GEAR TECHNOLOGY

THE JOURNAL OF GEAR MANUFACTURING

NOVEMBER/DECEMBER 1994

ANNUAL BUYERS GUIDE ISSUE

IMTS ROUNDUP

HOBBING WITHOUT COOLANT

INSPECTION BASICS

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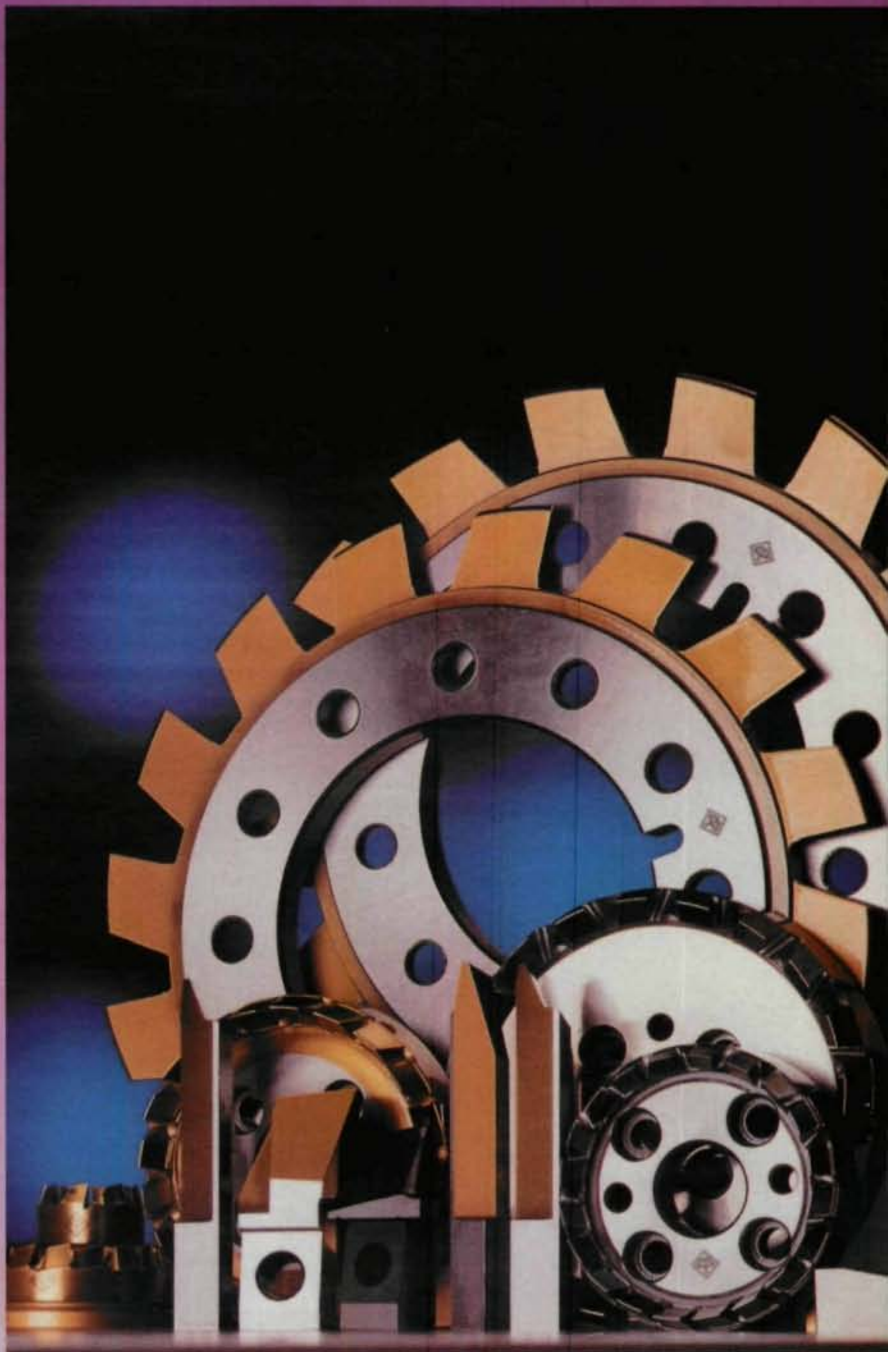

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Was it worth it all? What was to be learned from this manufacturing show-and-tell extravaganza?

Most noteworthy was the sense of optimism that pervaded the show. It's been a tough ten to fifteen years for both buyers and sellers in the machine tool business. Businesses closed or consolidated in record numbers. But we finally seem to have turned some kind of corner. Salespeople reported record numbers of machines sold off the floor, and one purchase order was written on the back of a business card because the buyer didn't want to wait to get back to the office to complete the paperwork. The slow but steady recovery seems to be the real thing this time.

An important subtext of this message is that overseas activity is picking up as well. Europe and Japan both seem to be recovering from their recent economic stumbles, and Australia, New Zealand, South America and South Africa are all showing signs of optimism and renewed economic strength. The rest of the globe is moving to upgrade its industrial base as well.

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IMTS provided confirmation, as if it were needed, of what the pundits have been telling us for years—manufacturing has gone global, and it is the wise manufacturer who looks outward when making business plans. The Germans and Japanese were expected at the show, but also notable were booths and entire mini-pavilions from everywhere from Spain to the People's Republic of China. The visitors were from everywhere as well. The International Business Center was always crowded. Everybody from Argentina to Taiwan sent trade association representatives. Economic and political differences that in the past kept people on the home side of their country borders have faded in the drive for technological upgrading and a piece of the profit pie. The place to look in the next ten years for both business opportunity and competition is outward, especially east, toward mainland China.

Also confirmed was the bit of popular wisdom that says, computerize to compete or be left behind. A lot of visitors to *Gear Technology*'s booth, especially those from small gear cutting shops, told us of the need to upgrade their older, manual machines to newer CNC equipment to meet customer demands. Everybody wants higher quality gears at lower cost, in less time and in smaller lots. The booths of the major manufacturers of gear machine tools reflected this trend. Key innovations all tended toward increasing output speed, raising quality, lowering per-piece cost and addressing environmental concerns. (See our IMTS Roundup on page 10 for more information.)

MARKETPLACE

by the lake

One of the major drivers of this trend is the computer chip, which supports both the most sophisticated CNC machines and the new manufacturing-oriented software for PCs. In both these arenas, upgrading is becoming easier than ever, as chip prices fall and software becomes more and more user-friendly. A growing number of packages for design and manufacturing are available in Windows®, DOS or Macintosh® formats, as are packages to assist factory management tasks from keeping tool inventories to tracking jobs to organizing the front office.

Another trend we spotted is the number of small job shops doing the research necessary to begin cutting gears. The logic seems to be that they have been preparing the blanks for years and sending them off someplace else to be cut. Now

PUBLISHER'S PAGE

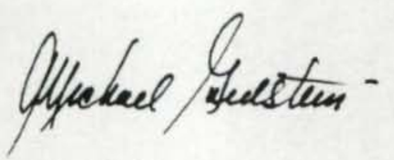
they're interested (drawn, perhaps, by the growing availability of affordable, user-friendly hardware and software) in adding gear cutting as a profit center to their other operations.

And this means what? More competition in an already small market. This is no time to sit back and rest on your laurels. The litany is familiar, but bears repeating: upgrade your equipment and your people, aim for higher quality and lower per-piece cost, be nimble, be aware, be sensitive to competition, not just from down the block but from across the oceans.

And speaking of upgrading your people, another trend we were pleased to see was the number of student groups trolling the aisles. Competition is not going to get any easier, and the key asset of the next decades will be trained and knowledgeable people. We need to be about the business of preparing the next generation of skilled engineers and operators. There is no better way to encourage the brightest and the best of our future manufacturers than to show them just what's out there for them to work on in the future.

The optimism at IMTS was unmistakable. There's money to be made out there. But, as always, it's not going to be made by the fainthearted or those unwilling to ride the rising tide of change crashing in on manufacturing.

The key lesson that came from nine days on our feet talking to gear manufacturers, buyers and sellers is this: Now is no time to sit down and rest. Keep moving or get left behind.



Michael Goldstein,
Publisher/Editor-in-Chief

COMPUTERS AND AUTOMATION LEAD IMTS INNOVATIONS

WILLIAM R. STOTT

Robots, computers and other signs of high technology abounded at IMTS 94, supporting the claim by many that this was one of the best shows ever. Many of the machines on display had so many robotic attachments and computer gizmos that they looked more like they belonged in some science fiction movie than on the floor of a machine shop.

The gear industry made a strong presence in this technological display, with more than 40 machinery and cutting tool manufacturers specializing in gear equipment. In addition, although our booth was considerably less high-tech than some, *Gear Technology* exhibited at IMTS for the first time ever. The staff had a chance to talk to many industry leaders, new subscribers, old fans and other dedicated gear enthusiasts. We also visited the booths of all the major gear equipment vendors to see what was new in the industry.

Most of the gear-industry manufacturers have been hard at work enhancing their machines with added CNC axes, greater flexibility and more user-friendly software. Today's machine is more versatile, with quick changeover times that are ideal for small-batch manufacturing. But they also run faster and with greater accuracy, making them ideal for shops in the automotive and other high-volume industries as well. Today's machines are smaller, faster and more accurate.

A good example of this new breed is a Gleason gear hobber aimed at the high-volume shops serving the automotive, appliance and power hand tool industries. The 125GH CNC 6-axis gear hobber has a rigid, cast iron frame to counteract the cutting forces of high-speed hobbing and produces gear qualities of up to AGMA 13. In addition, a patented hobhead provides low work arbor heights for greater workpiece support. The model on the show floor, equipped with an automatic loader and capable of hob changeover in under a minute, was used to cut transmission speed gears and small gears for power tool applications.

One of the most exciting new technologies on display at the show was Liebherr's revolutionary high-speed dry cutting hobber. Delivering up to 3000 rpm, the LC 82 CNC is capable of using carbide and cermet hobs for cutting speeds up to 2000 sfpm—without lubrication. This means greater accuracy and lower per-piece cost without the additional cost and environmental hazard of cutting oils. In addition, the LC 82 CNC occupies about one-half the floor space of previous models. (See also "Gear Hobbing Without Coolant," page 20.)

Automatic loading systems were also popular this year. For example, Reishauer's RZ 362A gear grinder was tended by a 7-foot, $^3/_4$-ton industrial robot, the ASEA Brown Aeneas IRB 3000. The grinder itself uses a creep-feed process, accomplishing in one pass what would otherwise take several passes by moving the workpiece both tangentially and axially with respect to the grinding wheel. Because the work spindle moves after each cycle, the robot must follow the spindle across the machine to load the workpiece in a different position with each pass. The 6-axis robot can be programmed for each part, allowing load and unload times of about eight seconds.

Koepfer introduced its Model 200 CNC gear hobbing machines, which can be equipped with a range of loading devices, from a simple gravity-fed magazine to a robotic gantry loader that allows material flow and communications to be integrated with other manufacturing processes, including washing, measuring, palletizing and transfer to other operations. The automation for each machine can be tailored to the needs of the customer.

Mitsubishi Machine Tools introduced two new machines at the show, the GC20 high-speed gear hobber and the ZG400CNC gear grinder. Both machines can be custom-fitted for flexible manufacturing systems with various automatic tool handling and loading devices. For example, options on the GC20 hobber include an automatic work changer, an automatic tool changer and an automatic jig changer. The ZG400CNC grinder's options include an automatic wheel change device, a workpiece conveyance system, an automatic meshing device and a workpiece measurement device.

Other gear machine manufacturers at the show introduced new machines or current production models with new features. Again, computer controls were highlighted at nearly every booth.

Stoffel Grinding Systems displayed a high precision grinding machine made by Reform Maschinenfabrik of Germany. The Reform ZSM 800 was specifically developed for precision grinding of straight and helical formed gears as well as straight and spiralled fluted broaches. It has eight numerically controlled axes, three of which are on the grinding wheel dressing device, which is capable of continually adjusting for wear on the grinding wheel to maintain the accuracy of the profile generated. Also, because of its quick changeover, this machine is especially well-suited to small batch sizes.

Bourn & Koch introduced its new 500 series CNC gear grinder, which is equipped with threaded CBN-plated wheels. The 500 Series grinders can support 2,000 pounds of fixture and part weight and parts up to 900 mm in length. In addition, the machines come with Bourn & Koch's copyrighted user-friendly software package for programming and operating the CNC controls.

Sunnen Products company introduced its EC-3500 Power Stroked Honing Machine, which uses a two-stage feed pressure feature to reduce cycle times by removing the bulk of the stock at high feed pressure and finishing the part at a lower pressure. The EC-3500 accommodates a wide variety of parts, including keyways, splines and other odd or unusual shapes.

