GEAR TECHNOLOGY

The Journal of Gear Manufacturing

1996 GEAR INDUSTRY BUYERS GUIDE

NOVEMBER/DECEMBER 1996

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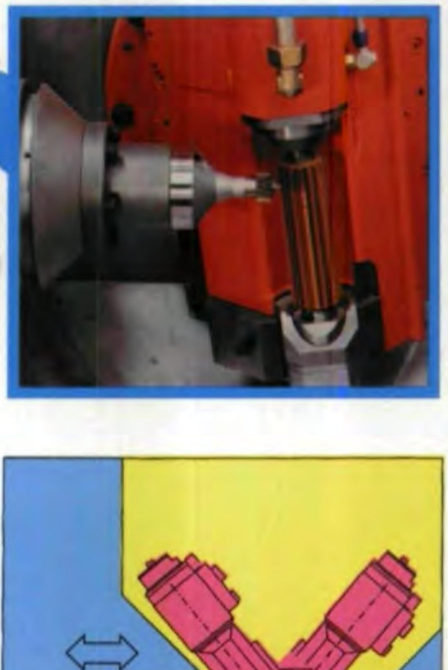

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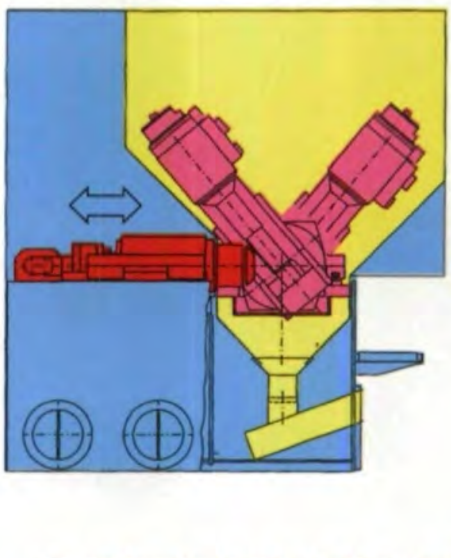

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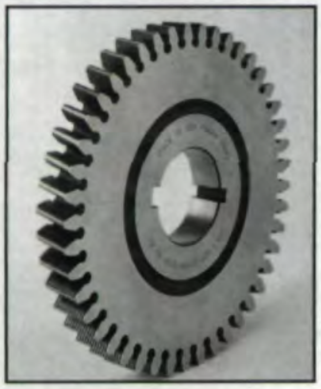

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Cover art courtesy of Liebherr-America, Saline, MI

GEAR TECHNOLOGY
The Journal of Gear Manufacturing

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VOL. 13, NO. 6

GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published bimonthly by Randall Publishing, Inc., 1425 Lunt Avenue, P.O. Box 1426, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $5.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office. Randall Publishing makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1425 Lunt Avenue, P.O. Box 1426, Elk Grove Village, IL, 60007.

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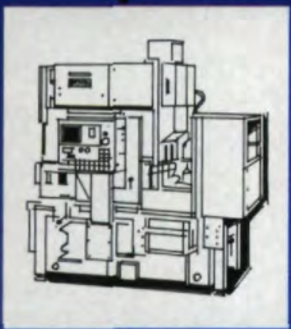

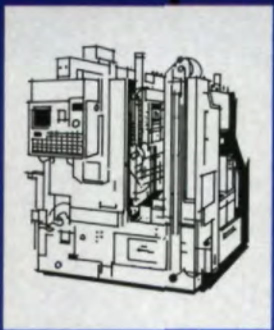

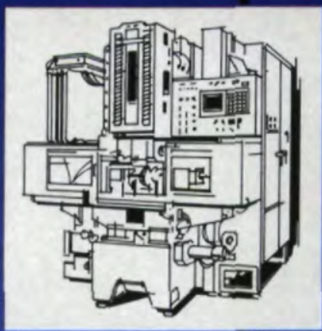

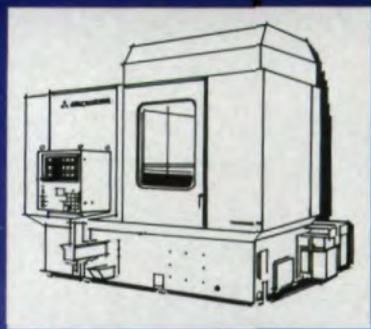

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Two columns for the price of one . . .

Just back from IMTS and once again, I'm struck by the enormous vitality and strength of the manufacturing sector of the U.S. economy. It has made a phoenix-like rise from the grave dug for it by pundits in the '80s and has come back more robust and competitive than ever.

True, it's not our father's factory floor on display at the show, but in most ways it's a lot better than he ever dreamed it could be. It's a lot cleaner and there's a heightened awareness of safety and health issues. Production is faster, more organized and at the same time more flexible. The new applications and processes would amaze Dad (they amaze me). The companies have a real global reach now, and the faces to be seen are from every corner of the planet. Doesn't look much like a dying sector of the economy to me.

IMTS itself gets bigger and better every two years. It now takes up all three buildings at McCormick Place, and "doing" the entire show requires the training and stamina of a triathlete. To counter the inevitable information overload caused by a show this size, the addition of "pavilions," including the one for gear machinery, are especially welcome. It was a real treat to have most major industry players all conveniently located in the North Building, where valuable time could be spent looking at machinery and talking to the experts rather than walking through miles of other booths.

The "hot" news at the Gear Generating Pavilion was the agreement in principal between Gleason and Pfauter (see our story on p. 16). The details of this agreement have yet to be worked out, but this is a story to watch over the next few months.

Industry trends continue much the same as they were at Gear Expo last November: Dry hobbing, faster speeds and feeds, more flexible manufacturing, and the growing presence of Windows-based software for all kinds of gear applications. The other good news is the reappearance of cheerful, smiling faces among the sales staffs. Business is very good for almost everyone, a welcome change from a few years ago, when popular wisdom had our industry on life support.

Meanwhile, back at the office . . . Our own newest ventures, The Gear Industry Home Page™, our electronic buyers guide for gear machinery, tooling and accessories, and *Gear Technology* online, are both off to a strong start. We have had over 3000 "hits," or page requests, originating everywhere from Malta to Malaysia in both August and September. Reports from advertisers on The Gear Industry Home Page™ are also positive.

The Gear Industry Home Page™ has had over 3000 "hits," or page requests, from everywhere from Malta to Malaysia in both the months of August and September.

We've now introduced our direct response forms, which allow Internet explorers to request information online. Advertisers get specific information, such as names, addresses and job titles, about inquirers, much as they would from people who fill out "bingo card" forms in print magazines.

Like everyone else on the Internet, we're learning to use this new medium as we go along. Some important facts we've discovered so far are these.

1. While the Internet doesn't make for a "paperless" office, it can radically reduce the amount of paper (and the expense of printing) you incur to reach your customers. The print bill alone for even a simple one- or two-page brochure can run to thousands of dollars even before you mail it. The same information disseminated on the Internet costs the amount of time it takes to generate the copy and get it up on line. And you have no mailing costs at all.

2. The Internet is an infinitely flexible medium for spreading the word about your company. Changes to your information can be made in a matter of minutes, at little or no additional cost. You never have to store the extra copies of anything or throw away hundreds of out-of-date (and expensive) versions of your literature.

3. The Internet can put you in touch with people you never dreamed would be interested in your product, ones you wouldn't necessarily find by renting a mailing list. The very public nature of this medium means that people from everywhere can check out your site with the ease of a few mouse clicks. True, you may attract some "tire kickers" this way, but you also can establish contacts with potential customers you never knew were there.

4. The people who use the Internet most right now are what marketers call "early adapters." They like new technology, and they're eager to use it. This attitude doesn't just apply to the Internet. They're just as interested in your newest products and services. They're the kind of potential buyers you want to attract.

As late as this summer, I was an Internet skeptic and let my staff talk me into this venture with some reluctance. Now that I've seen how the Internet works and the power it has to convey information about products and services quickly and inexpensively anywhere in the world, I've become a convert. The success of our own Internet ventures has convinced me that as time goes on, more and more of our business will be conducted in cyberspace. People and companies who establish their presence early and who learn how to market their companies and products on the Net will have an advantage over the competition.

Michael Goldstein
Publisher & Editor-in-Chief


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Standard Issues

Like making law and sausages, standards development is an important, but messy process.

Nancy Bartels

Standards are not unlike gears themselves: mundane, but complex, ubiquitous and absolutely vital. Standards are a *lingua franca*, providing a common language with reference points for evaluating product reliability and performance for manufacturers and users. The standards development process provides a scientific forum for discussion of product design, materials and applications, which can lead to product improvement. Standards can also be a powerful marketing tool for either penetrating new markets or protecting established ones.

No wonder then that their development and publication is an important part of the work of major technical societies, including AGMA. AGMA's input into gear standards development here and overseas causes ripples that reach all the way to the floors of the tiniest gear shops.

Because of the globalization of manufacturing, interest in developing common international standards has grown. AGMA plays an important role in this development. In addition to developing national standards, it serves as the secretariat for work on international gear standards. Working through ANSI, the American National Standards Institute, it is responsible for processing documents as they are developed. It also oversees and arranges the various committee meetings, organizes ballots, supervises editing, handles logistics, distributes reports of meetings, etc.

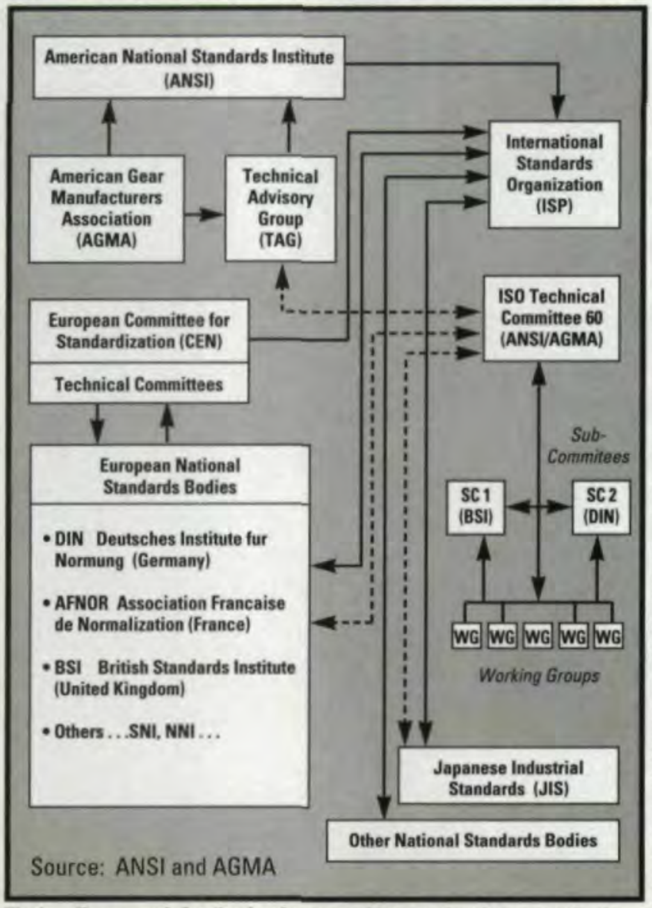

Fig.1 — Framework for the development of international gear standards.

Fig. 1 shows the relationship of the various national standards bodies. In reality, the process of developing common standards is not nearly so tidy. Different company and national interests, various interpretations and understandings about what is important, differing personalities and agendas on the part of the delegates, all have to be factored into the equation.

An Ever-Receding Horizon

In truth, developing all universal gear standards may not be possible, at least in the foreseeable future. For example, until U.S. gear buyers accept metric units, if they ever do, two sets of measurements will be used.

AGMA continues to develop its own standards for use in the U.S. Its goal is to harmonize its standards with those of ISO, but at the same time, parallel development continues. At present, AGMA has standards regarding some issues that ISO does not cover. ISO's 18 standards cover rating nomenclature, tooling and geometry, while AGMA's 58 standards also cover materials, enclosed drives, lubrication and other issues.

At the same time, AGMA closely evaluates ISO gear standards development and decides whether to incorporate its work into AGMA standards. It also sends delegates to ISO standards meetings to ensure that the U.S. has input into ISO standards development.

According to AGMA Technical Director, Bill Bradley, the goal of AGMA and ISO is to have good international standards that everyone can use. The approach to this goal is an incremental one. Standard by standard and meeting by meeting, AGMA and the other national standards-making organizations are working to bring their various standards closer and closer together.

Consensus by Compromise

According to Bradley, some of the issues that make international standards development an exercise in the fine art of compromise are the varying formulas used for determining gear performance and design, differences in understanding what these formulas mean and how they are to be implemented, differing national and company interests and different cultural expectations.

CURRENT AGMA STANDARDS PROJECTS

STANDARD/INFO SHEET	AGMA COMMITTEE	DOCUMENT NAME
903-AXX	7c	Scoring Design Guide–Aerospace Gears
912-AXX	3a	Mechanisms of Gear Tooth Failures
913-AXX	3a	Profile Shift (Addendum Modification)
916-DXX	3b	Fine-Pitch, On-Center Face Gears
917-BXX	3b	Design Manual; Parallel Shaft Fine-Pitch Gearing
920-AXX	3c	Plastic Gearing Materials
921-AXX	7g	Guide for Wind Turbine Drives
922-CXX	6e	Load Classification & Service Factors; Flex Couplings
923-AXX	5c	Gear Material Grade Specifications
924-AXX	5c	Metallurgical Practice for Ind. Carburized Gearing
925-AXX	5a	Lubrication Effects on Distress (Scuffing, etc.)
926-BXX	7c	Procedure for Carburized Aerospace Gears
927-AXX	5a	Gear Tooth Load Distribution Calculations
928-AXX	4b	Inspection Data Electronic Interchange Protocol
929-AXX	5b	Calculation for Bevel Gear Topland Tooth ....
930-AXX	3d	Load Capacity of Powder Metal Gears
931-AXX	4c	Calibration Alignment
1002-BXX	4a	Gear Cutting Tools, Fine- and Coarse-Pitch Hobs
1006-AXX	3c	Tooth Proportions for Plastic Gears
1106-AXX	3c	Metric Tooth Proportions for Plastic Gears
2003-BXX	5b	Rating Pitting Resistance & Bending Strength, Bevels
2009-AXX	4b	Classification & Inspection of Bevel Gears
2011-AXX	6a1	Wormgear Tolerance & Inspection Methods
2113-AXX	4c	Measuring Machine Calibration—Alignment
6001-DXX	5e	Design of Components of Enclosed Drives
6007-AXX	3c	Test Methods for Plastic Gears
6008-AXX	3d	Powder Metallurgy Gears
6009-AXX	6c	Gearmotor, Shaft Mount & Screw Conveyor Drives
6010-FXX	6b	Spur, Helical, Herringbone & Bevel Enclosed Drives
6011-HXX	7b	Specification for High-Speed Helical Gear Units
6025-DXX	4d	Vibration Enclosed Helical & Sprial Bevel Drives
6030-DXX	6a2	Design of Industrial Double-Enveloping Wormgears
6033-BXX	7a	Standard Marine Gear Units, Materials
6110-FXX	6b	Spur, Helical, Herringbone & Bevel Enclosed Drives
9001-BXX	6e	Lubrication for Flexible Couplings
9004-AXX	6e	Flexible Coupling Mass Properties
9008-BXX	6e	Dimensions for Gear Coupling Flanges
9009-DXX	6e	Nomenclature for Flexible Couplings
9102-AXX	6e	Metric Bores & Keyways for Flexible Couplings

Take the case of developing a formula for applying load to gear teeth as an example. There are a number of ways to do this. Which way should go into the standard? Should two or three ways be put in and let the user decide which to use, or should one be specified? If so, which one? Or should a new formula that incorporates the best of all of them be developed?

All of these issues—and similar ones for every standard—have to be hammered out.

One of the most obvious cultural differences that must be worked around is the reluctance of the U.S. to adopt the metric system. ISO wants—and needs to have—standards stated in metric. But it's not enough to convert measurements from one system to the other. ISO would prefer to have standards in "hard" metric; that is, developed in metric from the ground up. Such standards for gears are easier to work with if tooling is already set up in metric increments.

On the other hand, many U.S. companies are still oriented toward working in inches and feet, and it does not seem likely that the U.S. will abandon the old pound-inch measurement system any time soon. Given that fact, AGMA standards will have to accommodate both measurement systems for some time to come.

Another important difference that affects the way standards development shakes out is the manufacturing orientation of AGMA and other U.S. standards. "Standards development should be a market-driven process. There should be a market need for a given standard before it's developed," says Bill Bradley. "Standards are no good unless they are usable in a contract."

AGMA's standards tend to reflect the "state of the market," lagging behind the "state of the art." Typically, they rely on simple empirical equations in contrast to others, such as the DIN standards, which tend to include more complex equations based on element-by-element lab testing of ideal gears. Advocates of the DIN methods point out the advantages of a strong theoretical basis, while AGMA's supporters stress ease of use and years of successful applications over a wide range of sizes and configurations. Finding a common ground between these positions is a slow process.

A factor which is of less importance to Europeans, but which is crucial to U.S. standards, is the issue of product liability. In the U.S., standards have to be very explicit about their applicability, the range of their application, etc. Language like "... is outside the scope of this standard," is frequently found in U.S. standards. The less litigious nature of European countries makes that language unnecessary in ISO standards.

Corporate & National Interests

AGMA has long been encouraging manufacturers to get more involved in standards development by sending delegates to standards committee meetings. "They should be involved," says Bradley, "because they're the ones who know what the markets have been asking for. They have the field experience to say what's realistic."

But this involvement can impede compromise. Obviously, individual companies have specific interests they want protected. However, as time goes on, and American manufacturers become more globally oriented, the need for compromise becomes more apparent and looking beyond narrow self-interest becomes easier.

The same is true of various national interests. The way standards are written can, intentionally or not, favor practices in one country over those of another. Overcoming this national interest in the push for a common benefit is one more element that has to be accommodated in the process.

Perhaps surprisingly, this obstacle is not as big as it might be. "There's not as much nationalism or company protectionism as you might think," says Bradley. "People on the committees tend to think more about the technical aspects of the problem. We've all learned to develop a consensus."

A Knowledge Bank

In the midst of all this jockeying for position and accommodating a variety of interests, one important function of gear standards making tends to get lost: that of providing a repository of gear knowledge. The professionals who serve on the standards committees bring a wealth of theoretical and practical experience to the table. In the process of hammering out the final form of the standards, much of this knowledge gets preserved and transmitted. If gear standards served no other function, this would be a vital one.

"The U.S. gear industry is old and is consolidating," says Bradley. "There are fewer good, experienced gear engineers, and we need all of them to work on standards in order to keep up their quality. If one waits for others to do the standards development, they will! For the U.S. to continue to be truly competitive, we must participate and take a leadership roll in developing industry standards."

The 9000 Series Controversy

At present, the standards that are getting the most attention are the 9000 series of quality standards. AGMA does not have a comparable set of standards and has no official position on whether these standards should be adopted by individual companies. ISO 9000 series standards can be applied to the entire manufacturing process, but AGMA is interested only in gear standards. It does not write quality method standards.

