GEAR TECHNOLOGY

JANUARY/FEBRUARY 2001

The Journal of Gear Manufacturing

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FOCUS ON BEVEL GEARS

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FEATURES

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The Journal of Gear Manufacturing

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2001: A (Cyber) Space Odyssey

In 1968, Stanley Kubrick released the film *2001: A Space Odyssey*, based on the story by Arthur C. Clarke. Back then, 2001 was a long way off. It was the future, a time of unknown marvels, amazing discoveries and technological achievements. Now we're in 2001. But while Clarke's and Kubrick's visions of 2001 took place in *outer* space, what captures my imagination this year is *cyber*space.

I'd like to share my enthusiasm for the power and potential of the Internet. I've noticed that many gear company owners and managers are apprehensive about the Internet's effects on their businesses. Will the Internet collapse their market? Is business-to-business online purchasing the way to go, or is it going to put them out of business? Like the famous monoliths in *2001*, the Internet can be a source of confusion, mystery and anxiety.

One reason the Internet causes confusion is that it's constantly changing, being reinvented and improved, but that continual rebirth is actually one of the Internet's strengths. Once you discover the Internet's potential, the confusion and anxiety give way to an understanding and appreciation of its power and benefits.

I've been astonished over the years by the growth in traffic on our two Websites. Back in 1996, when we launched ***The Gear Industry Home Page***™, the Website received 3,000 page requests in its first month. Today, the two Websites together receive nearly 200,000 page requests per month. Something seems to be working, and many of you have told us that you're finding these Websites to be among the fastest and easiest that you've used and that you can quickly find what you want.

Also, as the Internet evolves, Websites are able to provide richer, more complex and more useful information. In fact, on page 41 of this issue, you can read about some companies that developed technology to allow their customers to design gears or receive training on the Internet with nothing more than a Web browser. We're also starting to see more and more use of multimedia, including audio and video.

Some of our advertisers will be using video this year as part of the upcoming *Show Central* on ***The Gear Industry Home Page***™. As in 1999, we will transform the real Gear Expo into an electronic expo. *Show Central* will be a meeting place where you'll be able not only to read about the show, but also to see and hear some products in action. If you plan to exhibit at Gear Expo in Detroit, *Show Central* is a great opportunity to demonstrate your products and services with video and sound to gear industry buyers not able to attend the real expo. Look for *Show Central*'s launch in May.

But *Show Central* and videos are only part of the Internet picture. One of the most valuable aspects of the Internet is its interactivity, which has allowed *Gear Technology* to create two successful Websites—focused places for buyers and sellers of gear equipment and power transmission products to meet, gather information and exchange ideas.

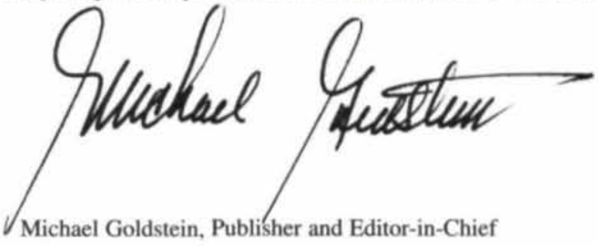
Visitors come every day to ***powertransmission.com***™ searching for manufacturers of gears and other power transmission components, such as motors, bearings and speed reducers, or to ***The Gear Industry Home Page***™ to find the suppliers of gear machine tools, gear cutting tools, inspection equipment, workholding devices and gear manufacturing services. With a few clicks, they can narrow their search based on product type and specification and easily send an e-mail message to all the suppliers that interest them. The visitor often receives responses from those companies in minutes or hours instead of days, weeks or months.

We've built the Websites on a model that tries to connect the buyers and sellers of gear-related products without getting in their way. Many industrial Websites offer services such as auctions and electronic commerce. While those other models may work for some industries, the time is just not right for ours. The products that most of you buy and sell are highly engineered, and customers often have to visit their potential suppliers' facilities and research the products before placing an order. Today, the Internet's best use is as a facilitator, bringing together someone who has a need with potential suppliers.

The Internet's power grows daily, its potential is nearly limitless, and it will continue to evolve. As the Internet changes, we'll be able to conduct more and more of our business online.

Visit our Websites to see how you can use this medium to contact suppliers and find potential suppliers of the products and services you buy. See how other companies are using the technology to communicate with their customers and potential customers. See which of your competitors are already there, reaching the customers who buy your products. Can you afford not to be there?

However you fit into the gear industry, we've created a place in cyberspace for you in 2001 as visitor, advertiser or both.



Michael Goldstein, Publisher and Editor-in-Chief

Large Ultrasonic Unit Makes a Big Splash in Immersion Inspection

Oceangoing ships, power plants and steel mills use large, powerful gearboxes—up to 100,000 horsepower. To make the gearboxes' pinions and shafts, a gear manufacturer may start with bar stock and stepped steel forgings up to 160 inches in length and 18,000 pounds in weight. Also, the bar stock may be up to 22 inches in diameter and the forgings up to 40 inches in diameter.

To make the gearboxes, the company machines the forgings and bar stock with keyways, holes, teeth or other features. But, before it can do that, the company has to inspect the parts for defects.

Lufkin Industries' new immersion ultrasonic inspection unit can handle bar stock and stepped steel forgings up to 160 inches in length and 18,000 pounds in weight. The bar stock also can be up to 22 inches in diameter and the forgings up to 40 inches in diameter.

"The big investment in machining is about to take place," says Walter Wozniak, president of Innovative Test Systems Inc. of Baton Rouge, LA. "You want to find any defects in the forging before you begin the expensive final machining."

Lufkin Industries builds large, powerful gearboxes. Until recently, it inspected its forgings and bar stock manually, with a hand-held transducer probe. But, Lufkin now has a new device to inspect its parts—an ultrasonic inspection unit capable of handling parts up to 40 inches in diameter, 204 inches in length and 18,000 pounds in weight.

Specially made for Lufkin, the unit is the first one of its size built by Innovative Test. Such large units can also be specially built by other companies, like Matec Instrument Companies Inc. of Northborough, MA, and Panametrics Inc. of Waltham, MA.

The unit consists of a scanner, tank and material-handling equipment. Parts are lowered into the water-filled tank and are laid on the material-handling equipment.

The tank's inside is 214 inches long, 55.5 inches wide, and 40 inches tall. It can hold about 2,000 gallons of water. Lufkin fills the tank with about 1,500 gallons, which reaches about 29 inches up the tank's walls. The remaining space is for the parts, which displace water inside the tank.

In the water, a stepped steel forging lays on the unit's material-handling equipment. The tank's inside is 214 inches long, 55.5 inches wide, and 40 inches tall and can hold about 2,000 gallons of water.

Welcome to* Revolutions*, the column that brings you the latest, most up-to-date and easy-to-read information about the people and technology of the gear industry.* Revolutions *welcomes your submissions. Please send them to* Gear Technology*, P.O. Box 1426, Elk Grove Village, IL 60009, fax (847) 437-6618 or e-mail* people@geartechnology.com. *If you'd like more information about any of the articles that appear, please circle the appropriate number on the Reader Service Card.

The scanner uses ultrasound to look for irregularities—cracks and voids—in the parts. The ultrasound signal reflects irregularities back to the unit's operator via the ultrasonic instrument display. The signal's reflected amplitude and time to return allow the operator to determine a defect's location on a part, its size, and its depth from the part's surface.

Wozniak designed the scanner and tank by scaling up one of his existing scanners and tanks. He also created the material-handling equipment himself.

The equipment uses powered, horizontal rollers to rotate parts inside the tank. According to Wozniak, the rollers' ability to handle 18,000 pounds was unusual for ultrasonic inspection units—"To me, that was what made it unique."

Wozniak explains the equipment couldn't have a fixed geometry because each Lufkin forging can have segments with different diameters and lengths.

"It had to adapt," Wozniak says of the equipment. "It's just a feature that makes it more versatile."

An operator can adjust the rollers for diameter and length and the probe for pitch and yaw. Also, the unit has four computer-controlled, motorized axes, allowing for rotation along the W axis and linear interpolation along the XYZ axes.

Using an operator pendant with a liquid crystal display screen, the operator teaches the forging's shape to the unit, calibrating the ultrasonic instrument for the thickness of each forging's different segments. The operator then pushes the "cycle start" button, and the unit takes over from there.

Delivered in September, the unit is now part of Lufkin's power transmission division, located in Lufkin, TX. The unit will be used daily once it's fully added into Lufkin's production process, replacing its old inspection method.

That method used manual contact ultrasonic testing, which was performed after final heat treatment and turning, but before the part was machined with keyways, holes, teeth or other features—inspecting a part with features would be difficult because of its irregular shape. The part was turned to have a smooth surface finish, placed in a lathe between centers and coated with oil.

The part was then rotated very slowly while an operator held a transducer probe against the part, the oil serving as the coupling between them. With the probe against the rotating part, the operator moved the probe slowly down the part's length and checked the ultrasonic-testing instrument for indications of defects.

Mark Townley, Lufkin's project coordinator for the unit, says the company got the new device to improve its inspection process. He explains that Lufkin bought several multi-tasking turning centers for the division's facility. The turning centers can take a raw forging and perform multiple operations, like turning, milling keyways and drilling holes.

But, to inspect parts, Lufkin had to either stop the turning centers after turning but before milling and drilling, or find another way to inspect parts before they were put in the turning centers.

"Of course, we didn't want to stop production," Townley says. So, they found another way: immersing the parts for ultrasonic inspection.

"The immersion inspection unit allows you to have a rougher surface finish on the part," Townley says.

Innovative Test created the unit to inspect parts that haven't yet been turned. Besides eliminating that preturning, the new unit improves on the old method in other ways:

- Inspection is automated and more efficient;
- Parts with rougher surface finishes can be inspected because immersion testing provides better coupling between part and probe than contact testing;
- The unit's automated scan stops and sounds an alarm when it finds a defect, eliminating the need for quality-assurance technicians to constantly watch the ultrasonic-testing instrument, as required in contact testing; and
- Lufkin no longer has to pre-turn parts before inspecting them because the unit

can inspect parts after heat-treating and before final turning.

The unit uses as many employees as the old method used, though it has added a step to Lufkin's production process.

During heat treating, parts can form scales on their surfaces. The unit could read those scales with pockets of trapped air as though they were defects. Lufkin now removes those scales by shot-blasting each part. The parts can then undergo immersion testing in the unit.

Still, Townley says Lufkin expects the unit to provide a faster and more thorough inspection than the old method. The company has limited experience with the unit and parts can vary widely in size, but Townley explains Lufkin expects an average-sized part would take about 30 minutes to inspect compared with about 90 minutes using the old method.

He adds that Lufkin also expects to save money through the reduced inspection time.

Circle 300

Spline Rolling Takes a New Form

Spline rolling with rack-shaped tools has long been one of the fastest and most economical methods of manufacturing splined, toothed or threaded parts, especially in high-volume industries, such as automobiles, trucks and marine and off-road vehicles.

Equipment manufacturers have recently introduced new machines in North America that may provide even more advantages in certain applications. Several manufacturers now offer vertical spline rolling machines in addition to the traditional horizontal models, and some of the machines now employ servomotors instead of hydraulics to drive the rack-shaped tools.

According to those manufacturers, the result is machines with more flexibility and programmability in smaller, more efficient packages.

Nachi Machining Technology Co. (formerly National Broach & Machine) of Macomb, MI, demonstrated its servo-driven PFM/NC vertical roll forming machine at IMTS 2000 in September. Although the servo drives are a recent addition, building vertical machines is nothing new to Nachi, which has provided them for more than 30 years.

The advantages of a vertical machine are numerous, according to Nachi. On a horizontal machine, any flex in the machine causes the upper slide to move more than the lower slide, says product manager Harvey Yera. On a vertical machine, the slides move equally, Yera says, and you get more consistency in the rolling of the part.

That consistency results in greater control over tooth-to-tooth variation in the spline, adds Nachi account manager Nick Carene.

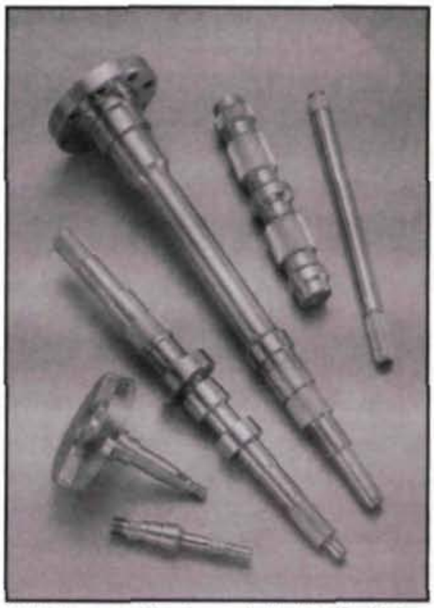
But the vertical machines' greatest advantage over horizontal machines of the same capacity may be their reduced size. "One huge advantage is floor space and cellular manufacturing," says Craig Everlove, president of Anderson-Cook Inc. of Fraser, MI. The company's newest machine is the servo-driven Marand 340V vertical spline roller.

Floor space is a primary selling point for other manufacturers as well. For example, the Nachi PFM/NC machines use 50 percent less floor space than a horizontal machine of the same capacity, says Raymond Wagner, vice president of marketing and sales for Nachi.

West Michigan Spline Inc. of Holland, MI, also manufactures vertical spline rolling machines. According to president Gary Hill, "the only advantage, in reality, is the floor space." Hill estimates that his company's vertical machines save approximately 25 percent to 30 percent of the floor space typically used by a comparable horizontal machine.

In addition to going vertical, many of the machines are going digital. Instead of the traditional hydraulic pumps, motors and cylinders to drive the motion of the rack tools, the newer machines employ electronically controlled servomotors.

Eliminating the hydraulic units reduces the size and weight of the machines even further than simply going vertical, but there are many other advantages, the manufacturers say.



Rolled parts. Courtesy of Nachi Machining Technology Co.

For example, with no hydraulic pumps or motors, the Nachi PFM/NC machines use 66 percent less energy than their hydraulically driven predecessors, Wagner says. "A byproduct is that it's also a much quieter machine. The servo-driven machines are 5-10 dB quieter than a typical hydraulic machine."

However, hydraulic machines are also getting quieter, says Hill. Today's hydraulically driven spline rollers typically operate within OSHA standards at well below 80 dB, he says.

Another advantage to the servo drives, Everlove says, is that they give the manufacturer more control over the motion of the slides that carry the rack tools. The servo drives make it easier to adjust the speed and synchronize the slides, he explains.

Yera agrees, and he points to that control as one of the main advantages of the servo drives. Although you can change the speed and force with a hydraulically driven machine, AC servo drives provide for easy programmability, Yera says. "With AC servo drives, you can vary the speed at any point in the rolling process."

The first three-quarters of the roll determines the quality of the part, Yera says. Slowing down the roll at the beginning reduces impact, minimizes oscillation and prevents slippage, which results

The PFM/NC machines from Nachi roll parts vertically (top). The machines are servo-driven (middle), and complex parts are "taught" via a handheld pendant (bottom).

in improved tooth-to-tooth spacing and composite index measurements, he adds. The programmability of the CNC machine allows the manufacturer to experiment and modify speeds to produce a better part.

In addition to the companies already mentioned, General Broach & Engineering Co. of Morenci, MI, uses servo drives on both its horizontal and vertical rolling machine models, according to the company's Website.

Because of the push toward cellular manufacturing, most of the spline rolling machine manufacturers have begun producing vertical machines, but not all have jumped on the servo drive bandwagon. Despite some apparent advantages of the new servo-driven vertical machines, some manufacturers have stuck to the traditional hydraulically driven models.

For example, West Michigan Spline manufactures vertical spline rolling machines, but their machines use hydraulics. The advantages gained by adding servo drives and CNC controls are simply not worth the price tag, says Hill.

A builder of only horizontal machines, Micromatic Textron of Holland, MI, uses servo technology for headstock positioning only. Instead of designing a completely new machine, the company has focused on improving the technology of its traditional models and finding other ways to increase productivity, says Bob O'Connor, sales manager for gear machinery. For example, O'Connor says, horizontal machines are getting longer and longer strokes, which allows the manufacturer to produce multiple splines on one part, larger diameter parts and parts with coarser pitches. While most of the vertical machines on the market have a maximum rack length of 48 inches, some of the horizontal machines allow racks as long as 60 inches or more.

Also, O'Connor says, the company is still waiting to see how well the servo-driven machines will hold up over the years. "The loads are fairly heavy in spline rolling," says O'Connor, who also suggests that some of the components needed in a servo-driven system may not hold up as well as their hydraulic counterparts. "Our concern was for the long run."

According to Hill, a user periodically will have to rebuild the hydraulic cylinders on a hydraulically driven spline roller. "If the machines are built correctly and the cylinders are lined up properly, they will last for seven to nine years," he says.

The engineers at Nachi say that their servo-driven system will hold up at least as well as a similar hydraulic system. "We know that the ball screws have a service life of at least 10 years," says Wagner.

Each type of machine has advantages and disadvantages, and both will require some kind of maintenance and refurbishing over their useful life. All the manufacturers agree that the customer should consider those issues carefully before deciding on one type of machine over another.

Despite the reservations of some manufacturers, the combination of servo drives and the vertical machine orientation seems to be a hit with customers, says Wagner. According to Wagner, Nachi has sold approximately 45 of the PFM/NC machines worldwide since the model was introduced about two years ago, with about 10 of those machines sold in the United States.

Circle 301 for Anderson-Cook Inc.
Circle 302 for General Broach & Eng. Co.
Circle 303 for Micromatic Textron
Circle 304 for Nachi Machining Technology Co.
Circle 305 for West Michigan Spline Inc.

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Suitability of High Density Powder Metal Gears for Gear Applications

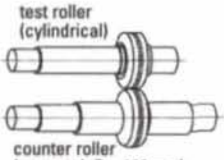
Dr.-Ing. Rainer Link and Dipl.-Ing. Gerd Kotthoff

Introduction

The implementation of powder metal (PM) components in automotive applications increases continuously, in particular for more highly loaded gear components like synchromesh mechanisms. Porosity and frequently inadequate material properties of PM materials currently rule out PM for automobile gears that are subject to high loads. By increasing the density of the sintered gears, the mechanical properties are improved. New and optimized materials designed to allow the production of high-density PM gears by single sintering may change the situation in the future.

