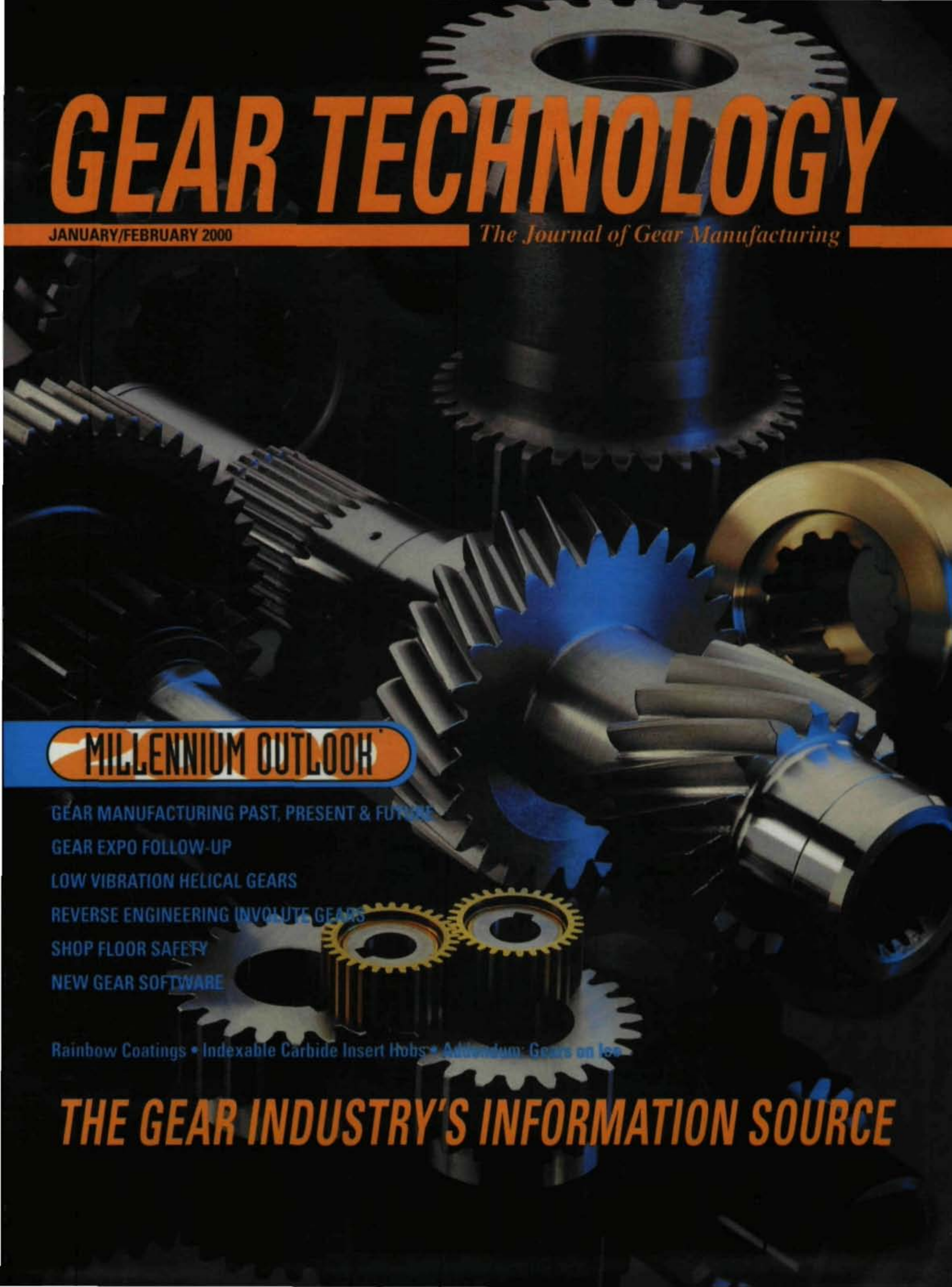

GEAR TECHNOLOGY

JANUARY/FEBRUARY 2000

The Journal of Gear Manufacturing

MILLENNIUM OUTLOOK

GEAR MANUFACTURING PAST, PRESENT & FUTURE

GEAR EXPO FOLLOW-UP

LOW VIBRATION HELICAL GEARS

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GEAR TECHNOLOGY

JANUARY/FEBRUARY 2000 *The Journal of Gear Manufacturing*

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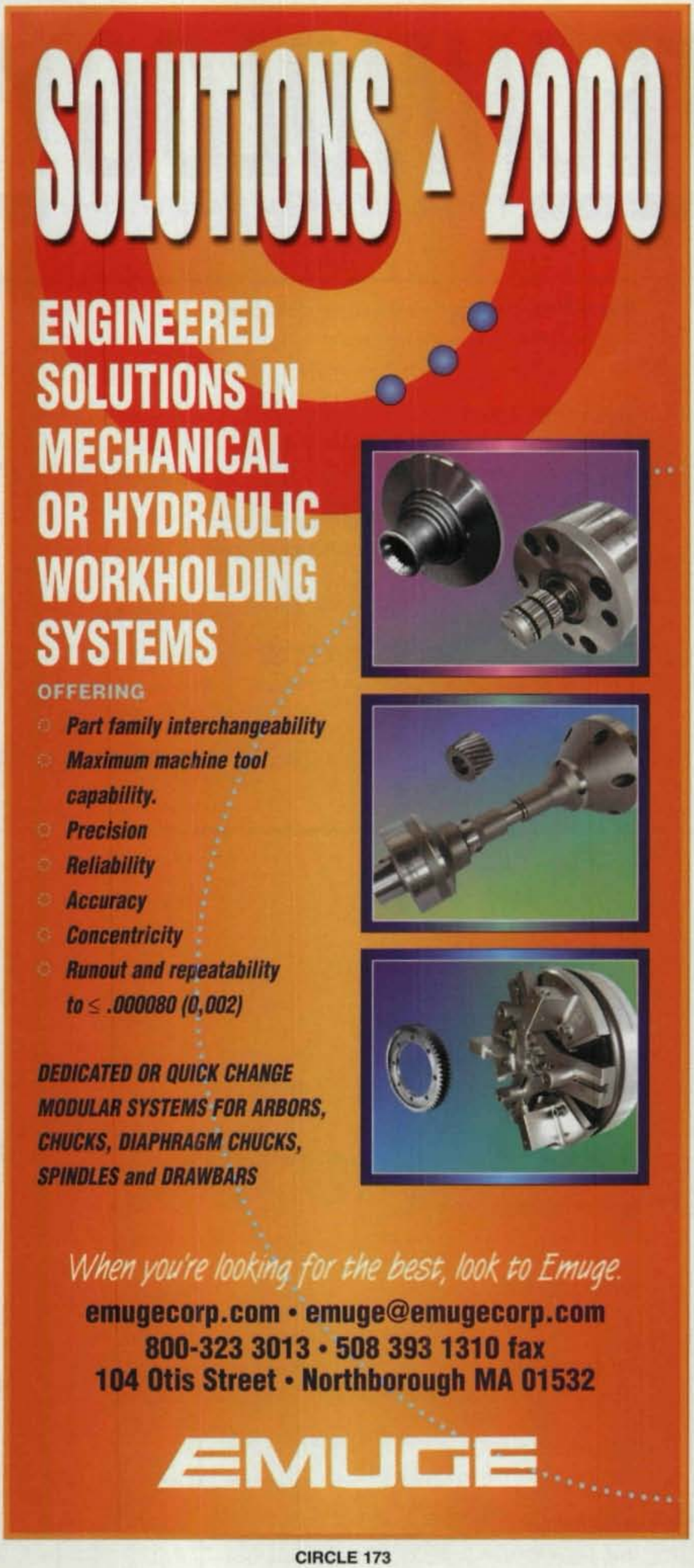

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GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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CIRCLE 186

THE BIGGER PICTURE

I learned much of what I know about the machine tool business from my father, who learned it from his father before him. One of the lessons he taught was that no matter how important the details seem, it's equally important to look at the bigger picture.

For example, before I inspected a machine, I would study the catalogs and make lists of all the features and sizes that I had to check. My father would tell me that after completing my checklist, I should step back from the machine, walk around it, away from the details, and see it as a whole. He said forcing yourself to look from a bigger perspective often lets you see what you would otherwise miss.

Very often, he was right. Once, when I inspected a cylindrical grinder, I forgot this lesson. Somehow, I overlooked the fact that the machine was built special, without a reciprocating table—the bed and the table were one piece. I had covered all the details but overlooked what some might say was obvious. Sometimes the obvious is the hardest thing to see. Today I realize that using a bigger perspective allows me to see problems and opportunities I wasn't expecting to find or didn't think to look for.

I was reminded of my father's wisdom at this year's Gear Expo. As many of you know, Gear Expo is the worldwide gear industry's premier event, and it has grown with each incarnation. There were far more exhibitors at this show than we've ever seen before. This means more money for the AGMA, which translates into more and better services for the industry as a whole.

