GEAR TECHNOLOGY

NOVEMBER/DECEMBER 1999

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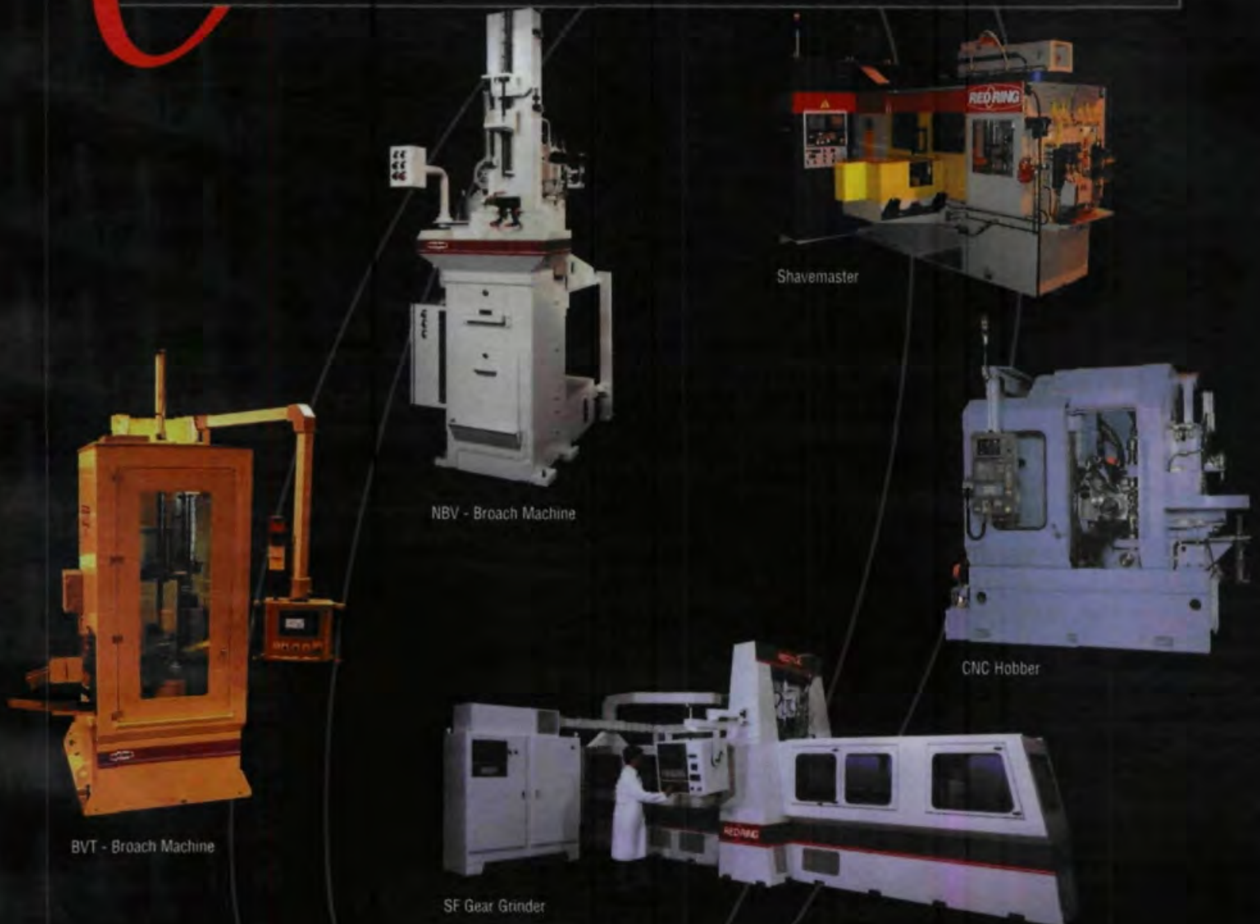

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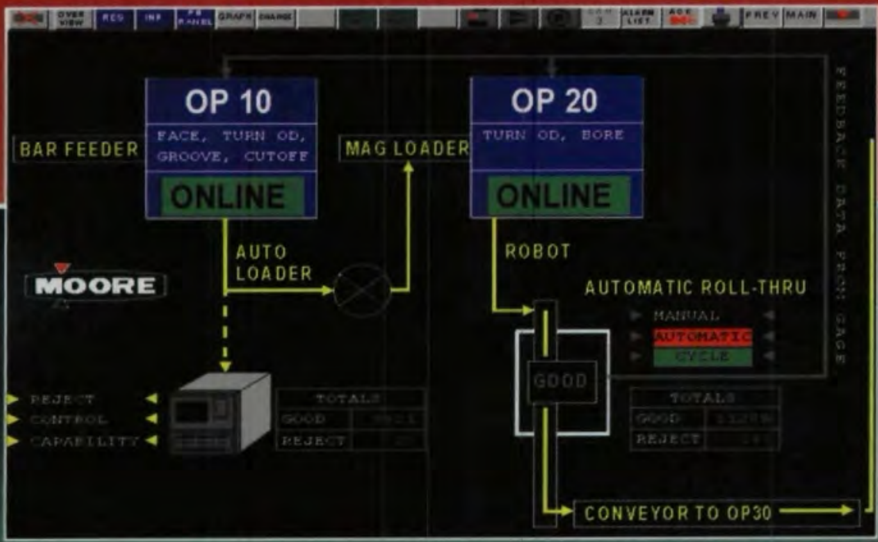

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The Success of Our Customers

No matter what business you're in, you need customers. More importantly, you need customers who can and want to pay for your goods or services. It's in our best interest to do everything we can to make sure our customers are successful with the products or services they buy from us, as I believe that our wages are paid not by our companies but by their customers.

This is true of any business—for publishers as well as gear manufacturers. For example, if an advertiser places an ad and forgets important information, like his phone number, it's more than being nice—it's good business—when I inform him that it would be wise to include it.

If the advertiser places an ad and he gets no response, whose fault is it? Does it matter? From my perspective, what matters is that he's not going to be successful with our magazine, and he's not likely to advertise again. What I want is more customers, not fewer, so if there's anything I can do to make him more successful, it's in my best interests to make sure he doesn't fail.

Sometimes it's easier to see these things when you're the customer. I've recently had an experience I'd like to share with you.

Not long ago we purchased a new computer for our office, directly from Micron Technology, Inc., one of America's largest mail order computer suppliers. We have several other Micron machines, and each of them has always performed well.

When this particular machine arrived, we found that for some reason it would not connect to our Novell network. We couldn't understand the reason, because every other machine we had ever bought, including our other Microns, attached to the network with no problem, right out of the box. Of course, we consulted Micron, and they were extremely diligent in trying to help us solve our problem. They had us send the machine back to them, where they worked on it, swapped out some parts, and tested it.

However, when we received the machine back, it still didn't work. Micron continued to work with us to try to solve the problem, and eventually we were put in touch with one of their Novell-certified network engineers. He, too, was baffled. From what he told us, the machine was supposed to do what we wanted and needed, and there should be no reason why it would not work for us.

This went on for some time. Finally, I received a letter from Micron's "Office of the President," which informed me that Micron was washing its hands of the problem, that they were unable to support 3rd party software (which in our case meant Novell). Despite all the efforts of the customer service people and the engineers who tried to help us along the way, this one letter made me feel as though the company didn't care that their product wasn't doing what they or I expected it to do. I responded with a letter of my own, expressing these feelings and asking what I was supposed to do with the machine now. Was I just out of luck?

Micron has yet to respond. Right now, the machine is sitting in a corner of our office, back in its box, and it hasn't been touched for months.

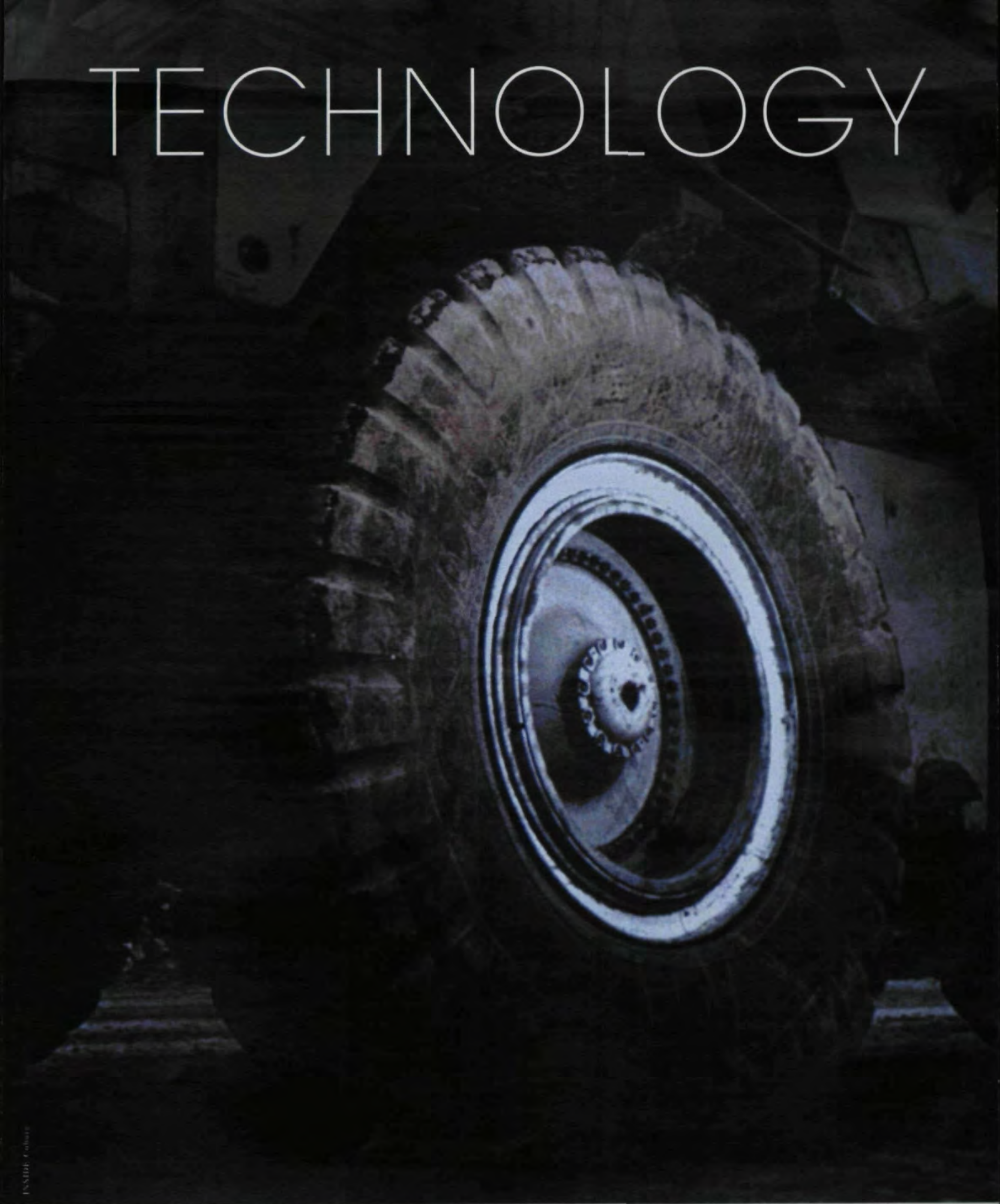
The really unfortunate thing is that except for the office of the president, Micron seems to have its act together. In fact, some of their sales literature sounds almost like I could have written it myself. The "About Micron" section of the company's Web page begins: "Micron Electronics is preparing for success. Your success." The section titled "Vision," ends with the statement "...ultimately, your success is our success...and we want to win."

How is it, then, that I fell through the cracks?

It seems to me that it's an awful waste for Micron to have spent all that time and money trying to help me only to have their "Office of the President" decide that doing business with me wasn't worth their time anymore. With one decision, the company's management not only undid all the goodwill that its employees had worked so hard to build, but they've caused irreparable damage to a relationship with a customer who, under other circumstances, would have bought from them again.

I understand the concept of cutting your losses, of not throwing good money after bad. Perhaps there are mitigating circumstances about which I am unaware. All I know is that I have a computer that won't work for me, and I feel as though I've been let down. I wonder if Micron's employees feel the same way.

Michael Goldstein,
Publisher and Editor-in-Chief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Land Speed Champion: The Turbinator III

The machine is called a streamliner. It is thirty-one feet in length and three feet wide. It weighs 3,400 lbs. and looks like something out of a science fiction movie. It's the Turbinator III and it's the machine that Don Vesco used when he broke the land speed record for wheel-driven, gas turbine automobiles (as opposed to thrust vehicles that use jet engines to reach speeds over 700 mph) out at Utah's Bonneville Salt Flats this year. Vesco's record-breaking speed was 417.529 miles per hour. To accomplish this, Team Vesco put an Avco Lycoming T-55-L 11A SA gas turbine helicopter engine in the car. The engine generates 3,750 horsepower at 16,000 rev/min—more than enough to push the Turbinator III to record-breaking speeds. In theory, the Lycoming could push the car past 600 miles per hour, 100 miles per hour or more over the tires' top rated speed!

Of course, speed isn't everything. There is also traction.

At speed, the tires are almost never firmly on the ground at the same time. According to Don Vesco, the driver, mechanic and co-designer of the Turbinator, the tires jump and skip over sections of the 11-mile course. This subjects the driver to vision-blurring vibrations and the drive train to varying loads as the car builds up speed and races for the finish line. That is in addition to the 9,000 lbs. of gear-stripping torque coming out of the Lycoming Turbine engine. That's enough to give any transmission designer night sweats.

The solution that Vesco and his gear designer, Bob Hodgkinson, came up with was to eliminate the transmission entirely. Instead, they built a gear reducer with three gears made from Carpenter's Aermet 100 steel. This, coupled with the locked 1:1 front and rear differentials, means that the Turbinator's drive train is actually a direct drive system. "We wanted to make the system as bullet proof as possible," Vesco explained. "The gears are AGMA 12 and were cut and ground from a single bar of Aermet 100 with the shafts integral to the gears." This allowed them to increase the strength of the parts and avoid the problems associated with shafts flexing and moving in their bearings.

What made this possible was the engine itself. According to Vesco, it is the turbine engine's blades, not the engine's power plant, that turn the driveshaft and the wheels. "It's basically an engine with a hollow output shaft running through the middle," said Vesco. "The output shaft comes out the front and has four fan blades in the back. The exhaust from the engine turns these fan blades. The fan blades, as they turn, drive the car." This means that the engine itself acts like a torque converter in an automatic transmission in that it builds up, yet never provides full power to the wheels due to a slight energy loss in the turbine itself. Therefore, it takes a little time for the wheels to catch up to the power plant.

The wheels aren't the only things that have to catch up to the power plant. It's taken Vesco himself a few runs to get used to driving that fast. "At first I was amazed, five miles gone and I didn't realize it," he said. "Now, I'm waiting for it. My mind is going as fast as the car." Today, that speed is 417.529 miles per hour. Next year, 500 miles per hour will be within their grasp. "With our highest ratio gear reducer and enough track, the car could probably go as fast as 700 miles per hour," said Vesco. "But right now, that's not realistic." Perhaps, but it is only a matter of time.

Circle 251

Don Vesco and the Turbinator III. Courtesy of Team Vesco.

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.

Holographic Measurements in 3D

Non-contact measuring systems have been electro-optical or laser-based in nature, the first taking a digital image of the part under inspection and comparing it to a digital nominal part, the second using lasers as a kind of touch probe. Both are precise methods, but the folks at Optimet believe that they have come up with something better. They have introduced holographic measurement to the art of gear metrology.

Optimet, a division of Ophir Optronics, Inc., has just developed a new way to precisely measure parts. Called the Conoprobe 1000, the unit is a general purpose, non-contact measurement probe that uses the concept of conoscopic holographic measurement to create three-dimensional digital images of the parts it measures quickly and from remarkable distances.

What is Conoscopic Holography? In regular holography, a three-dimensional image is formed when an interference pattern is created between two coherent light sources, such as lasers. The beams from these light sources, called the object beam and the reference beam, travel at the same speed but they follow differing courses. This creates what is called the Gabor Zone Lens (named after Denis Gabor, the Hungarian physicist who discovered holography in 1947) and the image.

Conoscopic holography is slightly different. It uses the ordinary and extraordinary components of a single coherent light beam passing through a uni-axial crystal to create the hologram. This conoscopic hologram has fringe periods that can be precisely measured.

The Conoprobe 1000. Courtesy of Optimet.

The Technology. This method uses concentric optics that function regardless of their position to key optical elements, making the system flexible and rugged while maintaining repeatable precision to $1/8000^{th}$ of the working range. The scale of the measurement, from sub-microns to meters, is adjusted by changing the objective lens on the probe. And because the probe is collinear, changing over to bending optics will permit measurements to be taken around blind corners.

The new system is also surface independent, meaning that it can create holograms from a greater variety of surfaces than previous non-contact methods. This includes very shiny objects as well as those with wide variations in reflectivity. It is also capable of working very close to grazing incidence, a mere five-degrees from normal incidence in all directions.

The Conoprobe 1000. Designed to be integrated into existing measurement systems, The Conoprobe 1000 is capable of taking up to 700 data points per minute while the probe is in motion. This permits the unit to develop precise holographic images of virtually any part including machine parts and tools, plastic and rubber industrial molds and components, auto parts, electronic parts and more.

Circle 252

The Coriolis Drive

It all started with an observation made over a century ago. If you lay two coins of the same size next to each other on a table and then roll one around the other, the coin in motion will rotate 720°. Why? The answer to this question, called the "Two Penny Paradox," is as valid for gears as it is for pennies and, according to Ken L. Baker, a design engineer for Fleetwood Systems, Inc., of Romeoville, Illinois, it is the basis for the Coriolis force, the principal upon which his Coriolis drive works.

According to Baker, the way that the Coriolis drive relates to the two penny paradox is like this: "A wheel turns around another wheel and it goes around two times, once because of the distance it has travelled and once because of the shape of the path." This is an example of a law in physics called conservation of angular momentum. The penny has to move an equal distance in two directions; therefore it has to rotate twice.

The same principal makes a rotating disk wobble as gravity pulls it down. "Roll a coin across a table and observe its motion after it begins to topple," said Baker. "It's propelled by linear momentum and rotational inertia while under the influence of gravity. it swerves into an ever-tightening spiral course and eventually starts wobbling around a single point. If you look at it closely, you'll see that it is rotating backwards."

Geometry can explain part of the phenomenon. Due to the angle of incline that the coin makes with the table, the radius of the path (and therefore its circumference) is shorter than that of the coin. "For each trip around the path," Baker explains, "the coin is required to make less than one complete rotation. At 1:1, no rotation at all would be required, but at greater differentials the rotation reverses for exactly the same reasons that cause the Two Penny Paradox." From that coin wobbling on the table it is just a short leap of the imagination to Baker's machine.

Baker's Coriolis Drive takes advantage of the difference in rotation between the wobbling action and the revolving action to act as a gearless speed reducer. With Baker's device, when you start it spinning, all it does is spin. But when you start it wobbling, some of that spinning motion is converted into that wobbling action. "For example, if you have it revolving at a speed of 100 rpm and it begins to wobble, and that wobble causes a 1 rpm precession motion, the original rotational speed will drop to 99 rpm." Taken together, the two rotational speeds still equal 100 rpm. This satisfies the law of conservation of angular momentum. What determines the amount of precession is the amount of wobbling. "The greater the force that wants it to fall (wobble)," explained Baker, "the greater the force that wants it to precess."

Rather than create the wobble with gravity, Baker chose to do it mechanically, to force the wheel to tilt. "The tilt will, itself, pull enough energy out of the wheel's rotation to cause the wheel to precess," said Baker. "I'll use that energy. That's my gear reduction. I'm leveraging one spinning motion against another spinning motion the way that gears leverage the short radius of one gear against the long radius of another gear. Gears use geometry, and what I'm using is physics. But both of them come from the same mathematics. They come from the same science."

Baker has developed a working demonstration model of his Coriolis drive that he is currently in the process of refining. Apart from bearings and a frame, the machine has only four moving parts—a drive shaft and disc mounted off center at an incline, a rotor on a fixed axle, a flexible universal-type coupling and an output shaft.

According to Baker, "The offset of the disc is what maintains a fixed angle of precession, as the central perpendicular axis of the disc is coaxial with that of the rotor. A projected extension of this inclined axis would intersect the major input/output axis at the exact center of the universal joint. Thus, by rotating the input shaft, the rotor and its axis are forced to precess about the major axis of the universal joint. This precessional motion induces rotation into the rotor, which causes the output shaft to rotate in the same direction and with the same force."