A conventional method of attaining high component density is shrinkage during sintering. The most effective way of increasing shrinkage with sintered steels is to execute sintering in the ferrite phased (α-phase). That finding inspired the development of the QMP MSP3.5Mo material, a water-atomized, pre-alloyed steel powder with a molybdenum content of 3.5 percent. Based upon that material, two new steel powders with a molybdenum content of 4.0 percent by weight have been developed. Because of the increased molybdenum content of 0.5 percent, the sintering behavior of the material is constant during the high temperature sintering process. With these materials—QMP MSP4.0Mo and MSP4.0Mo-0.1Nb steel powder—in collaboration with QMP Metal Powders GmbH and the Laboratory for Machine Tools and Production Engineering (WZL), investigations regarding the load-carrying capacity and the suitability as future materials for sintered gears were conducted. The investigations were carried out as a part of a project sponsored by the German Federal Ministry of Education and Research (BMBF, Project No. 03N3024).

The report covers investigations concerning the macro-pitting resistance under Hertzian pressure and sliding of sintered rollers made from the new developed steel powders MSP4.0Mo and MSP4.0Mo-0.1Nb. Tests on the tooth root and tooth flank load-carrying capacities of sintered gears have been conducted on gears with a module of 3.5 mm. The influence of shot peening on the properties of sintered gears made from MSP4.0Mo and MSP4.0Mo-0.1Nb was also investigated. The results of the sintered rollers and gears are directly compared to the fatigue properties of rollers and gears made from wrought steel. The single sintered PM gears with densities between 7.5 g/cm³ and 7.7 g/cm³ can attain tooth root and flank load capacities



combination of rollers:

test roller – counter roller

V1 – Reference
V2 – Reference
Reference – Reference

Reference: 20MnCr5

		V1	V2	Reference
alloy system		MSP4.0Mo	MSP4.0Mo -0.1%Nb	20MnCr5
compacting	P_1	P_1=650 MPa		
sintering (mixed gas H_2/N_2)	t_s, S_1	t_s=30 min, S_1=1290°C		
density (g/cm³)		7.58	7.63	7.86
Young's modulus E (N/mm²)		185,000	186,000	210,000
E (N/mm²)	$\bar{E} = \frac{2E_1E_2}{E_1+E_2}$	196,700	197,200	210,000

Figure 1—Work material variants and production parameters of the test rollers.

Dr.-Ing. Rainer Link
is a mechanical engineer and is managing director of QMP Metal Powders GmbH, the German subsidiary of QMP Ltd./Canada.

Dipl.-Ing. Gerd Kotthoff
is a mechanical engineer at Aachen University of Technology in Germany. Since 1996, he has been a research assistant in the "gear research group" at the university's Laboratory for Machine Tools and Production Engineering, in the lab's manufacturing technology department. Leader of the "gear investigation" working group, Kotthoff works in the fields of sintered gears, carrying capacity and damage analysis of gears.

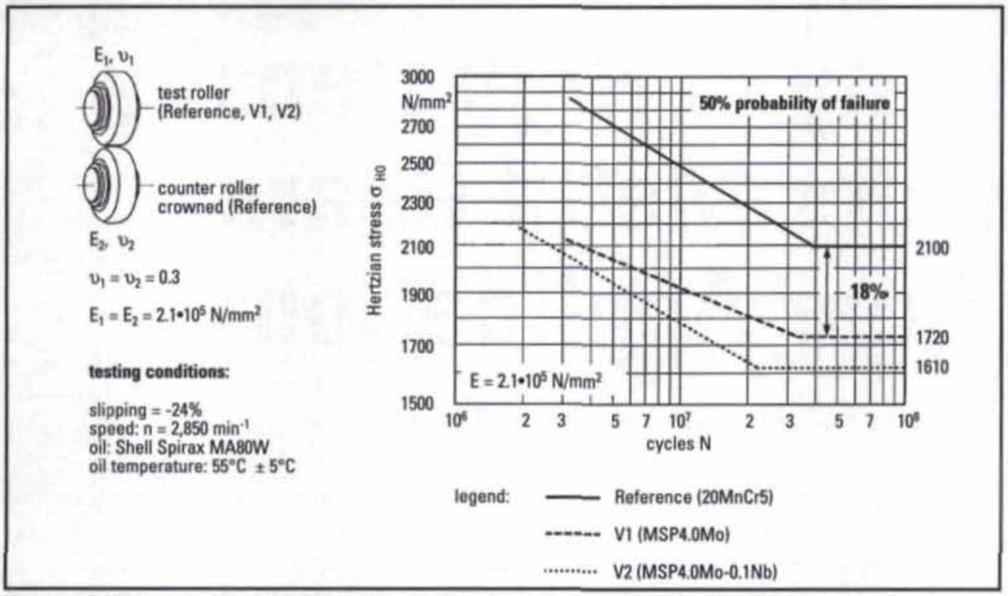


Figure 2: Rolling strength of the sintered variants as compared to the reference variant

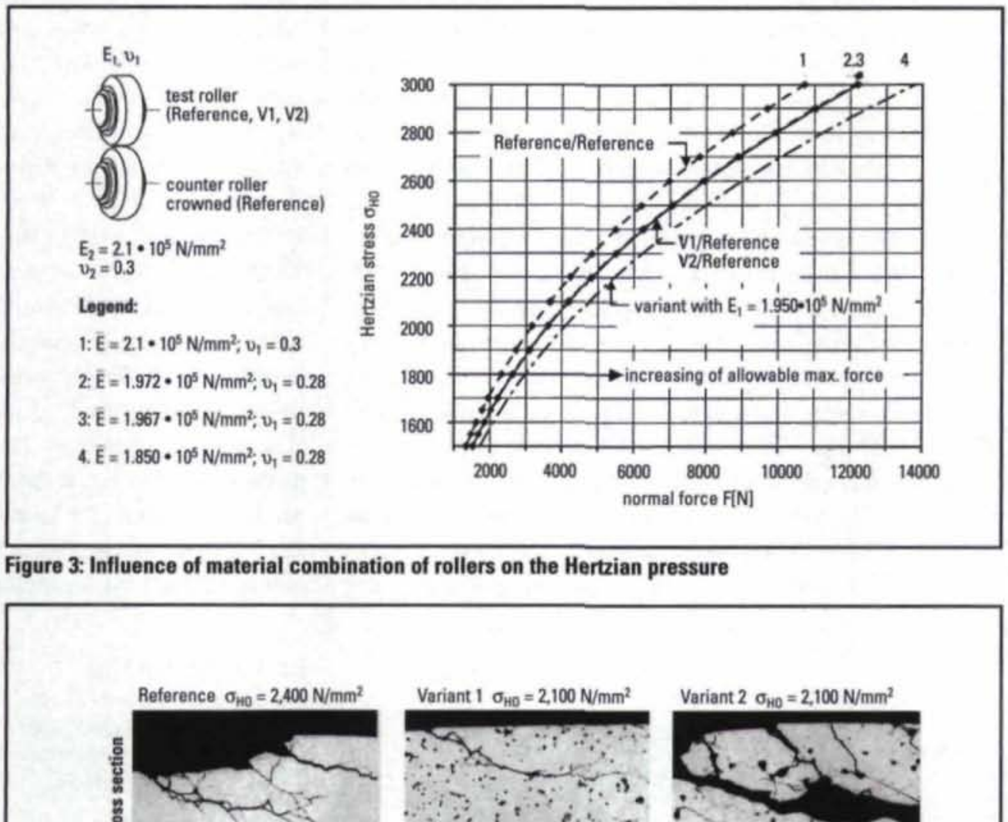


Figure 3: Influence of material combination of rollers on the Hertzian pressure

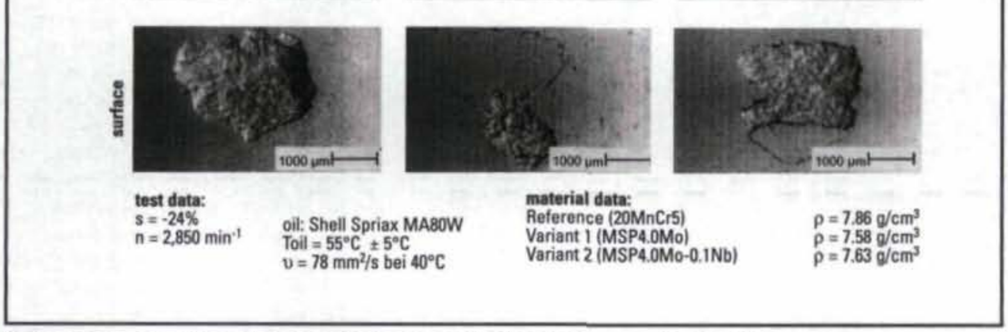


Figure 4: Cross section and surface of roll stressed rollers in the area of finite life

that are comparable to those obtained with DIN steels. Based on those results, high density PM materials could be suitable for future gear applications.

Investigation of rolling strength of sintered rollers

Material variants and geometry of rollers. Figure 1 shows the material and production parameters of the test rollers used in the WZL tests. The sintered test rollers were pressed from cylindrical circular blanks and plasma-carburized. The bores and running surfaces of the test rollers were then ground in the circumferential axis and the finished test rollers were shrunk onto steel shafts. The counter-rollers, manufactured solely from the case hardening steel ZF7B (20MnCr5) reference material, and the reference test rolls were machined as a single part and were case hardened. The sintered test pieces were pressed at $P_1 = 650$ MPa. The sintering temperature was 1290°C at a sintering time of $t_s = 30$ min. in an H_2/N_2 gas atmosphere. The density of the α-phase sintered materials is already very high, at 7.58 g/cm³ (V1) or 7.63 g/cm³ (V2). Figure 1 also shows the modulus of elasticity of the V1 and V2 sintered material variants and the mean modulus of elasticity used to calculate the Hertzian pressures encountered in the rolling tests.

Test procedure and results. The rolling strength tests on the PM rollers were conducted under typical gear conditions using a twin-disc test stand. The contacting materials in the running tests on variants 1 and 2 were a sintered cylindrical test roller and an embossed counter-roller made from the 20MnCr5 reference material (Figure 1). Two 20MnCr5 rollers were used in the reference test. Figure 2 shows the results of the roller tests.

The Hertzian pressure that can be withstood continuously by the single-sintered rollers is roughly 82 percent of the load-carrying capacity of the conventional 20MnCr5 case-hardening steel. The S/N-curves for variants V1 and V2 in Figure 2 are somewhat flatter than the reference variant, suggesting greater sensitivity to overload peaks. In Figure 2, the Hertzian pressures of the sintered variants were corrected with the aid of a standardized modulus of elasticity ($2.1 \cdot 10^5$ N/mm²) in order to achieve greater comparability of the load-carrying capacities of the various material combinations. For that correction, the diagram in Figure 3, which shows the Hertzian pressure depending on the applied normal force for different material combinations, was used.

The damage patterns for all materials in the tests were, however, approximately identical and resulted partly from the high density and homogeneous microstructure of the sintered rollers. Contrary to previous tests with rollers at densities of max. 7.2 g/cm³, in these investigations no wear at the sintered rollers occurred, and the failure mode was macropitting in all cases. As an example, Figure 4 shows the typical failure in the area of finite life for the investigated materials. The damages to the reference wrought steel and to the sintered variants V1 and V2 show similar forms of appearance. In the photos of the cross section, the cracks, starting below the surface in the area of the maximum equivalent stress, are shown. The surface shots show the macropitting at test end.

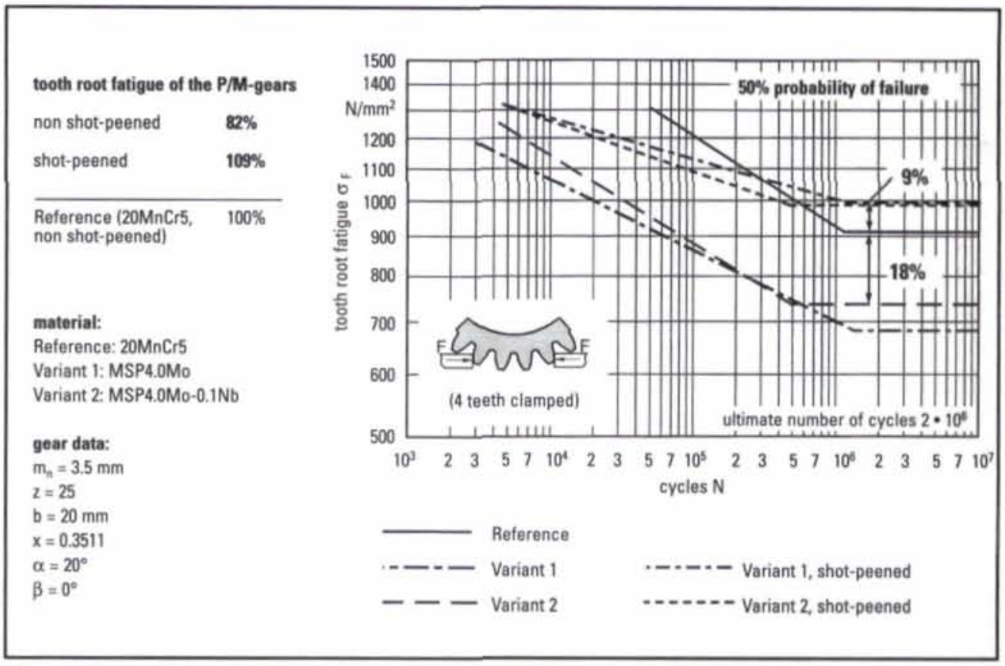


Figure 5: Tooth root load-carrying capacity of the sintered variants compared to the reference variant

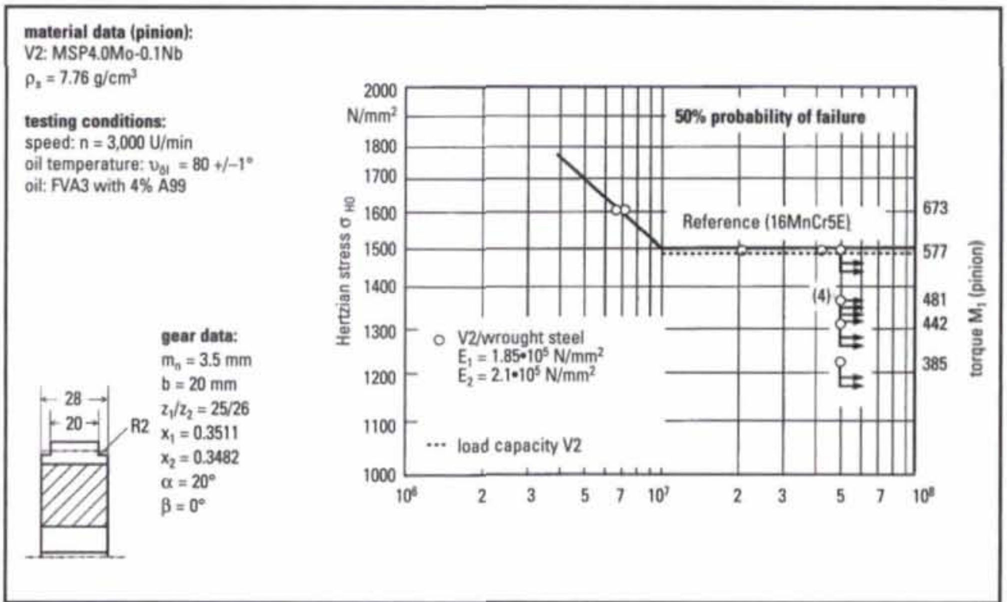


Figure 6: Tooth flank load-carrying capacity of Variant 2

Gear Tests

Additional gear tests (m_n = 3.5 mm; b = 20 mm; ß = 0°) for Quebec Metal Powders GmbH were performed using the molybdenum-containing materials listed in Figure 1 as part of the BMBF project. For reasons of time and cost, circular blanks of the sintered materials were pressed in a simple die, the gear teeth were machined and the parts were plasma-carburized and ground. The circular blanks were manufactured at a pressure of P_1 = 750 MPa. Sintering was carried out for t_s = 30 min. at 1290°C in an H_2/N_2 atmosphere. The density of the sintered rollers was ρ_1 = 7.72 g/cm³ for Variant 1 and ρ_2 = 7.76 g/cm³ for Variant 2. As in the rolling strength tests on the twin-disc test stands, S/N-curves for the case hardened 20MnCr5 reference variant and the two sintered material variants (V1 and V2) were determined in pulsator tests. Some of the sintered gears were additionally shot-peened using compressed air in order to enhance the load carrying capacity of the tooth root and likewise tested in the pulsator. To save time and cost, the load-carrying capacity of the

MEANINGS OF METALLURGICAL WORDS

compact—an object produced by the compression of metal powder, generally while confined in a die, with or without the inclusion of nonmetallic constituents.

density ratio—the ratio of the determined density of a compact to the absolute density of metal of the same composition, usually expressed as a percentage.

sintering—the bonding of adjacent surfaces of particles in a mass of metal powders or a compact, by heating.

Source: *Definitions of Metallurgical Terms*, ASM International.

***high density**—density higher than 7.5 g/cm³, which allows* higher loads compared to conventional, single sintered powders.

shrinkage—a pressed part will shrink during the sintering process, due to the bonding of the powder particles, such as the decreasing of diameter and height of a pressed circular blank.

Source: Dr.-Ing. Rainer Link, Dipl.-Ing. Gerd Kotthoff

20MnCr5 reference variant tooth root was not tested in the shot-peened state.