WMW Machinery demonstrated the new Niles profile gear grinder, which has two independent CNC-controlled grinding wheel slides, menu-driven CNC control and integrated software, which allows the measuring of profile, lead, pitch and runout of the workpiece while it is still clamped in the machine.

Kanzaki Kokyukoki demonstrated its new GFB-250/CNC-5 five-axis hard gear finishing machine for superfine finish surfaces on gears. The GFB-250 comes with an optional gaging feature, which activates an automatic dressing function whenever the gears produced fall outside the specified parameters.

Fellows Corporation demonstrated the latest generation of its 10-4 gear shaper. The machine was equipped with a GE Fanuc control system, providing it with two axes of control. Fellows' Vermont USA Machine Tool Group partner Bryant Grinding Corporation introduced its new Ultraline UL2 high speed grinding machine for grinding bores in gears, bearings, valve lifters and similar components.

American Pfauter exhibited a new hard finishing process for high-volume gear manufacturing. The KAPP VAC 61 CNC uses a Coroning® tool, a hardened steel ring with an internal gear configuration that generates an exact duplicate of the gear profile required on the workpiece when rolling the Coroning® tool. In addition, the machine can use two Coroning® tools, each plated with a different CBN grain size, to divide metal removal into roughing and finishing operations in one work cycle.

In other industry news, American Pfauter announced at IMTS that it would be taking over the North American sales and servicing of the Deckel Maho line of milling and machining centers. Deckel Maho was recently acquired by Gildemeister AG of Bielefeld, Germany. American Pfauter currently is the North American distributor for all Gildemeister turning products.

The Deckel Maho line includes 5-axis universal machining centers that could be used to make hobs, gearbox housings and other ancillary gear industry products. ■

If you would like additional information about any of the companies or products mentioned in this article, please circle the appropriate Reader Service number listed below.

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A Failure to Communicate

The Perils of Management By Initiative And What To Do About Them

Nancy Bartels

The two reports referred to in this article, "The Peoplewise™ Organization" and "House Divided: Views on Change from Top Management—and Their Employees," crossed our desks some weeks ago. They stimulated a fair amount of discussion here, and we hope they do the same in your offices. We welcome your responses. How do you view the corporate/competitive environment of the next few years? How do you see yourself and your company fitting in? Can these ideas work in the gear industry? Let us know what you think.

MANAGEMENT MATTERS

The CEO of Bigger & Better Gears is ecstatic. His latest cost-cutting programs, which implemented a team approach to production (eliminating two layers of supervisory staff), changed the inventory control system and established a new set of quality control goals, have cut his expenses in the last quarter by 40%. The expensive set of initiatives was worth it. B & B's competitive position looks much better; so does its bottom line; the stockholders will be pleased.

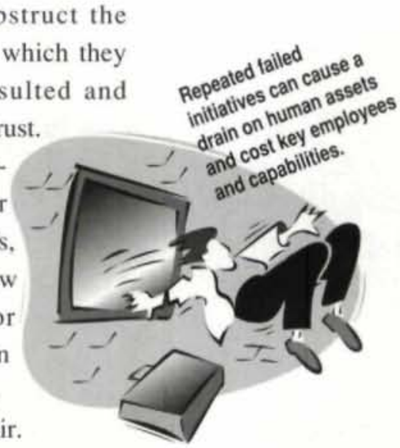
But at the other end of the plant, in the employee lounge, the quality-control manager is talking to a friend from accounting: "What a joke. We spent two days talking about our new philosophy of 'quality-based thinking.' Everybody was supposed to be free to pull product that didn't meet standards without waiting for approval. Then the first time there was a production crunch, we got dumped on for holding up the line. Now morale stinks. My people think they've been lied to. Frankly, I think quality is worse than before because now nobody cares. I don't know about you, but I'm polishing my resume."

Her friend replies: "Yeah. They let half the accounting department go. Of course, we still have the same amount of work, so we've hired back three guys as consultants. The only difference is that now they're billing us $100.00 an hour for their time. So much for cost cutting. If I hear about one more management initiative, I'm going to throw up."

And down on the production line, the shop steward is mulling over the three formal grievances he received this morning. That makes a total of eight for the month, more than were filed all last year. The revamping of inventory control is not working. If anyone had bothered to ask him, he could have told them it wouldn't. Now his people are disgruntled and are openly resisting the attempt to form production "teams." They're using the work rules in the union contract to obstruct the changes about which they were not consulted and which they distrust. They're frightened of another round of layoffs, and with a new contract up for negotiation in three months, strike is in the air.

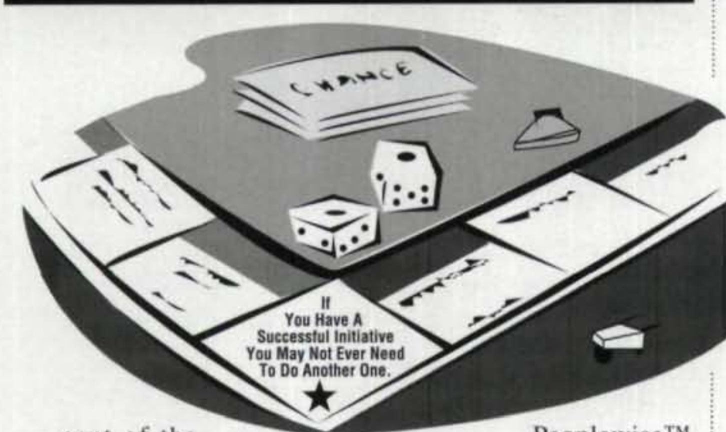
A nightmare scenario, you say. Never happen at my plant. Are you sure?

According to a survey of 3,500 North American executives and 3,000 non-managerial employees done last year by Kepner-Tregoe, a management consulting firm with offices around the world, this disparity between top management and employee perception of change



Nancy Bartels
is Gear Technology's Senior Editor.

MANAGEMENT MATTERS



initiatives is all too common; yet companies continue to implement program after program.

The survey, "House Divided: Views on Change from Top Mangement—and Their Employees," suggests that in the present hypercompetitive global manufacturing environment, many companies are suffering from "initiative addiction." Forty-two percent of the companies surveyed had undertaken *eleven or more* change initiatives, including strategy setting, employee empowerment, downsizing, customer service improvement, restructuring or productivity improvement, in the last five years. Companies that have already undertaken one such initiative are more likely to do so again, and most companies focus on the immediate bottom-line return of these programs rather than on the long-term competitive health of their companies.

The result in many cases is that these initiatives cause a steady drain on human assets, cost key employees and capabilities, foster the growth of cynicism, and permanently alter the concept of "employee loyalty." Short-term numbers may look good, but the long-term health of these companies is not so promising.

Shifting Paradigms

The reason for the apparent failure of these well-intentioned programs, according to another Kepner-Tregoe report, "The Peoplewise™ Organization," is a failure on the part of management to understand the shifting paradigms of the workplace. Historically, organizations have been seen as a collection of systems, processes and structures. To make change, you tinkered with the system. The basic assumption was that changing the system changed peoples' behavior.

The truth is, it's the other way around. "The Peoplewise Organization" quotes Amy Marks, Senior Vice-President of Human Resources at USF&G: "The same people tend to behave in the same way even when placed within different organizational structures. Organization structure and processes are enablers or inhibitors, but they don't define how an organization or an individual behaves." Any program that puts systems and structures ahead of the people who implement them runs the risk of spectacular—and expensive—failure.

The report suggests that the people-based model challenges the very way we look at running a business and managing people. According to Shari Johnson, a principal at Kepner-Tregoe who has worked with many automotive and heavy industry firms to implement change, even the tools for corporate success are different now. "It used to be that technology or access to large amounts of money or large infrastructures globally were competitive advantages. Now anyone has access to those things. Now it's what you do with your people and what your people do with technology that's the critical difference."

In this model, it's the people and their accumulated judgment, perceptions, experience, intuition and intelligence that will determine the success of the organization. And the way to best tap this collective wisdom is not the old top-down, pyramid-shaped management system. A more horizontal, flexible management model is evolving in some of the most successful companies.

Johnson says, "I see it going even beyond that. I see organizations that don't have official structures. Levels of management are going to greatly decrease. Already we're working with organizations that have at a particular site a plant manager, his staff and self-managed teams, and I think we're going to see a lot more of that."

If Johnson and the other change gurus are right, then the reason so many change initiatives fail becomes clear: corporations spend millions of dollars creating systems and structures for the next millennium and try to insert them into a 1960s performance environment. Then when the individual program fails to live up to its promise, the tendency is to move on to the next "new and improved" program and try it—every time dealing only with the symptoms, not the real problem. Mr. Banthoom Lamsam, president of the Thai Farmers' Bank, is quoted in the Kepner-Tregoe report: "So much change in organizations is little more than rearranging the chairs and tables. What's most important is to get the people to change."

Implementing People-Based Change

The fundamental point of people-based change is to look at what a company has done traditionally—manufacture a product—from a different point of view. Says Johnson, ". . . what this [model] basically says is 'Let's put a different focus on what we are doing and realize the importance of people as we go about doing it.'"

This is not to be confused with "management by warm fuzzies." According to Johnson, people-based management has nothing to do with making people feel good, but everything to do with corporate survival. "Your motivation is not to make people feel good and/or involved," she says. "Your motivation is to be better than your competitor." And the way to do that is to tap the collective wisdom of all your employees.

Step one is for top leadership—both management and employee—to determine a new set of values and beliefs that will be the basis for change at the company and to do so with the people directly involved in the change. This will call for a sharing of goals, ideas and strategies and for firm commitment on the part of everyone involved. It's not enough to write out a high-flown mission statement. Corporate leadership has to be willing to back it up with real time, real money and real change.

The second step is for management to demonstrate in significant ways its commitment to these new values by its behavior. Lip service is not enough. Says Johnson, "We are not just role-modeling things that are easy. If you say that independent decision-making is something you value in your organization, then you have to let people do it. You can't second-guess them."

The other important factor in implementing changes is to involve the people who will actually be affected by them. In a union shop, the union must be involved from the very beginning. At the Chrysler plant in New Castle, IN, one of Kepner-Tregoe's success stories, a plant in danger of being closed was turned around in two years to the point where it is

Any problem that puts systems and structures ahead of the people who implement them runs the risk of spectular-and expensive-failure.

actually hiring people. In this case, the head of the UAW and the vice-president of labor relations for Chrysler sat down together and hammered out what worker involvement should look like.

Johnson says that remembering the unique characteristics of unions is critical to success. Union leaders are elected, and they have to answer to their constituencies. They cannot be expected to take positions that will be perceived as hurtful to their members or will jeopardize their re-election.

Learning to work with the union contract is also important to implementing change. If management and union leadership sit down together early in the process and agree on values and beliefs and lay out goals, and if management shares corporate strategy and helps union leadership to understand where the organization is going, a union contract can become a tool for change. Johnson says, "We've gone through 50 to 80 years of interpreting every word to the letter, but our experience is that once you establish a win/win approach, a union contract is really a flexible instrument."

The other group that senior management has to bring into the picture is middle management and supervisory staff, particularly if the planned initiative is one that will affect this group's perceived power. Says Johnson, "A lot of these people have come up through the ranks. They've worked very hard to become supervisors, and now they see their power base being taken away, so they're extremely reluctant."

She adds, "The best way of getting something positive to happen is to sit down with them very early in the process. Begin to articulate what the supervisory role will look like in the new organization, what skills are needed, what values, what benefits."

Trust-Building

This early spade work is essential for building the trust necessary to make these kinds of broad initiatives work. But building trust is not easy, especially if your work force has been burned in the past by a number of failed initiatives. On the other hand, it's wrong to assume that you cannot begin an initiative until you have trust.

Trust is a process that builds on itself. Every

The face of company loyalty has been permanently altered and cynicism abounds.

successful transaction creates more trust for the next time. "There are always individuals who are looking, to a greater or lesser extent, for ways to prove that 'Here we go again,'" says Johnson, "but trust is the result of activities; it's not the precursor of change."

Trust is also a two-way street. Management has to trust that its employees want the company to succeed. Johnson says, "Our experience is that people want to be involved. Everybody in an organization from the CEO down to the hourly production worker is working for personal reasons, but they are also there to improve the organization's effectiveness at the point where they can have an impact on it, given the right environment in which to do that."

Sharing the corporate strategy and including employees in discussions of basic values reinforces these positive motivations.

The Dual-Track Approach

One major reason employees are so mistrustful is that change initiatives frequently bog down in the middle. They begin with great fanfare and hype, and six months later things are back to where they were. Then management decides it's time for a different initiative, and the process begins again. In the meantime, trust erodes and cynicism builds.

One way around this is the dual-track approach. Johnson recommends beginning with organizing for the short term to focus on some significant areas of improvement where you can facilitate quick turnaround. This tactic gives the signal that the potential for real change is there, and it produces tangible, measurable results.