While Baker freely admits that there are a number of applications where a Coriolis drive would not be a viable alternative to gears, he also holds that there are quite a few areas where his invention would, as he puts it, "outshine a gear motor and perform the same task more efficiently."

These applications include variable speed, low-friction motors and transmissions for applications ranging from small power tools, lawnmowers and pumps to motorcycle and helicopter engines and diesel locomotives.

Circle 253

Where You Want To Be

AGMA has just released a new 14-minute video designed to introduce students to the gear industry. The video, called "Where You Want To Be: An Introduction to the Gear Industry," was a cooperative venture between AGMA's Education Council and the AGMA Foundation. The project was undertaken to increase awareness of the gear manufacturing industry as a career option for high school and trade school students and their families. Twenty-eight gear manufacturers contributed to the AGMA Foundation in support of this effort.

The video presents gear manufacturing as an industry featuring modern, clean, high-tech facilities where employees will be trained to use the latest in computerized and electronic machinery. It also describes the gear industry as being competitive in pay and benefits, geographically distributed across the country in both rural and urban areas, and offering positions ranging from machining to design to management. Finally, gear manufacturers are shown as companies where a positive attitude will buy the opportunity to work in a dynamic and challenging atmosphere producing the high precision products that keep America competitive and on the move.

Copies of the video will be provided free of charge to AGMA member companies, and additional copies can be purchased from AGMA. Brochures, which support the message of the video, are also available. Gear manufacturers are encouraged to contact their local secondary and trade schools and provide copies of the video and brochures to the guidance staff. To obtain copies of the video and brochures, contact AGMA at (703) 684-0211.

Circle 254

Correction

We apologize for, and wish to correct, the following errors that appeared in the *Revolutions* article featuring Falk Corporation in the September/October 1999 issue of *Gear Technology*.

The name "Fimeston" should be spelled "Fimiston." The OEM for the mill located at Fimiston Mines is FFE Minerals of Australia. The flanges of Falk's large gears are locked together with tapered steel dowels, not locking pins. The pinions mating with these large gears are finished to AGMA 12 levels, not the ring gears themselves. Ring gear segments are finish cut to AGMA 10 tolerances with average tooth finishes falling around 63 to 100 RMS (not RMF). Average tooth finish is required because there are areas that could get as high as 125 RMS, and typical consultant specifications require a maximum of 125 RMS.

Again, *Gear Technology* apologizes for any confusion, inconvenience or consternation these errors might have caused.

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Definition and Inspection of Profile and Lead of a Worm Wheel

Dr. Donald R. Houser and Dr. Xiaogen Su

Introduction

Traditionally, profile and lead inspections have been indispensable portions of a standard inspection of an involute gear. This also holds true for the worm of a worm gear drive (Ref. 1). But the inspection of the profile and the lead is rarely performed on a worm wheel. One of the main reasons is our inability to make good definitions of these two elements (profile and lead) for the worm wheel. Several researchers have proposed methods for profile and lead inspections of a worm wheel using CNC machines or regular involute measuring machines. Hu and Pennell measured a worm wheel's profile in an "involute" section and the lead on the "pitch" cylinder (Ref. 2). This method is applicable to a convolute helicoid worm drive with a crossing angle of 90° because the wheel profile in one of the offset axial planes is rectilinear. This straight profile generates an involute on the generated worm wheel. Unfortunately, because of the hob oversize, the crossing angle between the hob and the worm wheel always deviates from 90° by the swivel angle. Thus, this method can be implemented only approximately by ignoring the swivel angle. Another shortcoming of this method is that there is only one profile and one lead on each flank. If the scanned points deviate from this curve, it produces unreal profile deviation. Octrue discussed profile inspection using a profile checking machine (Ref. 3).

If the swivel angle is not ignored, the involute profile used in Reference 2 does not exist, and the profile equation developed in Reference 3 does not apply. Thus, profile and lead inspection is not often performed to qualify a worm wheel. To verify the compatibility of the wheel tooth with that of a mating worm, the wheel is assembled with a master worm on a test rig and a rolling test is performed (Ref. 1). The contact pattern developed by painting the worm is used to judge the quality. This kind of rolling test works well in terms of functionality, but it does not give enough quantitative data to the designer and the hobbing machine operator. In other words, the rolling test results cannot be fully used for quality improvement.

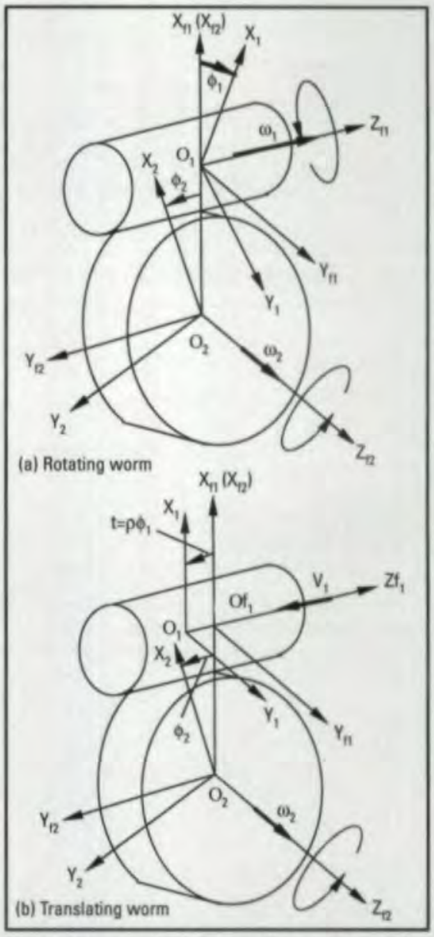

Fig. 1—Two equivalent meshing motions of a worm gear drive.

NOMENCLATURE

E	Center distance between the hob/worm axis and the wheel axis while meshing
X_1	$= [x_1, y_1, z_1]^T$, worm surface point vector
X_2	$= [x_2, y_2, z_2]^T$, wheel tooth surface point vector
m_{21}	The gear ratio (number of worm threads / number of wheel teeth)
n_1	$= [n_{x1}, n_{y1}, n_{z1}]^T$, normal vector at a worm surface point
t	$= -p\phi_1$, equivalent translation displacement of the worm
u	Surface parameter on the worm thread in radial direction
v_i^{12}	The relative velocity between part 1 (hob/worm) and part 2 (wheel) while meshing
α	Profile angle of the grinder
γ	Crossing angle between the worm axis and the wheel axis while meshing
ϕ_1	The worm rotation angle while meshing
θ	Surface parameter on the worm thread in circumferential direction
ρ	Screw parameter of the hob/worm, equal to the lead divided by 2π

Dr. Donald R. Houser

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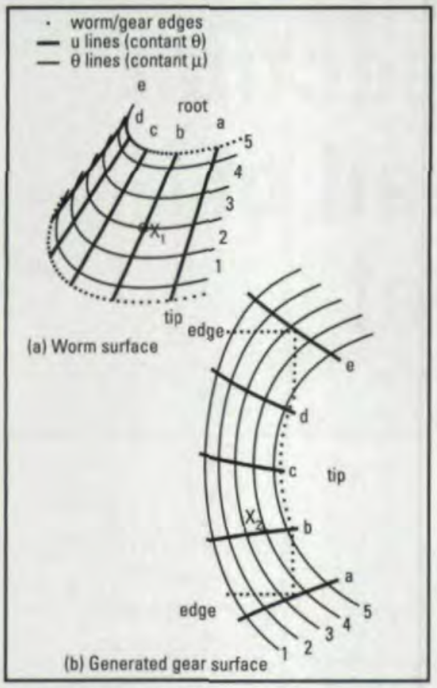

Fig. 2—*u* lines and *θ* lines of a ZK worm wheel.

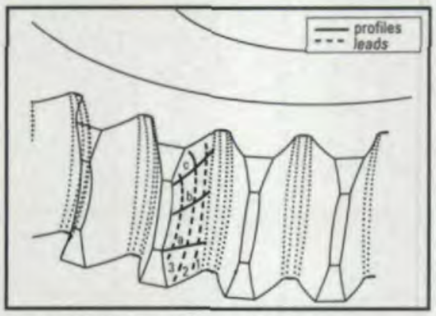

Fig. 3—Multiple profiles and leads.

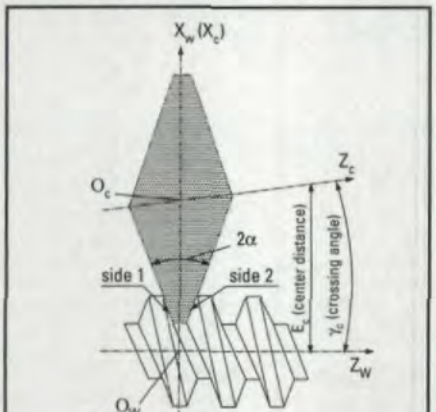

Fig. 4—Grinder for ZK-type of worm.

In this article, an explicit equation of the generated wheel tooth is derived. This equation applies to any type of single enveloping worm gearing. The crossing angle between the hob/worm axis and the wheel axis is not limited to 90°. Thus, this equation can also be used for non-right-angle worm gearing. Based on the explicit tooth equation, profiles and leads of a worm wheel are redefined. The new definitions are comparable to their counterparts of an involute gear. There are an infinite number of profiles (at different "face positions") and leads (at different "diameters"), as there are on an involute gear. All of the profile and lead curves can be expressed explicitly and can be readily measured by a CNC measuring machine. Inspection examples are given (a CMM is used for the measurement) to illustrate the application.

Explicit Expression of the Generated Worm Wheel Tooth

The geometry of a generated worm wheel is very complex. An explicit equation of the wheel tooth surface has not been found before. The traditional expression of the generated worm wheel tooth, as presented in Reference 4, is in the form of:

$$X = X(u, \theta, \phi_1) \qquad (1)$$

$$\text{Subject to } f(u, \theta, \phi_1) = 0 \qquad (2)$$

The constraint $f = (u, \theta, \phi_1)$ is the equation of meshing for cutting. The commonly used equation of meshing for worm gear drives was proposed by Litvin (Ref. 5). It is:

$$(z_1\cos\phi_1 + E\cot\gamma\sin\phi_1)\,n_{x1} + (-z_1\sin\phi_1 + E\cot\gamma\cos\phi_1)\,n_{y1} - \left[(x_1\cos\phi_1 - y_1\sin\phi_1 + E) - \rho\,\frac{1-m_{21}\cos\gamma}{m_{21}\sin\gamma}\right] n_{z1} = 0 \quad (3)$$

where $X_1 = [x_1, y_1, z_1]^T$ is the surface point vector and $n_1 = [n_{x1}, n_{y1}, n_{z1}]^T$ is the corresponding normal vector of the worm thread surface in a coordinate system attached to the worm itself (See Fig. 1). The expression $X_1 = X_1(u, \theta)$ of the worm thread of various types of single enveloping worm gear drives can be found in Reference 5.

Equation 3 has three parameters: u, θ and ϕ_1. Here u and θ are the two surface parameters of the meshing worm surface and variable ϕ_1 is the meshing parameter (the worm rotation angle in this equation). It is difficult to explicitly express any variable among u, θ and ϕ_1 in terms of the other two. With this equation of meshing, each point on the wheel tooth is associated with three variables that are constrained by the meshing equation (Eq. 3). This brings much inconvenience when performing surface description and surface computation (Ref. 6).

Our new expression for the generated worm wheel tooth is made possible with a new equation of meshing for worm gear drives. The new equation of meshing is based on an observation that *the rotation of the worm about its axis may be kinematically replaced by a translation along its axis* (See Fig. 1b). The relation between the rotation angle ϕ_1 and the translation t is

$$t = -\rho\phi_1 \qquad (4)$$

We will derive the equation of meshing with the translating meshing motion. The general equation of meshing for all types of gearing is

$$n_i \cdot v_i^{12} = 0 \qquad (5)$$

where i represents the coordinate system. For convenience, the fixed coordinate system S_{f1} (shown in Fig. 1b) is used. Coordinate system S_{f1} coincides with the coordinate system S_1 attached to the worm when the worm has zero translation. In coordinate system S_1,

$$X_1 = [x_1, y_1, z_1]^T \qquad (6)$$

$$n_1 = [n_{x1}, n_{y1}, n_{z1}]^T \qquad (7)$$

From Figure 1, the same point and its normal can be expressed in coordinate system S_{f1} as

$$X_{f1} = [x_{f1}, y_{f1}, z_{f1}]^T = [x_1, y_1, z_1 - \rho\phi_1]^T \qquad (8)$$

$$n_{f1} = [n_{xf1}, n_{yf1}, n_{zf1}]^T = [n_{x1}, n_{y1}, n_{z1}]^T \qquad (9)$$

The relative velocity at the meshing point in coordinate system S_{f1} is $v_{f1}^{12} = v_{f1}^1 - v_{f1}^2$, and
$v_{f1}^1 = [0, 0, -\rho\phi_1']^T$

$$v_{f1}^2 = \begin{vmatrix} i & j & k \\ 0 & m_{21}\phi'_1\sin\gamma & m_{21}\phi'_1\cos\gamma \\ x_1+E & y_1 & z_1-\rho\phi_1 \end{vmatrix}$$

$$v f_1^{12} = -m_{21}\phi'_1 \begin{vmatrix} (z_1-\rho\phi_1)\sin\gamma - y_1\cos\gamma \\ (x_1+E)\cos\gamma \\ \rho/m_{21} - (x_1+E)\sin\gamma \end{vmatrix} \qquad (10)$$

From equations 5, 9 and 10, we get the alternative equation of meshing:

$$[(z_1-\rho\phi_1)\sin\gamma - y_1\cos\gamma]\, n_{x1} + (x_1+E)\cos\gamma\, n_{y1} + [\rho/m_{21} - (x_1+E)\sin\gamma]\, n_{z1} = 0 \qquad (11)$$

Thus, the meshing parameter ϕ_1 can be expressed explicitly by the two surface parameters, u and θ, of the generating surface as

$$\phi_1 = \frac{(x_1+E)\cot\gamma\, n_{y1} + (\rho/m_{21}/\sin\gamma - (x_1+E))\, n_{z1} + (z_1 - y_1\cot\gamma)\, n_{x1}}{\rho n_{x1}} \qquad (12)$$

Through transformations, in the coordinate system S_2, attached to the wheel itself, the generated wheel tooth surface X_2 can be expressed as

$$\begin{aligned} X_2 &= R_z[-m_{21}\phi_1(u,\theta)]T_x(E)R_x(\gamma) \\ &\quad T_z(-\rho\phi_1(u,\theta))X_1(u,\theta) \\ &= X_2(u,\theta) \end{aligned} \qquad (13)$$

where $X_1(u, \theta)$ is the hob/worm thread surface expressed in the coordinate system S_1 attached to the hob/worm itself. The matrix $T_i(t)$ defines a translation of distance t along axis i, and the matrix $R_i(r)$ defines a rotation by an angle of r about axis i.

In this way, u and θ can be treated as two surface parameters of both the worm thread surface and the generated wheel tooth surface. Parameter θ is the rotation angle of the screw motion to form the hob/worm thread, and parameter u may have different physical meaning for different types of worm gearing. Equations 12 and 13 define a mapping point X_1 of the worm surface into point X_2 on the generated wheel tooth. A pair of lines (u, θ) specifies one point on the worm thread surface and its corresponding point on the generated wheel tooth. Figure 2a shows the u lines and θ lines on the surface of a worm thread. Figure 2b shows the corresponding u lines and θ lines on the surface of the wheel tooth generated by this worm.

The explicit expression of $X_2 = X_2(u, \theta)$ is significant. It reduces the level of complexity of the generated worm wheel tooth surface to that of a surface with analytical accessibility similar to that available for involute spur or helical gear teeth.

The same idea can be readily extended to the analysis of helicon gearing (Ref. 7) and the hobbing process. In helicon gearing, the pinion is actually a worm, and its rotation can be replaced by a translation along its axis to reduce the complexity of the kinematic analysis.

Definitions of Profile and Lead of a Worm Wheel

As with spur and helical gears, we desire definitions of profiles and leads that allow them to be defined at multiple locations across the tooth surface. For an involute spur/helical gear, the tooth surface can be written as:

$$X = X(\epsilon, f) \qquad (14)$$

where ϵ is the roll angle and f is the face position parameter. A pair (ϵ, f) determines a point and its normal on a certain tooth flank. The defined profiles and leads of the involute gear correspond to the ϵ lines and the f lines, respectively. If the parameter f is fixed at f_0, the curve $X = X(\epsilon, f_0)$ represents a profile of the gear at face position f_0; if the parameter ϵ is fixed at ϵ_0, the curve $X = X(\epsilon_0, f)$ represents a lead of the gear at roll angle ϵ_0.

An equation (13) of the generated worm wheel tooth similar to Equation 14 for the tooth of an involute gear has been developed:

$$X_2 = X_2(u, \theta) \qquad (15)$$

Here, we define the profiles and the leads of a worm wheel in a format similar to that used for an involute gear. From Equation 15, if the parameter θ is fixed at θ_0, the curve $X_2 = X_2(u, \theta_0)$ traced out by changing u is defined as a profile of the worm wheel tooth; if the parameter u is fixed at u_0, the curve $X_2 = X_2(u_0, \theta)$ traced out by changing θ is defined as a lead. The profiles and the leads defined in this way have explicit mathematical expressions, so the profiles and the leads can be programmed and measured with CNC measuring machines.

The profile defined by $X_2(u, \theta_0)$ is not a planar curve. It runs across the tooth surface from the root area to the tip area, and this profile is called a profile at parameter θ_0. The lead defined by $X_2(u_0, \theta)$ does not lie on one cylindrical surface. It runs across the tooth surface from one edge to the other, and this lead is called a lead at parameter u_0. There are an infinite number of profiles and leads on each flank (Fig. 3). Any surface point is the intersection between a profile and a lead, and there is one profile and one lead passing through the pitch point of the worm wheel.

Take ZK-type of worm gearing as an example. A ZK-type of worm is ground by a biconical grinder (Ref. 5), as shown in Figure 4. Parameter u is the distance from the apex of the cone to a point on the grinder profile. The u lines (profiles) and the θ lines (leads) on the hob/worm thread and the generated worm wheel are plotted as in Figure 2. In this case, the hob/worm profile is not the axial section of the hob/worm thread. It is the tangency line between the hob/worm grinder and the hob/worm thread. The hob/worm lead is the helix line. Because of the one-to-one mapping of points on the hob/worm thread to the points on the worm wheel tooth defined by Equation 13, a hob/worm profile generates a wheel profile, and a hob/worm lead generates a worm wheel lead. Obviously, the profile deviation and the lead deviation measured on the wheel directly reflect the errors of the hob and the hobbing settings. Thus, the inspection results can be more efficiently used for later quality improvement.

Figure 5 shows the profiles (*u* lines) and the leads (θ lines) of a ZA-type of worm gearing. In this case, the hob/worm profile is the axial section of the hob/worm thread, and the physical meaning of the parameter *u* is shown in Figure 6.

Inspection of Profile, Lead and Topography

The profiles and leads defined above have explicit equations, and a CNC measuring machine can be programmed to follow a profile/lead trace. For the purpose of inspection, the measured traces are compared with their theoretical position to produce the deviation charts. The deviation chart of the profile $X_2(u, \theta_0)$ is plotted against the parameter *u*, and the deviation chart of the lead $X_2(u_0, \theta)$ is plotted against the parameter θ.

There are two ways to perform the inspection of a wheel. First, the worm wheel can be inspected against the meshing process (the worm design and the meshing setup). The actual wheel tooth surface is compared with a virtual wheel, which is conjugate to the worm part. Large surface deviations are expected because of the difference between the hob and the worm. The deviation of the profile tells the amount of tip relief and root relief, while the deviation of the lead reveals end relief introduced by the hob oversize. Second, the wheel can be inspected against the hobbing process (the hob design and the hobbing setup). The deviation caused by the difference between the hob and the worm part will not show up as surface deviation. Because the hob shape changes due to resharpening and/or wear, the design dimensions of the hob are used. The measured deviation would now reveal the difference introduced by the decrease of the hob oversize. Very likely, the lead has a negative crowning rather than positive. This inspection may give a good idea on how the resharpening process affects the worm wheel surface.

A topographical chart can be obtained if a grid is made of points formed by profiles at different "face positions" and leads at different "diameters." Two different presentations can be used: the chart is plotted over a grid of parameter-*u* x parameter-θ or plotted over a grid of radius x face position.

Example of Worm Wheel Inspection

A 30-tooth, ZK-type worm wheel was inspected. The measured wheel tooth was compared with a virtual wheel tooth conjugate to the mating worm. Figure 7 shows profile traces for both sides of four separate teeth. The inspected teeth are the 1st, 8th, 16th and 23rd ones. The root relief shows up clearly, but the left flank has less tip relief than the right flank. A possible reason for this is nonsymmetry of the hob grinder, but it may come from totally different aspects, such as an orientation error of the wheel.