However, these standards have caused a good deal of controversy. Many people both in the U.S. and Europe feel that the ISO 9000 standards were never intended to be vehicles for third-party certification, but rather were meant to be used internally by companies for their own evaluation purposes. The development of a lucrative third-party certification industry, the concerns of smaller companies about the high cost of qualification, and the debates about the qualifications of registrars and consultants have led some to reconsider the entire ISO 9000 certification process.

The advent of the Big Three automakers' QS-9000 program has only complicated the issue. This program is not a product of the original ISO 9000 series, but a separate set of quality standards which is now being demanded by Ford, GM and Chrysler. The pros and cons of this program and its effect on the ISO 9000 series are the subject of still more debate.

AGMA's Overall Goal

The development of common standards may seem glacially slow at times, but progress is definitely being made. At any given time, AGMA has between twenty and twenty-five active committees at work on one and sometimes two or more standards. (See the attached list of current AGMA projects.) In addition, some committees are working on information sheets, which contain material that is not included in standards, but is useful or needed to apply standards effectively.

AGMA's goal is to bring AGMA and ISO standards into harmonization as soon as the gear industry will accept a single standard, but progress is slow and tedious. It takes two to three years to revise or develop a standard, depending on how active a committee is. And committees are all made up of volunteer members.

The Best of Times; The Worst of Times

Ironically, times like these, when business is good, can be one of the worst times for standards development. Some companies are too busy to let valuable employees have time away from the office to attend standards committee meetings. On the other hand, when business is poor, companies can't afford to let employees attend. Willingness and commitment on the part of both individuals and their employers are crucial to the success of the various standards committees.

International standards development may be a bit like making law and sausages—a messy process whose result is not necessarily to everyone's liking. But it is an important one. As business becomes more and more global, the push to harmonize standards, although it may come in fits and starts, will certainly continue. ○

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TECHNICAL CALENDAR

NORTON TOOLROOM SCHOOLROOM

The Norton Company offers this course in various cities around the country during the **weeks of Nov. 10 and 17**. The course is a one-day seminar focusing on how to select and use grinding wheels for optimum efficiency and results. It will cover grinding theory, bonded abrasive basics, wheel selection, dressing, superabrasives, mounting and truing and grinding wheel safety. Contact Norton at 508-795-5000 or fax 508-795-2688 for more information.

EDUCATION SYSTEMS WORKSHOP, INC.

Steel Mill Gearing Symposium, Sharaton Station Square Hotel, Pittsburgh, PA. Held **Nov. 13–14**, this course will cover steel mill drive systems using the gear units as reference points. The use of gear standards, optimum gear tooth modification metallurgy and drive lubrication for all types and geared drive systems for steel mills will be discussed. The course should be of particular interest to maintenance personnel, operators, engineers, metallurgists and researchers, as well as manufacturers of drive components, mill builders, service personnel and consultants. Contact ESW at 219-865-1318 for more information.

SME AUTOFACT '96

Conference and exhibition will be held **Nov. 12–14** at Cobo Center, Detroit, MI. Autofact '96 is billed as the industry's premier conference and exposition for products and processes for design engineering in manufacturing. Exhibits and seminars on a variety of subjects of interest to design and process engineers and managers, including CAD/CAM, EDM, rapid prototyping, systems and communications and factory automation. Contact SME at 800-733-4763, 313-271-1500 or fax 313-271-2861 for more information, or check the SME web site, *http://www.sme.org*.

AGMA GEAR SCHOOL

This final session of the year will be held at Richard J. Daley College, Chicago, IL from **Nov. 18–22**. The course is designed for employees with at least six months' experience in setup or machine operation, and it covers setup, gear inspection, gear calculations and basic gearing principles. Call Susan Fentress at AGMA, 703-684-0211 or fax 703-684-0242 for more information.

SPC AND METROLOGY FOR GEAR MANUFACTURING

Two-day course in SPC will be held **Jan. 21–22, 1997**, and a one-day mini-course in Understanding Gear Metrology will take place on **Jan. 23, 1997**. Both courses will be held in Indianapolis, IN, and are sponsored by SME. For more information, contact Cherrie Bacon at SME Headquarters, 313-371-1500, x 358 or e-mail: bacoche@sme.org. Information is also available on the SME web site, *http://www.sme.org*.

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U.S. POSTAL SERVICE STATEMENT OF OWNERSHIP, MANAGEMENT & CIRCULATION AS OF SEPTEMBER 29, 1996

Publication: Gear Technology, the Journal of Gear Manufacturing

ISSN No.: 0743-6858

Published: Bimonthly, 6 issues per year

Annual Subscription Price: $40.00

Mailing Address of Publication: 1425 Lunt Ave., Elk Grove Village, Cook County, IL 60007

Name & Mailing Address of Publisher: Michael Goldstein, 1425 Lunt Ave., Elk Grove Village, Cook County, IL 60007

Name & Mailing Address of Editor: Michael Goldstein, 1425 Lunt Ave., Elk Grove Village, Cook County, IL 60007

Name & Mailing Address of Managing Editor: Edward J. Mueller, 1425 Lunt Ave., Elk Grove Village, Cook County, IL 60007

Name & Mailing Address of Owner: Michael Goldstein, 1425 Lunt Ave., Elk Grove Village, Cook County, IL 60007

Known Bondholders: None

Nature & Extent of Circulation	Average No. of Copies Each Issue During Preceeding 12 Months	Actual No. of Copies of Single Issue Published Nearest to Filing Date
Total No. Copies	13,667	12,080
Paid and/or Requested Circulation (not mailed)	5	7
Mail Subscription	8,072	8,971
Total Paid and/or Requested Circulation	8,077	8,978
Free Distribution by Mail	4,725	2,242
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Total Distribution	13,551	11,991
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Total	13,667	12,080
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New Gear Developments at IMTS

The International Manufacturing Technology Show provided one of the biggest ever marketplaces for buying and selling gear-making equipment, with 121,601 attenders, making it the largest IMTS ever. The show took place September 4–11 at McCormick Place in Chicago, IL.

The gear industry made a strong presence at the show, with the introduction of the Gear Pavilion at IMTS. The new focus area allowed visitors to find most of the companies who sell gear manufacturing machinery all in one place.

Several key gear industry companies made announcements or introduced new machines that should have an impact on gear manufacturing for many years to come.

Gleason to Acquire Pfauter Group

Gleason Corporation shocked the gear industry just before the show opened by announcing that it had reached an agreement in principal to acquire all assets of the Hermann Pfauter Group, based in Ludwigsburg, Germany.

The purchase will include Pfauter's gear machinery manufacturing operations in Germany, Italy and the United States as well as the company's 76% interest in Pfauter-Maag Cutting Tools, L.P., located in Loves Park, IL. The Pfauter Group employs about 1,050 worldwide and had combined sales of $175 million in 1995.

According to Gleason and Pfauter management, the entire deal took place over the last few weeks before IMTS and was kept under tight wraps so an announcement could be made at the show.

"Pfauter has long been recognized as a leading supplier of cylindrical gear production equipment, as Gleason has for bevel gear production equipment. The combination of our two companies will create an excellent strategic fit that will expand our product line, substantially enhance our ability to provide our customers fast and effective solutions to their gear processing needs and offer significant benefits from combining technology, production capabilities and distribution channels," said James S. Gleason, chairman and president of Gleason Corporation.

Mitsubishi Debuts 3-in-1 Gear Center

A unique machine that combines hobbing, deburring and rolling in one machining center was demonstrated for the first time at IMTS by Mitsubishi Machine Tools USA.

The GT06R is aimed directly at automotive manufacturers—it can produce one AGMA Class 10 gear every 10–15 seconds. One machine and one operator can produce gears that leave the machine ready for heat treating.

The machine has a maximum hob speed of 4,000 rpm and a maximum table speed of 750 rpm. It measures 13.2 feet by 11.5 feet. Also available is a GT06S model, which replaces the rolling function with a shaving function to finish the gears.

Fellows Introduces Direct-Driven Shaper

The new FS180 Mark III CNC Hydrostroke gear shaper features six servo-driven axes of motion for higher-speed cutting cycles. In addition, the machine is being introduced at a *lower* price than that of the previous model.

The manufacturer claims the machine may reduce cutting cycle times by as much as 35% with speeds up to 2,000 strokes per minute. It handles pitch diameters up to 7" and face widths up to 1 1/4", which makes it appropriate for automotive transmission applications.

Gleason Knowledge System Demonstrated

The Gleason Works introduced a new software system for its PHOENIX 125GH CNC hobbing machine. The software, installed on a personal computer, provides the machine operator with setup, startup, operational, troubleshooting and maintenance information.

The system combines the knowledge of Gleason's technical experts to include complete fault diagnostics with suggested remedies, a complete set of replacement parts drawings, animated tutorials to explain key concepts and complex procedures and training modules to help the user get accustomed to the machine interface and control panels.

Bourn & Koch Redefines Small Footprint

The Model 25H hobbing machine demonstrated by Bourn & Koch Machine Tool Company is a 4-axis CNC hobber for 1" maximum diameter and 4" maximum face width gears.

The machine is almost a desktop model, occupying a 30" x 30" space on the floor. It includes auto hob shift, double cut and crowning capabilities and can use carbide or HSS hobs.

Star Cutter Introduces Tool & Cutter Grinder

Elk Rapids Engineering, a subsidiary of Star Cutter Company, demonstrated its new UTG-300 CNC five-axis tool and cutter grinder, which includes Windows-format software for sharpening hobs, shaper cutters, broaches, end mills, taper fluted tools and Maag-style cutters.

Pfauter-Maag Introduces Shaving Cutter Line

Pfauter-Maag Cutting Tools, L.P. announced that it has begun offering a complete line of shaving cutters, including standard, underpass, plunge and diagonal-type cutters in a range of sizes and accuracy capabilities.

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The Advantages of Ion Nitriding Gears

This process can eliminate the need for expensive post-heat treatment operations.

Robert Lamont, Jr. & A. Bruce Craven

When it comes to setting the standard for gear making, the auto industry often sets the pace. Thus when automakers went to grinding after hardening to assure precision, so did the machine shops that specialize in gearing. But in custom manufacturing of gears in small piece counts, post-heat treat grinding can grind away profits too.

One alternative that has yet to be fully exploited by the gearing industry is ion nitriding. General Motors' Allison Division has ion nitrided 4140 steel diesel engine gears, Ford has used the process for certain models, and perhaps a dozen commercial heat treaters around the United States provide ion nitriding services to machine shops. Here—from the perspective of a custom gear shop and a heat treater—are some of the advantages that ion nitriding offers gear makers.

Advantages of Ion Nitriding

For any manufacturing operation, grinding adds not only time and labor, but also an element of risk. Grinding has become a routine part of gear making, primarily because the heat treating processes that harden load-bearing parts such as gear teeth also introduce thermal stresses that cause distortion. But unlike induction hardening, a commonly used surface hardening process in which gear teeth are hardened tooth-by-tooth or one at a time, ion nitriding introduces favorable compressive stresses.

Table 1 — Case Depth

Steel Grade	Typical	Practical Maximum
1045	.001" – .002"	.002"
4140	.010" – .012"	.025"
4340	.008" – .010"	.015"
A-2, D-2, H-13	.008" – .012"	.015"
400 Series S/S	.004" – .006"	.010"
300 Series S/S PH S/S (17-4, 17-7, etc.)	.003" – .004"	.005"

Ion nitriding is performed in a precision-sealed vacuum furnace. After the air is evacuated (to less than 100 ppm of air), a small partial pressure of hydrogen and nitrogen gas is bled into the chamber, and the vacuum is maintained at about 5 torr (atmospheric pressure is 760 torr). Then, energizing the parts to a negative (approximately 500 volt) potential initiates an electrical plasma of gaseous ions. The positively charged ions are attracted to the part, subsequently reacting with the alloy elements of the steel part to form nitrides. The nitriding temperature is significantly lower than that of induction hardening or carburizing—specifically, 950°F. Moreover, with ion nitriding, there is no need for a liquid quench, eliminating another source of adverse stresses and distortion. Eliminating most heat treat-induced distortion is critical for any manufacturer, particularly smaller machine shops with limited equipment for secondary operations such as grinding and straightening.

Practical Applications

How do these theoretical advantages translate into everyday practice? At Atch-Mont Gear, a good customer requested a Class 10 gear with hardened teeth. A Class 10 gear is not that hard to machine, but typical practice for a 4140 gear (either annealed or pre-heat treated) would have been to induction harden the *gear teeth only* for better wear characteristics. The distortion introduced by induction hardening or carburizing lowers the class number (or precision) because of the high process temperature (in excess of 1600°F) and subsequent quench. Lacking the ability to grind all types and sizes of gears, Atch-Mont's only option for returning the gear to the required precision appeared to be sending the piece out for tooth grinding. This was cost prohibitive.

Fortunately, Atch-Mont has had some customers who requested gas nitriding with ammonia, so the company was familiar with nitriding's low-distortion benefits. Solar Atmospheres, a commercial heat treater specializing in vacuum processing, suggested the piece would be a good candidate for ion nitriding. Atch-Mont told the customer it couldn't *guarantee* Class 10, but could ion nitride and lap the gear teeth if necessary. The results were successful.

Ion Nitriding Worm and Pinion Shafts

Worm and pinion shafts are also good candidates for ion nitriding. Parts that are usually made from 8620 steel and carburized, or from 0.4 carbon medium alloy carbon steel and induction hardened need to be rough machined with extra material on the journals. This allows for finish machining to overcome the distortion resulting from carburizing or induction hardening. With ion nitriding, this is not a requirement.

Worm gears—typically made from 8620, 4615 or 1045 steel—have a tendency to unravel when carburized or induction hardened (because of the higher temperature process), which means they have to be ground afterwards to make them straight and true with respect to the bore (or centerline). At Atch-Mont, engineers found that by making the gears of pre-heat treated 4140 steel and ion nitriding them, nearly the same hardness could be achieved. Herringbone gears will respond with the same positive results.

At Solar Atmospheres, gears in the 10–12" diameter range are commonly ion nitrided, and gears of up to 30" in diameter can be accommodated. Gear materials most commonly ion nitrided are the medium alloys—the 4000 and 5000 series steels and, occasionally, the 6000 series steels. Stainless steel, which is very hard to gas nitride without mechanical or chemical surface treatments prior to processing, can be ion nitrided, although not as easily as the medium alloys. (The high percentage of chromium and nickel develops very hard surface nitrides that saturate the metallurgical structure quickly, making the ultimate case depths shallower than the alloy steels.)

Ion nitriding introduces minimum growth on the order of .0001—.0002" per side and requires less processing time than gas nitriding. But the real advantage for a machine shop is the reduced number of machining steps coupled with the quick turnaround, which results in faster manufacture. It can also give manufacturers more material selection choices. The resultant benefits are moderate surface hardness gains with deep case depths in medium alloy steels, high surface hardness with shallow case depths in stainless steels and high surface hardness with modest case depths in tool steels.

Masking

With ion nitriding, workpieces may have to be masked to insure that surface hardening occurs only where it is supposed to. Sometimes this is relatively easy; i.e., gears can be stacked, permitting nitriding of the teeth with just the topmost pieces requiring a mask to cover the face and bore. But even when individual pieces have to be masked with a stop-off paint—a time-consuming but effective process—Atch-Mont Gear feels it's well worth it to "get the gear we want."

Currently, ion nitriding is used for gears up to 30" or 36" in diameter. In fact, the authors believe it is technically feasible to produce ion nitrided gears that would compete with many carburized gear applications. Most ion nitriding heat treating shops do not have the equipment capability to handle the 30" or larger gears.

One of the factors contributing to the relative scarcity of ion nitriding is the high cost of the machinery required. As interest and demand increases, however, the large capital outlay is being overshadowed by the business potential, and companies like Solar Atmospheres are looking to this area for expansion.

It is this heavy investment in equipment, as well as a lack of education as to the potential of ion nitriding, that the authors believe have kept the process from taking off in the United States as it has in Germany and other European countries. In addition, equipment problems when ion nitriding was first introduced in this country created the image of an unreliable process that has stuck in the minds of some engineers. While this is no longer a valid objection, it is true that ion nitriding furnace operators must be carefully trained, as the process is more technically challenging than gas nitriding.

These factors need not concern custom gear makers or tool and die shops, however, since there are commercial heat treaters who have expertise in developing processes even for runs of one or two parts. With ion nitriding's ability to eliminate many secondary operations and to turn jobs around relatively quickly, it's a process worthy of the machinist's consideration. ○

Fig. 1 — A load of gears before (left) and after ion nitriding.

Fig. 2 — Parts as loaded for ion nitriding on the furnace hearth plate.

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A. Bruce Craven
is Vice President, Engineering, of Solar Atmospheres, Inc., Souderton, PA, a commercial vacuum heat treating company.

Dry Hobbing Saves Automaker Money, Improves Gear Quality

Dry hobbing delivers a breakthrough in productivity, economy, cycle times, tool life and part quality.

David Arnesen

It takes confidence to be the first to invest in new manufacturing technology. But the payback can be significant. That has been the experience at the Ford Motor Company's Transmission & Chassis Division plant at Indianapolis, IN, which boasts the world's first production application of dry hobbing.

Beginning in July 1994, Ford began installing Liebherr LC 82 CNC hobbing machines to hob steering pinions (SAE 1045, 22 Rc). According to Ford manufacturing engineers, dry hobbing with carbide cutters has reduced machining costs by 44%, shortened cycle time by 48% and increased tool life by a factor of 6. So far.

Goal No. 1: Improve Pinion Quality

The task at Ford's Indianapolis plant was to improve gear quality—surface finish and pitch diameter runout—and meet increased production demands. After determining that existing hobbing machines using standard coated HSS hobs with coolant were incapable of meeting the plant's targets, the engineers investigated new technology.

After extensive research and subsequent testing at Ford, carbide hobbing without coolant showed the most promise in meeting quality goals and offered the additional potential of greatly extended tool life and lower maintenance costs. During test cutting of the steel pinions, the process demonstrated a Cpk of 3.0, and tool life was far longer than was achieved with any steel hob. The process testing was completed using carbide hobs on a Liebherr CNC hobbing machine specifically designed for carbide dry hobbing.

More Speed, Greater Horsepower

To properly utilize the advantages of carbide, a hobbing machine must be capable of increased speeds and greater horsepower than is typical of conventional machines. The Liebherr machine table can achieve speeds up to 450 rpm; the hob head is equipped with a heavy duty drive that permits speeds up to 3,000 rpm with drive power to 18 kW (25 hp), several times that of the conventional hobbing machines at Ford.

The combination of carbide hobs with maximum diameter of 90 mm (3.6") and the new machines, which have cutter spindle speeds of 2,000 rpm, enabled hobbing at 850 sfpm, much greater than the capability of conventional production machines.