It also helps employees (and management) to "keep the faith" during the difficult middle phase of change when nothing seems to be happening or, worse, when the program seems like a failure. This is the place where it is both hardest and most important to sustain leadership, and, according to Johnson, the point where most initiatives fail. "It's like a rubber band. If you take your right hand and pull and then let go, it's going to go back to its original position."

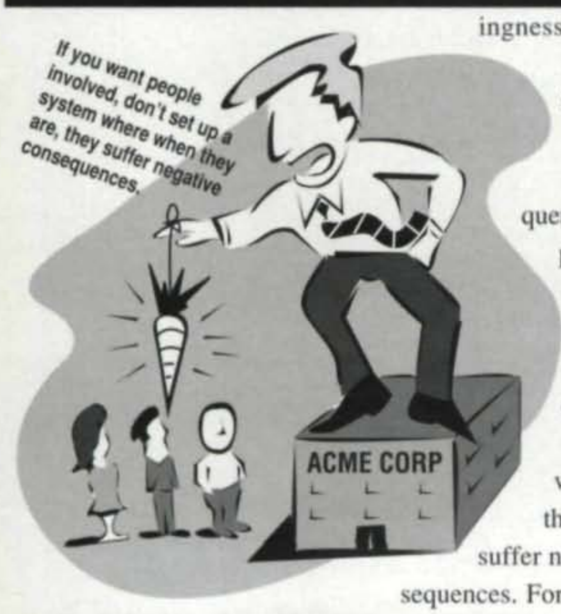
Breaking the Initiative Cycle—Beyond Trust-Building

Changing the corporate cultural environment is not unlike turning an aircraft carrier at sea: it takes time, and it's not a one-person job. But you can harness the people assets of your organization to initiate effective change by providing them with an environment that contains certain crucial elements.

First is role clarity. When the system is changing, people are unclear as to what their new roles should be. In a people-empowered organization, role clarity is a very difficult issue because the old, clearly defined organizational boxes into which everyone fit are gone. People need time to get used to a fluid structure that allows them to move in and out of different relationships given the particular task.

The second factor that will impact people's willingness to become actively involved in change is the consequences to them personally. If you want people to be involved, don't set up a system where when they are, they suffer negative consequences. For example, if suggestions are invited and then ignored, don't be surprised if no second round of suggestions is forthcoming.

MANAGEMENT MATTERS



The third factor is the inverse of number two. People need positive reinforcement. When employees respond in a positive way to change initiatives, say by accepting more responsibility or being innovative about the way they do their jobs, they need to encouraged. Says Johnson, "They need to hear, 'This is good. Keep doing this.'"

The people-based organization is an evolving one. At no point in developing such a structure do you arrive at the point where you can say, "Now we're there. Now we can stop." But such an organization is inherently agile. It can respond smoothly and effectively to the changing demands of the outside environment. It is also the way to break the initiative cycle. The reason is simple, says Johnson. "If you have a successful initiative, one that's working for you, you may not ever need to do another one." ■

Illustrations by Darryl Shelton of Shelton Design.

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CALENDAR

NOVEMBER 1–3
SME Seminars. "Heat Treating and Hardening of Gears" and "Understanding Gear Metrology." Ft. Mitchell, KY (Cincinnati area). Contact Susan Mihalik at (313) 271-1500, x384 for more information.

NOVEMBER 2–3
University of Wisconsin—Milwaukee. Short course in "Fast New Product Development." Radisson Hotel Metrodome, Minneapolis, MN. Covers techniques for getting greater yield from new product development dollars and improving company competitive position. Contact Richard Albers, (414) 227-3125.

NOVEMBER 14–18
AGMA Training School for Gear Manufacturing. Daley College, Chicago, IL. Hands-on training for shaping, hobbing and inspection. Contact AGMA headquarters, (703) 684-0211 or fax (703) 684-0242.

NOVEMBER 16–18
Center for Continuing Engineering Education, University of Wisconsin—Milwaukee. "Fundamentals of Gear Design." Complete coverage of the basic gear system aimed at the designer, user and beginning gear technologist. Contact Richard Albers, (414) 227-3125.

DECEMBER 1
Deadline for submission of abstracts for papers to be presented at the 1995 International Mechanical Engineering Congress & Exposition, November 12-17, 1995, San Francisco, CA. Papers are requested on the following subjects: dimensional measurement and control for sheet metal forming; material removal and surface modification; mechatronics for manufacturing; life cycle engineering; computer-aided tooling; sensors in electronic packaging; and concurrent design and manufacturing. Contact Elijah Kannatey-Asibu, Jr., University of Michigan at (313) 936-0408 or fax (313) 747-3170.

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Gear Hobbing Without Coolant

Dr. Lothar Ophey
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Introduction

For environmental and economic reasons, the use of coolant in machining processes is increasingly being questioned. Rising coolant prices and disposal costs, as well as strains on workers and the environment, have fueled the debate. The use of coolant has given rise to a highly technical system for handling coolant in the machine (cooling, filtering) and protecting the environment (filter, oil-mist collector). In this area the latest cutting materials—used with or without coolant—have great potential for making the metal-removal process more economical. The natural progression to completely dry machining has decisive advantages for hobbing.

	ADVANTAGES	DISADVANTAGES
FINISHING	Reduced machine time/increased tool life/improved quality	
MACHINE	Chip flushing	Filtration unit Refrigerator Fire Extinguisher Pumps and hoses
CUTTING OIL		Purchase cost Disposal cost Monitoring cost
ENVIRONMENT		Health risk Environmental hazard Contaminated chips
PROCESS		Additional part washing

Fig. 1 — Consequences of using cutting oil.

The Coolant

Coolants serve many purposes in metal removal. With their help, the workpiece and tool are cooled, wear is reduced and chips are flushed out of the machine. But there are essential disadvantages: the substantially increased cost of the machine because of the need to process and circulate the coolant, the cost of protecting the environment from oil mist, the costs of purchasing and disposing of the coolant, the cost of disposing of the contaminated chips and the strain on workers and the environment caused by coolant in all its forms.

In Europe, the purchase price of coolant today is about \$2,060 per cubic meter of oil and \$185 per cubic meter of emulsion. To those prices add disposal costs in the range of \$76 per cubic meter of used oil and \$185 per cubic meter of emulsion, as well as disposal costs of about \$6/ton for chips. These figures are valid at the moment, but we have to assume that they will skyrocket in the near future. A thorough examination of the subject can be found in the 1993 addresses to the Aachen Machine Tool Kolloquium (Ref. 2).

Since hobbing usually precedes heat treating, the use of coolant during metal removal also necessitates an additional wash operation. Fig. 1 clearly shows that the disadvantages of using coolant outweigh the advantages. Nonetheless, economic and technical considerations will not allow coolant to be abandoned in the immediate future.

The Tool

Elimination of coolant has far-reaching effects on the machine, tool and process. The tool must withstand the thermal and mechanical stresses of the process and still be economical; that is, it must allow large batch sizes with consistent workpiece surface quality. In this regard, modern cutting materials, such as carbide or cermet with suitable carbide coatings, open completely new perspectives.

Fig. 2 shows the progress that has been achieved in steel cutting speeds over the past few years because of improvements in cutting materials. Today, coated carbides and cutting ceramics allow speeds that are many times greater than the cutting speeds possible with classic tools or high-speed steels. For example, cutting ceramics allow cutting speeds of about 2,000 m/min. At the same time, the improved cutting materials have increased tool life, so that in the final analysis these new tools offer a substantial economic advantage in spite of their high cost.

The Machine

The machine design must be adapted to the new requirements of the coolant-free process. First the thermal load of the entire machine changes. According to Koenig, Severt and Berthold ("Cutting Without Coolant," Ref. 4), 75% of process heat is removed by the chips. Since there is no coolant to wash them away, the chips must be removed from the process in the most direct way possible so that the heat they contain is transferred out of the machine quickly. Furthermore, the use of modern cutting materials requires a different performance profile from the machine. Increased speeds and power are both necessary.

Fig. 3 shows the design of a modern hobbing machine that meets these requirements. Integrating the chip conveyor in the machine bed satisfies the requirement that the chips be centrifuged away from the process directly to the chip conveyor below. In addition, putting the chip conveyor at the center of the machine allows the side walls to be substantially steeper than they could be if the chip conveyor were built onto the side. In this way the chips take the shortest possible route out of the machine.

The table is driven by a compound, preloaded gear train that allows maximum speeds of up to 450 rpm. The hob head is equipped with a heavy duty drive that offers maximum speeds of 3000 rpm with a drive power of 18kW. With a maximum hob diameter of 90 mm, these result in a cutting speed of 850 m/min. These performance data—in comparison with the technology data used in current practice—leave sufficient reserves for further increases beyond the performance potential of today's cutting materials.

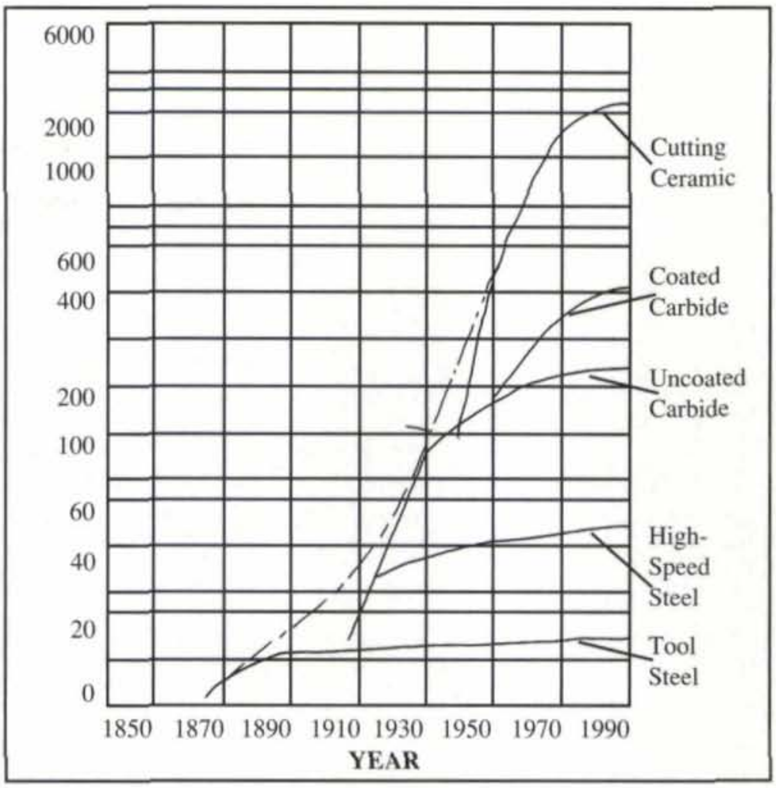

Fig. 2 — Development of Cutting Speed for Steels (See Ref. 1).

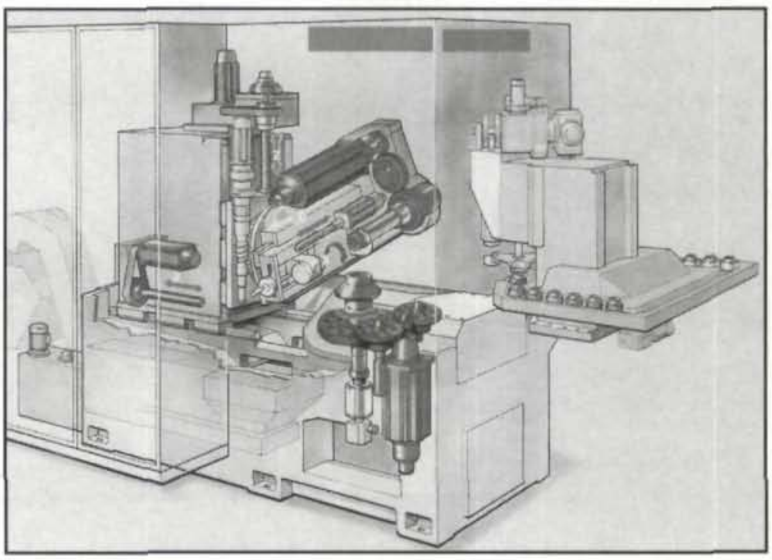

Fig. 3 — Concept Hobbing Machine for High-Speed Machining.

Since these enormously high cutting speeds reduce machining times to less than 10 seconds (depending on the workpiece), part change has to be considered an integral aspect of the basic machine design. For that reason, a conveyor system for part load/unload is integrated with the machine. Part change is so closely combined with workpiece clamping that the entire process is complete in about 2 seconds.