Figure 5 shows the S/N-curves for the conventional 20MnCr5 case-hardening steel reference variant and the V1 and V2 PM variants. The tooth root stress continuously withstood by the 20MnCr5 reference variant is approximately $\sigma_{F0} = 900$ N/mm². The equivalent value for the Variant 1 sintered gears is roughly 25 percent below that figure, at $\sigma_{F0} = 685$ N/mm². The value for Variant 2 is $\sigma_0 = 745$ N/mm², or about 18 percent below the reference variant. Shot peening increases the tooth root load-carrying capacity of the PM gears. Both PM variants achieve a continuously withstandable tooth root stress of $\sigma_{F0} = 1000$ N/mm² approximately, which is 9 percent above the tooth root load-carrying capacity of the unpeened reference variant.

Finally, load carrying capacity tests were carried out with the sintered variant V2. In the tests, the sintered test pinion was mating with a 16MnCr5 wrought steel gear, in order to investigate the sintered material V2 at the pinion. Figure 6 contains the test points already covered for variant V2, indicating the Hertzian pressure σ_{H0} and the torque M_1 applied to the pinion. The varying moduli of elasticity for the pinion ($z_1 = 25$) and the gear ($z_2 = 26$) were taken into account in calculating the Hertzian pressure. In the case of the sintered material, the modulus of elasticity determined ultrasonically on the sintered rollers ($\rho = 7.63$ g/cm³) was employed. An S/N-curve for 16MnCr5 wrought steel determined in earlier tests is also shown to indicate the comparative load-carrying capacities of sintered gears and 16MnCr5 wrought steel gears.

The results of the running tests show the slope of the S/N curve for Variant 2 is comparable with that for steel. The continuously withstandable Hertzian pressure for Variant 2 is roughly 97 percent of that for the steel material (50 percent probability of failure).

Conclusion

Innovative iron-molybdenum-based powder metallurgical materials were produced on the laboratory and production scale as part of the BMBF project on *New PM Materials.* The strength behavior of the materials was initially examined in extensive materials science test programs. Surface macropitting rolling tests and pulsator tests were then carried out at the WZL on sintered gears made with the newly-developed PM materials, in order to determine tooth-root load-carrying capacity. Rolling test results show that single-sintered, high-density PM rollers can achieve a continuously withstandable Hertzian pressure σ_{H0} representing some 82 percent of the rolling strength of the reference material. An analysis of available test roll damage patterns indicated no significant differences between damage to the high-density sintered rollers and the reference rollers. Of interest in this context is the fact that that high rolling strength was attained by single-sintered test rollers which had not been subjected to additional shot peening treatment. The tooth-root load-carrying capacity of the sintered gears was examined on gears with a module $m_n = 3.5$ mm in the unpeened and shot-peened states. The high-density PM gears attain roughly 80 percent of the load-carrying capacity of the reference gear in the unpeened state. Following additional shot peening, the tooth-root load-carrying capacity of the PM gears is 9 percent higher than that of the reference variant. Tooth-flank load-carrying capacity tests on Variant 2 (MSP4.0Mo-0.1Nb) PM gears show that fatigue strength values comparable to those for wrought steel can be expected from the high-density sintered gears.

Acknowledgment

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Robotic Automated Deburring of Aerospace Gears

Michael Nanlawala

Introduction

This report presents some interim results from an ongoing project being performed by INFAC, the Instrumented Factory for Gears. The purposes of this initial phase of the project were to demonstrate the feasibility of robotic automated deburring of aerospace gears, and to develop a research agenda for future work in that area.

Deburring of machined metal parts, such as gears, is a costly and labor-intensive process with associated quality, consistency and health risks. It is a particular problem and a major cost driver for gears that are considered aerospace- or precision-grade (AGMA Class 12 and above).

Wherever possible, gears are deburred by using simple mechanical equipment that is commercially available. However, complex gears that have specific chamfering requirements, as do precision-grade gears, must currently be deburred manually (Figure 1).

Manual deburring is not only a labor-intensive process, but it is also associated with the quality problems resulting from inconsistent manual operation; health-, safety- and environmental-related issues; and high indirect costs as a result of a high turnover of operators.

Automation of the deburring process can significantly reduce cost, improve productivity, and improve the quality and consistency of deburred edges. This situation has led to an industry-wide demand to replace manual deburring with a more efficient, reliable, and safer automated deburring system. The INFAC Robotic Automated Deburring research project was initiated to address that need. It is a joint technical effort being conducted by IIT Research Institute, United Technologies Sikorsky Aircraft, and United Technologies Research Center.

Using the robotic automated deburring system developed under the project, the INFAC team has successfully deburred a number of aerospace gears, ranging in size from 3 inches to 30 inches in diameter. The system uses commercially available, off-the-shelf hardware, including a six-axis

Fig. 1—Manual deburring is labor-intensive, inconsistent and expensive.

programmable robot, a programmable index table, various types of deburring heads, and several different types of cutters.

In addition to cost savings that, in some cases, exceeded 90 percent and substantial quality improvements, such an automated deburring system can eliminate potentially unsafe and relatively unhealthy working conditions. The system enables computer control and automation to be applied to the deburring processes, bringing it at last into the domain of computer integrated manufacturing.

Background

Machining processes, such as milling, drilling, turning, hobbing, or other gear tooth cutting operations, create burrs on the edges of metal parts when the cutting tool pushes material over an edge rather than cutting cleanly through the material. The size, shape and characteristics of the resulting burrs depend upon a number of process factors, such as tool material and its hardness, tool sharpness, tool geometry, cutting forces, ductility of the material being machined, the speed and feed of the cutting tool, and the depth of cut. A subsequent deburring operation is generally required after those machining processes to remove loose burrs from the machined edge and to apply a chamfer to remove the sharp corners. In addition to the removal of loose burrs, the deburring of the edge produces benefits, such as the removal of sharp edges, increasing the ease of assembly, prevention of edge chipping or breakage, and improvement of air flow over the edge of rotating parts. Removing sharp edges by deburring and chamfering also eliminates the possibili-

Michael Nanlawala

has more than 25 years of experience in manufacturing commercial-quality and aerospace-quality (ground tooth) gears of almost all types. He has been working as a senior engineer for IIT Research Institute for more than five years and has been actively engaged in various research projects to improve the quality and reduce the cost of manufacturing gears, primarily for aerospace applications. Nanlawala has a degree in mechanical and aerospace engineering from Illinois Institute of Technology, Chicago. He is a registered professional engineer (P.E.) in the state of Illinois. He is also a certified manufacturing engineer (CMfgE) with the Society of Manufacturing Engineers.

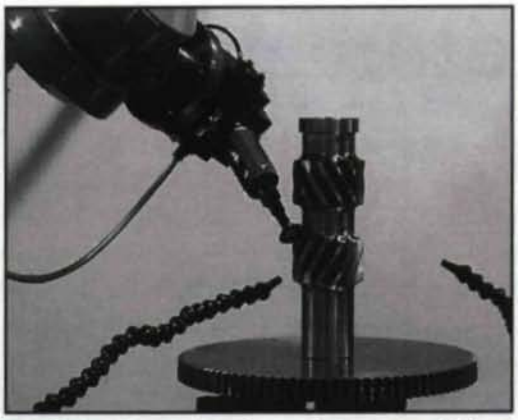

Fig. 2—The Single-Axis Compliant Head (SACH) from ABB deburring a double helical pinion.

ty of stress concentration and increases fatigue life.

Aerospace gears are usually precision ground to AGMA quality 12 to 14. For such gears, in addition to the required deburring of gear teeth, there are also very specific chamfering requirements, such as edge waviness and chamfer depth variability, surface finish, and the absence of under- or over-tempering of the deburred edges. Chamfer width must also be uniform along the entire gear tooth profile, as well as the root radius.

As mentioned earlier, wherever feasible, gears are deburred using relatively simple mechanical equipment. However, those machines lack the dexterity and the programmability that are essential to meet the specific chamfering needs of the usually complex-shaped aerospace gears. In general, such machines do a satisfactory job deburring and chamfering spur gears and helical gears with smaller helix angles, provided that the shape and size of the gear do not create an accessibility problem for the cutter, grinding wheel or grinding disc. In some cases, it is also feasible to deburr and chamfer helical gears with higher helix angles and spiral bevel gears using such mechanical equipment. However, to meet the specific chamfering requirements, the semi-chamfered gears need to be touched up manually after the automated operation. Further, secondary brushing operations are sometimes required to meet other chamfer requirements, such as edge radiusing and surface roughness. For those reasons, most aerospace gears are currently deburred and chamfered manually.

In a typical manual deburring and chamfering operation, a skilled operator removes material with a rotary file or a rotary grinding wheel or disc attached to a hand-held air driven or electrically powered tool.

Manual deburring is tedious, boring, laborious, very time consuming and thus very expensive. Manual deburring also produces inconsistent and often unsatisfactory results. Furthermore, manual deburring is ergonomically and environmentally undesirable, causing safety hazards, such as minor cuts, splinters, burns, bruises, and eye injuries. It may also cause long-term health hazards, such as arthritis, carpal tunnel syndrome, and illnesses associated with dust inhalation. Other disadvantages of manual deburring include a high rate of rework or scrap, additional inspection costs, lower productivity, high worker turnover, and high training cost to train new workers.

In a manual deburring situation, finishing operations can represent up to 20 percent of total production costs. Therefore, automating the deburring process can result in significant cost reduction, productivity improvement, and quality enhancement of deburred edges.

Robots are emerging as an economical solution to automating many types of processes. Historically, when robots were applied to less precise finishing operations like brushing, they have been shown to achieve more than a 50 percent reduction in processing times. Still, until recent improvements were developed, their accuracy has been prohibitively poor for use in the precision deburring of contoured edges. Those technological improvements include the introduction of precision robots having better than ± 0.004-inch repeatability and the development of deburring heads like the CADET (Chamfering and Deburring End of Arm Tool) and other commercially available force-controlled heads.

The strategy behind a force-controlled head is to use an industrial robot as a coarse positioning device, which carries and orients the force-controlled head to the appropriate part edge to be deburred and chamfered. Fine motion capabilities of the force-controlled head allow the tool to track edges based on force control, so that edge contours can be traversed and precise chamfer depths maintained in spite of unknown process variables including the robot's positional inaccuracies, deviations in part geometry (or contour), and fixturing errors. Force control has the added benefit with respect to gears of reducing the potential for grinding burn.

Robot Selection

Robots are available in different types and sizes. Most robots can be categorized into one of a few basic groups such as single-axis, multi-axis, SCARA (selective compliance assembly robot arms), Cartesian, cylindrical, etc. A minimum of six axes of movement is necessary to arbitrarily position and orient a tool and is therefore required to deburr the more complicated geometries of gears such as spiral bevels. The six-axis robot also makes it easier to manipulate the cutting tool to reach difficult access areas, such as narrow grooves, the very limited space between two gear faces or an adjacent shoulder and the gear face. As far as the robots are concerned, gear tooth deburring is a precision operation. Therefore, a robot selected for deburring preferably should have better than ± 0.003-inch repeatability. Furthermore, to minimize deflection, the robot arm should be more rigid than is required for most other operations. Stated another way, the end-of-arm payload capacity of the robot should be large enough that, under the weight of the end effector, deburring head, and cutting tool, the deflection of the arm will be minimal. A robot selected for the purpose of deburring should have its rated payload capacity preferably at least 50 percent higher than the maximum anticipated load at the end of the arm.

Considering the above factors, an ABB Flexible Automation robot, model No. IRB 2400/10, was selected for this study. The robot has a new S4 controller with the Rapid™ programming language. This robot's end-of-arm payload capacity is 10 kg, or approximately 22 lbs., and the reach of the arm is 59 inches.

Deburring Head Selection

While the robot itself is responsible for coarse positioning and orientation of the deburring tools, a specialized deburring head is needed to perform the actual processing. The deburring head functions much like a wrist at the end of the robot arm. The heads have either pneumatic compliance or electromagnetic force control that allows the cutter to "float" on the part edge and control the material removal rate. The head is thus able to adjust to process variations, including robot positional errors, part errors, fixturing errors and burr size to perform uniform material removal and minimize cutter loading, cutter wear and part burning.

Many deburring heads are available, and a large number were investigated. Three in particular yielded interesting results and will be discussed here. They included the Navy-developed CADET head, a single-axis compliant head (SACH) from ABB Flexible Automation, and a two-axis compliant head (TACH) from ABB. The SACH system is capable of being fitted with two different types of cylinders, one low-speed option (15,000 rpm to 40,000 rpm) and one high-speed option (45,000 rpm to 85,000 rpm). The low-speed option was used for deburring pinions, while the high-speed option was applied to gears. Another option considered early in the project was a high-speed, axially compliant device from ATI Industrial Automation. However, it was eliminated in preliminary assessments based on unacceptable surface finish and tool life.

The CADET head is not commercially available, and only a few prototypes exist. It has closed loop force control, making it easier to program since the trajectory points do not need to be as exactly specified. It also offers the best control over the material removal process because it operates in a closed force-feedback loop. The other two heads investigated are commercially available, off-the-shelf equipment and therefore less expensive to acquire, operate and maintain. The commercial heads also provide more options in cutter selection and allow operation at higher speeds than the CADET.

The CADET is a dual-axis force control head that uses a 5,000 rpm to 6,000 rpm electric spindle mounted within a force transducer assembly. The force transducer assembly is mounted within a two-axis gimbal that permits movement of the cutter tip in a direction perpendicular to the spindle axis over a 5-square centimeter work area. The gimbal is instrumented with position transducers in two axes, which enable measurement of cutter tip position. A unique dual-axis direct drive actuator, mounted above the transducer assembly and linked to the cutting process through the two-axis gimbal, provides the power for the cutting force control. The entire design is balanced gravitationally and dynamically in any orientation to minimize sensitivity to forces other than the cutting forces.

The CADET is controlled using a high-bandwidth, high-accuracy force servo loop. Fine motion capabilities of the CADET allow the cutter to track edges and control the material removal process based on force feedback, so that edge contours can be traversed and precise chamfer depths maintained in spite of process variations.

The SACH and TACH that were evaluated are produced by ABB Flexible Automation of New Berlin, Wisconsin. The range of motion for the SACH is ± 3.6°. Pneumatic grinders of the user's preference can be mounted in the head, including reciprocating filing tools or spindles of various speeds and configurations. In the present study, the SACH was fitted with various speed pneumatic spindles (15,000 rpm to 85,000 rpm) and used in conjunction with carbide cutters or grinding discs. It is shown in Figure 2. The TACH has ± 4 mm of two-axis radial pneumatic compliance and incorporates a 40,000 rpm or 85,000 rpm pneumatic grinder.

Cutting Tool Selection

The final component in the automated deburring system, after the robot and the deburring

Table 1—Process Development Findings[1]					
	2" RexCut™	1" RexCut™	1" CBN	3/16" Cylindrical Carbide Cutter	90° Conical Carbide or CBN Cutter
INFAC Spiral Bevel Pinion	SACH[2] • Uniform Chamfer • Good Surface Finish • Good Burr Removal	Limited Cutter Life	Not Tested	Not Tested	CADET • Uniform Chamfer • Rough Surface Finish • Good Blending
***INFAC LH 35°* Helical**	SACH • Uniform Chamfer • Good Surface Finish • Good Burr Removal • Blending Issues	Limited Cutter Life	Not Tested	Feature Interference	CADET • Feature Interference • Large Burr/Cutter Ratio
02035-12130-101 Double Helical (Bull Gear)	Feature Interference	Feature Interference	Feature Interference	TACH[3] • Uniform Chamfer • Good Surface Finish	Feature Interference
02035-12137-101 Double Helical Pinion (Sikorsky)	Feature Interference	SACH • Uniform Chamfer • Good Surface Finish • Good Burr Removal • Blending Issues	SACH • Uniform Chamfer • Questionable Surface Finish • Good Burr Removal • Good Cutter Life • Blending Issues	TACH • Uniform Chamfer • Good Surface Finish	Feature Interference
70351-38171-101 Spur	Not Tested	Limited Cutter Life	Not Tested	Feature Interference	ATI Turbac • Feature Interference • Rough Surface Finish • Non-uniform Chamfer
0351-08221-101 Spiral Bevel	Not tested yet. Anticipate similar success as 70358-06620-102	Limited Cutter Life	Not Tested	Feature Interference	Large Burr/ Cutter Ratio
70358-06620-102 Spiral Bevel	SACH • Uniform Chamfer • Good Surface Finish • Good Burr Removal • Limited Cutter Life	Limited Cutter Life	SACH • Uniform Chamfer • Some Cutter Loading • Some Teeth Experienced Chatter	Feature Interference	Large Burr/ Cutter Ratio

Footnotes
1. Shaded regions indicate processes that show feasibility.
2. SACH: Single-Axis Compliant Head
3. TACH: Two-Axis Compliant Head

head, is the actual cutting tool that physically removes the burrs from the gears and applies the chamfers. A variety of cutting tools were investigated, including:

• 2-inch RexCut™ disc cutter,
• 1-inch RexCut™ disc cutter,
• 1-inch CBN (cubic boron nitride) disc cutter,
• 3/16-inch cylindrical carbide cutter, and
• 90° conical cutter (carbide and CBN).

Various combinations of deburring heads and cutters were tested on several different gears, and a number of output parameters were observed. They included surface finish, chamfer uniformity, blending, cutter life, and overall quality of the process. The results and observations for those tests are summarized in Table 1. In it, each row represents one of the specific gears that were investigated. Each column represents one of the cutting tools used. Within the body of the table, for each gear/cutter combination, an assessment is listed as to whether that tool could be used with that gear or not, and if so, which head was utilized and what results were achieved. Successful combinations, demonstrating feasibility of the automated deburring process, are indicated in the table via shading.

As can be seen in Table 1, not all gear/cutter combinations proved to be successful. The cutter must access the gear tooth profile without hitting adjacent features. It must also have the required material removal capabilities and wear properties, and it must produce an acceptable surface finish. A lubricant, Aculube™, was used in most of the cutting trials. It was found to improve surface finish and extend the life of the cutter. The conclusion from this set of tests is that the cutters, more than the compliant heads that carry them, determine the success or failure of the processing procedures.