The higher cutting speed reduced machining times to approximately 22 seconds from 42 seconds previously with HSS. A workpiece load/unload mechanism built into the hobber and closely coordinated with workpiece

Courtesy of Liebherr-America

View of the pinion, hob and tailstock in the Liebherr LC 82. The workpiece load/unload mechanism built into the hobber, closely coordinated with workpiece clamping, reduced Ford's chip-to-chip time to about 4 seconds.

clamping reduced Ford's chip-to-chip time to about 4 seconds.

Because the pinions are held rigidly in place during machining by hydraulic gateways driven by cams, part movement or deflection is prevented, and the potential for runout, feed scalloping and chatter marks is reduced. The result is that surface finish improved to between .5 and .75 Ra from 1.1 to 1.5 Ra.

In the first year of production, Ford Indianapolis immediately achieved significant gains in tool life, more than offsetting the higher initial cost for carbide cutters. Because heat is the main factor affecting tool life, the engineers made several further changes to allow the cutter to run even cooler. These included different coatings, recently developed carbide materials and hob geometry.

To reduce heat build-up at the edge of the cutter and increase the shearing action, the rake angle was increased to 5°. The number of gashes was reduced to 12 from 15, allowing more room for chip evacuation.

Documented Benefits

Data from the Ford experience clearly points to the benefits of dry hobbing. According to Ford manufacturing engineers, tool life improved to 252,000 pinions per hob (14 regrinds) using dry carbide from 39,000 pinions per HSS hob (12 regrinds) on existing wet cutting machines. Machining cost fell by 44%. In addition, Ford found that the process is very stable, maintaining exceptional consistency well within the process capability specifications.

Increasing the cutting edge rake angle and changing the coating to TiAlN is now being tested, and Ford is now achieving up to 33,000 pinions per regrind, with the potential of getting nearly 300,000 pinions per cutter.

Courtesy of Liebherr-America

Dry hobbing produces Ford steering pinions in 48% less time, at 44% less cost and improved gear quality.

The primary goal was to improve quality and production economy, but the plant also achieved a Ford 2000 environmental goal by eliminating the use of cutting oils and coolants. Operators like the rapid, coolant-free cycling. It's environmentally safer and cleaner with no cutting oils and mist.

A search for a better quality pinion at Ford Motor Company yielded a process that not only produced a better surface finish, but reduced piece cost and cycle time. It also provided the additional advantage of coolant-free operation, saving costs and improving operator morale. ⭘

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1996 Article Subject Index

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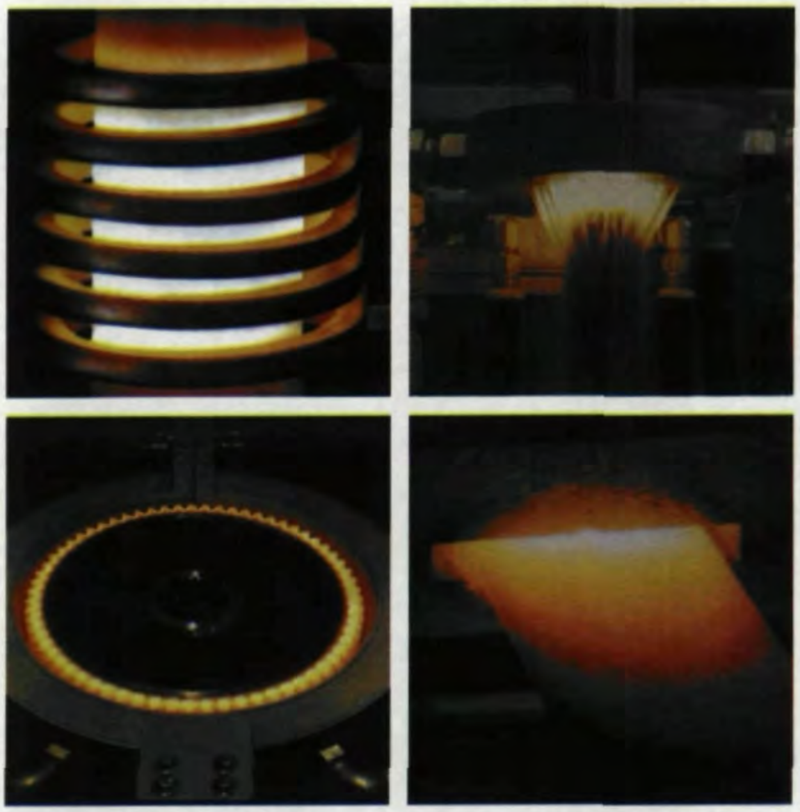

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Chamfering and Deburring External Parallel Axis Gears

Basavaraj Nyamagoudar

The chamfering and deburring operations on gear teeth have become more important as the automation of gear manufacturing lines in the automotive industry have steadily increased. Quieter gears require more accurate chamfers. This operation also translates into significant cost savings by avoiding costly rework operations. This article discusses the different types of chamfers on gear teeth and outlines manufacturing methods and guidelines to determine chamfer sizes and angles for the product and process engineer.

Why Chamfers?

Chamfers are needed in gears:

- To prevent nick and bump damage along the active tooth surface after the shaving or finishing operation;
- To prevent burrs and sharp edges which cause gear noise;
- To prevent the break-off of burrs and sharp edges during torque transfer when the gears have been assembled in boxes or transfer cases;
- For cosmetic reasons.

In the last few years, gear manufacturers have intensified their efforts to prevent or reduce nick and bump damage. Handling systems have ratchet conveyors, which prevent the gears from touching each other. Special baskets are used to protect the gears from accidental damage during heat treatment process. Operator training has stressed the careful handling of gears at every stage of production. In spite of all these steps, the problem still persists. The number of gears rejected because of nicks can range from 10–60% of a batch. Nicks modify lead or involute characteristics, causing meshing defects.

Chamfers significantly reduce noise while the gears mesh and effectively protect all vulnerable zones in the gear tooth.

Types of Chamfers

Four chamfers are shown in Fig. 1. Chamfer A is the tip chamfer along the lead produced by the preshave tool. B is the acute edge chamfer in cylindrical helical gears. C is the obtuse edge chamfer in cylindrical helical gears produced by cutting, grinding or rolling operations. D is the tip chamfer on end faces produced during the turning of blanks.

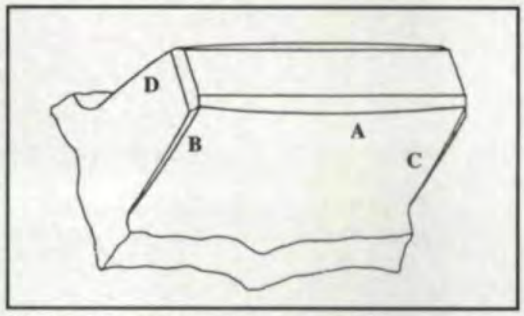

Fig. 1 — Types of chamfers on gear teeth.

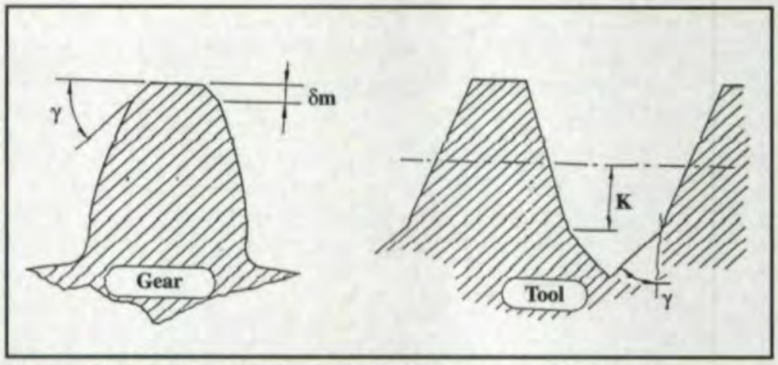

Fig. 2 — A) End of chamfer along lead; B) Basic rack of preshave tool.

The tip chamfer along the lead is generally executed while cutting the gear with either a hob or a shaper cutter which has a modified tooth profile called semi-topping. The size of the chamfer depends on the gear's diametral pitch (the module). Generally it is

$$\delta_m = 0.10\text{–}0.15 \text{ mm}$$
$$\gamma = 30\text{–}40°$$

See Fig. 2 for details.

It is difficult to maintain the size of the tip chamfer, since it is related to the tolerances of the outside diameters and gear tooth thickness. For example, gears with normal diametral pitches up

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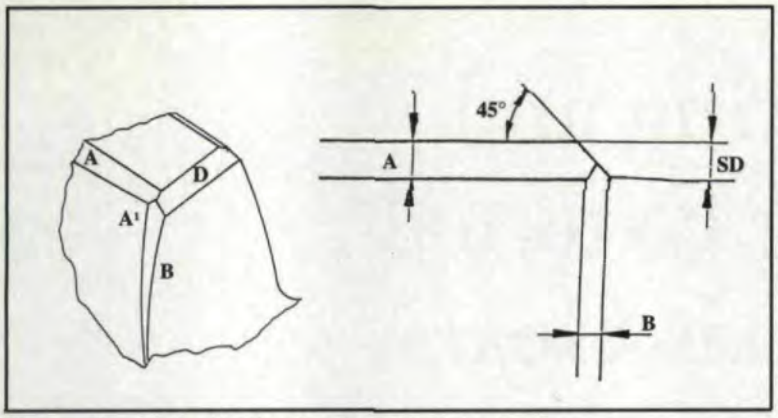

Fig. 3 — Gear tooth with edge chamfer and both tip chamfers.

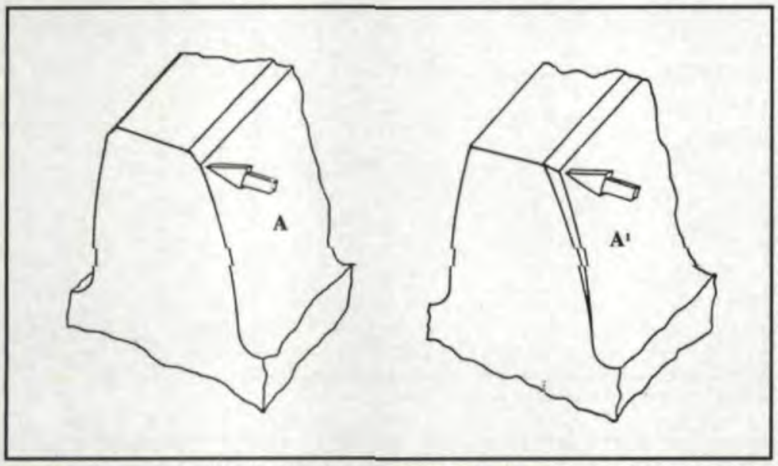

Fig. 4 — Gear tooth with tip chamfer and tip chamfer along lead and edge chamfer.

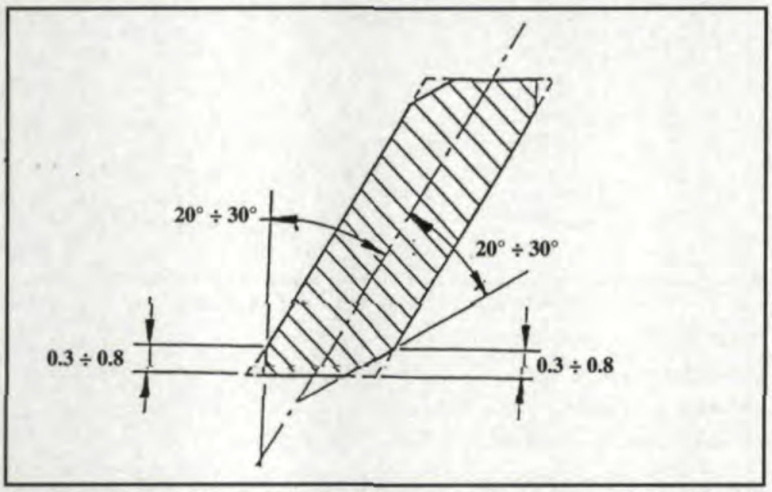

Fig. 5 — Chamfer angles must be set with exposed points as far away from the ends of the tooth as possible.

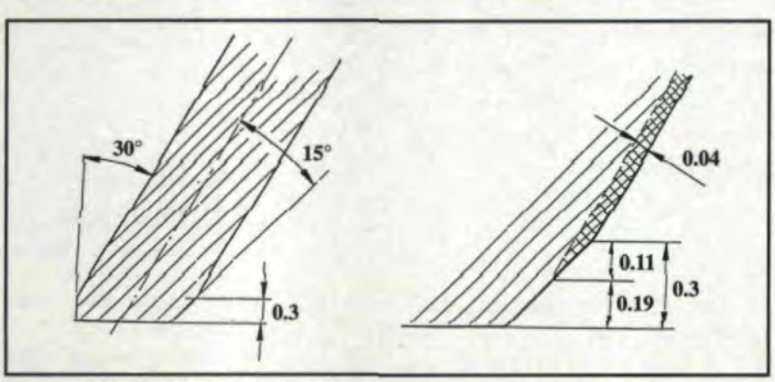

Fig. 6 — Shaving reduces the size of the chamfer to some extent.

to 8–10 (module 2.5–3.0) have an O.D. tolerance of roughly 0.008" (0.2 mm) and a variation of 0.004" per side (0.1 mm/side). The cutting tolerance on tooth thickness may be ± 0.0008" (0.02 mm), which affects the cutting tool position. The chamfer will have the following variation:

$$\delta_m = \frac{(0.0008)}{\tan \alpha_n}$$

where α_n = normal pressure angle

When $\alpha_n = 14°30'$, $\Delta\delta_m = 0.003"$ (0.077 mm).

When $\alpha_n = 20°$, $\Delta\delta_m = 0.002"$ (0.055 mm).

This variation is close to 50% of the nominal value of the chamfer size. This becomes much more significant when we are dealing with gears with a normal diametral pitch (NDP) of more than 20 (or module less than 1.25). The tolerances of the O.D. and the tooth thickness exceed the chamfer's nominal value. It then becomes necessary to cut the gears with "topping" tools, which simultaneously cut the teeth and the O.D.

Sometimes when it is necessary to use as much active profile as possible because tip chamfers reduce the working diameter and the line of action, gear designs do not allow tip chamfers. In some rare instances, only a few tenths of a millimeter make up the meshing continuity. Such constraints must be resolved during the early stage of a transmission design, and the designer must make accommodations for tip chamfer.

The chamfer "D" on end faces is required for assembly purposes and for smoother meshing. The chamfer "D," which is put on the gear during turning, can actually cause more nicks than it prevents. Usually the project engineer requires an end tip chamfer without paying too much attention to its size. From Fig. 3, it can be seen that as chamfer "D" is increased, chamfers "A" and "B" provide less protection. Therefore, it should be made as small as possible and never larger than the value

$$S_d = 0.5(a + b)$$

Another reason favoring reduction of the end tip chamfer to a minimum is the presence of hobbing and shaping burrs in this area. These burrs are not removed by the usual deburring tools and may be difficult to remove if they are large. Smaller burrs usually disappear during heat treatment or shot peening. If the chamfer "D" is large and has a heavy burr, sometimes it is necessary to employ an additional deburring tool.

From Fig. 4, it is clear that in the absence of an edge chamfer, point A is more exposed to nicking. With an edge chamfer, the most exposed point, A^1, is shifted towards the inside and is therefore less prone to nicks. The tip chamfer is rendered useless unless there is an edge chamfer. Edge chamfer dimensions do not have the constraints of tip chamfers, since they are made after the gear teeth are cut. Their dimensions are to some extent independent of gear tooth tolerances. Chamfer sizes range from 0.012" (0.3 mm) to 0.030" (0.8) mm. The angles need to be set so that the exposed points are as far away from the ends of the tooth as possible (see Fig. 5). As the helix angle increases, the chamfer angle (related to the tooth axis) decreases to less than 20°. For example, a 30° helix angle will lead to a 15° chamfer angle. There is some reduction in the chamfer size while shaving (Fig. 6). During this process, 0.0015" (0.04 mm) of stock is removed from each flank. If the original chamfer size was 0.012" (0.3 mm), the chamfer size after shaving would be

$$\delta_m = 0.3 - \frac{(0.04)\sin 45°}{\sin 15°} = 0.19 \text{ mm or } 0.0075"$$

Therefore, it is necessary to start with a larger size chamfer, maybe 0.024–0.030" (0.6–0.8 mm). The chamfer should be made without finishing with a step. Sometimes it is better to chamfer the root fillet even if this area is not susceptible to nicking. Fig. 7 shows the correct procedure for chamfering.

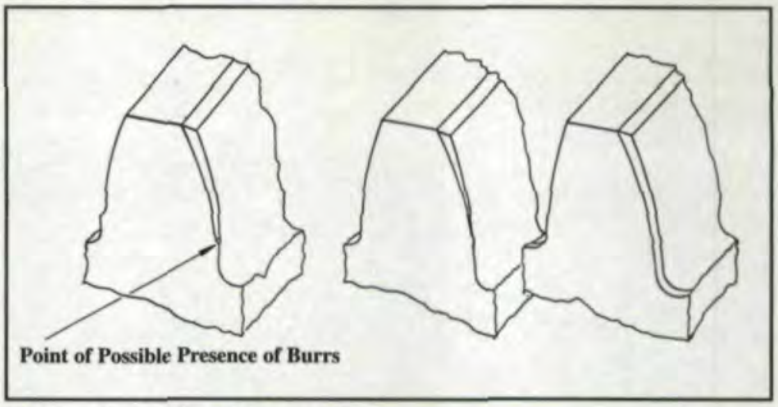

Fig. 7 — Correct chamfering procedure.

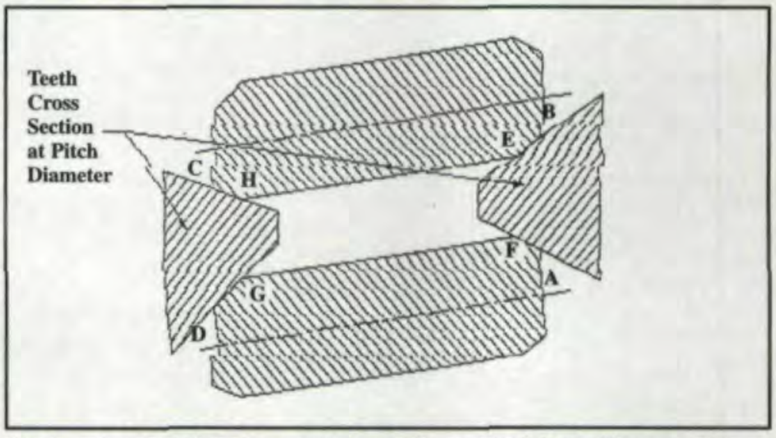

Fig. 8 — A cross section of gear and chamfering tool teeth in a rolling operation.

Production Methods

Edge chamfers can be produced by three different methods.

A cutting operation. There are two cutting methods. The machine may be designed to have a milling cutter and a gear train of CNC equipment to generate an involute. The milling cutter can be held steady with only one circular speed along its axis. In this case, the chamfer is uniform and parallel to the involute. This method produces a good chamfer, and there is no need for any additional deburring operations. On the other hand, milling is a costly operation, and it is difficult to chamfer gears lying adjacent to a shoulder using this technique. Cycle times are long in this method because of indexing, and tool life is poor.

