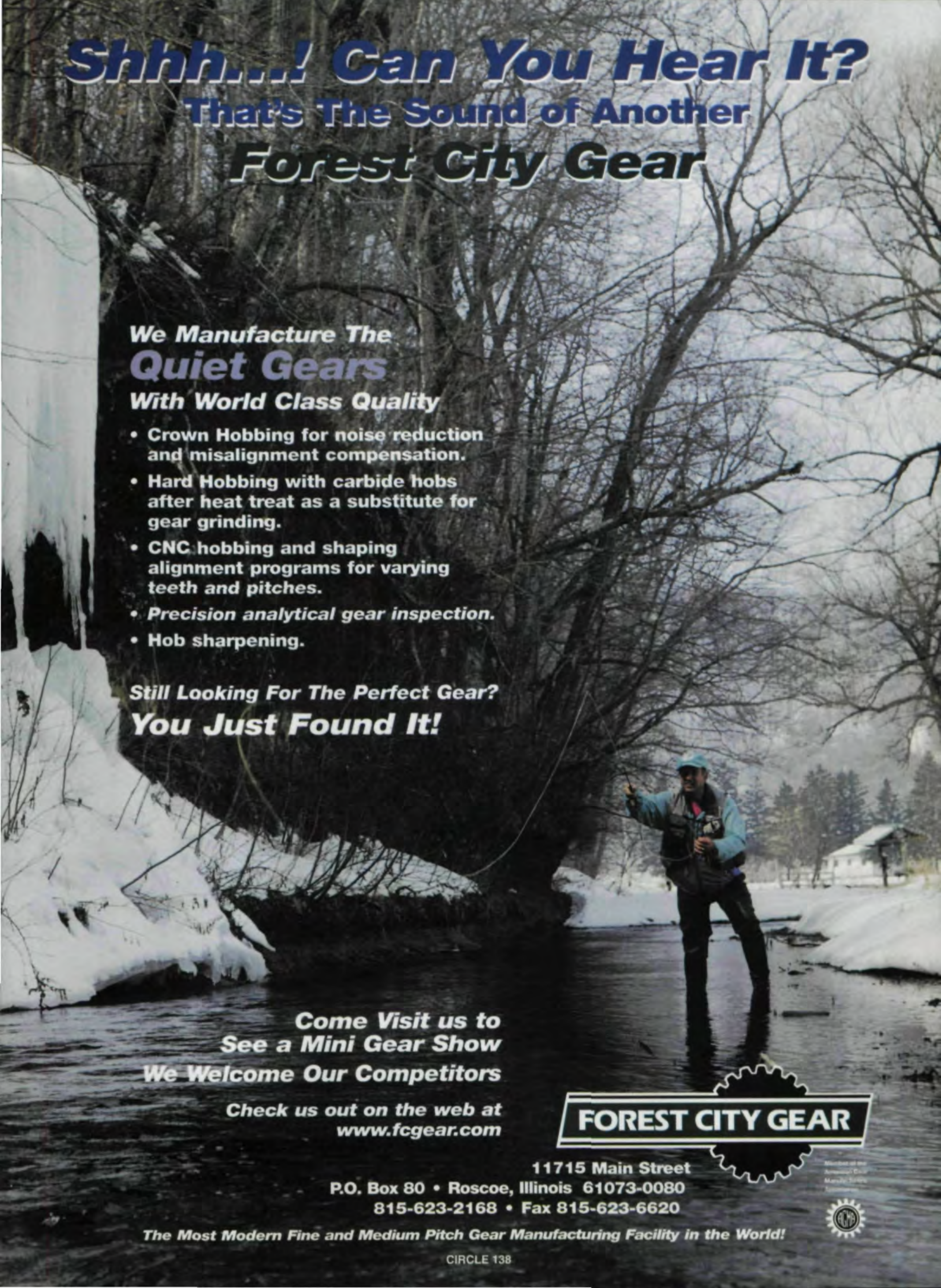
1.	California	74
2.	Florida	70
3.	Massachusetts	54
4.	Ohio	51
5.	Wisconsin	46
6.	Texas	42
7.	Washington	37
8.	*Illinois*	27
9.	New York	24
10.	Georgia	22
	Virginia	22

One of our faithful fans, Bill Rollins of South Windsor, CT, has found the answer. His recommendation: Go to your friendly neighborhood office supply store and look for a 2" vinyl binder with D-rings. According to Bill, one of these will hold two full years of Addendum columns (and all that other stuff in the magazine). The D-rings allow each issue to lie flat when it's opened for reading. You will have to use a three-hole punch on your magazines, but we've checked—the margins are deep enough to prevent making holes in the copy.

Now Martha says, get in there and tidy up your office.

If anyone has the plans for crocheting covers for the notebooks, don't call us. There's really just so much Martha Stewart we can stand. ○

The Addendometer: If you've read this far on the page and enjoyed it, please **circle 225.**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