Fig. 4 shows the prototype of the newly

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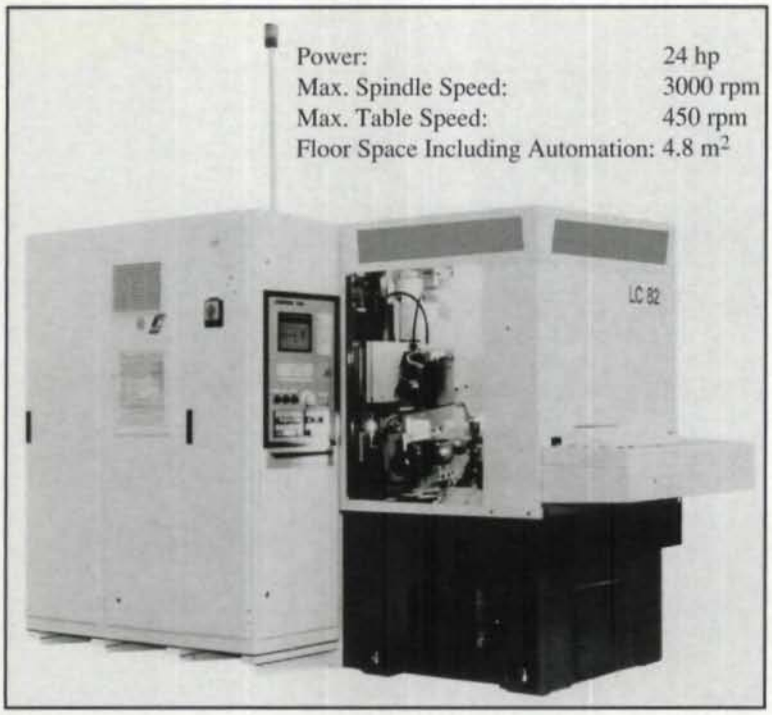

Fig. 4 — Hobbing Machine for High-Speed Machining.

Work Example: Speed Gear

Part Data:			
No. of Teeth	31		
Module (DP)	2 mm (12.7)		
Helix Angle	32° RH		
Face Width	18 mm (.71")		
Cutting Depth	5.8 mm (.23")		
Hob Data:			
Material	**HSS**	**CARBIDE**	**CERMET**
No. of Starts	3	1	1
No. of Gashes	30	30	30
Hob Diameter in mm (")	90 (3.5)	90 (3.5)	90 (3.5)
Hob Length in mm (")	70 (2.75)	70 (2.75)	70 (2.75)
Technology:	**HSS**	**CARBIDE**	**CERMET**
Coolant	Oil	None	None
Speed in m/min. (sfm)	120 (393)	450 (1475)	600 (1970)
Hob rpm	424	1590	2120
Axial feed in mm/tr. (ipr)	3 (.12)	4.5 (.18)	4.5 (.18)
Cutting time in sec.	25	14	10
Load/unload in sec.	3	3	3
Time per part in sec.	**28**	**17**	13
Costs: (Guide Values)	**HSS**	**CARBIDE**	**CERMET**
Hob Cost in $	2200	3500	5250
No. of Resharpenings	3	3	3
Cost/Resharpening in $	350	35	350
Parts/Resharpening	5400	6700	6700*
Tool Costs/Part in $	**0.15**	**0.17**	**0.24**
Machine Costs/Hour in $	75	75	75
MC-Costs per Part in $	**0.58**	**0.35**	**0.27**
Total Costs per Part in $	**0.73**	**0.52**	**0.51**

*Assumed

Fig. 5 — Hobbing without coolant (Cost/Performance Comparison).

developed heavy-duty hobbing machine and lists its fundamental technical performance characteristics.

In addition to the associated technological requirements, the current push toward "lean" manufacturing was taken into account. The internal functions of the machine were simplified as much as possible, and the electrical and mechanical designs were closely integrated. In this way, a production-ready machine was developed. Installation at the customer's plant is limited to setting it up and plugging it in. And the entire machine—including integrated automation—has a footprint of less than 5 m^2.

Machining Examples

For one of the test cuts, a gear that is typically used as a drive gear in passenger car transmissions was selected. The workpiece data are shown in Fig. 5.

The table shows the time that can be saved by using dry cutting with carbide or cermet tools rather than conventional wet cutting with HSS hobs.

The use of TiN-coated HSS hobs with coolant is considered the current state of the art. At cutting speeds of 120 m/min. with a feed of 3 mm/rev., the machining time is 25 seconds. TiN-coated carbide tools, used with a cutting speed of 350 m/min., make it possible to reduce the machining time to 17 seconds and eliminate the use of coolant. A further reduction to 10 seconds machining time is achieved with the use of cermet hobs. This process is also carried out without coolant. In all, there is an improvement of the overall machining time from 28 to 13 seconds; that is, today's standard value is reduced by more than half, or in other words, the capacity of the machine is more than doubled. With relation to hobbing, this increase in performance directly reduced piece costs by 15–25% before the savings from the elimination of coolant is taken into account. To be complete, our rough analysis of productivity increases would also have to include a recalculation of the steps in gear manufacturing such as extrusion molding (See "Cold Impact Forming of Geared Workpieces," Ref. 6). Simply switching hobs has the additional advantage of increasing the flexibility of the hobbing process.

Along with purely time-related issues, the targeted workpiece quality plays an essential role in assessment of the process. Fig. 6 shows the profile and lead measurements of a drive gear. The workpiece was cut with a TiN-coated cermet hob using the machining data given in the right-hand column of Fig. 5. The profiles of the left and right flanks are identical, showing that the process is stable. The same conclusion can be drawn from the leads, on which the feed marks show up as ripples about 16 µm in size because of the high feed rate. Influences on the leads and face width resulting from the increased workpiece temperatures associated with dry cutting can be corrected through suitable compensation strategies. The tooth-space measurement (Fig. 7) shows outstanding values for tooth-spacing error (DIN quality 4–5). The cumulative tooth-spacing error is also good (DIN quality 6–7), though it was affected by the excessive runout of the gear.

In summary, excellent machining results were achieved simultaneously with the enormous reduction in time from 28 to 13 seconds. This dry-cutting process is compatible with subsequent heat treatment and hard gear finishing (honing) or with an alternative finishing process, such as shaving and hardening.

For another test, a steering pinion was hobbed. Fig. 8 shows the steering pinion along with workpiece and technology data. The main hurdle with this workpiece is the need for smooth operation, which is hindered by large feed marks. For economic reasons, of course, the feed rate should be as high as possible. Derived from practical experimentation, the metal-removal rates in Fig. 8 represent a compromise between these opposing requirements. The steering pinion was machined with a TiN-coated, single-start carbide hob with 11 gashes and a diameter of 45 mm. Once again, no coolant was used.

Using the technological possibilities provided by dry cutting with carbide hobs reduces machining time by 50% compared to conventional machining with HSS hobs.

Fig. 9 documents the machining results in the form of profile and lead measurement. The small deviations on the profiles are due to the quality of the hob. The lead tracing shows ripples of about 2 µm caused by feed marks. The jump that can be seen on the lower part of the right flank was caused by a change in cutting force that resulted from a change in the workpiece diameter in this area.

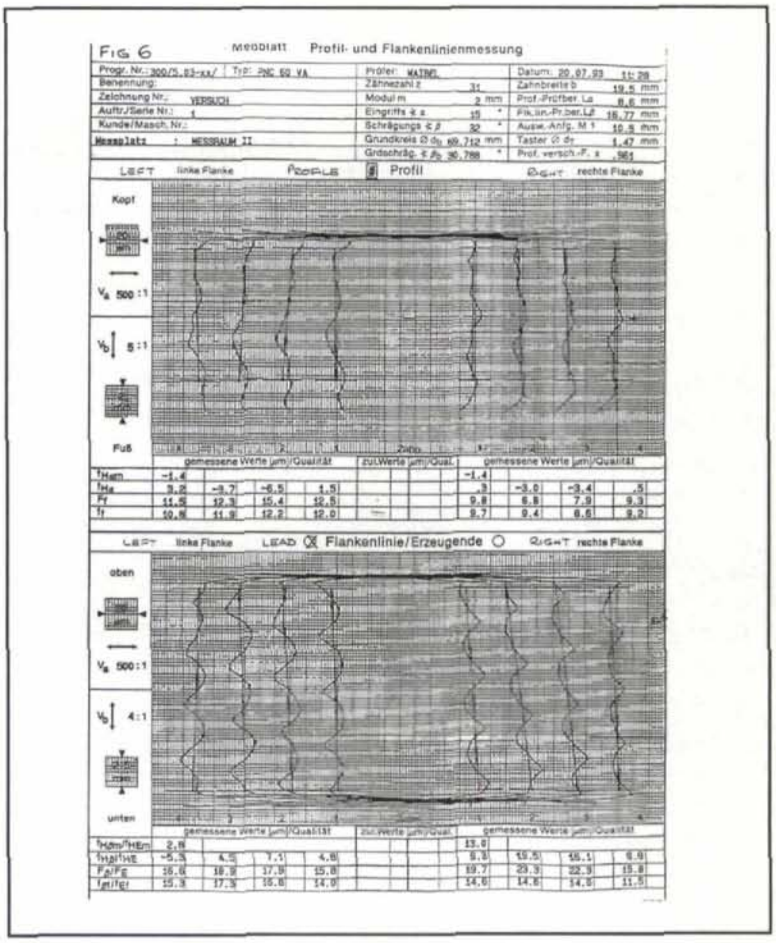

Fig. 6 — Profile and lead measurements of drive gear.

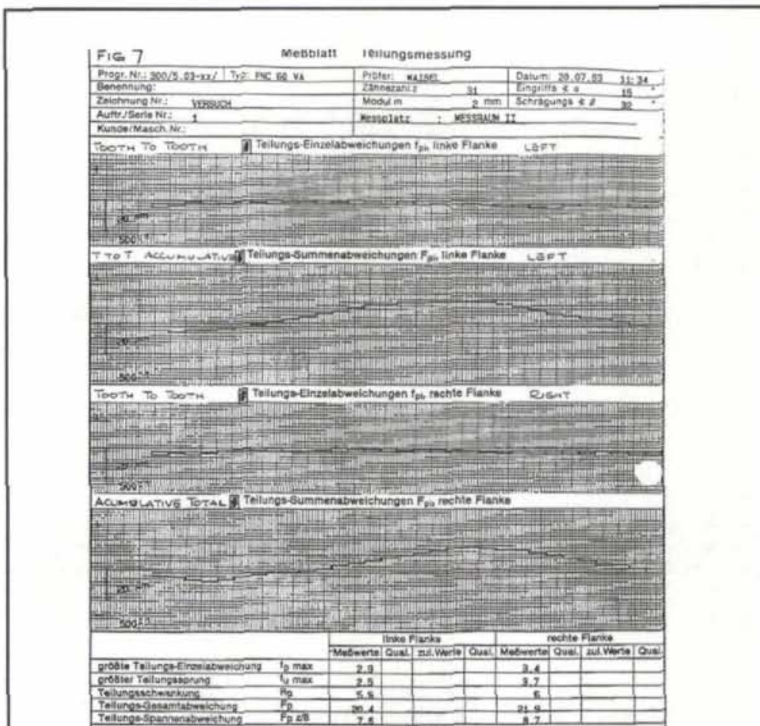

Fig. 7 — Tooth spacing error measurement.

Work Example: Steering Pinion		
Part Data:		
No. of Teeth	8	
Module (DP)	1.95 mm (20)	
Helix Angle	13.67° RH	
Face Width	26 mm (1.02")	
Cutting Depth	3.2 mm (.13")	
Hob Data:		
Material	**HSS**	**CARBIDE**
No. of Starts	1	1
No. of Gashes	11	11
Hob Diameter in mm (")	45 (1.75)	45 (1.75)
Hob Length in mm (")	100 (4)	100 (4)
Technology:	**HSS**	**CARBIDE**
Coolant	Oil	None
Speed in m/min. (sfm)	107 (360)	250 (820)
Hob rpm	760	1800
Axial feed in mm/tr. (ipr)	0.9 (0.35)	0.9 (0.35)
Cutting time in sec.	38	16
Load/unload in sec.	6	6
Time per part in sec.	**44**	**22**
Costs: (Guide Values)	**HSS**	**CARBIDE**
Hob Cost in $	600	2200
No. of Resharpenings	8	20
Cost/Resharpening in $	100	200
Parts/Resharpening	2700	2400
Tool Costs per Part in $	**0.06**	**0.12**
Machine Costs/Hour in $	75	75
MC-Costs per Part in $	**0.82**	**0.46**
Total Costs per Part in $	**0.88**	**0.58**

Fig. 8 — Hobbing without coolant (Cost/Performance Comparison).

The steering pinion has all the properties required for trouble-free actuation. Once again, using carbide hobs without coolant has direct economic advantages through shortened machining times as well as indirect advantages through the elimination of coolant.