A second way to cut a chamfer is to use a gear train or CNC equipment to index in conjunction with a cutter. The cutter has a reciprocating motion timed with the indexing motion. This type of operation usually produces the chamfer along a straight line. The advantage of this method is that no further deburring operation is required. Among the disadvantages is the fact that this method creates an uneven chamfer extending through the whole root. Sometimes burrs are left on the gear in the root area. Chamfering gears adjacent to a shoulder is also difficult with this method. Again, cycle times are long, and tool life is poor. This approach also requires a lot of operator assistance to maintain a good setup.

A grinding operation. In this method, a grinding wheel is used to produce the chamfers. The advantages are low cycle times and acceptable chamfers all around, but the grinding powder mixed with steel particles pollutes the atmosphere, creating Clean Air Act compliance problems and raising concerns about employee health and general environmental ethics. To counter the pollution effects, expensive filters and dust collectors are needed. Tiny burrs are created along the involute, and they need an extra cleaning operation like shot peen blast. A lot of operator assistance is required to maintain a good setup.

A rolling operation using special chamfer tools. This operation involves driving a chamfer tool in mesh with the gear under pressure. The pressure will plastically deform the material, producing the chamfer. Most of the material deformed plastically will flow out of the sides A, B, C and D (see Fig. 8). Tiny portions, about 0.0008" (0.02 mm), will rise up as tiny ridges inside the involutes E, F, G and H, and a very small portion will rise out of the tip chamfer (D) (Fig.1) produced by a turning operation. Because of this, the operation must be followed by a finishing operation like shaving or grinding. It is not recommended for finished cut parts.

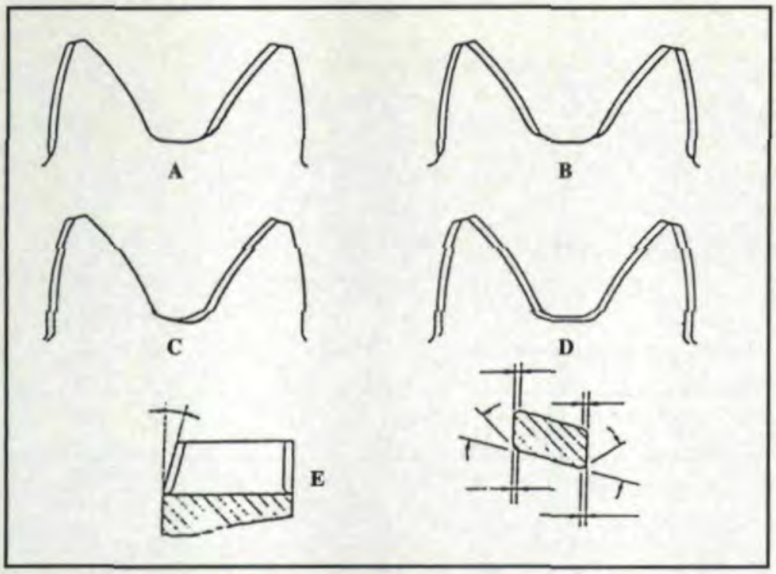

Fig. 9 — Types of edge chamfers.

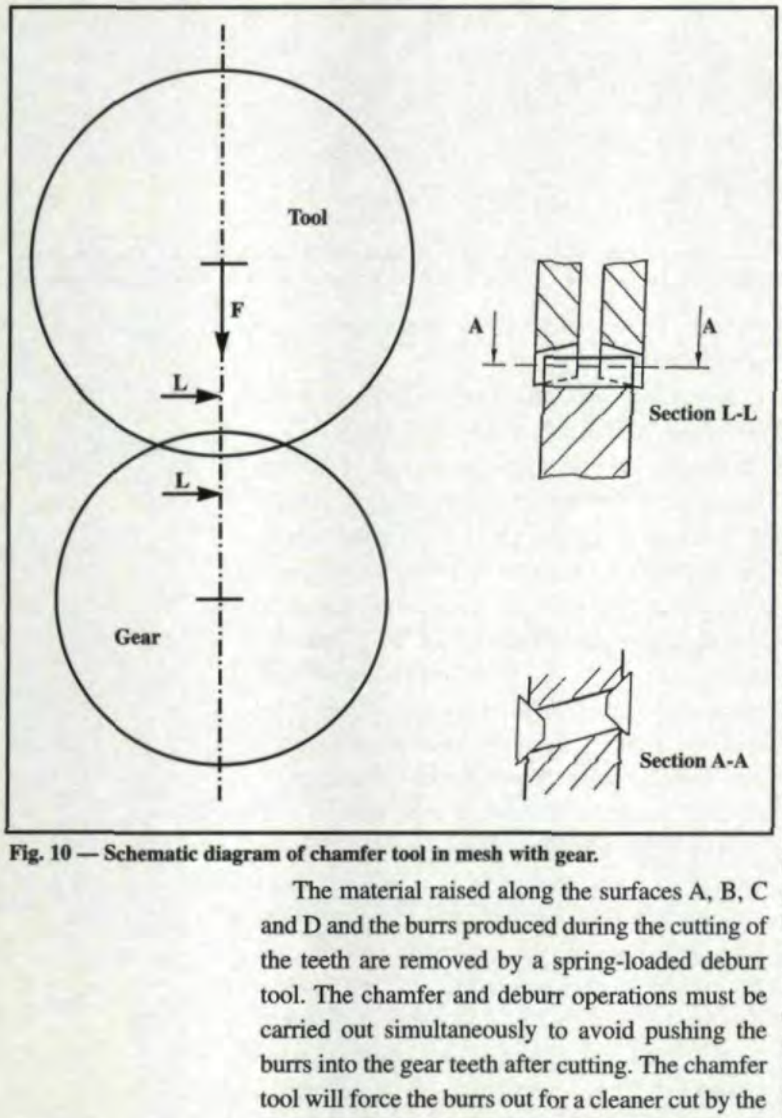

Fig. 10 — Schematic diagram of chamfer tool in mesh with gear.

The material raised along the surfaces A, B, C and D and the burrs produced during the cutting of the teeth are removed by a spring-loaded deburr tool. The chamfer and deburr operations must be carried out simultaneously to avoid pushing the burrs into the gear teeth after cutting. The chamfer tool will force the burrs out for a cleaner cut by the deburr tool. The material raised along the surface D can be minimized by designing the chamfer tool with an operating pressure angle that minimizes the sliding velocity toward the tip. A pair of burnishing tools can be added to the deburr tool group to remove the raised material along D.

The main advantage of this method is extremely long cutter life. It is quite common to chamfer more than 100,000 parts between resharpening. The machine cut cycle time is only 3–4 seconds, while the floor-to-floor cycle time varies from 7–15 seconds for pinion gears. Constant sizes of chamfer parallel to the involute and chamfering the root are possible. This method can chamfer/deburr any adjacent shoulder both on the gear side and the groove side.

Some stress points should be considered when producing edge chamfers by rolling. The plastic deformations of the material should produce residual stresses along the involute surface chamfer that would locally increase the surface stress limit and reduce the stress concentration factor, *thus enhancing the overall resistance of the chamfered* gear. It is essential to chamfer not only the acute angle called for on most drawings, but also the obtuse angle. This gives better protection from nicks and bumps and ensures homogeneous behavior of both the flanks of the gear under load because of the residual stress.

For simplest applications, the tool used on chamfering and deburring machines consists of a set of chamfering tools and a set of skiving tools to deburr lateral surfaces. Because of the force between the tool's springs and the gear's width once it enters into the tools, the two deburring tools will spread open. Chamfering and deburring tools run free on their own quills and self-center themselves on the center line of the gear, thus assuring symmetrical chamfers and complete removal of burrs.

The tool group on a one-head machine in the simplest form consists of one set of chamfer bevel gears and one set of cutter discs mounted together as a gang. The workpiece drives the complete tool group, since it is in mesh with the chamfering tool.

The various types of chamfers that can be achieved on either spur or helical gears cover the whole range usually required for any cylindrical gears. Examples of feasible chamfers include a) chamfering only on one flank without the root; b) chamfering both flanks without the root; c) chamfering one flank and part of the root; d) chamfering the complete profile; e) chamfering inclined faces (see Fig. 9).

Each problem can be evaluated individually and tooling engineered to suit specific applications. Cluster gears can be chamfered and deburred with machines having multiheads with two working stations. To work different gears on the same machine, the tools can be designed to keep a constant center distance between the workpiece and the tool in order to reduce the changeover time.

Chamfering Tools

Chamfering tools are engineered to generate the chamfer on the edges of the gear teeth. The chamfer is made by the rolling action of chamfering tools. In effect two bevel gears mate with the work gear only along the corner edges of its teeth. The force "F," provided by a pneumatic cylinder, represents the thrust necessary for rolling (see Fig. 10). Because of their bevel gear shape and balanced application (one pair of identical tools symmetrically coupled), opposed axial stresses are generated during rolling. As the tool group is free to move axially, it centers itself on the centerline of the gear width.

If the two tools are off center as in Fig. 11A, after the tool group is engaged, the gear will move axially until the forces are balanced. The final position is shown in Fig. 11B. This makes the chamfers symmetrical. These tools will work either spur or helical gears.

Fig. 12 describes a chamfering tool tooth. Besides being tapered, the teeth have an involute form enabling them to mesh with the gear and roll on its corners.

The angle of the tooth flanks of the chamfering tool depends on the gear helix angle and the angle of chamfers to be generated (Fig. 13).

$\beta 1$ and $\beta 2$ = chamfer angle required by part print drawing.

β = gear helix angle.

$\gamma 1$ and $\gamma 2$ = flank angle on the chamfering tool teeth.

$\gamma 1 = \beta + \beta 1$, and $\gamma 2 = \beta 2 - \beta$.

In order to have the chamfers correctly executed, the chamfering discs must be in such a position that the axes of the chamfer tools have the same helix angle as the gear (phasing along helix angle).

Special Cases

When a shoulder or radius is present on the side face of the gear, the chamfering operation cannot be completed all along the profile. The chamfer must end at least 0.012" (0.3 mm) before a step or a radius begins. In cases where the gear has an angled side face, it is necessary to engineer tools with properly modified pressure angles.

Chamfer Tool Resharpening

The chamfering tools are able to produce many thousands of pieces before resharpening. The chamfering tool teeth are not truly resharpened. Rather, the position of the chamfering disc is changed with respect to the gear so that afterward chamfers will be generated by a new area of the chamfer tool teeth that is not worn yet.

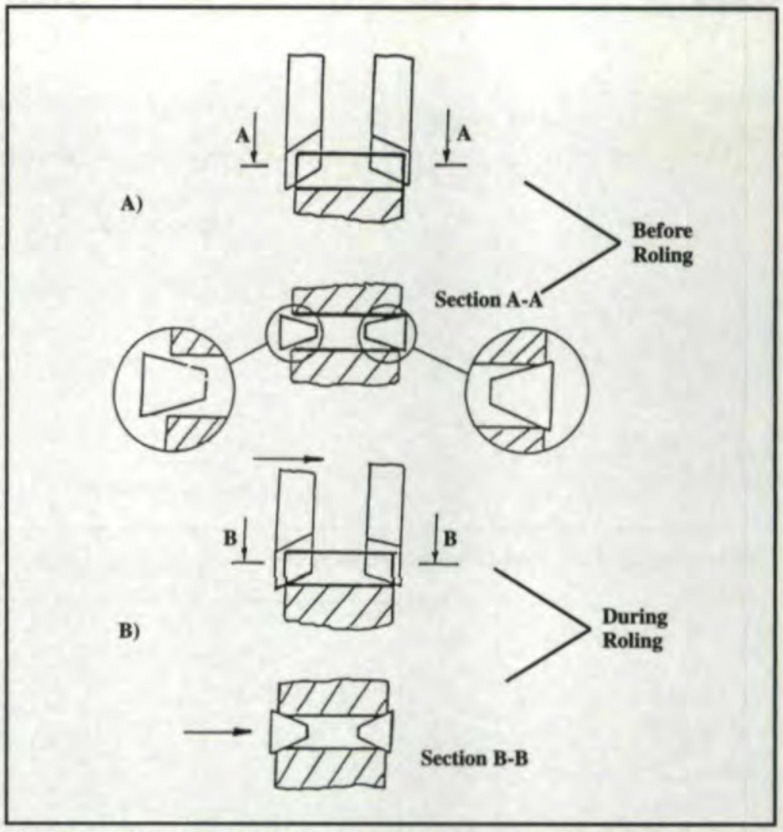

Fig. 11 — A) Nonsymmetrical chamfer tools; B) Symmetrical chamfer tools.

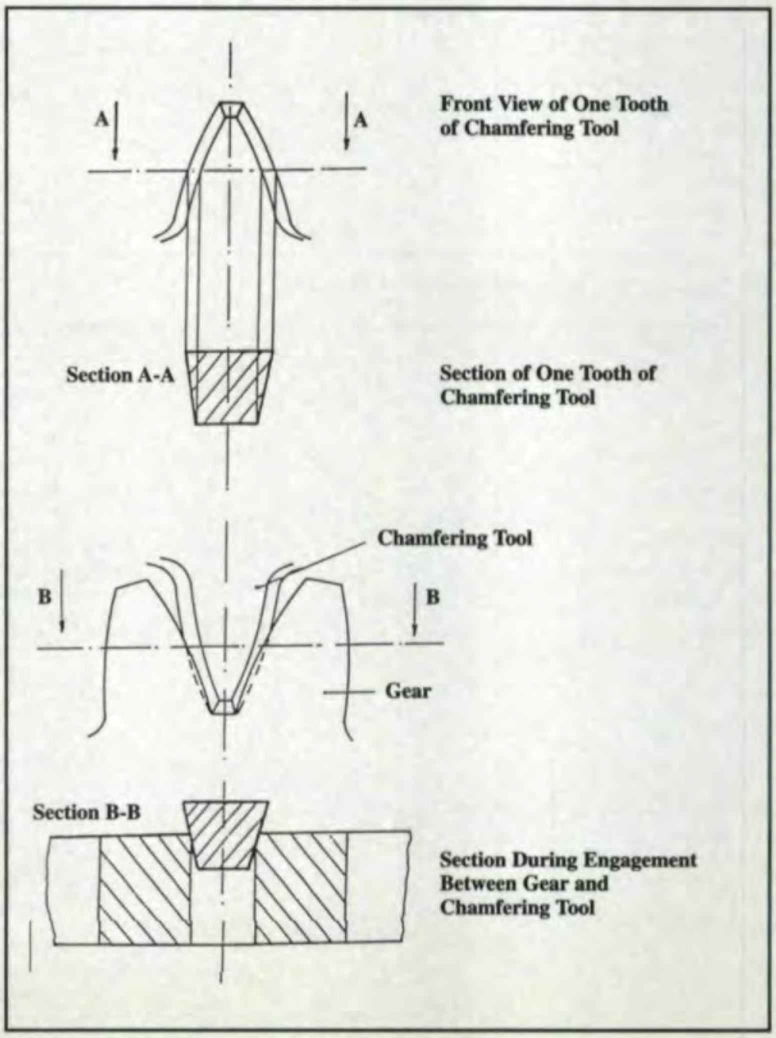

Fig. 12 — Gear tooth and chamfering tool tooth sections.

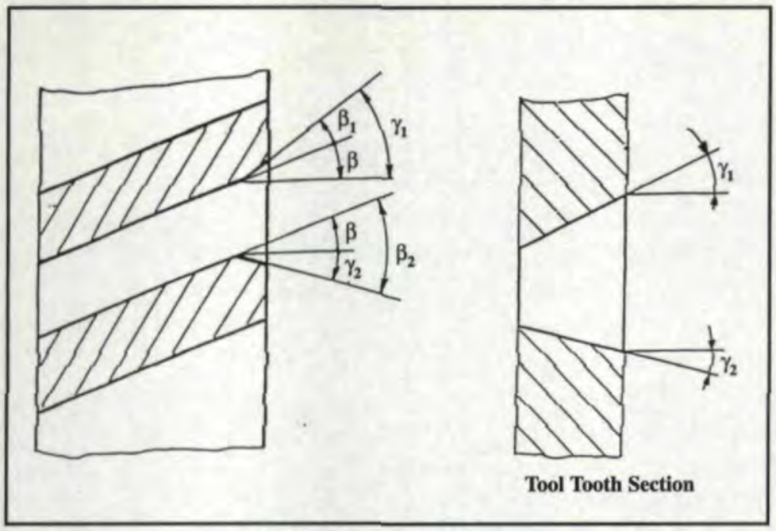

Fig. 13 — Section view of deburring tools in mesh with gear.

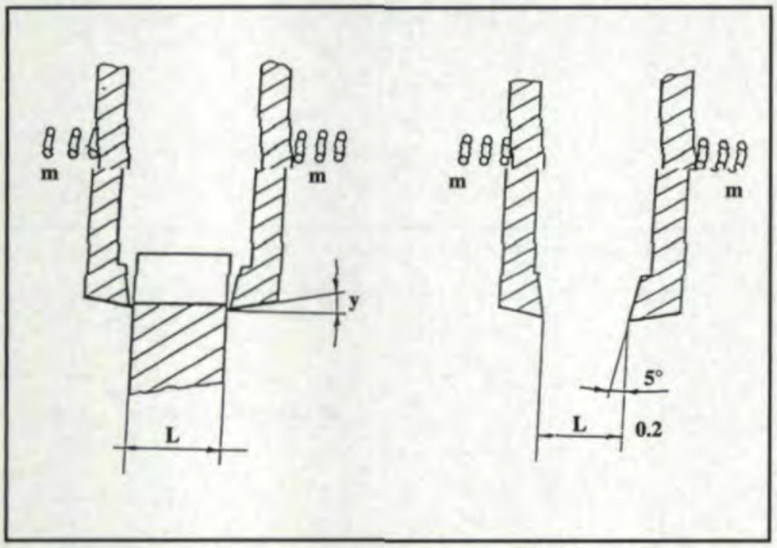

Fig. 14 — "R" type deburring tool in mesh with gear.

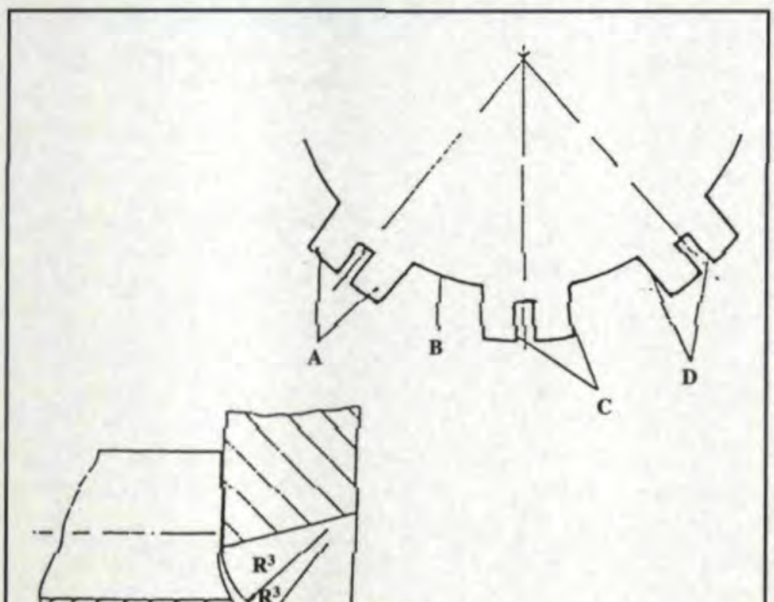

Fig. 15 — Cross sectional view of deburring tool.