But while the number of exhibitors has grown, the number of visitors dropped dramatically this year. Most people view the show as a machine tool show—a place to see, compare and buy gear manufacturing equipment. When I was down on the show floor, walking through the aisles, this is how I saw it, too. But then I tried a different perspective.

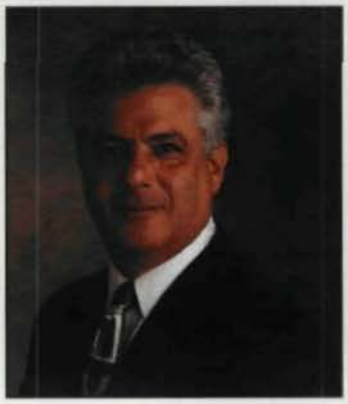
The Nashville Convention Center, where Gear Expo was held, has a viewing area above the show floor. From there, you can see the entire show. While I was up there, it struck me that this was much more than a machine tool show. The full view of Gear Expo revealed to me the entire gear industry, all in one place. I realized that for four days, we had access to the finest gathering of gear talent anywhere in the world. From my perch above the show, I saw gear manufacturers, materials suppliers, software vendors, consultants and cutting tool manufacturers, all of them valuable business contacts with knowledge about gears. Of course, the machine tool manufacturers were there as well, not just with salespeople, but also with the engineers, technicians and field service people who develop, design, build and troubleshoot the machines. For those who felt they needed even more gear knowledge, SME offered a series of gear clinics at the show.

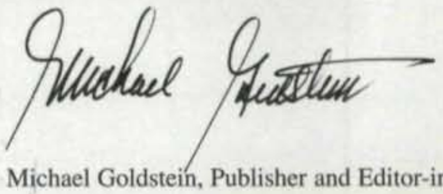
The value of these experiences cannot be overstated. The information, contacts and business opportunities made the trip to Nashville not only worthwhile, but essential to compete successfully in today's marketplace. By looking at Gear Expo as more than a collection of exhibitors, I was able to reap the benefits of everything the show had to offer. An opportunity not seen is an opportunity missed.

The gear industry is changing faster than ever, and access to information may be the key to success in the years to come. With this Millennium Outlook issue, we've tried to walk around the gear industry as if it were one of my father's machine tools. We've examined ourselves from different perspectives to see how other industries and global events have shaped the changes in our little industrial niche and how these factors will affect our future.