Figure 8 shows lead traces for both sides of the same four teeth. The end relief introduced by hob oversize is considerable. With the decrease of hob oversize, the amount of the end relief is expected to decrease. The swivel angle adopted for wheel hobbing has a direct impact on the slope of the lead. The accuracy of the middle face position may affect the slope of the lead trace. This accuracy is discussed in the next section.

Figure 9 and Figure 10 show the multiple profile and lead traces of one tooth of the same wheel. The profile traces were measured at three different θ values ("face positions"), and the leads were measured at three different *u* values ("diameters"). Different profile/lead traces may have different numbers of recorded points when the same increment of u/θ is used for the measurements because of the shape of the wheel tooth and the distortion of the mapping defined by Equation 13. As in the case of an involute gear inspection, the profile/lead traces on the same tooth at different locations should follow the same shape. In our inspection, it is found that the lead traces are quite similar to each other, while the profile traces differ from one another. We believe this is due to cutting scallops. These scallops create waviness on a profile trace, and the waviness shows up with different phases at different inspection positions. The effect of the

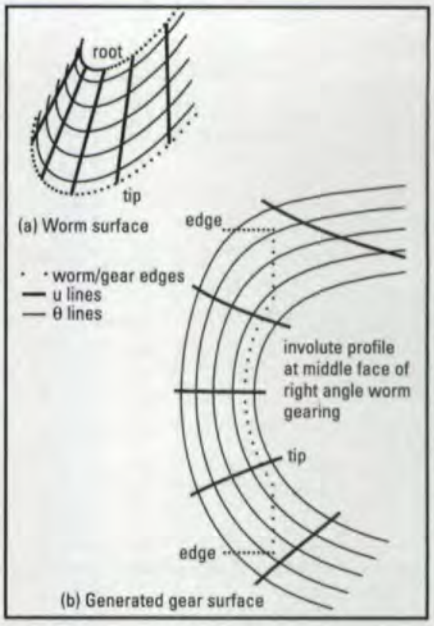

Fig. 5—Profiles (*u* lines) and leads (θ lines) of a ZA worm wheel.

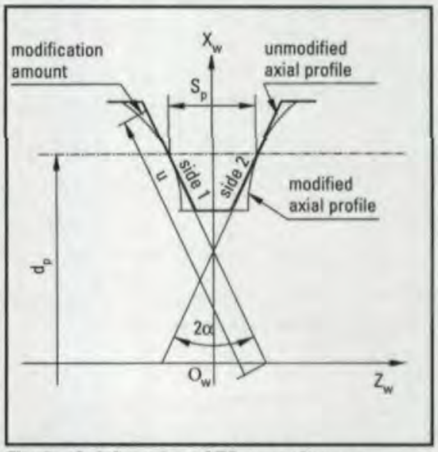

Fig. 6—Axial section of ZA-type of worm.

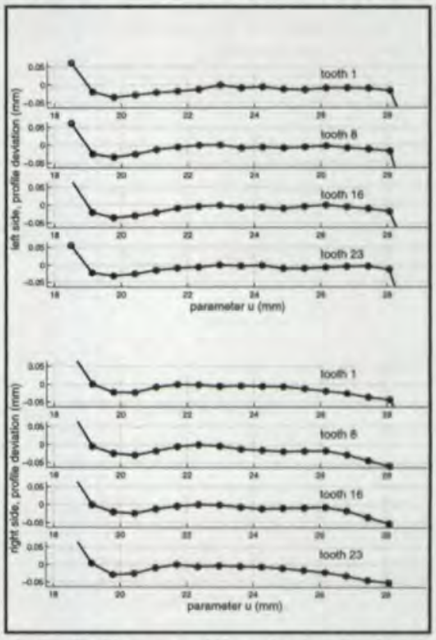

Fig. 7—Profile traces of four wheel teeth at "middle face position."

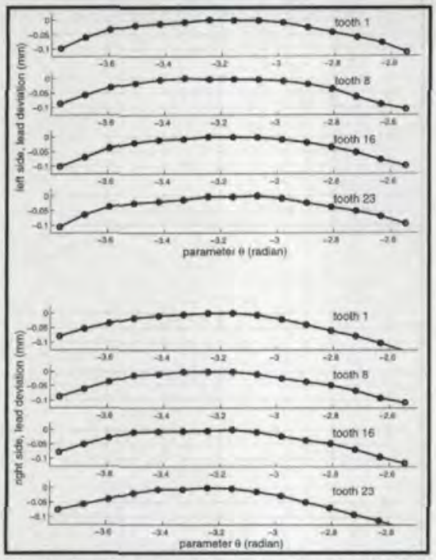

Fig. 8—Lead traces of four wheel teeth at "pitch diameter."

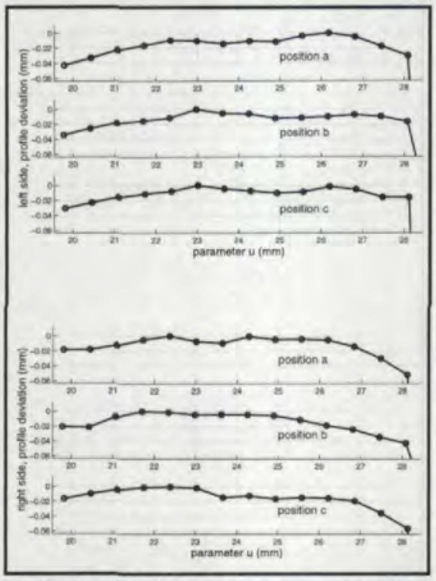

Fig. 9—Three profile traces of one tooth at three different "face positions."

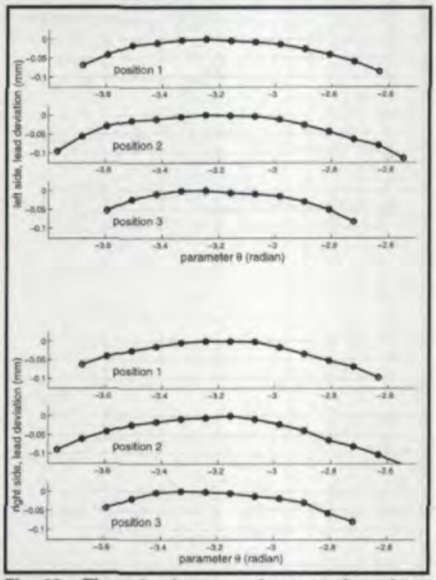

Fig. 10—Three lead traces of one tooth at three different "diameters."

scallops on the lead traces is not as large as that on the profile traces partly because the scallops run along the lead direction.

Figure 11 shows the topographical chart of the left flank of the first tooth. In total, 936 points were measured. The points are the intersection points between 40 leads (θ lines) and 30 profiles (u lines). In Figure 11a, the topographical deviation is plotted over a $u \times \theta$ grid, and in Figure 11b, the topographical deviation is plotted on a $R \times F$ grid. (R is the radius of the measured point, and F is its face position.) In Figure 11b, the points with a deviation of –0.0254 mm are also drawn. The shape formed by these points can be related to the contact pattern.

Measurement Reference Frame

One very important issue for the measurement and inspection of a worm wheel is the establishment of the reference frame. There are four types of reference misalignments: eccentricity, wobble, the middle face datum and the orientation of the teeth. Each of these misalignments affects the inspection results. As usual, the Z axis of the bore (or the shaft) is used as the wheel axis. To define the middle face datum, one end face position can be used, and the distance from the middle face datum to this end face must be strictly controlled during hobbing. The orientation of the wheel can be defined by a center direction of a tooth or the center direction of a tooth space. This can only be achieved by measuring points on two tooth flanks.

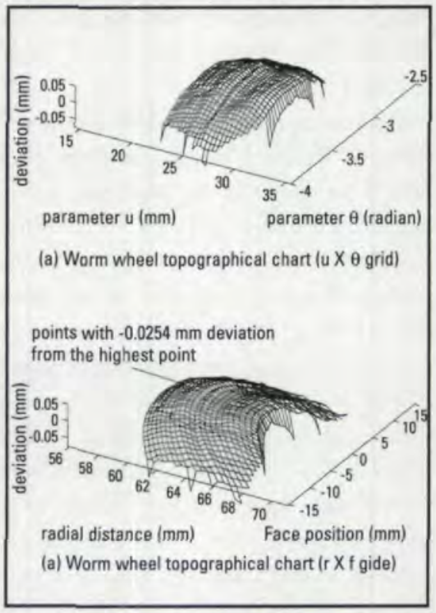

Fig. 11—Topographical inspection of a worm wheel tooth.

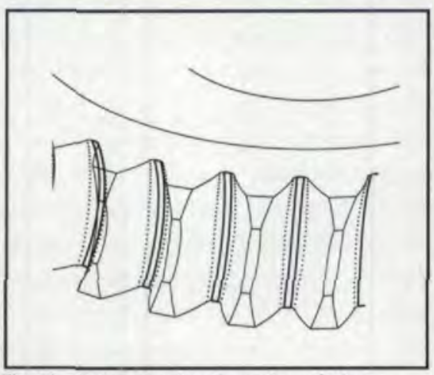

Fig. 12—Bottom land surface of revolution.

The effect of eccentricity and wobble on profile and lead inspection is similar to that of the inspection of an involute gear. A middle face datum misalignment introduces slopes on lead traces; the leads of the left side and the right side of one tooth tilt in different directions. The wheel orientation misalignment introduces slopes of profile traces, and the slopes of the left profile and the right profile have different directions.

To achieve a good middle face datum, the authors used the measurement data of the bottom land surface of revolution (see Fig. 12). The bottom land surface of revolution consists of all of the bottom lands between two consecutive teeth. Its shape is determined by three parameters: the hobbing center distance, the radius of the top cylinder of the hob and the amount of the swivel angle. This surface of revolution is symmetrical to the wheel's middle face position. If this surface is measured, surface fitting produces a very good middle face datum. There are two restrictions to apply this method: (1) the top blade of the hob must be straight; (2) the bottom land surface must be large enough for probe access.

Summary

In this article, we have presented new definitions of profiles and leads of a worm wheel based on an explicit equation of the generated wheel tooth surface. The new definitions are comparable to their counterparts of an involute gear. Then, the inspection of profile, lead and topography is discussed. Two methods of inspecting profiles and leads are proposed, and an inspection example of a

ZK-type worm wheel is given. The procedure to define a good reference frame for worm wheel inspection is also discussed. The explicit equation of the generated wheel tooth surface derived in this article applies to both right-axis and non-right-angle worm gearing. ○

Acknowledgment

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Hard Gear Finishing with a Geometrically Defined Cutting Edge

Prof. Dr.-Ing. Fritz Klocke and Dipl.-Ing. Thomas Köllner

Skive hobbing, hard skiving or skive shaping can be alternatives to gear grinding for post heat treatment finishing.

Introduction

The market demand for gear manufacturers to transmit higher torques via smaller-sized gear units inevitably leads to the use of case-hardened gears with high manufacturing and surface quality. In order to generate high part quality, there is an increasing trend towards the elimination of the process-induced distortion that occurs during heat treatment by means of subsequent hard finishing.

Intensive research activity into the hard finishing of gear flanks has produced an alternative to the widely used gear grinding process. Manufacturers now have the option of choosing a process that uses a geometrically defined cutting edge. This article describes problems and trends in hard machining with a defined cutting edge, presenting the skive hobbing, hard skiving and skive shaping processes. The key feature is the elucidation of individual process kinematics, tool geometries, tool materials and coating systems. A number of fields of application are also indicated.

Hard Finishing Tooth Flanks With A Defined Cutting Edge

Nowadays, most gears are case-hardened after roughing in order to enhance their wear resistance and load-carrying capacity. With unfavorable part geometries, however, heat treatment leads to substantial hardening distortion. Because of today's standards for high quality gears, subsequent hard finishing of the tooth flanks is often needed (Fig. 1).

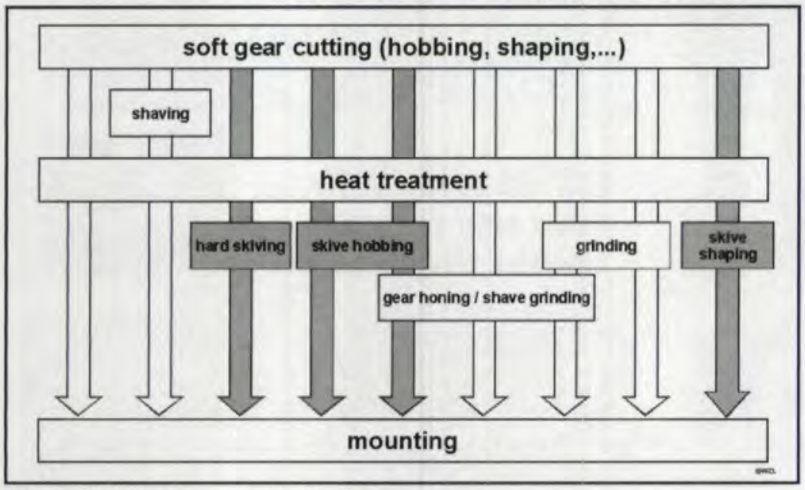

Fig. 1—Finishing external cylindrical gears.

The dominant finishing process used to compensate for hardening distortion is currently gear grinding, which can be used to machine very hard surfaces with great precision. Despite successful sophistication of grinding technology, machining with a geometrically undefined cutting edge remains a time-consuming process with correspondingly substantial machine and personnel costs. There is, therefore, a desire to substitute machining operations with a geometrically defined cutting edge for the present grinding process. Sophisticated tool materials and cuttings now permit the use of defined-edge processes like peeling, skive hobbing, hard skiving and skive shaping to finish hardened tooth flanks.

Apart from higher removal rates, defined-edge processes have the advantage of combining some soft and hard machining operations on the same machine. This enables the manufacturer to save the purchasing costs for a gear grinding machine. Another positive factor is the low energy consumption for defined-edge machining. Finally, a dry cut is often feasible, eliminating the use of cooling lubricants with their high disposal costs and environmental risks.

One drawback of hard finishing with a geometrically-defined cutting edge is lower process reliability due to the possibility of sudden tool failure resulting from breakage at the cutting edge. This is caused by the relatively low toughness of the carbide tool material. The disadvantage of "low process reliability" and the drawback of "essential minimum chip thickness" are closely linked. If the chip thickness is too small, no chip is cut; the work material is merely pushed aside, increasing friction and pressure on the cutting edge and causing early failure. The minimum chip thickness needed for a chip to form is also a drawback in terms of the accuracy-to-size that can be achieved as compared to grinding. Defined-edge hard cutting has difficulty in achieving the kind of machining accuracies possible with grinding. Especially high surface-quality requirements can only be met to a certain extent because process-specific deviations in the generating cut are mirrored on the surface of the part.

Suitable Tool Materials

Machining hardened ferrous materials demands tool materials with strength properties that match the special needs of hard cutting technologies and which possess adequate mechanical and thermal shock resistance, especially in discontinuous cutting operations. Great hardness and edge stability, low adhesion, high thermal stability, adequate toughness and a homogeneous fine-grained structure are often conflicting requirements imposed by hard finishing on a tool material. The choice of tool material is also affected by economic considerations (Ref. 6).

Micrograin Carbides

WC/Co-based micrograin carbides have recently become an important factor in gear-making technology. Carbides are sintered materials consisting of a soft metallic binder phase (cobalt), in which the carbides—in this case tungsten carbide—are embedded. Micrograin carbides of the same composition but with carbide grain sizes below 1 µm possess greater hardness and resistance to compressive stress than conventional carbides with a grain size of roughly 1 to 3 µm. Tungsten-carbide and cobalt-based carbides with average tungsten-carbide grain diameters ≤ 0.5 µm are termed ultra-micrograin carbides.

Micrograin carbides are also characterized by their very high bending and tensile strength, since both hardness and bending strength can be raised with a WC-crystal size below 1 µm. Modern manufacturing technologies also produce extremely fine-grained homogeneous microstructures. A product of this kind, consisting, for example, of 94% WC and 6% Co, measured by mass, achieves a hitherto unattained combination of hardness (2000 HV 30) with bending strength (4000 N/mm2) (Fig. 2), which would have been considered impossible even a few years ago (Refs. 4, 5 & 11).

The rise in hardness as the tungsten-carbide grain size decreases reduces abrasive wear, while the 50% increase in bending strength, which has positive effects on edge stability, and its suitability for machining hardened materials with minimal allowances to grinding quality recommend this tool material for gear production (Ref. 7). Combined with improved coating technologies, it opens the way to reducing the chipping of the cutting edge, which determines tool life and increases process reliability.

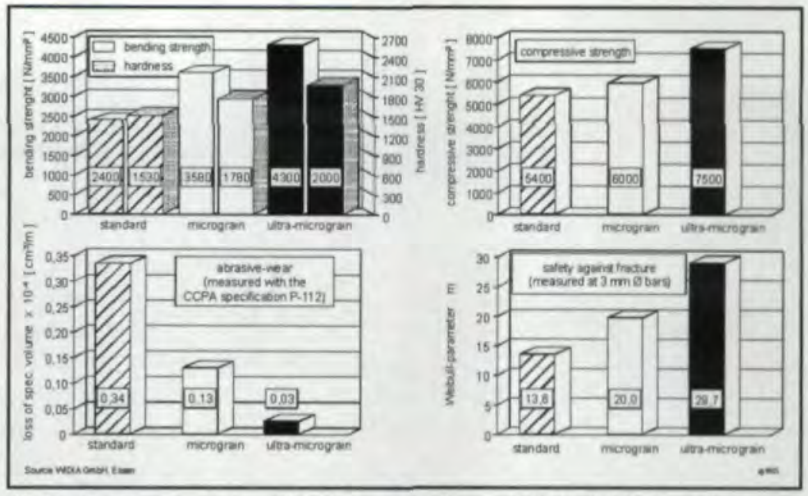

Fig. 2—Parameters of various WC-6-Co carbides (Source: WIDIA GmbH, Essen, Germany).

Coating Technology

The use of coated carbides and high-speed steels in machining is state-of-the-art technology. The hard, thin film increases the abrasion resistance of the coated tool material, reduces tool-part adhesion and acts as a barrier to diffusion. The substrate material carrying the film must ensure good support and give the substrate-coating composite adequate thermal resistance and toughness. The prerequisite for the wear-protective effect of the film is adequate coating-substrate adhesion, even when the tool is exposed to thermal and mechanical shock. CVD (chemical vapor deposition) and PVD (physical vapor deposition) techniques are employed to apply the coating to the cutting tools (Refs. 4 & 11).

One drawback of the high-temperature CVD method (T > 1000°C) is the risk that the cutting edge will become brittle. The PVD process, in which the coating is deposited on the substrate in a low temperature range (200°C to 600°C), reduces the risk of cutting edge embrittlement. PVD coating of carbide tools is now state-of-the-art technology; titanium nitride (TiN) is the dominant coating material. Other coating materials based on TiN have been developed; and of these, titanium carbon nitride (TiCN) and titanium aluminium nitride (TiAlN) have already become commercially significant (Refs. 4 & 11).

Wear On Coated Carbides

Wear is highly significant for cutting processes, substantially affecting the finished product and the reliability of the process. Tool wear is caused by adhesion, diffusion and oxidation phenomena

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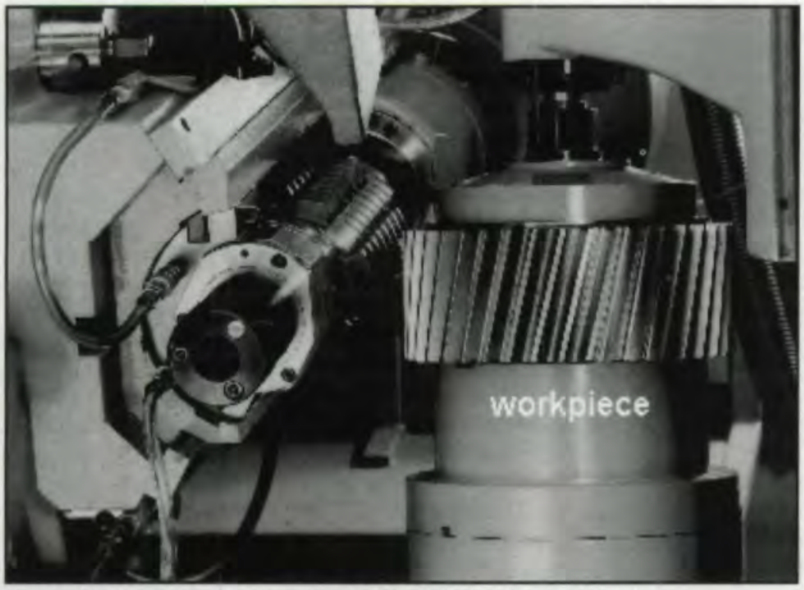

Fig. 3—Tool-workpiece configuration in skive hobbing. Source: Pfauter.