Each chamfering disc can be utilized three or four times. When the chamfers no longer have a constant size from one gear tooth to another when the rolling stress rises, or when each single chamfer is no longer uniform along the profile, it is time to grind the chamfering discs in such a way that a new rolling area will contact with the edges of the gear teeth.

Deburr Tools

Deburring tools are large diameter discs whose external rims are ground to the rake angles necessary for cutting action. The distance between the two discs is not constant because they can move axially either under the action of the springs ("m" shown in Fig. 14) or as a consequence of the self-centering with the gear to be deburred.

In the rest position, the spring pressure on the deburring discs brings their separation distance to a minimal value, which is about 0.008" (0.2 mm) less than the minimum gear width. If the distance between the discs were fixed, the discs themselves would hit the outside diameter of the workpiece, chipping it when discs are plunge-fed towards the workpiece. To avoid this, the cutting edge of each disc is provided with a tapered lead-in whose size is large enough to avoid hitting the outside diameter of the gear to be deburred. The first contact must occur between the lead-in surface and the workpiece outside diameter.

The deburring discs are rotated by the workpiece itself, and the burrs are removed through a true skiving action on the gear lateral faces. Generally 100,000 pieces or more in some cases can be deburred before resharpening the tool. The tool life between resharpenings depends upon a number of factors. They are

- The hardness and machinability of workpiece material;
- The thickness of burrs and the size of the requested chamfer;
- The length of the deburred area (workpiece whole depth);
- The presence of steps, radii or shoulders, which may interfere with the tool cutting edge;
- The correct resharpening and assembly of the tool group.

Special Cases

For gears with shoulders or radii, special types of deburring tools are designed for a correct action of the deburring discs in order to avoid the interference. To deburr a gear with a radius (see Fig. 15), a special type of deburring tool known as an "R" type tool is used. Due to the spring loading action, the burrs are uniformly and cleanly skived off the surface by the tool following the profile of the gear. The same tool also performs the deburring of the straight portion. The radius form protuberances A are alternated with the cutting edges B, which work the straight portion of surface S like a standard deburring tool. Protuberances A remove burrs from the radii by means of the true cutting action of the cutting edges C or D according to the direction of rotation. Portion B skives the straight faces as far as .008" (0.2 mm) to 0.012" (0.3 mm) above radius R^3.

When the surface to be deburred is tapered, specially tapered deburring tools with many inclined slots are used to generate an adequate number of sharp cutting edges. During helical gear cutting with either a hob or with a shaper cutter, burrs are usually left on the acute edge (where the tool comes out of the gear). The relative traverse movement between the deburring tool and the gear must push the burr toward the tooth and not toward the space.

Deburring Tool Sharpening

Wear can be removed by grinding either surface E or surface H (see Fig. 16A). Stock size removed must be 0.008" (0.2 mm) or its multiples in the direction of the disc's axis. The disc thickness reduction is compensated for by shifting the spacers.

With no gear between the tools, the discs are in the conditions shown in Fig. 16B. The springs push the disc and the spacer against the shoulder flange. When the gear enters the discs, it forces the discs apart, thus moving the tool from the shoulder flange and creating a gap approximately 0.004" (0.1 mm) between flange and spacers (see Fig. 17). After resharpening the gap will not be the same. In order to return to the initial conditions, a space 0.008" (0.2 mm) thick will have to be shifted from position 1 to position 2 as shown in Fig. 18. After every resharpening, it is necessary to check the lead in chamfer size so that it lies outside of the gear when the tool contacts the gear. ○

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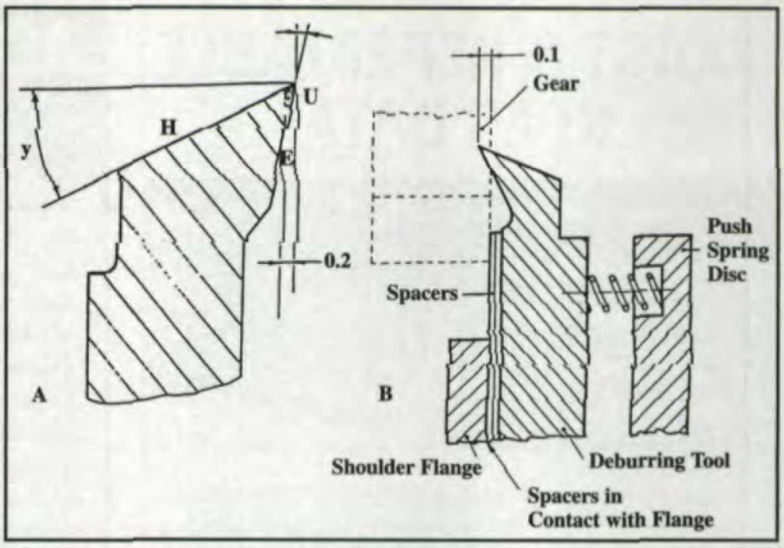

Fig. 16 — Principle of deburring tool operation.

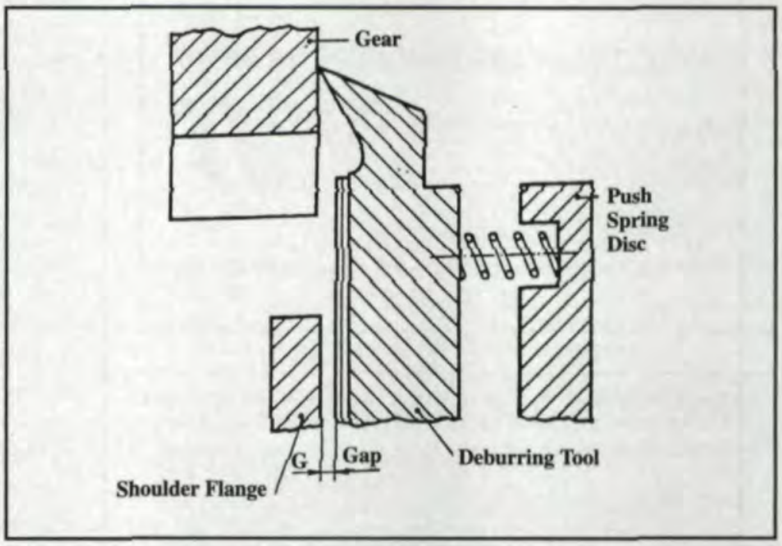

Fig. 17 — Cross sectional view of deburring tool with spacers and springs.

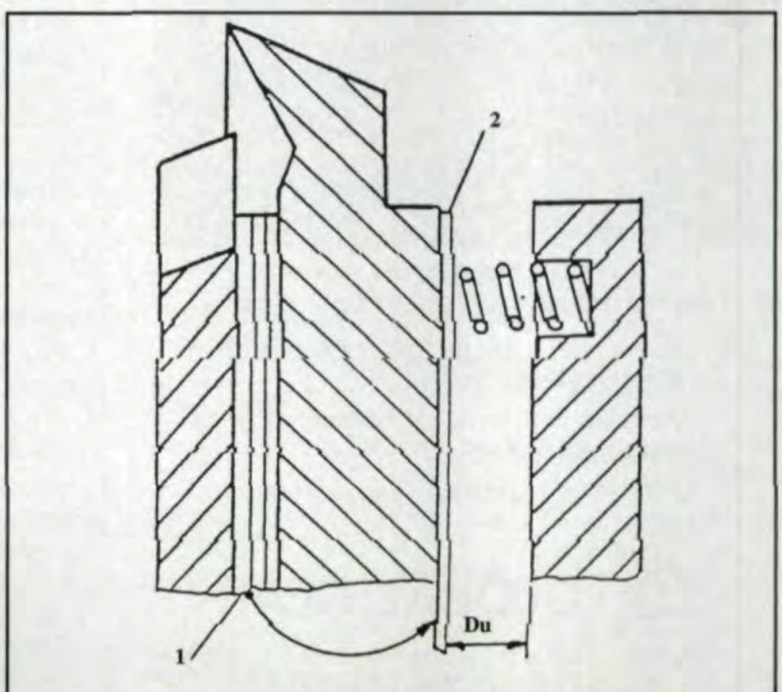

Fig. 18 — Position shift after resharpening.

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Franke Gear Works Inc.
Gear Motions
Gear Group International
The Gear Works Seattle
GEARCOA
Gears & Drive Systems
Gears for Industry Inc.
Geartronics Industries
Generated Gear & Machine
Harder Precision Components
Harnischfeger
Highway Machine Co.
Hua Yang Machine Co.
Intech Corp.
Keystone Powdered Metal Co.
Krupp Engineering Inc.
Lamont Gear
Lawler Gear Corp.
Linamar
Mid-State Machine Co.
Modified Gear & Spline
Moore Gear Manufacturing Co.
Moore Machine & Gear
National Broach & Machine Co.
Patterson Gear & Machine
Perry Technology
PIC Design
Progressive Engineering
Qualicast Corp.
Riverside Spline & Gear
Robotronix
Schwartz Precision Gear
Sinter Metals Inc.
Southern Gear & Machine
Standard Steel Specialty
TPI Powder Metallurgy
Trogetec Inc.
Trojon Gear Inc.
Vic Machine Tools Corp.
Viking Air Tools
Wedin Intl. Inc.
Winzeler Gear
Worcester Gear Works
Xtek Inc.
Yieh Chen Co. Ltd.

Gears—Spiral Bevel
A. W. Sadler Machine
ABA-PGT Inc.
Advance Gear & Machine Corp.
Aero Gear Co.
Akron Gear & Engineering
Alpha Gear Drives, Inc.
Amarillo Gear Co.
Arrow Gear Co.
Asco Sintering Co.
Ashot Ashkelon Industries
ATA Gears Inc.
Bengal Industries Inc.
Boeing Precision Gear
Bonfiglioli UK
Boston Gear
Carbon City Products
Case Corp.
Caterpillar Industrial Products Inc.
Chicago Gear-D. O. James
Ciateq A.C.
CMD (UK) Ltd.
Curtis Machine Co. Inc.
Dana Corp.
Designatronics
Electrex Ltd. (India)
Engranes Industriales Rivera
Engratec de Mexico
Engrecon S.A.
Fairfield Mfg. Co.
Falk Corporation
Flender Corporation
Flender-Graffenstaden
Foote-Jones/Illinois Gear
Gear Group International
The Gear Works Seattle
Gears & Drive Systems
The Gleason Works
HICO
Hua Yang Machine Co.
Intech Corp.
Keystone Powdered Metal Co.
Krupp Engineering Inc.
Labeco
Merger Corp.
Midwest Gear & Tool
Milford Gear Works
Moore Gear Manufacturing Co.
Nanchang Gear Works
New Venture Gear Inc.
Philadelphia Gear Corporation
Philadelphia Gear — GSD
PIC Design
Power Eng. & Mfg. Ltd.
Precision Gear Co.
Presrite Corp.
The Purdy Corp.
Robotronix
Rockwell Intl.
Sinter Metals Inc.
Southern Gear & Machine
Thomson Micron, L.L.C.
Von Ruden Mfg.
Wedin Intl. Inc.
Westech Gear

Gears—Spur
A. W. Sadler Machine
ABA-PGT Inc.
Accu-Prompt Inc.
The Adams Company
Advance Gear & Machine Corp.
Aerocom Industries Inc.
Akron Gear & Engineering
Albro Gear & Instrument
Alliance Gear Inc.
Alpha Gear Drives, Inc.
American Machine Works
Ancon Gear & Inst.
Anderson-Cook Inc.
Aplus Engineering Inc.
Arrow Gear Co.
Asco Sintering Co.
Ashot Ashkelon Industries
Ashot U.S.A. Inc.
Axicon Technologies
Bengal Industries Inc.
Bilgram Gear Co.
Boeing Precision Gear
Bonfiglioli UK
Boston Gear
Bourn & Koch Machine Tool
Boxx Gear Mfg.
Buckeye Gear Co.
Bucyrus-Erie Co.
Calicut Eng. Works Ltd.
Capstan Atlantic
Carbon City Products
Caterpillar Industrial Products Inc.
Chardam Gear Co.
Charles A. Templeton Mach. Inc.
Charles Bond Co.
Chicago Gear Works
Chicago Gear-D. O. James
Ciateq A.C.
Cincinnati Gear
Clarke Gear Co., Inc.
Cloyes Gear & Products
CMD (UK) Ltd.
Columbia Gear Corp.
Commercial Gear & Sprocket
Cornell Forge Co.
Cunningham Industries
Curtis Machine Co. Inc.
Cyclo Transmission Ltd.
Dabko Industries Inc.
Dana Corp.
Davis Tool & Engineering
Dayton Gear & Tool
Dearborn Gear & Tool
Designatronics
Dynamic Tool Grinding Service
Eaton Corp.
Electrex Ltd. (India)
EMCO Gears
Engranes Industriales Rivera
Engratec de Mexico
Engrecon S.A.
Equitable Engineering
Fairfield Mfg. Co.
Fairlane Gear Inc.
Falk Corp.
Federal Gear Corp.
Fellows Corp.
Flender Corporation
Flender-Graffenstaden
Foote-Jones/Illinois Gear
Forest City Gear Co.
Franke Gear Works Inc.
Fuller Company
Gear Group International
Gear Motions
Gear Systems Inc.
The Gear Works Seattle
GEARCOA
Gears & Drive Systems
Gears for Industry Inc.
Geartronics Industries
General Electric
Generated Gear & Machine
The Gleason Works
GW Plastics
Hand Screw Machine
Harder Precision Components
Harnischfeger
Highway Machine Co.
Howard's Machine Shop
Hua Yang Machine Co.
Insco Corp.
Intech Corp.
Invincible Gear Co.
Invo Spline Inc.
KA-Wood Gear & Machine
Keller Machine Co.
Keystone Powdered Metal Co.
Krupp Engineering Inc.
L + H Welding & Machine
Lamont Gear
Lawler Gear Corp.
M.J.H. Gear & Tool Co.
Merit Gear Corp.
Micron Instrument Corp.
Mid-State Machine Co.
Midwest Gear
Midwest Gear & Tool
Milford Gear Works
Mobile Pulley & Machine Works
Modified Gear & Spline
Molon Gear & Shaft
Moore Gear Manufacturing
Moore Machine & Gear
Mostar Gear & Machine
Murray Brothers Mfg.
Nanchang Gear Works
National Broach & Machine Co.
New Venture Gear Inc.
Niagara Gear Corp.
Nordberg-Lokomo Oy
O'Neill Gear
Omni Gear & Machine
Ontario Drive & Gear
Patterson Gear & Machine
Pennsylvania Pressed Metal
Perry Technology
Philadelphia Gear Corp.
Philadelphia Gear — GSD
PIC Design
Power Eng. & Mfg. Ltd.
Precision Gear Co.
Precision Gear Inc.
Precision Gears Inc.
Presrite Corp.
Process Industries
Progressive Engineering
The Purdy Corp.
Qualicast Corp.
R.L. Wagner & Assoc.
RD Industries
Reef Gear Mfg.
Riley Gear Corp.
Riverside Spline & Gear
Robotronix
Rockwell Intl.
Schafer Gear Works Inc.
Schwartz Precision Gear
SDMG
Sepac Electric Clutch & Brake
Southern Gear & Machine
St. Marys Carbon Co.
Thomson Micron, L.L.C.
Tifco Gage & Gear
TPI Powder Metallurgy
Trogetec Inc.
Trojon Gear Inc.
U.S.E.M.
Vic Machine Tools Corp.

Von Ruden Mfg.
Waldemar Design & Machine
Wedin Intl. Inc.
Westech Gear
Windsor Gear Co.
Winzeler Gear
Wohlert Corp.
Worcester Gear Works
Xtek Inc.
Yieh Chen Co. Ltd.

Gears—Straight Bevel

A. W. Sadler Machine Co.
Accu-Prompt Inc.
The Adams Company
Advance Gear & Machine
Aero Gear Co.
Akron Gear & Engineering
Alliance Gear Inc.
Alpha Gear Drives, Inc.
American Machine Works
Arrow Gear Co.
Asco Sintering Co.
Ashot Ashkelon Indust.
Ashot U.S.A. Inc.
Bengal Industries Inc.
Bilgram Gear Co.
Bonfiglioli UK
Boston Gear
Boxx Gear Mfg.
Calicut Eng. Works Ltd.
Capstan Atlantic
Carbon City Products
Case Corp.
Caterpillar Industrial Products Inc.
Chardam Gear Co.
Charles A. Templeton Mach. Inc.
Charles Bond Co.
Chicago Gear Works
Chicago Gear-D. O. James
Ciateq A.C.
Clarke Gear Co., Inc.
CMD (UK) Ltd.
Commercial Gear & Sprocket
Cornell Forge Co.
Curtis Machine Co. Inc.
Dabko Industries Inc.
Dayton Gear & Tool
Designatronics
Engranes Industriales Rivera
Engratec de Mexico
Engrecon S.A.
Fairfield Mfg. Co.
Falk Corp.
Federal Gear Corp.
Foote-Jones/Illinois Gear
Gear Group International
Gear Motions
The Gear Works Seattle
Gears & Drive Systems
Gears for Industry Inc.
GEARCOA
Geartronics Industries
Generated Gear & Machine
The Gleason Works
GW Plastics
Hua Yang Machine Co.
Intech Corp.
Keystone Powdered Metal Co.
Krupp Engineering Inc.
Labeco
Lamont Gear
Lawler Gear Corp.
M.J.H. Gear & Tool
Merger Corp.
Midwest Gear & Tool
Milford Gear Works
Moore Gear Manufacturing Co.
Moore Machine & Gear
Nanchang Gear Works
New Venture Gear Inc.
Perry Technology
Philadelphia Gear Corporation
Philadelphia Gear — GSD
PIC Design
Power Eng. & Mfg.
Precision Gear Co.
Presrite Corp.
Process Industries
Progressive Engineering
Robotronix
Rockwell Intl.
St. Marys Carbon
Sinter Metals Inc.
Southern Gear & Machine
Thomson Micron, L.L.C.
TPI Powder Metallurgy
Von Ruden Mfg.
Waldemar Design & Machine
Wedin Intl. Inc.
Westech Gear
Windsor Gear Co.
Winzeler Gear
Worcester Gear Works
Xtek Inc.
Yieh Chen Co. Ltd.