Excellent results have thus far been achieved with 0.040-inch thick grinding discs of the RexCut™ product. The cutters are the same as those currently used in the industry for gear finishing using non-robotic equipment. They are aggressive and fit well into small root radii. They produce very good surface finish and uniform chamfers. The larger diameter RexCut™ products (2-inch diameter or greater) have sufficient life and fit within the features of many of the more complex parts. Using the cutters with a compliant head and a robotic positioning device greatly enhanced their usefulness. Unlike most machines being used currently for gear deburring, the robot permits optimal orientation and positioning of the cutters for each feature being processed. The compliant heads provide force control to protect the gears from grinding burn, to extend cutter life and to adapt to inherent positional errors of a dexterous robot.

Parts like the double helical bull gear do not permit the use of those discs due to interference with adjacent features. Luckily, carbide cutters were shown to be successful for the gears.

The CBN (cubic boron nitride) discs under investigation, while not suffering from the cutter life problems of the RexCut™ discs, do produce a rougher (yet most likely acceptable) surface finish, and some cutter loading and chatter were observed. Future work should develop the process parameters for improving the deburring process with the CBN cutters.

Path Programming

In addition to component selection, the programming of motions is an essential step in the development of an effective automated deburring system. Since the INFAC system is robot-based, a robotic type of path programming algorithm was used.

Figure 3 illustrates the typical nomenclature used in programming most of the gear paths for this study. Each tooth edge—that is, the obtuse edge and the acute edge—was programmed using one or two points at the root (either a single pRM or both pRMO and pRMA), a point near the root but on the tooth profile (pEAPO and pEAPA), a point at the midpoint of the profile (pMAPO and pMAPA), a point at the outer end of the profile (pSAPO and pSAPA) and one or two points at the nose of the gear (either a single pNOS or both a pNOSO and pNOSA).

Those points were programmed using the teach pendant by first finding an orientation for the head/cutter that is accessible to all points on a tooth side (acute or obtuse). Next, each point is jogged to and taught. If deburring is being performed with a carbide cutter, then cutter abrasion is not an issue and each point is programmed into the edge (depressing the compliance) by 1 mm to 2 mm. Thus, when the program is executed, the compliance of the head should be depressed to a depth of 1 mm to 2 mm throughout the cut. In the case of an abradable cutter like the RexCut™ wheels, the cutting depth bias is addressed using the robot programming language's RelTool function, which is used to permit program offsets in the direction of wear. In this case, the points are taught by jogging the robot to a position just touching the edge. The compliance depth programmed using the RelTool function then drives the disc into the edge (against the compliance) in the compliance direction of the tool (head) coordinate system.

The cutter orientation was chosen to be roughly perpendicular to the bisector of the edge at the midpoint of the tooth profile, i.e. the edge normal. However, for a helical or spiral bevel gear tooth, that means the acute profile generally requires a different cutter orientation than does the obtuse profile. That is why currently available non-robotic deburring machines with fixed cutter orientation cannot produce a uniform chamfer on both sides of such gear teeth. It would be preferable to reorient the cutter in the root so that the acute side and the obtuse side both have their own optimum orientations and there is one continuous cut. Unfortunately, early trials showed that the increase in robot dynamics associated with reorienting the robot produced divots in the gear tooth edge. The efforts of this study have, therefore, focused on programming trajectories that maintained a constant head/cutter orientation throughout the cut, per side. A natural consequence of not changing the orientation during the cut is that there will be a region of each tooth edge where a blend from one cut to the next must take place (usually in the root).

It may be possible to develop a means of reorienting with minimal dynamics. Approaches might include adjusting the maximum permissible reorientation speed or playing with the zone data (both position and orientation). Also, one must use care that the tool center point (TCP) is accurately defined when making reorientations while cutting.

It is important in programming with a robot to allow for both static and dynamic robot error in fixturing, cutter, part, and other process errors. Thus, the programmer is always thinking about the worst case positional errors and allotting clearance for such errors. For example, in programming a start point between two teeth, one should leave sufficient room between the cutter and adjacent features to account for possible process errors. With modern robots, this typically requires a minimum clearance of 0.03 inches.

One should also take advantage of inherent degrees of freedom in the system to allow room for error. For example, in programming for flank milling cutting with a cylindrical cutter, the three

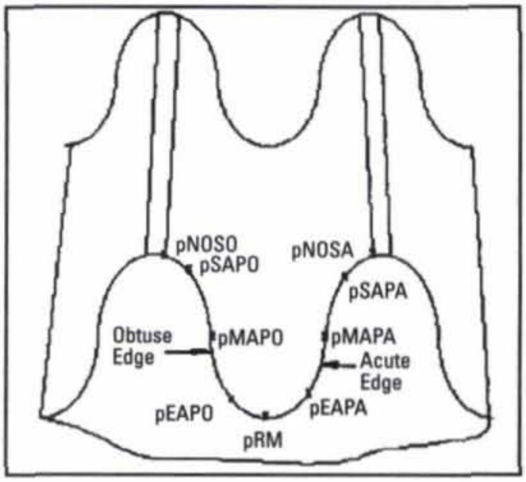

Fig. 3—Programming nomenclature used to program gear tooth profile.

Table 2—Double helical bull gear processing parameters.

Cutter	Head	Grinder Rotational Speed	Feed Rate Override	Compliance Pressure	x, y, z Euler Angles (degrees)	Automated Processing Time	Time Savings
3/16" Ball End Cylindrical Cutter MA Ford 42187530	ABB 40/240 2-axis Head	Approx. 35 krpm Free Speed	30% Override	40 psi	Acute -138.98 -6.77 -131.578 Obtuse -177.987 31.739 133.227	2 hours	10 hours

degrees of freedom for positional errors are accommodated as follows:

- Errors along the axis of the cutter are accommodated by symmetry along the axis of the cutter.
- Errors normal to the edge are accommodated through compliance in the head.
- Errors along the tangent to the edge are accommodated by the fact that they are aligned with the direction of feed.

In programming the disc cutter:

- Errors tangent to the disc at the point of contact are accommodated by symmetry at this point.
- Radial errors are accommodated by compliance in the head.
- Errors perpendicular to those are accommodated by the fact that they are aligned with the feed direction.

It was found that a better blend at the root between the acute and obtuse sides of the tooth could be achieved with a layered approach. That could be done, for example, by starting with a cutting pass on the acute side of each gear tooth, then a pass on the obtuse side of each tooth, then a final finishing pass on the acute side. Also very important to achieving a good blend is that the chamfer angles from the acute and obtuse passes must match as much as possible over the blending region.

Selectively cutting the acute and obtuse edges has the added benefit of permitting the operator to incorporate that selectivity into the final operator program. Thus, the program could be made to allow the operator to selectively choose to make another pass on the acute or obtuse side, depending on which looked as though it needed another pass. Keep in mind, though, that switching back and forth is the best way to accomplish a smooth blend. Making too many passes on one side without finishing with a final pass on the other side can leave a noticeable divot at the start point. Fortunately, the deeper the chamfer is, the less the chamfer opens per pass because the force is proportional to the area of the cut.

Example: Double Helical Bull Gear

One of the most challenging of the gears tested in this investigation was a 30-inch diameter, 10-diametral pitch, double helical bull gear. That particular gear has two helical gear surfaces, separated by a gap of approximately three-quarters of an inch. Processing parameters that were found to work effectively are summarized in Table 2. In that table, the compliance pressure is measured close to the deburring head. The *x*, *y* and *z* Euler angles give the orientation of the tool coordinate system with respect to the robot base coordinates.

After a manual deburring operation, the bull gear had an inconsistent finish and many divots. After processing with the automated deburring system, the edges were smooth and uniformly chamfered. Time spent to deburr this gear manually was approximately 12 hours. Time to deburr using the automated system was approximately two hours, or a savings of 10 hours, about 80 percent.

Example: Double Helical Pinion

Another challenging gear to deburr was the pinion that drives the bull gear in the example above. That pinion contains two helical surfaces, approximately 2.5 inches in diameter, also a 10-diametral pitch with a 35° helix angle and a three-quarter inch gap. There is also an integral 10-inch diameter spur gear on the same shaft.

The double helical pinion was processed using the 3/16-inch carbide cutter. The burrs were not an obstruction to the process and a uniform chamfer was produced in spite of them. Time to process the gear was reduced from 150 minutes for manual operation to 15 minutes for automated operation.

Chamfering Results

Another issue of interest is chamfering quality and uniformity. The automated deburring system has been applied to different types of aerospace gears including:

- 10-diametral pitch spur gears,
- 35° and 45° helical gears,
- 35° double helical pinions and gears, and
- 4- and 5-diametral pitch spiral bevel gears and pinions with 30° and 35° spiral angles.

Figure 4 shows data on the results of cutting some of the more challenging gears and pinions. The plot shows the average, maximum and minimum chamfer widths measured for all teeth. Because the maximum and minimum chamfer width did not exceed the typical ± 0.010 inch tolerances and the surface finish was good, the process was deemed successful.

Admittedly, the acute edge came out smaller than the obtuse edge for several of the gears. The goal of the testing was not to produce the correct chamfer width so much as to achieve acceptable chamfer width uniformity and surface finish. Once the uniformity is achieved on each side, the chamfer widths can be matched by changing the number of passes across the acute or obtuse edge or by adjusting other parameters like the cutting force or feed rate.

Future Work

The results presented here represent interim findings of an ongoing project at INFAC, the Instrumented Factory for Gears. One of the goals of this initial part of the project was to assess the feasibility of developing an automated deburring system for aerospace gears. To that extent, this phase has been considered successful. The feasibility of the automated system was demonstrated by deburring different sizes (from 3-inch to 30-inch diameters) of spur, helical, double helical and spiral bevel gears and pinions. For this purpose, a six-axis robot, a programmable indexing table and commercially available deburring heads were utilized. Such a simple system was more than adequate to conduct the feasibility study. However, for such a system to operate more efficiently in a production setting, a number of improvements in areas like programming, fixturing, cutters and cutting parameters may be necessary. A brief list of potential areas for future work follows.

Offline programming. Programming the robot offline can increase the robot's productive time and also reduce development or prove-out time considerably, since any unexpected problem in fixturing, path programming, or operating the robot can be detected and resolved before the robot is loaded with the desired program.

Tool wear compensation. To maintain consistency in the width of the chamfer, it is necessary that the cutting tool diameter remains constant. That is not a problem with cylindrical cutters. However, when very thin, fiber-bonded RexCut™ discs are used, an appreciable amount of tool wear is experienced. That tool wear must be compensated for, and that can be accomplished by a simple touch probe.

Application of CBN cutters. Another approach to handle the tool wear problem is to use longer CBN-coated disc cutters. In the feasibility phase, such cutters were used on a limited basis. More development is required in that area.

Brushing operations. In the case of gears being deburred after hardening and grinding, brushing is often necessary to remove minor secondary edges and also to improve surface finish. In such cases, brushing is normally performed manually. That expensive manual brushing could also be eliminated by integrating brushing with robotic deburring and chamfering.

Automatic tool changes. To accommodate different types and sizes of gears, it may be necessary to use various deburring heads and cutters. In such cases, setup time or changeover time can be reduced and the robot's actual productive time increased by integrating some sort of automated tool changing system. A number of manufacturers have developed such systems, and they could be integrated into the robotic deburring system with little trouble.

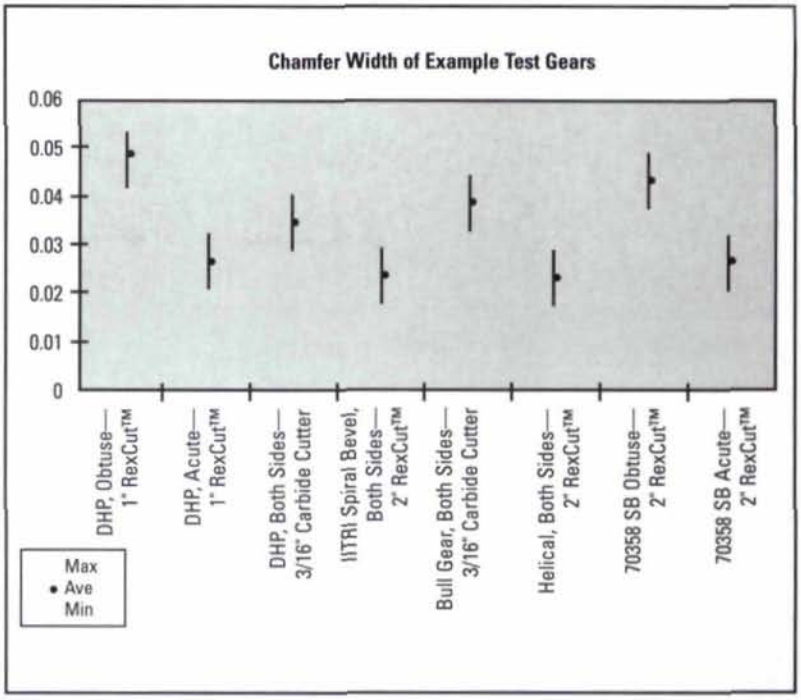

Fig. 4—Chamfer width and consistency from tooth to tooth for various test gears and processes.

Conclusions

The following conclusions can be summarized for this project, based upon work performed to date:

- Robotic automated deburring of aerospace gears is feasible and has been demonstrated on spur, helical, double helical, and spiral bevel gears from 3 inches to 30 inches in diameter.
- Both deburring and chamfering of aerospace gears can be achieved with an automated system.
- A successful automated deburring system for gears can be constructed from commercially available, off-the-shelf components.
- Quality and consistency of deburred and chamfered edges were increased in gears processed with the automated system, as compared with manually processed gears.
- Careful cutter selection is essential to achieving high-quality automated deburring.
- Process time for automated deburring was often as much as 90 percent shorter than manual deburring.
- Cost savings achieved through automated deburring, primarily through time savings and scrap reduction, is estimated at an average of 65 percent, as compared with manual deburring. ○

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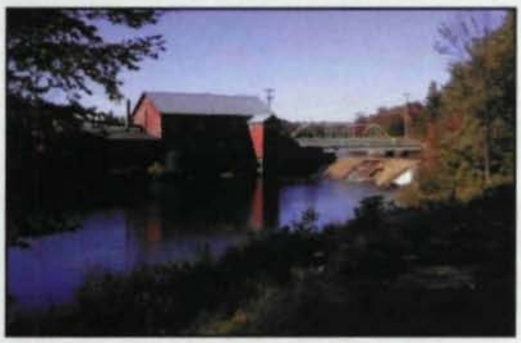
FOCUS ON BEVEL GEARS

Photo courtesy of Robert E. Smith

It seemed incredible to me that the wooden teeth on the large gear have been running at least since the Martin family took over the business 31 years ago. They have had no tooth failures in all that time, and they don't know how long the gears were running before the family bought the mill.

Water Powered Machinery

Photo Essay by Robert E. Smith



In one of my many visits to northern New York state, which includes the St. Lawrence River (Thousand Islands Region) and the Adirondack Mountains, I visited Croghan, a village on the Beaver River, which is fed by the Stillwater Reservoir in the Adirondack Mountains. At the base of a dam within the village, I found the remnants of a water turbine and a bevel gear drive system. Having worked for The Gleason Works for many years, I was intrigued by the remains of the bevel gears, which appeared to have had wooden teeth at one time.

Several years later, someone told me there was still an operating water wheel and drive on the other end of the dam, so I had to return for another visit. I found a company called the Croghan Island Mill Lumber Co., Inc. It is currently owned by the Martin family, and I met Jim Martin.

The family has owned the business since 1969. Before that, Martin's father worked for the previous owner for 30 years. There has been a similar business on site for about 150 years, according to Martin's research. They do custom millwork for restorations—moldings, window frames and sashes, etc.

At one time, there was a sawmill on the other end of the dam, where I had seen the original remains of the turbine and bevel gear drive. The sawmill had used a water wheel called a Rodney Hunt wheel for power, but the mill burned down about 1950.

The Croghan Island Mill uses a James Leffel water wheel, made by a company that used to be in Springfield, Ohio. Someone bought the drawings and claims to have replacement parts available. The water drop is 9 feet. The turbine is about 5 feet in diameter and 2 feet high. According to Martin, it generates about 70 HP, enough to drive all their machines at one time. The current water wheel has been in use since about 1912.

The gear drive is a speed increasing pair of bevel gears, with a ratio of 1.5:1. The bevel drive gear, attached directly to the turbine shaft, is about 48 inches in diameter, with 66 teeth. The pinion is 32 inches in diameter and has 44 teeth. The pinion is metal, while the gear is a casting with slots in it. The teeth are hardwood, and they are held in the slots by wedges on the underside. The teeth have a tapered "involute-like" shape and were originally made by a company in Carthage, NY. The company probably no longer exists. Martin has one new tooth, which can be used as a pattern.

It seemed incredible to me that the wooden teeth on the large gear have been running at least since the Martin family took over the business 31 years ago. They have had no tooth failures in all that time, and they don't know how long the gears were running before the family bought the mill. The wooden teeth are worn considerably thin at the outer ends, so that they look more parallel today. The wear pattern indicates that the gears are not mounted properly, relative to each other, but as they wear, there is more face width of the teeth carrying the load. They occasionally apply some grease to the teeth, from a barrel that was on site when they took over the business. About once a year, they have to replace or adjust the wooden pillow block just above the turbine.

The drive shaft goes into the building and is belted down below the main floor. From there, the power is distributed to other drive shafts near the various machines. The machinery includes table and band saws, planers, joiners and sanders. All the machines are from the late 1800s to early 1900s and are still used daily.

During the winter, the water in the top of the tower freezes, especially on weekends, when the turbine is shut down. The next morning, they pour some rock salt around the turbine shaft at the surface. Ten minutes later, the shaft is free and can be started up. Sounds like a pretty reliable and inexpensive source of energy. ⚙

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Robert E. Smith
is the principal in R.E. Smith & Co., a gear consulting firm in Rochester, NY, and one of Gear Technology's *technical editors. He has more than 50 years of experience in gearing and is the author of numerous papers and articles. He is also very active in AGMA standards development.*

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CIRCLE 113

The Basics of Spiral Bevel Gears

Dr. Hermann J. Stadtfeld

This article also appears as Chapter 1 in the Gleason Corporation publication "Advanced Bevel Gear Technology."

