GEAR TECHNOLOGY

NOVEMBER/DECEMBER 2004

The Journal of Gear Manufacturing

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FEATURES

- IMTS Follow-Up
- The Key to Gearbox Purchasing
- Remedies for Hob Cutting Edge Failure due to Chip Crush
- Non-Standard Cylindrical Gears
- High Performance P/M Gears

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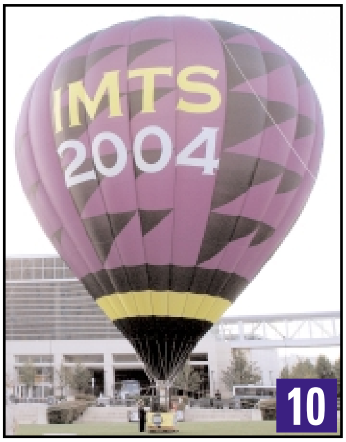

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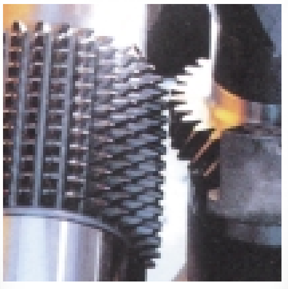

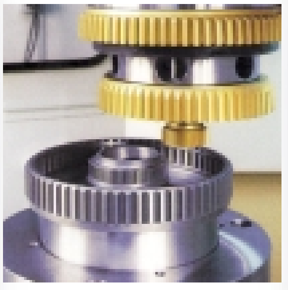

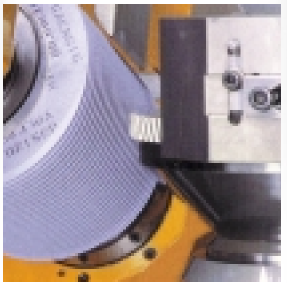

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Breath of Fresh Air

Whew. IMTS is over, and I'm relieved, in more ways than one.

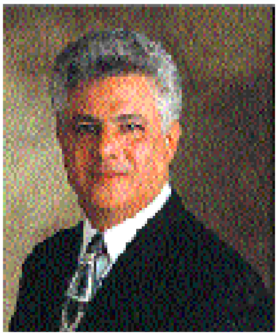
Like many of you who exhibited and attended, I'm relieved because IMTS is a big, long, grueling show, and getting through it is an accomplishment in itself. I'm also relieved because I went to the show with some apprehension, but I left with considerable optimism that the gear industry is alive and well.

The raw numbers from IMTS don't tell the real story. In 2002, attendance at the show was 85,000. This year, it was 86,000. On the face of things, that doesn't seem like much cause for celebration. But I was there. I saw the faces of the exhibitors, and I could read the change in attitude by looking at their eyes and at the way they carried themselves. While the overall show experienced only a small increase in attendance, the feeling in the gear pavilion was very upbeat and positive. Psychologically, the change since a year ago at Gear Expo was quite dramatic. Exhibitors and attendees seemed like different people than they were at previous shows—everyone seemed more confident, enthusiastic and revived.

Many gear machine tool exhibitors told us that customers weren't just shopping, they were buying. Customers were very focused and purposeful. They were armed with lists of projects and specific problems that needed solving, as well as lists of suppliers they wanted to see. Perhaps most importantly, they came with shopping lists of machine tools they wanted to buy. Several exhibitors told us they sold machine tools right off the show floor.

In recent years, we've become accustomed to the exhibitors and trade show sponsors putting a good face on things, in spite of the lack of business. But this year, there *was* business, and it showed in the attitudes of the exhibitors. (See our IMTS follow-up article beginning on page 10 to read some of the comments from major exhibitors.)

Those positive feelings carried over into *Gear Technology*'s first bi-annual IMTS Dinner, held at Maggiano's restaurant in Chicago. At the dinner, nearly 60 IMTS exhibitors, gear industry suppliers and gear manufacturers had the opportunity to eat, meet and network. They reaffirmed how successfully they thought the show was going, and they told us how busy they were. We even saw among this group the developing of new contacts and relationships that could lead to future business.



Even outside IMTS, there seems to be a lot of activity in the gear industry. Before the show, I spoke to a number of gear manufacturers who weren't going to IMTS. It wasn't that they didn't need new technology or more equipment. They just didn't have time to make the trip because they were too busy making gears. There seems to be more demand, more activity and more business in the gear industry than the raw numbers from IMTS would indicate.

A breath of fresh air can be powerful medicine—both financially and psychologically. IMTS reaffirmed my feeling that our industry is on the upswing. By all indicators, 2005 should be a prosperous year for the gear industry. Hopefully, the level of activity we're seeing now will continue for some time—right up through and beyond Gear Expo 2005, which takes place October 16–19 in Detroit.

IMTS showed that the gear industry is not only alive, but growing again. I'm excited about the future of our industry, which is why I'm already looking forward to Gear Expo—and you should be, too.

So start making your plans now.
I'll see you at Gear Expo next fall.

Michael Goldstein, Publisher & Editor-in-Chief

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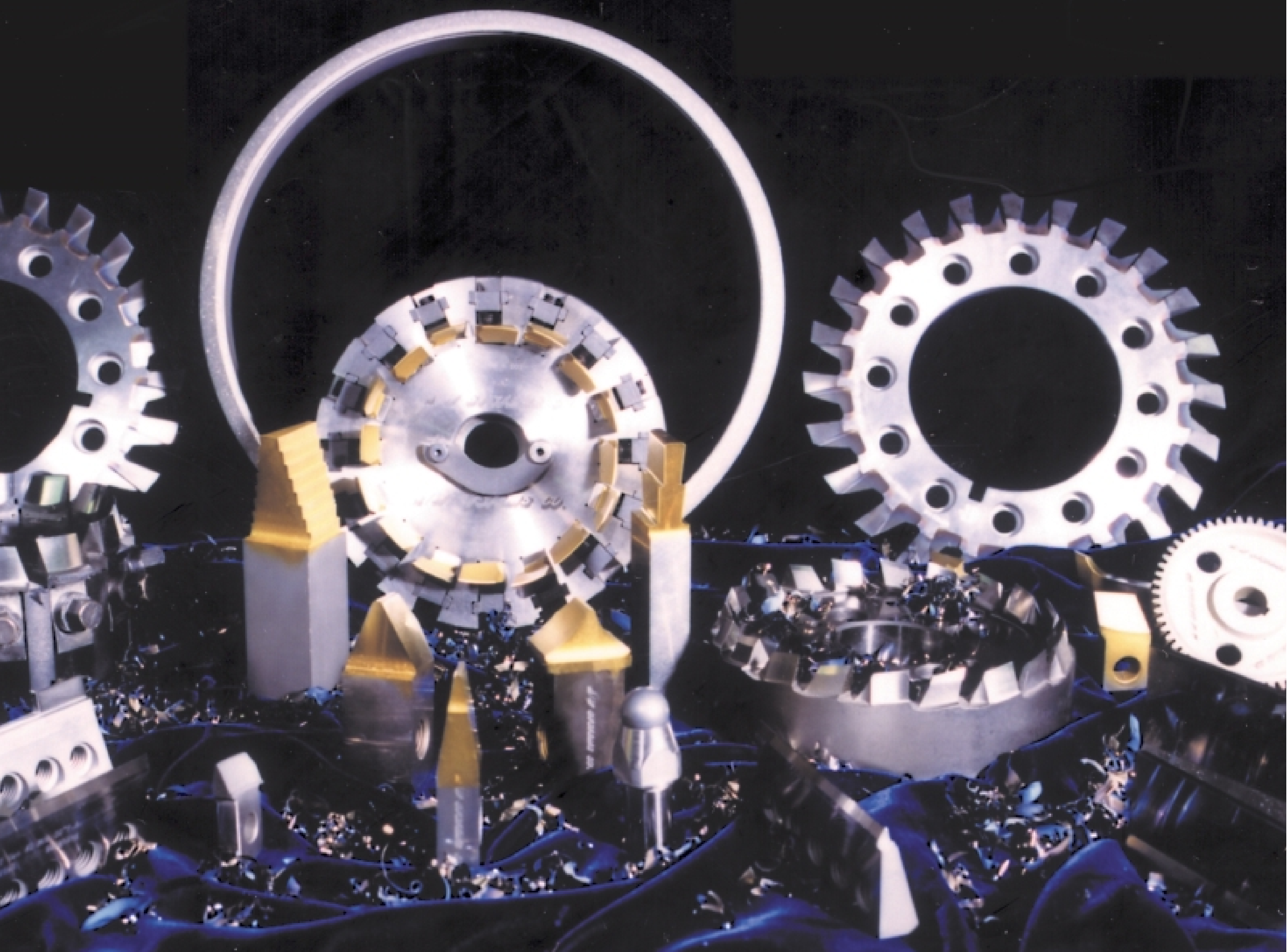

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November 17–19—Dimensioning and Tolerancing Principles for Gages and Fixtures. School of Continuing Education, University of Wisconsin—Milwaukee. Milwaukee, WI. This course is suitable for professionals interested in learning ASME and ANSI practices for the newly approved standard Y14.43-2003 for the design, dimensioning and tolerancing of GO gages, NOGO gages, functional gages and fixtures. Course topics include setting master discs and rings, design constraints, coefficient of expansion, similiarities and differences between gages and fixtures. $1,095. For more information, contact the School of Continuing Education by telephone at (414) 327-2121.

November 26—KISSsoft Shaft Analysis Seminar. Gauteng, South Africa. A day of information on KISSsoft covering shafts, gear optimization, and modeling of systems/powertrain. Free. For more information, contact KISSsoft AG on the Internet at *www.kisssoft.ch.*

December 7–9—Variable Drives Frequency Course. Best Western Inn, Kansas City, KS. Teaches attendees energy saving techniques**,** power transmission principles (speed, torque and horsepower), bypass systems, speed/torque control methods and power distribution considerations. This course is also being held December 14–16 in Omaha, NE, and January 14–16 in Minneapolis, MN. $1,100. For more information, contact National Technology Transfer Inc. by e-mail at *sales@nttinc.com* or by telephone at (800) 922-2820.

December 13–16—Gear School 2004. Gleason Cutting Tools facility, Rockford, IL. Broken into sessions called Fundamentals, High Speed Steels and Coatings, Cutting the Gear, Gear Inspection and a tour of the Gleason plant. $895. For more information, contact Gleason by telephone at (815) 877-8900 or on the Internet at *www.gleason.com*.

January 11–14—Shaft Gear Analysis, Theory and Calculation. Istanbul, Turkey. Day one introduces shaft bearing and calculation. An introduction to gears and their calculation and optimization are covered on the second and third days. The final day focuses on KISSsoft drive trials. The price is broken down by day, with the first and fourth days each at €25 and the middle days at €50 apiece. For more information, contact the sponsors at *hanspeter.dinner@kisssoft.ch* or *oguz.kurt@baysangear.com.*

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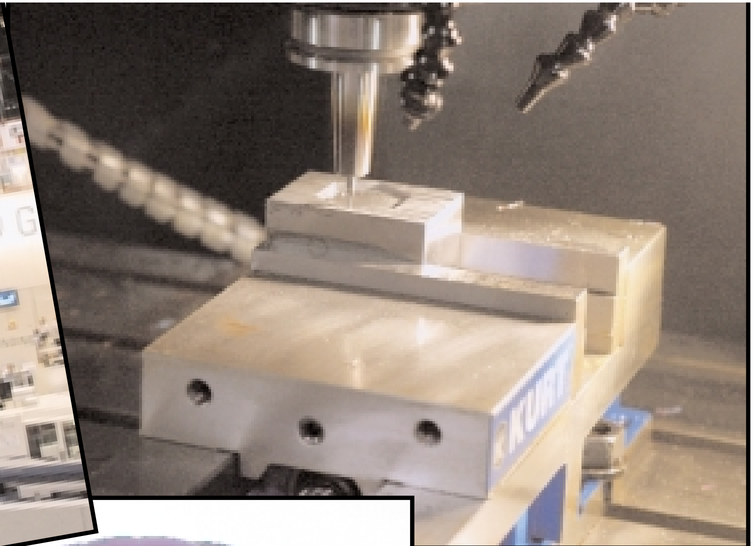
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IMTS 2004: Recovery in the Gear Pavilion

Tom Lang liked what he saw in the Gear Generation Pavilion at IMTS 2004. Standing in his booth, Kapp Technologies' vice president/general manager talked with many attendees during the show and afterward said: "We had an increase of both quality and quantity of visitors."

IMTS BY THE NUMBERS			
	IMTS 2000	IMTS 2002	IMTS 2004
Exhibitors	1,300+	1,300+	1,200
Space Occupied	1.4 million sq. ft.	1.2+ million sq. ft.	1+ million sq. ft.
Attendees	100,000	85,000	86,000

IMTS '04 hadn't, by any means, recovered from America's economic recession in 2001 and its subsequent, erratic recovery. Attendance had plummeted from 100,000 at IMTS 2000 to 85,000 at the '02 show, but it was stable at 86,000 at this IMTS. In the Gear Pavilion, it appeared more than stable. Several gear industry exhibitors reported attendance was up at their booths compared with IMTS '02 and had reactions similar to Lang's.

"This experience surpassed 2000 and 2002," said Mark Hiscock, vice president–American sales for Gleason Corp. "Attendance was up about 16 percent, with more serious inquiries and discussion/optimism for future programs. We actually closed orders on seven machines at the show."

New Gear Shaping Machine from Bourn & Koch

The Fellows HS650 gear shaping machine from Bourn & Koch Inc. was one of the new machines attracting interest at IMTS '04.

"There was quite a bit of interest there," says Bourn & Koch president Tim Helle, "and we found a number of quality leads."

The gearless gear shaper has 50% fewer parts than its predecessors and is compatible with the previous tooling, Helle says. It contains a gearless CNC guide designed to match the Hydrostroke's high stroking speed with a high performance rotary action.

The gear shaper has a GUI interface that allows users to input gear geometry and then view the construction of the physical workpiece on the screen. The gear shaper is easily movable in a two-pick package. Its complete machine enclosure has a slop chip evacuation surface and a modular, multiple platform package.

For more information, contact Bourn & Koch of Rockford, IL, by telephone at (815) 965-4013 or on the Internet at *www.bourn-koch.com.*

A Bigger Phoenix from Gleason

The 600 HC CNC gear cutting machine from Gleason Corp. is a bigger version of the earlier Phoenix 275 HC and has additional bevel gearing capacities.

Dave Melton, communications manager, says this new machine can open the company up to new gearing markets like off-highway gears.

Among its attributes are its cutting capability for gears as large as 600 mm and a monolithic column design that places the operator in close proximity to the cutter and work spindle. Also, the machine takes up 35% less floor space than comparable models in its class, according to the company's press release.

The 600 HC uses Gleason's machine manager software and runs on a Fanuc 160i CNC controller that simplifies setup and operation in a Windows environment.

In addition, shorter axis travels as well as higher feeds and speeds of the direct drive spindle, improve both wet and dry cutting applications and cycle times when compared to other models in the class, according to Gleason's press release.

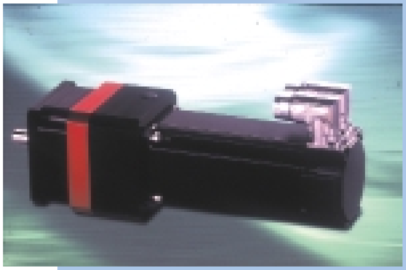
With one machine already en route to a new owner, the 600 HC has been 18 months in the works, from the time of its first prototyping. Gleason is still testing some aspects, says Melton, but is excited about this entry in the gear market.

For more information, contact Gleason of Rochester, NY, by telephone at (585) 473-1000.

New Gearhead from Danaher Motion

The Micron Gearhead RediMount Motor Mounting System from Danaher Motion features a three-step mounting procedure that allows all Micron gearheads to connect to many available motors.

Product manager Howard Horn says, "Basically, the RediMount is easy, error-free and allows the gearhead to be mounted to any motor on today's market. The modular design allows mounting kits to be maintained in the field and permits the same mounting kit to be used across Micron's entire family of products."



A specially designed input housing and sleeve that can accommodate any motor mounting dimensions are key to the gearheads' easy mounting, Horn says.

In addition, the mounting system has a self-aligning hub that maintains concentricity between the motor shaft and gearhead. Inside this, a pre-installed pinion eliminates normal pinion setting procedures.

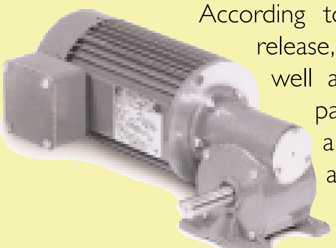
For more information, contact Danaher of Wood Dale, IL, via *Howard.Horn@DanaherMotion.com.*

New Inverter Duty Gearmotors from Baldor

Baldor introduced its new inverter duty gearmotor line at IMTS '04.

Eric Frey, gear product specialist at Baldor, says, "These units require absolutely no maintenance and are permanently lubricated with synthetic oil. Right-angle gearmotors feature our exclusive internal oil expansion chamber that allows our gearmotor to be mounted in any approved position without having to relocate a breather vent."

The induction-hardened, ground steel worm and bronze gear provide a smoother operation, cooler running and increased efficiency, Frey says.



According to the company's press release, a range of gear ratios as well as both right angle and parellel shaft configurations are available to meet application needs.

For more information, contact Baldor of Fort Smith, AR, by telephone at (479) 646-4711 or on the Internet at *www.baldor.com*.

David Goodfellow echoed the comment. “We did receive several machine orders during the show, which did not happen in ’02,” said the president of Star SU LLC. “The decisionmakers were there.”

Francis J. “Butch” Wisner, president/COO of Nachi Machining Technology Co., was in his company’s booth, but he had only a limited amount of time to observe attendance. His reason, though, could be another measure of good activity in the Gear Generation Pavilion: “I was in meetings virtually the entire show,” he said. “There were more proj-ect discussions and specific application work accomplished during this show.”

Liebherr Gear Technology Co. differed in its IMTS opinion. “The show was fair,” said Reinhold Cordella, a regional sales manager for Liebherr. “Better than in ’02, but not as good as in ’98 or 2000.”

Interest in gear-making equipment also extended to the Tooling & Workholding Systems Pavilion in Hall E, in the basement of McCormick Place’s lakeside building. LMT-Fette manufactures a number of tooling products, but its president, Brian Nowicki, said the company had serious customers concerning its gear cutting products.

Nowicki added there was serious customer interest in all of LMT Fette’s product areas—“Far better than that of ’02.”

And according to accounts, the attendees included large percentages of serious customers.

“Over 120 customers expressed interest in receiving additional information about our products after the show,” Lang said. “Of those, we expect at least 20–25 percent to be potential future sales.”

That translates to about 24–30 potential customers, about the same as Wisner expected. He said Nachi probably had

Chicago Mayor Richard M. Daley visited the Gear Generation Pavilion at this IMTS.

IMTS attracted 86,000 visitors this year.

30 very serious customers during IMTS '04 for gear and spline cutting equipment.

Marshall Krumpe, president of LeCount Inc., estimated that his company had about 30 percent serious customers, including "very serious conversations" with six customers and new interest for more tooling sales among some current ones.

"LeCount is a small company with a niche market," Krumpe said, "so it does not take a lot of show traffic to make for a good experience."

In Hall E, according to Nowicki, LMT-Fette had double the number of sales leads compared with the '02 show, with Sept. 9 alone bringing in 66 percent of the company's '02 total.

Ross Deneau, vice president–manufacturing for gear cutting tool manufacturer A/W Systems Co., was relieved by his estimate of the show's good days: 25 percent serious customers, 75 percent browsers. He recalled the '02 mix as 5 percent serious customers, 95 percent browsers—"It was bad."

Moreover, the good activity inside the show seemed to mirror the companies' business outside it.

"Busy show, busy year," Hiscock said. "The activity at the show supported what we have seen in sales and what other economic indicators have been suggesting. Orders are up significantly from the last couple of years."

Likewise, Cordella said IMTS '04 largely reflected Liebherr's business: "It's increasing, but at a slow rate."

"Business is definitely up since '02," Goodfellow said. "The general gear industry is up, especially in the higher


The Gear Generation Pavilion at IMTS 2004.

Star SU and LeCount Form Distribution Agreement

Star SU and LeCount Inc. announced an agreement for the sales and distribution of expanding mandrels, spline mandrels, concentric rings and custom mandrels in North America through Star SU sales.

Marshall Krumpe, president of LeCount, explains, "This is similar to them taking on a new product line like what they did for Bourn & Koch or Fellows, except that we're a lot smaller. We're a little niche market that they're embracing as a sales opportunity. We have high hopes that we can work well together."

The kick-off date for this partnership was Oct. 1, although LeCount shared booth space with Star SU at IMTS in September. Training has begun for the sales team, which will soon be making joint calls. In addition, the LeCount sales brochures are downloadable from the Star SU website.

Star SU of Hoffman Estates, IL, is the U.S. sales and manufacturing unit of Samputensili S.p.A. These companies represent gear machine and gear tool manufacturing producers of gear cutting, finishing, and tooling equipment.

LeCount, based in White River Junction, VT, manufactures mandrels and custom tooling for holding bore-type cylindrical workpieces for inspection.

Chip Brettell, founder & CEO of LeCount, David Goodfellow, president of Star SU, and Brad Lawton, chairman of Star SU, (left to right) are partners in a new distribution agreement.

New Measuring Machine from Carl Zeiss

One of the machines generating interest at the Carl Zeiss booth at this year's IMTS was the Surfcom 2000, which was sold to a customer at the show.

The Surfcom 2000 measures contour and surface roughness with a single sensor and instrument. Bob Wasilesky, product manager for SF&G (surface form and geometry) products, says, "With one system, you can get geometric figures in any possible configuration. Normally, you have to use two pieces. The 2000 is extremely accurate with measurement ranges of 10 mm resolution to one-millionth of an inch."

The Surfcom 1500 generated interest at the show as well, Wasilesky says. This machine takes surface roughness measurement only and can move 360° around the x- and y-axes.

This single-key operation takes fully automatic measurements with one click. Best of all, says Wasilesky, it takes 10 minutes instead of the usual 60. "The problem with taking these measurements usually involves the setting up," he says. "Our system sets itself up."

Finally, Zeiss featured the Roundcom, a roundness measuring machine that uses air-bearing systems with drives z, r and θ.

"This is a solid, rigid machine that is capable of reading nano-measurements," Wasilesky says.

For more information, contact the Carl Zeiss IMT division, of Osseo, MN, by telephone at (763) 533-9990 or on the Internet at *www.carlzeiss.com*.

quality gear production, such as grinding and hard finishing."