Gears—Worm

A. W. Sadler Machine
ABA-PGT Inc.
Accu-Prompt Inc.
The Adams Company
Advance Gear & Machine
Akron Gear & Engineering
Alliance Gear Inc.
Alpha Gear Drives, Inc.
American Machine Works
Anderson-Cook Inc.
Aplus Engineering Inc.
Bengal Industries Inc.
Bilgram Gear Co.
Bonfiglioli UK
Boston Gear
Bourn & Koch Machine Tool
Boxx Gear Mfg.
Buckeye Gear Co.
Calicut Eng. Works Ltd.
Charles A. Templeton Mach. Inc.
Charles Bond Co.
Chicago Gear Works
Chicago Gear-D. O. James
Ciateq A.C.
Cincinnati Gear
Clarke Gear Co., Inc.
CMD (UK) Ltd.
Commercial Gear & Sprocket
Cone Drive Operations
Dayton Gear & Tool
Delroyd Worm Gear
Designatronics
EMCO Gears
Engranes Industriales Rivera
Engratec de Mexico
Equitable Engineering
Fairlane Gear Inc.
Falk Corp.
Federal Gear Corp.
Fellows Corp.
Flender Corporation
Foote-Jones/Illinois Gear
Forest City Gear Co.
Franke Gear Works Inc.
Gear Group International
Gear Motions
Gear Systems Inc.
The Gear Works Seattle
GEARCOA
Gears & Drive Systems
Gears for Industry Inc.
Geartronics Industries
General Electric
Generated Gear & Machine
GW Plastics
Harder Precision Components
Harnischfeger
Holroyd Machine Tool
Hua Yang Machine Co.
Insco Corp.
Intech Corp.
Invincible Gear Co.
KA-Wood Gear & Machine
Lamont Gear
Lawler Gear Corp.
M.J.H. Gear & Tool Co.
Merger Corp.
Mid-State Machine Co.
Milford Gear Works
Moore Gear Mfg.
Moore Machine & Gear
Mostar Gear & Machine
O'Neill Gear
Omni Gear & Machine
Patterson Gear & Machine
Pennsylvania Gear
Perry Technology
Philadelphia Gear Corporation
Philadelphia Gear —GSD
PIC Design
Power Eng. & Mfg. Ltd.
Precision Gear Co.
Precision Gear Inc.
Precision Gears Inc.
Process Industries
Progressive Engineering
Riley Gear Corp.
Riverside Spline & Gear
Robotronix
Schafer Gear Works Inc.
Schwartz Precision Gear
SDMG
Southern Gear & Machine
Tifco Gage & Gear
Trojon Gear Inc.
U.S.E.M.
Vic Machine Tools Corp.
Wedin Intl. Inc.
Westech Gear
Windsor Gear Co.
Worcester Gear Works
Yieh Chen Co. Ltd.

Gears—Other

Anderson International Corp. — Pinions
Clarke Gear Co., Inc. — Face Gears
CMD (UK) Ltd. — Planetary Gears
Commerical Gear & Sprocket — Ratchets, Jaw Clutches, Large Diameter Gears
Cone Drive Operations — Double-Enveloping Worm Gears
Fairfield Mfg. Co. — Axle Shafts
Federal Gear Corp. — Gearbox Repair & Reconditioning
Flender-Graffenstaden — High-Speed & Epicyclic Gears
Franke Gear Works Inc. — Double-Enveloping Worm & Gear Sets

Fuji Univance Corp. — Gear Transmissions
GEARCOA — Evolid Gears
Geartronics Industries — Generated Pinion Rods
Hand Screw Machine — Serrations for Strapping
Kaman Aerospace Corp. — Helicopter Gearboxes
Keller Machine Co. — Custom Gears & Sprockets
Lovejoy Inc. — Gear Couplings
Michigan Automatic Turning — Spline Rolling
Micron Instrument Corp. — Gearheads
Milford Gear Works — Pulleys, Serrations, Ratchets
National Broach & Machine — Prototypes
Parker Industries Inc. — Custom Gears
Philadelphia Gear Corporation — Epicyclic
Presrite Corp. — Forged Tooth Gears
The Purdy Corp. — Zerol Bevel Gears, Curvic Couplings
Spline Gauges Ltd. — Oil Test Gears
Sussex Gear Company Inc. — Linear Actuators
Thomson Micron, L.L.C. — Planetary Gearheads
Wedin Intl. Inc. — Ground Gears
Westech Gear — Specials
Xtek Inc. — Couplings, Gear Assemblies
Yieh Chen Co. Ltd. — Gear Pumps

Splines

A. W. Sadler Machine
ABA-PGT Inc.
Accu-Prompt Inc.
The Adams Company
Advance Gear & Machine Corp.
Aerocom Industries Inc.
Akron Gear & Engineering
American Machine Works
Ancon Gear & Inst.
Anderson-Cook Inc.
Aplus Engineering Inc.
Arrow Gear Co.
Asco Sintering Co.
Ashot Ashkelon Indust.
Bilgram Gear Co.
Boeing Precision Gear
Boston Gear
Bourn & Koch Machine Tool
Boxx Gear Mfg.
Buckeye Gear Co.
Bucyrus-Erie Co.
Calicut Eng. Works Ltd.
Capstan Atlantic
Carbon City Products
Caterpillar Industrial Products Inc.
Chardam Gear Co.
Charles A. Templeton Mach. Inc.
Chicago Gear Works
Chicago Gear-D. O. James
Ciateq A.C.
Cincinnati Gear
Clarke Gear Co., Inc.
Cloyes Gear & Products
CMD (UK) Ltd.
Columbia Gear Corp.
Commercial Gear & Sprocket
Curtis Machine Co. Inc.
Dabko Industries Inc.
Dayton Gear & Tool
Dearborn Gear & Tool
Deco-Technologies
Eaton Corp.
Elmass North America
EMCO Gears
Engranes Industriales Rivera
Engratec de Mexico
Engrecon S.A.
Equitable Engineering
Fairfield Mfg. Co.
Fairlane Gear Inc.
Federal Gear Corp.
Foote-Jones/Illinois Gear
Forest City Gear Co.
Franke Gear Works Inc.
Gear Motions
Gear Systems Inc.
The Gear Works Seattle
GEARCOA
Gears for Industry Inc.
Geartronics Industries
Generated Gear & Machine
Global Gear
Hand Screw Machine
Harder Precision Components
Harnischfeger
Highway Machine Co.
Howard's Machine Shop
Hua Yang Machine Co.
Invo Spline Inc.
KA-Wood Gear & Machine
Keystone Powdered Metal Co.
Krupp Engineering Inc.
L + H Welding & Machine
Lamont Gear
Lawler Gear Corp.
Linamar
Lovejoy Inc.
M.J.H. Gear & Tool Co.
Mattoon Precision Mfg.
Michigan Automatic Turning
Mid-State Machine Co.
Midwest Gear
Midwest Gear & Tool
Milford Gear Works
Modified Gear & Spline
Moore Gear Manufacturing Co.
Moore Machine & Gear
Nanchang Gear Works
National Broach & Machine Co.
New Venture Gear Inc.
Niagara Gear Corp.
O'Neill Gear
Omni Gear & Machine
Ontario Drive & Gear
Patterson Gear & Mach.
Perry Technology
Philadelphia Gear Corporation
Philadelphia Gear — GSD
Power Eng. & Mfg. Ltd.
Precision Gear Co.
Precision Gear Inc.
Precision Gears Inc.
Process Industries
Progressive Engineering
The Purdy Corp.
R.L. Wagner & Assoc.
Reef Gear Mfg.
Rhinestahl Corp.
Riley Gear Corp.
Riverside Spline & Gear
Robotronix
Rockwell Intl.
Schafer Gear Works Inc.
SDMG
Sepac Electric Clutch & Brake
Sinter Metals Inc.
Southern Gear & Machine
St. Marys Carbon Co.
Tifco Gage & Gear
TPI Powder Metallurgy
Trojon Gear Inc.
Viking Air Tools
Von Ruden Mfg.
Wedin Intl. Inc.
Westech Gear
Windsor Gear Co.
Worcester Gear Works
Xtek Inc.
Yieh Chen Co. Ltd.

Sprockets

Aero Gear Co.
Buckeye Gear Co.
Cloyes Gear & Products, Inc.
Commercial Gear & Sprocket
Dabco Industries
Foote-Jones/Illinois Gear
KA-Wood Gear & Machine
Keller Machine Co.
Milford Gear Works
Pennsylvania Gear
Precision Gear Co.
Schwartz Precision Gear
SDMG
Wohlert Corp.

GEAR MANUFACTURING MACHINES

Broaching Machines

Best Engineering Co.
Colonial Tool Group
Detroit Broach Co.
Elmass North America
General Broach & Engineering
Jack Dustman & Assoc.
Miller Industrial Services Inc.
National Broach & Machine Co.
The Ohio Broach & Machine Co.
Sales Consultants
Ty Miles Inc.

Chamfering Machines

American Sykes Co.
American Wera Inc.
Ataka Engineering Co.
Basic Incorporated Group
Best Engineering Co.
Eltech Inc.
GMI
The Gleason Works
Jack Dustman & Assoc.
Redin Corp.
Schenck Turner
SU America
V&R Associates
WMW Machinery Company

Deburring Machines

American Sykes Co.
Basic Incorporated Group
Best Engineering Co.
Bourn & Koch Machine Tool
Eltech Inc.
GMI
The Gleason Works
Harper Surface Finishing Systems
Holroyd Machine Tools
Jack Dustman & Assoc.
Progressive Technologies
Redin Corp.
Schenck Turner
SU America
V&R Associates

EDM Machines

Agie USA, Ltd.
Basic Incorporated Group
Bluegrass Precision Machinery
Charmilles Technologies
Current EDM, Inc.
Easco-Sparcatron
EDM Solutions
Engemaq U.S.A.
Hansvedt Industries Inc.
Hitachi EDM Products
KGK International/ Sodick EDM
LeBlond Makino Machine Tool Co.
Mitsubishi EDM/MC Machinery
Okamoto Corp., EDM Division
Raycon Corp.
Sales Consultants
Vic Machine Tools
Victek Machinery Inc.
Xermac, Inc.

Generating Machines

American Pfauter L.P.
Ataka Engineering Co.,
Basic Incorporated Group
Bourn & Koch Machine Tool
The Gleason Works
Koepfer America L.P.
Liebherr-America
National Broach & Machine Co.
Trogetec Inc.
V&R Associates
Vic Machine Tools
WMW Machinery Company

Grinding Machines

American Pfauter L.P.
Basic Incorporated Group
Bluegrass Precision Machinery
Bourn & Koch Machine Tool
The Daniluk Corp.
Eltech Corp.
The Gleason Works
GMI
Hermes Machine Tool
Höfler Maschinenbau GmbH
Hoglund Technology
Holroyd Machine Tools
Lapmaster Intl.
Liebherr-America
Meccanica Nova Corp.
Miller Industrial Services Inc.
Mitsubishi Machine Tool
National Broach & Machine Co.
Normac Inc.
Okamoto Corp EDM Division
Reishauer Corp.
Sales Consultants
SU America
Sunnen Products Co.
USACH Technologies
V&R Associates
WMW Machinery Company

Heat Treating Equipment

Abar Ipsen Industries
Ajax Magnethermic
Bluegrass Precision Machinery
Can-Eng Furnaces Ltd.
Contour Hardening Inc.
Custom Electric Mfg.
Inductoheat Inc.
K.H. Huppert Co.
Metaplas Ionon
MIFCO/McEnglevan Industrial Furnace
Pacific Industrial Furnace
Pillar Industries
Quench Press Specialties Inc.
Surface Combustion
Therm Alliance Co.
Tocco Inc.
Walmil Company

Hobbing Machines

Ace World Company
American Pfauter L.P
Basic Incorporated Group
Best Engineering Co.
Bourn & Koch Machine Tool
Fayscott Co.
Fellows Corp.
The Gleason Works
Ikegai America Corp.
Koepfer America L.P.
Liebherr-America
Mitsubishi Machine Tool
National Broach & Machine Co.
Sales Consultants
V&R Associates
Vic Machine Tools
WMW Machinery Company

Honing Machines

American Pfauter L.P
Basic Incorporated Group
Bluegrass Precision Machinery
Engis Corp.
The Gleason Works
Miller Industrial Services Inc.
National Broach & Machine Co.
Reishauer Corp.
Sunnen Products Co.

Inspection Machines

Alpha Precision Inc.
American Pfauter L.P
American Sykes Co.
Basic Incorporated Group
Best Engineering Co.
Bluegrass Precision Machinery
Bourn & Koch Machine Tool
D.I.G.I.T.
Fellows Corp.
FGT Gage & Systems
The Gleason Works
ITW Heartland
Kokusai Inc.
Liebherr-America
M&M Precision Systems
Mahr Corp.
Manufactured Gear & Gage
Moore Products Co.
National Broach & Machine Co.
NewAge Industries Inc.
Ono Sokki Technology
Precision Gage Co.
Profile Engineering
Progressive Tech.
Roto-Technology Inc.
Spline Gauges Ltd.
SU America
United Tool Supply
V&R Associates

Keyseating Machines

Basic Incorporated Group
Elmass North America
Mitts & Merrill L.P.

Lapping Machines

Basic Incorporated Group
Bluegrass Precision Machinery
Engis Corp.
The Gleason Works
Lapmaster Intl.
Liebherr-America
Miller Industrial Services Inc.

Measuring Machines

Alpha Precision Inc.
American Pfauter L.P.
American Sykes Co.
Basic Incorporated Group
Best Engineering Co.
Bluegrass Precision Machinery
Brown & Sharpe Mfg.
Fellows Corp.
The Gleason Works
Holroyd Machine Tools
Krautkramer Branson
M&M Precision Systems
Mahr Corp.
Moore Products Co.
National Broach & Machine Co.
Ono Sokki Technology
Precision Gage Co.
Profile Engineering
Roto-Technology Inc.
Spline Gauges Ltd.
United Tool Supply

Shaping Machines
American Pfauter L.P.
Basic Incorporated Group
Bluegrass Precision Machinery
Bourn & Koch Machine Tool
Elmass North America
Engranes Industriales Rivera
Fellows Corp.
Liebherr-America
Mitsubishi Machine Tool
National Broach & Machine Co.
V&R Associates
WMW Machinery Co.

Shaving Machines
American Pfauter L.P.
Basic Incorporated Group
Bluegrass Precision Machinery
Elmass North America
The Gleason Works
GMI
Mitsubishi Machine Tool
National Broach & Machine Co.

Spline Rolling Machines
GMI
Micromatic Textron
National Broach & Machine Co.

Testing Machines
American Stress Technologies
American Sykes Co.
Basic Incorporated Group
D.I.G.I.T.
Eltech Inc.
The Gleason Works
Holroyd Machine Tools
Jack Dustman & Assoc.
Krautkramer Branson
Liebherr-America
M&M Precision Systems
Mahr Corp.
Manufactured Gear & Gage
Moore Products Co.
National Broach & Machine Co.
NewAge Industries Inc.
Ono Sokki Technology
Parker Industries Inc.
Precision Gage Co.
Profile Engineering

Turning Machines
Basic Incorporated Group
Bluegrass Precision Machinery
The Daniluk Corp.
Fellows Corp.
Hermes Machine Tool
Miller Industrial Services Inc.
Mitsubishi Machine Tool
Sales Consultants
Vic Machine Tools
WMW Machinery

Worm Milling Machines
American Pfauter L.P.
Basic Incorporated Group
Bourn & Koch Machine Tool
Koepfer America L. P.
WMW Machinery Company

Gear Manufacturing Machines—Other
American Wera Inc. — Polygon Cutting Machines (Profilating)
Ataka Engineering Co., Ltd. — Cutter Sharpening Machines
Bazell Technologies — Coolant Filtration Equipment
Eltech Corp. — Worm Grinding Machines
Finishing Equipment Inc. — Cleaning Machines
Hoglund Technology Corp. — Computerized Wheel Dressers
Ikegai America Corp. — Hob Sharpeners
Liebherr-America — Hob Sharpening, Worm Grinding
Manufacturing Technology Inc. — Inertia/Friction Welders
Mahr Corp. — Hand-held Gear & Spline Inspection Tools
NewAge Industries Inc. — Hardness Testers, Auto Traverse
Progressive Technologies — Surface Treatment
Raycon Corp. — Laser Welders
Reishauer Corp. — Thread & Worm Grinding Machines
Sala/BLM Corp. — Sawing Machines
United Tool Supply — Gages
Walmil Company — Parts Washers

GEAR MATERIALS

Gear Blanks
Accurate Specialties
Akron Gear & Eng.
American Machine Works
Ancon Gear & Inst.
Bengal Industries Inc.
Boeing Precision Gear
Capstan Atlantic
Clarke Gear Co., Inc.
Clifford-Jacobs Forging
Cornell Forge Co.
Dabko Industries Inc.
Dayton Gear & Tool
Designatronics
Dura-Bar
Elmass North America
EMCO Gears
Engratec de Mexico
Fairlane Gear Inc.
Fuller Company
Gear Motions
The Gear Works Seattle
Generated Gear & Machine
Harder Precision Components
Howard's Machine Shop
Intech Corp.
Krupp Engineering
Linamar
Mattoon Precision Mfg.
Mid-State Machine Co.
Milford Gear Works
Mobile Pulley & Machine Works
Moore Machine & Gear
PIC Design
Presrite Corp.
Process Industries
Qualicast Corp.
RD Industries
Reef Gear Mfg.
Riverside Spline & Gear
Robotronix
Schmid Tool & Eng.
Teledyne Portland Forge
Tifco Gage & Gear
Trogetec Inc.
Van Becelaere Machine
Viking Air Tools
Wells Manufacturing
Wohlert Corp.

Plastics
A & E Gears BV
American Machine Works
Bengal Industries Inc.
Dayton Gear & Tool
The Gear Works Seattle
Hoechst Celanese Corp.
Howard's Machine Shop
Intech Corp.
Trogetec Inc.

Powder Metals
Alpha Sintered Metals
Asco Sintering Co.
Capstan Atlantic
Carbon City Products
Cloyes Gear & Products
The Gear Works Seattle
Interlake
Metal Powder Industries Federation
TPI Powder Metallurgy
TPS Inc.

Steels
Ace World Company
American Machine Works
Crucible Service Centers
Dayton Gear & Tool
Elmass North America
The Gear Works Seattle
Impact Strategies
Krupp Engineering
Latrobe Steel Co.
Moore Machine & Gear
RD Industries
Trogetec Inc.

Other
Crucible Service Centers — High-Speed Steels for Cutting Tools
Dura-Bar — Cast Iron, Continuous Cast Iron
Intech Corp. — Plastic-Metal Composite
Teledyne Portland Forge — Precision Closed-Die Forgings

Trogetec Inc. — Laser Stampings
Wells Manufacturing — Iron

GEAR SERVICES

Consulting

Advance Gear & Machine Corp.
American Pfauter L.P.
Aplus Engineering Inc.
Applied Mechaniques
Aston Metallurgical Services
Axicon Technologies
Best Engineering Co.
C-Dot Engineering
Chicago Gear Works
Ciateq A.C.
Dabko Industries Inc.
Dayton Gear & Tool
Drive Systems Technology
Dynamic Metal Treating
Engranes Industriales Rivera
Fairfield Mfg. Co.
Gary P. Mowers, P.C.
The Gleason Works
Guy Crader Consulting
GW Plastics
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Impact Strategies
Intech Corp.
Jack Dustman & Assoc.
James Reid Gear Services
Management & Engineering Tech.
Manufactured Gear & Gage
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Gears & Drive Systems
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Harder Precision Components
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RD Industries
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Riley Gear Corp.