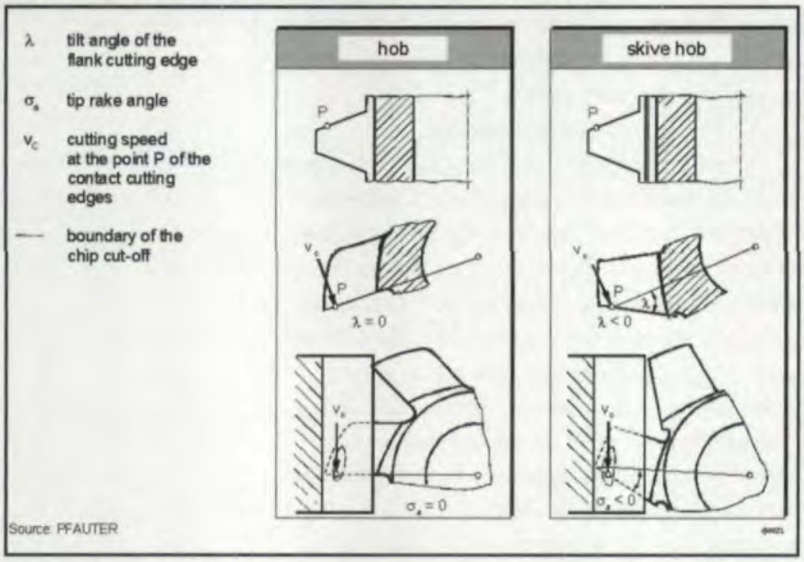

Fig. 4—Negative rake angle on the skive hob.

during the machining operation. Adhesive coating failure and cohesive and adhesive coating wear are potential wear mechanisms during hard finishing with a defined cutting edge (Refs. 3 & 8). Apart from wear mechanisms affecting the film coating, wear phenomena including chipping, transverse and ridge cracks, abrasion, adhesion and diffusion may also occur on the substrate where it is uncoated or unprotected due to coating wear (Refs. 7 & 11).

The wear mechanisms noted above are not independent of one another, but have overlapping causes and effects on wear. For example, abrasive wear or chipping may be promoted or even initiated by adhesion or diffusion on the carbide. In general, however, it is true to say that, together with abrasion at low cutting speeds, adhesion and, at high cutting speeds (cutting temperatures), diffusion and oxidation phenomena are the primary determinants of tool wear (Ref. 7).

Skive Hobbing

Skive hobbing (Refs. 1, 3, 7, 8, 10, 11 & 12) is a continuous process employing a geometrically defined cutting edge in a rotary cutting action with an interrupted cut for finishing pre-cut, hardened gears. Its primary tasks are to eliminate hardening distortion caused by heat treatment and to improve surface quality. Its process kinematics are identical with those of hobbing, enabling both the gear cutting and finishing processes to be performed on the same machine (Fig. 3).

The process kinematics of skive hobbing are based on a generating spiral drive in which the tool and the gear contact one another at an angle. Potential profile modifications of the workpiece have to be introduced, whereas modifications of the flank line can be made by adapting the machine motions. Process kinematics are characterized by a combined generating and spiral feed motion.

The rolling motion results from the differential speeds of rotation of the skiving hob and the workpiece; the speed of rotation varies inversely with the number of teeth. The spiral motion required to machine the full width of the workpiece is superimposed on the rolling motion. In order to achieve this, the tool is shifted along the workpiece axis, entailing a simultaneous additional rotation of the workpiece. The magnitude of this additional rotation is calculated to produce a spiral motion from the axial motion of the tool and the additional rotation of the part. The cutting speed in skive hobbing is equivalent to the circumferential velocity of the tool.

The term skive hobbing is derived from the "skiving cut." This type of cut is essential for creating the small chip cross-sections required to machine the hardened material. As an aid in this task, the tools are given a negative rake angle, which acts as a negative tilt angle on the tooth flanks (Fig. 4). This produces an enlarged active cutting-edge length and a "pulling cut," which is intended to offer greater resistance to the stresses involved in machining hardened steel.

One tool is sufficient for all gears with the same reference profile in skive hobbing. Owing to the process kinematics, the enveloping profile of the tool is based on a worm and has straight-flanked cutter teeth. The workpiece corresponds to the worm wheel. The cutter teeth are arranged spirally over the circumference of the skiving hob and separated by flutes. Each cutter tooth corresponds to one rolling position for profiling the tooth gap and always removes an identical chip. If the skiving hob is worn, it can be sharpened on a separate machine, on which the face of the tool is reground.

Skive Hobbing Process Characteristics and Applications

Prior to skive hobbing, the tooth gap must be rough-machined to a stage at which the tip of the skiving hob does not make contact, and only the flank cutting edges are involved in the machining operation. Otherwise there would be a risk of chipping. The tooth root can be freed by roughing with an increased tip factor or by pre-hobbing with a protuberance. The centering of the skiving hob in the workpiece gap is also of great importance for the finished result. Because of the high forces encountered in machining hardened steel, the skive hobbing machine requires high static and dynamic stiffness in addition to geometric and kinematic accuracy.

Skive hobbing is carried out at cutting speeds of v_c = 30–110 m/min for any helix angle of the workpiece and modules m_n = 1–40 mm. The cutting speed has to be reduced as the size of the part increases, owing to the longer contact lengths in the machining process and the higher resulting thermal stress. Axial feeds range from 1–5 mm/workpiece revolution; small feeds are selected to match high workpiece accuracy requirements. Owing to the small chip thicknesses concerned, skive hobbing should be performed in climbing cutting, in order to reduce the stress on the cutting edges. The skive hob can be shifted during the hobbing operation to distribute wear evenly over the tool.

Skive hobbing is used as a finishing operation or as a roughing process to prepare for subsequent finishing by eliminating hardness distortions and reducing grinding allowances. This process sequence is frequently employed for large-module workpieces. The quality limits are determined mainly by the characteristic feed markings and enveloping cut deviations. Subsequent gear honing can remove these on small-module gears. Gears which cannot be ground because of their geometry can be skive hobbed. Batch sizes range from one-off to large-series production.

Hard Skiving

Hard skiving (Refs. 1, 2, 3 & 7) is a continuous defined-edge process using an interrupted cut. Although its process kinematics are based on a generating spiral drive as in the case of skive hobbing, hard skiving cannot be carried out on a skive hobbing machine but requires the purchase of its own machine. This is due to the changed tool-workpiece configuration as compared to the skive hobbing principle (Fig. 5).

Because of the generating spiral drive, the skiving gear and workpiece mesh on skewed axes of rotation. A spiral motion is superimposed on the rotation-speed-dependent generating motion. This results from the displacement of the tool parallel to the workpiece axis, entailing an additional simultaneous relative rotation of the workpiece. As a result of this superimposed generating and spiral motion, the cutting edges of the skiving gear slide along the tooth flanks of the workpiece and skive the material over the full width of the gear tooth. The inclination of the skiving path to the generatrix on the tooth flank creates a surface structure favorable to the noise behavior of the gears.

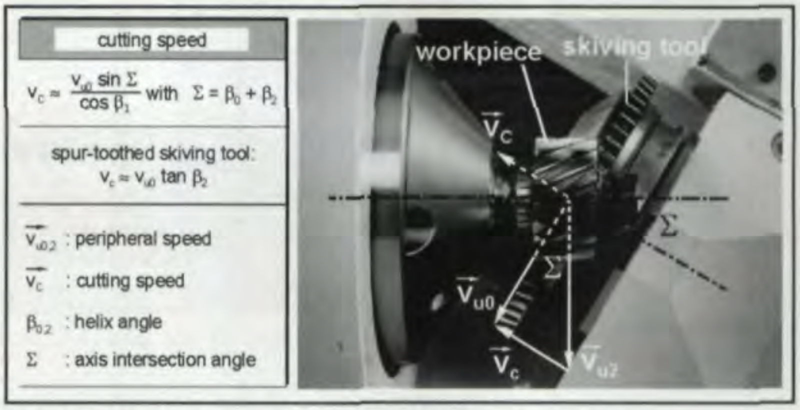

Fig. 5—Tool-workpiece configuration in skive hobbing. Source: Pfauter.

The cutting speed for hard skiving is a product of the difference in the circumferential velocities of the skiving gear and the workpiece. Owing to the generating spiral drive, the component of sliding velocity perpendicular to the cutting edges of the tool is approximately equal to the cutting speed (Fig. 5). It may therefore be stated for a spur skiving gear that

$v_c \approx v_{u0} \cdot \tan\beta_2$.

If the helix angle of the gear $\beta_2 = 0°$, the cutting speed will be v_c = 0 m/min. This means that spur-toothed workpieces cannot be machined with spur-toothed skiving gears. Spur-toothed tools, however, do have substantial advantages as compared to helical tools. For this reason, hard skiving is currently carried out only with spur-toothed skiving gears and is confined to the machining of helical gears.

Hard skiving tools take the form of an undercut cylindrical gear, because the process kinematics determine a cylindrical envelope profile of the skiving gear. They consist of carbide rings with slightly conical or even cylindrical gear teeth on their external cylindrical surfaces.

Hard Skiving Process Characteristics and Applications

Hard skiving is carried out in a module range m_n = 1–3 mm and at cutting speeds of v_c = 40–90 m/min and axial feeds 0.1–0.25 mm/workpiece revolution. The machinable helix angles of the workpiece are restricted to β_2 = 15–40°. The con-

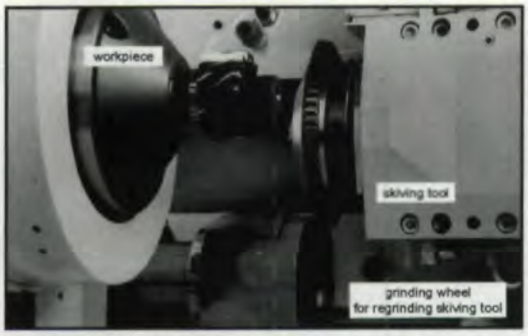

Fig. 6—The skiving tool can be reground in the machine. Source: Pfauter

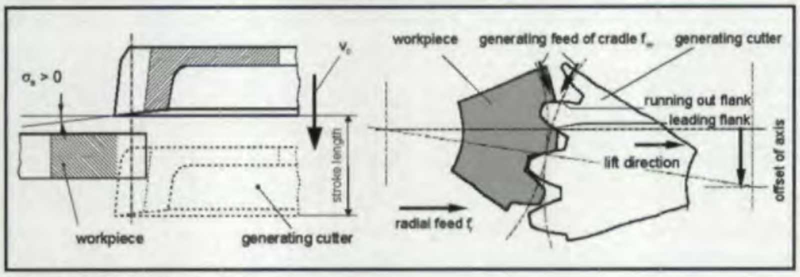

Fig. 7—Shaping kinematics.

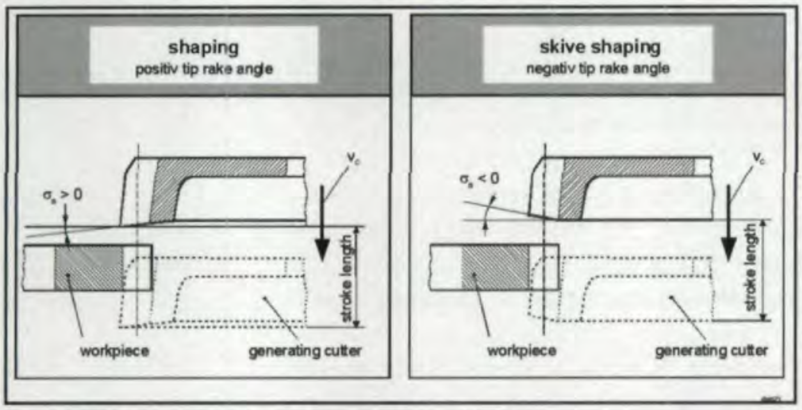

Fig. 8—Negative rake angle on a cutting gear for skive shaping.

ventional cutting is used for hard skiving. An allowance of 0.13 mm per flank can be removed in one cut. The allowance should be as small as possible, in order to save tool costs and keep process forces low.

Hard skiving tools are generally part-specific. A specially designed skiving gear is needed for each workpiece. The rake faces lie in a plane perpendicular to the tool axis. This means that the skiving gear can be reconditioned at the end of its tool life by a simple, low-cost flat grinding operation in the machine (Fig. 6).

Hard skiving is currently performed as a single-flank operation, even though two-flank machining would allow shorter production times. One advantage of this approach is that the right and left flanks of the gear can be machined with different shaft angles, prolonging the tool life of the skiving gear through larger effective tool orthogonal clearances; another is that workpiece quality can be improved by a more uniform passive force curve over the axial path.

Hard skiving is suitable only for medium- to large-scale production, especially for large-series production in the automotive industry. The gears involved usually have profile bearing and crowning. Desired depth crownings can be taken into account through a modified skiving gear profile. Crowning is generated by means of adapted machine motions.

Skive Shaping

Skive shaping (Refs. 4, 9 & 11) is a discontinuous defined-edge process that uses a translatory cutting motion to finish rough-cut hardened cylindrical gears. Its process kinematics are identical with those of shaping (Fig. 7), enabling soft machining and hard finishing to take place on the same machine.

The sequence of motions is characterized by the generation between a cutting gear and workpiece mounted parallel to one another. Chips are removed in the direction of the flank line through an axial cutting motion of the tool gear, referred to as a working stroke. During the subsequent reverse stroke, the work table or the tool is lifted to prevent a collision between the cutting gear and the workpiece. Skive shaping is performed without any axial offset, i.e. without lateral displacement of the machine stand. This is the only means of ensuring uniform infeed on both flanks. Collision problems that are encountered in roughing operations with a shaping machine do not occur in skive shaping, owing to its nature as a finishing cut (Ref. 9).

In order to withstand the initial cutting stresses on hardened steel more effectively, the rake angle of the shaping gear used in skive shaping is negative, causing a negative tilt angle on the tooth flanks (Fig. 8).

The involute tooth flank is profiled by means of generated cuts. A cutting-gear tooth generates a workpiece gap. The flanks of the cutting-gear tooth are involute in form and, as is in skive hobbing, the tools are not part-specific except for necessary profile modifications. The face of a worn shaping gear is reground on a separate machine in order to sharpen the cutting edge.

To achieve a generating motion, the workpiece and cutting gear move simultaneously with the axial stroke motion, in accordance with the ratio between their numbers of teeth. The generating feed is the distance described at the pitch circle per double stroke (double stroke DS = working stroke + reverse stroke). The number of generated cuts is dependent on the generating feed. An increase in generating feed reduces the number of generated cuts.

Skive Shaping Process Characteristics and Applications

In skive shaping operations, it is necessary to ensure that machining takes place only with the flank cutting edges. The rough-cut workpiece gap must be machined appropriately and the cutting gear properly centered. In order to prevent the tip corners of the shaping gear from participating in the cut, an allowance of 0.1 mm/flank should also be left. Cutting speeds are in the range v_c = 20–40 m/min. Gear deviations characterized by a pitch-circle gap are still an unsatisfactory feature. Profile-corrected tools and higher stiffnesses of the overall system may lead to improved profile accuracy.

Hard gear finishing in cases where the contact point is severely restricted by neighboring design elements may be very difficult or impossible to realize. The special advantages of skive shaping, manifested in the short tool run-on, are apparent in these applications. Both continous double helical teeth and double helical gears can be hard finished using this process, as can gears on stepped shafts or even crown gears. The machining of clutch gears is also conceivable. Batch sizes may be small or large.

One potential application for skive shaping lies in hard finishing of internal gears. Internal gears are a major component of planetary gear systems, which represent an increasingly large proportion of mass-produced gear systems. Owing to enhanced performance requirements for power gear trains, users are demanding cost-effective hard finishing technologies for internal gears. Whereas hard broaching is economically feasible only in large-series production, an unsatisfactory tool transition, e.g. via neighboring design elements, is often the only obstacle to the use of such technologies as skive hobbing, gear grinding and gear honing. Skive shaping, by contrast, is inherently suitable for finishing operations on internal gears.

Conclusions

The finishing of hardened tooth flanks after heat treatment is of growing importance due to increasing demands for high gear quality and smooth running. Currently, the dominant finishing process for elimination of hardening distortion is gear grinding. Sophisticated tool materials however, already point the way to defined-edge technologies.

Skive hobbing, hard skiving and skive shaping are defined-edge processes suited to the hard finishing of gears. These generating techniques make use of micrograin carbide tools. Skive hobbing tools are spirally shaped; hard skiving and skive shaping tools are cylindrical. There are also differences in process kinematics and potential applications.

Skive hobbing can be used with any batch size from one-off to large series production across a broad range of geometrical workpiece dimensions. Hard skiving, by comparison, is suited only to series and large-scale production of helical gears with dimensions customary in the car industry. A common feature of both processes is their low-noise surface structure.

In cases where the contact point is severely restricted by neighboring design elements, hard gear finishing can preferentially be achieved by skive shaping. One potential application of skive shaping is the production of internal gears, which have come to represent an ever-increasing proportion of gears manufactured in series production and which frequently cannot be machined by other processes. Skive shaping is fundamentally suited to this task. ○

Acknowledgement

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M&M PRECISION SYSTEMS NAMES NEW GENERAL MANAGER

Wes Blankenship

M&M Precision Systems Corporation of Dayton, Ohio, has appointed Dr. Wes Blankenship general manager of M&M's Dayton operations, overseeing all of the business activities for M&M's Dayton metrology and motion products.

Blankenship has a strong background in both gear manufacturing and metrology systems. Prior to joining M&M, Blankenship served 12 years with General Motors in a variety of technical and leadership roles, most recently as Director, GM Gear Center and engineering group manager for Advanced Powertrain Development. He holds a doctorate in mechanical engineering from Ohio State University.

NEW TRANSMISSION PLANTS UNDER CONSTRUCTION

Toyota and General Motors are each building new transmission manufacturing plants in the United States.

Toyota West Virginia has started construction of an automatic transmission plant to complement the new V6 engine facility currently operating at the company's Buffalo, West Virginia site. It is scheduled to begin producing automatic transmissions in early 2001 and will employ an additional 200 workers.

General Motors Corp. will build a $250 million transmission manufacturing plant in White Marsh, Maryland. Construction on the Allison Transmission plant, which is expected to employ at least 500 autoworkers, is expected to begin within the year.

CHARLES P. COVINO, FOUNDER OF GENERAL MAGNAPLATE CORP., RETIRES AS CEO

Dr. Charles P. Covino has retired as Chief Executive Officer of General Magnaplate Corporation. Dr. Covino will remain as chairman of the board of the company, which he founded in 1952. He will also be available to consult on special projects for the company as needed. Magnaplate's new president and CEO is Candida Aversenti. Edmund Aversenti, formerly vice president for corporate operations, has been made Chief Operating Officer, a position formerly held by Mrs. Aversenti. He remains secretary of the corporation.

Dr. Covino is probably best known as the inventor of HI-T-LUBE®, for which he was awarded one of his 92 patents. With the lowest verified coefficient of friction, HI-T-LUBE® is cited by the *Guinness Book of World Records* as being "the world's most slippery solid lubricant."

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CIRCLE 108

TECHNICAL CALENDAR

November 8–12. AGMA Training School for Gear Manufacturing: Basic Course. Richard J. Daley College, Chicago, IL. The Training School for Gear Manufacturing provides five days of classroom and hands-on training. The diverse curriculum includes basic gearing, efficient machine set-up techniques, accurate gear inspection and gearing calculation. For more information, call AGMA at (703) 684-0211 or visit their Web site at *www.agma.org*.

November 9–12. Machine Parts '99. Shanghai, China. A professional showcase exclusively for the growing machine parts industry in China, the show will have a full array of products on display including standard and nonstandard fasteners, gears, chains, springs and powder metallurgical products, as well as related processing equipment, materials and instruments. For more information, contact Business and Trade Fairs, Ltd. at (852) 2865-2633 or via e-mail at *enquiry@bitf.com.hk*.

November 14–19. 1999 International Mechanical Engineering Congress and Exposition. Opryland Hotel Convention Center, Nashville, TN. The Congress will include hundreds of technical sessions and exhibitors. Manufacturers, designers and suppliers will present products, services and technology that will enable engineers and industry leaders to face the increasing challenges of the next millenium. For more information contact June Leach-Barnaby at ASME at (212) 591-7795 or call toll-free at (800) 843-2763.