Summary

For ecological and economic reasons, the use of coolants in production has been at the center of debate for some time. The advantages and disadvantages are well known, and there have already been numerous attempts to develop economical dry cutting methods. Improvements in tools and the incorporation of dry-cutting requirements in a suitable machine design have established the prerequisites for eliminating coolant from the hobbing process. This elimination leads to other process advantages, which in direct comparisons have already yielded considerable economic advantages in favor of dry cutting. The positive ecological balance results in still more pluses, which also show up as cost reductions. ■

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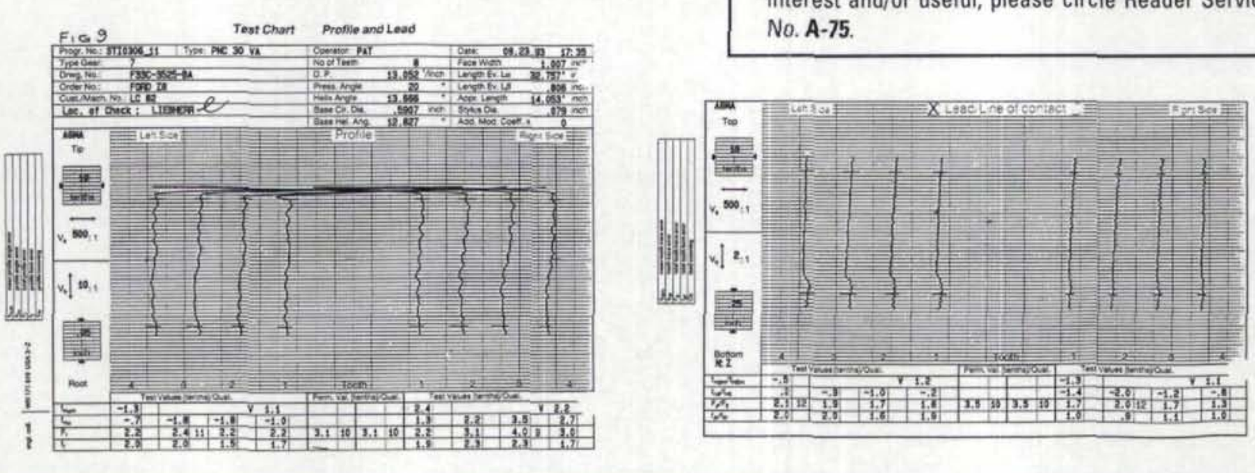

Fig. 9 — Profile and lead measurements.

ADVERTISERS INDEX

New Innovations in Hobbing — Part II

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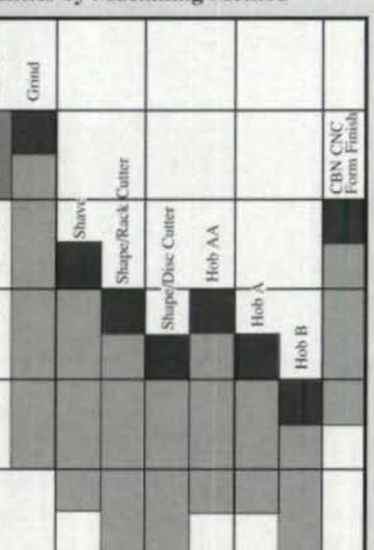
Introduction

The first part of this article, which ran in the September/October 1994 issue, explained the fundamentals of gear hobbing and some of the latest techniques, including methods of hob performance analysis and new tool configurations, being used to solve specific application problems. In this issue, the author continues his exploration of hobbing by describing the effects of progress on requirements in accuracy, as well as the latest in materials, coatings and dry hobbing.

Achievable Gear Qualities by Machining Method



DIN Fr	DIN fp	DIN Ff	DIN Fβ	DIN fi	DIN Fi	AGMA
4	2/3	3	1	2/3	4/5	15
5	3/4	4	1	3/4	5/6	14
6	4/5	5	3	4/5	6/7	13
7	5/6	6	4	5/6	7/8	12
8	6/7	7	5	6/7	8/9	11
9	7/8	8	6	7/8	9/10	10
10	8/9	9	6	8/9	10/11	9
11	9/10	10	7	9/10	11/12	8
12	10/11	11	8	10/11	12	7

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

Possible only under special conditions ■

SOURCE COMPARISONS: DIN 3962 (1974) and AGMA 390.03
NOTE: SEE THE ACTUAL STANDARDS FOR EXACT COMPARISONS

Fig. 1

Accuracy Improvements

While considerable progress has been made toward solving application problems, part requirements are becoming more and more demanding, to a point where the quality level expected from the tool has to be raised. It has long been understood that there is a very direct relationship between the accuracy of the hob and the quality of the part being produced. It has been common to see the quality requirement of the tool raised from Class B to Class A or even Class AA. There are even applications for which the requirement actually exceeds the industry standards to a point of developing tolerances that are Class AAA.

For an idea of the "normal" quality levels that are achievable with different manufacturing processes, refer to Fig. 1.

The two elements in the hob that directly affect the quality of the gear being produced are the lead in one pitch and the profile. In a single-thread hob, if the errors in these elements are added together, the result will be equivalent to the involute error possible in the part.

Historically, the method to measure this error is a conventional lead check and profile check (Fig. 2). With this method, it is possible to find the worst spot in the lead and add it to the profile error and be relatively confident that this will represent the worst-case involute error.

The use of CNC inspection equipment makes it possible to take this measurement directly. The line-of-action check (Fig. 3) enables the evaluator to review the combination of the lead and profile in one step. The method involves making the same movement axially as checking the lead, but in addition, the probe is moved radially to simulate the contact pattern realized when hobbing the gear. One drawback to the present method of line-of-action check is that it represents only one generating zone of the hob.

With multiple-thread hobs, a similar approach to evaluating the accuracy can be used with the addition of one more element, referred to as thread-to-thread error. In these cases, the sum of the lead error in one pitch, the profile error and the thread-to-thread error will give the involute error that can be expected. This additional element limited the use of multiple-thread hobs to roughing and pre-finishing operations, but today hob manufacturers can produce very accurate multiple-thread hobs.

With the introduction of the latest CNC technology to the grinding and inspection of hobs, tolerances that were virtually impossible to hold now are maintained routinely. In some cases, the thread-to-thread error has been held within .0001–.0002". As mentioned earlier, the requirements of today's tools have in some cases even surpassed the industry standards. Here Class AAA tolerances that are equal to 60% of Class AA have been developed. Of course, it must be understood that in these cases, the sharpening tolerances, hub faces, hub diameter, bore, etc., all must be modified to support the tight tolerances on lead and profile.

Materials

When the idea of improving the productivity of an application is discussed, one area that normally receives considerable attention is the substrate material of the tool. The intent of this article is not to give a complete description of the different grades of steel, but instead to raise the level of awareness about the multiple possibilities for a solution to a specific problem. The successful introduction of particle metallurgy some years ago has given the application engineer materials with characteristics of wear resistance, toughness and red-hardness levels (Fig. 4) considerably better than the original high-speed steels.

The general direction of the industry in recent years has been to upgrade the steel for a given application, normally by increasing its alloy content. The advantages of this approach can be realized in a number of different areas. The first one is the improved life factor, which results in increased lineal inches cut per sharpening when compared to the initial base grade. A table showing relative life

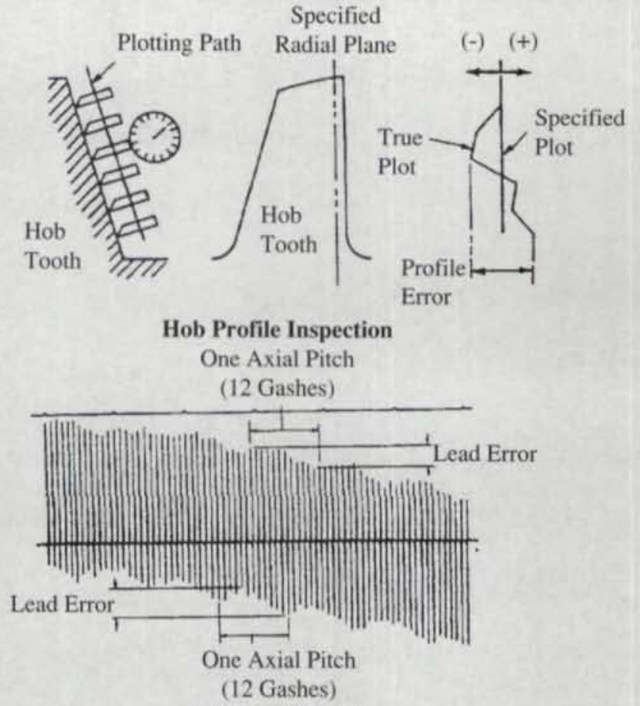


Fig. 2 Hob Lead Chart

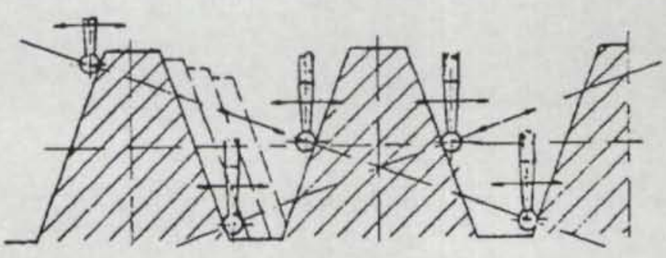


Fig. 3 Line-of-Action Check

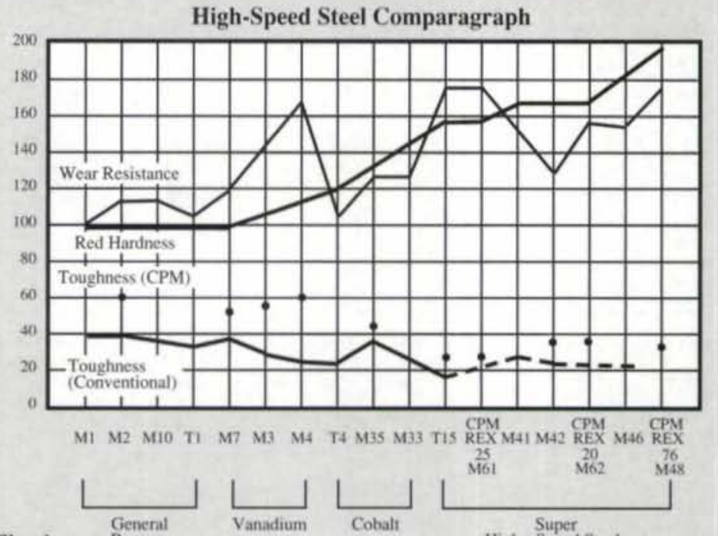


Fig. 4

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is Vice-President of Engineering with Pfauter-Maag Cutting Tools. He is the author of many articles and papers on gear cutting subjects.

(Percent Relative Life)				
M3	M4	M35	M42	REX20
100	115	110	110	110
REX45	REX76	T15	ASP23	ASP30
110	120	120	100	110

Fig. 5

(Percent Relative Feed)				
M3	M4	M35	M42	REX20
100	105	100	115	115
REX45	REX76	T15	ASP23	ASP30
115	115	115	100	100

Fig. 6

(Percent Relative Speed)				
M3	M4	M35	M42	REX20
100	100	120	125	125
REX45	REX76	T15	ASP23	ASP30
120	200	200	100	120

Fig. 7

(Percent Relative Price)				
M3	M4	M35	M42	REX20
100	100	115	125	125
REX45	REX 76	T15	ASP23	ASP30
125	175	165	100	125

Fig. 8

factors as compared with M3 steel for different high-speed steels is shown in Fig. 5. The figures in this table and the two that follow depend on how aggressively the original tool is being applied. Actual results may vary, but generally this will give the manufacturer a good place to start.

In addition to the increase in tool life, the gain achieved in productivity improvements is another area that deserves attention.

In a typical hobbing application, approximately 85% of the total manufacturing cost is machining cost. This machining cost is directly related to feeds and speeds in any given application. Some typical figures for relative feeds and speeds are shown in Figs. 6 and 7.

When compared with the total manufacturing cost per metal-cutting operation, the price of the tool is minor. It is not uncommon for the purchase cost of a tool to amount to only about 5% of the total cost per part. With this in mind, it follows that simply buying the cheapest tool is not an effective way of reducing cost. If the purchase price of the tool is combined with the cost of resharpening and recoating, we find that the tool cost is approximately 15% of the total. Relative price increases compared with M3 steel are shown in Fig. 8. This table takes into account both the increase due to material cost and the additional machining cost encountered by the tool manufacturer.