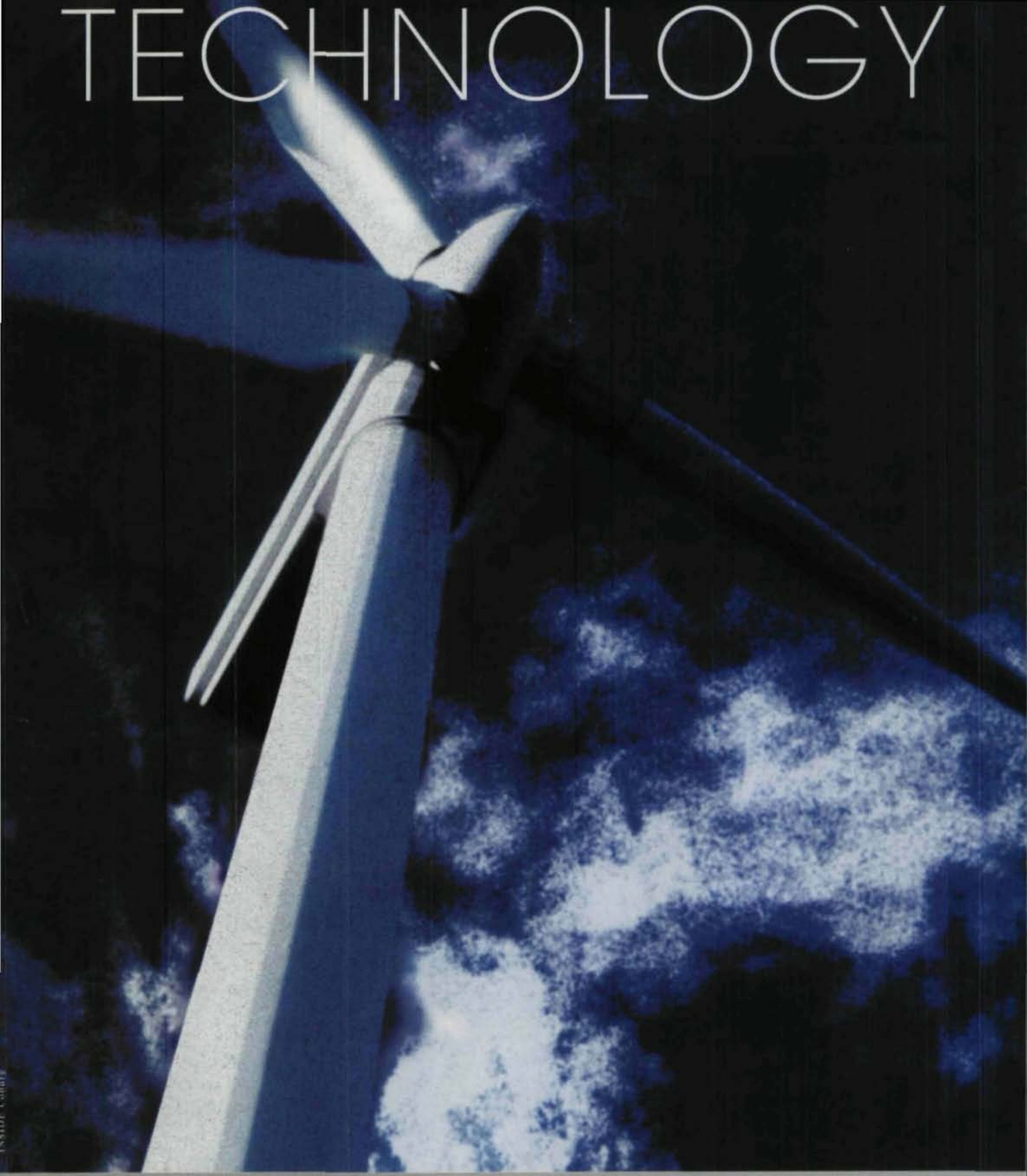
Our talks with some of the leaders in the gear industry have revealed how dependent we are on the rest of the world and, in some cases, how defenseless we are against it. The whims of economy, politics, war and industry can either carry us or bury us, depending on how quickly we adapt to change.

The pace of change will continue to accelerate in the coming years, and our industry will have to keep up with these changes in both traditional and novel ways. We must challenge ourselves to view our companies and our industry with fresh eyes and from different points of view. We can't allow the comfortable, familiar perspective of our everyday routine to restrict what we're able to see, because what will seem obvious to us in the future is probably lost in the details of today.





Michael Goldstein, Publisher and Editor-in-Chief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CIRCLE 112

Will Rainbow Coating Lead to Manufacturing Gold?

Gear manufacturers have used coated cutting tools to obtain dramatic increases in productivity over the past decade. Titanium nitride (TiN), titanium aluminum nitride (TiAlN) and titanium carbonitride (TiCN) coatings have become the norm for gear cutting tools.

Space Age Concepts of Dayton, OH, claims to have the next generation of coatings for cutting tool applications, and according to company CEO Daryl Blessing, gear manufacturers who have tried it have had great success.

The Laser-Cut 964 Rainbow Coating is made up of 10 elements, which are applied in a single ultra-thin layer by the process of physical vapor deposition. The exact makeup of the coating is proprietary, but the end result is a Rockwell hardness in the 92–94 range, a coefficient of friction of .027 and coating thickness of 65 millionths of an inch.

Because of the number of elements involved and some special processing steps, the coating costs approximately 25% to 30% more than TiN. Also, the coating process takes about 10–12 hours, compared to about 3–4 hours for TiN.