November 15–18. Gleason Pfauter Hurth Basic Gear School. Loves Park, IL. A comprehensive, four-day course consisting of a coordinated series of lectures given by engineering, production and inspection staff members. The course is designed for those new to gear manufacturing who are seeking a basic understanding of gear geometry, nomenclature, manufacturing and inspection. Also held December 6–9. For more information contact Gleason Pfauter Hurth at (815) 877-8900.

December 1–3. Fundamentals of Gear Design I. Center for Continuing Engineering Education, the University of Wisconsin at Milwaukee, Milwaukee, WI. This is Part 1 of a 2-part course, covering the history of gear design, basic gear tooth nomenclature, types of gears and their arrangements, the theory of gear tooth action and failure modes and prevention. The course has been updated to provide a more comprehensive coverage of the important topics regarding the fundamentals of gear design technology. For additional information about this course, contact Richard G. Albers, program director, at (414) 227-3125. To sign up, contact the registration office at (414) 227-3139 or (888) 545-4700.

February 29–March 2, 2000. South-Tec Charlotte2000 Advanced Productivity Exposition (APEX). Charlotte Convention Center, Charlotte, NC. Billed as the South's largest manufacturing event. For more information contact SME at (800) 733-4763 or visit their Web site at *www.sme.org*.

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Coordinate Measuring Machines and the Gear Industry

Charles Cooper

Gears are extremely complex shapes. Coordinate measuring machines, or CMMs, are designed to measure complex shapes. It seems to follow that CMMs would, therefore, be the ideal tool for measuring gears. But the answer is not so simple.

While coordinate measuring may be the preferred way to quickly and accurately inspect bevel gears, manufacturers of parallel axis gears have long relied on their spline gages, roll testers and mechanical elemental gear checkers for involute and lead inspection. More recently, they've added CNC generative gear testers and single flank inspection machines to their repertoires.

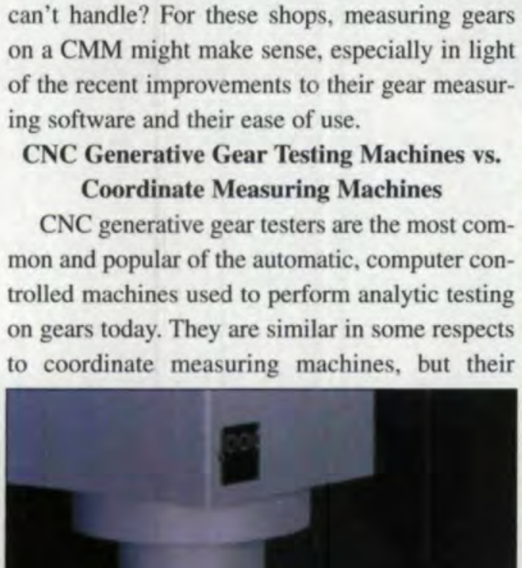
But what about shops that make all types of gears, or shops that need to measure splined shafts, gearbox housings or other custom components that a dedicated gear inspection system can't handle? For these shops, measuring gears on a CMM might make sense, especially in light of the recent improvements to their gear measuring software and their ease of use.

CNC Generative Gear Testing Machines vs. Coordinate Measuring Machines

CNC generative gear testers are the most common and popular of the automatic, computer controlled machines used to perform analytic testing on gears today. They are similar in some respects to coordinate measuring machines, but their design and programming are strictly attuned to testing gears. According to Mark Cowan, director of metrology for M&M Precision Systems of Dayton, OH, "CNC generative gear testers are considered to be the fastest, most precise way of measuring parallel axis gears." Considered turnkey systems, these machines are made so that the machinist on the shop floor can enter the necessary data and test the piece he is working on in accordance with AGMA standards. These machines are called generative because they work in much the same way as their mechanical predecessors, using a probe to physically trace out, or generate, the involute shape and lead. According to Cowan, the process of CNC generative testing works like this: "To measure an involute, the probe is positioned at the base radius of the part and then driven along the linear tangential axis at the same tangential velocity as the rotary at that radius. So, you have a mechanical linkage that drives the probe along and actually generates the profile. The probe is actually scanning along the involute, measuring deviation or error in the tooth form."

On the other hand, a coordinate measuring machine records numerous axis positions as data points, which are then used to build-up the 3-D model of the part. "That's a more complicated process," said Cowan, "because it's almost like measuring the part backwards. What the CMM does is move the probe around the tooth flank in some given plane. Then it fits a theoretical form around that plane and computes deviation from that. For example, say you're moving a probe from the root diameter to the OD. If you're on a helical part, the actual place where the probe is contacting is moving because the helix angle on a gear changes when you go from the root to the OD even though the lead stays the same. You have to compensate for that. Unless you have a canned program written by the CMM manufacturer, it's not a simple thing to program a CMM to measure a gear."

Above: Spriral bevel gear being inspected on a CMM. Courtesy of Brown & Sharpe.



Right: Worm being inspected on a CMM. Courtesy of Brown & Sharpe.

Because of this complexity, which offsets the flexibility that is the main strength of coordinate measurement machine technology, the machines are considered by many to be too difficult to use for regular shop floor personnel. According to Robert E. Smith, president of R.E. Smith & Co., Inc., a Rochester, NY-based gear metrology consultant and the co-chair of AGMA's Inspection and Handbook Committee, "CMMs are very capable machines and can be very accurate. But to me, it takes more of an engineer to run that machine than a shop person. If you have a CNC generative machine, most of the shop people would be capable of running that." The reason, according to Smith, is the complexity and user-hostility (as opposed to user-friendliness) of the programming, and the time and skill it takes to set up and calibrate the equipment. "I have lots of problems with the [CMM] gear software," said Smith. "For example, with some software you can't input DP. It's written for module. So, if you're doing a gear here in the U.S., and it's the DP system, why should a guy sit down with a hand calculator when he's got this big computer sitting there?"

Of course, not everyone agrees with this perceived user-unfriendliness. "Ten years ago, you'd have to sit down and write a Fortran program," said David Genest, director of marketing and corporate communications for Brown & Sharpe. "Today it's much easier. You can download CAD files or use application-specific software." As compared to CNC generative testers, Genest sees the two technologies and their driving software as fairly comparable, the only real difference being the familiarity of gear people with gear machines.

CMM Advantages

Coordinate measurement machines have a number of applications and advantages that gear manufacturers should understand and consider. These can be divided into two broad categories: bevel gears and quality control.

Precision Bevel Gears. One area where coordinate measuring machines are needed is with bevel gears. According to Cowan, the main reason why CMMs are preferred for this work is that bevel gears are not easily described in 3D. "The normal vector is constantly changing in three dimensions as you move from one place to the next on the form of a bevel tooth. You can't really generate the motion, so you have to go to different points to take it [the measurements]." Having to rely on data points means having to rely on coordinate measuring machines to get the job done. Smith agrees. "If you want to measure a bevel gear tooth shape, a coordinate measure-

HYBRID MACHINES—GEAR TESTERS OF THE FUTURE?

There is an emerging class of machine that is neither a true coordinate measuring machine nor a true CNC generative gear tester. These machines are attempts to combine the best features and abilities of both machine types in a single, integrated system that offers true, three-dimensional volumetric capabilities.

Next Dimension. Still undergoing beta tests, the Next Dimension 430 from Process Equipment Company is a dedicated gear tester that mixes CMM and generative tester technology to produce a very flexible gear metrology tool. According to Dick Considine, the software engineer on the ND 430 project, "The ND 430 is a volumetrically mapped coordinate measuring machine that is designed to do gear inspection." The difference is that this machine can measure features on a gear that traditional CNC generative testers cannot in ways that other gear testers cannot. "CNC generative testers can give you relative measurements," said Considine. "We can give you absolute and relative measurements."

The software driving the machine is a Windows 98-based package that is entirely configurable to the customer's needs. "With gear systems, one of the things in the industry is that most software packages out there haven't been designed. They have evolved. They've been around for a long time and they've been added to until there are now hodge-podges of stuff out there. Our system is brand new, the software totally rewritten and it's fully compliant with all three standards—ISO, AGMA and DIN."

Because it is so early in the machine's existence, the engineers at Process are still figuring out all the applications that the ND 430 will be able to perform. "In addition to gear measurement," said Considine, "it will be able to do a lot of other things such as measuring cams relative to gears, keyways relative to gears and gears relative to gears on the same assembly. Normal gear machines can't do that."

Radiance 1006. The Radiance Radial Measuring System is designed primarily for rotary tasks. While this naturally includes gears, the Radiance is not restricted to them. Rather, the machine is capable of scanning a variety of cylindrical and rotary parts as well as hobs, shafts, cams and other pieces. According to Jack Epstein, TSK product manager and the developer of the Radiance concept, the Radiance was developed to solve the problem of dual machine use. "Companies often use generative gear testers as well as CMMs to check their gears," said Epstein. "That's extra expense, extra training and extra floor space. The Radiance solves all that."

For gear makers, the Radiance offers a lot. The machine can measure all the features of a gear including teeth, faces, shafts, bolt hole circles and more. In fact, it has been designed to inspect any feature on a gear that needs verification. Users only have to learn to use a single software package, and the unit is as comfortable on the shop floor as it is in the lab. Added to this, the great flexibility the machine gets from its CMM ancestry makes it a very powerful tool to have in the shop. "The machine is best suited for rotary or cylindrical parts," said Epstein. "it can handle anything up to a meter diameter—gears, shafts, hobs—without fixtures. The machine senses part orientation and measures normal to any feature with the probe traveling 360° around the stationary part."

These two machines are both precise instruments capable of micron-level resolution and both are programmed to give gear people the information they need to qualify a part or to adjust machine tool settings. While all of this is promising, they are also both very new.

The Radiance Radial Measuring System. Courtesy of TSK America.

"A CMM typically used to measure prismatic parts can, in an instant, be used to measure gears," said Rolf Dettler, an applications engineer for Carl Zeiss. "For manufacturers of both items, it is an ideal solution. The capital investment is far less than buying two separate machines."

ment machine is the way to go. But it's a special machine, special software, it's expensive. The only people who'd have it are your aircraft or automotive people."

One example of a gear maker using coordinate measuring machines is Aero Gear. This Connecticut-based gear manufacturer for the aerospace industry sees their Brown & Sharpe Chameleon® coordinate measuring machine, which they use to check spiral bevel gears, as a major plus to their operation. The Chameleon® is equipped with Brown & Sharpe's Quindos software, programming that is specifically designed to interface with their Gleason Phoenix grinder's Super G-AGE system. According to Carl Russo, a process engineer for Aero Gear, "Ease of setup prompted us to use CMMs. We do mostly small quantity jobs, and we needed a fast way to inspect gears and splines. Once you create a program, you can check parts much quicker."

Aero Gear's coordinate measurement setup allows them to maintain tight process control by feeding the data from inspected parts directly into the gear grinders. "We get these coordinate point files from The Gleason Works so we can make our own summaries," said Russo. "Then we get a coordinate file for the CMM and measure the topography of a workpiece on both sides. Then, after the machine has done that, we have it measure the pitch error and runout." More measurements and calculations are made to create what has come to be called a digital or theoretical master. "We create the so-called theoretical master file," said Russo. "Depending on the customer requirements, we'll get their reference master and measure that relative to the coordinate file we calculated and alter that original file to match the customer's actual master."

Next comes the comparison of a production workpiece with this digital master stored in the CMM's computer. By comparing the workpiece to the digital master, the machine generates an error data file. This error file, which details how far the dimensions for each tooth vary from nominal, is then fed into the Phoenix machine's Super G-AGE system software. The G-AGE system then creates a correction file that changes the grinding summary for the machine, correcting the errors.

General Quality Control. This area includes fulfilling vendor certification requirements, checking the quality of parts shipped, process monitoring and control, tooling qualification, tool wear monitoring and gage qualification. In many areas, CMMs are considered the method of choice for quality control applications. They can test manufacturing processes for dimensional accuracy, perform statistical certification of part quality, detect tooling problems, recertify gages and other measurement tools, and use dimensional data to find and correct problems in the manufacturing process.

At Aero Gear, the CMM has the first and last word on quality control. "The gear grinder or gear shaper will make a first piece, and then we'll have a first piece inspection on the CMM," said Russo. "Then, as the operator runs the part, we'll generally use a spline gage or roll the parts on a redliner to monitor the quality. Then we also do a last piece inspection so we have first and last piece element charts. If it's a large quantity, we'll do a couple a day on the CMM."

CMMs In The Lab and On The Floor

Over the years, as CMM technology has become more accessible to machine tool operators and others working on the shop floor, the amount of training needed to operate coordinate measurement machines has been greatly reduced. There are those in the gear industry who might disagree with that assessment, but the trend toward easier programming and greater accessibility is certainly there.

The programming also allows coordinate measurement machines to be automated. This, and advances in machine design and construction, has made it practical to take coordinate measurement machines out of the lab and place them on the shop floor.

Lab CMMs. Gear metrology labs are clean, climate-controlled rooms designed to limit or eliminate environmental variations in measurement results. This level of precision and control is needed because lab machines are used more for troubleshooting and inspection.

Portal machines are one example of a dedicated laboratory CMM. Highly accurate machines, Portal machines utilize a moving granite base rather than a moving bridge. This provides greater accuracy and movement control than is possible with a moving bridge. "They tend to be larger," said Genest. "They tend to be made out of granite, not aluminum, and they're slower than shop floor machines."

Shop Floor CMMs. Coordinate measuring machines on the shop floor are a hardier breed, better able to deal with the heat, dirt and vibration associated with active machining operations. These machines are used primarily for process control in large automotive and aerospace shops to check parts during a production run. "Generally, they're automatically loaded and driven," said Genest. "The part programs are downloaded when

CMM inspecting a spur gear. Courtesy of Carl Zeiss, Inc.

the parts arrive and all the operator does is say, 'run.' All the programs are generally done up front because the machines in the factory come with all the fixturing and all the parts programming in place. It's a turnkey. The user interface is like a McDonalds interface: I got part 12, I want to inspect it, run."

Shop floor machines are designed to be clean, fast and to adapt to temperature changes. They are made of aluminum because granite absorbs oil, is slow moving and changes with temperature very slowly. "Years ago," said Genest, "we thought that was the cat's meow and aluminum was the scary stuff that changed very rapidly. But that's what you want in a shop floor machine. When the temperature changes you want the machine to change instantly. You don't want it to be slowly twisting and turning. You want to design a machine that doesn't twist, that just grows longer or shorter. It's very easy to compensate for that."

Accuracy and Tolerances. The major difference between shop floor CMMs and laboratory machines is accuracy. For coordinate measuring machines, precision is measured in terms of volumetric accuracy—the total cumulative error of all measurements taken along all three axes. According to Genest, the very best lab CMMs have a volumetric accuracy to under 1 micron, while their shop floor counterparts are, at best, accurate to under 10 microns. This is a very important distinction given the way tolerance measurement works.

"If you have a tolerance of a part that's 10 microns, a very tight position tolerance, you need a machine that's ten times more accurate than that tolerance to really resolve whether it's right or wrong," said Genest. To be certain that a part is within tolerance, your measuring equipment has to be far more precise than the tolerance you are looking for. "The problem," said Genest, "is that tolerances are getting so tight now that the 10-1 rule is now threatened. It's down to 5-1, or maybe 3-1 now." For gear manufacturers, that means the tolerances being demanded today are reaching the limits of the measurement precision of the machines. If this trend continues, it will raise the question of uncertainty as to whether the part is really within tolerance. "The lower you drop it," said Genest, "the more you run the risk that you are shipping bad parts." When it reaches 1-1, the uncertainty of the measurement will be 50%, meaning that accuracy and tolerance will be a coin-toss.

Costs. According to both Cowan and Smith, the kind of coordinate measuring machine that would be useful to gear manufacturers, one with a rotary table, scanning probe, sufficient precision and the right software, would be as much as or more than a generative gear tester, somewhere in the $300,000 to $500,000 range. "That does not include the cost of training the operators," said Cowan. "When you buy a dedicated gear inspection system, it comes with any training that's required, typically only a couple of days." With some brands of CMM, it's much different, Cowan said. "You have to take an operator and train him for at least a week, if not more, in order to be able to learn the language to write part programs."

According to Genest, the cost of a CMM is comparable to generative gear testers, and Brown & Sharpe includes all the hardware and software, as well as installation, documentation, certification, calibration and training. "The training on the CMM software takes about a week," said Genest. "If you were a gear manufacturer, you would probably then take an advanced course in the specific gear applications you would be working with." For that operator to take a part that's handed to him, throw it on the machine and measure it in under an hour can take six months. "It depends on the operator's expertise," Genest continued. "If you have someone who is very computer literate and has a firm grasp of the three-dimensional aspects of geometry, then it goes a lot quicker."

Comparable machine costs means that even with the added training required for specific applications, a gear manufacturer who also makes shafts and bearings, gear boxes or other parts may find that the CMM is more economical due to the machine's greater flexibility. "A CMM typically used to measure prismatic parts can, in an instant, be used to measure gears, " said Rolf Dettler, an applications engineer for Carl Zeiss. "For manufacturers of both items, it is an ideal solution. The capital investment is far less than buying two separate machines." All they would have to do is program the machine to examine their products, and there are software packages available from a variety of sources including Brown & Sharpe, Zeiss, The Gleason Works and others, to make that programming easier. On the other hand, dedicated gear shops that make parallel axis gears would likely find CNC generative gear testers, machines designed and developed to work exclusively with gears, better suited to their operations.

The Future of Coordinate Metrology: Digital Masters

One of the reasons that coordinate measurement technology has become so important to the gear industry recently is the 1998 determination by NIST and the Department of Defense that electronic master gears are a viable adjunct to the physical master gears used for final acceptance decisions relating to

According to Mark Cowan, director of metrology for M&M Precision Systems of Dayton, OH, "CNC generative gear testers are considered to be the fastest, most precise way of measuring parallel axis gears."

CNC generative gear tester. Courtesy of M&M Precision Systems Corp.

THE BASICS OF COORDINATE MEASURING MACHINES

What precisely is a coordinate measuring machine? The most basic definition is a machine, either manual or automatic, that takes measurements along three axes to define a three-dimensional shape using a sensor, called a probe, that is brought into direct contact with the object being measured. The probe contacts discreet points along the surface of the object, a gear for example. Measurements are taken from these data points, run through the CMM's software and related to a three dimensional Cartesian coordinate system. The accuracy of the CMM is governed, in part, by the machine design itself, but mostly by the type of probe being used.

Probes. Manual coordinate measuring machines use hard or fixed probes (ball, tapered plug or edge). These are placed in contact with the part to be measured by the operator, who then manually initiates the taking of the measurement. The next step up is the touch-trigger probe, which closes a switch when it contacts the part. This is more accurate, and the feedback generated by this kind of probe is what allowed DCC (direct computer control) of CMMs. Perhaps the most sensitive kind of probe is the continuous scanning probe. This kind of probe does not measure separate data points like the touch-trigger or fixed probes. Instead, it measures the deflection of the probe pin in all three axes. This allows the machine to compensate for any deflection during the measurement process while providing feedback for continuous scanning. Continuous scanning means that the probe follows the contours of the part being measured. This collects a great deal of data, far more than touch-trigger or fixed probes can provide, making it useful for inspecting variable part geometries.

More exotic, non-contact methods such as electro-optical sensors or lasers are used when a physical probe isn't practical or in applications where the part being measured cannot be touched. With electro-optical sensors, an image of the part is compared to a digital master stored in the CMM's memory. Lasers are another method of noncontact coordinate measurement. "They work like a touch probe," said Mike Berlin, U.S. product manager for Mahr. "The laser generates discreet data points in the X,Y and Z axes based on the reflection of the laser from the part being scanned." These data points are stored in the machine's computer and the 3D model is built up in the usual way. Lasers, however, are limited to materials that offer enough reflectivity to produce a viable return.

Construction. There are various types of coordinate measuring machines on the market today including fixed and moving bridge type machines; cantilever, gantry and column machines; single and dual horizontal arm machines; and measuring robots. Still, all have certain things in common. Typically, the machines have a heavy base, usually granite, that is either placed on the floor or fixed to it. This supports the part being measured. Over that, depending on the design, there are rails and carriages that move the probe in any of the three axes. In bridge-type machines, for example, there would be Y-axis rails attached to the base. The bridge, holding the rails and carriage for the X-axis, would move along these rails. This, in turn, supports the Z-axis and the probes. Air or roller bearings are used, depending on the environment, to provide smooth movement through all three axes. On some highly accurate laboratory machines called Portal machines, the bridge remains motionless while the granite base moves. While slower, this is considered more accurate and repeatable.