Riverside Spline & Gear
Roto-Technology Inc.
Schafer Gear Works
Scott Machine Tool Co.
Southern Gear & Machine
Spline Gauges Ltd.
Tifco Gage & Gear
Trogetec Inc.
UBM Corp.
Ultron Incorporated
Viking Air Tools
Wedin Intl. Inc.
Westech Gear
Winzeler Gear

Shot Peening
Ashot Ashkelon Indust.
Ashot U.S.A. Inc.
Boeing Precision Gear
Cincinnati Gear
Columbia Gear Corp.
Dayton Gear & Tool
Fairfield Mfg. Co.
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Progressive Technologies
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Stearns Financial — Machinery Financing
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Gearesearch Assoc.
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ABA-PGT Inc.
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Ciateq A.C.
Dabko Industries Inc.
Designatronics
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Gearsoft Design
Geartech
The Gleason Works
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NASA Lewis Research
PC Enterprises
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Brighton Industries
Brown & Sharpe Mfg.
Euro-Tech Corporation
Gearesearch Assoc.
The Gleason Works
Krautkramer Branson
M&M Precision Systems
Metrscope Corp.
Moore Products Co.
NCADT
PC Enterprises
Precision Gage Co.
R.H. Software
Roto-Technology Inc.
Scott Machine Tool Co.
Software Engineering Service
Trogetec Inc.
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NCADT
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National Broach & Machine
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Roto-Technology Inc.
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Use this index to locate the complete contact information for each company listed in the Products and Services Directory. *Gear Technology* advertisers are shown in boldface type. To find the pages on which their ads appear, see the Advertisers Index on page 32.

While *Gear Technology* has made every effort to ensure that company names and addresses are correct, we cannot be held responsible for errors of fact or omission.

If your company is not listed, and you would like to be included in 1997, call 847-437-6604, fax 847-437-6618 or e-mail us at *people@geartechnology.com*, and we will add you to our mailing list.

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Fax: 513-771-0485

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847-824-8327

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319-583-3591
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213-770-1955

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Fax: 313-973-3053

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908-493-2812
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Australia
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E-mail: udiashot@inter.net.il

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212-223-4050
Fax: 212-223-4156

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Fax: 773-929-0773
E-mail: as@mos.com

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Fax: 216-356-0289

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Nagoya Aichi
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Fax: (81) 52-772-0692
E-mail: ataka@mxb.meshnet.or.jp

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Fax: 415-934-3131
E-mail: axicon@aol.com

B

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716-693-8557
Fax: 716-695-1995

Barit International Corp.
3384 Commercial Ave.
Northbrook, IL 60062
847-272-8128
Fax: 847-272-8210

Basic Incorporated Group
Basic Machine Tools Div.
P. O. Box 36276
Los Angeles, CA 90036
213-933-7191
Fax: 213-933-7487
E-mail: patrik@loop.com

Bates Technologies Inc.
P. O. Box 213
9059 Technology Dr.
Fishers, IN 46038-0213
317-841-8805
Fax: 317-841-9443

Bazell Technologies
5066 Commercial Circle
Concord, CA 94520
510-603-0900
Fax: 510-603-0901

Becker Gearmeisters Inc.
245 Hallock Rd.
Stony Brook, NY 11790-3022
800-423-2537
Fax: 516-751-0205

Bengal Industries Inc.
11346 53rd St.
Clearwater, FL 34620
813-572-4249
Fax: 813-573-2428

Best Engineering Co.
P. O. Box 510797
2385 S. 162nd St.
New Berlin, WI 53151-0797
414-784-2200
Fax: 414-784-2541

BestMetal Corp.
925 Dieckman St.
Woodstock, IL 60098
815-337-8800
Fax: 815-337-8803

Bilgram Gear Co.
Eight Union Hill Rd.
W. Conshohocken, PA 19428
610-828-7200
Fax: 610-828-9428

Bluco Corp.
509 Weston Ridge Drive
Naperville, IL 60563
800-535-0135
E-mail: bluco@concentric.net

Bluegrass Precision Machinery
442 Three Springs Rd.
Bowling Green, KY 42104
502-842-7201
Fax: 502-842-7242

Boeing Precision Gear
6006 W. 73rd St.
Bedford, Park, IL 60638-6106
708-728-2000
Fax: 708-728-2009

Bonfiglioli UK
Unit 5 Grosvenor Grange
Woolston, Warrington, Cheshire
WA1 4SF United Kingdom
44 (925) 852664
Fax: 44 (925) 852668

Boston Gear
14 Hayward St.
Quincy, MA 02171
617-328-3300
Fax: 617-479-6238
E-mail: boston.gear@industry.net

Bourn & Koch Machine Tool
2500 Kishwaukee St.
Rockford, IL 61111
815-965-4013 x320
Fax: 815-965-0019

Boxx Gear Mfg.
1314 Central Pkwy. SW
Decatur, AL 356012
205-355-4611
Fax: 205-355-4661

Brighton Industries Corp.
15 Essex Rd.
Paramus, NJ 07010
201-368-3933
Fax: 201-368-8743

Brown & Sharpe Mfg. Co.
200 Frenchtown Rd.
North Kingstown, RI 02852
401-886-2369
Fax: 401-886-2970

Buckeye Gear Co.
5130 Richmond Rd.
Bedford Heights, OH 44146
216-292-6424
Fax: 216-292-6454
E-mail: skidmore@earthlink.net

Bucyrus-Erie Co.
1100 Milwaukee Ave.
S. Milwaukee, WI 53172-0500
414-768-4361
Fax: 414-768-4750

C

C-Dot Engineering
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Plymouth, MI 48170-2660
313-420-2075
Fax: 313-420-1279

Calicut Eng. Works Ltd.
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26A Camac St.
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Can-Eng Furnaces Ltd.
P.O. Box 235
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905-356-1327
Fax: 905-356-1817

Capital Associates International
4598 Valleyview Dr. Ste. 5200
West Bloomfield, MI 48323
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Capstan Atlantic
10 Cushing Dr.
Wrentham, MA 02093
508-384-3100
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Carbon City Products
Metal Powder Products Div.
150 Ford Rd.
St. Marys, PA 15857
814-834-2886
Fax: 814-834-9091

Case Corp.
700 State St.
Racine, WI 53404
414-636-0266
Fax: 414-636-7132

Caterpillar Industrial Products Inc.
100 N. E. Adams St.
Peoria, IL 61629-4375
309-675-5451
Fax: 309-675-6457

Chardam Gear Co.
40810 Brentwood
Sterling Heights, MI 48310
810-795-8900
Fax: 810-795-8908

Charles A. Templeton Mach. Inc.
P. O. Box 2566
2727 N. Golder
Odessa, TX 79760
915-332-2932
Fax: 915-332-0412

Charles Bond Co.
1035 Louis Dr.
Warminster, PA 18974
800-922-0125
Fax: 215-957-7999

Charmilles Technologies Corp.
560 Bond St.
Lincolnshire, IL 60069-4224
847-913-5300
Fax: 847-913-5340

Chicago Gear-D.O. James
2823 W. Fulton St.
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Chicago Gear Works
1805 S. 55th Ave.
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Chowgule Matrix Hobs Ltd.
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Cincinnati Milacron
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Cincinnati, OH 45209
513-841-8100
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CJT/Koolcarb
1040 W. Fullerton Ave.
Addison, IL 60101
630-543-7144

Clarke Gear Co. Inc.
8058 Lankershim Blvd.
N. Hollywood, CA 91605
818-768-0690
Fax: 818-767-5577

Clifford-Jacobs Forging Co.
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Champaign, IL 61824-0830
217-352-5172
Fax: 217-352-4629

Clipper Diamond Tool Co.
47-16 Austell Place
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718-392-3671
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Cloyes Gear & Products Inc.
P. O. Box 528
615 W. Walnut
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501-963-2105
Fax: 501-963-2163

CMD (UK) Ltd.
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Colonial Tool Group Inc.
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Colorado School of Mines
ASPPRC
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Fax: 303-273-3795

Columbia Gear Corp.
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530 County Road 50
Avon, MN 56310
320-356-7301
Fax: 320-356-2131

Commercial Gear & Sprocket
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800-491-1073
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Comtorgage Corp.
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Slatersville, RI 02876
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Cone Drive Operations
Div. of Textron Inc.
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Traverse City, MI 49685-0272
616-946-8410
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Consulting & Design Service
17033 E. Aloe
Fountain Hills, AZ 85268
602-837-8283
Fax: 602-837-8211

Contour Hardening Inc.
7898 Zionsville Rd.
Indianapolis, IN 46268
317-876-1530
Fax: 317-879-2484

Cornell Forge Co.
6666 W. 66th St.
Chicago, IL 60638
312-767-4242
Fax: 312-767-9443

Crucible Service Centers
5639 W. Genesee St.
Camillus, NY 13031-0991
315-487-0800
Fax: 315-487-4028

Cunningham Industries
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Stamford, CT 06902
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Current EDM Inc.
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Mountain View, CA 94043
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Curtis Machine Co. Inc.
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D. A. Stuart Co.
Metalworking Div.
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Fax: 630-655-1088

D.I.G.I.T.
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Fax: 219-481-3115

The Daniluk Corp.
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405-745-6644
Fax: 405-745-6646

Davis Tool & Engineering
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Detroit, MI 48228
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Fax: 313-837-7220

Dayton Gear & Tool
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Dayton, OH 45449
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Fax: 513-866-0408
E-mail: dgear@rcinet.com

Dearborn Gear & Tool Co.
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Fax: 313-581-3115

Deco-Technologies
1360 E. Big Beaver
Troy, MI 48083
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Delroyd Worm Gear
Division of IMO
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Detroit Broach Co.
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Greer, SC 29651
864-879-7641
Fax: 864-879-7693

Detroit Flame Hardening
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Fax: 313-891-3150

Diamond Black Technologies, Inc.
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Conover, NC 28613
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Dianamic Abrasive
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Fax: 810-280-2733
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Disston Precision Inc.
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Philadelphia, PA 19135
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Fax: 215-338-7060

DMS Inc.
554 W. Wood
Palatine, IL 60067
847-359-7882
Fax: 847-359-8481

Drewco Corp.
3745 Nicholson Road
Franksville, WI 53126
414-886-5050
Fax: 414-886-5872

Drive Systems Technology
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Glen Mills, PA 19342-1519
610-358-0785
Fax: 610-358-2776

Dura-Bar
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Woodstock, IL 60193
815-338-7800
Fax: 815-338-1549

Dyer Company
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1500 McGovernville Road
Lancaster, PA 17604-4966
800-631-3333
Fax: 717-569-6721
E-mail: dyer@dyergage.com

Dynamic Metal Treating Inc.
7784 Ronda Drive
Canton Twp., MI 48187
313-459-8022
Fax: 313-459-7863

Dynamic Tool Grinding Service
872 Ridge Avenue
Lombard, IL 60148
630-620-5044
Fax: 630-620-0177

E

Easco-Sparcatron
Division of Liquid Drive Corp.
10799 Plaza Dr.
Whitmore Lake, MI 48189
313-449-4443
Fax: 313-449-4447

Eaton Corp.
Highway 29 South
Kings Mountain, NC 28086
704-937-7411
Fax: 704-937-4354

EDM Solutions
2010 E. Touhy Ave.
Elk Grove Village, IL 60007
847-981-3361
Fax: 847-981-0158

Educational Systems Workshops, Inc.
P.O. Box 472
Dyer, IN 46311
219-865-1318
Fax: 219-865-2775

Electrex Ltd. (India)
Power Tools Div.
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Bangalore 560058
India
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Germantown, WI 53022
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Eltech Inc.
9841 York Alpha Dr.
North Royalton, OH 44133
216-582-8195
Fax: 216-582-8226

EMCO Gears
4329 N. Kedzie
Chicago, IL 60618
312-539-1315
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Engemaq U.S.A.
Montville Business Center
20 Chapin Rd., Unit 1002A
Pine Brook, NJ 07058
201-808-2665
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Engis Corp.
105 W. Hintz Rd.
Wheeling, IL 60090
847-808-9400
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Engranes Industriales Rivera
EIRSA, de C.V.
Apartado Postal 75-094
Mexico City D.F. 07750
Mexico
(52) 5-587-8266
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Engratec de Mexico
Poniente 128 #425
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Rod Mal. Rondon KM 42.4
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Sao Paulo 06500-970
Brazil
(55) 11-424-1777
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Equitable Engineering
1840 Austin
Troy, MI 48099
810-689-9700
Fax: 810-689-0281

Ernst Winter & Son Inc.
P.O. Box 1006
100 Wilhelm Winter St.
Travelers Rest, SC 29690
864-834-4145
Fax: 864-834-3730

Esgard, Inc.
P.O. Drawer 2698
Lafayette, LA 70502
318-234-6327
Fax: 318-234-0113

Etna Products Inc.
P.O. Box 630
16824 Park Circle Dr.
Chagrin Falls, OH 44022
216-543-9845
Fax: 216-543-1789

Euclid Heat Treating Co.
1408 E. 222nd St.
Cleveland, OH 44117
216-481-8444
Fax: 216-481-3473

Euro-Tech Corporation
14665 W. Lisbon Rd.
Brookfield, WI 53005
414-781-6777
Fax: 414-781-2822

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Fairfield Mfg. Co.
P. O. Box 7940
U. S. 52 South
Lafayette, IN 47903-7940
317-474-3474
Fax: 317-477-7342
E-mail: fairfld@aol.com

Fairlane Gear Inc.
8182 Canton Center Rd.
Canton, MI 48187
313-459-2440
Fax: 313-459-2941

Falk Corp.
P.O. Box 492
Milwaukee, WI 53201-0492
800-545-5215
Fax: 414-937-4359

Fayscott Co.
225 Spring St.
Dexter, ME 04930
207-924-7331
Fax: 207-924-5510

Federal Gear Corp.
38134 Western Pkwy. Unit #1
Willoughby, OH 44094
216-946-4327
Fax: 216-946-8018

Fellows Corp.
Precision Dr.
Springfield, VT 05156
802-886-8333
Fax: 802-886-8561

FGT Gage & Systems Inc.
2624 S. 162nd St.
New Berlin, WI 53151
414-827-0558
Fax: 414-782-3210

Finishing Equipment Inc.
3640 Kennebec Dr.
St. Paul, MN 55122
612-452-1860
Fax: 612-452-9851

Fiske Brothers Refining Co.
Lubriplate Div.
129 Lockwood St.
Newark, NJ 07105
800-733-4755
Fax: 201-465-5736

Flender Corporation
P.O. Box 1449
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Elgin, IL 60123
847-931-1990
Fax: 847-931-0711

Flender-Graffenstaden
1589 Aztec Ln.
Mount Pleasant, SC 29464
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Fax: 803-856-0104

Foote-Jones/Illinois Gear
2102 N. Natchez Ave.
Chicago, IL 60635
773-622-8000
Fax: 773-622-8176

Forest City Gear Co., Inc.
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11715 Main St.
Roscoe, IL 61073-0080
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Fax: 815-623-6620
E-mail: fyoung@firecraker.com

FPM Heat Treating
1501 S. Lively Blvd.
Elk Grove Village, IL 60007
847-228-2525
Fax: 847-228-5912

Franke Gear Works Inc.
4401 N. Ravenswood Ave.
Chicago, IL 60640
800-311-8425
Fax: 800-311-8426

Fuji Univance Corp.
38505 Country Club Dr., Ste. 204
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Fuller Company
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Gears for Industry Inc.
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General Broach & Engineering
50325 Patricia
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General Electric Marine Products Div.
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General Magnaplate Corp.
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Generated Gear & Machine
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Hand Screw Machine
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Hane Industrial Training
120 S. 7th St.
Terre Haute, IN 47807
812-232-0753
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Hangsterfer's Labs Inc.
P.O. Box 128
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Liebherr-America Inc.
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Saline, MI 48176
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Linamar
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Southfield, MI 48076
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Lindberg Heat Treating
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Brookfield, WI 53005
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Lovejoy Inc.
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CIRCLE 108

18 Things You Should Know About SPC for Gears

Dr. Hans Bajaria

Statistical Process Control (SPC) and statistical methods in general are useful techniques for identifying and solving complex gear manufacturing consistency and performance problems. Complex problems are those that exist in spite of our best efforts and the application of state-of-the-art engineering knowledge.

Statistical methods approach these problems *results-backward* as opposed to *knowledge-forward*. For example, the knowledge-forward approach would seek consistencies in gear profile, lead, runout, etc., with the assumption that consistencies improve performance. The results-backward approach, on the other hand, will analyze the situations starting from assembly performance. It will then relate performance variation to specific gear characteristics.

In other words, we use our gear expertise in a knowledge-forward approach. When this fails to solve a problem, we should use the results-backward approach. Once critical gear characteristics are determined, we can begin attempting to achieve consistency.

Let us begin by describing six SPC fundamentals and six statistical applications for gear design and manufacturing. These will lead us to an effective sequence for applying statisical methods.

Six Fundamentals of SPC

SPC is only a subset of statistical methods helpful in analyzing complex problems. These methods can be a useful set of tools for carrying out investigations of our manufacturing processes. SPC can chart the output of any process to examine whether the process condition is stable, has an excessive variation or is off-target. Furthermore, SPC can offer clues to strategies for correcting these conditions. Additional statistical tools can help us establish relationships between problematic process conditions and suspect variables.

1. ***Multivariate (T^2) Charts*** are useful in understanding and controlling correlated performance characteristics. The performance characteristics of assemblies, such as noise, durability, ease of maneuverability, etc., are likely to be correlated. That means, for example, that trying to reduce the noise may result in losing maneuverability, or improvement of maneuverability may result in a reduced durability, and so on. The problems associated with correlated characteristics can only be defined with the use of a multivariate chart (see Fig. 1).

2. ***Multivariate (T^2) Charts*** are also useful in understanding and controlling input gear characteristics. Gear characteristics are most likely to be correlative because they are generated simultaneously. In practical terms, we can state that when characteristics are correlated, each individual characteristic can be within specification, and yet jointly they constitute a statistical instability.

3. ***Multi-vari Charts*** are useful in analyzing size as well as shape problems. For example, four teeth on a gear measured by conventional means may all individually be within specification, and yet differences among them may be the root cause of a problem. A proper way to define a problem that takes into account characteristics of each tooth individually as well as differences among the four teeth is a multi-vari chart (See Fig. 2).