Gearing Principles in Cylindrical and Straight Bevel Gears

The purpose of gears is to transmit motion and torque from one shaft to another. That transmission normally has to occur with a constant ratio, the lowest possible disturbances and the highest possible efficiency. Tooth profile, length and shape are derived from those requirements.

With cylindrical gears, it is easier to understand that the involute profile provides a constant ratio and is insensitive to center distance displacement. The generating principle of an involute is derived from a straight rack with straight tooth profile. A particular gear, rolling in the rack with constant center distance to the rack, requires involute flank surfaces. A shaping tool with the shape of a rack can machine a gear with a perfect involute flank form. Figure 1 shows a cylindrical gear rolling in a rack.

To understand the bevel gear tooth geometry, one might first observe the case of straight bevel gears. If the generating rack used to derive the cylindrical gear involute is bent in a horizontal plane into a circular shape, it results in a crown gear, which is used to derive the flank form of bevel pinion and gear. In the case of straight bevel gears, the crown gear or generating gear can be placed between the pinion and gear assembly. Its center is located exactly at the intersection point of the pinion and gear shafts.

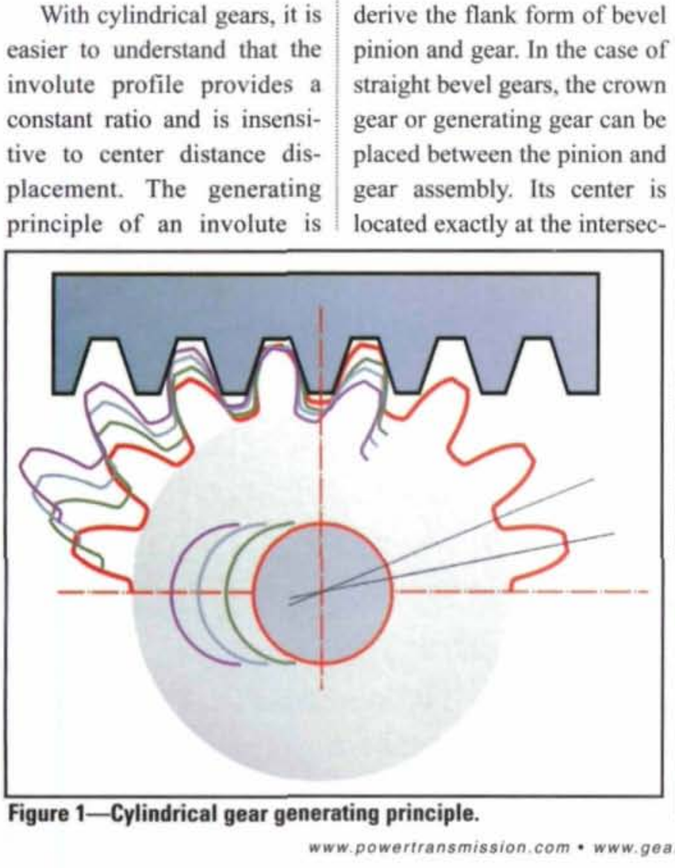

Figure 1—Cylindrical gear generating principle.

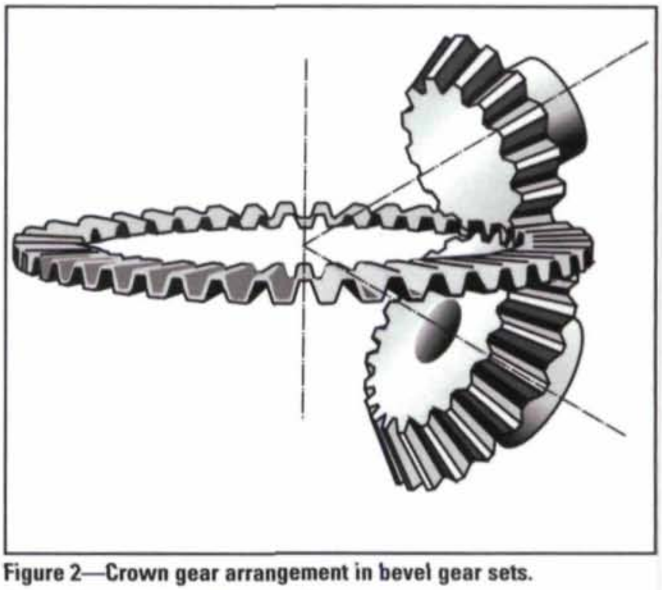

Figure 2—Crown gear arrangement in bevel gear sets.

As a mental exercise, the crown gear should consist of a very thin material like aluminum foil. In that case, it is possible for all three elements to be in mesh at the same time.

Figure 2 shows how the pinion is located at the backside of the crown gear and meshes with the "negative teeth," while the ring gear is placed at the front side of the crown gear and meshes with the "positive teeth." If such an arrangement is possible, then the kinematic coupling conditions of the bevel gear set are fulfilled, which means the pinion and gear can mesh with each other, too.

A single profile of the generating gear generates a gear on its one side and the mating member on its other side. The profile and lead are straight, which causes a straight lead and an octoid profile on the generated teeth. The octoid basically is the bevel gear analog of an involute. The octoid provides a constant ratio and makes the gears insensitive to displacements perpendicular to the pitch line.

Circular Cutting Tools and Spiral Bevel Gears

A face cutter comes with many blades to increase productivity. It generates a curved tooth shape, which provides

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is vice president of research & development with The Gleason Works, a leading manufacturer of bevel and cylindrical gear manufacturing equipment. He has written numerous articles on the theory of gearing and on practical aspects of gear manufacturing.

increased face contact ratio, tooth rigidity and adjustability to load-dependent deflections.

In the case of a single index face milling method, the tooth lead function is circular, as the blade in the cutter performs a circular motion, while the generating gear rests in a fixed angular position.

The tooth profiling between the cutter and the generating gear does not require any rotation of the generating gear. The virtual generating gear is formed by the cutter head in a non-generating process. In Figure 3, the rotating blades in the cutter head can be understood to represent one tooth of the generating gear.

As explained earlier, the generating gear is the bevel gear equivalent of the straight rack for generating a cylindrical gear tooth. Therefore, it is understandable that the generating gear tooth profile is a mirror image of the blade profile (it is not an involute or octoid).

If a pinion blank without teeth is positioned in front of the generating gear and then moved towards the cutter, the blades will cut the same trapezoidal profile of the generating gear into the pinion. The pinion slot produced in that way has two defects. First, the profile will not allow rolling between pinion and generating gear (compare to the rack and cylindrical gear tooth in Figure 1). Second, the pinion slot does not have the proper depth along the face width. As soon as the teeth have a spiral angle and the slot inclines to an angle on an axial plane, the teeth wind around the work gear body. In a fixed angular position, just the heel section, for example, is cut to the proper depth.

The roll motion rotates the virtual generating gear and the work gear with the proper ratio while they are engaged (similar to the linear motion of the rack, Figure 1, in conjunction with the gear rotation).

Since the generating gear is just virtual and doesn't physically exist, the cutter that simulates one tooth of the generating gear has to rotate around the generating gear axis. With this rotation (roll motion), the cutter blades work their way from the heel to the toe and generate the proper octoidal profile along the entire face width. The start

A SINGLE PROFILE OF THE GENERATING GEAR GENERATES A GEAR ON ITS ONE SIDE AND THE MATING MEMBER ON ITS OTHER SIDE. THE PROFILE AND LEAD ARE STRAIGHT, WHICH CAUSES A STRAIGHT LEAD AND AN OCTOID PROFILE ON THE GENERATED TEETH. THE OCTOID BASICALLY IS THE BEVEL GEAR ANALOG OF AN INVOLUTE. THE OCTOID PROVIDES A CONSTANT RATIO AND MAKES THE GEARS INSENSITIVE TO DISPLACEMENTS PERPENDICULAR TO THE PITCH LINE.

roll position is normally on the side of the tooth with the big diameter (heel). The roll motion ends when the profile generating "arrives" at the opposite side of the face width (toe).

That procedure was for machining one slot. To machine the next slot, the cutter withdraws, and the work indexes one pitch. The spiral angle is the inclination angle of the curved tooth tangent to the radius vector from the intersection point of pinion and gear axis (see Figure 4). Because of the curved shape of the tooth length, different points along the face width have different spiral angles. The nominal spiral angle of the spiral bevel gear or pinion is the angle measured from the center of the tooth.

It is possible to use a bevel generating gear that is identical to the ring gear. The pinion is in that case generated by rolling with the bevel generating gear, and the gear is manufactured simply by plunging the cutter to full depth without rolling (non-generated form cutting).

A straight tooth bevel gear set has contact lines that are parallel to the pitch line (Figure 5, top). The first contact between a generating gear tooth and a pinion tooth starts, for example, in the root and moves during the rotation of the two mating members along the path of contact straight up to the top. The contact lines represent the momentary contact between the two flanks in mesh.

With a spiral bevel gear set, the contact lines are inclined relative to the pitch line orientation. Unlike the contact lines of the straight bevel gear set, the contact lines of the spiral bevel gear set have different lengths. The bottom of figure 5 shows the movement of the contact from heel top to toe root. The very short contact length increases from the beginning of the roll towards the center of the face width and reduces as the roll approaches the exit at the toe end.

The contact lines between pinion and generating gear are identical to the contact lines between cutter blades and pinion flanks.

Single Index Process—
Face Milling

In a single index process, just one slot is cut at a time. For the non-generated member only, the cutter rotates and is fed into the work gear to the full depth. After reaching the full depth, the cutter withdraws and the work indexes one pitch to the next desired slot position (Figure 6, right side). The process repeats until all slots have been machined. The resulting flank lead function is a circular arc.

Machining a generated member is done by plunging at the heel roll position first. After plunging, the roll motion begins, and generating of the flanks from heel to toe occurs. The flank lead function for a face milled, generated gear is a circular arc that is wound around a conical surface.

The manufacturing of a face milled bevel gear pair is possible in a five-cut process or in a completing process. The five-cut process consists of the following five independent operations:

1. Gear roughing (alternate roughing blades),
2. Gear finishing (alternate finishing blades),
3. Pinion roughing (alternate roughing blades),

Figure 3—Circular cutting tool and virtual generating gear.

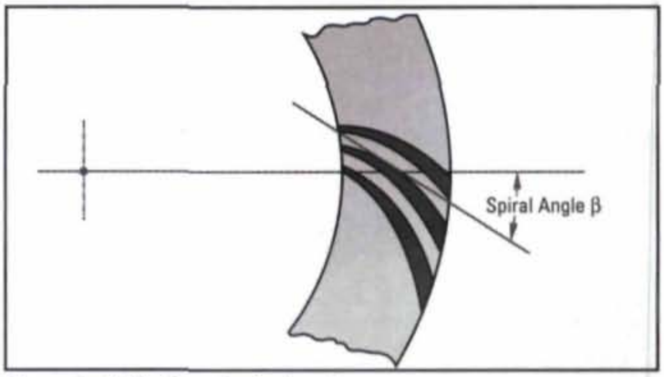

Figure 4—Definition of spiral angle.

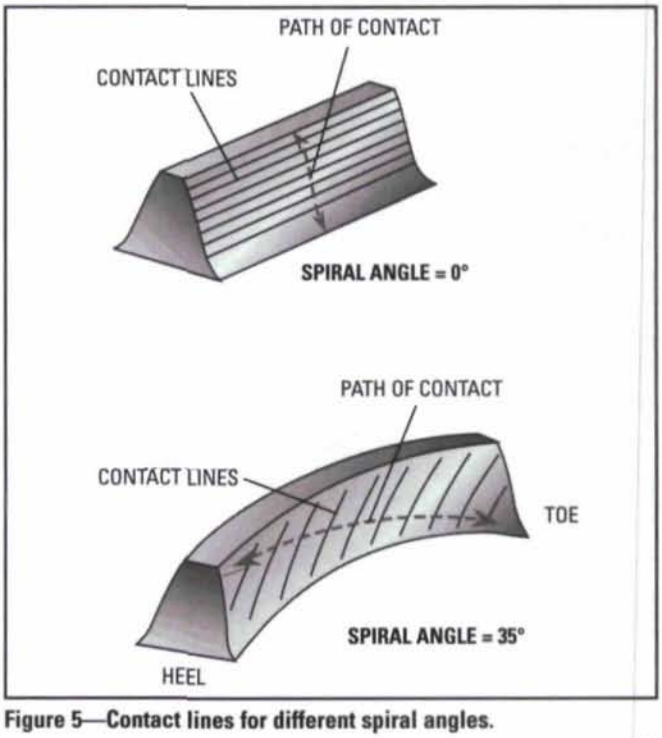

Figure 5—Contact lines for different spiral angles.

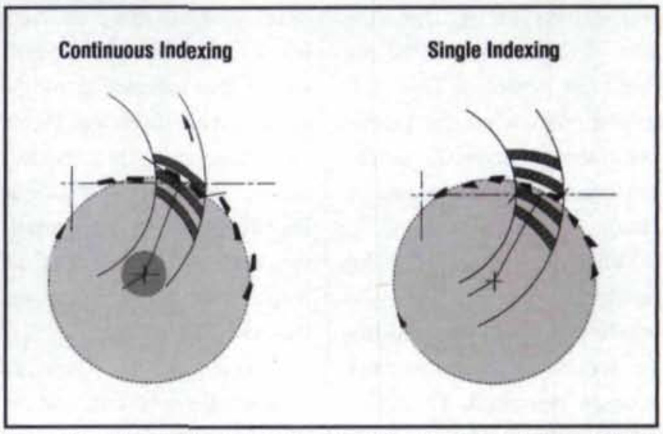

Figure 6—Kinematic principle of continuous indexing vs. single indexing.

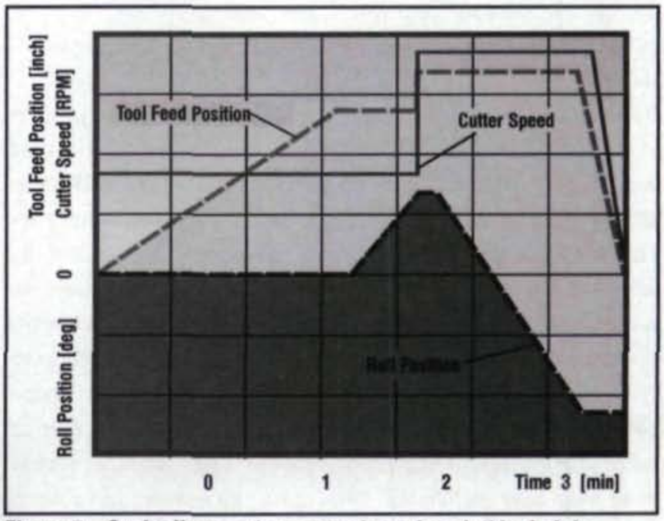

Figure 7—Cycle diagram for generating a face hobbed pinion.

4. Pinion finishing convex (inner blades only), and
5. Pinion finishing concave (outer blades only).

A completing process uses two combined operations:

1. Gear roughing and finishing (alternate roughing-finishing blades) and
2. Pinion roughing and finising (alternate roughing-finishing blades).

Continuous Indexing Process—Face Hobbing

A continuous cutting process consists of continuous rotations and a feed motion only. While an outer and an inner blade move through a slot of the work gear, the work gear is rotating in the opposite direction. The relation of the cutter rpm and the work rotation is equivalent to the ratio between the number of work gear teeth and the number of cutter head blade groups (starts). The resulting flank lead function is an epicycloid. The effective cutting direction of the blades in the cutter head is not perpendicular to the cutter radius vector (like in the single indexing process). The blades are moved in the cutter head tangentially to an offset position to accommodate the correct orientation with respect to the cutting motion vector. The pitch points on the cutting edge of inner and outer blade have an identical radius. The right slot width is achieved with the angular distance between the outer blade (first) and the following inner blade. The left portion of Figure 6 shows the kinematic relationship and the orientation of the blades relative to cutter and cutting motion.

Balancing of the tooth thicknesses between pinion and gear can only be realized by different radii of inner and outer blade pitch points, since the spacing between the blades is given by the cutter head design and therefore remains constant.

While one blade group (like shown in Figure 6) is moving through one slot, the work rotates in the opposite direction, such that the next blade group enters the next slot. That way, all the slots around the work gear are cut at about the same time. The feed motion to feed the cutter to the full depth position is therefore slower than in the single index process.

A non-generated work gear is finished when the full depth position is reached. To get the highest possible spacing accuracy, a dwell time is applied to the non-generated member. The aim of the dwell motion is to allow each blade to move once more to each slot, which takes N slots to pass by, where N is the number of cutter starts times the number of gear teeth. N is equivalent to as many ring gear revolutions as the cutter has starts.

For a generated pinion, a roll motion follows the plunging cycle in the center roll position (the cutter does not cut the full depth yet). The roll motion after plunging moves the cutting action to the heel; both plunging and rolling to heel is part of the roughing cycle. At the heel roll position, the cutter advances to the full depth position, the cutter rpm increases to a finishing surface speed, and a slow roll motion from heel to toe follows. When arriving at the toe (end roll position), all teeth of the generated work gear or pinion are finished (see Figure 7).

Heat Treatment of Bevel Gears

Heat treatment follows the soft cutting operation. The generally used low carbon steel has to be carburized on the surface, by case hardening for example. The heat treatment is finished with the quenching operation that provides a surface hardness in the

A NON-GENERATED WORK GEAR IS FINISHED WHEN THE FULL DEPTH POSITION IS REACHED. TO GET THE HIGHEST POSSIBLE SPACING ACCURACY, A DWELL TIME IS APPLIED TO THE NON-GENERATED MEMBER. THE AIM OF THE DWELL MOTION IS TO ALLOW EACH BLADE TO MOVE ONCE MORE TO EACH SLOT, WHICH TAKES N SLOTS TO PASS BY, WHERE N IS THE NUMBER OF CUTTER STARTS TIMES THE NUMBER OF GEAR TEETH. N IS EQUIVALENT TO AS MANY RING GEAR REVOLUTIONS AS THE CUTTER HAS STARTS.