One area that has shown significant advances in the past few years is the ability to tailor the hardening of high-speed steel to the performance of a specific application. This allows the tool manufacturer yet another opportunity to address wear or failure concerns. The approach that has been taken consists of hardening the tool to a higher or lower hardness than what might be considered "normal." In fact, we have seen occasions where even one point higher or lower in hardness can make the difference between catastrophic failure and success.

Next in the series of material improvements is the field of carbide tools. There has been a great deal of effort to apply carbide in situations where high-speed steel hobs normally would be used. The main reason for this is to take advantage of the high production rates that are possible with carbide. The gear hobbing industry has realized that in many cases, the relatively high tool cost of a carbide hob can more than be offset by the reduction of machining cost.

The availability of some newer grades of carbide have solved some of the earlier problems of applying carbide tools. The cutting process of hobbing is a very severe interrupted cut that demands certain characteristics to assure success. Intensive research in the past few years has led to the development of micrograin carbide, which addresses the problems associated with this process.

One factor that must be taken into consideration when applying carbide is the speed at which the hob is being run. In many cases, the machinery needs to be capable of speeds two to three times faster than those used with high-speed steel in order to take full advantage of what carbide has to offer. There is even a possibility of failure if these speeds are not possible. Running these speeds, of course, reduces the machining cost significantly while at the same time yielding extended life as compared with high-speed steel.

A comparison of the quality of parts that were cut with a high-speed steel hob and parts cut with a carbide hob, each at the optimal conditions, shows a great advantage in favor of the carbide hob (Fig. 9). The reason is the lower force components resulting from the conventional process, the lower number of threads, a lower axial feed and the higher cutting speeds.

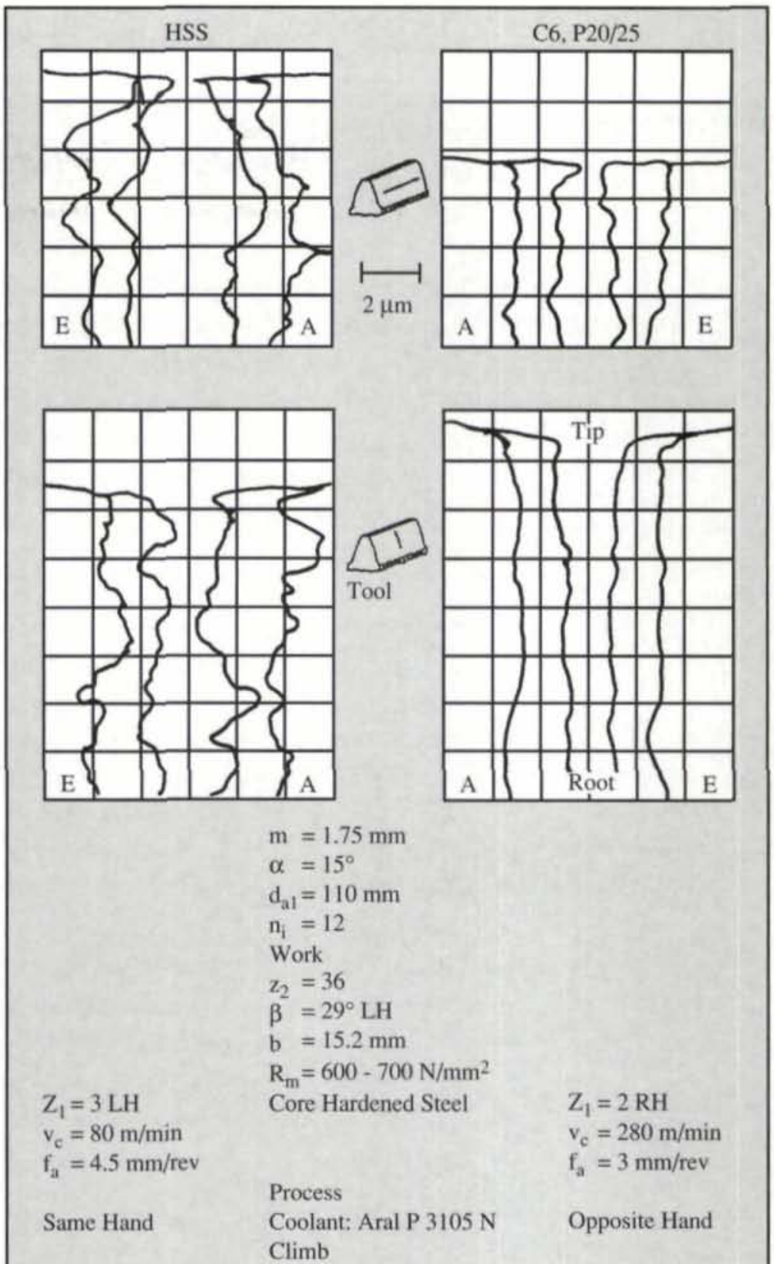

Fig. 9

Coatings

Since the early 1980s, titanium nitride coatings have been very successful at improving the process of hobbing. This coating proved to be extremely adaptable to most applications and gained acceptance relatively quickly within the gear cutting industry. It is assumed the reader is familiar with the advantages of coatings in general, so a detailed explanation of economic justification is not offered with this article.

In recent years, there has been considerable work to improve on what titanium nitride had done within this industry. The number of hard coatings that are available has increased dramatically. Today, there are as many as a dozen different coatings and multilayer coatings available to choose from. Some of these include

- TiCN—Titanium Carbonitride
- TiAlN—Titanium Aluminum Nitride
- CrN—Chromium Nitride
- CrC—Chromium Carbide

All of these coatings have certain advantages. Titanium nitride is very versatile, while some of the newer coatings are more application-specific. For example, TiCN has shown promise in areas that are very abrasive (cast iron), where TiN may not be performing at an acceptable level. TiCN, on the other hand, is somewhat sensitive to temperature, so in cases where high speeds are attempted, this coating may not show the same improvements. It seems that in cases where temperature is an issue, TiAlN may be a better selection. There has been some work recently applying TiAlN to high-speed steel in dry hobbing attempts for just that reason.

It now becomes even more important for the end user to work very closely with the tool manufacturer to coordinate the design, material, application and coating to obtain the best possible solution to a specific process. It is still generally accepted that a starting point for the addition of coatings is TiN. It may not be the final solution, but the user can begin with a relatively high level of comfort as to the success of the coating.

Dry Hobbing

One last area to explore is the recent work being done in dry hobbing of gears. This subject has a number of areas being developed, but the common goal is to successfully hob gears without using coolants. The advantages of hobbing without coolant are numerous, including cost reduction in

- Cleaning/washing parts
- Filtration
- Chip disposal (clean)
- Coolant requirement
- Coolant additives

These factors, as well as the environmental issue of disposal, have driven the efforts to progress with this new technology. There are a number of different approaches to how this can be accomplished. The actual solution, as with the new coatings, may prove to be dependent on the application. The basic methods to develop this technology can be grouped as

- High-speed steel hobs
- Carbide hobs
- Cermet hobs

High-speed steel hobs have been applied with TiAlN coatings with initial success. The material removal rate of this application is comparable to carbide hobbing at high speed and low feed. The tool life was even better than a TiN-coated tool with oil coolant.

Carbide tools have been applied as both coated (TiN) and uncoated. Considerable care must be used to select the best grade of carbide for each application. The ability of carbide to withstand high temperatures while providing very high wear resistance has significantly affected the success of the approach.

Cermet materials are multi-component cutting materials generally based on titanium carbide (TiC), with nickel (Ni) as a binder matrix. They were primarily developed to provide thermal stability, edge-holding ability and toughness. In many cases, coating this type of tool can also improve its performance. There are certain advantages as well as risks involved with applying this material in the hobbing applications.

The advantages include:

- Three to six times the life of carbide
- Higher cutting speeds

The possible risks include:

- Process fine tuning—slight deviations from the optimal setup can result in catastrophic failure.
- Limited toughness characteristics compared to carbide. This currently limits the maximum feed rates.
- Grinding difficulty and cost. These facts result in tool prices in the range of two to three times the price of a carbide tool. This material is more susceptible to grinding cracks.

Conclusion

It should be apparent to the reader that there have been significant improvements in gear cutting technology. The goal, as stated in the opening comments, should always be to improve the process in all respects. The advances in new technology will continue in the years to come, and it must be the responsibility of everyone to exploit the advancements. Simply to continue with the process as it was developed years ago is not good enough in today's market. To fully utilize the latest in these developments, it becomes even more important to get the tool manufacturer involved in the early stages of this optimization cycle. It should also be evident that the final solution for success can be considerably different depending on the results expected, even within the same application. One point to keep in mind, however: all processes have room for improvement. ■

Acknowledgement: *This article was first presented at the SME Gear Processing and Manufacturing Clinic, April 1994, Indianapolis, IN.*

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Quality Gear Inspection — Part II

GEAR FUNDAMENTALS

Robert E. Smith
R. E. Smith & Co., Inc.
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Diagnostics

This section will deal with the use of gear inspection for diagnostic purposes rather than quality determination. The proper evaluation of various characteristics in the data can be useful for the solution of quality problems. It is important to sort out whether the problem is coming from the machine, tooling and/or cutters, blanks, etc. An article by Robert Moderow in the May/June 1985 issue of *Gear Technology* is very useful for this purpose.

Machine Problems. The following techniques and devices will indicate when problems originate with the machines.

Lead and Involute Charts. Lead charts will often indicate problems with machine alignment as well as blank mounting (see Fig. 1). A comparison of Examples 1 and 3 in this figure is instructive. Whether the charts of both sides of the teeth are parallel is a good clue to the source of the problem.

Accumulated Pitch vs. Runout Data. If a gear comes directly off a hobber (no subsequent finishing operations) and has a very low runout, but a high accumulated pitch or total index variation, there is probably a problem with a worn-out table drive gear set.

Hob Problems. Hob problems generally show up in involute charts. These problems have several possible causes. The hob could be made very accurately, but sharpened or mounted poorly; or it could be a hob that was made with excessive runout at the time of original manufacture. Even if it is sharpened and mounted correctly, it will not cut a good gear. This problem usually shows up as some form of waviness or slope error in the involute charts (see Fig. 2). These characteristics of slope or waviness may very well fit within the allowable bandwidth of the appropriate AGMA K chart, but the gear may still be unsuitable for many applications, especially when noise is an issue. One must study the characteristics in order to sort out the cause. A good example is the difference between Examples 4 and 5 in Fig. 2. If the waviness is the same on all teeth, the problem is probably within the hob or the accuracy of the mounting. If the waviness is different on every tooth, the cause is likely to be a machine looseness problem.

Hob Feed Marks. When parts are hobbed at a high feed rate, such as for pre-shaving, scallops in the surface characteristics are very evident. Generally, these scallops are so deep that involute charts are quite useless. Usually the only valid data are lead charts. The slope of the charts can show if the lead is correct, and the

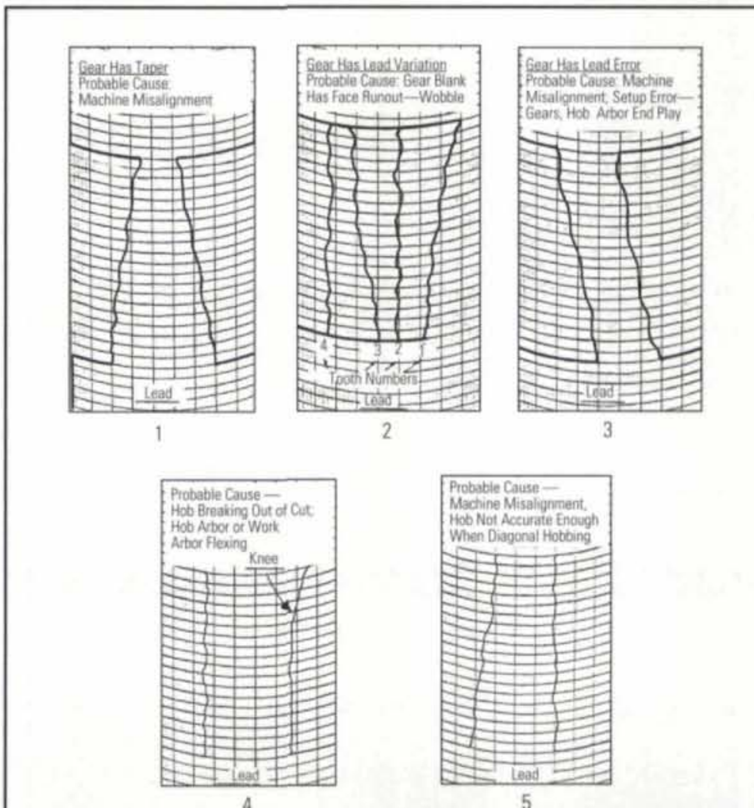
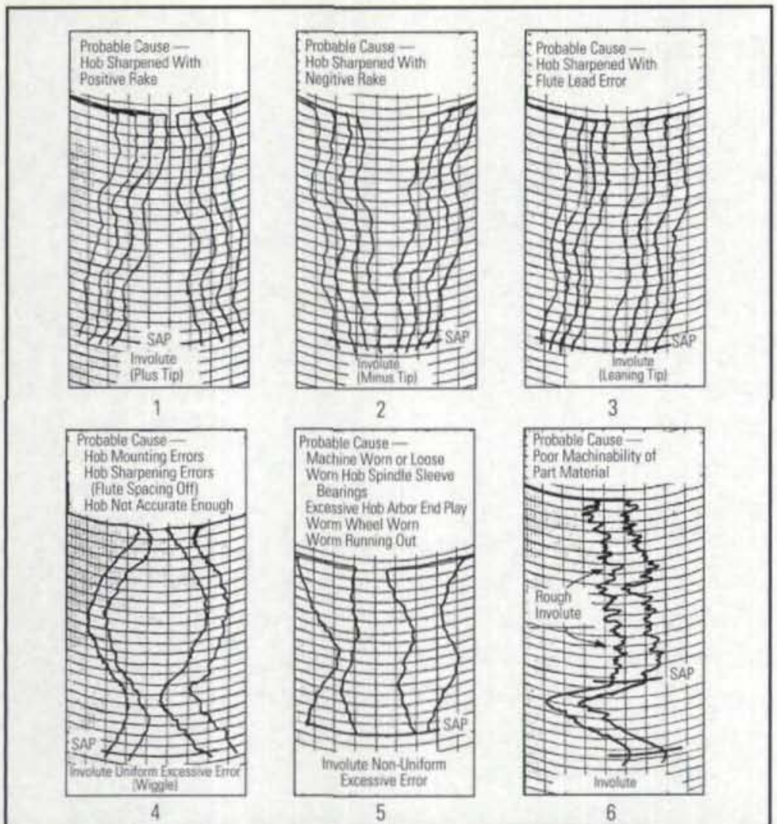