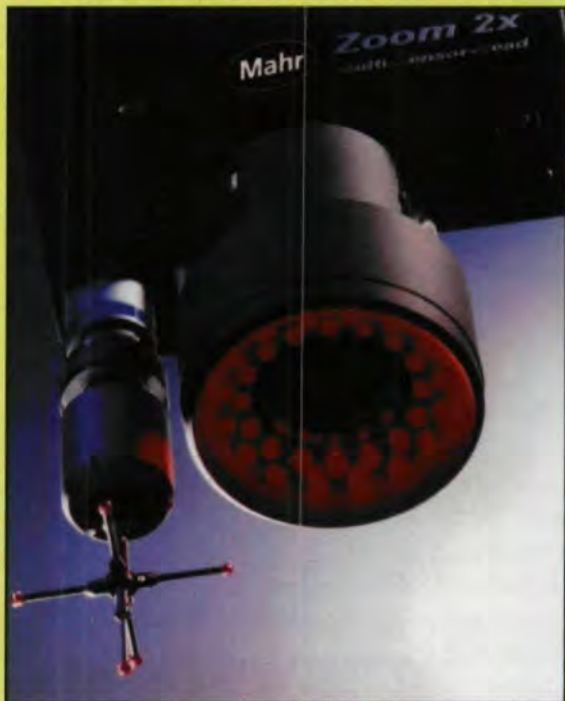
CMM Probes and gears. Courtesy of Brown & Sharpe.

Positioning is determined by the measurement system within each of the axes, often glass scales mounted on each axis with an electro-optical system that uses light reflected off the scale to read the position.

Programming. Finally, there is a computer to collect and process the measurement data. The software used by these machines is such that a part's data can be programmed into the machine to be used as referents for the part being measured.

The software found in today's CMMs is modular and easily interfaced by icon or menu-driven operating systems. Additionally, the software found in many CMMs today is capable of statistical analysis, mathematical computations, links with CAD, CAE, CAM and other outside systems. Some CMM software packages include special purpose analysis and application modules including real-time statistical analysis, flexible gaging, best-fit analysis, and contour measurements and comparisons.

All of this makes coordinate measuring machines extremely flexible. According to David Genest, director of marketing and corporate communications for Brown & Sharpe, "They can measure any part that will fit into the machine, making them ideal for manufacturers who produce many different kinds of parts."



Combination video, laser and touch probes. Courtesy of Mahr Corporation.

precision spiral bevel gears and that such digital masters will play a greater role in the future.

In a sense, coordinate measurement machine technology is based on the idea of a digital master. In order for the machine to perform the inspection of a part, it must be able to compare the measurements it takes from the production piece with a set of nominal values. Whether those values are fed into the CMM's computer manually, through a first piece inspection or are derived from a CAD drawing, the result is the same—a range of nominal data that performs as a master part. Because these data points are precise measurements, the same level of interpretation is not required as with other kinds of testing, e.g. roll testing, where marking compound is applied and the results interpreted.

The DoD report, called "Electronic Gear Master State-of-the-Art Review," was sponsored by the U.S. Army Aviation and Missile Command and carried out by the IIT Research Institute and INFAC, the Instrumented Factory for Gears. The report was published in September, 1998. The study was based on the need to reduce the cost of helicopter transmission components. The method under consideration in the study was the elimination of physical master gears. According to the report, "Inspection and testing are major cost drivers in the production of precision gears, especially spiral bevel precision gears, and represent a key target for reducing the cost of helicopter transmission components."[1] There were three objects of the study. The first was a feasibility study of eliminating physical gear masters from precision spiral bevel gear manufacturing. The second was the development of a standardized methodology for inspecting spiral bevel gears as a potential approach for using CMM technology for final part acceptance. The third object was to define an approach for establishing and defining a standard methodology, procedure and technology for allowing the use of coordinate measurement machines for final acceptance of precision spiral bevel gears.

The focus of the study was precision spiral bevel gears. For the study's purposes, precision was defined as AGMA 12 or greater. During the survey it was found that digital masters based on coordinate measuring machines do offer lower costs, greater flexibility and better documentation of the desired engineering configuration. It was also found that the CMM was able to eliminate the subjectivity of roll testing.

The report concluded that "The use of coordinate measuring machine technology has made a tremendous impact on the manufacture of precision spiral bevel gears, resulting in higher quality and lower cost." The report also concluded that "it is further evident that electronic masters may play a greater role in future gear designs, but the precision spiral producers and users will always want a physical master."[1]

Conclusion

Coordinate measuring machines may be a long way from displacing CNC generative gear testers, but they are making a great contribution to the gear industry, especially among aerospace and automotive manufacturers. The idea of the electronic or digital master gear is being explored while probe and sensor technology, as well as CMM software, are being improved. Combined, these developments promise growth in the use of a machine that is, today, already as ubiquitous in industry around the world as any other machine tool. ❍

1. INFAC. "Electronic Gear Master State-of-the-Art Review," Sept. 1998.

According to Robert E. Smith, "CMMs are very capable machines and can be very accurate. But to me, it takes more of an engineer to run that machine than a shop person. If you have a CNC generative machine, most of the shop people would be capable of running that."

Charles M. Cooper
is the senior editor for Gear Technology.

PRODUCTS & SERVICES INDEX

Welcome to the *Gear Technology* Buyers Guide 2000 Products & Services Index. Use this index to locate the names of companies according to the products and services they provide. The complete mailing address, phone and fax numbers and e-mail and Web site addresses of each company are listed in the Company Index (p. 45). *Gear Technology* advertisers are shown in boldface type. To find the pages on which their ads appear, see the Advertisers Index on page 17.

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

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Bevel Gear Generating Machines
American Machinery
Ataka Engineering
Basic Incorporated Group
Gleason-Pfauter GmbH
The Gleason Works
Klingelnberg Söhne GmbH
Liebherr Gear Technology
Oerlikon Geartec AG
Sales Consultants
V & R Associates
WMW Machinery

Broaching Machines
American Broach & Machine Co.
American Machinery
Ann Arbor Machine Co.
Apex Broach & Machine
B.H. Jones Machine & Gage
Broaching Machine Specialties
Colonial Tool Group Inc.
Crankshaft Machine Group
Detroit Broach
Fässler Corp.
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Kingsford Broach & Tool
Miller Industrial Service
National Broach & Machine
Ohio Broach & Machine
Oswald Forst GmbH
Sales Consultants
Ty Miles Inc.
U.S. Broach & Machine

Burnishing Machines
ITW Heartland
M&M Precision Systems

Chamfering Machines
American Machinery
American Wera Inc.
Ataka Engineering
Basic Incorporated Group
Chamfermatic Inc.
Eltech Inc.
Gleason-Hurth GmbH
Gleason-Pfauter GmbH
GMI
Liebherr Gear Technology
Mitsubishi Machine Tools
On-Line Services, Inc.
Redin Corporation
Schenck Turner
SPF Specialties Ltd.
SU America
V & R Associates
WMW Machinery

Deburring Machines
American Machinery
Basic Incorporated Group
Burlytic Systems
Chamfermatic Inc.
Eltech Inc.
Gleason-Hurth GmbH
Gleason-Pfauter GmbH
The Gleason Works
GMI
Holroyd
Liebherr Gear Technology
Mitsubishi Machine Tools
On-Line Services, Inc.
Redin Corporation
Schenck Turner
SPF Specialties Ltd.
SU America

Gear Cutting Machines
Basic Incorporated Group
Bourn & Koch
Cole Mfg. Systems, Inc.
GCTS Inc.
The Gleason Works
Klingelnberg Söhne GmbH
Koepfer America, L.L.C.
Lees Bradner
Liebherr Gear Technology
National Broach & Machine
Oerlikon Geartec AG

Gear Grinding Machines
American Machinery
Basic Incorporated Group
Belden Machine Corp.
Bluegrass Precision
Bourn & Koch
Cole Mfg. Systems, Inc.
Eltech Inc.
Gleason-Pfauter GmbH
The Gleason Works
GTI Technologies
Hermes Machine Tool
Höfler Maschinenbau
Hoglund Technology
Huffman Corporation
Kapp Sales & Service
Klingelnberg Söhne GmbH
Liebherr Gear Technology
Miller Industrial Service
Mitsubishi Machine Tools
National Broach & Machine
Oerlikon Geartec AG
Okamoto Corp EDM Div.
Reishauer Corporation
Sales Consultants
SU America
Wilton Machinery
WMW Machinery

Gear Rolling Machines
FGT Gage & Systems Inc.
ITW Heartland
National Broach & Machine

Hard Gear Finishers
Bourn & Koch
The Gleason Works
Koepfer America, L.L.C.
Liebherr Gear Technology
National Broach & Machine

Hobbing Machines
American Machinery
B.H. Jones Mach. & Gage
Basic Incorporated Group
Bourn & Koch
GA-Heartland
GCTS Inc.
Gleason-Pfauter GmbH
The Gleason Works
Hermes Machine Tool
Jamal Gear Machinery
Koepfer America, L.L.C.
Lees Bradner
Liebherr Gear Technology
Mitsubishi Machine Tools
Mitsui Machine Technology
National Broach & Machine
Reishauer Corporation
Sales Consultants
V & R Associates
WMW Machinery

Honing Machines
Basic Incorporated Group
Bates Technologies
Belden Machine Corp.
Bluegrass Precision
Fässler Corp.
Gleason-Hurth GmbH
Gleason-Pfauter GmbH
The Gleason Works
GTI Technologies
Liebherr Gear Technology
Micromatic Textron
National Broach & Machine
Reishauer Corporation
Sidley Diamond Tool Co.
Sunnen Products Co.

Inspection Machines
Alpha Precision Inc.
American Machinery
American Stress Technologies
Basic Incorporated Group
Bluegrass Machinery
Bourn & Koch
Cole Mfg. Systems, Inc.
D.I.G.I.T., Inc.
FGT Gage & Systems Inc.
Gleason-Pfauter GmbH
Holroyd
ITW Heartland
Jamal Gear Machinery
Klingelnberg Söhne GmbH
Kokusai Inc.
Krautkramer Branson
Liebherr Gear Technology
M&M Precision Systems
Mahr Corporation
Manufactured Gear & Gage
Micro Gear
Miller Industrial Service
Moore Measurement Solutions
National Broach & Machine
Oerlikon Geartec AG
Ono Sokki Technology,
Precision Gage Co.
Profile Engineering, Inc.
Roto-Technology, Inc.
Russell, Holbrook & Henderson, Inc.
Spline Gauges Ltd.
TSK America

Keyseating Machines
American Machinery
Elmass North America
Mitts & Merrill L.P.
Ohio Broach & Machine

Lapping Machines
Bluegrass Precision
Gleason-Pfauter GmbH
The Gleason Works GmbH
Lapmaster International
Liebherr Gear Technology
Oerlikon Geartec AG
Wilton Machinery

Measuring Machines
Alpha Precision Inc.
American Machinery
Basic Incorporated Group
Bluegrass Precision
Bourn & Koch
Dyer Company
FGT Gage & Systems Inc.
ITW Heartland
Klingelnberg Söhne GmbH
Krautkramer Branson
Liebherr Gear Technology
M&M Precision Systems
Mahr Corporation
Miller Industrial Service
Precision Gage Co.
Process Equipment Co.
Profile Engineering, Inc.
Russell, Holbrook & Henderson, Inc.
Spline Gauges Ltd.
TSK America
United Tool Supply

Rack Millers and Cutters
Bourn & Koch

Shaping Machines
American Machinery
Basic Incorporated Group
Bluegrass Precision
Bourn & Koch
Elmass North America
Fellows Corp.
Gleason-Pfauter GmbH
The Gleason Works
Hermes Machine Tool
Liebherr Gear Technology
Micromatic Textron
Mitsubishi Machine Tools
WMW Machinery

Shaving Machines
American Machinery
Basic Incorporated Group
Bluegrass Precision
Bourn & Koch
Gleason-Hurth GmbH
Gleason-Pfauter GmbH
The Gleason Works
Liebherr Gear Technology
Mitsubishi Machine Tools
National Broach & Machine

Spline Grinding Machines
Bourn & Koch Machine
The Gleason Works
Liebherr Gear Technology
National Broach & Machine
Wilton Machinery

Spline Milling Machines
Basic Incorporated Group
Bourn & Koch
The Gleason Works
Wilton Machinery

Spline Rolling Machines
Anderson-Cook, Inc.
Caledonian Midwest Sales
Colonial Tool Group Inc.
Ernst Gröb AG
General Broach & Eng.
M&M Precision Systems
Micromatic Textron
National Broach & Machine

Testing Machines
American Machinery
Bourn & Koch
Dyer Company
Fellows Corp.
FGT Gage & Systems Inc.
Gleason-Pfauter GmbH
GMI
Klingelnberg Söhne GmbH
Kowalski Heat Treating
Krautkramer Branson
Liebherr Gear Technology
Manufactured Gear & Gage
Micro Gear
Oerlikon Geartec AG
Ono Sokki Technology,
Precision Gage Co.
Profile Engineering, Inc.
Russell, Holbrook & Henderson, Inc.
Spline Gauges Ltd.
Trisys
UBM Corporation

Thread, Worm and Flute Milling Machines
American Machinery
Basic Incorporated Group
Eltech Inc.
GCTS Inc.
Gleason-Pfauter GmbH
The Gleason Works
Holroyd
Koepfer America, L.L.C.
Reishauer Corporation
WMW Machinery

Other Gear Manufacturing Machines
American Wera Inc.—*Polygon Cutting (Profilating)*
Ataka Engineering—*Cutter Sharpening Machines*
Belden Machine Corporation—*Bore Finishing Machines*
Colonial Saw Co.—*Hob Sharpeners*
DoAll—*Sawing Machines & Blades*
GMI—*Tooth Rounding & Pointing Machines*
Hoglund Technology Corp.—*Computerized Wheel Dressers*
Interstate Tool Corp.—*Herringbone Cutter Sharpening Fixture*
Manufacturing Technology Inc.—*Friction Welding Machines*
Meccanica Nova—*Combination Gear OD, ID and Face Grinders*
Mitsubishi Laser—*Laser Cutting Machines*

Oberlin Filter Co.—*Filtration Equipment, Pressure Filters*
One Cryo Inc.—*Cryogenic Tempering Equipment*
Raycon Corporation—*Laser Welders*
SPF Specialties Ltd.—*Skiving Machines*
Ty Miles Inc.—*Ballizing Machines*
USACH Technologies Inc.—*ID & Face Grinding Machines*

NON-GEAR MACHINES

Abrasive Waterjet Machines
Huffman Corp.
Richel Inc.

Cutter Inspection/Setting Machines
Klingelnberg Söhne GmbH
Liebherr Gear Technology
Oerlikon Geartec AG
Spline Gauges Ltd.

Cutting Tool Sharpening Machines
American Broach & Machine Co.
American Machinery
B.H. Jones Machine & Gage
Basic Incorporated Group
Colonial Saw Co.
Gleason-Hurth GmbH
Gleason-Pfauter GmbH
Huffman Corporation
Interstate Tool Corp.
Klingelnberg Söhne GmbH
Koepfer America, L.L.C.
Mitsui Machine Tech.
National Broach & Machine
Russell, Holbrook & Henderson, Inc.
Star Cutter Co.
SU America

EDM Machines
Ann Arbor Machine Co.
Bluegrass Precision
Charmilles Technologies
Easco-Sparcatron
Hansvedt Industries Inc.
KGK International Corp.
Makino
Mecatool USA Ltd.
Okamoto Corp EDM Div.
Raycon Corporation

Form Grinders
The Gleason Works
Huffman Corp.
Liebherr Gear Technology
National Broach & Machine
Oerlikon Geartec AG
SU America

Heat Treating Equipment
Ajax Magnethermic Corp.
Basic Incorporated Group
Bluegrass Precision
Can-Eng Furnaces Ltd.
Contour Hardening, Inc.
Engineered Heat Treat
Fluxtrol Manufacturing
The Grieve Corporation
Holcroft
Inductoheat Inc.
K.H. Huppert Co.
Klingelnberg Söhne GmbH
Kowalski Heat Treating
Lepel Corporation
McEnglevan Industrial Furnace
National Broach & Machine
Pacific Industrial Furnace
Pillar Industries
Quench Press Specialists
Radyne Corporation
Surface Combustion, Inc.
TOCCO Inc.
Therm Alliance Co.
V.T.M. Co. Ltd.

Lasers
B.H. Jones Machine & Gage
Huffman Corp.
Process Equipment Co.

Machining Centers
Bourn & Koch

Milling Machines
American Machinery

Quenching Presses
Klingelnberg Söhne GmbH
Kowalski Heat Treating
Liebherr Gear Technology
Wabash MPI

Thread Grinders
B.H. Jones Machine & Gage
Holroyd
Huffman Corp.
Klingelnberg Söhne GmbH
Liebherr Gear Technology
Normac, Inc.
Reishauer Corp.
SU America

Tool & Cutter Grinders
B.H. Jones Machine & Gage
The Gleason Works
Huffman Corp.
Klingelnberg Söhne GmbH
Liebherr Gear Technology
National Broach & Machine
Oerlikon Geartec AG
Star Cutter Co.
SU America
Wilton Machinery

Turning Machines
American Machinery
Bluegrass Precision
Hermes Machine Tool
Miller Industrial Service
Sytec Corporation
V & R Associates
WMW Machinery

Other Non-Gear Machines Tools
Belden Machine Corporation—*Multi-spindle Drill Tap, Work Cells*
The Grieve Corporation—*Industrial Ovens*
Jamal Gear Machinery Ltd.—*Grinding Wheel Dressing Machines*
Process Equipment Company—*Laser Welders, Capacitor Discharge Welders & Special Machines*
Star Cutter Co.—*Broach Sharpeners*

GEAR MATERIALS

Bar Stock
Bunting Bearings Corp.
Dura-Bar
Lovejoy Steel—York
Steel Industries, Inc.

Cast Iron
The A.B.A. Company
Adobe Precision Gear
Dura-Bar
Ferry-Capitain Industries
Great Taiwan Gear Ltd.
Lovejoy Steel—Cincinnati
Lovejoy Steel—York
Qualicast Corp.
Rush Gears Inc.
Sales Consultants
Scot Forge
Wes-Tex Gear Inc.
Zhuhai Intercontinental Pulleys Ltd.

Gear Blanks
Accurate Specialties Inc.
Adobe Precision Gear
Akron Gear & Engineering
Ann Arbor Machine Co.
Arrow Gear Company
Bengal Industries
Blanchat Machine Co.
Bunting Bearings Corp.
Capstan Atlantic
Cornell Forge Co.
Dabko Industries Inc.
Dura-Bar
East Point Foundry
Edgewater Steel Ltd.
Elmass North America
Ferry-Capitain Industries
The Gear Works—Seattle
Horsburgh & Scott
Howard's Machine Shop
Lovejoy Steel—Cincinnati
Lufkin Ind. Gear Repair
McInnes
Milford Gear Works
Mobile Pulley & Machine
Moore-Addison
Nordex, Inc.
Orlandi Gear Co.
Penntech
PIC Design
Presrite Corp.
Process Industries
Pulley Manufacturers Inc.


Handbook of Metric Gears

Softwares Inc.
Intech Corporation
Interstate Tool Corp.
Ion Vacuum Technologies
J&E Hofmann Engineering
Jack Dustman & Assoc.
James Reid Gear Services
Kowalski Heat Treating
Labeco
McGinty Gear
Manufactured Gear & Gage
Mechanical & Structural Design & Software
Metal Powder Industries Federation
Milburn Engineering, Inc.
Milford Gear Works
Milwaukee Gear Co.
Moore Gear Mfg. Co.
Moore Machine & Gear
Moore Measurement Solutions
Mostar Gear & Machine
Mr. Gears, Inc.
Nixon Gear Inc.
Oerlikon Geartec AG
Packer Engineering
Performance Gear Systems, Inc.
Powertrain Engineers
Precision Engineering
Precision Gear Inc.
Progressive Steel Treating
R. Cushman & Assoc.
R.E. Smith & Co.
Reilly Engineering Inc.
Richel Inc.
Riley Gear Corp.
Roto-Technology, Inc.
Santasalo North America
SBR Consulting
Schafer Gear Works, Inc.
Spicer Industries Inc.
Spline Gauges Ltd.
Star Cutter Co.
Stork Technimet
Sussex Gear Company
Swiglo Metallurgical Consulting
Taiga Engineering Group
Tifco Gage & Gear
Trogetec Inc.
U.S. Tech Corp.
Ultron Incorporated
Van Gerpen-Reece Engineering
Wedin International, Inc.
Westech Gear
Wes-Tex Gear Inc.