However, the combination of properties achieved allows both faster cutting and increased tool life, Blessing says.

The coating has been applied to all forms of gear cutting tools, including hobs, shaper cutters, broaches and bevel gear cutting blades. "Our gear manufacturing customers get as much as three to four times the tool life before the tool needs resharpening," Blessing says.

Also, because the coating is so thin, gear manufacturers can regrind their tools more times than with other types of coatings, Blessing says. "In some cases, they've seen as many as 10 to 11 regrinds per hob."

The coating can be applied to most cutting tool materials, including stainless steel, tool steel and carbide. Coated tools can be used to machine typical gear materials, such as 4140 steel, as well as a variety of more unusual or exotic materials such as aluminum, titanium or high nickel-content steels used in aerospace and other special applications. "You can basically machine any material that you'd like," Blessing says.

The combination of hardness and lubricity also makes the coating an ideal candidate for dry cutting, either with high speed steel or carbide hobs, Blessing says.

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

The same combination of properties gives Laser-Cut 964 promise as a coating for wear parts. In fact, at least one major automotive manufacturer is using the coating to increase life and improve performance of internal engine parts, Blessing says.

Circle 251

The Laser-Cut 964 Rainbow Coating from Space Age Concepts.

Carbide Insert Hobbing

Very large gears, those with 3/4 DP for example, present certain problems for gear manufacturers. Such gears could have a tooth height of 3" or more and be 40 feet in diameter. According to Ron Schomann of LMT-Fette, the surface speed of a conventional high-speed steel hob has to be reduced to almost nothing on such a large tooth profile. "If the gear or pinion to be machined has a hardness of approximately 300 HB, the machinability chart for conventional hobbing calls for a surface speed of no more than 10 m/min (33 feet). The corresponding spindle revolution on a 14" diameter hob would then be as low as 8 rpm. With a feed rate of 1–1.5 mm (.040"–.060") and a gear face width of 1 meter (40"), it is easy to imagine that the machining time becomes astronomically long. We are not talking in terms of hours. It takes many days to complete a gear or pinion of these dimensions."

In order to speed up hobbing operations of large gears and pinions, engineers at Wilhelm Fette GmbH, Hamburg, Germany, have developed a unique hob design that uses indexable carbide inserts. The cutter body has a precise helical path on which the tooth segments are accurately placed. To ensure maximum accuracy for the tool, these segments must be precisely machined and placed. For maximum rigidity, the insert seats are arranged tangentially. On hobs for DP 5–2.5 (module 5–10), one long insert covers the entire tooth profile. For DP 2.4 (module 11) and larger, a number of inserts in staggered locations are used to cover the profile. According to Schomann, the design concept, called ICI, is a combination of the known advantages of the hobbing process with the performance of carbide and the economy of indexable inserts.

"Changing and regrinding large conventional hobs is very time consuming and expensive," said Schomann. "Large hobs don't allow the same amount of shift steps as smaller hobs because the pitch is so big, so the wear factor becomes more noticeable. With the ICI hob, the inserts that show the most wear can be rotated or exchanged while the hob stays in the machine." Other advantages to the system, Schomann mentions, include the ability to utilize the four cutting edges on each insert before having to replace it; the option of using different kinds of inserts for different operations, such as roughing, semi-finishing or skive hobbing. This last can be important in the manufacture of large gears and pinions because these components can show considerable distortion or "unwind" after heat treating operations.

"When using an ICI hob for skiving," said Schomann, "the grinding operation that usually follows has a much shorter cycle time because all of the distortion has already been removed." The ease with which these hobs can be repaired, which is often impossible with conventional carbide hobs, is also an advantage. "Hob segments can be exchanged," said Schomann, "which saves the tool from being discarded." The chief benefit of the system, however, is speed.

Tests were carried out by one of LMT-Fette's customers comparing the ICI hob with a conventional high-speed steel hob. The material was steel with a hardness of 330–375 HBn, the OD of the gear was 35", face width was 7" and the DP was 2.8. Three gears were cut with each hob and the results were dramatic. With the HSS hob, the total floor to floor time was 349 minutes. The ICI hob showed no insert wear after the three gears were cut and its total floor to floor time was 79 minutes. According to

An indexable carbide insert hob being loaded for shipment.