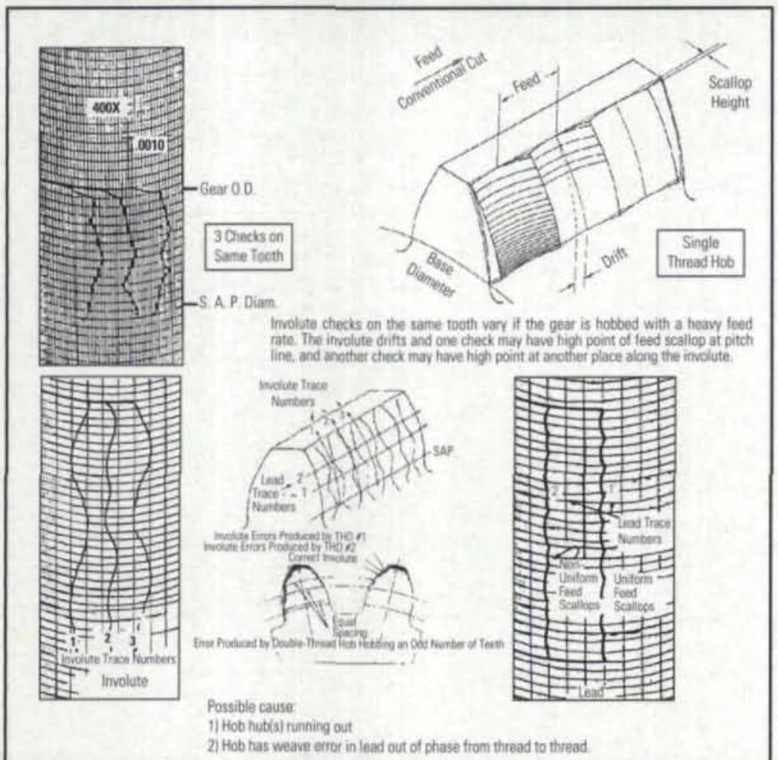
Fig. 1 — Lead and involute chart.

Robert Moderow, *Gear Technology*, May/June 1985.



Robert Moderow, *Gear Technology*, May/June 1985.

Fig. 2 — Lead and involute chart.



Robert Moderow, *Gear Technology*, May/June 1985.

Fig. 3 — Lead and involute chart.

depth of the waves will tell if there is stock for cleanup in the shaving operation. However, the apparent random waviness in the involute charts makes them invalid for the determination of profile shape (see Fig. 3).

Conjugacy—Noise and Transmission Error. As mentioned earlier, K charts are not very useful for diagnosing gear noise and transmission error problems. Other techniques, such as separate determination of "mean involute slope" and waviness in involute charts, should be used for these evaluations. AGMA Q7 or Q8 gears can be made that are noisy, and Q13 or Q14 gears can be made that are quiet. Fig. 4 shows involute traces from a gear that is about a Q7 in terms of runout. The effect of runout shows up in the traces as a variation up to .00066" in slope. However, the mean involute slope is only .00015", and it matches its mate properly. (See the middle example in Fig. 4.) Originally, the mean involute slopes for the gears were like the upper example in Fig. 5. These gears were noisy. Experimentally, gears were also made with the mean involute slope characteristics of the bottom example, and these also were quiet. In all cases, the runout would make them a Q7 set of gears, and they would have slope variation. This points out the inadequacy of the traditional methods of quality determination as far as noise is concerned.

ISO Approach. The International Standards Organization (ISO) uses a different approach to the evaluation of involute and lead charts. In the main body of the standard, they use a rectangular tolerance zone, much as AGMA uses the K chart. However, in an Annex, they have alternate methods of evaluation that are more appropriate for diagnostic evaluation and the control of noise and transmission error.

This process involves doing a least-squares-best-fit line (usually a straight line) to the involute or lead trace (see Fig. 6). This line is laid on the trace and the various parameters, such as slope, average slope, waviness and total error, are read and quantified independently. This is much more useful for many applications and diagnostics.

In addition, the ISO standards give recommended tolerances for accumulated pitch error and transmission error. These are characteristics that are much more direct and functional.

Good Measuring Equipment

Good measuring equipment is essential for achieving quality gear measurements. There are two basic types of gear measuring machines: the older, traditional mechanical generative machines and the newer Computer Numerical Control (CNC) generative or Coordinate Measuring Machines (CMM).

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Mechanical Machines. The mechanical machines, an example of which is shown in Fig. 7, use means such as base disks, sine bars, levers, formers, etc., to generate the theoretical motion such as involute or helix (lead). A probe on the tooth surface then measures the variation between the actual tooth surface and the theoretical shape being generated. Usually a recorder of some type makes the resulting charts.

CNC or CMM Machines. The newer CNC machines come in two types. On some, the CNC is used to generate the theoretical motion, much as the older mechanical machines did (see Fig. 8). On the other hand, CMMs measure the tooth forms by moving the probe to a series of X, Y, Z, and θ locations. High resolution and accuracy is necessary.

Calibration. Whether the machines are mechanical or CNC, alignment and calibration are necessary in order to have confidence in the results. Any machine should be calibrated on a regular basis. A new standard, AGMA 2010, Part 1, is in the final stage of preparation. Part 1 deals with involute, but a standard for other parameters will follow, and the same principles apply.

The first step is to check the alignment of the machine for squareness, parallelism, runout of centers and spindle, etc. Then mount a certified artifact such as an involute master. Many measurements are then made and plotted on X and MR bar charts for a statistical evaluation of capability. This establishes bias and variability (accuracy and confidence levels) for the machine. Remember that resolution is not the same as accuracy.

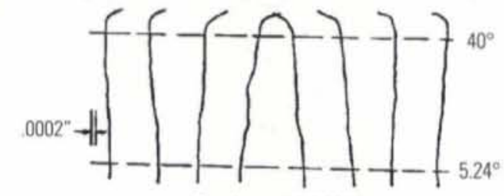
Certified Masters. Unfortunately, the National Institute of Standards and Technology (NIST) has not calibrated and certified masters for about ten years. The recent work by the calibration committee of AGMA has stimulated interest by NIST in resuming its efforts in artifact calibration. A project is now under way to set up a calibration service again.

Cost of Inspection. Many people seem to find it hard to justify the cost of good inspection equipment. After all, the inspection machines don't make chips. However, the best cutting or grinding machine in the world doesn't automatically make good gears. There are still a lot of other variables, such as the cutting tool and its mounting, the gear blank and its mounting, work-holding equipment, operator, etc. If you don't have good inspection equipment and practices, bad product can become very expensive in terms of lost time, poor quality and bad customer relations.

One should look hard at the true cost of not having good equipment compared to the cost of buying it.

A Look At The Competition

A good example of the value of good inspection equipment and practices was found at the 1991 AGMA Gear Expo. A Japanese plastics gear manufacturer was displaying gears made to AGMA quality levels of Q10 to Q11. Our American plastics and sintered gear manufacturers typically claim the ability to make only Q6 to Q7 gears. What is the difference? Good diagnostic measuring equipment and practices. Even though this company is making fine-pitch gears (20 DP and finer), it regularly uses CNC elemental measuring machines and even single-flank testers to mea-



Results — 1/10,000"

	Left Flank				Right Flank			
	4	3	2	1	1	2	3	4
fHa	1.9	3.6	-3	-6.6	-4.4	-5.5	0.8	3
fHam (MIS)			-1				-1.5	

Fig. 4 — Involute traces with runout.

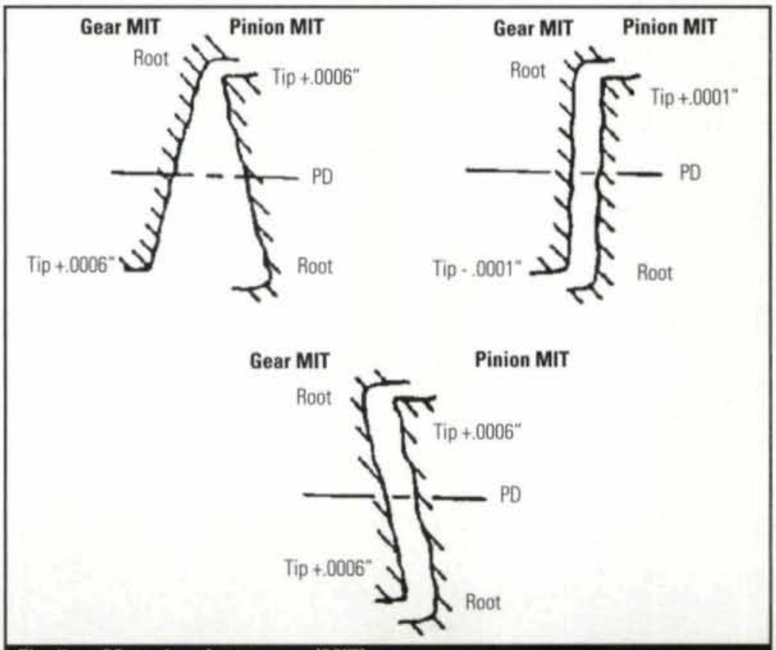


Fig. 5 — Mean involute traces (MIT).

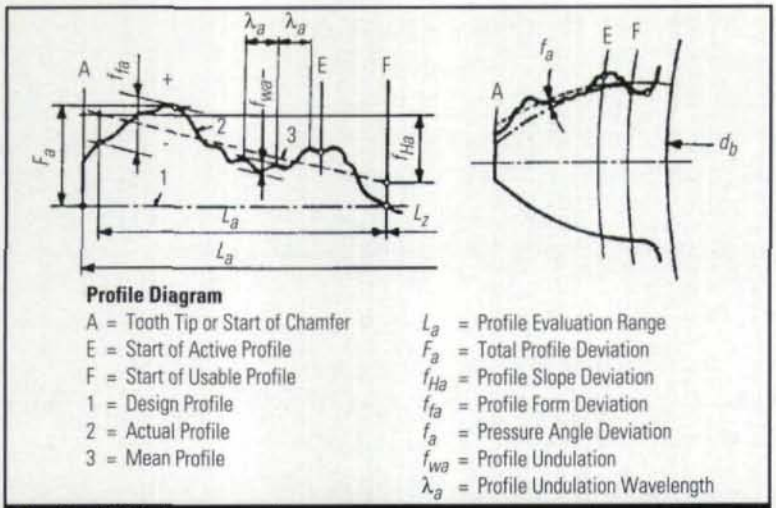


Fig. 6 — ISO tolerance system.