Cryogenics

American Brazing
Best Engineering, Inc.
C-B Gear & Machine Inc.
Dynamic Metal Treating
Hauni Richmond, Inc.
Horsburgh & Scott
Hudapack Metal Treating —Elkhorn
Hudapack Metal Treating —Glendale Heights
Iron Bound Heat Treating
J&E Hofmann Engineering
Jasco Heat Treating Inc.
Kowalski Heat Treating
Metlab
One Cryo Inc.
Paulo Products Co. —Bessemer
Paulo Products Co. —Memphis
Paulo Products Co. —Murfreesboro
Paulo Products Co. —Peculiar
Paulo Products Co. —St. Louis
Progressive Steel Treating
Sales Consultants
Sun Steel Treating Inc.
Trogetec Inc.

Custom Gear Manufacturing

ABA-PGT, Inc.
Acme Gear Company
ACR Industries, Inc.
The Adams Company
Aero Gear, Inc.
Albro Gear & Instrument
Allied Gear Co.
Amarillo Gear Company
American Machine & Gear
Ann Arbor Machine Co.
Arrow Gear Company
Arte Corporation
Avon Gear Co.
B & R Gear and Machine
Circle Gear and Machine
Barit International Corp.
Bevel Gears (India)
Biddle & Mumford Gears
Bodine Electric Company
Bourn & Koch
Calicut Engineering Works
Carnes-Miller Gear Co.,
C-B Gear & Machine Inc.
Channel Power Transmission, Inc.
Chardam Gear Co.
Chicago Gear-D.O. James
Chicago Gear Works
CIATEQ
Circle Gear and Machine
Columbia Gear Corp.
Commercial Gear & Sprocket Co. Inc.
Crown Gear B.V.
Cunningham Industries,
Custom Stock Gear & Machine
Davall Gear Company Ltd.
Dearborn Gear & Tool
Emerson Power Transmission
Engranes Industriales Rivera, S.A. de C.V.
Ferry-Capitain Industries
Fisher's Gear and Machine
G&N Rubicon Gear, Inc.
Gear Company of America
Gear Master Engineering
Gear Works, Inc.
Geartec, Inc.
Generated Gear & Machine
Gerhardt Gear Company
Graziano Trasmissioni
Halifax Rack & Screw Cutting Co. Ltd.
Holroyd
Invincible Gear Co.
J&E Hofmann Engineering
Jamal Gear Machinery
Klingelnberg Söhne GmbH
Kreiter Geartech
Lawler Gear Corp.
Lees Bradner Div.
Linn Gear Co.
M.J.H. Gear & Tool Co.
mG miniGears Inc.
Midwest Gear & Tool
Modified Gear & Spline,
Moore Machine & Gear
Moore Measurement Solutions
Nissei Corporation
Nixon Gear Inc.
O'Brien Gear Company
Oliver Gear, Inc.
Omni Gear
Orlandi Gear Co.
P.H. Precision Products
Performance Gear Systems, Inc.
Phillips-Moldex Co.
Precipart Corporation
Precision Gear Co.
Qualicast Corp.
Raycar Gear & Machine
Reef Gear Mfg., Inc.
Richel Inc.
Riley Gear Corp.
Schafer Gear Works, Inc.
Seitz Corporation
Selector Spline Products,
Spicer Industries Inc.
STD Precision Gear & Instrument, Inc.
Suda International Gear Works Ltd.
Trojon Gear Inc.
Unique Power Products
Wedin International, Inc.
Wiscon Products, Inc.

Cutting Tool Sharpening

Action Gear & Broaching
American Broach & Machine Co.
American Machine & Gear
Apex Broach & Machine
B.H. Jones Machine & Gage
Bean Tool, Die & Eng.
Best Engineering, Inc.
C-B Gear & Machine Inc.
Dayton Gear & Tool
Forest City Gear
Fubri s.r.l.
Gear Company of America
Gerhardt Gear Company
Gleason-Pfauter GmbH
Gleason Pfauter Hurth Cutting Tools
The Gleason Works
Interstate Tool Corp.
Ion Vacuum Technologies
J&E Hofmann Engineering
Jamal Gear Machinery

JRM International, Inc.
Koepfer America, L.L.C.
Koro Sharpening Service
Lawler Gear Corp.
Micromatic Textron
Mill Max Tools Pvt. Ltd.
Mitsubishi Machine Tools
Moore Gear Mfg. Co.
Mr. Gears, Inc.
Multi-Arc Inc.
National Broach & Machine
Oerlikon Geartec AG
Richter Precision Inc.
Ronson Gears Pty. Ltd.
Sales Consultants
Schafer Gear Works, Inc.
Star Cutter Co.
SU America
Universal Gear Co.
Wedin International, Inc.

Fault Analysis

Adobe Precision Gear
Applied Mechaniques
Ashot Ashkelon Indust.
Ashot USA Inc.
Aston Metallurgical Services Co. Inc.
C-B Gear & Machine Inc.
CETIM
Chicago Gear-D.O. James
CIATEQ
The Cincinnati Gear Co.
D.L. Borden, Inc.
Davall Gear Company
Fairfield Mfg. Co.
Forest City Gear
Horsburgh & Scott
Hy-Mech Systems Inc.
I.S.P.J.A.E.
J&E Hofmann Engineering
Lambda Research
Lufkin Industries Gear Repair
Mechanical & Structural Design & Software
Milburn Engineering, Inc.
Modern Industries Inc.
Mr. Gears, Inc.
NASA Glenn Research Ctr.
National Metrology
Packer Engineering
Paulo Products Co. —Peculiar
Philadelphia Gear Corp. —Houston
Powertrain Engineers
Progressive Steel Treating
R. Cushman & Assoc.
Reilly Engineering Inc.
Stork Technimet
Trogetec Inc.
Wedin International, Inc.
Westech Gear
Wes-Tex Gear Inc.

Gear Coatings

Cutting Edge Products, Diamond Black Technologies
Diamonex Incorporated
The Duffy Company
Dynamic Metal Treating
General Magnaplate Corp.
The Gleason Works
Great Taiwan Gear Ltd.
J&E Hofmann Engineering
Mitsubishi Machine Tools
Multi-Arc Inc.
Sun Steel Treating Inc.
Surface Technology, Inc.

Gear Design

ABA-PGT, Inc.
Action Gear & Broaching
Adobe Precision Gear
Advance Gear & Machine
Aero Gear, Inc.
Akron Gear & Engineering
Allied Devices Corp.
Ann Arbor Machine Co.
Aplus Engineering Inc.
Applied Mechaniques
Arrow Gear Company
Arte Corporation
Ashot Ashkelon Indust.
Ashot USA Inc.
Axicon Technologies
Barit International Corp.
Bevel Gears (India) Pvt.
Blanchat Machine Co.
Bodine Electric Company
Capstan Atlantic
Carbon City Products
Caterpillar Industrial Products Inc.
C-Dot Engineering
CETIM
Channel Power Transmission, Inc.
Chicago Gear-D.O. James
CIATEQ
The Cincinnati Gear Co.
CMD (UK) Ltd.
Columbia Gear Corp.
Contour Hardening, Inc.
Crown Gear B.V.
Custom Gear & Machine
D.L. Borden, Inc.
Davall Gear Company Ltd.
Dearborn Gear & Tool Company, Inc.
Drive Systems Technology
Drivetrain Technology Ctr.
Dynamic Tool Grinding
Emerson Power Transmission
Fairfield Mfg. Co.
Ferry-Capitain Industries,
Gear Works, Inc.
The Gear Works—Seattle
Gearesearch Assoc.
Geartech Ltd. - Tecnologia de Engrenagens
Global Gear
Graziano Trasmissioni
Great Taiwan Gear Ltd.
GW Plastics
Harder Precision Components
HMC
Horsburgh & Scott
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Insco Corporation
Intech Corporation
Involute Simulation Softwares Inc.
J&E Hofmann Engineering
Klingelnberg Söhne GmbH
Kreiter Geartech
Labeco
Lufkin Industries Gear Repair
McGinty Gear
Mechanical & Structural Design & Software
mG miniGears Inc.
Milburn Engineering, Inc.
Milford Gear Works
Milwaukee Gear Co.
Moore Machine & Gear
Mr. Gears, Inc.
Nixon Gear Inc.
Oerlikon Geartec AG
Omni Gear
O'Neill Gear
Packer Engineering
PC Enterprises
Pennsylvania Gear Corp.
Penntech
Performance Gear Systems, Inc.
Phillips-Moldex Co.
Power Engineering & Mfg.
Powertrain Engineers
Precipart Corporation
Precision Engineering
Qualicast Corp.
R. Cushman & Assoc.
Reilly Engineering Inc.
Riley Gear Corp.
Rj Link International
Ronson Gears Pty. Ltd.
Santasalo North America
SBR Consulting
Seitz Corporation
Spicer Industries Inc.
Spline Gauges Ltd.
Sussex Gear Company
Taiga Engineering Group
Tifco Gage & Gear
Trogetec Inc.
UFE Incorporated
Unique Power Products
Van Gerpen-Reece Engineering
Von Ruden Mfg.
Wedin International, Inc.
West Industries Inc.
Westech Gear
Wes-Tex Gear Inc.
Winzeler Gear
Xtek Inc.

Gear Engineering

ABA-PGT, Inc.
ACR Industries, Inc.
Action Gear & Broaching
Adobe Precision Gear
Advance Gear & Machine
Aero Gear, Inc.
Akron Gear & Engineering
Allied Devices Corp.
Ann Arbor Machine Co.
Aplus Engineering Inc.
Applied Mechaniques
Arrow Gear Company
Arte Corporation
Ashot Ashkelon Indust.

Ashot USA Inc.
Axicon Technologies
Barit International Corp.
Bevel Gears (India) Pvt.
Biddle & Mumford Gears
Blanchat Machine Co.
Bodine Electric Company
Calicut Engineering Works
Capstan Atlantic
C-Dot Engineering
CETIM
Chicago Gear-D.O. James
CIATEQ
The Cincinnati Gear Co.
CMD (UK) Ltd.
Columbia Gear Corp.
Contour Hardening, Inc.
Crown Gear B.V.
Custom Gear & Machine
D.L. Borden, Inc.
Dabko Industries Inc.
Davall Gear Company
Dayton Gear & Tool
Dearborn Gear & Tool Company, Inc.
Drive Systems Technology
Drivetrain Technology
Dynamic Tool Grinding
Emerson Power Transmission
Fairfield Mfg. Co.
Federal Gear Corp.
Ferry-Capitain Industries
Foote-Jones/Illinois Gear
Gear Company of America
Gear Research Institute
Gear Works, Inc.
The Gear Works—Seattle
Gearesearch Assoc.
Gears & Drive Systems
Geartech Ltd.—Tecnologia de Engrenagens
Generated Gear & Machine
Global Gear
Graziano Trasmissioni
Great Taiwan Gear Ltd.
Harder Precision Components
Horsburgh & Scott
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Insco Corporation
Intech Corporation
Involute Simulation Softwares Inc.
J&E Hofmann Engineering
Kreiter Geartech
Labeco
Lufkin Industries Gear Repair
Lyon Gear
Mechanical & Structural Design & Software
mG miniGears Inc.
Milburn Engineering, Inc.
Milford Gear Works
Milwaukee Gear Co.
Modern Industries Inc.
Moore Machine & Gear
Mostar Gear & Machine
Mr. Gears, Inc.
NASA Glenn Research
Oerlikon Geartec AG
Omni Gear
O'Neill Gear
Patterson Gear & Machine
Pennsylvania Gear Corp.
Penntech
Performance Gear Systems, Inc.
Perry Technology Corp.
Philadelphia Gear Corp.—Houston
Phillips-Moldex Co.
Power Engineering & Mfg.
Powertrain Engineers
Precipart Corporation
Precision Engineering
Process Industries
Qualicast Corp.
R. Cushman & Assoc.
Reilly Engineering Inc.
Riley Gear Corp.
Rj Link International
Santasalo North America
SBR Consulting
Seitz Corporation
Spicer Industries Inc.
Spline Gauges Ltd.
Sussex Gear Company
Taiga Engineering Group,
Tifco Gage & Gear
Trisys
Trogetec Inc.
UFE Incorporated
Unique Power Products
Van Gerpen-Reece Engineering
Vesta Works USA, Inc.
Wedin International, Inc.
West Industries Inc.
Westech Gear
Wes-Tex Gear Inc.
Winzeler Gear
Xtek Inc.

Gear Grinding Services

Acme Gear Company
ACR Industries, Inc.
Advance Gear & Machine
Aero Gear, Inc.
Allied Gear Co.
American Machine & Gear
Ann Arbor Machine Co.
Aplus Engineering Inc.
Arrow Gear Company
Ashot Ashkelon Indust.
Ashot USA Inc.
Bevel Gears (India) Pvt.
Blanchat Machine Co.
The Broach Masters Inc.
Caterpillar Industrial Products Inc.
C-B Gear & Machine Inc.
Chardam Gear Co.
The Cincinnati Gear Co.
CMD (UK) Ltd.
Columbia Gear Corp.
Custom Stock Gear & Machine
Davall Gear Company Ltd.
Dayton Gear & Tool
Fairfield Mfg. Co.
Federal Gear Corp.
Foote-Jones/Illinois Gear
G&N Rubicon Gear, Inc.
The Gear Works—Seattle
Gears & Drive Systems
Generated Gear & Machine
Gerhardt Gear Company
Great Taiwan Gear Ltd.
Hamilton Gear
Hanover Gear Mfg. Co.
Höfler Maschinenbau
Horsburgh & Scott
Insco Corporation
Invincible Gear Co.
Ion Vacuum Technologies
J&E Hofmann Engineering
Jamal Gear Machinery
Kreiter Geartech
Lawler Gear Corp.
Lufkin Industries Gear Repair
Lyon Gear
Major Gauge & Tool Co.
Merit Gear Corp.
mG miniGears Inc.
Midwest Gear Corp.
Milwaukee Gear Co.
Modern Industries Inc.
Modified Gear & Spline,
Nakanishi Gear
National Broach & Machine
Niagara Gear Corp.
Nixon Gear Inc.
O'Brien Gear Company
Oerlikon Geartec AG
Oliver Gear, Inc.
Omni Gear
Overton Gear & Tool
Patterson Gear & Machine
Pennsylvania Gear Corp.
Penntech
Philadelphia Gear Corp. —Houston
Precision Gear Co.
Precision Gear Inc.
Process Industries
Pro-Gear Company, Inc.
The Purdy Corporation
Raycar Gear & Machine
Riley Gear Corp.
Riverside Spline & Gear
Ronson Gears Pty. Ltd.
Seitz Corporation
Selector Spline Products
Spline Gauges Ltd.
Tifco Gage & Gear
Trogetec Inc.
Unique Power Products
Westech Gear
Wedin International, Inc.
Xtek Inc.

Heat Treating Services

Accurate Ion Technologies
ACR Industries, Inc.
Advanced Material Process
Aero Gear, Inc.
Aerocraft Heat Treating
Ajax Magnethermic Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
American Brazing
American Metal Treating
Aplus Engineering Inc.
Applied Process Inc.
Arrow Gear Company
Ashot Ashkelon Indust.
Ashot USA Inc.
Blanchat Machine Co.
Calicut Engineering Works
Caterpillar Industrial Products Inc.
The Cincinnati Gear Co.
Commercial Steel Treating
Contour Hardening, Inc.
D.L. Borden, Inc.
Detroit Flame Hardening
Disston Precision Inc.

Drivetrain Technology Ctr.
Dynamic Metal Treating
Engineered Heat Treat
Edgewater Steel Ltd.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Fellows Corp.
Ferry-Capitain Industries,
Fluxtrol Manufacturing
Foote-Jones/Illinois Gear
FPM Heat Treating
Gear Company of America
General Surface Hardening
Generated Gear & Machine
Gleason-Pfauter GmbH
Gleason Pfauter Hurth
The Gleason Works
Great Taiwan Gear Ltd.
Hamilton Gear
Hauni Richmond, Inc.
Horsburgh & Scott
Hudapack Metal Treating —Elkhorn
Hudapack Metal Treating —Glendale Heights
Industrial Metal Treating
Iron Bound Heat Treating
J&E Hofmann Engineering
Jasco Heat Treating Inc.
Kolene Corporation
Kowalski Heat Treating Co.
LAI East/Laser Applications, Inc.
LAI Midwest, Inc.
LAI Southwest, Inc.
Linn Gear Co.
Lufkin Industries Gear Repair
Merit Gear Corp.
Metal Improvement
Metlab
mG miniGears Inc.
Mill Max Tools Pvt. Ltd.
Milwaukee Gear Co.
Modern Industries Inc.
Molon Gear & Shaft
Moore Gear Mfg. Co.
Mr. Gears, Inc.
Multi-Arc Inc.
National Broach & Machine
Nitrex Metal Technologies
Overton Gear & Tool
P.H. Precision Products
Patterson Gear & Machine
Paulo Products Co. —Bessemer
Paulo Products Co. —Memphis
Paulo Products Co. —Murfreesboro
Paulo Products Co. —Nashville
Paulo Products Co. —Peculiar
Paulo Products Co. —St. Louis
Penn Machine Company
Pennsylvania Gear Corp.
Penntech
Philadelphia Gear Corp. —Houston
Phillips-Moldex Co.
Progressive Engineering
Progressive Steel Treating
Qualicast Corp.
Richter Precision Inc.
Rush Gears Inc.
Shore Metal Technology
Sun Steel Treating Inc.
Surface Technology, Inc.
TOCCO Inc.
Trogetec Inc.
U. S. Axle Inc.
Unique Power Products
Wall Colmonoy Corp.
Wedin International, Inc.
Welduction Corp.
West Industries Inc.
Westech Gear
Xtek Inc.

Inspection Services

ACR Industries, Inc.
Action Gear & Broaching
Allied Devices Corp.
Alpha Precision Inc.
American Stress Technologies, Inc.
Ann Arbor Machine Co.
Aplus Engineering Inc.
Arrow Gear Company
Ashot Ashkelon Indust.
Ashot USA Inc.
Aston Metallurgical Services Co. Inc.
Avon Gear Co.
Axicon Technologies
Bean Tool, Die & Engineering
Best Engineering, Inc.
Blanchat Machine Co.
Bucyrus International, Inc.
Carnes-Miller Gear Co.,
C-B Gear & Machine Inc.
CETIM
The Cincinnati Gear Co.
Columbia Gear
Contour Hardening, Inc.
Davall Gear Company Ltd.
Drivetrain Technology
Edgewater Steel Ltd.
Euro-Tech Corp.
Fellows Corp.
Ferry-Capitain Industries,
Forest City Gear
Fubri s.r.l.
Gear Company of America
The Gear Works—Seattle
Generated Gear & Machine
Gerhardt Gear Company
Great Taiwan Gear Ltd.
Harder Precision Components
Horsburgh & Scott
ITW Heartland
J&E Hofmann Engineering
Kowalski Heat Treating Co.
Krautkramer Branson
Kreiter Geartech
Lufkin Industries Gear Repair
Lyon Gear
M&M Precision Systems
Mahr Corporation
Manufactured Gear & Gage
Merit Gear Corp.
Milwaukee Gear Co.
Modern Industries Inc.
Moore Machine & Gear
Moore Measurement Solutions
Mr. Gears, Inc.
National Metrology
Niagara Gear Corp.
Nixon Gear Inc.
Overton Gear & Tool
Packer Engineering
Patterson Gear & Machine
Paulo Products Co. —Peculiar
PC Enterprises
Pennsylvania Gear Corp.
Penntech
Performance Gear Systems, Inc.
Perry Technology Corp.
Philadelphia Gear Corp. —Houston
Phillips-Moldex Co.
Precision Gage Co.
Precision Gear Co.
Precision Gear Inc.
Process Industries
Profile Engineering, Inc.
Pro-Gear Company, Inc.
Progressive Steel Treating
Qualicast Corp.
Raycar Gear & Machine
Riley Gear Corp.
Riverside Spline & Gear
Roto-Technology, Inc.
Santasalo North America
Schafer Gear Works, Inc.
Scott Machine Tool Co.
Seitz Corporation
Spline Gauges Ltd.
Stork Technimet
Tifco Gage & Gear
Trisys
Trogetec Inc.
Trojon Gear Inc.
Ultron Incorporated
Unique Power Products
Wedin International, Inc.
West Industries Inc.
Westech Gear
Wes-Tex Gear Inc.
Xtek Inc.

Shot Peening

ACR Industries, Inc.
Ashot Ashkelon Indust.
Ashot USA Inc.
Blanchat Machine Co.
Edgewater Steel Ltd.
Fairfield Mfg. Co.
Generated Gear & Machine
Great Taiwan Gear Ltd.