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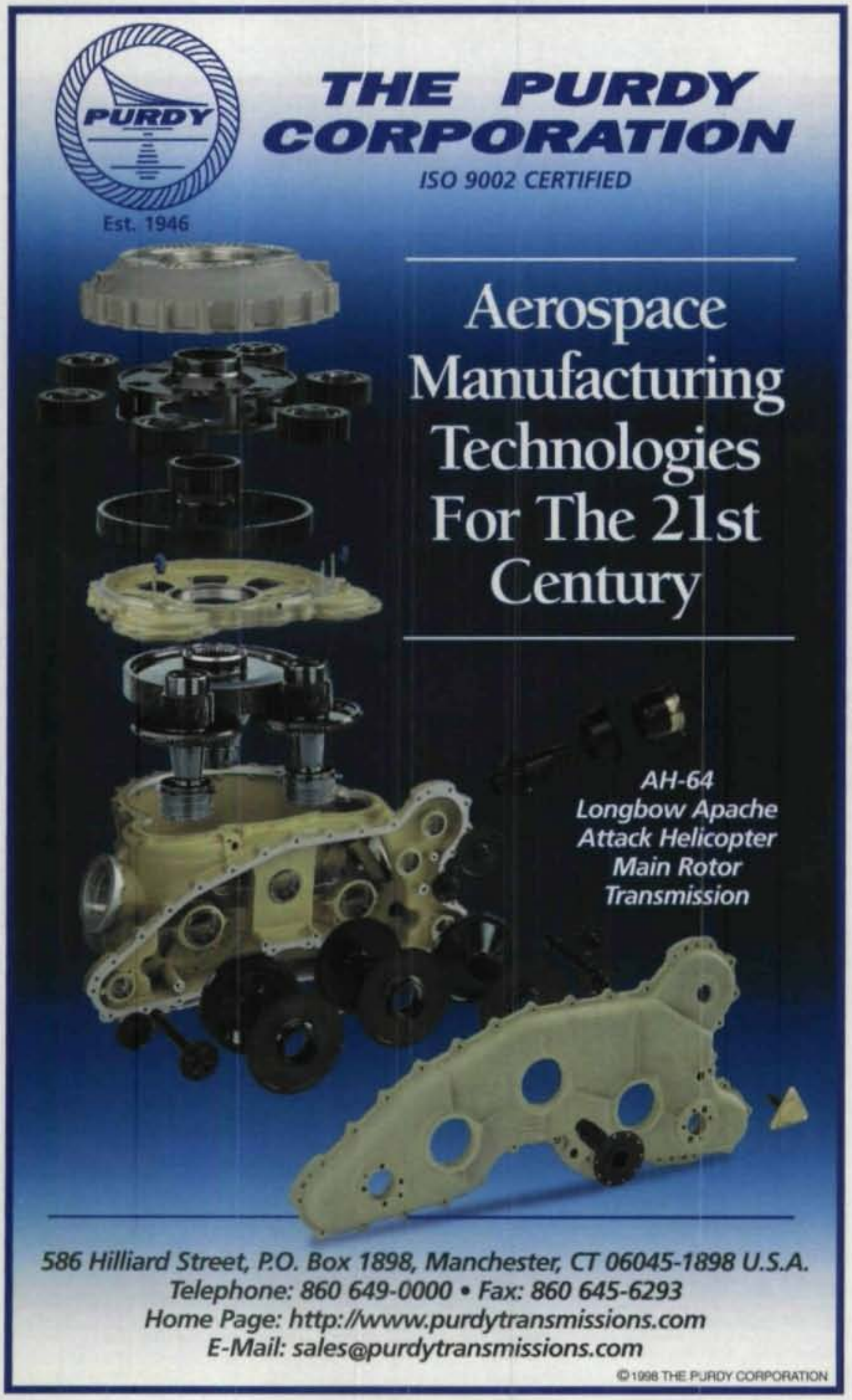
Schomann, after the above tests were carried out, the tool was equipped with carbide inserts for skiving a hardened gear of similar size. "The 60 Rc gear was machined with 248 SFM and .160" feed rate per table revolution," said Schomann. "There was no detectable wear on the TiN-coated carbide inserts after machining eight gears, each with 61 teeth and a face width of 5.5 inches.

The initial cost of ICI hobs is high, but according to Schomann, these tools become economical when you take into account maintenance problems such as tooth chipping, cracking or breakage; excessive flank wear; accidents and downtime due to sharpening. "When all of these factors are considered," said Schomann, "the use of a hob with indexable carbide inserts becomes an economical investment."

Circle 252



CIRCLE 146

Machine Tool Technology Training Survey

The Tooling and Manufacturing Association (TMA), a local not-for-profit trade association serving 1,600 plastics and metalworking companies and suppliers in the Chicago area, asked its member companies to rank several educational areas for potential entry-level employees. The goal of the survey was to aid school boards and local advisory councils in their decision-making processes as related to manufacturing technology programs. The educational areas designated were academics, manual machining, CNC training and CAD training. The respondents were asked to rank each educational area in order of preference with 1 being the most important and 5 being the least important attribute. TMA received 162 survey responses from member companies and six written responses.

Study Procedure. The study examines the Chicago precision metalworking industry as a group, as well as by individual area. This includes precision machining, moldmaking, diemaking and machine building. The study also examines influencing factors such as company size, manual, and CNC machine use.

Results and Opinions. Chicago area metalworking companies rank manual machining as the most preferred education area, followed by manual machining/CNC training, academics, CNC training and CAD training.

The survey concluded that the best prepared students for the precision metalworking industry should have a combination of manual machining, CNC machining, and CAD training. Students should enroll in math classes stressing algebra, geometry and trigonometry. Science classes such as physics and chemistry are also important.

For a copy of the complete survey, contact the TMA Education Department at (847) 825-1120, ext. 322 or e-mail Dan Kiraly at *dkiraly@tmanet.com*.