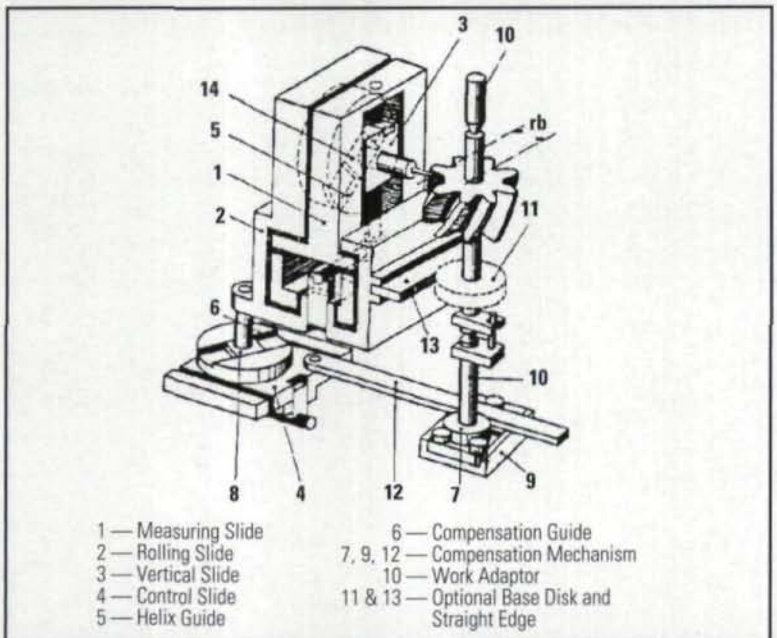


Fig. 7 — Mechanical generative involute and lead tester.

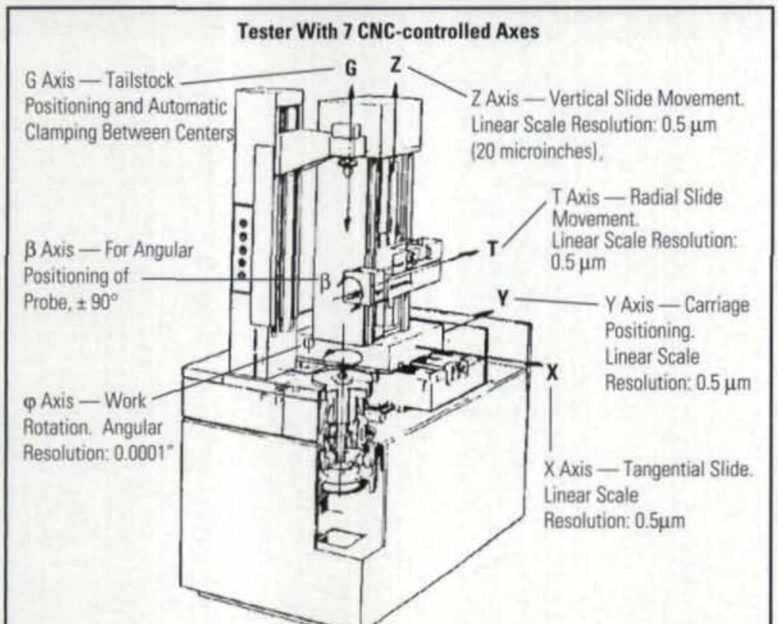


Fig. 8 — Generative machine involute and lead tester.

sure gear quality. The company also has a good symmetrical gear blank design that promotes uniformity of teeth around the gear.

American gear manufacturers in this field only use double-flank testers. They can't really tell what tooth form they are making or even know what is wrong when the product doesn't meet the specifications. Double-flank testers are not good measuring devices for diagnosing problems; therefore, engineers don't do the iterations necessary to develop good gears. One of the major reasons that American plastic gear quality is as low as Q6 or Q7 is that the gears have too much runout caused by not centering the hole in the center of the gear. This should be an easy problem to solve with proper mold and cavity design.

Better measuring techniques would soon point manufacturers in the right direction for meeting the competition and opening up new potential markets for their products. Their products are very uniform from piece to piece, so it is just as easy to make all parts good as to make all parts bad.

Conclusions

Process Control. More use should be made of elemental inspections rather than double-flank composite methods. This also applies to gears that are finer than 20 DP. This kind of information fosters better diagnosis of problems as well as better process control.

Standards. Our AGMA standards need changing. Elemental tolerances and inspection need to be extended to finer pitches (even as far as 80–100 DP). We should be using accumulated pitch variation rather than runout. The standard should also allow the optional use of single-flank inspection as well as double-flank and elemental methods.

One way of doing this is to make use of the new ISO standards currently being developed and published. In fact, AGMA is now very active in the development of these standards, and perhaps someday that is what our gear industry will be using. ■

References:
1. Moderow, Robert H. "Gear Inspection and Chart Interpretation," *Gear Technology*, Vol. 2, No. 3, May/June 1985, p. 30.
Acknowledgement: *First presented at the AGMA 21st Annual Gear Manufacturing Symposium, October 10–12, 1993. Reprinted with permission.*

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Abar Ipsen Industries, Bensalem, PA	**37**													●														
Accu-Prompt/Kleiss Engineering, Little Canada, MN											●																	
Adcole Corp., Marlborough, MA																	●											
Ajax Magnethermic, Warren, OH	**37**													●														
Amarillo Gear Corp., Amarillo, TX	**38**										●																	
American Metal Treating Co., Cleveland, OH	**46**														●													
American Pfauter, L. P., Loves Park, IL	**IFC, 39**									●		●					●					●						
American Sykes, Beavercreek, OH	**25, 39**						●										●											
American Wera, Inc., Ann Arbor, MI				●			●			●																		
Applied Process, Inc., Livonia, MI															●													
Ardrox, Lake Bluff, IL		●					●																					
Ash Gear & Supply, Southfield, MI							●																					
ATA Gears, Cleveland, OH and Finland	**37**										●																	
A/W Systems, Madison Heights, MI							●																					
Axicon Technologies, Berkeley, CA	**4, 39**																							●				
Balzers Tool Coating, North Tonawanda, NY					●																							
Barit International, Northbrook, IL							●																					
Basic Incorporated Group, Los Angeles, CA	**18, 39**								●	●		●				●						●	●					●
Bourn & Koch Machine Tool Co., Rockford, IL	**25, 39**									●		●					●					●						
Broaches Inc., Roseville, MI	**39**		●																									
Can-Eng Furnaces, Ltd., Niagara Falls, NY														●														
Cardinal Spline Gage, Royal Oak, MI																										●		
Cincinnati Gear Co., Cincinnati, OH	**37**										●																	
Cincinnati Steel Treating Co., Cincinnati, OH	**38**														●													
Computer Sales & Maintenance, Arden, NC																								●				
Cone Drive Textron, Traverse City, MI																								●				

Contour Hardening, Inc., Indianapolis, IN														●														
Crucible Service Centers, Camillus, NY	**9, 39**																				●							
Datacut, Inc., Ardsley, NY																								●				
Debur Corp., Chelmsford, MA								●																				
Dessau Diamond Tool, Saddle Brook, NJ												●																
Detroit Broach Co., Auburn Hills, MI			●																									
Diagrind, Inc., Orland Park, IL												●																
Diamond Black Technologies, Inc., Conover, NC	**19, 39**				●																							
Dianamic Abrasive Products, Inc., Troy, MI												●																
Dynamic Metal Treating Inc., Canton Twp., MI	**37, 38**				●										●													
Elmass North America, Germantown, WI			●																									
Eltech, Inc., North Royalton, OH							●																					
Engis Corp., Wheeling, IL		●							●			●							●									
Euro-Tech Corp., Brookfield, WI																											●	
Extrude Hone Corp., Irwin, PA								●	●							●												
Fairlane Gear, Inc., Plymouth, MI	**39, 48**										●																	
Fayscott Co., Dexter, ME										●																		
Fellows Corporation, Springfield, VT										●		●										●						
Fette Tool Systems, Inc., Brookfield, WI							●																					
FGT Gage & Systems, Brookfield, WI																	●											
Forest City Gear, Roscoe, IL											●																	
Gahan Precision, Chicago, IL																											●	
Geartech Software, Inc., Albany, CA	**46**																							●				
Giddings & Lewis, Inc., Fond du Lac, WI			●														●											
Gleason Works, Rochester, NY				●					●	●		●				●			●									
GMI, Independence, OH	**5, 12, 39**							●	●	●													●					
Gould & Eberhardt Gear Machinery Corp., Webster, MA										●																		
Hommel America Inc., New Britain, CT																	●											
Huppert, K. H. Co., South Holland, IL														●														
Inductoheat Inc., Madison Heights, MI	**37**													●														
Ingersoll Cutting Tools Co., Rockford, IL							●																					
Invo Spline Inc., Warren, MI																	●			●						●		
ITW Components & Tools, Glenview, IL	**39**						●				●									●								
ITW Heartland Components, Chicago, IL																	●											
ITW Southern Gage/Zero Systems, Erin, TN																											●	
JRM International, Rockford, IL				●			●	●																				
Koepfer America, Inc., South Elgin, IL										●																		●
Kokusai, Inc., Indianapolis, IN																	●											

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Koro Sharpening Service, Maple Grove, MN	38						●																					
Krautkramer Branson, Lewistown, PA																	●											
Kromhard Twist Drill Co., Akron, OH							●																					
Lapmaster International, Morton Grove, IL																			●									
Lepel Corp., Edgewood, NY														●														
Liebherr Machine Tool, Saline, MI	6, 39						●			●		●					●					●						
Lindberg Heat Treating, Melrose Park, IL	38														●													
M & M Precision Systems Corp., West Carrollton, OH	2, 39																●											
McEnglevan Industries, Danville, IL														●														
Merit Gear Corporation, Antigo, WI	17, 39										●				●													
Metal Improvement Company, Paramus, NJ															●													
Mētrscope, Greenville, SC																								●				
MHI Machine Tools U.S.A., Itasca, IL										●		●										●	●					
Micromatic Textron, Holland, MI							●									●									●			
Midwest Gear & Tool, Inc., Warren, MI	17, 39										●																	
Mitts & Merrill, L.P., Harvard, IL																		●										
Moore Products, Spring House, PA																	●											
Multi-Arc Scientific Coatings, Rockaway, NJ					●																							
National Broach & Machine Co., Macomb, MI	BC, 39		●									●				●							●					
National Metrology, Sunapee, NH	46																●											
New Age Industries, Willow Grove, PA																	●											
Niagara Gear Corporation, Buffalo, NY	37, 39												●															
Normac, Inc., Arden, NC	39, 47											●																
Ono Sokki Technology, Inc., Addison, IL																	●											
Parker Industries, Inc., Bohemia, OH	15, 39						●													●						●		
PC Engineering, Sedona, AZ																								●				

Pfauter-Maag Cutting Tools, Loves Park, IL	**1, 40**				●		●						●		●													
Pillar Industries, Menomonee Falls, WI	**37**													●														
Precision Gage Co., Inc., Chicago, IL																	●											
Procedyne Corp., New Brunswick, NJ														●														
Process Industries, Schiller Park, IL	**15, 40**										●																	
Profile Engineering, Inc., Springfield, VT																	●											
Pro-Gear Co., Depew, NY													●															
Redin Corp., Rockford, IL								●																				
Reef Gear Manufacturing, Inc., Mt. Clemens, MI											●																	
Reishauer Corp., Elgin, IL												●				●												
Richter Precision, East Petersburg, PA					●																							
Roto-Technology, Dayton, OH	**40, 47**																●											
Russell, Holbrook & Henderson, Inc., Waldwick, NJ	**8, 40**						●																					
Schmitt Industries, Inc., Portland, OR																	●											
Schunk Intec, Inc., Raleigh, NC	**36**																										●	
Software Engineering Services, Rockford, IL	**46**																							●				
Star Cutter Co./Starcut Sales, Inc., Farmington Hills, MI	**40, 41**				●		●					●																
SU America, Oak Park, MI							●					●																
Sunnen Products Co., St. Louis, MO	**16, 40**															●												
Surface Combustion, Inc., Maumee, OH	**40**													●														
Sytec Corp./Benemac, S.A., Essex, CT																	●											
Therm Alliance, Detroit, MI														●														
Thermal Products, Tualatin, OR														●														
Thermcraft Inc., Winston-Salem, NC														●														
Tifco, Inc., Wixom, MI											●															●		
Tocco, Inc., Madison Heights, MI	**40, IBC**													●														
Toolink Engineering, Boulder, CO																											●	
Ty Miles, Inc., Westchester, IL			●																									
United Tool Supply, Cincinnati, OH	**40, 48**																●											
Universal Technical Systems, Rockford, IL																								●				
Van Gerpen & Reece Engineering, Cedar Falls, IA																								●				
Wendt Dunnington, Chester Spring, PA	**8, 40**											●																
Winter, Ernst & Son, Inc., Travelers Rest, SC	**40**											●																
Winterthur Corp., Worcester, MA												●																
WMW Machinery, Inc., West Nyack, NY												●																
Zeiss, Carl, Inc./IMT Division, Minneapolis, MN	**36**																●											

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