Also, several exhibitors agreed that economic prospects were good. Nowicki talked about prospects in both general and gear manufacturing. "LMT has seen an upward swing in the overall U.S. manufacturing economy and is expecting double digit sales growth to report for 2004 in all of its business segments," he said. "In the gear cutting industry, LMT is experiencing growth in excess of 30 percent."

Krumpe's indicators for a good future included the show itself and LeCount's new North American distributor, Star SU: "The rest of this year and 2005 should be good growth years."

"We expect 2004 to finish with a bang and 2005 to continue strong," Hiscock said. "IMTS supported this in terms of discussion and future programs."

Kapp also agreed, somewhat.

"Our business has been steadily increasing since the middle of the year, and the flow of customers at our booth reflected that interest," Lang said. But he expected the upswing to end. "We believe that within the next two quarters, we will see a peak in the current demand cycle."

Whatever the future may hold, though, Deneau himself was encouraged by IMTS 2004.

After the '02 show, A/W Systems wasn't sure it would exhibit at the '04 one, he said. But the company did and: "We're going to do it again in '06."

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Understanding the Application: A Key to Economical Gearbox Purchases

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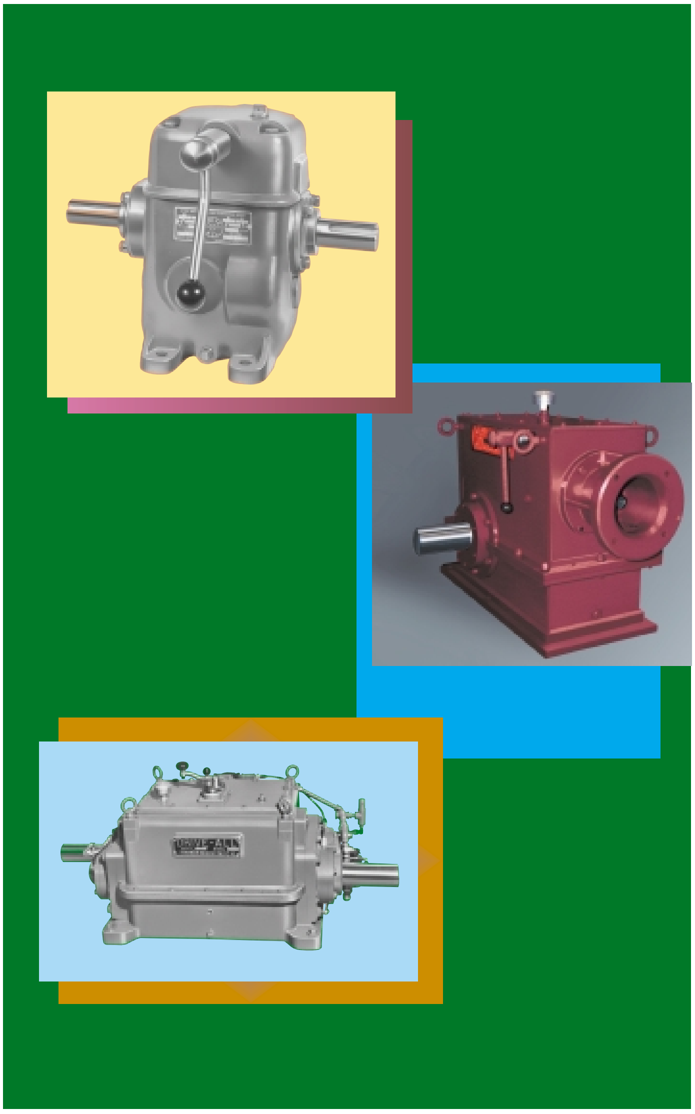

Above photos courtesy of Drive-All Manufacturing Co. of Harbor Beach, MI.

On a highway, a compact pick-up truck struggles to tow a 30-foot boat up a steep grade. Inside the pick-up, the owner curses himself. He saved money leasing a smaller truck but sees now that he really needed a bigger, pricier vehicle, one suitable for this job.

In industry, a buyer/specifier of gearboxes faces situations every day in which he must weigh the price of a unit against its suitability for an application. He also needs to avoid the truck owner's mistake; his choices will last a lot longer than a 36-month lease. So he has to carefully consider the long-term needs of his application. To make a successful choice, a great gearbox at a fair price, the buyer needs to take the time to prepare a complete and accurate specification before sending out requests for quotes.

Various trade and technical associations have done a good job of developing specifications for some applications. If a buyer's equipment must comply with API, AGMA, AISI or similar standards, he'll find most of the hard work has already been done. Still, if he hasn't reviewed the current versions of these standards, then he might be surprised at what is or isn't "in there" today. Technical, regulatory, and legal requirements change over time and more than one buyer has found out too late that "they don't make them like they used to."

In the absence of an established third-party specification, a buyer has to know the gearbox requirements for his application and has to be able to describe them to possible suppliers. For critical equipment, the buyer may want to engage a consulting engineer familiar with his industry to develop a custom specification, identify qualified suppliers and evaluate their responses.

Regardless of how a buyer creates a specification, it should address the following questions:

1. What's the application?
2. What's the prime mover?
3. What's the duty cycle?
4. What are the external connections?
5. What's the desired service life?
6. What's the operating environment?
7. What quality assurance system does the supplier use?

These questions and their answers influence the gearbox that will be provided for a specific project. Getting the right gearbox involves more than meeting a target service factor. Certain applications, for example, have typically been served by specific types of gears for reasons that may not be readily apparent to a new buyer/specifier of gearboxes.

A buyer needs to know and be able to describe an application in detail. He needs to provide a framework for identifying key elements that will make a "traditional" gearbox successful and for evaluating proposals that may seem a bit out of the ordinary.

A good example of a non-traditional gearbox that wasn't right for its application: the initial failure of carburized and hardened gearboxes from the late 1970s/early 1980s that were used in pumpjack service. Demand for pumpjacks was booming and was being met as much as possible, as fast as possible via the manufacture of through-hardened double helical and herringbone gears.

Buyers, however, needed so many gearboxes that they sought new sources to meet the supply crunch, and a European company was ready with modified versions of its very successful carburized parallel shaft reducers. The "new" drives easily met the service factors established over the years with much smaller, lighter, and less costly packages. The "old style" boxes were roughly the size of an office desk, their replacements were closer to the size of an extra large suitcase.

Unfortunately, the new reducers couldn't accommodate the extreme cyclic loading of the familiar "rocking horse" pumpjack mechanism. There was nothing intrinsically "wrong" with carburized and hardened gearing in a cyclic load situation. Careful consideration of the system dynamics, however, could have prevented the failures and saved lots of time and money. The application needed every bit of the higher strength capacity built into the through-hardened gears. Once the carburized reducers were selected for similar strength service factors, they were

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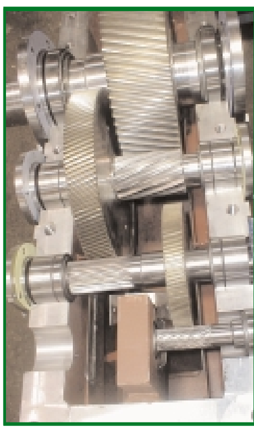
used successfully in pumpjacks. The new specification, however, increased their size and brought their overall costs closer to the traditional gearboxes.

Today, through-hardened gears remain in strong demand for pumpjacks.

Changing technology may occasionally make it worthwhile to investigate "new" approaches to a problem, but a buyer needs to make certain that innovators prove the suitability of their gearboxes for his particular application.

Likewise, the buyer needs to know and communicate aspects of a common application that his company is doing in new or different ways. Without such knowledge, he and his supplier can't adjust properly while selecting a gearbox.



1. What's the application?
2. What's the prime mover?
3. What's the duty cycle?
4. What are the external connections?
5. What's the desired service life?
6. What's the operating environment?
7. What quality assurance system does the supplier use?

The pumpjack example illustrates a key point in defining the intended use of a gearbox: System dynamics, the relationship of tooth load to position in the rotational cycle, must be understood to properly specify a gearbox. Specifying isn't just a horsepower/speed/ratio problem. The pumpjack's mechanism consistently put a high peak load on the same spot on the gear. This load put a premium on tooth strength.

Other applications may place a premium on positional accuracy. Still other devices, notably multi-cylinder pumps, could have several peak loads during a rotational cycle. Also, batch processing equipment may have a load profile that changes over the course of operation because of work done to the raw material. A buyer needs to know about these dynamics and describe them to suppliers so they can use their experience with similar devices to tailor a gearbox to match a buyer's application characteristics.

Following directly from system dynamics is the prime mover. A buyer should understand the prime mover to be used in a particular application. It makes a difference whether the prime mover is a fixed-speed electric motor, a variable-speed AC drive, or a variable-speed DC drive. It also makes a difference whether the AC or DC drive is computer-controlled. The advent of computer-controlled, variable-speed drives makes it possible for companies to fine tune their processes to a degree unheard of even five years ago.

A buyer needs to specify the prime mover because, in the case of the computer-controlled drives, gearbox suppliers would have to discard many assumptions from their experience with the non-computer-controlled drives. For example, they couldn't simply assume 200% starting torque and move on to the next question. The computer-controlled drives, their torque diagrams and acceleration curves require close attention, as do their dynamic braking characteristics. Also, internal combustion engine drive packages behave differently since the adoption of computer controls, and suppliers have to rethink many long-held assumptions concerning their use, too.

Computers also affect another aspect of gearbox specification: the definition of the duty cycle. Duty cycle isn't just how many hours per day the equipment will be run or how many starts-per-hour can be expected. Sophisticated data logging devices make it possible to determine just how many rotational cycles will be run at specific load levels and speeds. This technology has helped improve reliability in many applications, most notably wind turbine gearboxes, where even a few "spikes" over the design peak loads can result in greatly shortened service life. If a company is embarking on a major redesign of a product or an upgrade to an existing process line, the company's buyer might want to obtain an instrumented test of the current setup. As an alternative, he could have a consulting engineer familiar with similar equipment prepare an estimated duty cycle for inclusion in the gearbox specification.

In some cases, typical duty cycles have been published in academic papers or trade association standards. Duty cycle information allows a supplier to perform a "Miner's Rule" calculation on the gears to estimate their life expectancies. Similar techniques are applied in the calculation of bearing L-10 life.[1]

Bearings are a key reason that buyers need to know the external connections of their systems. Different types of couplings transfer misalignment forces to the shafts in different ways. Some bearing arrangements, particularly plain or babbited bearings on high-speed drives, are very sensitive to externally caused misalignments. Some coupling designs dampen torque fluctuations in the system to the benefit of the gears and bearings. Other couplings reduce the peak loads seen at start-up. In some cases, the weight of the coupling itself must be considered in evaluating bearing life.

There are many different types of couplings offered for commercial sale and each one has unique characteristics that can affect a gearbox. So a buyer needs to select the couplings for his gearbox or needs to know what effects he wants and doesn't want so his supplier may recommend a specific type of coupling.

Service life is a key assumption in every gearbox design but is seldom disclosed in a manufacturer's catalog. Thirty years ago, gear capacity was calculated based on allowable stresses being unchanged after the gears were used for 10 million cycles. This was less than a year's service for a 1,750 rpm shaft. In the years since, the gear industry has learned a lot about long-term serv-ice, and AGMA life curves no longer flatten out. Most new enclosed drives are designed around 10,000 hours of life at a 1.0 service factor. This is a far more reasonable value for industrial service but probably not conservative enough for very large drives that may be used for 40 or 50 years. Consequently, a buyer might want to specify 20,000 hours for most custom drives and 100,000 hours on very large units that will be grouted into place.

On the opposite side of this issue are applications where it's known that the gearboxes will be used for a very short period of time, operated only intermittently, or are expected to be replaced frequently. Designing for short service life is perhaps a more challenging task than getting equipment to last because of the size, weight, and cost constraints typically imposed. Regardless of the application, however, a buyer should know what design life to specify.

He should also ask suppliers what options they have that might be best suited to the equipment's operating environment. Beyond the usual question of ambient temperature range (which affects a gearbox's thermal rating and resulting accessories), the buyer should know about his application's exposure to the elements, including dust, sunlight, and chemical vapors. Access to the units for routine maintenance, such as oil and filter changes or gear inspection, is also important. Special paint treatments, seal materials, seal arrangements, or lube system accessories are relatively inexpensive to add when the equipment is designed but very costly to retrofit.

Options are a key area in evaluating competing bids because a buyer may find some suppliers insisting on including certain options while others may include only what is absolutely required by the specification. Initial cost saving can quickly disappear if changes have to be made after the order is placed or the equipment is delivered. For example, a buyer once purchased several gearboxes for his mill, which was built under strict requirements for automated equipment monitoring. In several process lines, each gearbox was fitted with a sensor to prevent start-up if the oil level was too low. A neighboring line was equipped with a gearbox that had no sensor. Predictably, it was the only burned-out gearbox from the commissioning process. The same day as the burnout, a very angry maintenance manager placed a rush order for oil-level sensors.

As with motor vehicles, gearbox "quality" can be judged by a variety of standards. Dimensional accuracy, material cleanliness, heat treat consistency and component robustness are critical to long-term performance. Unless the gearbox being purchased is straight out of a supplier's catalog, buyers are wise to ask about the quality system in place at the manufacturer's facility and what acceptance tests are performed. Some buyers feel most comfortable requiring bidders to comply with ISO 9000 requirements. Others prefer a more hands-on approach and want to witness the final tests. If a project has specific quality requirements (such as material certification, load tests, or lost motion checks) they can greatly affect cost and lead time. To avoid unpleasant surprises, the buyer is wise to address these requirements directly in the product specification. In the case of standard out-of-the-catalog gearboxes, buyers could do worse than follow the old Packard slogan: "Ask the man who owns one!" Successful manufacturers don't feel threatened by a potential customer asking for references.

Like the guy choosing between a larger truck and a smaller one, no buyer wants the wrong gearbox for his application. So a buyer should start his selection process with a detailed understanding of the application. ⚙

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[1] L-10 life refers to the number of hours at which 10% of the bearings will have failed. Average life is represented by L-50 and is assumed to be five times the calculated L-10 life.

Remedies for Cutting Edge Failure of Carbide Hob due to Chip Crush—Some Results of Evaluation by this Method in the Automotive Industry

Masaharu Komori, Masaoki Sumi and Aizoh Kubo

<u>Management Summary</u>

This is the second of two related articles on cutting edge failure of carbide hobs due to chip crush. The first article was published in *Gear Technology*'s September/October 2004 issue.

The earlier article introduced a hobbing simulation program for clarifying the clearance between hob cutting edge and work gear tooth flank.

In this article, the simulation is applied to some practical industrial problems of dry hobbing, i.e. chipping failure of a carbide hob's cutting edge.

Influencing factors are investigated, and the bases for finding countermeasures against chipping are shown. This method has been applied to some practical cases of problems in the mass production of automotive gears, and good results were obtained.

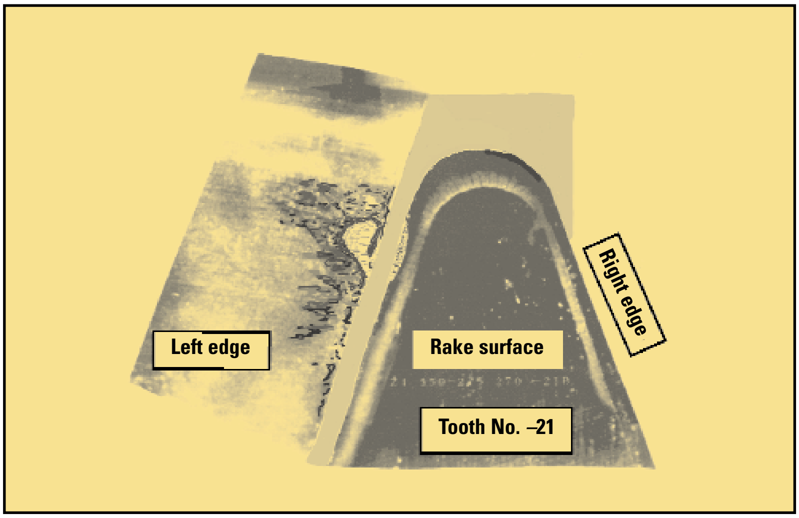

Figure 1—Chipping of carbide hob cutting edge under dry cutting.

Abstract

Dry hobbing is friendly to the environment, increases productivity and decreases manufacturing cost, but it often suffers failure of the hob cutting edge or problems with the surface quality of manufactured gears' tooth flanks. In the previous report, a simulation method to calculate the clearance between hob cutting edge and work gear tooth flank during hobbing was developed. In this report, this simulation is applied to some practical industrial problems of dry hobbing, i.e. chipping failure of a carbide hob's cutting edge and coarse, scratched surface finishes on hobbed gears' tooth flanks—perhaps due to chip crush. The simulation explains the mechanism of such actual failures in detail. Based on the simulation, the Distance of Single Edge Cutting (DSEC) of a hob tooth is proposed to be an index of pinching and crushing of chips that could intrude into the clearance between hob cutting edge and work gear tooth flank. Influencing factors on DSEC are investigated, and the bases for finding countermeasures are shown. This method has been applied to some practical cases of problems in mass production of automotive gears, and good results were obtained.

Introduction

Dry hobbing often has problems, such as chipping of hob cutting edge and coarse surfaces on manufactured gears' tooth flanks. Chip crush between hob cutting edge and work gear tooth flank is considered a major cause of these problems. However, the mechanisms of chip crush and influencing factors on it have not been clarified, so we know of no method today to prevent or solve the problems caused by chip crush.

In the previous report (Ref. 1), a simulation method to evaluate conditions of chip formation and clearance between hob tooth cutting edge and work gear tooth flank was proposed, where the trace of each hob cutting edge relative to the work gear is calculated. This proposed method explains the mechanism of chip crush between hob cutting edge and work gear tooth flank and enables evaluation of probability of chip crush.

In this report, the influence of gear dimensions, hob dimensions and cutting conditions on chip crush is investigated by the proposed method. A countermeasure to prevent chip crush is clarified and its effect is confirmed by applying it to actual industrial cases of hobbing.

Comparison of Simulation Result and Actual Hobbing

It is possible to evaluate the changing conditions of generated chips and clearance between hob cutting edge and work gear tooth flank by comparing tooth groove shape before one revolution of the work gear, the trace of the previously acting cutting edge, and that of the object cutting edge, which are calculated by the proposed hobbing simulation (Ref. 1). The hob tooth for generating the center of the work gear's tooth groove is defined as tooth No. 0. The teeth acting before No. 0 have a minus sign, those acting after it have a plus sign. The side edge on the left is called the hob's left edge and the side edge on the right is called the hob's right edge (compare with Fig. 1).

Figure 1 shows chipping failure of a hob cutting edge when a right-hand helical gear (module 2.75, pressure angle 20°, number of teeth 62, helix angle 30° and addendum modification factor –0.6) is dry cut by a right-hand carbide hob (four threads and outer diameter 100 mm) under a climb feed of 2.5 mm/revolution.

Figure 2 shows the simulation results for the cutting edge of hob tooth No. –21, which is expressed by traces on each normal-to-axis slice of a work gear by regular intervals as shown in Figure 3(b). The object tooth groove is behind the work gear body and is observed from a viewpoint below the work gear, as shown in Figure 3(a). In Figure 2, the inclined line on each slice for different z_s positions represents the work gear's tip circle and the vertical line shows the trace of each point on the cutting edge of hob tooth No. –21.

The thin broken curves represent the tooth groove shape formed before the work gear's last revolution. The thin curves represent the trace of the cutting edge of hob tooth No. –22 acting before No. –21's cutting edge. The bold lines represent the trace of the cutting edge of No. –21.

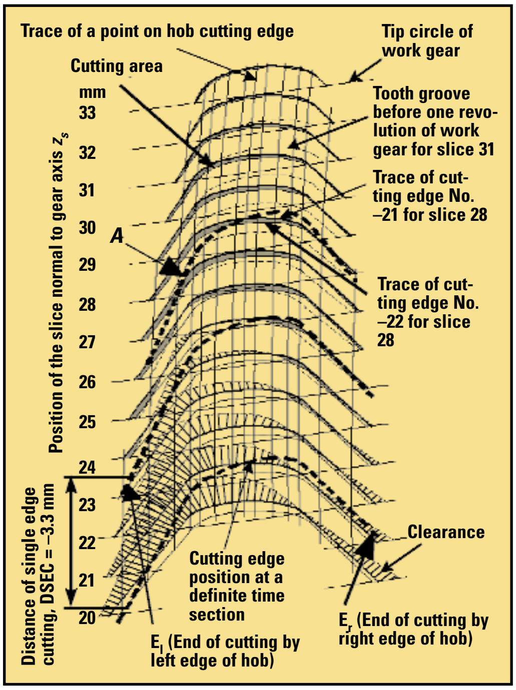

Figure 2—Cutting area (gray area) and clearance (hatched area) on each slice of tooth groove normal to gear axis, which are expressed by traces of hob cutting edges.

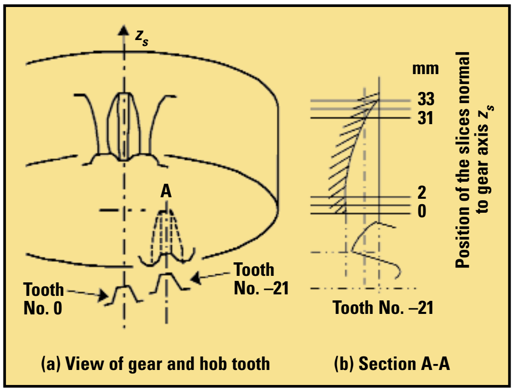

Figure 3—Definition of slices normal to gear axis.

The gray area, where the trace of No. –21's cutting edge is deeper than any other trace, shows the cut area with No. –21's cutting edge.

On the other hand, at the hatched area, where the tooth groove before one revolution of the work gear or trace of the cutting edge of hob tooth No. –22 is deeper than that of tooth No. –21, there is clearance between hob cutting edge and work gear tooth flank.

Figure 4 shows traces of the hob cutting edge on the normal-to-gear-axis slice at z_s = 28 mm and 24 mm. The whole cutting edge acts on the slice at z_s = 28 mm. At the slice near z_s = 24 mm, the upper left edge has finished cutting and the cutting area is divided in two. At the end of cutting by hob tooth No. –21, the right cutting edge acts alone, also seen in Figure 2. The two-dimensional expression on the normal-to-gear-axis slice shown in Figure 4 enables easy recognition

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Remedies for Cutting Edge Failure of Carbide Hob due to Chip Crush

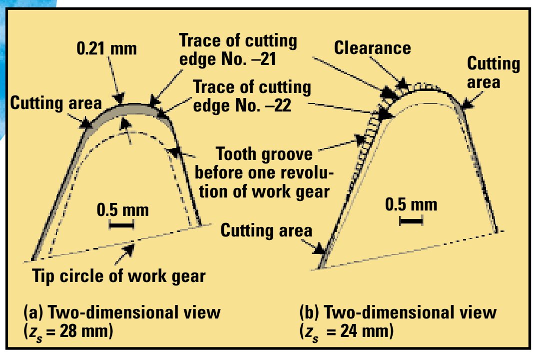

Figure 4—Expression of cutting area and clearance between cutting edge of hob tooth No. –21 and the work gear's tooth flank.