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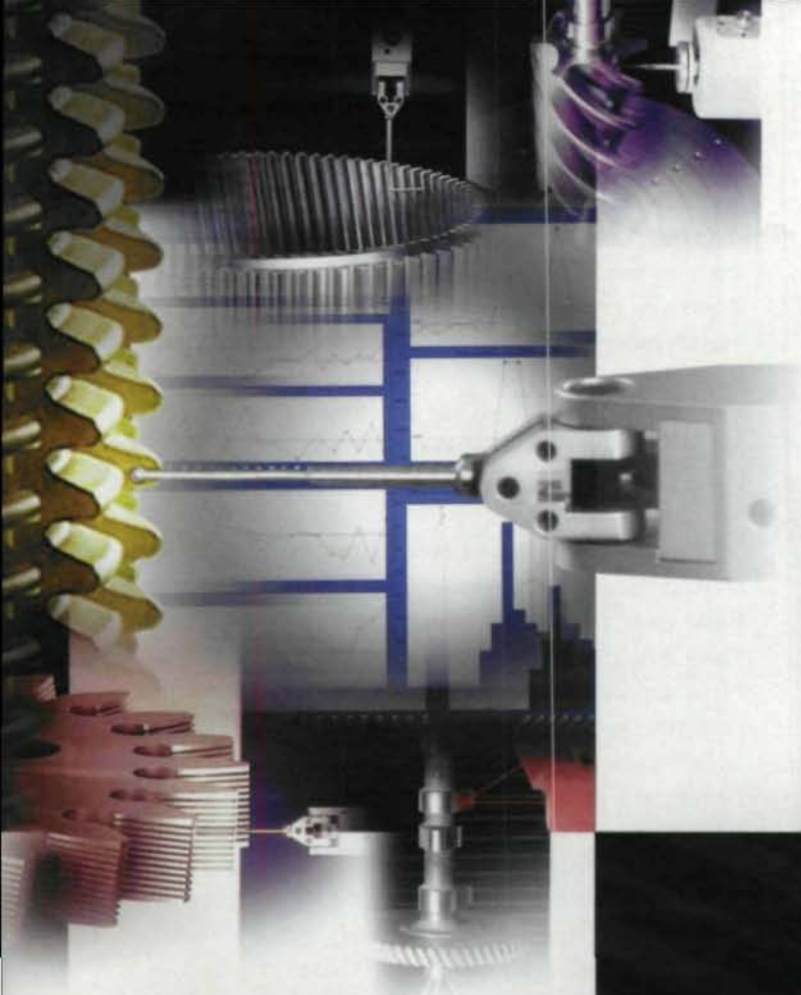

TECHNICAL CALENDAR

January 10–13. The Falk School. Milwaukee, WI. The Falk School is a four-day course designed to familiarize working maintenance mechanics with field-practical, factory-approved installation, alignment, maintenance and failure analysis procedures for Falk gear drives and couplings. Workshops are designed to provide maximum familiarity with logical, hands-on service techniques, and are deliberately kept flexible to accommodate the interests and experiences of the students. Twenty-four sessions are scheduled throughout 2000, two per month. For more information visit Falk's Web site at *www.falkcorp.com* or call (262) 317-1420.

January 24–27. Three Courses from SME: Fundamentals of Broaching, Heat Treating & Hardening of Gears, and Basic Gear Design and Manufacturing. Detroit (Troy), MI. These three courses are offered separately. The Fundamentals of Broaching introduces the student to the broaching process; examines the care, storage and maintenance of broaching tools including sharpening and reconditioning; discusses turning, heat treating and grinding and offers pointers on troubleshooting. Heat Treating and Hardening of Gears offers presentations on austempering, induction hardening, parts washer management, minimizing gear distortion and gas nitriding as applied to gears. Basic Gear Design and Manufacturing is also a clinic and it offers presentations on gear basics, Cylkro angular face gear transmissions, manufacturing methods and machines, shaving and broaching. There will also be a tour of the National Broach & Machine Company in Macomb, MI. These courses are sponsored by the Society of Manufacturing Engineers. For more information contact Lynn Albertson at (313) 271-1500 or send e-mail to *albelyn@sme.org*.

February 13–16. Metalform 2000. Nashville Convention Center, Nashville, TN. More than 250 exhibitors will participate in Metalform 2000, with exhibits covering 74,000 square feet of space. All areas of metalforming will be represented including tooling, stamping, slide forming, roll forming, fabricating, welding, assembly and automation. Attendance is expected to include more than 7,000 industry professionals. Sponsored by the Precision Metalforming Association. For additional information call (216) 901-8800.

March 20–25. Hannover Fair 2000. Hannover, Germany. The Hannover Fair is the largest and most influential international trade show for industrial technology. Qualified professionals including buyers, distributors, politicians and journalists come from 100 countries to identify the latest products and trends in every sector. Over 300,000 qualified attendees, 7,500 exhibitors from 70 countries, 2.75 million square feet of display space. For more information contact Hannover Fairs USA, Inc. at (609) 987-1202 or log onto their Web site at *www.hfusa.com*.

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Low Vibration Design on A Helical Gear Pair

Professor Dr. Eng. Kiyohiko Umezawa

Helical gear pairs with narrow face width can be theoretically classified into three categories over the contact ratio domain whose abscissa is the transverse contact ratio and whose ordinate is the overlap contact ratio. There is a direct relation between vibration magnitude and shaft parallelism deviation. To clarify the effect of the tooth deviation types on the vibration behavior of helical gear pairs, performance diagrams on vibration are introduced. The acceleration levels of gear pairs are shown by contour lines on the contact ratio domain. Finally, the performance of gears with bias-in and bias-out modifications is discussed considering the effect of the shaft parallelism deviation with use of the developed simulator on a helical gear unit. It becomes clear that there is an asymmetrical feature on the relation between the vibration magnitude of a gear pair and the direction of each deviation.

The Helix Angle and the Transmission Behaviors of a Driven Gear. The author numerically solved the deflections of a thick plate with finite width (Ref. 15) and a rack shaped cantilever (Ref. 16) under a concentrated load (as shown by Olsson in Ref. 1) by using the finite difference method. Furthermore, the load distribution along the line of contact and the compliance of a helical gear tooth pair from the start of meshing to the end of meshing have been revealed (Ref. 17–19).