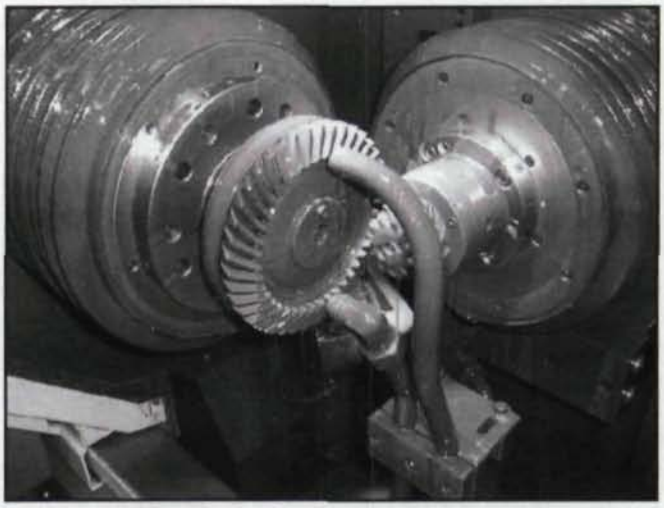

Figure 8—Lapping of a bevel gear set.

Figure 9—Grinding of a bevel pinion.

range of 60 to 63 Rc (Rockwell C). The pinion may be 3 Rc harder than the ring gear to equalize the wear and reduce the risk of scoring. The core material stays softer and more ductile, with a hardness in the range of 30 to 40 Rc.

The distortions from heat treatment are critical to the final hard finishing operation. The kind of heat treatment facility (salt bath, furnace or continuous furnace), as well as the differences between the charges of blank material, has a significant influence on the gear distortion. The gear, which is mostly shaped like a ring, loses its flatness (it gets a face run-out) via the hardening procedure. The pinion, in most cases, is shaped like a long shaft that loses its straightness (radial run-out).

In addition to the blank body distortions, heat treating causes a distortion of the individual teeth. The spiral angle changes, the flank length curvature is reduced and the pressure angle changes. To achieve the best results, attention has to be paid to processing and handling of the parts through the furnace. Quenching the ring gears with a quench press assures good flatness of the heat-treated ring gears, for example.

Hard Finishing of Bevel Gears

The final machining operation after heat treatment should provide a good surface finish and remove flank distortions. The most common process used is lapping. Pinion and gear are brought into mesh and rolled under light torque. To provide an abrasive action, a mixture of oil and silicon carbide is poured between the teeth (Figure 8). A relative movement of pinion and gear along their axes and a movement in offset direction is created, such that the contact area moves from toe to heel and back numerous times.

The lapping process improves the surface finish, leaves a desirable micro-structure on the flank surfaces and removes heat treat distortions to some extent. The metal removal is not uniform in the different flank sections and varies from set to set, since the pinion and gear are used as tools to hard finish each other. This is the reason why lapped sets have to be built as a pair; lapped pinions and gears are not interchangeable.

The lapping surface structure is not oriented in the direction of the contact lines, thus providing a good hydrodynamic oil film between the contact areas. The lapping structure also tends to deliver side bands in a noise frequency analysis, which makes the gear set appear to roll more quietly.

During the lapping process, a pinion and a gear are always machined and finished at the same time. The time to lap a pair is equal to or shorter than the time to machine one member using another finishing method. Therefore, lapping is often called the most economical bevel gear finishing process.

Another finishing option is grinding of bevel gears, which is limited to face milled (single index) bevel gears. The grinding wheel envelops a single side or an alternate completing cutter (Figure 9). Today's technology does not allow the use of a grinding tool in a continuous indexing process. The advantage of grinding is the manufacturing of an accurate flank surface with a predetermined topography. The process allows the constantly repeated production of equal parts. Building in pairs is not necessary.

Lapped pairs used in vehicles require an oil change after the first 1,000 miles because of abrasive particles introduced to the tooth surfaces during lapping. A further advantage of grinding over lapping is that such an oil change is unnecessary with ground spiral bevel gears.

A process between lapping and grinding with respect to surface speed and relative motion is honing. Honing trials on bevel gears have been done, but they haven't been proven successful.

Skiving is a hard cutting process. A tool material such as carbide or boron carbonitride is used on the cutting edge. The cutting machine setup is identical to that for soft machining. The blade point dimension is wider than the one for soft cutting, such that a 0.005-inch uniform stock removal per flank takes place. Skiving delivers a high quality part accuracy and a fine surface finish. Skiving is applied to small batches of mostly larger gear sets. The advantage of skiving is the use of the same cutter head (only with different blades) and the possible use of the same cutting machine. That makes the investment in machines and tools a minimum.

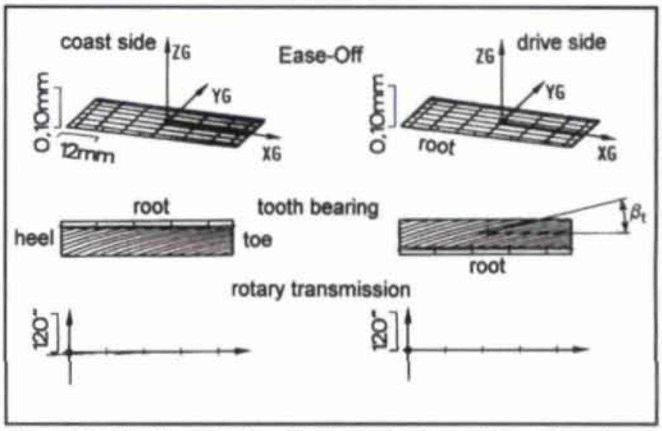

Figure 10—Tooth contact analysis result of a conjugate bevel gear set.

Some Bevel Gear Conventions

The expression "bevel gears" is used as a general description for straight and spiral bevel gears as well as hypoid gear sets. If the axes of the pinion and gear do not intersect but have a distance in space, the gear set is called a hypoid gear set. The name is derived from the hyperbolic shape of the "pitch cones." For simplification, the blanks are still manufactured with a conical shape.

The convex gear flank rolls with the concave pinion flank. This pair of flanks is called the "drive side." The direction of rotation where those flanks contact the pinion drives is called the drive direction. The drive side direction is always used in vehicles to drive the vehicle forward. The reverse direction is subsequently called the coast side (vehicle rolls downhill, foot is off the gas pedal, wheels drive the engine). In some cases, the coast side is used to drive the vehicle, but it is still called the coast side.

Ease-off is the presentation of flank form corrections applied to pinion and/or gear. The ease-off topography is defined in the ring gear coordinate system, regardless of where the corrections were done (pinion, gear or both).

Protuberance is a profile relief in the root area of the flank, which prevents flank damage resulting from "digging in" of the mating tooth's top edge. Protuberance is realized with a cutting blade modification.

Localized Tooth Contact

When bevel gear sets are cut according to the crown gear or generating gear principle, the result is a conjugate pair of gears. Conjugate means pinion and gear have a line contact in each angular position. While rotating the gear in mesh, the contact line moves from heel top to toe root. The motion transmission happens in each roll position with precisely the same constant ratio. Roll testing is done in specially designed bevel gear test machines. If a marking compound (paint) is brushed onto the flanks of the ring gear member, a rolling in mesh under light torque makes the contact area visible. In the case of a conjugate pair, the contact area is spread out over the entire active flank. That is the official definition of the

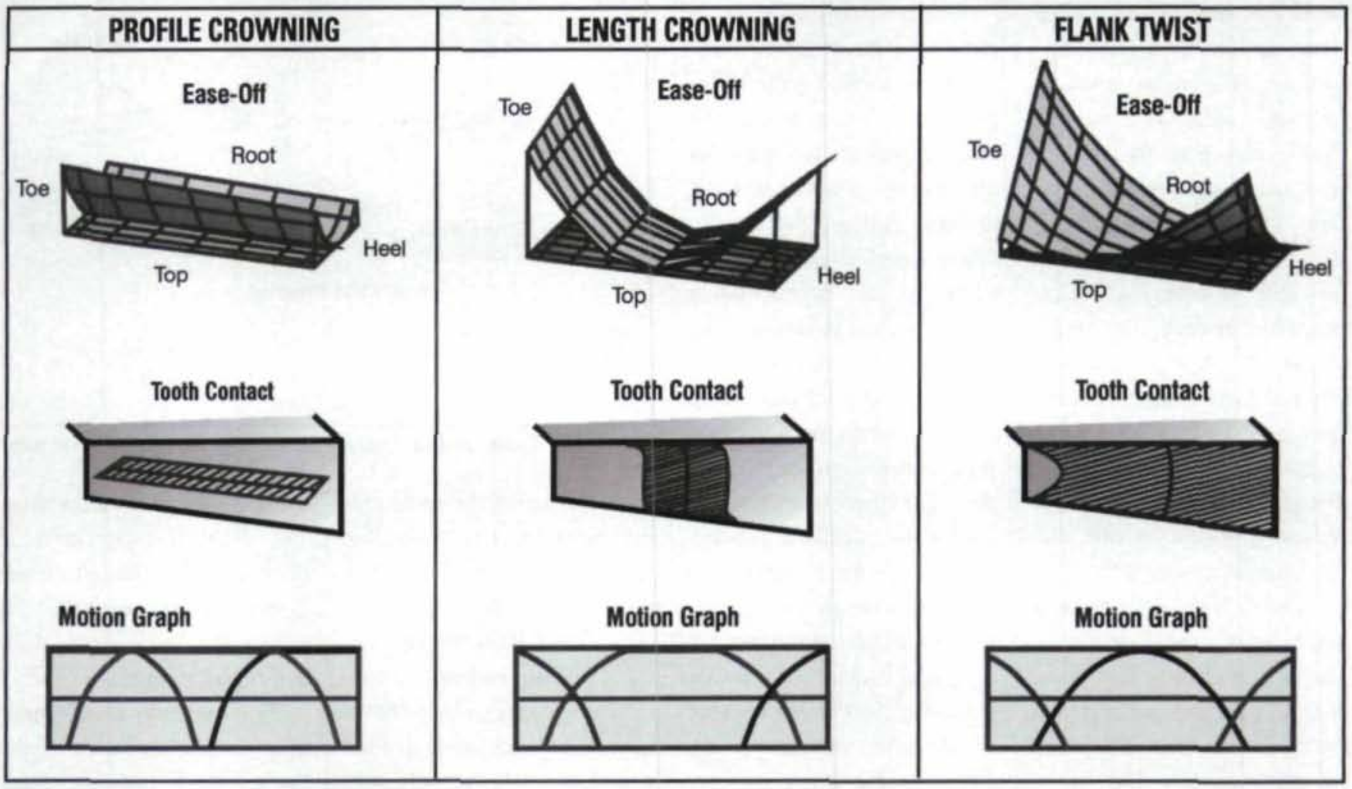

Figure 11—Tooth contact analysis of profile crowning, length crowning and flank twist.

contact area. It is the summation of all contact lines during the complete roll of one pair of teeth.

Conjugate bevel gear pairs are not suitable for operation under load and deflections. Misalignment causes a high stress concentration on the tooth edges. To prevent those stress concentrations, a crowning in face width and profile direction is applied to nearly all bevel pinions. The amount of crowning has a relationship to the expected contact stress and deflections.

To analyze tooth contact and crowning, computer programs for tooth contact analysis (TCA) were developed. Figure 10 shows the TCA result of a conjugate bevel gear set. The top section of Figure 10 represents a graphic of the ease-off. The ease-off represents the sum of the flank corrections, regardless of whether they were done in the pinion or gear member. The octoidal profile and curved lead function are filtered out. Therefore the ease-off is a "flat" zero topography for conjugate gears. The tooth contact is shown below the ease-off. Tooth orientation is indicated with "heel, toe and root." The coast and drive sides show a full contact, covering the entire active working area of the flanks. The lower diagram in Figure 10 is the transmission error. Conjugate pairs roll kinematically exactly with each other. That roll is reflected by points on graphs that match the abscissas of the diagrams. Each point of those graphs has a zero value (ZG-direction), so they cannot be distinguished from the base grid. The base grid and graph are identical and drawn on top of each other. That characterizes a conjugate pair of gear flanks. The transmission graph always displays the motion variation of three adjacent pairs of teeth.

To achieve a suitable flank contact, today's flank corrections mostly consist of three elements, shown in Figure 11. Profile crowning (Figure 11, left) is the result of a blade profile curvature. Length crowning (Figure 11, center) can be achieved by modification of the cutter radius or by a tilted cutter head in conjunction with blade angle modification. Flank twist (Figure 11, right) is a kinematic effect resulting from a higher order modulation of the roll ratio (modified roll) or cutter head tilt in conjunction with a machine root angle change.

The three mentioned flank modifications can be combined, such that the desirable contact length and width, path of contact direction and transmission variation magnitude are realized. The TCA characteristics (contact pattern and transmission variation) are chosen to suit the gear set for the expected amount of contact stress and gear deflections. ○

References

1. Stadtfeld, H.J. *Handbook of Bevel and Hypoid Gears: Calculation, Manufacturing and Optimization*, Rochester Institute of Technology, Rochester, NY, 1993.

Falk Offers Workshops in 2001 for Gear Drives and Couplings. Falk Renew Facility, New Berlin, WI. The Falk Corp. is offering four-day, "hands-on" workshops to train people about maintaining Falk gear drives and couplings through The Falk School. The company is accepting registration for 2001 for the school. Scheduled throughout 2001, classes are limited to eight students, with registration on a first come, first served basis. For more information or to register for a workshop, contact The Falk School via *www.falkcorp.com* or via e-mail at *falkinfo@falkcorp.com*.

Chick Workholding Solutions Offers New Seminar. Chick Workholding Solutions Inc. is offering a one-day seminar for determining workholding solutions for CNC machining centers for people involved in planning, setting up and operating such centers. Held throughout 2001, the seminar consists of a lecture and examples of various projects and techniques. For more information on a seminar in your area, call Glee A. Jesteadt at (800) 33-CHICK.

Jan. 16–18—Orlando 2001 Advanced Productivity Exposition. Orange County Convention Center, Orlando, FL. Located in Hall D2, the machine tool and manufacturing exposition is being held with technical courses focusing on manufacturing technologies and processes. The exposition is sponsored by the American Machine Tool Distributors' Association, AMT—The Association For Manufacturing Technology, and the Society of Manufacturing Engineers (SME). The courses are sponsored by SME. For more information, visit the SME Website at *www.sme.org* or call SME Customer Service at (800) 733-4763.

Feb. 20–22—SOUTH-TEC 2001 GREENVILLE: Advanced Productivity Exposition. Palmetto Expo Center, Greenville, SC. The exposition has been rescheduled to the above dates. The exposition will include technical and business-related courses and clinics about technologies and business topics. It is sponsored by the American Machine Tool Distributors' Association, AMT—The Association For Manufacturing Technology, and the Society of Manufacturing Engineers (SME). For more information, visit the SOUTH-TEC Greenville Website at *www.sme.org/greenville* or call SME Customer Service at (800) 733-4763.

March 26–29—WESTEC 2001: Advanced Productivity Exposition. Los Angeles Convention Center, Los Angeles, CA. The exposition will have the Annual Job Shop Pavilion and the new Rapid Prototyping and Tooling Pavilion. It will also have a series of technical and business-related courses and clinics addressing technologies and business topics. The exposition is being sponsored by the Society of Manufacturing Engineers (SME), the American Machine Tool Distributors' Association and AMT—The Association For Manufacturing Technology. For more information, visit the WESTEC Website at *www.sme.org/westec* or call SME Customer Service at (800) 733-4763.

April 7–8—RI/SME Student Robotic Challenge 2001. Robert Morris College, Pittsburgh, PA. The event is a robotics automation contest for students in North America and is sponsored by Robotics International of the Society of Manufacturing Engineers (RI/SME). For more information, visit the SME Websites at *www.sme.org* or at *www.manufacturingiscool.com*. Or, contact Katie Ferrell at *ferrkat@sme.org* or at (313) 271-1500 ext. 1704.

April 23–28—HANNOVER FAIR 2001: World's Leading Fair for Industry, Automation, Innovation. Hannover Fairgrounds, Hannover, Germany. The exhibition program will consist of factory automation; IT/software; power transmission and control; compressed air technology, factory equipment and tools; subcon technology; energy; research and technology. The U.S. project team includes Brad Miller, Ellen McDevitt and Ingrid Abell at Hannover Fairs USA Inc., 103 Carnegie Center, Princeton, NJ 08540, Phone: (609) 987-1202, Fax: (609) 987-0092, E-mail: *hannoverfair@hfusa.com*.

April 26–28—Precision Machining Technology Show (PMTS) 2001. Greater Columbus Convention Center, Columbus, OH. The show is meant for screw machine product producers and their suppliers and will feature the latest technology in the precision machined products industry. Products on display will include the latest single- and multi-spindle turning machines and turning centers, CNC machining centers and productivity enhancements. There will be a Computer Technology Pavilion with job shop software. There will also be technical sessions meant to help manufacturers streamline operations, increase productivity and reduce costs. The show is sponsored by the Precision Machined Products Association, as well as Modern Machine Shop and Production Machining magazines. For more information, people can visit *www.mmsonline.com/pmts* or call Michelle Jenkins at (800) 950-8977.

April 28–May 1—American Foundry Society 105th Casting Congress. Hyatt Regency DFW, Dallas/Fort Worth, TX. The international show will include educational sessions and tabletop exhibits and provide a forum for exchanging metalcasting information and technology. For more information, contact Steve Robison, the society's casting congress coordinator, at 505 State St., Des Plaines, IL 60016, Phone: (800) 537-4237 or (847) 824-0181, Fax: (847) 824-7848.

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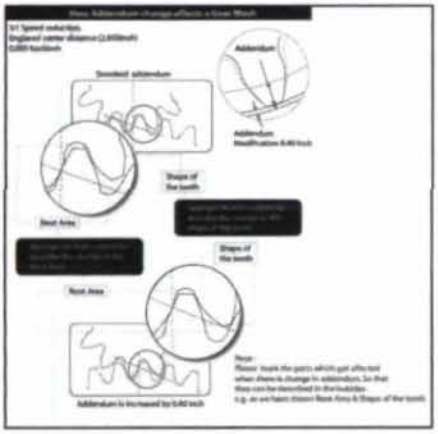
Welcome to our Software Bits page. Here we feature new software products for gear design, manufacturing and testing. To get more information on these items, please circle the Reader Service Number shown. Send your new product releases to: *Gear Technology*, 1401 Lunt Avenue, Elk Grove Village, IL 60007,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



Online Gear Training from UTS

Universal Technical Systems of Rockford, IL, has introduced Web-based training for gear designers based on its popular line of gear design software and its basic and advanced gear training curriculum, which the company has used in its in-person gear training programs since 1985.