Multi-vari and multivariate charts are different. Multi-vari charts analyze variations within a given characteristic, whereas multivariate charts analyze

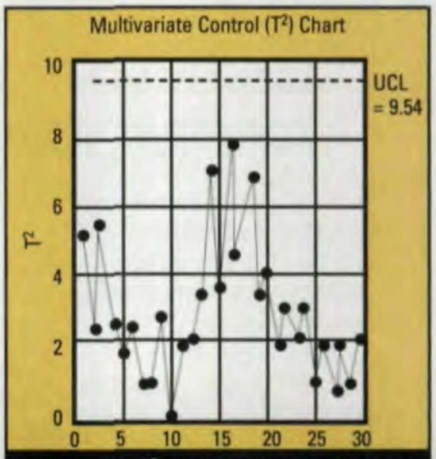

Fig. 1 — This T^2 chart combines 3 characteristics—tip, form and high point—in a single entity.

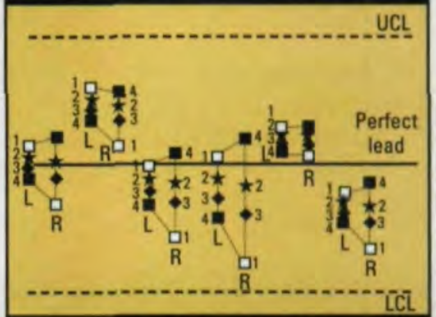

Fig. 2 — A multi-vari chart showing lead variation on 4 left and 4 right teeth simultaneously.

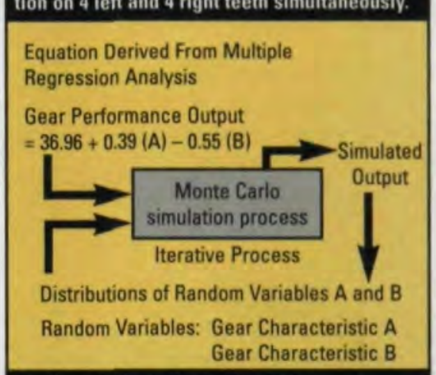

Fig. 3 — A Monte Carlo simulation.

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relation and variation between two or more characteristics.

4. *Multivariate Analysis* is useful in analyzing process instabilities and relating them to process variables. An instability is characterized by an abnormal condition on a control chart. To understand the source of unstable behavior, we generally analyze process variables. If process variables are stable, then we look for the explanation elsewhere. Multivariate analysis captures the missed opportunites in analyzing process variables that we have prematurely concluded to be noncontributory. For example, (A) incoming material condition, (B) workpiece speed and (C) tool feed may all appear to be within normal range when analyzing an instability visible on a control chart. Conventional wisdom leads us to look elsewhere for the root cause. A multivariate chart will offer additional help by analyzing T^2_{AB}, T^2_{AC}, T^2_{BC} and T^2_{ABC}. If this aid is not utilized, it is possible that the instability may remain a mystery.

5. *Multiple Regression Analysis* is useful in establishing relationships between gear performance characteristics and gear characteristics. Neither worst-case tolerancing nor statistical tolerancing alone are sufficient to fully understand how gear characteristics affect the performance of assemblies containing gears. Such understanding can only be developed through probabilistic relationships based on actual data rather than any theoretical considerations. Multiple regression analysis helps develop this relationship.

6. *Monte Carlo Simulations* are computer-based, iterative statistical procedures wherein we determine targets and ranges of critical gear characteristics to match targets and ranges of performance. The inputs to the simulation processes are probabilistic equations and targets and ranges of gear characteristics. The output from the simulation processes are the target and range of performance (see Fig. 3).

Six Applications for SPC in Gear Manufacturing

1. Acceptable as well as unacceptable production of gears can best be characterized by using SPC. Gear characteristics that fall within specifications are not in themselves indications of the quality of the processes that produced them. For example, an acceptable gear profile is judged by a specified envelope. However, the process that created the envelope is a multivariate process; that is, three characteristics that make up the gear profile—tip, form and high point—are produced simultaneously. A correct judgment about the process condition responsible for these characteristics can only be made with a T^2 chart. Any decisions regarding process actions based on specifications tend to produce either overreactions or underreactions. While gear metrology is very advanced, it does not go far enough in integrating SPC for process actions.

2. Effects of design and production of gear characteristics on gear performance can best be characterized by using SPC. Gear characteristics are simultaneously

generated and therefore, we must judge their acceptability together, rather than discretely. The issue of joint acceptability does not get enough coverage either in standards or at gear design and manufacturing conferences.

3. Output performance characteristics of assemblies containing gears, such as durability, noise, ease of transmission under quickly changing inputs and smoothness of transmission, are correlated to one another. Knowledge of these correlations is critical to the SPC of assemblies. These correlations can be quantified using statistical methods.

4. Suspect gear characteristics that contribute to poor performance of assemblies are most likely correlated to one another. Knowledge of these correlations is critical to the SPC of gear manufacturing processes. These correlations can be quantified by using statistical methods.

5. Manufacturing precision of gear characteristics is uneconomical until statistical relationships between gear characteristics and assembly performance are first established. In one example, a lead variation was found to be almost 95% out of specification, and yet assemblies containing the gears with such excessive variation only suffered 5% reject rate. If we rush to solve the lead variation problem at great ex-pense, there is no guarantee that the 5% assembly reject rate will go down. How a 95% out of spec gear characteristic can cause only a 5% assembly fallout can be explained only through statistical relationships.

6. Without the use of statistical methods, it is almost impossible to separate the effects of machining and heat treating on manufacturing variation. Without such clear separation, fully resolving variation problems is impossible.

Recommended Sequence for Deploying SPC & Statistical Methods

1. Establish a statistical relationship between assembly performance and gear characteristics. Then select eight assemblies with acceptable performance and eight assemblies with borderline or unacceptable performance. It may not be easy to find 16 assemblies if you are in the prototype stage. In that case, select the following alternate route to generating 16 assemblies. Take two assemblies. Any gear assemblies will have a minimum of four parts. By swapping these four parts between two assemblies, you can generate 16 assemblies for purposes of statistical analysis. Use multiple regression to analyze the data and generate an equation between performance characteristics and gear characteristics.

2. Use Monte Carlo simulations to establish targets and ranges of gear characteristics to match performance targets and ranges.

3. Investigate whether any correlations exist among critical gear characteristics. Use correlation analysis.

4. If correlations are high, use a multivariate (T^2) chart to monitor the output.

5. If correlations are low, use either average and range (X-R) charts (Fig. 4) or

individuals and moving range ($\bar{X}$-MR) charts (Fig. 5) for monitoring each individual gear characteristic. To select either set of charts, first determine whether a process output is homogeneous or heterogeneous. Do this by taking a group of five consecutive pieces and examining its range. If the range is one-half of the specification range or lower, the process output is homogeneous. Otherwise it is heterogeneous. If the process is homogeneous, use X-MR charts for monitoring process output. If the process is heterogeneous, use $\bar{X}$-R charts.

6. Because differences among teeth are contributing factors to ultimate gear performance, a multi-vari chart must accompany all the other charts to understand and control tooth-to-tooth variation within a gear.

The above described sequence is an investigative use of SPC. If any problems are uncovered as a result of this exercise, we can begin the solution process. If no problems are uncovered, we may choose to use SPC from this point on in the process for monitoring output. Inappropriate variations can then serve as a warning of incipient problem conditions.

Statistical tools may come to the rescue when you are confronted with puzzling gear problems. SPC, a results-backward approach, is a complement to the more traditional knowledge-forward approaches to gear problem solving. Once you develop expertise in the use of these methods, you will find they also accelerate and improve the productivity of your knowledge-forward approaches as well. ✪

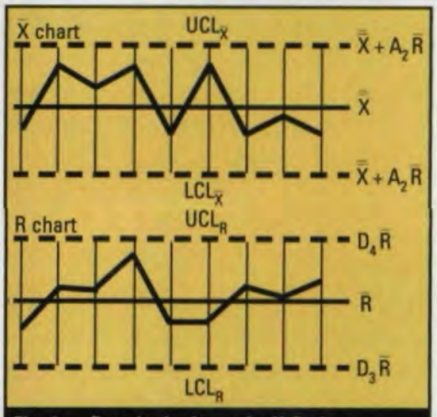

Fig. 4 — Data in the form of a X-R chart.

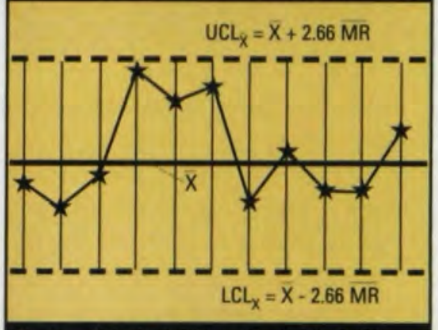

Fig. 5 — Data in the form of individuals (X).

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PRODUCT NEWS

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.

Vertical Honing Machine

Sunnen's new CK-21 computerized vertical honing machine is designed for precision honing of 3/4" (19 mm) to 8" (203 mm) bores in applications such as small engine blocks, air compressor cylinders, valve bodies and aircraft cylinders. The unit features a microprocessor based control system that enables the operator to control all aspects of the production cycle. The machine has a 3 hp (2.2 kW) spindle motor, and its new hone heads are designed for use with superabrasives. It has a real-time graphic display, will hold the geometry of the bore to within 2 tenths (6 microns), depending on the application, and allows for two different spindle speeds and multiple feed rates during a single honing cycle.

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Digital AC Servomotors

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Circle 326

Deburring Machines

Feintool Equipment Corp. is marketing the complete line of Vobhag deburring machines, which come equipped with optional PC-based process controls to compensate for brush or fleece wear automatically. All models let users fine-tune speeds of both head and brushes to "debug" the deburring process without hardware changes. The units all use linear guides to position the Rotex head to ensure the rigidity necessary for high-force fleece deburring. The control area and work zone are sealed and separate from one another for operator safety and to guard against drive contamination.

Circle 327

Vibration Monitor

Schenck Trebel introduces the Vibrocontrol 920, a single channel monitor, which the company says is flexible, dependable and provides maximum protection for motors, fans, pumps and other equipment critical to operations. It accepts virtually any type pickup, including velocity sensors and 2-, 3- or 4-wire accelerometers. A program provides password protection and allows pre-programming of limits for warning devices. The VC920 features a 4-20 mA output for system integration with a PLC and a buffered output for instant vibration analysis. It accepts all power supplies (115/230 V A/C, 24 V DC) and is easily mounted on rails or within a cabinet enclosure.

Circle 328

Brinell Hardness Tester

NewAge Industries, Inc., announces the HB3000 Series Brinell hardness tester with motorized dead-weight load application and automatic readout options to reduce sources of error in Brinell testing. The basic tester operates in any Brinell range from 62.5 to 3000 kg loads and with 2.5, 5 or 10 mm ball indentors. The capacity is 9" vertical and 4.5" throat depth. The BOSS Automatic Readout Option uses a hand-held scanning head that views the Brinell impression. The software measures the impression at many angles to derive the Brinell hardness and impression diameters. Outputs include histograms, X-Bar & R charts and RS 232 output to a printer, computer or data gathering system.

Circle 329

Small Size Broaching Tools

National Broach's SPIRALGLIDE broaching tooling is now available in smaller diameters. It is now available in sizes from 3/4" to 12". According to the manufacturer, the SPIRALGLIDE series offers a unique configuration which provides constant tooth engagement with the workpiece, giving longer tool life, more pieces per sharpening, the ability to accommodate shorter lengths of cut, quieter operation and the virtual elimination of vibration.

Circle 330

Deburring/Cleaning System

SurfTran's TEM C-250 deburring system with automation and parts conveyor linkage to a SurfTran 5-station open tank cleaning system offers a way to deburr and clean parts for assembly at rates up to 360 parts per hour. The C-250 deburrs by means of an instant burst of high heat, eliminating all burrs and contaminants internally and externally.

Circle 331

Hawkeye™ Borescope

Gradient Lens Corp. announces the introduction of its Hawkeye™ 12" borescope and optional 90° adapters for non-destructive testing, visual inspection and quality control in manufacturing and tooling. The Hawkeye is a portable, precision optical instrument featuring a high-intensity light source. It operates on AA batteries and enables users to perform close inspection of any opening larger than 0.165" (4.2 mm). It can also be used with standard high-power fiber optic light guides and is video adaptable. The optional 90° adapters allow sideways viewing to further extend the borescope's usefulness.

Circle 332

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Gears on Film

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

In our unceasing attempt to further educate our readers—and find new and creative ways to waste time at work—the Addendum staff has spent many long hours (and many dollars on popcorn) to bring you our latest research on gears in film.

We'll be assigning ratings (1 gear = pretty awful; 4 gears = terrific) to the movies based on the following qualities: impressiveness of the gears, relevance to the plot, prominence in the film, star quality and dramatic interpretation.

Modern Times (1936). Our nominee in the Classic Gear Movie category is Charlie Chaplin's last film without dialogue (or almost without it anyway), and may be one of his finest. In it Chaplin plays a hapless victim of modern factory life, while a very young Paulette Goddard plays his love interest, known only as "The Gamin."

The plot, which might have been co-written by Charles Dickens, Victor Hugo, Scott Adams and the Monty Python gang, is a darkly comedic look at the Depression-era struggles of ordinary people trying to survive in an industrialized society.

We're sorry to say that the gears play metaphorical villains, but they're nasty in the grand tradition of movie bad guys. If not quite as evil as Olivier's Richard III or as funny as Alan Rickman's Sheriff of Nottingham, they make worthy symbolic opponents, and they're considerably more obvious as symbols than Charles Foster Kane's Rosebud. They're also very sexy, as gears go, and they film wonderfully in black-and-white.

Our only quibble is that in a couple of crucial scenes, some of the gears are running backwards. But then maybe it's not fair to expect someone to be both a directorial genius and a gear engineer. Rating: ⚙⚙⚙⚙.

The Rock (1996). An action/adventure flick with Nicolas Cage as an FBI biochemical weapons specialist and Sean Connery as the only man ever to have escaped from Alcatraz.

The gears—or in this case, gear segments—come into play after terrorists steal some chemical weapons and take over "The Rock." Connery, Cage and a small band of Navy SEALs must sneak into Alcatraz, disarm the weapons and save San Francisco from total destruction.

At a crucial point in the plot, Connery must roll underneath a series of giant pendulums with gear teeth on their bottoms while avoiding spouts of flame shooting up from the floor. We're not entirely sure what this contraption is supposed to be. The gear teeth don't appear to mesh with anything, and we don't know why flames are shooting up from the floor, but it's really cool and scary-looking. Rating: ⚙⚙⚙.

The Metaphysics of Gears

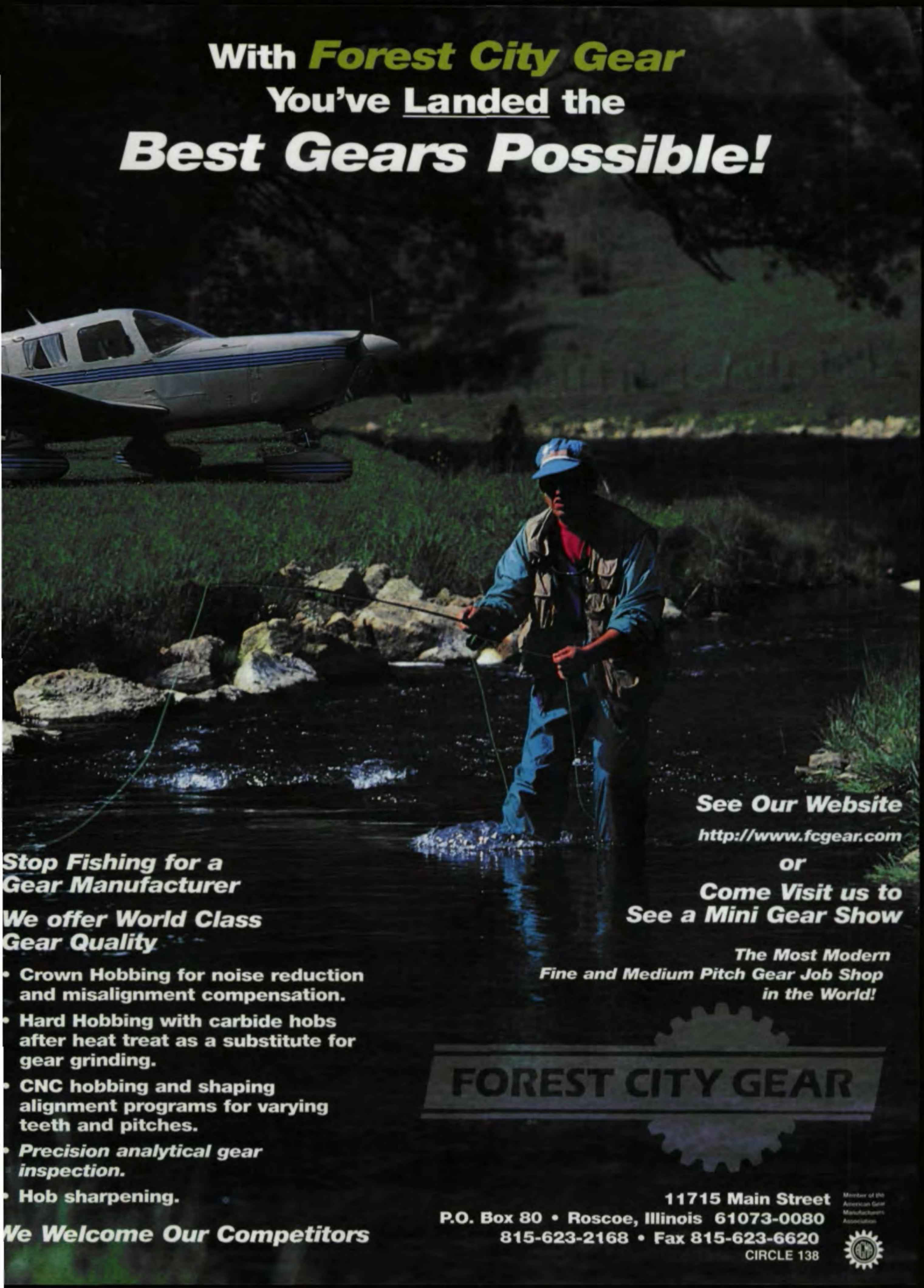
To answer the question, what is a real gear, we have consulted no less an authority than Eliot K. Buckingham. Mr. Buckingham comes down on the side of the stationary objects. He says, "... to my mind, a single gear is a piece of metal with projections on it. A gear is designed to be operated with another gear or gears. You do not design a single gear ...

"If a gear has to be moving to be a gear, what are all those things in planetaries, and often differentials, that don't move, but are absolutely necessary to proper performance, and have all the appearance of being gears, with teeth and all?"

He approaches the "Biggest Gear in the World Question" using the same logic: "Actually, the largest gear in the world is a cog railroad, since the rail is a rack, which is a segment of a gear of infinite diameter."

Since no discussion of either philosophy or movies is complete without a dissenting point of view, Addendum is waiting for yours. If you have nominations for our Gear Movie Hall of Fame or another philosophical viewpoint on the ontology of gears, let us know. We have a new referee's whistle we'd love to try out. ⚙

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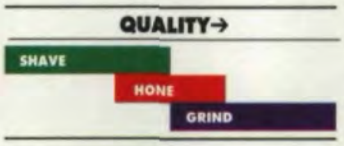

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