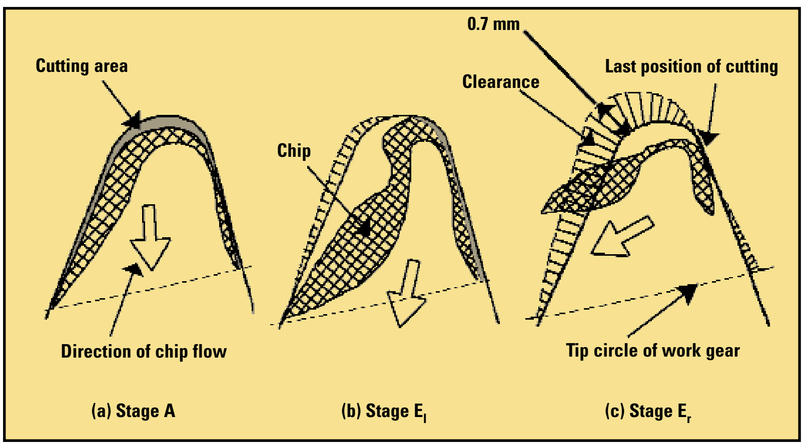

Figure 5—Direction of generated chip flow on rake surface of hob tooth at each cutting stage.

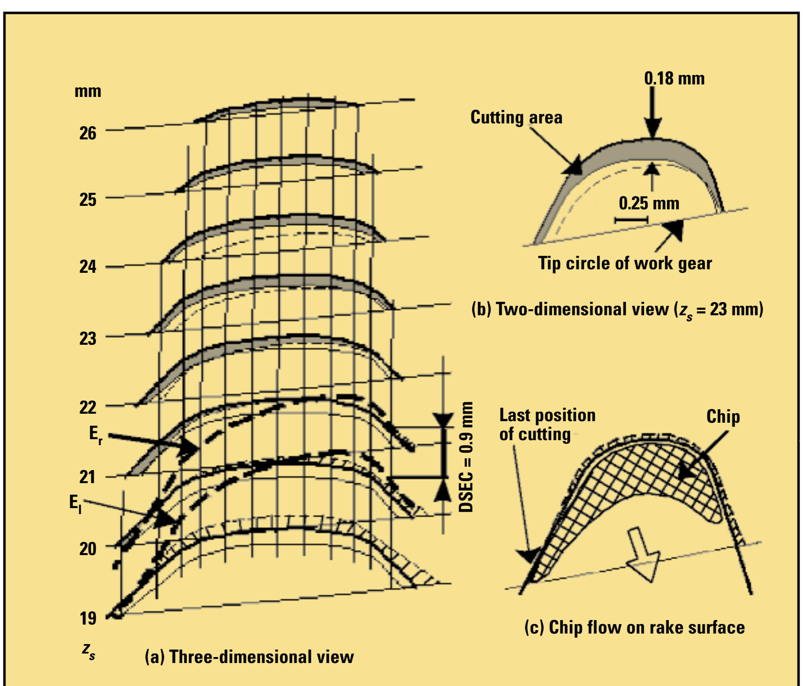

Figure 6—Cutting area, clearance and chip flow on rake surface for tooth No. –14 under standard conditions.

of the accurate size of cutting area and clearance.

Figure 2 also presents the chip formation process. The bold broken curve shows the cutting edge position at a definite time section. The hob's left cutting edge begins cutting each slice earlier than the right cutting edge because of the hob set angle, in this case. Edge position E_l corresponds to the end of cutting by the left edge and E_r to the end of cutting by the right edge. The tooth groove is cut only by the hob's right cutting edge in the axial range between E_l and E_r. That range is –3.3 mm (a plus sign means that the right edge finishes cutting before the left edge). This axial distance is defined here as DSEC (Distance of Single Edge Cutting).

Figure 5 shows a supposed movement of a generated chip on the hob's rake surface from the simulation for stages A, E_l and E_r in Figure 2. The whole tooth groove is cut simultaneously in Figure 5(a), so the chip moves toward the hob's tooth root. The hob tip and left cutting edge finish their work at stage E_l (compare with Fig. 2) in Figure 5(b), the right cutting edge acts alone at stage E_r (compare with Fig. 2) as shown in Figure 5(c). At that stage, the chip moves toward the hob's left edge. A large part of the already generated chip can surely reach the position near the hob's left cutting edge. However, the clearance between the left cutting edge and the work gear tooth flank appears in the process between A and E_l (compare with Fig. 2) and becomes larger. In such a situation, a generated chip could intrude into the clearance and chip crush could occur. The chipping position of the hob cutting edge in Figure 1 corresponds well to the position of

Table 1—Standard Specifications of Gear, Hob and Cutting Conditions.

a) Specifications of Gear		
Module	m	2.5
Pressure angle	α	20°
Number of teeth	z	59
Helix angle	β	30° RH
Cutting depth		5.875 mm
Addendum modification factor	x	0
Outside diameter	d_a	175.32 mm
(b) Specifications of Hob		
Module	m_0	2.5
Pressure angle	α_0	20°
Outside diameter		85 mm
Number of threads	z_1	4 RH
Lead angle		7.57°
Number of gashes	G_n	16
Amount of protuberance		0 mm
Radius of top corner		0.90 mm
(c) Cutting conditions		
Feed of table revolution		2 mm/rev.
Direction of feed		Climb
Hob set angle	Γ	22.43°

clearance in Figure 5(c). That means a main cause of that chipping is judged to be chip crush.

Chip crush does not always occur even if there is clearance and a generated chip moves toward the clearance. A chip might not intrude into the clearance or might pass through the clearance without crush. Chipping of the cutting edge is not actually observed on tooth No. –21's neighboring hob teeth, although there is no big difference in simulated results for the condition of chip formation and the behavior of clearance for hob tooth No. –21 and for its neighboring hob teeth.

The occurrence of chip crush may also be influenced by chip curl and work gear tooth flank surface condition, and it is difficult to predict exactly whether chip crush occurs or not. The proposed simulation is able, however, to evaluate the probability of chip crush. Evaluating this probability is industrially useful.

Influence of Gear Dimensions on Chip Crush

The cutting of a gear whose dimensions are shown in Table 1(a) by the hob in Table 1(b) under the cutting conditions in Table 1(c) is provided as an example. Figure 6 shows the simulation result for hob tooth No. –14. The result of the investigation in the following section confirms that general characteristics of chip crush are not much influenced by the difference in hob cutting edge, and it can be seen from the analysis by taking cutting edge No. –14 as a representative cutting edge. Figure 6(b) shows traces of the cutting edge on the normal-to-gear-axis slice at z_s = 23 mm.

Failure of a cutting edge often becomes a problem when a large chip is generated. Figure 6(c) shows the chip condition on a hob's rake surface before the end of cutting. DSEC is short (0.9 mm) in this case, although only the left cutting edge remains in work at that stage. That means the time when a chip moves toward the hob's right cutting edge is short and the distance of the chip's movement is short as well. In addition, the clearance near the right cutting edge is small due to the short DSEC. There is therefore little probability of chip crush under those conditions.

Influence of addendum modification factor. Figure 7 shows the simulation result for hobbing a gear in which addendum modification factor *x* is changed from 0 to 0.5 or –0.5. The tip diameter of the work gear is changed from that of Figure 6 according to the change of addendum modification factor *x*. For a gear of *x* = 0.5, DSEC becomes longer (3.4 mm) and the clearance between cutting edge and work gear tooth flank is larger. The lower illustration in Figure

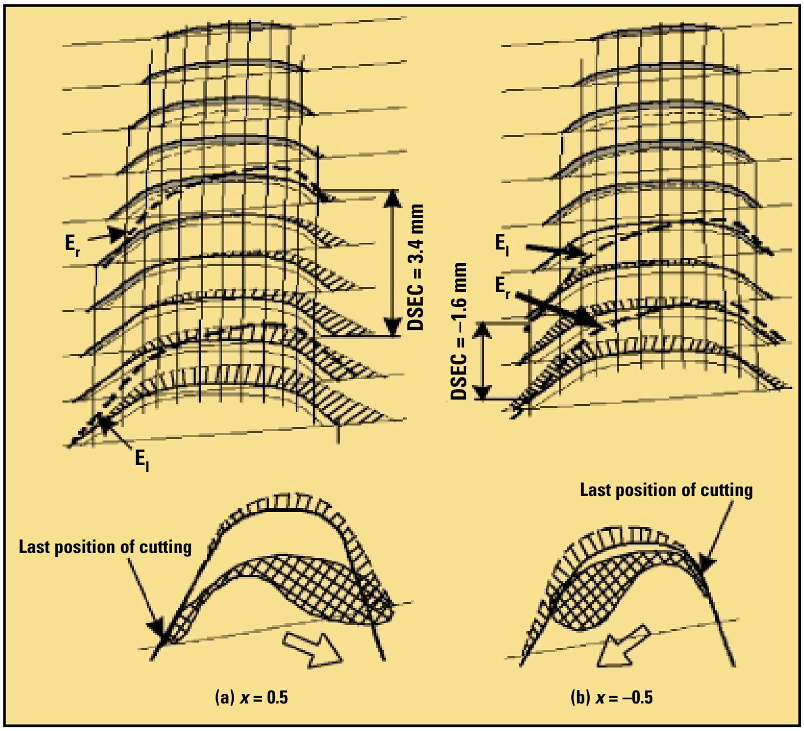

Figure 7—Influence of addendum modification factor x of gear.

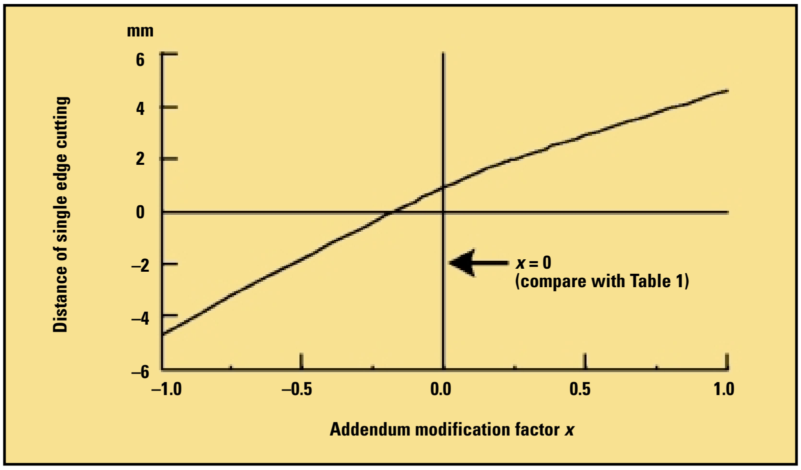

Figure 8—Effect of addendum modification factor of gear on DSEC.

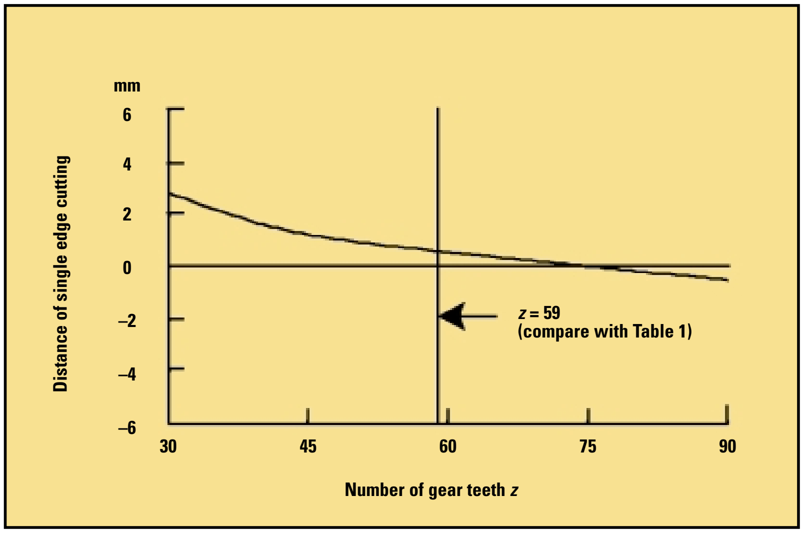

Figure 9—Effect of number of gear teeth on DSEC.

Remedies for Cutting Edge Failure of Carbide Hob due to Chip Crush

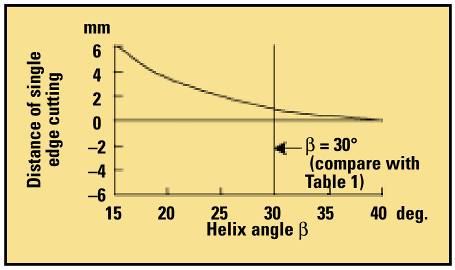

Figure 10—Effect of gear helix angle on DSEC.

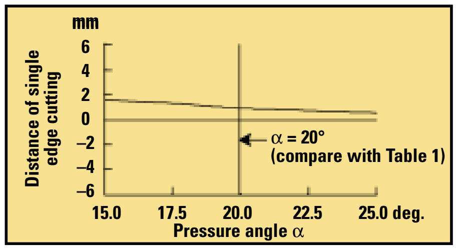

Figure 11—Effect of gear pressure angle on DSEC.

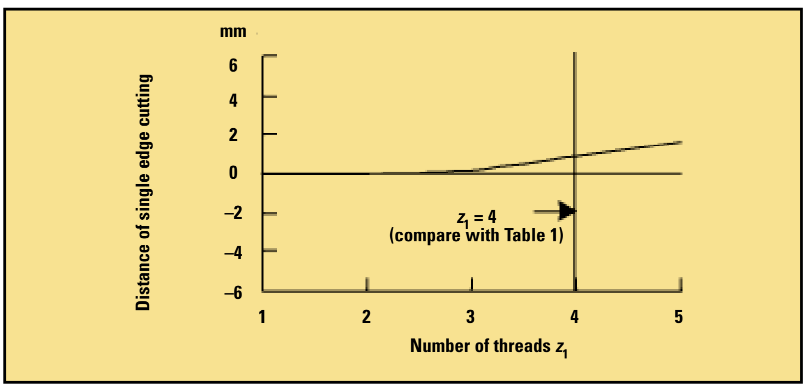

Figure 12—Effect of number of hob threads on DSEC.

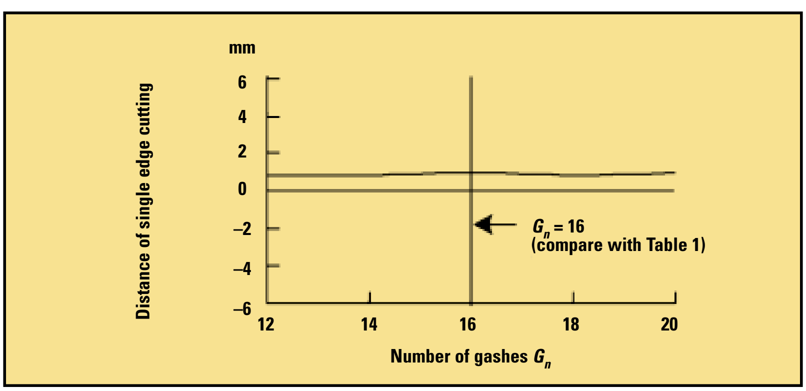

Figure 13—Effect of number of hob gashes on DSEC.

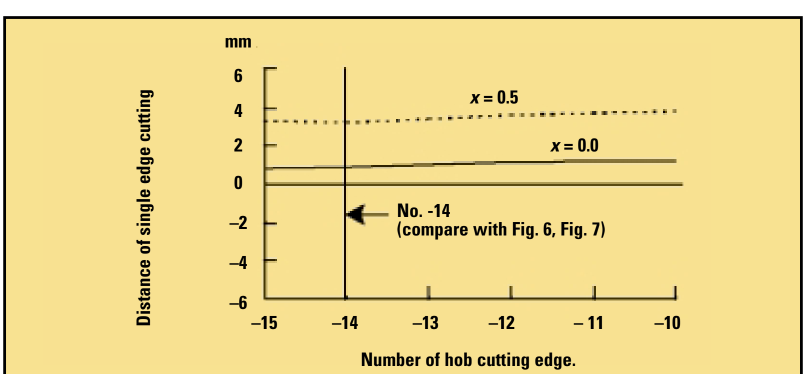

Figure 14—Difference in DSEC at different hob cutting edges.

7(a) shows the condition of chip formation on the hob tooth's rake surface. The chip moves toward the clearance near the right cutting edge because the left cutting edge acts alone for a long time. Those conditions imply a high probability of chip crush.

DSEC is –1.6 mm for a gear of $x = -0.5$ (see Fig. 7(b)). That means that only the right cutting edge acts at the end of cutting, which is opposite to the previous examples. A large clearance appears near the left cutting edge, and a chip could crush between the cutting edge and the work gear's tooth flank.

The large absolute value of DSEC implies large clearance and large chip movement on the hob tooth's rake surface—in other words, a high probability of chip crush. DSEC can therefore be taken as an index for evaluating the probability of chip crush.

It can be difficult to determine a clear DSEC threshold for chip crush. But, in the above two cases, a DSEC with an absolute value of 0.2 or 0.3 would be considered small enough.

DSEC increases according to an increase of the addendum modification factor, as shown in Figure 8). The DSEC value changes from a minus to a plus. That means that whether the cutting edge at the end of cutting is left or right depends on the addendum modification factor of the work gears.

DSEC becomes 0 when $x = -0.2$. That is, the left and right cutting edges finish cutting at the same time and there is little probability of chip crush under such conditions. The change of addendum modification factor from 0.2 increases the probability of chip crush. In actuality, it is known that small differences in gear dimensions result in large differences in the difficulty of dry hobbing. This fact is partly confirmed by the simulation result shown in Figure 8.

Influence of tooth number, helix angle and pressure angle. Figure 9 shows the influence of a gear's tooth number on DSEC. DSEC is approximately 0 when tooth number is large, but the value changes somewhat when the tooth number is small.

Figure 10 shows the result of investigating helix angle. It is clear that DSEC approaches 0 when the helix angle increases. That suggests a rather high probability of chip crush in the case of hobbing gears with small helix angles.

The result of investigating pressure angle is shown in Figure 11. There is no big influence from pressure angle on DSEC.

Influence of Hob Dimension and Cutting Condition

Figure 12 shows the relationship between number of hob threads and DSEC, where the number of threads is changed from the value shown in Table 1 and a parameter, such as hob set angle, is adjusted according to that change for the simulation. The probability of chip crush is very low for hobs with one or two threads because DSEC is near 0, but the probability of chip crush increases when a hob with a large number of threads is used.

The result concerning number of hob gashes is shown in Figure 13. It is clear that number of gashes has little influence on the probability of chip crush.

Figure 14 shows the change in DSEC at different hob cutting edges, where work gears of addendum modification factors of 0 and 0.5 serve as examples. It is clear that the DSEC changes very little for each hob cutting edge. That means that any hob cutting edge can be taken to analyze the probability of chip crush.

Figure 15 shows the influence of hob set angle. The values in parentheses show the amount of modification to the hob set angle from its original value. DSEC changes much due to the change in hob set angle. Arrangement of hob set angle is considered a powerful way of changing the conditions of chip formation and the behavior of the clearance.

A short pitched hob or a long pitched hob has a different pressure angle and module but has the same normal pitch compared with the original standard hob. The same gear can be cut by such a short/long pitched hob. Figure 16 shows the change in DSEC by such a short/long pitched hob under fixed normal pitch. DSEC decreases according to an increase of module and pressure angle. That result means a short/long pitched hob can change the condition of chip formation and the behavior of the clearance to prevent chip crush.

Method to Solve Problems due to Chip Crush

Problems concerning chip crush often occur in the trial-cut stage or early stage of mass production. The problem must be solved by changing parameters unrelated with gear dimension because gear dimension cannot be changed at that time. The condition shown in Figure 7(a) is taken here as an example, and the trouble due to chip crush at the right cutting edge is to be solved. DSEC must be decreased because DSEC

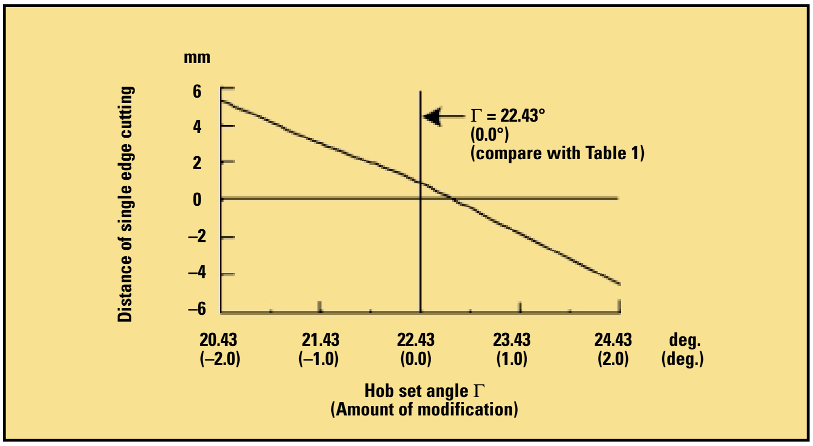

Figure 15—Effect of hob set angle on DSEC.

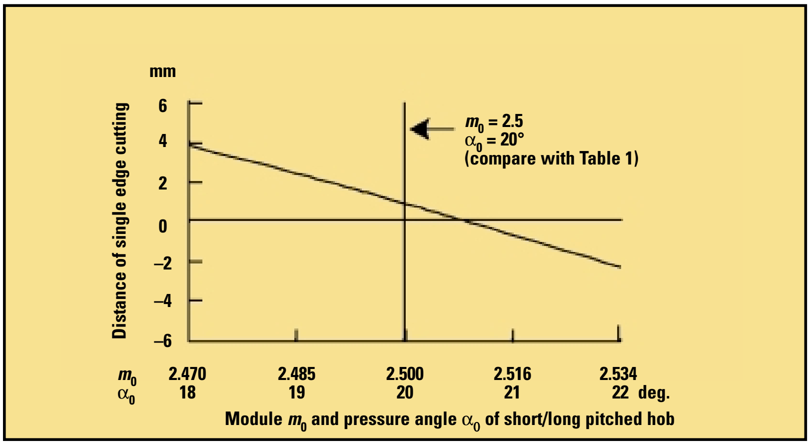

Figure 16—Effect of short/long pitched hob on DSEC.