"What we have learned is that for people who have not worked with gears before, getting a good understanding of the fundamentals and developing meaningful insights into how various parameters impact the gear performance takes quite some time," says UTS president S.M. "Jack" Marathe. "That results in increased design time, and frequently the company is unable to come up with the best designs for their needs."

The online training begins with gear basics such as the involute curve, how it's generated, and basic gear terminology. Students proceed through an examination of the interaction of such factors as base, pitch, outside and root diameters; line of center and line of action; pitch point and base pitch; addendum and dedendum; working and whole depth; pressure angle; clearance; and backlash.

At the advanced level, students work with actual design examples, such as an electric motor driving a fan and a turbine/alternator reduction gear.

The online gear models are interactive, with both static and animated graphics. The student is able to see immediately how changes in various parameters affect gear performance. "A person sitting at his terminal, wherever he is, can change one parameter and see the effects on the fly," says Marathe.

UTS will offer two courses—*Fundamentals of Gearing* and *Fundamentals of Plastic Gear Design*—on its Website in the first quarter of 2001.

Circle 321

New Gear Analysis Software Package

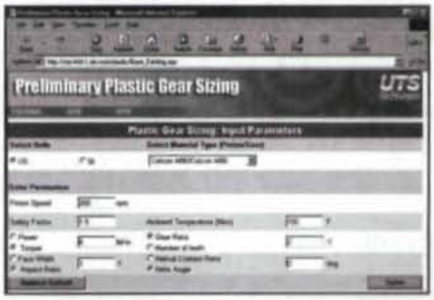
Manufactured Gear & Gage of Elgin, IL, announces the release of its new software package for gear measurement and process control. The software is designed to work with Manufactured Gear & Gage's high-speed automatic and bench-top composite double-flank gear roll testers.

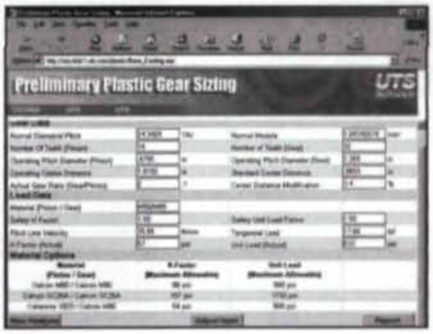
The Windows-based software runs on a personal computer to provide a diagnostic interface to the data acquisition process. The software also includes a customizable database for user configuration of test data, part data, master gear and setting master data and parameters.

The Manufactured Gear & Gage software includes a variety of modules for center distance and lead/taper station tests. Results can be stored and analyzed for automatic calibration, master gear subtraction and statistical process control, including gage repeatability and reproducibility.

For more information about the new software, contact Manufactured Gear & Gage at (630) 377-2496 or send e-mail messages to *mgg3@microthought.com.*

Circle 322





Plastic Gear Design on the Web

Universal Technical Systems of Rockford, IL, has developed *Preliminary Plastic Gear Sizing*, a Web-based program for the preliminary design of plastic gears. The online tool was developed for Ticona, a manufacturer of plastic materials from Summit, NJ, and UFE, a plastic gear manufacturer in Stillwater, MN.

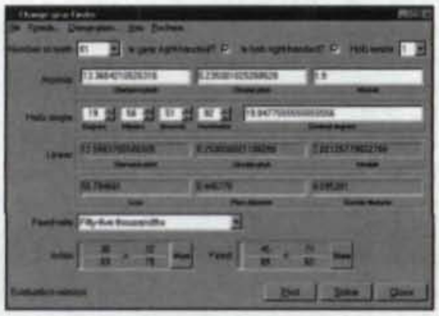
The application was designed for UFE and Ticona customers, who may not have the experience or software in-house to develop plastic gear designs without help. *Preliminary Plastic Gear Sizing* runs on an ordinary Web browser, without the need to download special software. The customer assumes control of the transaction and does the design over the Web, saving design time and lead time. The vendor saves cost and gets a more complete customer design requirement right away.

The application asks the user to accept default data or enter data of his own for such parameters as pinion speed, torque, safety factor, gear ratio, helix angle and operating temperature.

The online application takes the user's input data and performs calculations based on UTS software. UTS has leveraged two of its key technologies—*TK Solver* and *RuleMaster*, a rules engine for the Web—in the development of the product. *TK Solver* is the environment in which the gear design model is run. *RuleMaster* is used to mount the model on the Web. The application uses formulas from UTS's gear design program *60-610, Plastic Gear Geometry and Load Analysis.*

The preliminary design data are displayed in another browser screen. If the user chooses, the data can be packaged in a separate report form that can be printed. The interface includes links to the Ticona, UFE and UTS Websites.

Circle 323



Change Gear Finder

Helixware Software of Savannah, GA, introduces its *Change Gear Finder* software, used for finding the index and feed gear trains needed to cut helical gears using the nondifferential method on both differential and nondifferential hobbing machines.

Change Gear Finder is a 32-bit program for Windows 95/98/NT and Windows 2000 that finds the most accurate change gears based on user input.

The user enters various information, such as the index and feed constants for the gear hobber, the hob's number of leads and the gear's normal pitch, helix angle and number of teeth. Then the program solves for the best combination of change gears based on the change gears available from the user's inventory.

According to Helixware, the software finds a solution in about a minute on Pentium II or faster machines.

Additional information and an evaluation version of the software are available at *www.helixware.com.*

Circle 324

Zontec Offers SPC Program for $999

Zontec has a 32-bit, entry-level SPC program for $999: *Synergy 2000 LE.* The program provides real-time operation on Windows 95, 98, and NT, as well as 2000-based personal computers and local area networks.

People can use *Synergy 2000 LE* to combine attribute, variable and pareto data in one databank and to contain processes with samples of up to 25. Also, they can trace using 12 ID fields and record corrective actions using two notes fields.

The program has screen displays that can be customized, can create reports with up to eight charts per page, can receive direct input from measurement devices, and has integrated messaging.

A demonstration program can be obtained by downloading it from Zontec's Website at *www.zontec-spc.com* or by phoning Zontec at (800) 955-0088 or (513) 648-0088.

Circle 325

New Software Feature Lets CMMs Intuit Desired Measurement

International Metrology Systems Inc. has a new software feature that lets a CMM intuitively decide desired measurement without operator input. A developer of CMMs and measuring software, International Metrology made available the *Smart Measure* feature in *Virtual DMIS* CMM software.

Built into the software with algorithms, the feature lets a user touch a part with the probe, and *Virtual DMIS* does the rest. *Smart Measure* is valid for point, line, plane, circle, cylinder, cone and sphere and is active on both manual and CNC CMMs.

Smart Measure enables prismatic features to be inspected without traditional personal-computer interaction. Also, when used on articulated arm CMMs, the feature makes it significantly easier to operate those devices, according to International Metrology.

For more information, contact Keith Mills, International Metrology Systems Inc., 37100 Plymouth Road, Livonia, MI 48150, Phone: (734) 591-3800, Fax: (734) 591-3850, E-mail: *mills@dmis-cmm.com.*

Circle 326

Software Accurately Simulates Resin Flow in a Mold, Companies Say

Composite Design Technologies Inc. and Liquid Process Performance Prediction Inc. announced they teamed up to provide a solution for accurately simulating complex curvature parts using liquid composite manufacturing techniques.

Liquid composite molding (LCM) includes manufacturing processes that involve injection of resin into a mold cavity filled with fibrous reinforcement, eliminating prepreg tape manufacture and layup.

CDT and L3P's solution consists of two connected programs. *FiberSIM* is

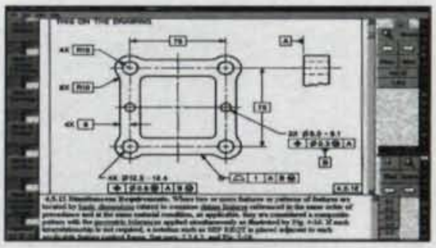
CDT's CAD integrated composite design software, and *LCMFLOT* is L3P's mold filling analysis software. According to the two companies, the programs are connected so companies using this composite manufacturing method can more accurately simulate the flow of resin through a mold without the expense and time involved in building and testing a prototype mold.

With information from *FiberSIM*, *LCMFLOT* simulates the mold filling process more accurately today, the companies say, because porosity variations can now be taken into account. Besides calculating spatial variations in porosity, *LCMFLOT* was devised to integrate time variations in porosity because of compressing of the reinforcement, opening of the mold during injection, and other factors. *LCMFLOT* also takes into account resin race tracking around the mold edges, variations of resin viscosity with time and temperature, resin chemical reaction, and curing.

CDT develops software solutions for composite design and manufacturing. L3P provides commercial software used in composite manufacturing to simulate resin injection through fibrous reinforcements.

For more information about *FiberSIM*, contact Composite Design Technologies Inc. at (781) 290-0506 ext. 300 or visit the company's Website at *www.cdt.com.* For more information about *LCMFLOT*, call (514) 843-1761 or visit the company's Website at *www.l3p.qc.ca.*

Circle 327



Tec-Ease Provides Electronic Version of ASME's GD&T Standard

Tec-Ease Inc. announced the release of an electronic version of the ASME Y14.5M-1994 Standard on geometric dimensioning and tolerancing (GD&T): *Y14.5M-1994 Standard-Ease.*

A provider of educational materials about GD&T, Tec-Ease describes the version as user-friendly, letting a person quickly find the text and graphics that fit his applications. Using a mouse, he can click on a figure referenced in a paragraph or a paragraph referenced in a figure. The desired figure or paragraph will appear in a separate viewing window.

The version includes other features:

- hotlinks of GD&T terms, paragraphs and figures;
- full search capability, which finds every occurrence of a term;
- split screen of text and graphics;
- pop-up definitions;
- an index;
- ability to zoom in on a graphic to see greater detail;
- previous and next arrows available on graphics and text.

A demonstration program can be downloaded from Tec-Ease's Website at *www.tec-ease.com.* For more information, call (888) 832-3273.

Circle 328

SolidWorks Has New Product for Making 3D, Interactive Websites

SolidWorks Corp. announced Sept. 25 a new product for creating Web pages with 3D, interactive content: *3D Instant Website.* A provider of 3D CAD software, SolidWorks described the new product as allowing "users to publish interactive 3D images with a single mouse click."

The product has templates for publishing SolidWorks designs. The customizable templates and style sheets use standard XML and XSL conventions to define the Web pages' information and presentation. Also, *3D Instant Website* supports several standard, 3D interactive viewing formats, including eDrawings, CATWeb, Metastream and RealityWave.

For more information and a product demonstration, call SolidWorks at (800) 693-9000 in America or (978) 371-5000 outside America. For an online demonstration, people can visit SolidWorks' Website at *www.solidworks.com.*

Circle 329

CORRECTION

The following companies' contact information did not appear correctly in our annual buyers guide, which appeared in the November/December 2000 issue. We apologize for any inconvenience to the companies and their customers. The corrected addresses appear below.

Acme Gear Company
130 West Forest Avenue
P.O. Box 779
Englewood, NJ 07631
Ph: (201) 568-2245
Fax: (201) 568-0282
james@acmegear.com
www.acmegear.com

ACR Industries, Inc.
15375 Twenty-Three Mile Rd.
Macomb, MI 48042
Ph: (810) 781-2800
Fax: (810) 781-0152
www.acrind.com

Becker Gearmeisters Inc.
235 Harrison Ave.
Miller Place, NY 11764
Ph: (800) 423-2537
or (631) 821-3967
Fax: (631) 821-3870
EGB4Gears@aol.com

The Cincinnati Gear Company
5657 Wooster Pike
Cincinnati, OH 45227
Ph: (513) 271-7700
Fax: (513) 271-0049
sales@cintigear.com

Clarke Gear Co.
8058 Lankershim Blvd.
North Hollywood, CA 91605
Ph: (818) 768-0690
Fax: (818) 767-5577
clarkegear@earthlink.net
www.clarkegear.com

Commercial Steel Treating Corp.
31440 Stephenson Hwy.
Madison Heights, MI 48071
Ph: (248) 588-3300
Fax: (248) 588-3534
www.commercialsteel.com

D.A. Stuart Company
4580 Weaver Parkway
Warrenville, IL 60555
Ph: (630) 393-0833
Fax: (630) 393-0834
www.d-a-stuart.com

Engineered Heat Treat, Inc.
31271 Stephenson Hwy.
Madison Heights, MI 48071
Ph: (248) 588-5141
Fax: (248) 588-6533
www.ehtinc.com

Fairfield Manufacturing Co. Inc.
U.S. 52 South
P.O. Box 7940
Lafayette, IN 47903-7940
Ph: (765) 772-4000
Fax: (765) 772-4001
sales@fairfieldmfg.com
www.fairfieldmfg.com

General Broach & Engineering, Inc.
50325 Patricia
Chesterfield, MI 48051
Ph: (810) 598-7594
Fax: (810) 949-8007
tkillop@uei-machinetool.com
www.generalbroach.com

Laser Machining, Inc.
500 Laser Drive
Somerset, WI 54025
Ph: (715) 247-3285
Fax: (715) 247-5650
tbenson@lasermachining.com
www.lasermachining.com

LMT-Fette
18013 Cleveland Pkwy, Suite 180
Cleveland, OH 44135
Ph: (800) 225-0852
or (216) 377-6130
Fax: (216) 377-0787
lmtfette@lmtfette.com
www.lmtfette.com

OSU-GearLab
The Ohio State University
206 West 18th Avenue
Columbus, Ohio 43210
Ph: (614) 292-5860
Fax: (614) 292-3163
houser.4@osu.edu

Precipart Corp.
90 Finn Court
Farmingdale, NY 11735
Ph: (631) 694-3100
Fax: (631) 694-4016
sales@precipart.com
www.precipart.com

Precision Gears, Inc.
N13 W24705 Bluemound Rd.
Pewaukee, WI 53072
Ph: (262) 542-4261
Fax: (262) 542-1592
pgears@execpc.com
www.precisiongears.com

Spline Gauges Ltd.
Piccadilly Kingsbury Near
Tamworth, Staffs. B78 2ER
England
Ph: (44) 1827-872771
Fax: (44) 1827-874128
www.splinegauges.co.uk

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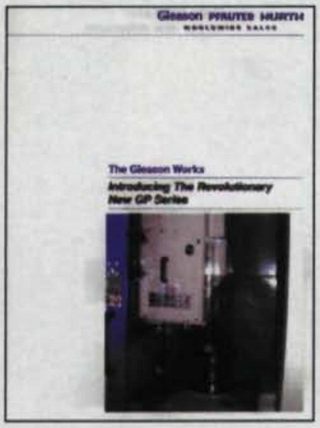
COMPONENT GEAR MANUFACTURING

Literature available from The Cincinnati Gear Company provides information covering its facilities and expertise in component gear manufacturing, including hobbing and cutting, grinding, turning, boring, milling and inspection. The brochure includes product photos and specifications, as well as manufacturing capabilities.

CIRCLE READER SERVICE #149



GLEASON INTRODUCES THE ELECTRONIC GUIDE SHAPER

Small-lot helical gear production will never be the same with the New GP300 ES Revolutionary Electronic Guide System. Users of the GP300 ES Gear Shaper can increase their chipmaking time by eliminating the need to change guides for new workpiece leads.
For more information, contact:
The Gleason Works
716-473-1000

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OLS
1231 W. Bagley Rd.
Berea, OH 44017
Phone: (440) 243-6251
Fax: (440) 243-6568
Email: *info@olsmachine.com*
Website: *www.olsmachine.com*

CIRCLE READER SERVICE #147

AUSTEMPERING IMPROVES MATERIAL TOUGHNESS

Our 8-page brochure is an information-packed guide to the Austempering process, a high performance heat treatment for ductile iron, gray iron, and steel for improved toughness, wear resistance, and fatigue strength. Learn how to boost product performance, and reduce costs.
Call Applied Process, Inc., 734-464-2030 or visit http://www.appliedprocess.com

CIRCLE READER SERVICE #169

DURA-BAR

Continuous cast iron from Dura-Bar performs like free-machining steel but with 10% less weight. And Dura-Bar's superior noise and vibration damping characteristics make for quieter running gears. Available in diameters from 5/8"-20" and lengths of 6'-20'. Contact Dura-Bar for the latest data on gear noise.

Phone: 800-227-6455
Fax: 815-338-1549
E-Mail: ***sales@dura-bar.com***
Internet: ***http://www.dura-bar.com***

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GLEASON CUTTING TOOLS CORPORATION

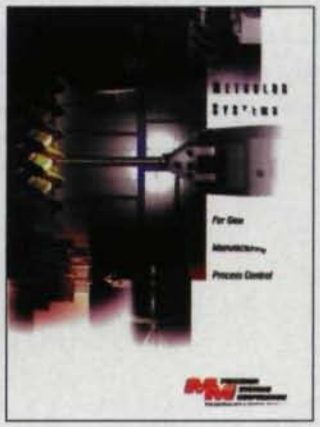
A full color catalog showing the product capabilities of our worldwide and Loves Park, Illinois facilities. We manufacture high-speed steel and carbide hobs, shaper cutters, shaving cutters, bevel blades, form cutters, CBN wheels and thin film coatings. Heat-treat, resharpening and recoating services are available.
Gleason Cutting Tools Corporation
Telephone 815-877-8900
E-mail: *gctc@gleason.com*

CIRCLE READER SERVICE #153

METRIC GEARS

NEW 456–page catalog features technical specs for over 3400 standardized metric gear components: spur, helical and internal gears, straight and helical racks, straight and spiral bevel gears, worm and worm gears, and more in modules 0.5-10.
Quality Transmission Components
2101 Jericho Tpk, Box 5416
New Hyde Park, NY 11042
PHONE: 516-437-6700
FAX: 800-737-7436
WEB: http://www.qtcgears.com

CIRCLE READER SERVICE #144



METROLOGY SYSTEMS

M&M metrology systems are designed for universal application and ease of operation-making them ideal for a wide range of inspection and process control tasks. This brochure describes how they employ **generative motion** via **linear interpolation** for lead and involute measurement. M&M software can be used on remote or networked PC's for SPC study or data entry. For a free copy, call 937-859-8273 or fax 937-859-4452.