When the face width is constant, i.e. three times the whole depth, the relation between the helix angle and the calculated behaviors of the driven gear under loading is shown in Figure 1. These results are analyzed assuming that the normal pitch P_{tn}, normalized with the whole depth, is 0.6. Then the whole contact ratio is calculated for each helix angle. The overlap ratio is calculated from this whole contact ratio and the assumption that the transverse contact ratio is ε_a=1.4. This contact ratio was calculated for a spur gear pair when the normal pitch P_{tn} is 0.6

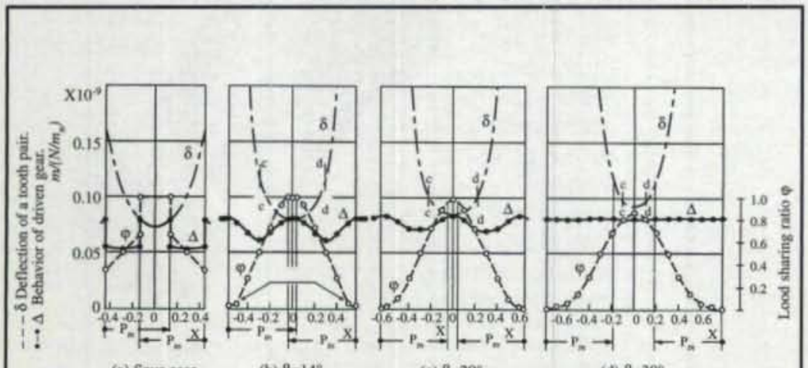

Fig. 1—The behaviors of the driven gear and the helix angle with b/h = 3.0.

When the helix angle is 14° (Figure1a), the sum of the transverse and overlap contact ratio is smaller than 2. Therefore, this pair of gears transmits load alternately with one pair and with two pairs of mating teeth. The load sharing ratio for this pair of gears varies more smoothly than that of spur gears. But sometimes knobs appear on this curve when the meshing condition transits from one pair meshing to two pairs meshing.

When the helix angle is 20° or 30° (as shown in Figures 1c and 1d), the total contact ratio is over 2. The gears alternately transmit load with two and three mating pairs of gear teeth, the load sharing ratio varying smoothly. The behavior of the driven gear, or the transmission error, also varies smoothly. Especially when the helix angle is 30°, the overlap contact ratio is over 1.0 and the behavior changes very smoothly with little fluctuation as shown.

Three Categories of a parallel axes gear pair. Theoretical and experimental studies on static meshing behavior under load have proven that a power transmission parallel gear pair can be classified into three categories on the contact ratio domain based on its facility for reducing vibration as shown Figure 2.

Vibration Magnitude and Shaft Parallelism

The relation between vibration and parallelism of axes was investigated for three kinds of helical gear pairs classified into three categories. Two kinds of shaft misalignment were implemented, in-plane and out-of-plane deviation. For realizing the out-of-plane or the in-plane parallelism, the pedestal of the driving gear shaft was tipped in the vertical plane or in the horizontal plane, respectively. The vibration was measured by two accelerometers attached directly to the driven gear blank surface.

Dimensions of test gears and test apparatus. Test gear pairs were designed to belong to each category classified over the contact ratio domain, and are named H1, H2, H3 and H4 as shown in Figure 2. Dimensions of each gear pair are displayed in Table 1. All test gears were hardened about Hrc55, and finished by the MAAG 30-BC Gear Grinder. Tooth profile and tooth traces are made with as little deviations as possible.

Shaft misalignment set up. Shaft misalignment was created by placing several thickness gages on the surface of the base plate or on its side surface for the out-of-plane or in-plane deviation (Fig. 3). Thickness gages of 0.1–0.4 mm were used and the angular deviations realized were about 0.5×10^{-3} rad and 1.1×10^{-3} rad. The amount of the out-of-plane and the in-plane deviation was measured with two dial indicators. Gear shaft misalignment was introduced for both the leading and trailing side bearings.

Influence of the out-of-plane deviation. The relation between rotational vibration response vs. speed and out-of-plane deviation for the gear pair H3 is shown in Figure 4. With proper alignment (as indicated by "no error"), acceleration increases with the speed. Being observed in the cases of the gear pairs H1 and H2, the peak cannot be recognized for these gear pairs without deviation.

When 13μm edge to edge deviation exists at the leading side, the peak appears at about 2700 rpm, which is ascribed to the second harmonic resonance. As the error increases to 29μm, acceleration increases over the whole speed range and the peak occurrence shifts towards a lower speed. However, when an error of 14μm exists on the trailing side, there is no remarkable increase in vibration. When the error increases to 30μm, peaks appear at the higher harmonic resonance, and the acceleration levels becomes high.

Influence of the in-plane deviation. For the gear pair H3, the relation between the rotational vibration response and the in-plane deviation is shown in Figure 5. In the case of an error on the trailing side, the vibration of this gear pair is not influenced by the error. With an error on the leading side, the acceleration level becomes high, and higher harmonic resonance peaks appear. However, the vibration behavior of the pair is not as influenced as with the out-of-plane deviation.

Performance Diagrams on Vibration

To clarify the influence of tooth deviations on vibration, a simulator for the rotational vibration of a helical gear pair was developed. Performance diagrams on vibration with acceleration levels shown by contour lines on the contact ratio domain are included.

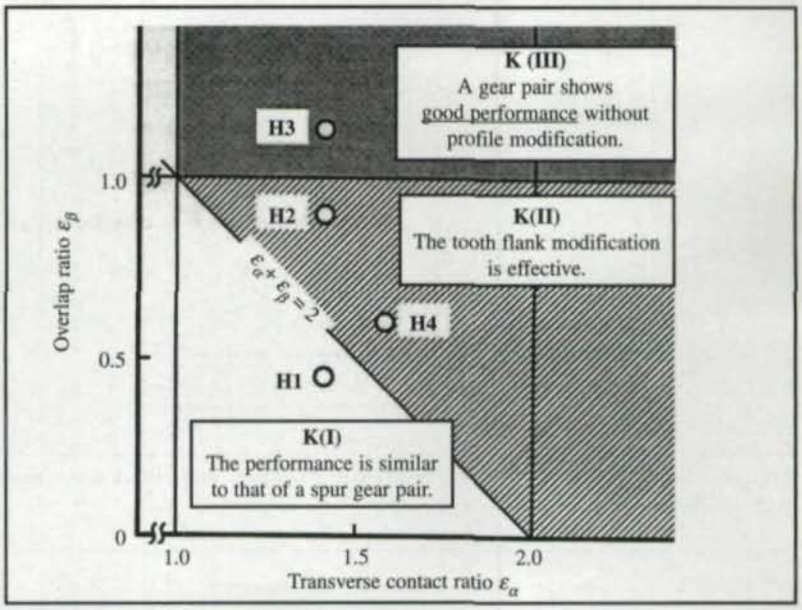

Fig. 2—Classification of parallel pairs.