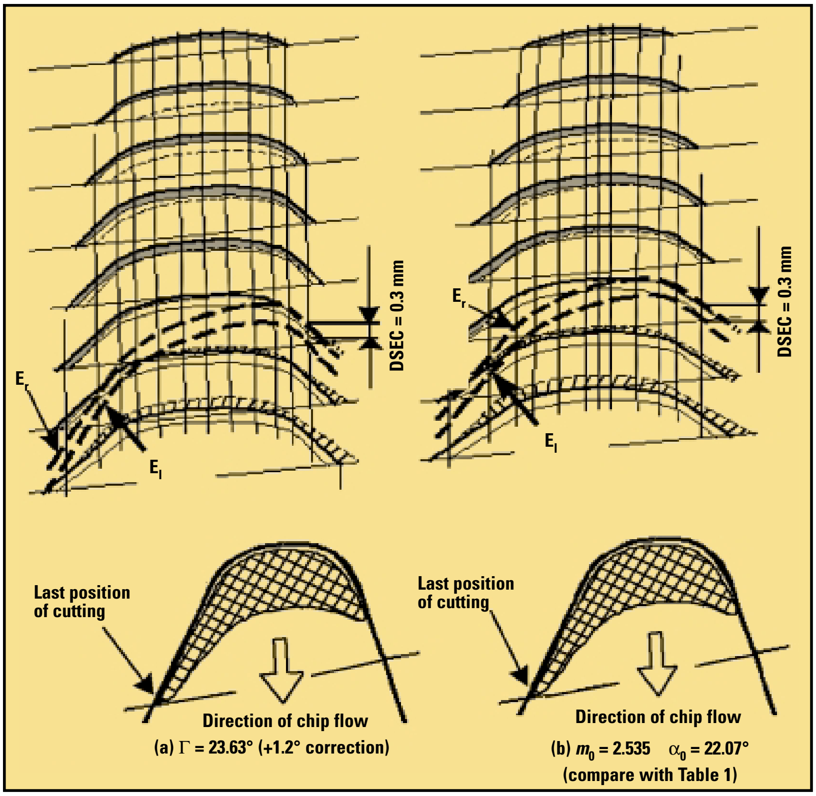

Figure 17—Improvement of cutting condition by modifying hob set angle or applying long pitched hob (m_0: hob module, α_0: hob pressure angle).

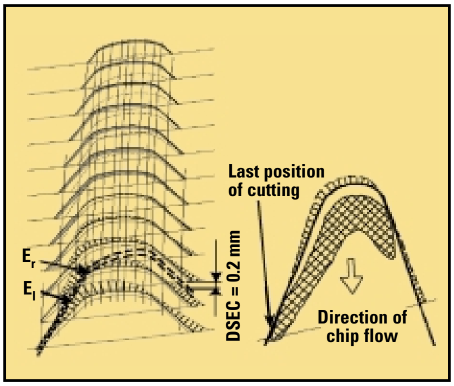

Figure 18—Simulation result when countermeasure against hob chipping is applied by providing a hob set angle modification of –0.75 degrees.

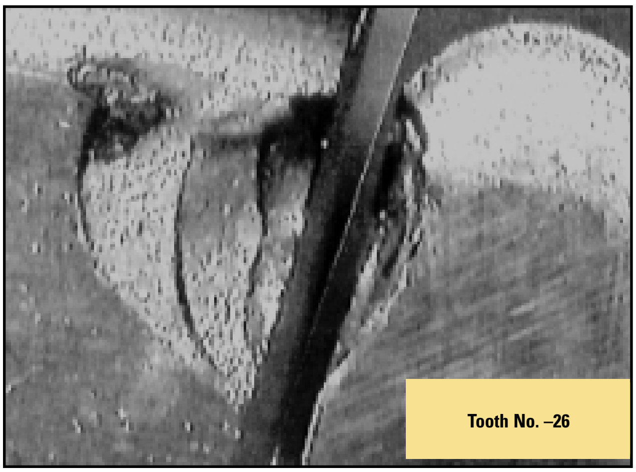

Figure 19—Chipping of carbide hob cutting edge (Example 2).

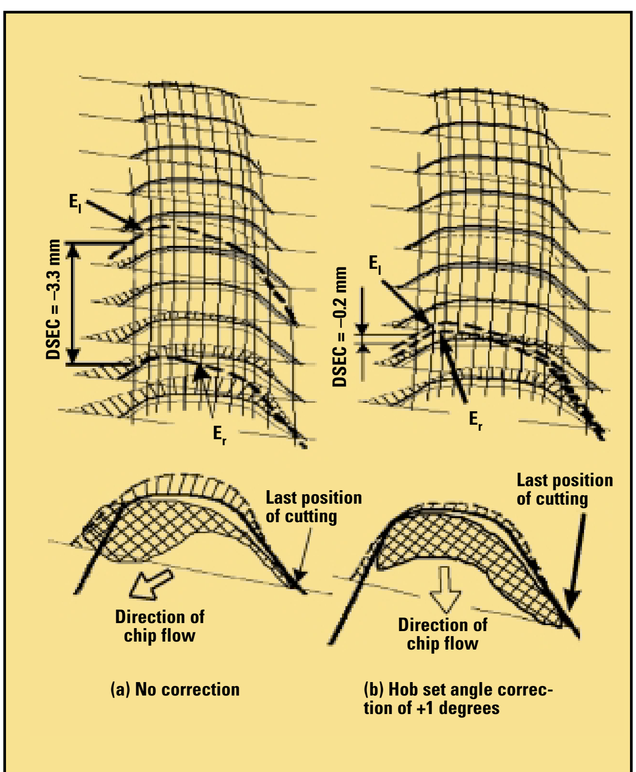

Figure 20—Simulation result for hob tooth No. –26 for Example 2, where hob set angle modification of +1 degree is provided.

is long (3.4 mm) under that cutting condition. An increase in hob set angle leads to a decrease in DSEC as shown in Figure 15. DSEC can also be decreased by applying a long pitched hob of larger module and pressure angle. Figure 17(a) shows the simulation result for +1.2 degree modification of hob set angle and Figure 17(b) shows the case of incorporating a long pitched hob of module 2.535 and pressure angle 22.07 degrees. It is clear that the DSEC value approaches almost 0 by the proposed methods and the probability of chip crush is expected to be lower.

Application to Actual Problems of Hobbing

Failure of hob left cutting edge (Example 1). The chipping shown in Figure 1 is used here, where simulation results are shown in Figure 2. Figure 18 shows the simulation result, where hob set angle is changed by –0.75 degrees. DSEC changes from –3.3 mm (see Fig. 2) to 0.2 mm. This countermeasure was applied to an actual case involving mass production of automotive gears, and the chipping problem was completely solved.

Failure of hob left cutting edge (Example 2). Figure 19 shows chipping of the cutting edge of hob tooth No. –26, which was observed when a left-hand helical gear (module 2, pressure angle 20 degrees, number of teeth 31, helix angle 35 degrees and addendum modification factor 0.33) is dry cut by a left-hand carbide hob (three threads) with a climb feed of 2.5 mm/rev. The same chipping failure occurred repeatedly at the same position on the hob tooth. Figure 20(a) shows the simulation result corresponding to the hobbing conditions of Figure 19. Chip crush at the hob's left edge is judged to be the cause of chipping because DSEC is long (–3.3 mm).

Figure 20(b) shows the result of the simulation where hob set angle is modified by +1 degree. The absolute DSEC value is decreased to 0.2 mm. In actual mass production, this correction of hob set angle was used. The chipping failure of the hob cutting edge disappeared.

Failure of hob right cutting edge (Example 3). (Ref. 2) Figure 21 shows chipping of hob cutting edge No. –14, which was observed when a right-hand helical gear (module 2.4, pressure angle 20 degrees, number of teeth 69, helix angle 30 degrees and addendum modification factor 1.0) is dry cut by a right-hand carbide hob (four threads) with a climb feed of 2 mm/rev. Figure 22(a) shows its simulation result. Chip crush is regarded as a main cause of the chipping shown in Figure 21 because DSEC is long (4.0 mm).

DSEC can be decreased to –0.2 mm by modifying hob set angle by +1.5 degrees, as shown in Figure 22(b). Clearance at the right edge becomes smaller as well. This remedy was applied to an actual case, and the problem of chipping failure was solved.

These actual cases confirm that the proposed remedies are useful at preventing hob failure due to chip crush.

Conclusion

Failures of hob cutting edge or problems with the surface quality of manufactured gears' tooth flanks are often problems in dry hobbing. These problems are usually caused by chip crush between hob cutting edge and work gear tooth flank. In this report, the behavior of chip formation and the changing state of clearance between hob cutting edge and work gear tooth flank is investigated by the proposed simulation method to develop the method to prevent chip crush. The following items are concluded:

(1) It is confirmed that the position of chipping on the hob cutting edge corresponds very well to the position of chip crush estimated from simulation. That means the probability of chip crush can be evaluated by utilizing the proposed simulation method.

(2) DSEC, i.e. the axial distance concerning a work gear where only a single edge cuts the tooth groove, can be taken as an index for evaluating the probability of chip crush: a larger absolute DSEC value means a higher probability of chip crush.

(3) Addendum modification factor, helix angle, number of gear teeth, hob set angle and short or long pitching of hob have a strong influence on DSEC. However, pressure angle, number of gashes, and hob tooth difference have little influence. Hobs with large numbers of threads, e.g. three or more threads, result in larger DSEC values.

(4) The solution for problems with chipping of hob cutting edges due to chip crush is to lower the DSEC. For that, we propose as follows: (1) using a short/long pitched hob of modified module and pressure angle or (2) changing the hob set angle. These methods make it possible to prevent chip crush without changing the dimensions of manufactured gears. The method has been applied to actual chipping problems in mass production of gears in some Japanese automotive companies and successful results have been achieved. ✪

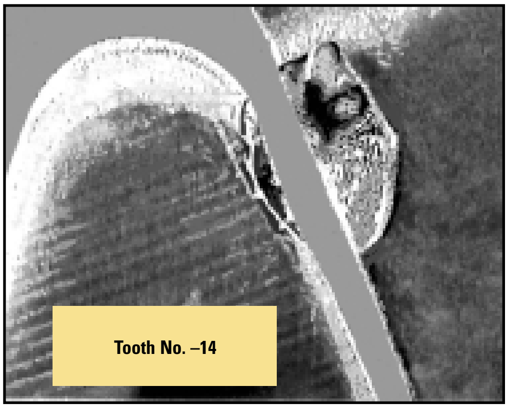

Figure 21—Chipping of carbide hob cutting edge (Example 3).

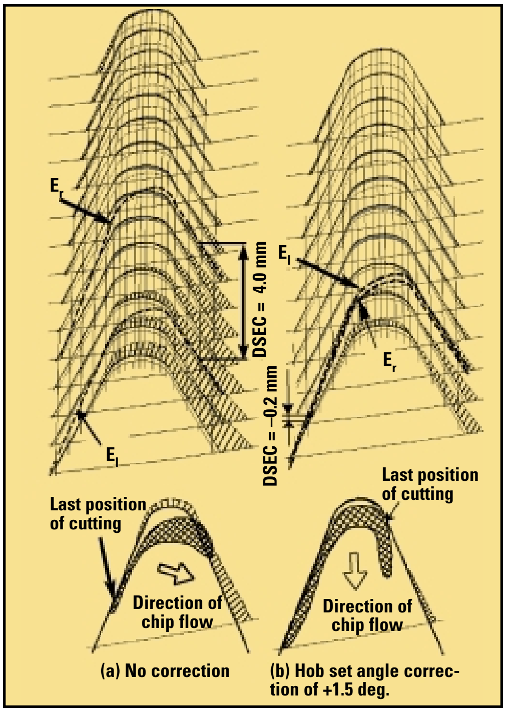

Figure 22—Simulation result for hob tooth No. –14 for Example 3, where hob set angle modification of +1.5 degrees is provided.

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The paper was also presented with its current title at the ASME/AGMA 2003 International Power Transmission and Gearing Conference, held Sept. 3–5, 2003, in Chicago, Illinois. It was also published in *Proceedings of the 2003 ASME Design Engineering Technical Conferences & Computers and Information in Engineering Conference*.

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Non-Standard Cylindrical Gears

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Abstract

This paper examines three gear geometries, each of which has special features not found on standard cylindrical gears. The first are high pressure angle spur gears where the pressure angle has been maximized at the expense of contact ratio. High pressure angles result in higher forces, but the stresses are less and are mostly compressive, leading to good fatigue resistance. The second design is a curved face width gear, giving a higher contact ratio compared to spur gears and lower contact and bending stresses. These gears are similar to double helical gears in that there are no axial forces. The third gear is a tapered face width gear, in which the addenda, dedenda and tooth width are all tapered. The benefits are that tooth engagement is gradual and compensation for center distance variations can be achieved by relative axial adjustment. All these gears were made of plastic materials.

Management Summary

Curved face width (CFW) spur gears are not popular in the gear industry. But these non-metallic gears have advantages over standard spur gears: higher contact ratio, higher tooth stiffness, and lower contact and bending stresses.

CFW gears also provide better operating features. Tooth height decreases in the sections away from the gear center, so a lower sliding friction is expected with consequences on the gear's thermal behavior. They axially locate each other, improving meshing when misaligned. There also are no axial forces inherent in helical gears.

For spur gears, load sharing follows the classic "top hat" shape with a sudden change when moving from partial load to full load. With a CFW gear, tooth contact and load changing are gradual like a helical gear. This should lead to smoother running, quieter gears compared to spurs.

But CFW gears are difficult to design and mount in gear trains. For certain tooth geometries, the gear train is sensitive to center distance variations.

Gears with high pressure angles (> 20°) are generally viewed as unsuitable due to lower contact ratios and higher noise levels. These gears, however, benefit from having stronger tooth forms and lower contact stresses and are more efficient due to shorter sliding distances. With dry-running plastic gears, the increased efficiency means lower running temperatures and, because of plastic's resilience, no noticeable noise difference. If the gears are fully lubricated, the high pressure angles result in higher entrainment velocities, leading to advanced lubrication. The authors tested 30° pressure angle gears and "extreme" 40° pressure angle gears with measureable improvements in strength and running temperatures.

Tapered face width gears can adjust backlash by axial movement of one of them. Such adjustment is much easier than backlash adjustment via radial center distance adjustment. The tapered face width principle can be applied to spur and helical internal and external gears and rack and pinion sets, so it is a versatile means of employing backlash control in, for example, automotive steering systems.

Introduction

The annual production of plastic gears now outnumbers the production of metal gears (more than 500 million per year for cars alone). However, the design of plastic gears relies heavily on the experience gained from many years of designing and manufacturing steel gears. Work in the United Kingdom and Romania has focused on increasing the transmissible power density of polymer gears. The basic geometry used for polymer gears is mainly determined from standard tooth proportions as recommended in steel gear standards. The work described sought to provide gears of superior performance designed to non-standard forms where pressure angles, addenda and dedenda are chosen for maximum efficiency and load carrying capacity. The forms suggested here are novel in concept and differ considerably from conventional practice.

The authors are primarily concerned with the design and practical aspects of plastic and polymer composite gears. The aim is to improve the performance of these gears in order that the transmissible power levels are raised so that plastic gears can be employed in a wider range of products. Historically, plastic gears have followed steel gear practice in terms of tooth proportions. However, since the primary manufacturing method is a molding process, almost any profile can be considered (i.e. tooth forms are not a function of the cutting process). This provides an opportunity for designing novel gear forms.

Wear is the predominant mode of failure for dry running gears, but root bending fatigue or pitch line fracture are also commonplace (Ref. 1). In the case of lubricated plastic gears, pitting can also arise. Plastic gears are particularly susceptible to temperature. In the case of dry running plastic gears, large friction forces will arise, and these can lead to high temperatures. It is not uncommon for the combined bulk and flash temperatures to exceed the melting temperature of the plastic, which will result in high wear rates (Ref. 2). Even if the temperatures are below the melting point, the mechanical properties of plastics are affected by heat and, for example, the elastic modulus decreases markedly with temperature, altering the contact ratio and load sharing. Thus, any design procedures and innovations which might reduce running temperatures and/or reduce tooth stresses in plastic gears are worth examining.

The gears described in this paper challenge the accepted wisdom of cylindrical gear design first by examining the effects of pressure angle, the benefits of a curved face width gear and the advantages of tapered face width gears, which permit gradual tooth engagement without the need for a helical tooth form.

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Non-Standard Cylindrical Gears

Table 1			
Pressure angle (deg)	20	30	40
Contact ratio	1.65	1.35	1.12
Center distance extendibility (mm)	1.43	0.98	0.37

(30-tooth spur gear, module 2 mm, standard proportions)

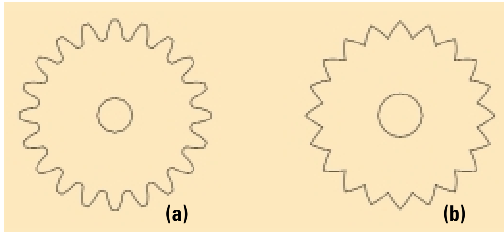

Figure 1—Showing (a) a standard 20° profile compared to (b) a 40° high pressure angle profile.

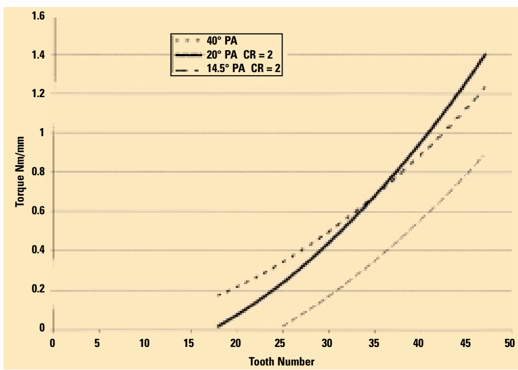

Figure 2—Comparison of torque capacity against tooth number for different pressure angles.

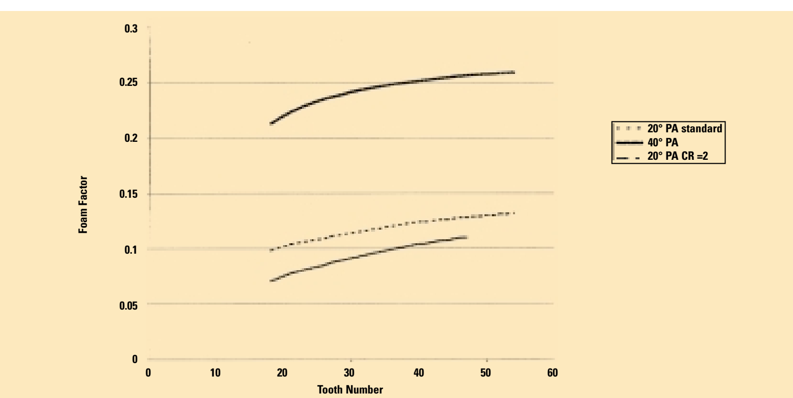

Figure 3—Showing Lewis form factor against tooth numbers for gears of varying pressure angles.

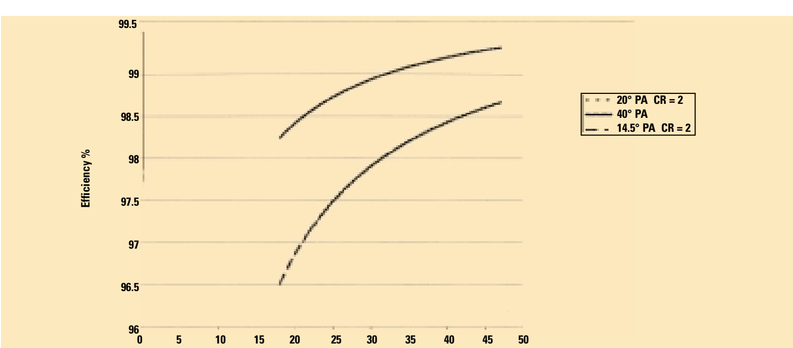

Figure 4—Showing variation of efficiency with tooth numbers for different pressure angles.

High Pressure Angle Gears

The aim: To investigate the potential of high pressure angle gear tooth profiles in polymer and polymer composite materials. A preliminary study showed that such tooth profiles could lower contact and bending stresses and increase efficiencies compared with gears of standard proportions. Studies on tooth forms showed that wear for gears molded with high 25° pressure angles was less than at standard (20°) or low (14.5°) pressure angles (Ref. 3). This raised questions as to what extent the pressure angle might be increased still further to reduce wear. A brief study was conducted for this application to investigate effects of pressure angle on sliding velocity, contact stress, tooth bending stress and efficiency. High pressure angle (30° and 40°) gears were injection molded from acetal (the benchmark material), a glass-filled nylon (high performance polymer composite) and PEEK (to permit high temperature operation). Tests were performed under dry and oil-lubricated conditions.

High pressure angle gear geometry results in a reduction of the addendum and the elimination of the top land.

It also results in an increase in the radius of the involute at the pitch point, (see Fig. 1), which will manifest itself as a reduction in both the contact and bending stresses (the section modulus increasing with pressure angle) as well as a reduction in sliding velocities. Figure 2 shows the transmissible torque per mm face width against tooth number at constant Hertzian contact stress for a 40°, 20° and 14.5° pressure angle gears (18 teeth is about the minimum for this 40° pressure angle). The 20° and 14.5° pressure angle gears both have a contact ratio of 2. Also, Table 1 shows the effects of changing pressure angle on contact ratio and center distance extendibility.

The Lewis form factor for these gears is shown in Figure 3. This factor becomes questionable as an indication of tooth bending strength for the 40° pressure angle gear since radial load is not considered. The line of action of the force acting on the teeth for the majority of the contact period falls within the extent of the tooth root. This implies there is no bending of the tooth form and that both flanks of the tooth are in compression. This factor might be important for a number of brittle materials that have good strength in compression but break under moderate tension. Preliminary Finite Element Analysis (FEA) indicates that the profile of the 40° pressure angle gear teeth shows an improvement in tooth bending stress compared to the standard profile, even allowing for the difference in load sharing.

An unexpected result was the discovery that the apparent efficiency increased with pressure angle (Fig. 4). In nearly every case, contact and bending stresses and efficiency for the high pressure angle gear indicate improved performance. This higher efficiency mostly results from the reduced contact ratio of the high pressure angle design. If gears with low pressure angles were modified, such as by reducing their outside diameters, the claimed efficiency benefits would largely, possibly completely, disappear.