CIRCLE READER SERVICE #152

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Manufacturing Technologies Contribute Almost $1 Trillion to Economic Progress, Study Says

The Association For Manufacturing Technology released a new study which concluded that machine tools and related advanced manufacturing technologies contributed nearly $1 trillion to the country's economic progress during the past five years.

The study, *Producing Prosperity—Manufacturing Technology's Unmeasured Role in Economic Expansion,* explains why the growth in durable goods-producing industries is not the full measure of the benefits associated with advanced manufacturing technologies.

"Machine tools and technologies other than computers and microprocessors receive inadequate credit for America's prosperity," said the study's author, Joel Popkin of Joel Popkin and Company, Washington, D.C.-based economic consultants.

"For the last several years, a puzzling gap has existed between what traditional economics was telling us about productivity and what the economy has actually done," said Association President Don F. Carlson. "This study allows us to see the light. Moreover, because it is focused on only the manufacturing technology industry, this study may well be only the tip of the iceberg. It is likely that other manufacturing industries have a similar tale to tell."

According to the study, productivity gains in manufacturing fostered other benefits:

- *Gains in labor productivity in the* durable goods industry created an extra $618 billion of output (in 1996 dollars) during the 1992–1998 period.
- Those producers saved $25.3 billion in carrying costs between 1992 and 1997 because of a decline in inventory requirements per dollar of sales attributable to advanced manufacturing processes.
- Eight key industries—including metal foundries, fabricated structural metal and other industrial machinery—saved a combined total of $24.3 billion in payroll costs in 1997 alone—and $80 billion between 1992 and 1997—because of productivity increases.
- The gains saved slightly more than $100 billion in the cost of consumer durable goods from 1996 to 1999.
- Consumers are saving billions from product quality improvements, like cars with higher fuel efficiency, which saved $50 billion in 1999.

Also according to the study, many people have benefited from the advances, including:

- Manufacturers, who make higher-quality products faster and at lower cost;
- Consumers, who pay less for higher quality goods that perform better and last longer; and
- Workers in the manufacturing sector, who acquire new skills and earn higher real wages.

People can get a copy of the report by downloading it from *www.mfgtech.org.*

Machine tool consumption goes up 19 percent in September, Associations Say

U.S. machine tool consumption increased 19 percent in September, to an estimated $581 million, according to the American Machine Tool Distributors' Association and The Association For Manufacturing Technology.

That increase was compared with the revised estimate of $487 million for August. September's estimated total was also an increase of 9 percent compared with the estimated $531 million for September 1999. For the year-to-date, consumption was an estimated $4.5 billion, up 3 percent compared with the same period in 1999.

Those estimated figures were extrapolated from data submitted by companies participating in the United States Machine Tool Consumption report.

Also, U.S. machine tool consumption was broken down into five regions. The regional figures are based on actual data from the report's participating companies and are as follows:

Northeast Region—Consumption rose from $49.4 million in August to $68.05 million in September, a 37.7 percent increase. September's consumption was up 10.5 percent compared with last September. For the year-to-date, consumption totaled $543.95 million, a 10.2 percent increase compared with the same period in 1999.

Southern Region—Consumption rose from $49.51 million in August to $52.93 million in September, a 6.9 percent increase. But, September's consumption was down 11.2 percent compared with last September. For the year-to-date, consumption totaled $500.67 million, a drop of 0.1 percent compared with the same period in 1999.

Midwestern Region—Consumption rose from $146.06 million in August to $171.94 million in September, a 17.7 percent increase. But, September's consumption was down 2.8 percent compared with last September. For the year-to-date, consumption totaled $1.26 billion, a drop of 10.1 percent compared with the same period in 1999.

Central Region—Consumption rose from $60.74 million in August to $76.19 million in September, a 25.4 percent increase. September's consumption was up 14.3 percent compared with last September. For the year-to-date, consumption totaled $558.69 million, a 5.2 percent increase compared with the same period in 1999.

Western Region—Consumption rose from $64.35 million in August to $72.17 million in September, a 12.2 percent increase. September's consumption was up 84.6 percent compared with last September. For the year-to-date, consumption totaled $516.68 million, a 50.9 percent increase compared with the same period in 1999.

Philadelphia Gear Announces Reorganization Plan

Philadelphia Gear Corp. announced Nov. 10 that it is reorganizing its manufacturing and service operations.

The reorganization is part of the company's nationwide strategic plan. Under its plan, the company will be closing its Philadelphia manufacturing plant, but it will expand its four regional service centers to include engineering and manufacturing capabilities and will open a fifth center.

A manufacturer of large, high capacity precision gears, Philadelphia Gear has centers in Chicago, Houston, Los Angeles and Newport, DE. The fifth center will open in Birmingham, AL, in 2001. Also, the company will move its Newport center to nearby New Castle, DE.

"Our strategic plan, which we've been implementing over the past few years, is designed to help reduce lifecycle costs for power transmission equipment for our customers," said Gerry Rooney, Philadelphia Gear's president and CEO. "Our facilities, which are in close proximity to most of our customers, will allow us to maximize our levels of support and service."

Philadelphia Gear also announced that it will move its gear manufacturing operation from King of Prussia, PA, to its Los Angeles operation. Key administration, MIS, sales, support and engineering personnel will move to new offices in Norristown, PA.

"Internet technology allows us to put our operations near the customer, yet have real-time access to our world-class engineering staff in Norristown," Rooney said.

Timken Company to Sell U.K. Tool and Die Steel Operations

Timken Company announced Oct. 17 that it intended to sell the tool and die steel operations of Timken Latrobe Steel—Europe to a group of private local investors. According to Timken, the buyers intended to continue the business, offering customers a full range of products.

Having signed a letter of intent to sell, Timken said it has started consultations for transferring the Sheffield, England-based tool and die steel operations. Timken added it would refocus its growing high-speed steel business in the United Kingdom as part of Timken Desford Steel's operations.

The sale of the tool and die steel operations was expected to be complete by the end of the year.

Tell Us What You Think . . .

If you found these items of interest and/or useful, please **circle 332.**

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If you would like to respond to this or any other article in this edition of *Gear Technology*, please fax your response to the attention of Randy Stott, managing editor, at 847-437-6618 or send e-mail messages to *people@geartechnology.com.*

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

Inductoheat Announces New Stationary Process for Hardening Crankshafts

Inductoheat Inc. announced its new stationary hardening process for crankshafts that doesn't involve crankshaft rotation.

A manufacturer of induction heating equipment, Inductoheat said the system hardens and tempers V8, V6 or 4-cylinder crankshafts in one quarter of the floor space of traditional systems–while providing four times the tooling life. According to Inductoheat, the system's other advantages include low cost, low part distortion, maintainability, modular tooling, offline part qualification, reliability and simple operation.

For more information, call 248-585-9393 or visit Inductoheat's Website at *www.inductoheat.com.*

Circle 335

Brown & Sharpe Has New CMMs with Single-point Probing, High Speed Scanning

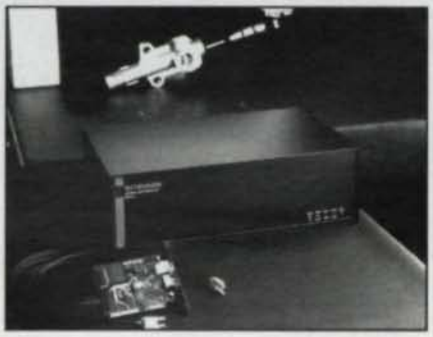
Brown & Sharpe announced it has combined single-point probing and high speed scanning in its new Global series of coordinate measuring machines (CMMs).

The CMMs can be equipped with different sensors and software for a wide range of measurement and inspection tasks, including first piece inspection, layout inspection, reverse engineering, tool set up, process control and storage.

Global CMMs are available in two configurations, status and image, with measuring ranges from X 900 millimeters, Y 1200 millimeters, Z 800 millimeters to X 1200 millimeters, Y 3000 millimeters, Z 800 millimeters.

For more information, contact Brown & Sharpe, 200 Frenchtown Road, North Kingstown, RI 02852-1700, Phone: (800) 766-4673, Fax: (401) 886-2552, Web: *www.brownandsharpe.com.*

Circle 336



Renishaw Offers New Universal CMM Controller

Renishaw has a new UCC 1 universal CMM controller best suited for OEM and retrofit applications on a variety of CMMs.

Renishaw said the new controller optimizes the CMM/probe interface for maximum part check speed and accuracy and combines a super-fast scanning capability with easy-to-install, easy-to-use operation to boost inspection efficiency and throughput.

Using the controller, speeds greater than 300 mm/sec. (12 in./sec.) can be achieved. Also, in tests using a CMM with a Renishaw SP600M scanning probe, a 100 mm (4 in.) ring gage was scanned at 100 mm/sec. (4 in./sec.) with a resulting form deviation of less than 2 μm (0.00008 in.).

The UCC 1 supports a range of CMM probe systems, like conventional touch-trigger; strain gage and laser probes; manual and motorized probe heads; probe and stylus changers; and the servo positioning systems.

For more information, contact Denis Zayia, CMM products manager, at Renishaw Inc., Phone: (847) 843-3666, Fax: (847) 843-1744.

Circle 337

Heartech Precision Announces Press Fit Tooling

Heartech Precision Inc. announced Nikken Press Fit tooling. HPI said the tooling allows for deep cavity, die/mold and standard end mill fixturing that is less expensive than conventional shrink fit setups, with tooling changeovers possible in as few as ten seconds.

With the Press Fit system, clearance is uniform, runout accuracy is less than 3 microns and direct face contact is made and maintained. Also, the system has 0.01 taper and bumper pin technology, which HPI said provides unmatched gripping torque. Heartech added that those features create much greater cutting capability, especially in deep cavity and die/mold applications.

For more information on the Nikken tooling system, contact Preben Hansen, national sales manager, at Heartech Precision Inc., 1299 Lunt Ave., Elk Grove Village, IL 60007-5617, Phone: (847) 593-6000, Fax: (847) 593-6005, Website: *www.hpi-heartech.com,* E-mail: *sales@hpi-heartech.com.*

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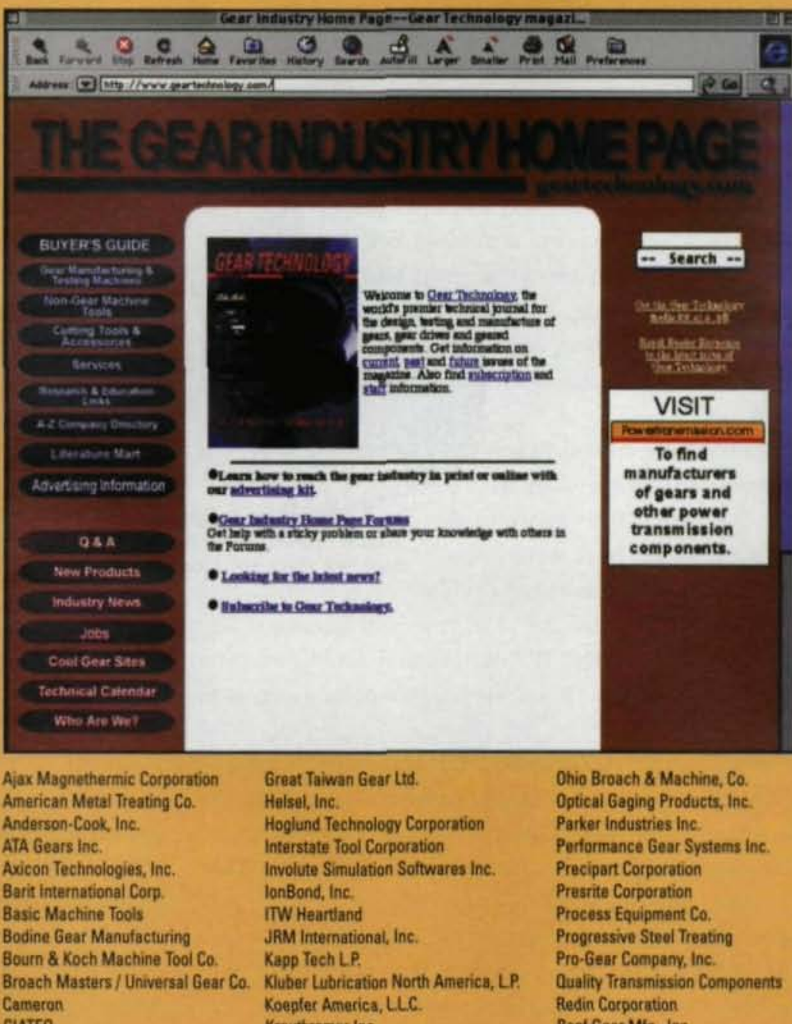

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CIRCLE 184

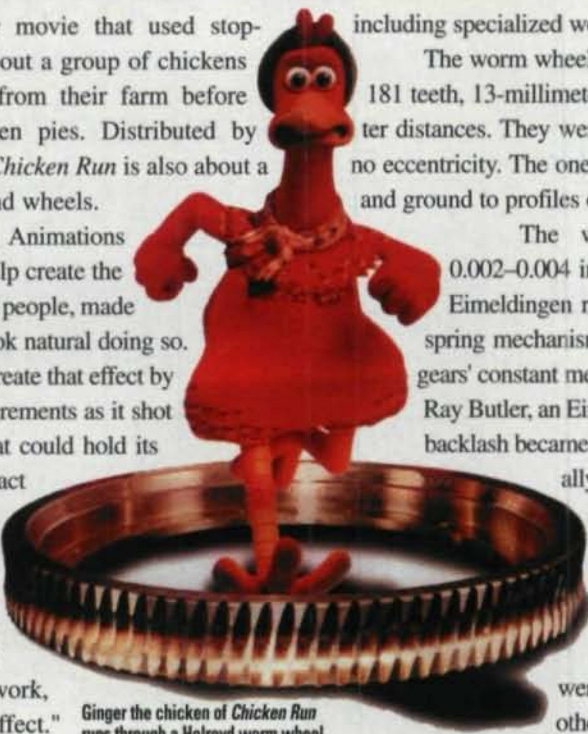
Special Gears Help Hatch a Summer Movie

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

Chicken Run—the summer movie that used stop-motion clay figures—is about a group of chickens laying a plan to escape from their farm before they're turned into chicken pies. Distributed by Steven Spielberg's DreamWorks, *Chicken Run* is also about a group of specially-made worms and wheels.

To make its movie, Aardman Animations needed special wormgear sets to help create the movie's special effect: chickens and people, made of clay, who walk and talk—and look natural doing so. The British movie company could create that effect by moving the clay figures in small increments as it shot a scene, but it needed a camera that could hold its exact position and repeat its exact motion in a scene as figures were slightly adjusted, again and again and again.

"That's what was critical," says Tom Barnes, the movie's technical director. "Because of the way we work, just about everything is a special effect."



Ginger the chicken of *Chicken Run* runs through a Holroyd worm wheel.

"A simple shot may take weeks to film," he adds, explaining that a camera might move only 3 degrees or 4 degrees in one shot, but might move those few degrees over several weeks—perhaps 1 degree a week. "It was very important for a camera to hold a position accurately."

To get such cameras, Aardman needed new camera mounts. According to Barnes, the company's cameras were from the 1930s, with old, manual mounts that had been motorized.

"They were not particularly backlash free," he says. "They were not very stable mechanically overall."

Aardman arranged to buy new mounts made by Eimeldingen UK Ltd. of Bath. Eimeldingen produces precision rotary tables. Inside those mounts were specially-made wormgear sets from Holroyd, key parts in the mounts and the success of the movie.

"If there had been backlash problems, then we would not have been able to make the film the way that we wanted to," says Alan Gregory, Aardman's mechanical development engineer.

"The film is all about creating an illusion," Barnes says. "Anything that makes the film look awkward takes away from the audience's attention to the film."

Aardman needed gear sets that provided a gearbox ratio of 181:1, based on the camera's weight and the weights of various lenses that might be used. Holroyd provided those gear sets. Based in Milnrow, England, Holroyd makes precision gears—including specialized wormgears.

The worm wheels were made of phosphor bronze, with 181 teeth, 13-millimeter face widths and 100-millimeter center distances. They were precision ground to have practically no eccentricity. The one-start worm shafts were case hardened and ground to profiles of 5 microns.

The wormgear sets had backlashes of 0.002–0.004 inches, so the cameras wouldn't vibrate. Eimeldingen reduced the backlash even more with a spring mechanism in the camera mount to maintain the gears' constant meshing and to compensate for wear. Ray Butler, an Eimeldingen senior engineer, estimates the backlash became about 10 times smaller, making it virtually zero. "It becomes difficult to measure at that level," he says, "but about 10 times."

Barnes says the new wormgear sets improved the appearance of *Chicken Run* in two ways: "Any camera moves were smoother than they would have been otherwise" and "The repetition was more accurate and consistent."

Each camera mount had two wormgear sets, one set for movement on the horizontal axis and one set for movement on the vertical axis. The sets provided 360 degrees of movement on both axes.

"We wanted the 360 degrees of movement to give us the flexibility we required," Barnes says.

With new mounts, the cameras could be moved to almost any angle and be remotely controlled by computer. The controls permitted movement in fine increments and with precise positioning, providing the required camera angles and distances.

With cameras able to repeat their moves more accurately and consistently, Aardman could reduce the number of scenes that had to be corrected or reshot after production. The new mounts, about 30, were used every day. Aardman needed a year and a half to make *Chicken Run*, which was shot in Bristol, England.

"They performed faultlessly," Barnes says of the gear sets, "I couldn't have wished them to be better." ○

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