CIRCLE 164

Graziano Transmissioni
Hydro Honing Laboratories
J&E Hofmann Engineering
Kowalski Heat Treating Co.
Metal Improvement Company, Inc.
Moore Gear Mfg. Co.
Mr. Gears, Inc.
NASA Glenn Research Center
Patterson Gear & Machine
Paulo Products Co. —Memphis
Pennsylvania Gear Corp.
Penntech
Progressive Technologies
Sales Consultants
U. S. Axle Inc.
Wedin International, Inc.
West Industries Inc.

Stock Gear Manufacturing

Arrow Gear Company
Berg, W.M.
Bevel Gears (India)
Calicut Engineering Works
Channel Power Transmission, Inc.
Chicago Gear-D.O. James
Chicago Gear Works
Custom Stock Gear & Machine
Davall Gear Company Ltd.
Emerson Power Transmission
Gear Company of America
Generated Gear & Machine Inc.
Gerhardt Gear Company
Graziano Transmissioni
Halifax Rack & Screw Cutting Co. Ltd.
J&E Hofmann Engineering
Linn Gear Co.
M.J.H. Gear & Tool Co.,
Moore Machine & Gear
Performance Gear Systems, Inc.
Quality Transmission Components
Reef Gear Mfg., Inc.
Riley Gear Corp.
Seitz Corporation
Selector Spline Products,
Spicer Industries Inc.
Stock Drive Products/Sterling Instrument
Wedin International, Inc.
Wiscon Products, Inc.

Tool Coating

Balzers Tool Coating Inc.
Barit International Corp.
Best Engineering, Inc.
Cutting Edge Products, Inc.
Diamond Black Technologies
Diamonex Incorporated
Dynamic Metal Treating
Eltech Inc.
Fellows Corp.
Fubri s.r.l.
General Magnaplate Corp.
Gleason-Pfauter GmbH
Gleason Pfauter Hurth
Cutting Tools
The Gleason Works
GMI
Great Taiwan Gear Ltd.
Ion Vacuum Technologies
Multi-Arc Inc.
Reid Tool Service Inc.
Richter Precision Inc.
Russell Holbrook & Henderson
Star Cutter Co.
SU America
Sun Steel Treating Inc.
Surface Technology, Inc.

Other Services

ABA-PGT, Inc.—*Gear Injection Molding*
Abrasive Technology Inc.—*Gear Honing*
ACR Industries, Inc.—*Manufacture Turbine Engine Gearboxes and Helicopter Transmissions*
Akron Gear & Engineering—*Large Diameter Turning, CNC Milling*
American Brazing—*Brazing*
American Gear & Engineering—*Slotting, CNC Turning*
American Metal Treating—*Gear Induction Hardening*
Arte Corporation—*Plastic Injection Molding*
ASM International—*Training, Education, Books*
Aston Metallurgical Services Co. Inc.—*Metallurgical Testing Lab*
Axicon Technologies—*Gear & Drivetrain Testing (Noise and Load/Life), Rapid Prototyping*
Becker Gearmeisters—*Preventive Maintenance, Calibration, Certification*
Bodine Electric Company—*Custom Gearbox Design*
Chamfermatic Inc.—*Deburring/Chamfering Services*
Chandler Machine Co.—*Wire EDM Service*
The Cincinnati Gear Co.—*Gearbox Overhaul & Field Service*
Cold Forming Technology, Inc.—*Production & Prototype Spline and Thread Rolling*
Cutting Edge Products, Inc.—*Metal Ion Implantation*
Davall Gear Company Ltd.—*Spiroid® and Spiradrive® Gear Systems*
Deco Products Company—*Zinc-cast Gears*
Drive Systems Technology, Inc.—*Failure Analysis, All Phases of Gear Consulting*
Drivetrain Technology Center—*Testing & Measuring*
East Point Foundry—*Custom Casting*
Eltech Inc.—*Hob Sharpening*
Euclid Heat Treating Co.—*Induction Hardening*
Fluxtrol Manufacturing—*Induction Heat Treating*
GCTS Inc.—*Process Engineering*
Guy Crader Consulting—*Gear Manufacturing Engineering Consultant*
Halifax Rack & Screw Cutting Co. Ltd.—*Gear Rack Manufacture*
Horsburgh & Scott—*Gear Drive Rebuilding (All Manufacturers)*
Industrial Technology Institute—*ISO 9000 Training*
J&E Hofmann Engineering—*Installation Service*
Keystone Threaded Products Div.—*Worm Rolling*
Kolene Corporation—*Molten Salt Bath Heat Treating*
Koro Sharpening Service—*Hob Sharpening*
Kreiter Geartech—*Gearbox Repair*
LAI East/Laser Applications, Inc.—*Waterjet Cutting, Laser Cutting, Laser Welding, Laser Marking, Laser Surface Improvement, Laser Drilling*
LAI Midwest, Inc. .—*Waterjet Cutting, Laser Cutting, Laser Welding, Laser Marking, Laser Surface Improvement, Laser Drilling*
LAI Southwest, Inc. .—*Waterjet Cutting, Laser Cutting, Laser Welding, Laser Marking, Laser Surface Improvement, Laser Drilling*
Lambda Research—*X-Ray Diffraction Laboratory*
McGinty Gear—*Spline Design*
Manufacturing Technology—*Friction Weld Gears Together*
Mechanical & Structural Design & Software—*Gear Failure Analysis*
Modern Industries Inc.—*Metallurgical Evaluation*
Moore-Addison—*Gear Blanking*
NASA Glenn Research Center—*Gear and Transmission Testing*
Paulo Products Company—*St. Louis —Brazing*
Peerless-Winsmith—*Manufacture Gear*

Reducers
Performance Gear Systems, Inc.—*Plastic Gear Design, Inspection, Prototyping & Manufacturing*
Precision Gear Co.—*Hobbing, Shaping, Bevel Gear Mfg., Worm Gear Mfg.*
Precision Engineering—*Error Analysis of Backlash—Position Error for Gears & Entire System*
Progressive Technologies—*Thermal Spray Grit Blasting, Abrasive Waterjet*
The Purdy Corporation—*Metrology*
REM Chemicals—*Gear Finishing*
Richter Precision Inc.—*PVD Coating Equipment*
RTS Rework Inc.—*Polishing*
Seitz Corporation—*Rapid Tooling, Prototyping Gearboxes and Assembly Actuators*
Selector Spline Products, Inc.—*Gear Racks*
SIFCO Selective Plating—*Job Shop Plating*
The Society of Manufacturing Engineers—*Educational Programs*
Spicer Industries Inc.—*Injection Molded Gears*
Stork Technimet—*Failure Analysis and Testing*
Sun Steel Treating Inc.—*Ion Nitriding*
Surface Technology Inc.—*Diamond Coating*
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Tri-Wire, Inc.—*Wire EDM Job Shop*
Trogetec Inc.—*Feasibility and/or conceptual gear design & mfg.*
Trojon Gear Inc.—*Gear & Spline Cutting*
Turbo-Finish of America—*Deburring, Turbo Abrasive Machining*
Wedin International, Inc.—*Spline & Rack Mfg., Ball Screw Mfg., Acme Screw & Bronze Nut Mfg., 24-hour Ball Screw Repair Services*
Welduction Corp.—*Induction Heat Treating*

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C-Dot Engineering
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Gearesearch Assoc.
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Hoglund Technology
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Machine Tool Builders
Moore Measurement Solutions
Normac, Inc.
Richel Inc.
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C-Dot Engineering
CETIM
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Best Engineering, Inc.—*Tool Crib Management Software*
Bourn & Koch Machine Tool Co.—*Change Gear/Setup Software*
DP Technology Corp.—*CAD/CAM Software*
Euro-Tech Corp.—*Spline Inspection*
Extrude Hone—*Surface Finish Measurement Software*
GB Gear Shop Tools—*Calculations*
Gearesearch Assoc.—*Gear Scoring Analysis*
Geartech—*Gear Life Analysis*
Geartech Ltda.—Tecnologia de Engrenagens—*Mechanical Design*
Gerhardt Gear Company Inc.—*Quality Rating*
Hoglund Technology—*Gear Manufacturing Software License*
Industrial Technology Institute—*Document & Data Control*
Krautkramer Branson—*Inspection Data Management*
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Meccanica Nova Corp.—*Grinding Machine Software*
Mechanical & Structural Design & Software—*Strength & Fatigue Analysis Software*
NASA Glenn Research Center—*Bearing/Seal*
Trogetec Inc.—*Shop Floor Gear Design & Manufacuring Software*

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Gleason-Pfauter GmbH—*Honing Tools*
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Universal Gear Co.—*Shank & Disc Cutters*
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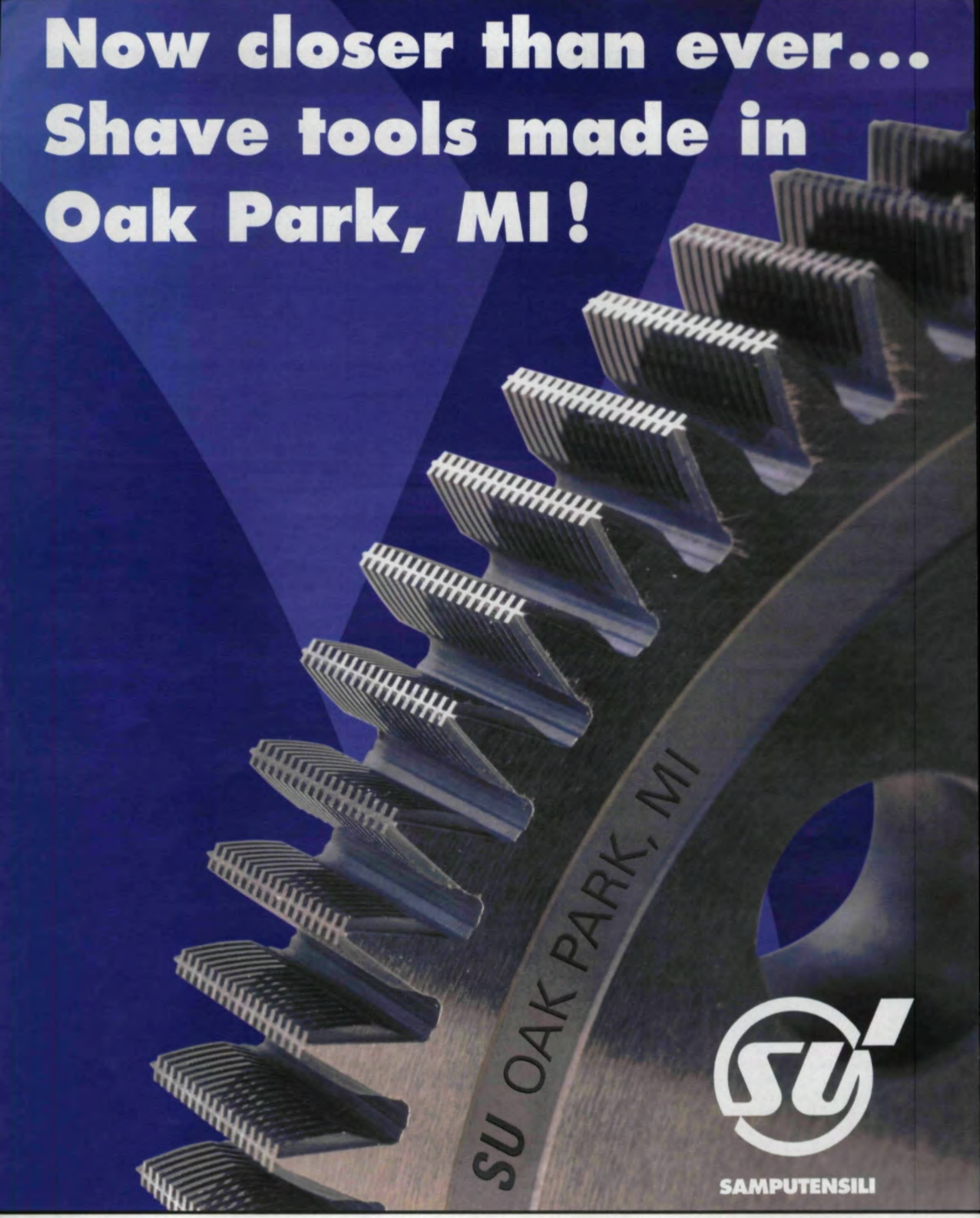
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The Adams Company
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Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.

New Speed Reducer and Gear Coupling from Dodge

Dodge, a Rockwell Automation company, has introduced the Maxum Concentric Speed Reducer. Fractional to 1,600 HP, with ratios 2.25–194.6 available, the Maxum meets or exceeds the latest AGMA standards for proven reliability. The unit is available in scoop, top mount and base plate configurations. High strength cast iron housings provide strength and rigidity while standard double-lip and optional Viton® seals help keep lubricants in and contaminants out.

The new Dodge Gear Coupling is manufactured from forged steel for longer service life and features a high torque rating for efficient downsizing. The Gear Coupling provides the most power dense coupling that Dodge offers, its high torque ratings and large bore capacities enhancing these power dense qualities. In addition, the Gear Coupling protects against misalignments and offers a superior sealing system.

For more information on the Maxum Concentric Speed Reducer or the Dodge Gear Coupling, contact Rockwell Automation—Dodge/Reliance at (864) 281-2171.

Circle 300

New DuPont Additive for Polymer Compounding Applications

DuPont Performance Lubricants introduces Fluoroguard™, a colorless, odorless and chemically inert polymer additive based on fluorinated synthetic oil. This patented technology improves the properties of both thermoplastic and thermoset polymers by increasing abrasion resistance, making parts last longer. Targeted for use in gears, bushings, O-rings, seals and polymer films among other applications, Fluoroguard™ internally lubricates parts to improve their mechanical performance without affecting their chemical properties. This helps reduce wear and eliminates the need for external lubrication.

Fluoroguard™ also offers processing benefits by improving melt flow and release properties, reducing machine torque and die build-up, and increasing extrusion rates. Because of its thermal stability (up to 300° C), Fluoroguard™ can be incorporated into most polymers using conventional processing equipment.

For additional information about Fluoroguard™, call (800) 424-7502 or visit the DuPont Web site at *www.lubricants.dupont.com*. To discuss your particular application or to obtain a sample, contact Bruce Ulissi at (302) 651-7391 or via e-mail at *bruce.p.ulissi@usa.dupont.com*.

Circle 301

Brown & Sharpe Unveils Xact Technology

Brown & Sharpe has announced the release of Xact Quindos measurement and inspection software. Xact Quindos combines the versatile Quindos software with elements of Brown & Sharpe's new Xact technology. It is the first in a series of software releases that will combine Xact technology with existing Brown & Sharpe software programs.

Xact Quindos is designed to work with most CAD systems to facilitate the inspection process and provide an advanced level of process control. The first release of Xact Quindos includes an advanced CAD interface that allows users to download CAD files for use in constructing part programs and documenting the dimensions of parts using CAD geometry. The software also offers three choices of program simulation—full machine, probe head or probe sphere—to verify the part program. Xact Quindos runs in the NT operating system, making it fully PC compatible and Y2K compliant.

For more information, contact Brown & Sharpe at (800) 766-4673 or log on to *www.brownandsharpe.com*.

Circle 302

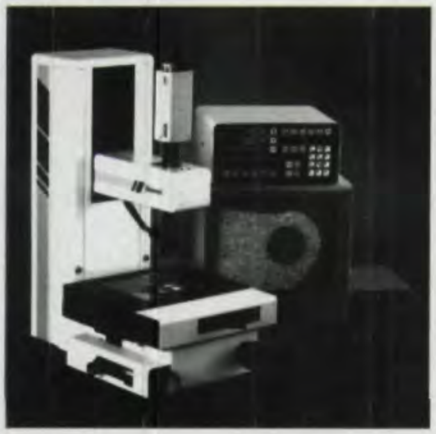
Mijno Introduces New Right-Angle Gearheads

Mijno Precision Gearing has introduced the first members of a new family of right-angle, low backlash precision gearheads. Named Type MRA, the new line features an efficient and quiet bevel gear output stage integrated into Mijno's servo-grade, all-planetary Type MNT in-line gearhead series.

These new right-angle gearheads mount readily to metric face-and-shaft servomotors. They can also be specified for easy mounting to NEMA size 23, 34 and 42 servo or stepper motors. The Type MRA gearheads are useful in machine configurations where their geometry enables a more compact device. When installed in a machine, the right-angle gearhead and motor package can hug the side of the machine rather than stick out.

Typical applications include packaging equipment, assembly machinery, factory automation devices and robotic installations. For more information, contact Tom Provencher at Mijno at (847) 698-9041 or via e-mail at *mijno@aol.com*.

Circle 303



Compact Manual Vision System

The L. S. Starrett Company has introduced the new MV646 Manual Vision System, a non-contact, video-based three-axis inspection system. The MV646 uses a high resolution digital color video camera and comes equipped with a 14" monitor and a 6.5:1 zoom lens system. Optional auxiliary magnification lenses are available. The unit has an aluminum base and features a precision work stage with a 6" x 4" measuring capacity and 6" of Z measurement. The system is manually operated by precision hand wheels and offers a built-in quick-release mechanism allowing rapid travel in both the X and Y axes.

X, Y and Z linear accuracy is within 0.00016"; repeatability X and Y are within 0.0001" and Z-axis repeatability at 200x magnification is +/- 0.0002"; resolution is 0.00004" and the maximum workpiece weight is 40 pounds.

For more information, contact Irmi Black at The L. S. Starrett Company, Metrology Systems Division, at (770) 590-7737 or log on to *www.starrett.com.*

Circle 304

CMI Offers New Coating Thickness Measurement Instruments

The CMI 700 Series is a microprocessor-driven benchtop system, which can accurately measure a wide range of coatings at the touch of a button including nonmagnetic coatings over magnetic substrates, nonconductive coatings over conductive substrates and electroplated nickel over magnetic substrates.

The CMI 700 is a non-destructive test instrument built to withstand hostile work environments. A large, high-contrast backlit display with a menu-driven operator interface makes it versatile and easy to use.

For more information on the contact CMI International at (847) 439-4404 or visit their Web site at *www.cmiinternational.com.*

Circle 305

New Acetal Copolymer Improves Part Yield and Offers Tighter Tolerances

Acetech XLS™ from A. L. Hyde is an easy to machine, low stress acetal copolymer that improves part yield and allows tighter tolerances. Features include no centerline porosity, excellent dimensional stability and wear properties, and good chemical resistance. It exceeds requirements for physical properties, stress and centerline porosity per ASTM D 6100 S-POM0211, LP and complies with FDA requirements for direct food contact.

Acetech XLS™ acetal copolymer is ideal for machining a wide variety of parts. For very intricate parts, lower stress and better dimensional stability means less warping. That, combined with no centerline porosity results in parts with outstanding appearance and mechanical integrity. Acetech XLS™ is also a good choice to replace materials such as steel, brass, bronze and aluminum to help reduce part weight, improve wear or chemical resistance, reduce factory noise or the need for lubricants.

For more information call (856) 227-0500 or call toll-free (800) 234-HYDE.

Circle 306

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Green!

You go, and if your name is Ryan Boxx, you go faster than everyone else. Boxx became the fastest 15-year-old in America this summer when he won his division of the National Hot Rod Association's Junior Drag Racing League National Championship.

Boxx drove a car sponsored by B&R Machine and Gear Corp. of Sharon, TN. Bennie R. Boxx, Ryan's father, is president of B&R, and he says he couldn't be more proud of his son.

He won the 15-year-old bracket by beating out 97 other competitors in two days of time trials and two days of elimination rounds. In the championship race, Boxx drove the one-eighth mile distance in 9.12 seconds in his 5hp Briggs & Stratton engine-powered racer.

As national champion, Boxx received a $5,000 college scholarship, a champion's medal, and a trophy known as the "Wally." In addition, Boxx will attend the NHRA annual awards banquet in November, where he will be presented with a custom made leather jacket and where he'll have a chance to compare notes with pro-level racers.

Boxx became involved in racing with the encouragement of his family—in particular, his cousin, Terry Boxx Jr., who also participates in the sport.

Over the summer, Boxx competed in local races at the Northwest Tennessee Motorsports park in Gleason, TN. There he earned enough points to qualify for an entry at the national championship, which was held in July 1999 at the Indianapolis Raceway Park in Indianapolis, IN.

Boxx plans to continue his racing career in 2000, but according to his father, he wants to move up to a full-size car. "He's been in this about five years," says the elder Boxx, "and he's ready to move up to the big cars."

Bennie Boxx plans to support his son in racing for as long as Ryan is interested, but it's obvious from talking to him that someday he'd like to see his son pursue the family business. Ryan Boxx has been hanging around the gear shop his entire life. "He usually comes around here after school." his father says. "Although he prefers to work more on the computers, I'd like to get him into cutting gears." ✪

Ryan Boxx and his division-winning car.

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


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