Still, high efficiency has two rewards for plastic gears. One is economy, and the second reward is a lower running temperature for a given transmitted power. Material properties deteriorate with increasing temperature so that, at low temperatures, the material will be stiffer and stronger. High pressure angle gears are not normally favored because of higher normal loads for a given transmitted torque, low contact ratios and higher noise. Our preliminary studies show that other advantages (such as low stresses, higher efficiency) might more than outweigh these considerations, resulting in a higher transmitted power for a given size of gear.

Finally, the higher resilience of plastics means that the operating noise levels are less than those for steel. Thus, noise considerations may not be a problem. During the subsequent tests, mesh temperatures, efficiency and noise were recorded. Average dynamic coefficients of friction will be back-calculated from measured efficiencies, so the results can be compared to gears made from the same materials, but of standard 20° pressure angle form. It will be possible to take the design a stage further and include high pressure angles with a helical tooth form. This would result in even higher transverse pressure angles as well as improved load sharing. Should the results prove promising, other materials might be investigated, such as ceramics. Thus, if high pressure angle gears are successful, there will be considerable future research and development potential.

Curved Face Width Gears

Curved face width gears (Fig. 8), have been developed in Russia (Ref. 4) and by Gleason in the U.S., but, due to their complex geometry, few engineers are aware of their existence. The particular advantages these gears have over standard spur gears are higher contact ratios and lower

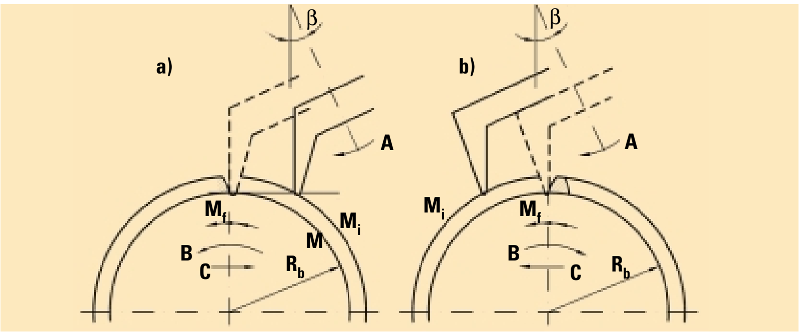

Figure 5—Gear tooth flank generation.

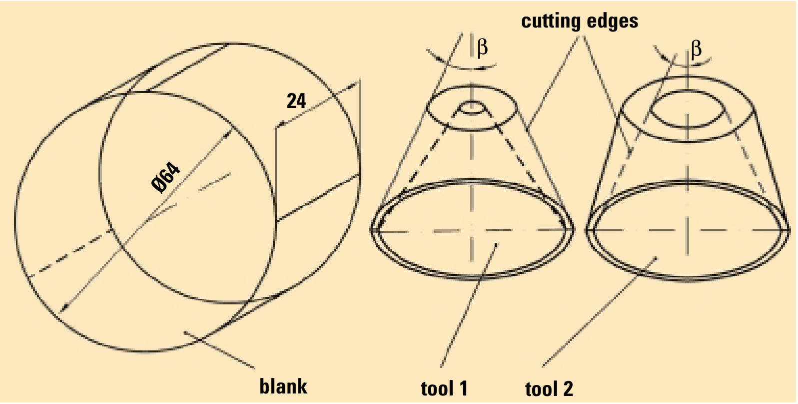

Figure 6—Showing the solid primitives used to simulate the curved face width gear teeth generation.

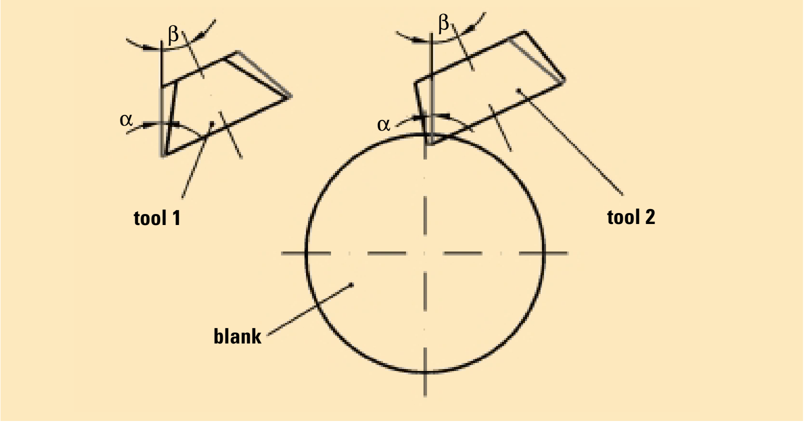

Figure 7—Simulation of the tooth cutting process.

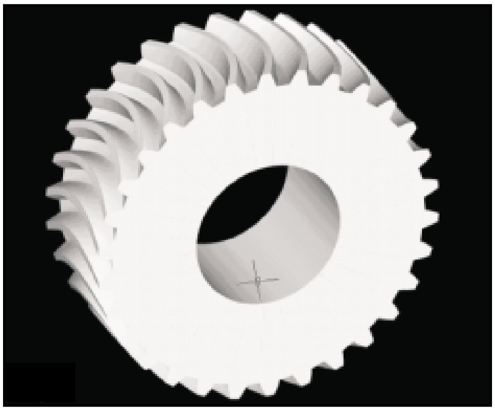

Figure 8—Pictorial representation of the curved face width spur gear, with modified geometry.

contact and bending stresses, due to the double curvature of the tooth flanks. They axially locate each other, offering better meshing in plane misalignment conditions, and there are no axial forces, which are inherent in helical gears. The difficulty in gear train mounting and, for certain tooth geometries, a sensitivity to center distance variations are the only two serious disadvantages.

The curved face width spur gear described in this article differs from previous curved face width gears in that they have a modified geometry with a variable tooth height and width along the gear face width. Reduced bending stresses, lower sliding velocities and, when run in oil, enhanced lubrication conditions were expected. The shape of these gears makes the design of a molding die commercially impractical. Hence this proposed design is suitable only for machined gears, plastic or metal. Such gears must be mounted with close control of relative axial position, generally not required for spur or helical parallel-axis gears (Ref. 5).

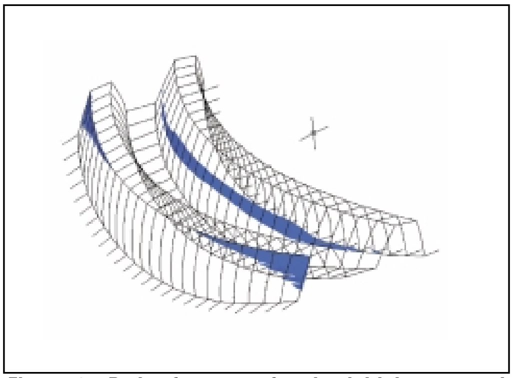

Figure 9—Path of contact for the initial gear tooth contact.

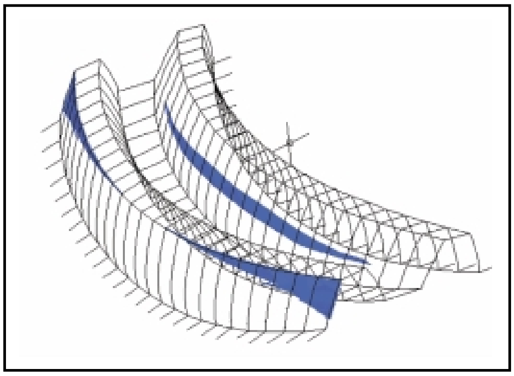

Figure 10—Path of contact after 1° rotation.

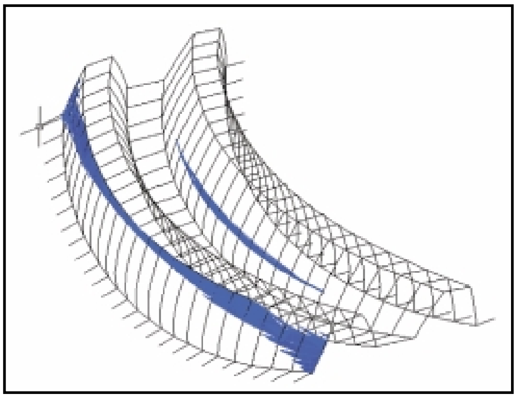

Figure 11—Path of contact after 3° rotation.

The kinematics of the gear generation process. Two different cutters were used for the concave and convex tooth flank generation. Figure 5 illustrates the kinematics of the generation process, where the tools are working in the half-width plane of the blank. The normal sections of the cutters show straight lines for the imaginary rack-cutter flanks, with a zero pressure angle. The designed geometry for the tooth flanks is based on the following kinematic principles:

- the cutting tool performs rotational motion (A) about its inclined axis, leading to a curved tooth along the gear face width and a variation in tooth height;
- the gear being generated is rotated about its axis (B) and is provided with translational motion (C), tangential to the base circle of the gear (R_b), in order to obtain the rolling motion required for involute tooth form generation.

Two phases are necessary in order to generate the entire gear. The cutting process starts with the tooth-by-tooth concave flank generation (Fig. 5a) followed by the convex flank generation (Fig. 5b), where a new tool is used, properly positioned relative to the already cut concave flank.

Simulation of the gear generation process. The modified geometry of the curved face width spur gears described here requires a theoretical investigation before the gears can be made. A numerical simulation of the gears' generation and mesh, based on the traditional conjugate surface generation theory, was developed by one of the authors (Ref. 6). The complexity of the gear tooth geometry implied complex mathematical calculations and large computer programs. The authors used the advantages of solid modeling techniques in order to obtain a complete representation of the gear. The gear design model can be further used for the gear generation error analysis, for finite element analysis and for rapid prototyping.

To simulate the kinematic generation of the curved face width gear flanks, the blank and the tools are modeled by cylindrical and conical solid primitives using solid modeling methods with conveniently chosen dimensions. Work previously done by the authors on measuring and comparing the performance of plastic gears led to a "standard" gear being used that has a 20° pressure angle, 30 teeth of module 2 mm and addendum equal to the module. In order that the curved face width gear could be compared to standard geometries, the first curved face width gears were made the same size. Thus, a gear blank of 64 mm diameter and 24 mm face width (Fig. 6) was made. The rotational motion of the two cutters about their own axes was replaced by the solids "Tool 1" and "Tool 2," obtained by rotating the tool's normal sections around the same axis, using the REVOLVE command. The rotational motion of the blank was performed incrementally by using a ROTATE3-D command, with an angular increment; its translational motion was also done incrementally.

The tool successively intersects the blank until the generation of a tooth flank is completed (Fig. 7). The removal of the "material" is done using a Boolean subtraction operation, performed by the SUBTRACT command. The automatic development of the procedure enables a dynamic view of the process and a representation of the gear to be made (Fig. 8).

Gear meshing simulation. A theoretical analysis of the gears in mesh shows that the contact line depends on the magnitude of the transmitted torque and on the gear alignment. When the concave side of the pinion tooth enters mesh, contact starts at the tooth dedendum, at the end of the gear face width and extends to the midpoint of the face width, leading to a concave curve of contact. Similarly, contact on a tooth's convex flank determines a convex curve of contact, starting at the tooth dedendum, at the gear's mid-section. The facilities offered by the solid modeling technique enabled the gear mesh to be simulated, in order to investigate the path of contact. Using the virtual models and the dynamic simulation of the gear meshing, the theoretical path of contact was obtained from a virtual model of the ideal gear train.

Figures 9–11 show several representations of the path of contact on the pinion teeth's convex flanks (a 0.1 mm interference was used for the path representation). The initial contact shown in Figure 9, obtained by hand positioning of the virtual gear, corresponds to an arbitrary point along the theoretical line of contact. The gear train was next rotated by 1° (Fig. 10) and then 3° (Fig. 11), to obtain the contact path during gear meshing. Analyzing the tooth contact, it is obvious the "contact line" is a spatial curve, which changes in curvature during the mesh cycle.

Bending stresses and deflections in curved face width gears. The authors designed a modified geometry for the plastic curved face width spur gears in order to enhance the load capacity and to avoid excessive tooth deflection. The database obtained from the gear generation simulation was used to analyze the gear tooth resistance, using finite element analysis procedures. Stresses and stiffness of a curved face width gear were compared to those of a standard spur gear.

Curved and straight spur gears were modeled using COSMOS/M set to the following geometrical parameters: modulus 2 mm, 30 teeth and 24 mm face width. Poisson's ratio for the plastic material used in the gear's manufacture, Ertalon 66SA, was 0.3; and the tensile modulus of elasticity was 3,450 MPa. The analysis was developed for two teeth in mesh under the applied loads given in Table 2 and shown in Figure 12.

Table 2

Torque [Nm]	Von Mises stresses [N/mm^2]	Maximum deflection [mm]
4	1.18	0.014
6	1.77	0.021
8	2.36	0.027
10	2.96	0.035
12	3.55	0.041

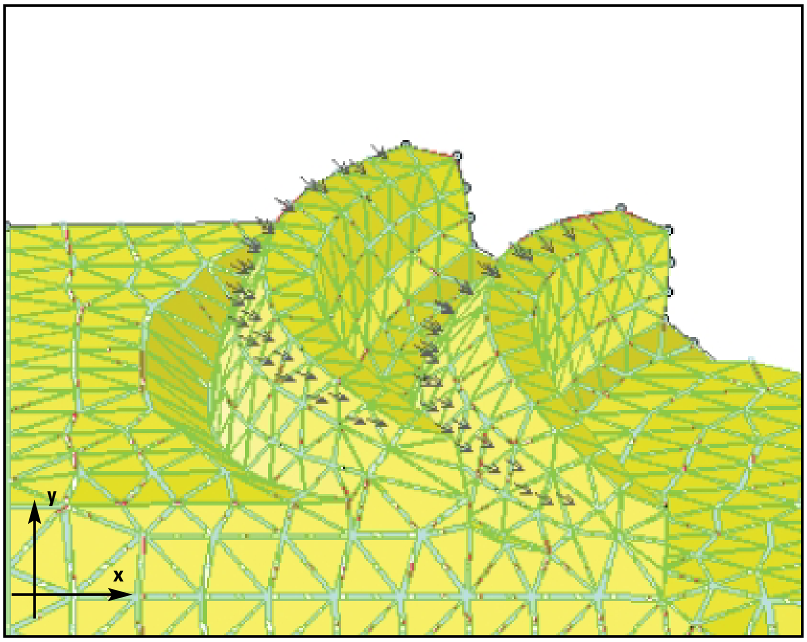

Figure 12—Showing the applied loads.

Non-Standard Cylindrical Gears

Table 3

Torque [Nm]	Von Mises stresses [N/mm^2]	Maximum tooth deflection [mm]
4	10.78	0.017
6	16.47	0.022
8	21.55	0.033
10	27.59	0.043
12	32.64	0.051

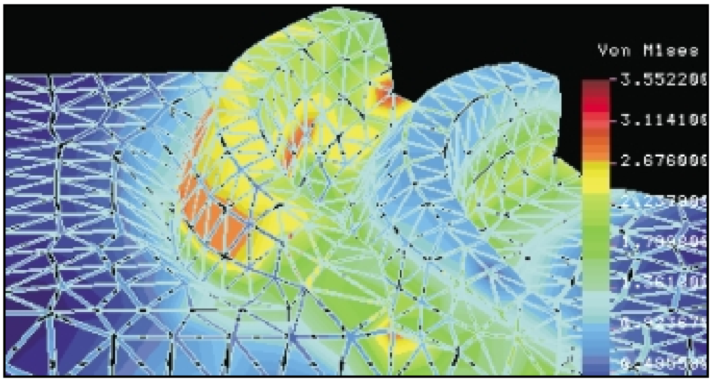

Figure 13—Von Mises stress distribution.

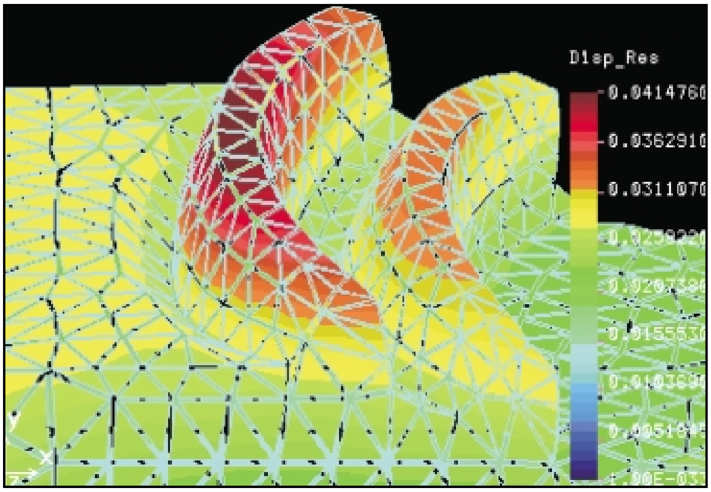

Figure 14—Distribution of curved face width tooth deflections.

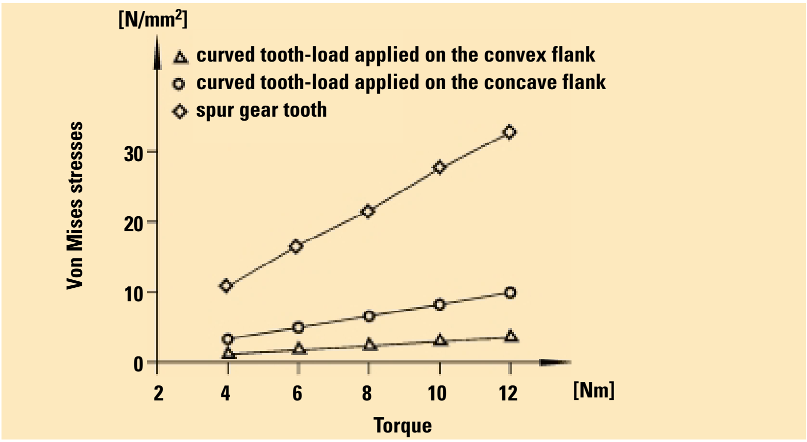

Figure 15—Comparison of maximum stresses in curved face width and standard spur gears.

Table 2 lists the results of the tooth bending stresses and deflections for a standard region of the curved face width gear—a continuum divided into 18,348 linear tetrahedral elements interconnected at 3,721 nodes. For the maximum load applied (12 Nm), Figures 13 and 14 illustrate the distribution of the Von Mises stresses and the tooth deflections, respectively.

Figure 13 shows that maximum stresses are concentrated on the dedendum of the tooth with load applied close to its addendum. Figure 14 shows that maximum tooth deflection appears in the gear mid-face width, at the tooth addendum. Due to variable tooth height and width, the tooth stiffness can differ, as shown by the variation of tooth deflection along the gear face width. It can be seen that, close to the gear face width ends, the tooth deflection decreases by approximately 20% compared to the gear mid-section tooth deflection. A similar analysis, done for the curved face width gears with the load applied on the concave flanks, showed higher bending stresses concentrated on the tooth dedendum and similar maximum displacements of the tooth addendum, at the gear's mid-face width.

The analysis of the spur gear tooth bending resistance was also developed, for the same applied loads. The results are given in Table 3 and show the high bending stresses developed compared to the curved face width gears; the bending stresses developed in standard spur gears being approximately 10 times higher than the curved gear tooth stresses. The result of the finite element analysis on the bending resistance is summarized in Figure 15.

Tapered Gears

The tapered gear design utilizes the principle of access and recess action within a single gear. At the mid-plane, the geometry of the tooth form is substantially standard. The gear has a linear taper so that the profile is modified to access action at one end of the gear and recess action at the other. The matching meshing gear must have a similar taper and the access region must mesh with the recess portion of the mating gear. This condition can be satisfied when the direction of the taper is inverted (Fig. 16). For spur gears, this profile results in the flanks of the teeth being slightly helical and a small end thrust will be generated when torque is transmitted. Interestingly, the direction of the axial force is the same for both drive and overrun conditions.

Another feature of the gear profile is the ability of the gears to compensate for center distance variation or backlash by adjusting the relative axial position of the gears. This results from the taper in the tooth width. The taper of the gears is in all proportions linear with axial position, so that the addendum, dedendum and tooth width all change proportionally (Fig.17). This produces a shape that has a natural draft angle on all external surfaces, facilitating the manufacture of these gears by some molding process. This process might be cavity molding for plastic gears or sintering or forging for metal gears.

The contact ratio varies across the plane of the meshing gears, and the slight helical profile of the flanks provides a small phase difference between the ends of the gear. The important feature is that the contact ratio changes smoothly as the mesh progresses so that the teeth are gradually loaded and unloaded. This feature should help to make these gears quiet in operation. The beam strength of the tooth profile should be comparable with conventional gears' tooth profiles. The second moment of area is that the tooth root is larger for the tapered gear profile than for a standard tooth.

The tapered gear can also be made helical (Fig. 18) with a different helix angle on the opposite flanks of the teeth. In this case, left- and right-handed helical gears are required. A special case is where the helix angle is made so that one flank of the tooth is straight while the other is helical. For example, an axial reaction force might be generated while the gear pair is driving and no such force is generated during overrun.

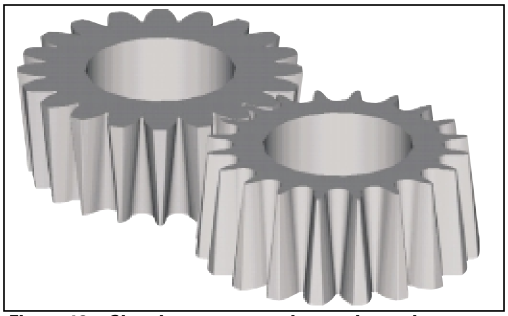

Figure 16—Showing two tapered gears in mesh.

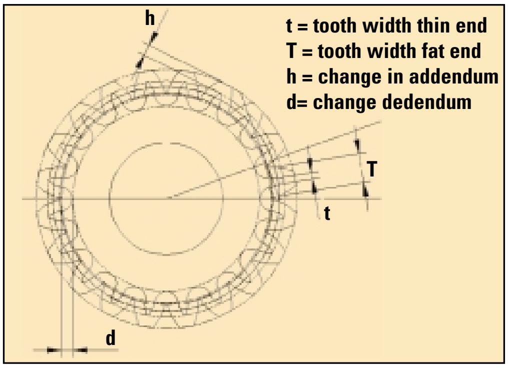

Figure 17—Comparison of the extremes of profile for the tapered gear.

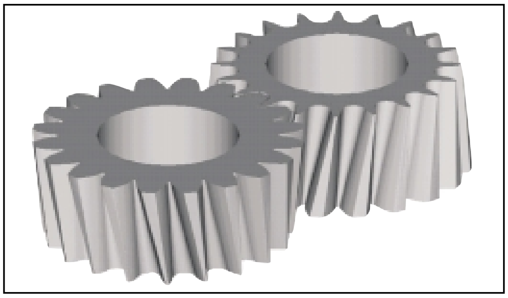

Figure 18—Showing a pair of helical tapered gears.

Conclusions

Three novel gear types are examined in this paper, each offering some benefits over conventional cylindrical gears. High pressure angle gears of the same materials have withstood higher loads than gears of standard geometries. Noise has not been a problem. Curved face width gears are shown to provide lower stresses compared to spur gears of the same dimensions. These gears are manufactured by cutting the plastic, and though this form of production results in less accurate gears, these gears run satisfactorily and demonstrate their capacity to operate at higher torque levels than conventional spur gears. Tapered face width gears are modeled and manufactured using rapid prototyping techniques. The main advantages of the tapered gears are the ease of manufacture by molding techniques, including sintering and forging. Kinematically, they offer a degree of action that effectively provides mesh overlap. The gears provide tolerance to mold shrinkage due to the adjustability of the mesh by axial displacement. ☼

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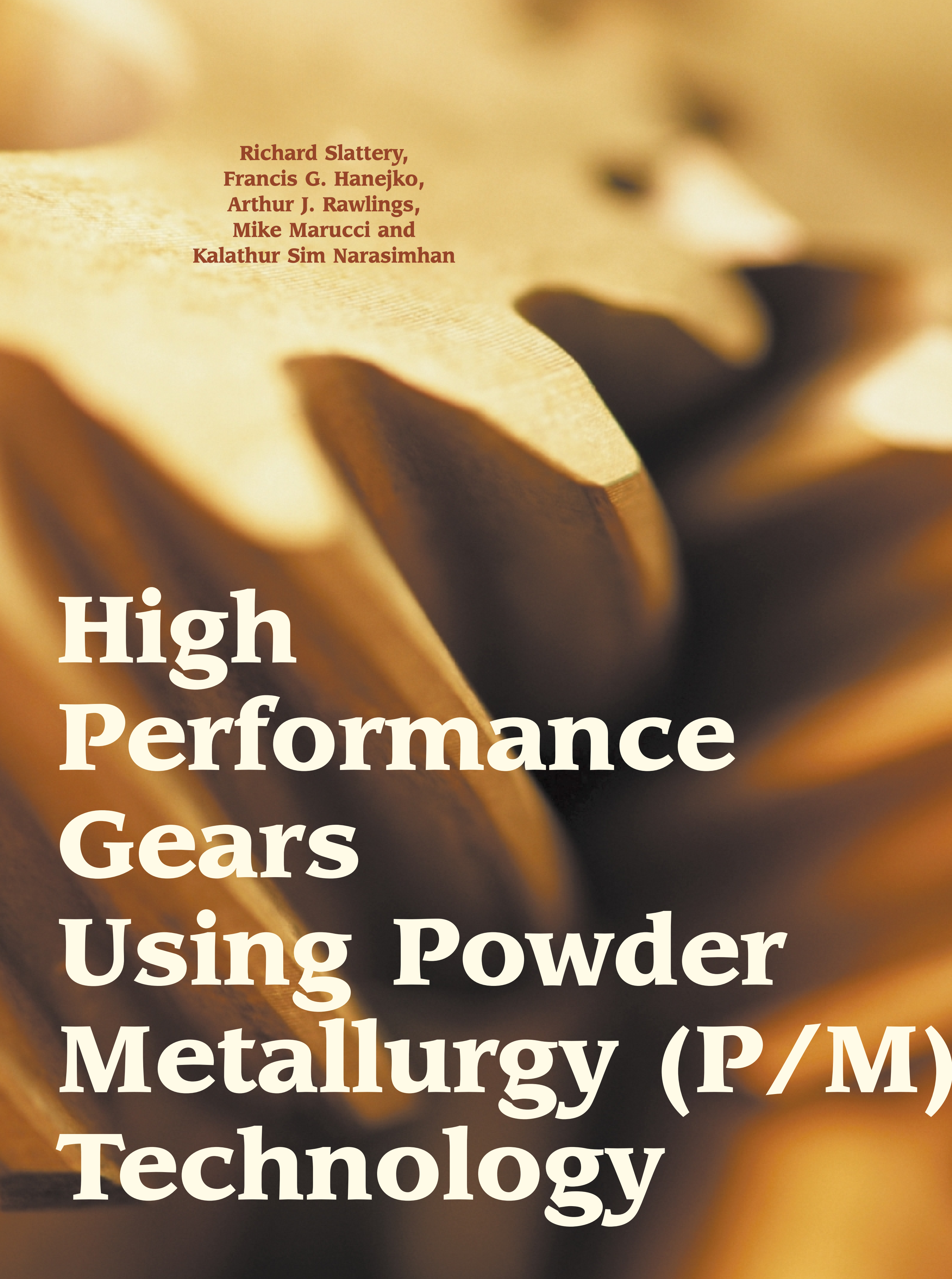

Richard Slattery,
Francis G. Hanejko,
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High Performance Gears Using Powder Metallurgy (P/M) Technology

Management Summary

Powder metallurgy (P/M) techniques have proven successful in displacing many components within the automobile drive train, such as: connecting rods, carriers, main bearing caps, etc. (Ref. 1). The reason for P/M's success is its ability to offer the design engineer the required mechanical properties with reduced component cost.

Powder metallurgy is also a proven technology to produce high strength gears for the automotive market. P/M techniques can manufacture spur gears with overall part densities up to 7.5 g/cm^3 via today's powder production, compaction and sintering processes—combined with double pressing. However, helical gears are more difficult to produce to these same densities because the geometry does not lend itself to the double press/double sinter process.

But advances in powder production, compaction, and sintering—combined with secondary operations—have enabled core part densities up to 7.4 g/cm^3 and fully dense tooth flanks in helical gears.

Abstract

To close the gap between conventional P/M and wrought steel, a process is needed that enables P/M gear producers to manufacture helical gears with sintered densities greater than 95% pore free via single press/single sinter processing. This higher density provides enhanced mechanical properties with a higher elastic modulus (Ref. 2). High density provides better mechanical properties, such as tensile strength, fatigue, and impact toughness. Still, even minor amounts of porosity can have a significant negative effect on certain characteristics. In particular, high performance gears require full density in the critical stress region to withstand the high Hertzian contact stresses.

Secondary processing, such as surface densification, enables the production of a highly engineered porous core component with full or near full density in the critical stress region of the gear (Ref. 3). What is needed is to merge the practice of surface densification with higher core densities to expand the potential applications for P/M.

Described in this paper is a P/M parts-making technology capable of producing single pressed and sintered helical gears with core densities approaching 7.4 g/cm^3. Description of a prototype run will be presented with the resulting sintered part densities and part-to-part variability. To further enhance the performance and geometry of these helical gears, they were subsequently surface densified via rolling. Improvements in the surface density and gear quality will be described.

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High Performance Gears Using Powder Metallurgy (P/M) Technology

Introduction

At the present time, P/M is successful in two primary performance areas. The first is in density ranges of less than 7.1 g/cm^3 with low- to medium-strength requirements. The second main application area is fully dense P/M via powder forging. Here a sintered preform is hot forged to near pore-free density, maximizing the mechanical properties of the P/M component.

An example of a part family that offers significant volume opportunities for the P/M industry are helical gears used in the planetary gear sets of automatic transmissions. The requirements of these gears are high surface hardness, good core toughness, fatigue strength for tooth bending, rolling contact fatigue resistance, and high density to resist pitting and sub-surface spalling during service (Ref. 4). Currently, these gears are machined from either AISI 8620 steel or AISI 5120 steel carburized and machined to meet the dimensional specifications.

Conventional press and sinter technologies offer low production cost to produce these parts; however, the corresponding mechanical properties are inadequate. Powder forging a blank and then machining it will give the required mechanical properties but at a cost that is prohibitive. It is speculated that a technology enabling core densities ≥ 7.4 g/cm^3 with a fully dense surface will meet the mechanical property requirements of this application, yet be economically competitive.

In an effort to satisfy the diverse mechanical requirements of these helical pinion gears, Capstan Atlantic and Hoeganaes Corp. collaborated on the implementation of a new compaction technology (AncorMax D™) that enables the attainment of high core densities without the need to preheat the powder. The advantage of this process is its greater flexibility in the manufacture of high-density P/M parts. It will be demonstrated that this process can produce helical gears with sintered densities approaching 7.4 g/cm^3.

Following compaction and sintering, Capstan employed its proprietary surface densification technology to densify the high stressed region of the gear. This technology, coupled with the attainment of the proper heat-treated microstructure, can produce gears that approach the performance of wrought steel gears.

The AncorMax D Process

The AncorMax D process is a patent pending premixing technology that optimizes both the lubricant and binder additions to achieve an increase of 0.05–0.15 g/cm^3 in density relative to a conventional premix (Refs. 5, 6).

Coupled with this increase in green and sintered densities, the AncorMax D process offers reduced alloy segregation, reduced dusting, superior flow, and enhanced die fill (Ref. 7). These factors give the opportunity for greater consistency and higher quality P/M parts.

Attaining high-density, single press, single sinter P/M parts has been an objective of the P/M industry for many years. ANCORDENSE™ processing was introduced approximately eight

Table 1—Alloy Test Matrix (FLN2-4405).

	Base Material	Nickel, % by weight	Graphite, % by weight	Lube, % by weight	Premix Technique
1	FL-4400	2.0	0.6	0.75	Standard Premix
2	FL-4400	2.0	0.6	0.55	AncorMax D

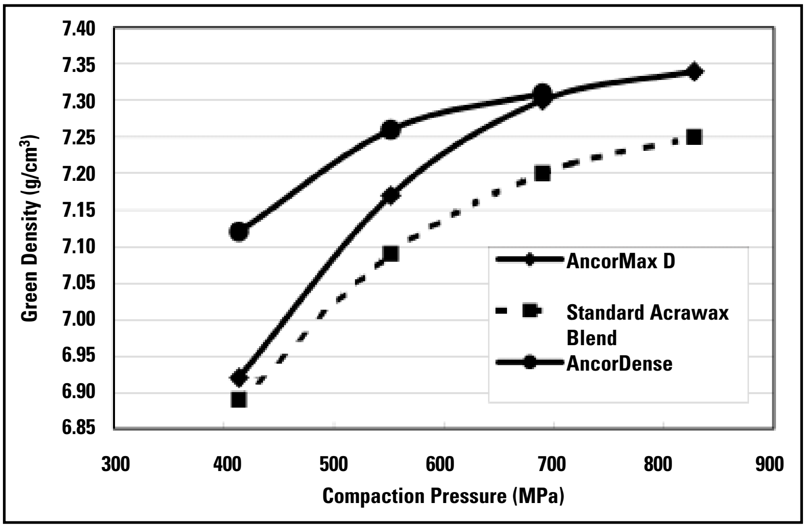

Figure 1—Comparison of the compressibility of a regular premix with AncorDense and AncorMax D.

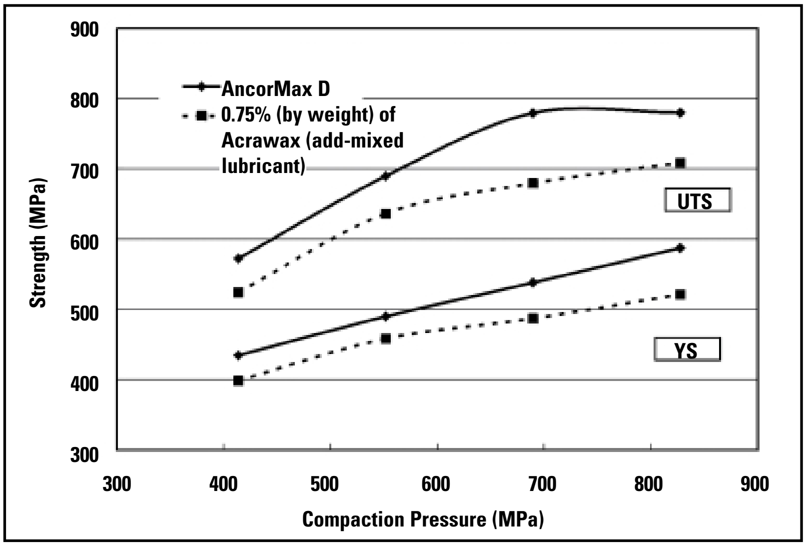

Figure 2—Strength of FLN2-4405 sintered at 1,120°C (2,050°F).

years ago; it is a technology that requires preheating the die, punches, and powder to approximately 120–150°C (250–300°F) (Ref. 8).

The challenge of maintaining consistent temperature during the compaction process has prevented widespread acceptance of this processing technique. The AncorMax D system requires only die heating in the range of 60–70°C (140–160°F). The powder remains unheated until it enters the die cavity.

The advantages of this system include the aforementioned density gain of 0.05–0.15 g/cm^3, less ancillary equipment, and reduced powder waste. Limitations include a maximum part length of approximately 25 mm (1.0 in.) due to limited heat transfer in the powder and the continued need for a heated die. Also, compaction pressures greater than 550 MPa (40 tsi) are a prerequisite to attain the improvement in density.

Shown in Figure 1 is a comparison of the green density vs. compaction pressure for an FLN2-4405 material made via regular premixing, ANCORDENSE premixing, and AncorMax D premixing. General observations from this chart are as follows: the ANCORDENSE premix gives the highest green densities at the lowest compaction pressures, and the maximum green density achieved for ANCORDENSE and AncorMax D are nearly the same.

The benefit of the AncorMax D processing is observed at compaction pressures greater than 40 tsi (550 MPa). The maximum density achieved with either the ANCORDENSE or AncorMax D technology is dependent upon the pore-free density of the premix with a limiting value of 98% of the pore-free density (PFD).

Properties of AncorMax D FLN2-4405

To illustrate the potential benefits of using the AncorMax D process, a comparison of the mechanical properties of an FLN2-4405 premix processed via two routes was performed. Table 1 shows the test alloy matrix.

Reference is made to Figure 1 for the compressibility curve for the two materials. It is noted that compaction pressures greater than 550 MPa (40 tsi) show an increase in green density. However, with the compaction pressure at 415 MPa (30 tsi), the increase in density is minimal. In addition to compressibility samples, standard MPIF dog bone tensile samples were compacted with a die temperature of 63°C (140°F). Rotating bending fatigue (rbf) samples were produced by machining standard test samples from blanks also compacted at a die temperature of 63°C (140°F). All samples were sintered under the following conditions.

- Continuous Belt Furnace,
- Standard Water Jacket Cooling,
- Sintering Temperature: 1,120°C & 1,230°C (2,050°F & 2,300°F),
- Time at Temperature: 25 min., and
- Atmosphere: 75%N_2, 25%H_2 (by volume).

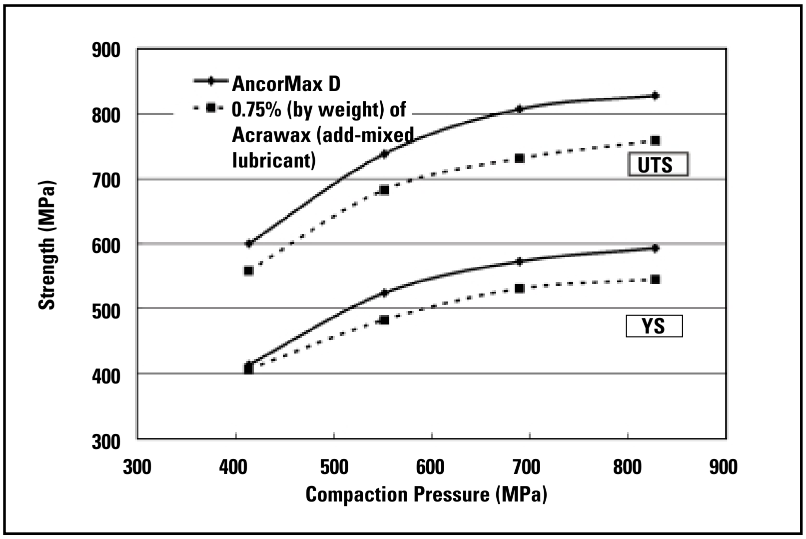

Figure 3—Strength of FLN2-4405 sintered at 1,260°C (2,300°F).

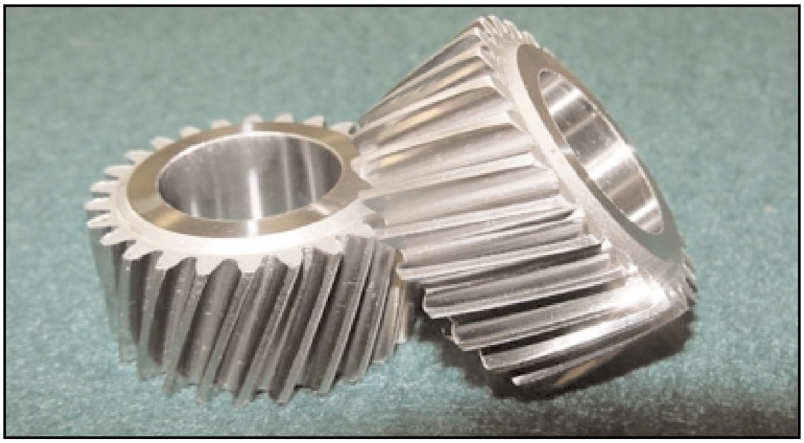

Figure 4—Photograph of helical gear pressed in the collaborative effort. Note gear has a 22° helix angle with an OAL of 22.5 mm. The major diameter of the gear is 42.5 mm and the ID of the gear is 23.5 mm.

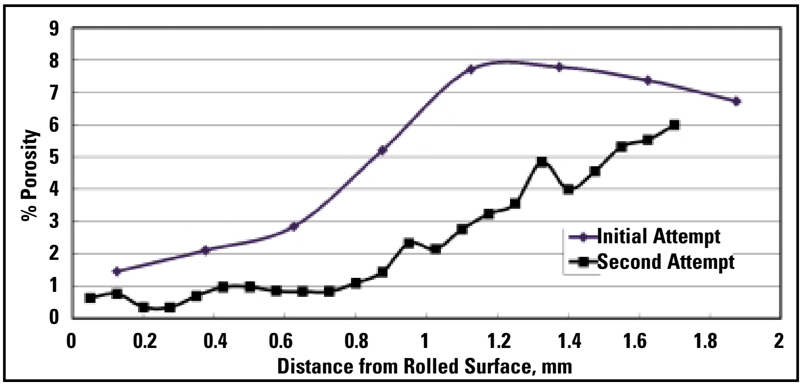

Figure 5—Porosity profiles of roll densified test samples.

Increasing the density of a P/M component increases the tensile and fatigue strength of the finished part. Figures 2 and 3 demonstrate that the 0.10 g/cm^3 increase in density achieved with the AncorMax D processing results in a 10% increase in ultimate tensile strength (UTS) and yield strength (YS) at equivalent compaction pressures. Additional increases in strength can be achieved by increasing the sintering temperature from 1,120°C to 1,260°C (2,050°F to 2,300°F) by comparing the data presented in Figures 2 and 3.

The rbf data presented in Table 2 demonstrates the same beneficial effect of increasing density on the fatigue survival limits. The 0.10 g/cm^3 increase in density yields approximately a 10% increase in fatigue life.

The rbf survival limits for the samples sintered at 1,230°C (2,300°F) are lower than the samples sintered at 1,120°C (2,050°F). This superior fatigue performance of the 1,120°C sintered material is related to the heterogeneous microstructure. At 1,120°C, the admixed nickel does not completely diffuse into the iron matrix, resulting in a nickel-rich second phase that acts to arrest crack propagation.

Conversely, the homogeneous microstructure of the high temperature sintered samples lack these crack-arresting particles with a resulting decrease in fatigue performance (Refs. 9, 10).

Prototype Production of a Helical Gear

To verify the production capability of the AncorMax D process, Capstan Atlantic and Hoeganaes Corp. collaborated in the compaction and sintering of the helical gear shown in Figure 4.

Table 2—RBF Data for AncorMax D Processed FLN2-4405.

Compaction Pressure, MPa	Sintering Temp., °C	90% Survival Limit, MPa	UTS, MPa	% of UTS (90%)	Density g/cm^3
690	1,120	266	759	34.4	7.34
830	1,120	292	745	38.2	7.41
690	1,230	252	759	32.5	7.38
830	1,230	273	841	31.8	7.44

Table 3—Green Density Results of Helical Gear Trial.

Premix	Gear OAL, mm	Green Density at 550 MPa, g/cm^3	Green Density at 690 MPa, g/cm^3	Green Density at 830 MPa, g/cm^3
Standard Premix	12	7.12	7.26	7.26
	19	7.13	7.25	7.28
	25	7.03	7.25	7.28
AncorMax D	12	7.24	7.34	7.38
	19	7.25	7.32	7.34
	22.5	7.05	7.28	7.34

During this effort, a standard premix material consisting of FLN2-4405 composition (Table 1) was compacted as a reference at pressures ranging from 550–830 MPa (40–60 tsi) in non-heated tools at a press speed of ~8 strokes per minute.

Phase two of the trial involved compaction of an AncorMax D premix of the same FLN2-4405 composition (with the exception of the lubricant addition and type) utilizing the same helical gear tooling. Compaction pressures of 550–830 MPa (40–60 tsi) were utilized with a die temperature of 65°C (150°F). In both compaction trials, the part height was varied from 6 mm (0.25 in.) up to approximately 25 mm (1.0 in.).

Results from the compaction trial are summarized in Table 3. Similar to the results achieved with laboratory test samples, the AncorMax D gears exhibited an overall density increase of approximately 0.05–0.10 g/cm^3 compared to the standard premix at equivalent compaction pressures. One notable aspect of this work demonstrated that the AncorMax D with its reduced lubricant level gave satisfactory compaction and ejection up to a part height of 22.5 mm.

Compacting gears with overall lengths (OAL) greater than 22.5 mm resulted in high die ejection forces with corresponding poor surface finishes.

Part-to-part weight variability of the gears produced with the AncorMax D process showed reduced scatter relative to the standard material (Table 4). This reduced scatter will lead to reduced dimensional variation in the production of the actual component.

After compaction, the gears were sintered at 1,120°C (2,050°F) in a 90%N_2, 10%H_2 (by volume) sintering atmosphere for approximately 30 minutes at temperature. The sintered gears were evaluated for sintered density; the results are presented in Table 5. More than 3,000 gears were compacted during this pre-production effort. Twelve sectional densities were evaluated by sectioning a part into four quadrants around the diameter and into three height regions. The result of this analysis is shown in Table 6.

It is worth noting that the density gradient from top to bottom and around the circumference is uniform within +/– 0.02 g/cm^3. This uniformity of density is significant because uniform density throughout the part minimizes distortion during sintering.

Methods to Improve the Physical Properties of P/M Components

Achieving higher sintered density is perhaps the primary method to improve the performance of a P/M part. However, recent experimental work has shown that heat treat practice and secondary operations can also have a significant effect on actual part performance. This section will review recent advancements in these processes and demonstrate how these advances can lead to improved gear performance.

It is well known that carburizing produces favorable compressive stresses on the surfaces of components. This phenomenon applies to P/M components as well. Several researchers have found a 15–20% improvement in rotating bending fatigue properties (Refs. 11, 12). In addition, the lower carbon core produces a material with greater impact toughness and core ductility.

Despite the positive effect of carburizing on mechanical properties, one key material characteristic in which P/M falls short of wrought steels is in the area of rolling contact fatigue resistance. In rolling contact fatigue, the high subsurface stresses resulting from the gear contact area and relative slip have shown the need for full density in the critical stress regions to withstand the Hertzian contact stress associated with rolling contact fatigue of high performance gears.

To improve the gear performance of P/M components, surface densification is sometimes used to densify the highly stressed region of the part, without affecting the core characteristics.

Benefits of surface densification can include:

- A composite structure with a pore-free case and a porous core,
- Potentially lower component cost because the high density region is only in the critical stress region of the part,
- Improved gear geometry and tolerance because the P/M gear is rolled against a precision roll die, and
- Potentially add the ability to crown the tooth of the densified P/M gear.

Surface densification is a process that locally densifies the surface of a pressed and sintered P/M preform. The concept of densifying only the surface is that maximum Hertzian stress in a gear is developed in the near surface region of the gear and diminishes with increasing distance from the surface. Thus, a gear with a surface densified case (to the appropriate depth) will give rolling contact fatigue properties equivalent to a wrought steel gear. Process development at Capstan Atlantic showed that the depth of the pore-free densified layer can range from a mini-

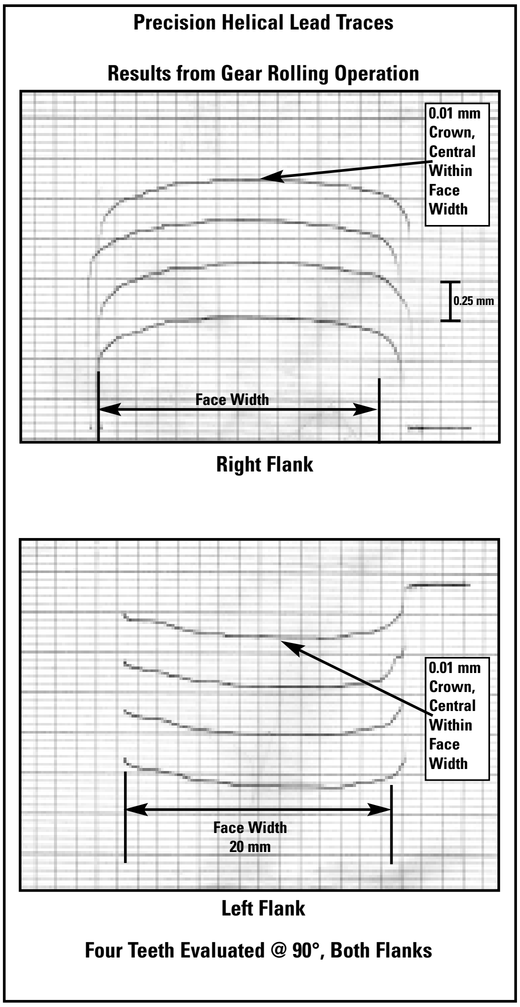

Figure 6—Gear tooth lead error traces on rolled densified helical gears taken at 90° intervals on the gears.

Table 4—Part-to-Part Weight Variability @ 830 MPa.

Process	Var. 1σ gms	Range gms.
Standard Premix	0.48	1.66
AncorMax D	0.20	1.10

Table 5—Sintered Density of Helical Gears at 1,120°C (2,050°F).

Premix	Gear OAL, mm	@550 MPa g/cm³	@690 MPa g/cm³	@830 MPa g/cm³
Standard Premix	12	7.12	7.24	7.28
	19	7.12	7.25	7.29
	25	6.99	7.18	7.23
AncorMax D	12	7.26	7.41	7.45
	19	7.28	7.43	7.45
	22.5	7.07	7.43	7.45

Table 6—Density Variations within a Sintered Helical Gear, g/cm³.

Position	North (front of die)	South	East	West
Top	7.38	7.40	7.37	7.41
Middle	7.37	7.39	7.40	7.39
Bottom	7.41	7.39	7.40	7.40

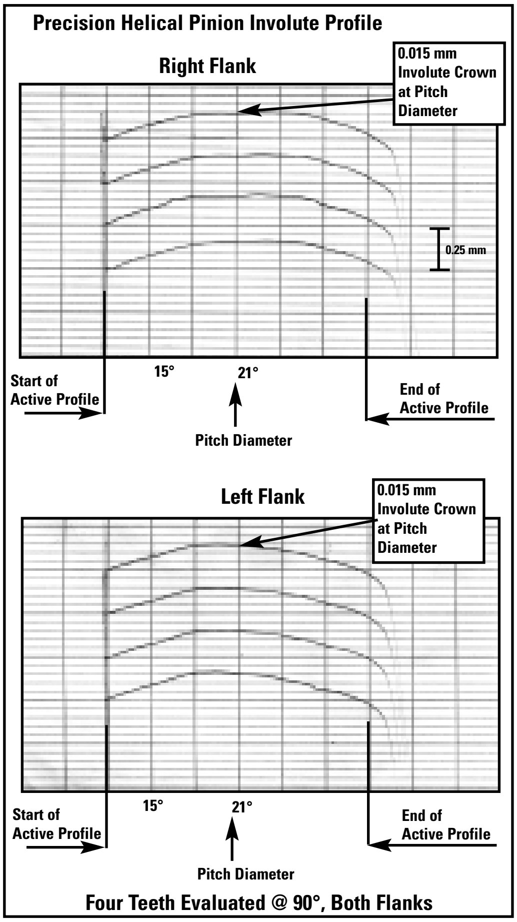

Figure 7—Involute gear traces on rolled densified helical gears taken at 90° intervals on the gears.

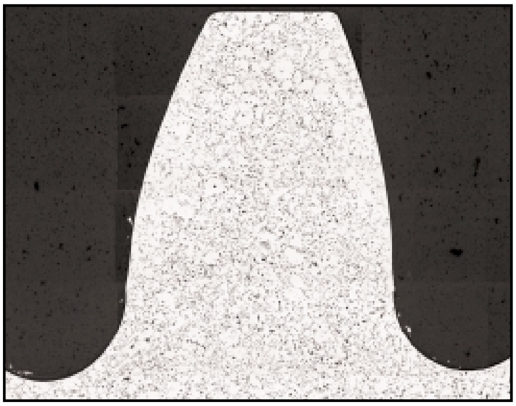

Figure 8—Photomicrograph of rolled densified helical gear tooth taken through crowned section.

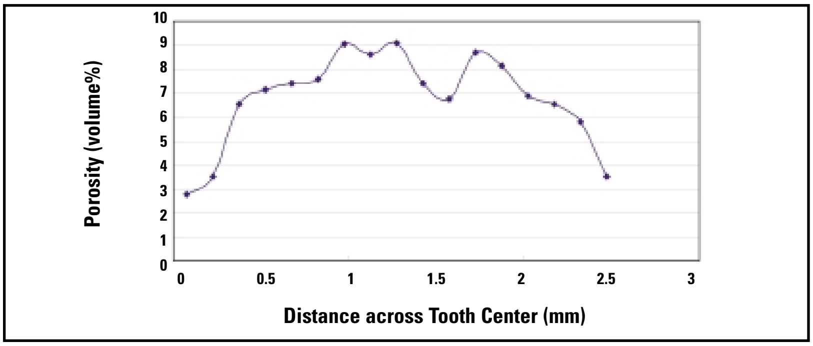

Figure 9—Density gradient of rolled densified helical gear tooth measured at crowned region.

mum of 0.38 mm to greater than 0.70 mm.

Figure 5 presents metallographic analysis of the porosity distribution for cylindrical test specimens that were densified via surface rolling to two distinct depths. Near full density was achieved at subsurface distances up to 0.75 mm (0.030 in.). Beyond the densified layer, the porosity level increases to the level of the as-sintered component.

The data shown in Figure 5 demonstrate the versatility of the rolling process in producing densified layers as well as the ability to densify to specific depths depending upon the requirements of the final application. This densified layer produces improvements in the rolling contact fatigue results as shown by Sanderow (Ref. 13).

In addition to the benefits of improved rolling contact fatigue, the surface densification has the added benefit of improved gear geometry and the possibility of incorporating crowning on the surface of the gear.

Production of Surface Densified Gears

This section of the paper will describe the actual production of a surface densified helical gear shown in Figure 4. The intent of this section is to outline the steps necessary to achieve surface densification and the resultant gear geometries and densification profile.

Machining. P/M is often considered a net shape process that requires little or no machining. However, machining is sometimes required to incorporate undercuts, cross-holes, etc. Machining is also used to improve the dimensional accuracy of some P/M components. Machining of P/M gears, unlike their wrought steel counterparts, is limited to the inside diameter. The benefits from this single machining operation are: precise inside diameter tolerances and near perfect alignment of the gear teeth to the central axis of the gear.

Gear rolling. As briefly described earlier, another potential operation for the enhancement of gear geometry, as well as tooth fatigue endurance is gear rolling. With the incorporation of a specifically engineered rolling process, one has the ability to achieve optimum tooth alignment while surface densifying the gear teeth to depths in excess of 0.7 mm. An additional benefit of this operation is a "mirror-like" surface finish achieved on the tooth flanks, resulting in a much quieter running gear, which is critical in satisfying ever-increasing NVH requirements among our customer base.

Shown as Figures 6 and 7 are the gear traces evaluating gear tooth lead error and involute profile. Beyond the necessity to densify the surface and improve gear quality, another challenge presented by this application is the requirement of a "crown" central within the face width of the gear (shown in the lead traces) along with a peak involute at the pitch diameter of the gear (shown in the involute traces).

First, looking at the lead traces (Figure 6), notice that the start and stop points of the trace are at the same level, while there is a positive crown in the middle of the trace. Typically with P/M gears, we would see a hollow in the central region of the face width of the tooth caused by the low dense region at or about the middle of the gear's face width.

We call this the "density dip" effect. The compaction of a high density gear preform with uniform density top to bottom, minimized this "density dip." Thus in combination with a specifically engineered rolling process, a 0.01 mm crown was created on both gear flanks.

The involute profile of the gear, or the "tooth shape," is a function of not only the rolling operation, but also the as-pressed tooth shape. To yield a specific involute profile, one must utilize more of a systems approach. Note on the involute traces that the peak positive involute is at the theoretical pitch line of the gear.

In addition to the dimensional and surface finish benefits realized by rolling, surface densification can also occur. Typically, where required, gear tooth flanks are densified to a depth of 0.3–0.7 mm. The primary benefits of this surface densification are increased fatigue life by inducing compressive stresses on the tooth surfaces and wear resistance.

Shown in Figure 8 is the photomicrograph of the surface densified helical pinion. The gear was sectioned at a 22° angle to the vertical to show the uniformity of densification on the leading and trailing sides of the gear tooth.

Figure 9 shows the depth of densification on the gear. This first attempt at densifying the helical pinion produced a less dense case than what was developed on the toroidal test samples. The reasoning for the more porous case is simple: The rolling conditions were not optimized. Prior experience at Capstan Atlantic has produced densified layers in gears equivalent to the test samples (data shown in Fig. 5). What made this particular effort more challenging was incorporating the crowing on the gears. Capstan Atlantic had not attempted to roll a P/M gear with a crown prior to this effort; thus the deformation behavior is not completely understood.

Additional trials with rolling this gear form are certain to produce the desired densified layer and form detail.

Summary

The sintered density distribution within a P/M component is paramount to obtaining good mechanical property performance. Described in this paper is a new parts-making process utilizing a unique binder/lubricant system (AncorMax D) that enables the production of high-density P/M parts through a combination of moderate die temperature 65°C (145°F) plus higher compaction pressures.

It was demonstrated that sintered densities up to 7.4 g/cm^3 are possible using laboratory test samples of an FLN2-4405 material. In addition to the high density, it was demonstrated that the density uniformity from top to bottom and around the circumference is quite consistent.

The laboratory testing was extended to the prototype production of a helical gear with a 22° helix angle. As observed in the laboratory production of test samples, the AncorMax D showed a similar density improvement in the helical gear of 0.05–0.10 g/cm^3 greater compared to a standard premix of FLN2-4405. The prototype production of the AncorMax D premix had reduced part-to-part weight variability, resulting in reduced finished part variability.

Beyond the development of the new binder/lubricant system, surface densification is a manufacturing technology capable of producing full density on the surface of the gear with full densification ranging from a minimum of 0.38 mm (0.015 in.) to a maximum of 0.70 mm (0.028 in.).

This surface densification creates a composite component giving the benefits of pore-free density in the critically stressed case region of the part with ~95% density in the core to provide for the required core properties. In addition to the densified case structure, the surface finish of the rolled part is better than that of a ground finish.

The processing route proposed for the high performance helical gear is as follows:

- Compact to 7.3+ g/cm^3 density using the AncorMax D processing,
- Sinter,
- Machine bore for concentricity (if necessary),

This paper was presented under the title "Powder Metallurgy of High Density Helical Gears" at the 2003 International Conference on Powder Metallurgy & Particulate Materials, held June 8–12, 2003, in Las Vegas, Nevada, and was published in the conference's proceedings, *Advances in Powder Metallurgy & Particulate Materials.* The paper is republished here with permission from the conference's sponsor, the Metal Powder Industries Federation.

- Surface densify up to 0.70 mm (0.028 in.),
- Carburize, and
- Finish machine as required.

This processing offers the mechanical properties of a high-density part, the surface fatigue resistance of a wrought part, and potentially the low cost inherent to P/M processing.

Surface densification gives the following advantages:

- Pore-free tooth surface,
- Excellent ("mirror-like") surface finish,
- Increased wear resistance,
- Reduced noise,
- Improved corrosion resistance,
- Minimal tooth-to-tooth & total composite error,
- Redirects helix angle to improve gear tooth lead while incorporating a tooth crown,
- Customized tooth profile, and
- Improved fatigue endurance.

It is worth noting that the carburizing step develops a hard wear resistant surface layer plus produces desirable surface compressive stresses that give enhanced bending fatigue characteristics. Increases in the survival limit of rotating bending fatigue samples are on the order of 15–20%. Additionally, carburizing gives a desirable acicular martensitic microstructure in the case region (Ref. 13). The synergistic effect of surface densification and carburizing offers the end-user the potential for wrought steel gear performance with the low cost inherent with P/M processing.

Finally, and perhaps most significantly, surface densification has the added benefit of producing a part with high dimensional precision. Lead and involute gear checking of the as-rolled gear shows that the gear error is equivalent to a conventionally machined wrought steel gear.

Additionally, the roll densification process was able to produce a crown on the gear that further enhances the NVH performance of the gear. Gear crowning is impossible to achieve through P/M part compaction, but this feature—and its consistency—can be produced as a direct consequence of the uniformity of sintered density throughout the part and of the expert engineering of the rolling process.

Additional experimental work is required to produce the helical gear with the depth of densification achieved in the test samples. However, significant progress was made in the potential production of this component via P/M processing. The next steps include:

- Densifying the gears to 0.030 in. (0.70 mm),
- Carburizing the part to measure the potential distortion during heat treatment,
- Simulated gear testing to verify the performance of the proposed processing, and
- Actual gear testing of the finished gears to qualify the process. ⚙

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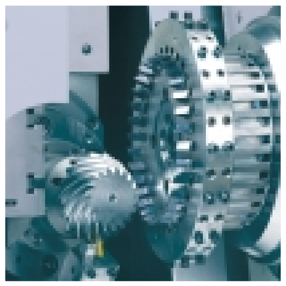
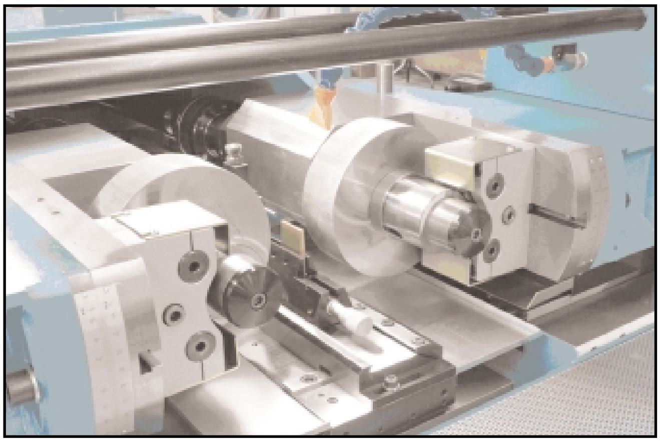


Hirings, Promotions & Acquisitions



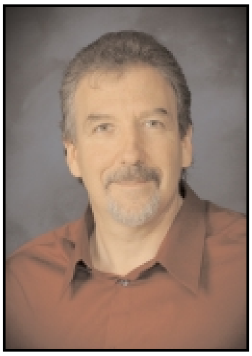
Leistritz Buys Rolling Machine Division

Leistritz Produktionstechnik GmbH of Nuernberg, Germany, has acquired the rolling machine division of Revue Thommen AG of Tenniken, Switzerland.

According to the company's press release, design and manufacture of the rolling machines will remain with Thommen's engineers in Switzerland, with managerial control in Nuernberg. Sales and service will operate out of Leistritz's existing Allendale, NJ, facility. The new entity will be called Leistritz Thommen GmbH. With the addition of these machines, Leistritz now offers whirling, keyseating, end facing and rolling capabilities.

Suitable applications for the two companies include the production of threads, worms, screws, knurls and splines.

New Managers at M&M Precision



Mark Cowan

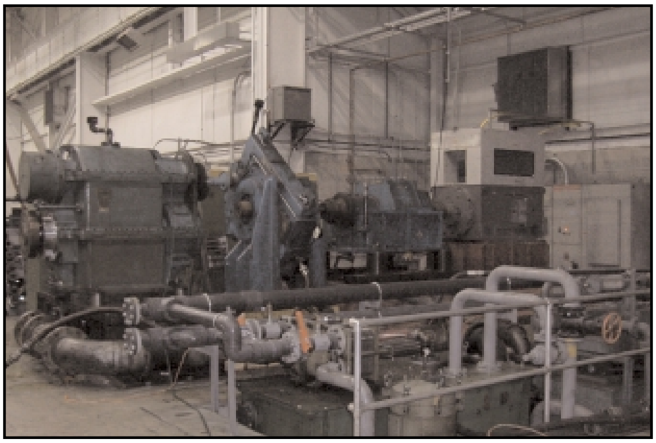
Mark Cowan and John Zahora joined M&M Precision Systems Corp. of West Carrollton, OH, in management positions.

According to the company's press release, the two are both re-joining M&M with decades of gear experience.

John Zahora

Cowan, now manager of software development, has worked at Mahr GmbH, ZF of Batavia, OH, and Process Equipment of Tipp City, OH.

Zahora, whose new title is business unit manager of the special machines division, has more than 20 years of experience in lean manufacturing and product improvement. He previously worked at Process Equipment.



Philadelphia Gear Acquires New Test Stand

Philadelphia Gear Corp. announced the availability of a new 1,500 hp test stand at its Eastern Regional Service Center in New Castle, DE.

According to the company's press release, this acquisition extends Philly Gear's diagnostic testing capabilities for high speed and high torque gearboxes to the East Coast. A similar test stand is in place in the company's Lynwood, CA, facility.

The test stand is powered by Philly Gear's own hydroviscous clutch in order to run qualification testing on repaired gearboxes prior to reinstalling the units. It provides no-load testing of gearboxes up to 60,000 hp and speeds up to 120% of the tested gearbox speed as rated by the American Petroleum Institute.

In addition, it can facilitate better repair and maintenance service at the Philly Gear locations because the company can now spin larger gearboxes at higher speeds.

Paulo Products Receives 2nd NADCAP Accreditation

The Kansas City, MO, facility of Paulo Products Co. joins another of the company's divisions—American Brazing of Willoughby, OH—in receiving its NADCAP accreditation.

Paulo Kansas City now conforms to NADCAP heat treatment standards in large continuous belt equipment as well as atmosphere batch and vacuum equipment.This should further help serve the aerospace, defense and other markets, according to the company's press release.

Paulo Products provides engineering solutions in heat treating, brazing and metal finishing, and specializes in vacuum, batch, induction and large continuous belt treatment.

United Gear Installs New Inspection Equipment

United Gear & Inspection has installed a new M&M Precision gear inspection machine to double its inspection capacity.

According to the company's press release, this equipment provides the latest technology in dimensional checking for pitch, helix angle and profiles with 3- and 4-axis pitch capabilities. It allows for discrete checking for various gear types and a wide range of quality control processes for profiles, leads and involutes of gears.

The company hopes this will help in its project to attain TS-16949 certification, according to their press release.

New Sales Reps for Philadelphia Gear

Ron Wilson

Ron Wilson, Mark Voelkel and Rick Wilson were appointed as sales reps at Philadelphia Gear Corp. for the Southwest, Gulf Coast, and Western service territories, respectively.

Mark Voelkel

Ron Wilson, a veteran sales engineer, was most recently with Rexnord/Prager Gear. His new responsibilities include developing and servicing accounts in the Houston area.

Mark Voelkel has more than 20 years of experience in gear sales, most recently as an account manager for Revak Turbomachinery, in the southeastern U.S. His new territories include southern Mississippi, Georgia, Alabama and Florida.

Rick Wilson

Rick Wilson will be responsible for accounts in the following areas: Arizona, New Mexico, and southern Nevada. He has been in sales for 10 years, with his most recent position having been manager of Applied Industrial Technologies.

Schleifring Acquires Walter Grinders

Körber Schleifring GmbH will acquire the machinery sector of Walter AG, which will now be known as Walter Maschinenbau GmbH, as long as antitrust approval goes through.

According to the company's press release, it has also acquired Czech Republic-based Walter Kurim s.r.o., U.S.-based Walter Grinders, and Walter Japan KK. This latest acquisition will enable Schleifring to expand its range of services.

Schleifring-owned companies operate independently in their respective business sectors. Walter Maschinenbau GmbH will retain its sites in Tübingen, Hanover, Kurin (Czech Republic) and Fredericksburg, VA (U.S.)

Penna Flame Hires Mark Farley

Mark Farley

Mark Farley was hired as a manager of induction services at Penna Flame.

Farley has 18 years of experience in contoured gear tooth hardening and induction hardening and has lectured for the Society of Manufacturing Engineers on the topics.

Penna Flame Industries of Pittsburgh, PA, provides flame hardening and roll manufacturing services.

Phillips Accepts VP Position at Gleason

Bob Phillips

Bob Phillips was appointed senior vice president of the tooling products group at Gleason Corp.

Prior to this assignment, he served as vice president of engineering at Gleason since 1999. Phillips has held engineering and management positions at the Barber-Coleman Co. and also at Pfauter-Maag Cutting Tools.

According to the company's press release, his new responsibilities include leadership of the engineering department and manufacture and sale of Gleason tooling products worldwide.

In addition, he will lead a global organization with a single focus on tooling products and driven by implementation of lean manufacturing principles.

Recent Appointments at Inductoheat

John Hooper was named vice president of operations for Inductoheat, an Inductotherm company located in Madison Heights, MI.

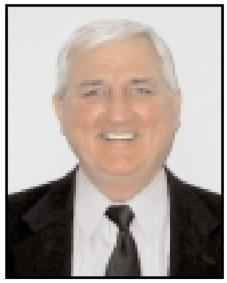
The company also announced Laurie Taylor's promotion to director of customer relations.

According to the company's press release, Hooper was for-

Laurie Taylor

merly president of Radyne Corp. in Milwaukee, WI, and managing director of Inductoheat Europe. Among his new responsibilities will be ensuring that shipments leave on time and meet customer expectations. Hooper has worked for Inductotherm for the past 30 years.

Taylor has also worked for Inductotherm Group for 15 years, most recently as advertising director for the group. She will now be responsible for finding solutions to customer issues.



John Hooper

Inductoheat designs and manufactures induction heating equipment.

Precision Parts Acquires Precision Gear

Precision Parts International acquired Precision Gear, a manufacturer of high precision gearing for specialty aviation applications, on August 23.

Precision Gear is the third company acquired by Precision Parts, and the latter plans to continue adding companies to its list, says CEO Mike Bryant. “We’re looking for the next acquisition to take place within the next six months and the rest over the course of five to seven years,” he says.

In addition to its current facilities in Ohio, Indiana and South Carolina, Precision Parts would like to buy companies in Europe and the Pacific due to increasing customer demand.

Eventually, the Precision Parts divisions will be split 50/50 between automotive and non-automotive companies, Bryant says. Currently, the divide is about 80/20.

Among other changes in the service will be a greater emphasis on design and assembly work.

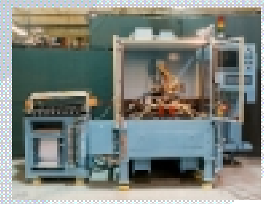
“OEMs are forcing more supply base consolidation and suppliers who will provide a higher level of product design,” he says.

Bryant was appointed CEO of the $200 million Precision Parts Co. Prior to this appointment, he was president of GenCorp.’s GDX automotive division.

In addition, Michael Niemiec was appointed CFO. Previously, he was vice president of operations and strategic initatives at TRW Automotive.

Mahindra & Mahindra to Acquire SAR Auto Parts

Indian conglomerate Mahindra & Mahindra is in the final rounds of negotiations to acquire SAR Auto Products, a Rajkot, India-based manufacurer of gears and transmission components for tractors and other off-highway equipment.



High Speed Automatic Functional Tester

Precision Checking Heads

SAR Auto manufactures more than 100,000 gears a month and is currently a supplier to Mahindra & Mahindra, as well as other major tractor manufacturers.

Pyromaitre Announces Indian Joint Venture

Pyromaitre, a Canadian manufacturer of high speed metal stress relieving equipment, has announced a joint venture with Hightemp Furnaces Ltd. of India.

The joint venture will take up the manufacture of Pyromaitre stress relieving furnaces for the first time in India, according to company reports.

Pyromaitre stress relieving equipment is used for high-speed stress-relief of critical components such as gears, CV joints and springs.

Equity Firm Acquires Majority of VCST

Fox Paine & Co. LLC, a San Francisco-based private equity firm, has acquired a majority stake in VCST Industrial Products N.V., a Belgium-based automotive company that also owns VCST Powertrain (formerly Reef Gear), located in Detroit, MI.

Belgian investment firm Navas Investments B.V. holds a minority stake in VCST. Members of current management are also expected to acquire a minority stake in the company, according to VCST's press release.

In a written statement, Carlo Spoors, managing director of VCST, said, "We are excited to begin our partnership with Fox Paine, who, together with VCST's management team and employees, will help VCST realize its full potential by building upon our customer relationships."

VCST Industrial Products, headquartered in Sint Truiden, Belgium, develops and produces highly engineered components for vehicles, including engine and transmission gears, transmission shafts and aluminum valve blocks.

Magna Completes Purchase of New Venture Gear

Canadian auto parts supplier Magna International Inc., based in Aurora, Ontario, has completed its acquisition of Syracuse, NY-based New Venture Gear, formerly a wholly owned subsidiary of DaimlerChrysler Corp.

The transaction involves the creation of a new joint venture, which will be known as New Venture Gear Inc. The new company will be owned 80% by Magna and 20% by DaimlerChrysler. The agreement has Magna scheduled to acquire the remaining portion from DaimlerChrysler in 2007.

The transaction includes New Venture Gear's manufacturing facility in Syracuse, NY, its R&D center and sales offices in Troy, MI, and a manufacturing facility in Roitzsch, Germany.

In a press release, Frank Stronach, Magna's chairman and interim CEO, said, "We are pleased to complete this important transaction and welcome more than 3,800 new employees, including more than 3,500 in Syracuse, New York, to the Magna family. We also appreciate the cooperation we received from local and state officials in New York. With a strong manufacturing and development presence in Syracuse and in Europe, excellent technologies and a skilled and motivated workforce, we have a strong base on which to grow our drivetrain business in the coming years."

Magna has approximately 81,000 employees in 217 manufacturing operations and 49 product development and engineering centers in 22 countries.

GE To Supply Canada With 660 New Wind Turbines

GE Energy has been selected to supply up to 660 wind turbines, totaling 990 megawatts of wind-generated electricity, for eight projects in Quebec to be placed online from 2006–2012, according to a company release.

According to Hydro-Quebec, the agency responsible for the project, the new contracts represent the largest single award for new wind generation capacity in the history of the global wind energy industry.

The new turbines are the result of Quebec government decrees requiring the installation of at least 1,000 megawatts of additional wind capacity by 2012. Quebec currently has 113 megawatts of wind capacity.

GE Energy will supply the wind turbines to Cartier Wind Energy and Northland Power Inc./Northland Power Income Fund, the contractors who won the bids for the turbine projects.

Power Transmission Association Releases Purchasing Report

The latest report from the Power Transmission Distributors Association (PTDA) claims that U.S. and Canadian end-users consider product quality/reliability to be among the most important factors in their purchasing decisions.

American end-users participated in a study conducted by the Reed Research Group. Canadian surveys were conducted through *Plant* magazine.

According to Reed's press release, on-time delivery was considered the most important factor in choosing between power transmission vendors in the U.S.

Product knowledge and follow-through were also rated highly. Among U.S. buyers, 47% based decisions on price. The same held true for 50% of Canadian buyers.

Other results are available for purchase by end-users in the U.S. for $49.95 to PTDA members and $349 to non-members. Canadian results are available only to PTDA members for free by visiting *www.ptda.org*.

Sypris Closes on Dana Plant Purchase

Sypris Solutions announced the completion of its purchase of Dana Corp.'s manufacturing campus in in Toluca, Mexico.

Sypris and Dana have an 8-year supply agreement that entails furnishing Dana with a wide range of drivetrain components. According to Sypris' press release, the outsourcing agreement will take place in phases over the next few years and will cover approximately $500 million in business.

Initial shipments will begin immediately from Toluca with the components to be incorporated into the steel and drive train assemblies for sale.

Dana Corp.'s manufacturing site in Toluca includes four buildings that have been leased back to Dana for use in certain manufacturing and final assembly operations.

The plant currently supplies the heavy vehicle technologies and systems group of Dana with forged and machined components, axle shafts, knuckles, ring gears, steel arms and input shafts.

The price tag was approximated at $15.6 million, including inventory. In addition, 460 people will be transferred to Sypris as a part of the transaction.

Executive Promotions at Hawk

Steven J. Campbell was promoted to senior vice president at Hawk Corp. and president of the company's performance racing segment.

According to the Hawk's press release, Campbell has worked for 20 years on various sales, marketing, strategic planning and international expansion projects. He joined Hawk in 2000 as president of the company's Wellman Products Group, a role he will continue in his new position.

The Wellman Group also appointed Thomas Jaros vice president and general manager of Wellman's original equipment business, Stuart Weitzman vice president of aftermarket services, Giovanni Paolo Nani managing director of Europe, Albert Chong vice president of business development and sourcing in the Asia-Pacific region and David Hanson general manager in China.

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Grinders and Other Products

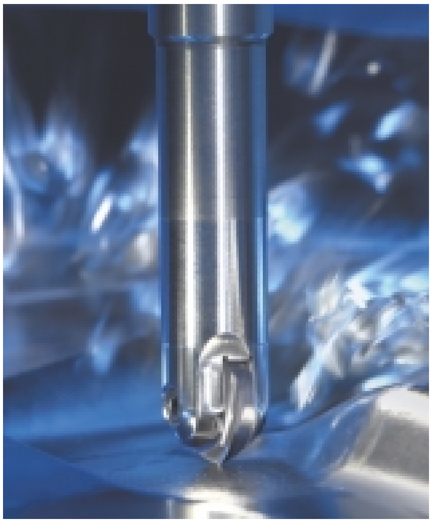
New Linear Motion Threader

The GS:TE:LM from Drake Manufacturing is a full helix thread grinder that automatically corrects wheel form for helical path interference or generates forms from standard plated wheels.

According to the company's press release, the machine can grind threads, splines, key slots, rings and other forms in a single set-up on one machine. In addition, the grinder monitors acoustical emissions to optimize the dress and grind process.

Other features include linear motors on linear ways, Drake's Smart Spindle and Smart Form technology, a polymer base and Fanuc CNC system.

For more information, contact Drake Manufacturing of Warren, OH, by telephone at (303) 847-7291.



New Ball Nose Insert from LMT-Fette

The WPR-D helical ball nose insert from LMT-Fette was designed in response to problems associated with machining complex contoured workpieces. It uses a helical cutting edge that results in the incremental entry of the cutter and reduces vibration.

According to the company's press release, these cutting edges are always under load for increased stability and further reduced vibration due to penetration.

The low and equal cutting forces enable milling operations with greater chipping depth and higher chip removal rates with less wear.

For more information, contact LMT-Fette of Cleveland, OH, by telephone at (800) 225-0852 or on the Internet at *www.lmtfette.com*.

New Grinder for Gear Cutter Blades

The SBG cutter grinder from ANCA can grind parts to +/–5 microns, and it includes a chuck and palletized auto load that is specifically designed to handle gear cutting blades.

The grinder features a 24 hp, 10,000 rpm spindle, an automatic wheel changer for 200 mm wheels, a 3,000 rpm headstock and a high-volume pick-and-place type autoloader.

According to the company's press release, the development software allows users to enter information from a remote workstation and make geometry compensations locally. Different stick geometries can be loaded into the pallet for processing.

The grinder is equipped with a patented Big Plus wheel mounting system for ultra high precision running of the grinding wheel. Complete changeover time of the wheel pack, coolant system, workholding collet and pallet is less than three minutes.

For more information, contact ANCA of Farmington Hills, MI, by telephone at (248) 477-5588.

New Right Angle Gearhead from Alpha Gear

The new HG right angle gearhead from alpha gear drivers Inc. can achieve an efficiency greater than 96% with a backlash of 4 arc-minutes, according to the company's press release. Other features include a ratio of *i* = 3–10 and an acceleration torque of 20–640 Nm.

The HG is designed for compact servomotor applications, such as packaging and converting machinery, handling and gantry robots and flatbed machinery. Available in five sizes, it can mount to servomotors using a universal system.

For more information, contact alpha gear of Elk Grove Village, IL, by telephone at (847) 952-5301 or on the Internet at *www.alphagear.com*.

New Bore Gauge from Marposs

The M1Star MBG mechanical bore gauge from Marposs is designed for manual mechanical use in precision checking of I.D., ovality or taper of through bores, and blind and super blind bores.

According to the company's press release, the gauge features a mechanical measurement system that lasts for more than 10,000,000 measuring cycles and allows interfacing with any dial indicator, digital indicator or pencil probe. Its application range is 0.12–11.81" (3–300 mm).

The gauge also includes a measuring

head that allows self-retooling and reconditioning by replacing the removable nosepiece and contacts. Only one master is needed for the zero setting.

For more information, contact Marposs of Auburn Hills, MI, by telephone at (248) 370-0404.

New Advancement in Inertia Friciton Welding

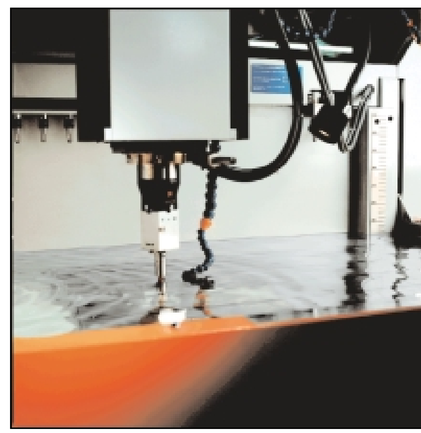
The inertia friction welding cycle from Manufacturing Technology can now orient parts using inertia or direct drive friction welding. The company is awaiting patent approval on this technology.

According to the company's press release, the overall weld cycle is shorter, and the time it takes for the spindle's deceleration from weld speed to zero is always longer in the inertia cycle. The longer adjustment period assists with accuracy.

Weld data is used to reproduce deceleration during the weld so adjustments needed to duplicate the deceleration are smaller and easier to make.

Other features are more spindle positions for the same weld, no over-specification for drives and motors, and orientational compatibility with the inertia welding process

For more information, contact Manufacturing Technology of South Bend, IN, by telephone at (574) 233-9489.



New EDM Fluid from Hangsterfer's Laboratories

The Crystal Brite EDM fluid from Hangsterfer's Laboratories was designed for use in both high and low amperage spark erosion processes.

According to the company's press release, the EDM fluid is a mixture of ultra-pure hydrocarbons with the latest synthetic technology, increasing metal removal rates by 30% due to the more efficient flushing and filtration methods. Therefore, particulates are prevented from returning to the electrode workpiece interface.

Fluids are odorless and do not contain solvent-based hydrocarbons.

For more information, contact Hangsterfer's Laboratories Inc. of Mantua, NJ, by telephone at (800) 433-

5823 or on the Internet at *www.hangsterfers.com*.

New Bearing Steels from NSK

The newest steels, "Z", "EP" and "SHX" from NSK provide spindle bearings with resistance to seizure and minimum levels of heat generation.

According to the company's press release, these steels have reduced amounts of non-metallic oxide because of the clean steel-making process.

"Z" steel is the company's standard material of manufacture for the new angular contact and cylindrical roller bearings. Bearings made from this steel have 1.8 times longer service life than conventional vacuum degreased steel, according to NSK.

The "EP" steel was made more reliable due to a new evaluation technique in which fewer large sized particles are removed than vacuum arc remelted steel or refined "Z" steel.

Lastly, the "SHX" steel integrates the operating stability and low heat generation of "Z" and "EP" steels. This steel can be used as a bearing material in motorized machine tool spindles where the possibility of bearing seizure exists.

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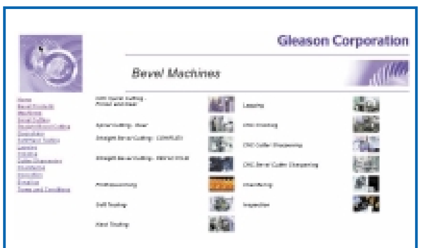

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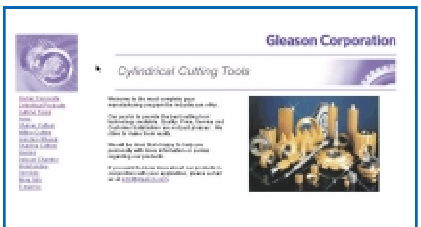

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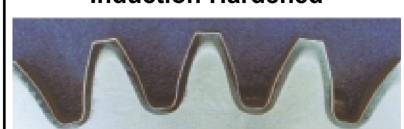

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Statement of Ownership, Management, and Circulation

1. Publication Title **GEAR TECHNOLOGY, The Journal of Gear Manufacturing**	2. Publication Number **0 7 4 3 _ 6 8 5 8**	3. Filing Date **Sept 24, 2004**
4. Issue Frequency **BI-MONTHLY**	5. Number of Issues Published Annually **6**	6. Annual Subscription Price **$ 55.00**
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1425 Lunt Ave., Elk Grove VIllage, IL 60007

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Editor *(Name and complete mailing address)*

Michael Goldstein, 1425 Lunt Ave, Elk Grove Village, IL 60007

Managing Editor *(Name and complete mailing address)*

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13. Publication Title **Gear Technology, The Journal of Gear Manufacturing**	14. Issue Date for Circulation Data Below **September/October 2004**

15. Extent and Nature of Circulation		Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies *(Net press run)*		14,968	15,277
b. Paid and/or Requested Circulation	(1) Paid/Requested Outside-County Mail Subscriptions Stated on Form 3541. *(Include advertiser's proof and exchange copies)*	8,840	8,732
	(2) Paid In-County Subscriptions Stated on Form 3541 *(Include advertiser's proof and exchange copies)*	-	-
	(3) Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Non-USPS Paid Distribution	375	386
	(4) Other Classes Mailed Through the USPS	-.	-
c. Total Paid and/or Requested Circulation *[Sum of 15b. (1), (2),(3),and (4)]*		9,361	9,118
d. Free Distribution by Mail *(Samples, compliment ary, and other free)*	(1) Outside-County as Stated on Form 3541	2,632	2,884
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e. Free Distribution Outside the Mail *(Carriers or other means)*		2,390	2,325
f. Total Free Distribution *(Sum of 15d. and 15e.)*		5,022	5,209
g. Total Distribution *(Sum of 15c. and 15f)*		14,383	14,327
h. Copies not Distributed		585	950
i. Total *(Sum of 15g. and h.)*		14,968	15,277
j. Percent Paid and/or Requested Circulation *(15c. divided by 15g. times 100)*		65 %	63.63%

16. Publication of Statement of Ownership
☐ Publication required. Will be printed in the **November/Dec 2004** issue of this publication. ☐ Publication not required.

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GEARS R US

The kid who wants to be just like his gear-loving dad when he grows up will hit the jackpot this Christmas if Santa uses *Gear Technology*'s holiday buying guide.

Plastic gears may not be in the windows at FAO Schwarz, but we know there's a market out there. Toys marketed towards kids as young as three years old are causing youngsters to think about life in the factory.

Tomy Toys has produced a game called "Gearation," which features 11 brightly colored moving gears on a plastic surface with a magnetic top.

Preschoolers on up can remove and add to the mix and watch in fascination as the gears flip or speed up with the push of a button.

Sunny days chasing the clouds away. I'm on my way using my Sesame Street Gear Creations from Fisher Price.

Gear Refrigeration Magnets are a spin-off of this game. These battery-powered gears are driven by a central gear with an on-off switch and also have the important function of affixing drawings to the fridge.

Fisher Price's Sesame Street Gear Creations lets kids build and connect gears with their favorite characters.

The Dizzy Fun Land will be a tool for any budding architects. Manufactured by Learning Resources, the motorized and molded plastic set called Gears! Gears! Gears! includes a hand-held motor, carousel, Ferris wheel, bumper cars, roller coasters and dozens of gears spinning every which way.

The Safari Express Motorized Gear Set was created for an older crowd—early grade school. This 127-piece concoction includes a motorized engine, crank-up pulley, and trainlike lights and sound effects. Five animals can ride along as passengers, and a tour guide keeps the locomotive moving—right though the warehouse district.

For the millennium-minded kid who moves faster than any train, the M Gear Aero Robot can easily be morphed into a jet. Both this and the M Gear Lunar Robot are made by Learning Resources as well. The aero robot is a blue creature whose multi-colored gear wheels keep it skimming the ground's surface. Kids can then assist its metamorphosis into a plane.

The Lunar Robot operates on the same concept but changes into an all-terrain vehicle at the whim of an 8-year-old. Combat-ready in red, this was designed to run over rough surfaces like the moon or the desert. Certainly excellent preparation for life in the third grade!

The market for gear toys obviously has been overlooked by the advertising industry. Just look at the myriad of website when you type "gear toys" into any search engine. Between wooden gear toys, interactive puzzles and whatever else pops up between now and December, this could be the easiest holiday season ever for a lot of gear industry fathers. Just don't forget—as pretty as the colors are in the Gears 'N Gizmos set—mothers would probably rather receive a little blue Tiffany's box under this year's tree!

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The Gearless Gear Shaper™

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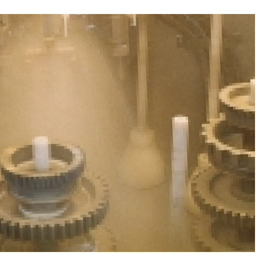
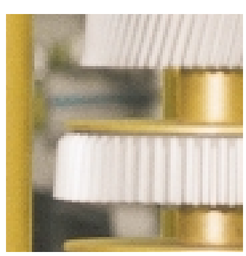
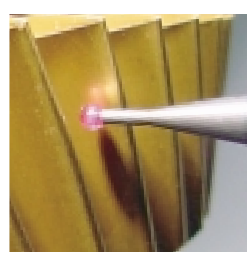
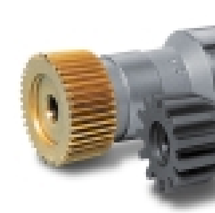
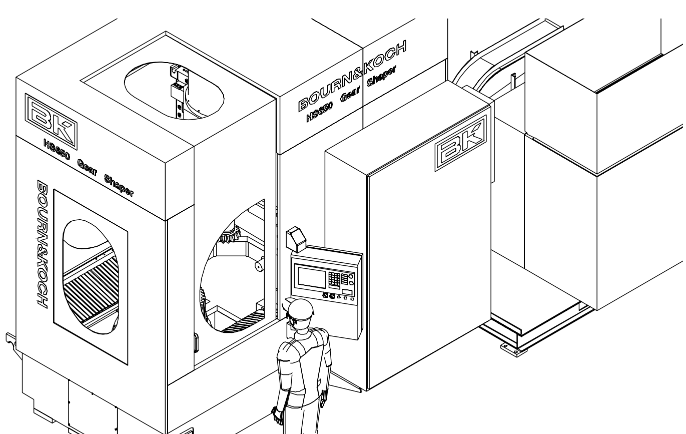
Our wide range of standard and special shaper cutters and comprehensive services will bring your cost per piece down and your production in shape.











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