Table 1—Dimensions of test gear pairs.

Gear pair	H1	H2	H3	H4
Normal module	3.5			4
Number of teeth	30			29
Helix angle (deg)	30			15
Pressure angle (deg)	20			
Face width (mm)	10	20	25	28
Addendum modification coefficient	–0.17			0
Transverse contact ratio	1.4			1.57
Overlap contact ratio	0.45	0.91	1.14	0.58

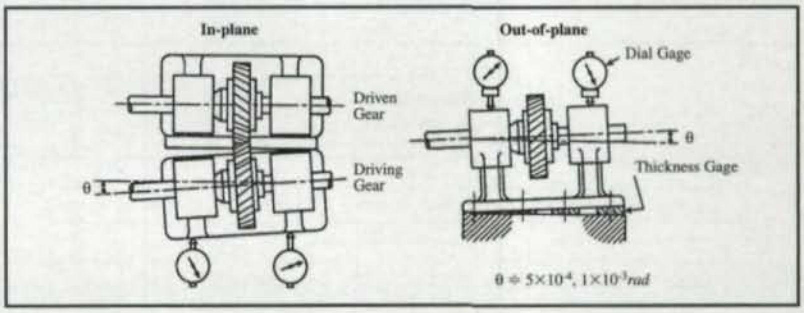

Fig. 3—Shaft misalignment setup.

Theoretical Analysis on the Vibration of a Helical Gear

Model of motion. Considered along the line of action of a helical pair, imaging at the center line of the plane of action, the rotational motion of a power transmitting helical gear pair can be treated as a single degree of freedom system similar to the case of a spur gear pair, i.e., the tooth is treated as a spring and the gear blank as a mass, by the following equation.

$$M\ddot{\delta}+D\dot{\delta}+K(t,\delta)=W+F(t,\delta) \qquad (1)$$

Dr. Kiyohiko Umezawa

(1938-1998) was a professor in the precision and intelligence laboratory at the Tokyo Institute of Technology, Tokyo, Japan. At the Institute, he used his expertise in gear design, machine dynamics, vibration and acoustical measurement to work on reducing sound and vibration in gear units. Dr. Umezawa died suddenly at the age of 60 while on a short vacation after presenting this paper at the AGMA 1998 Fall Technical Meeting.

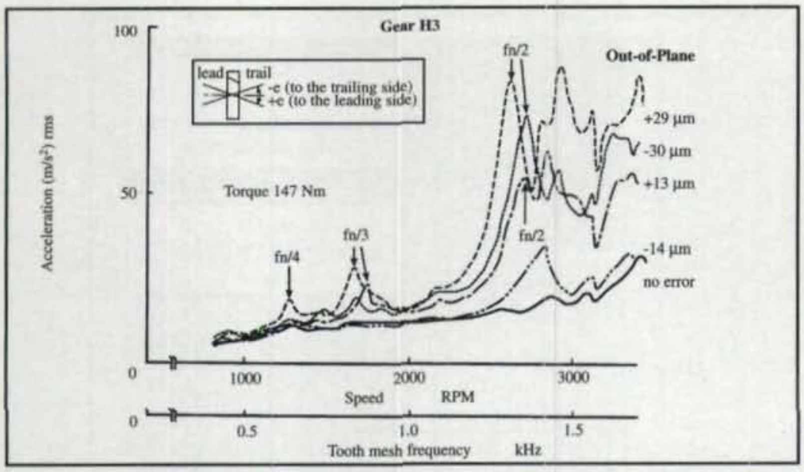

Fig. 4—The relation between the rotational vibration and rotational speed (H3) (Influence of the out-of-plane).

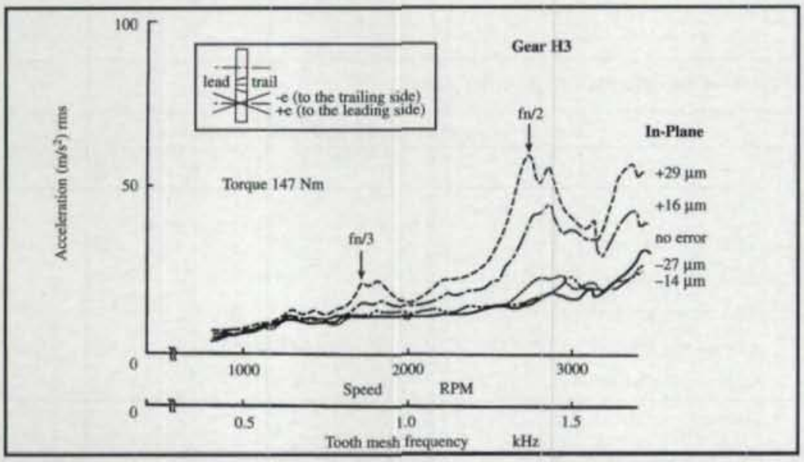

Fig. 5—The relation between the rotational vibration and rotational speed (H3) (Influence of the in-plane deviation).

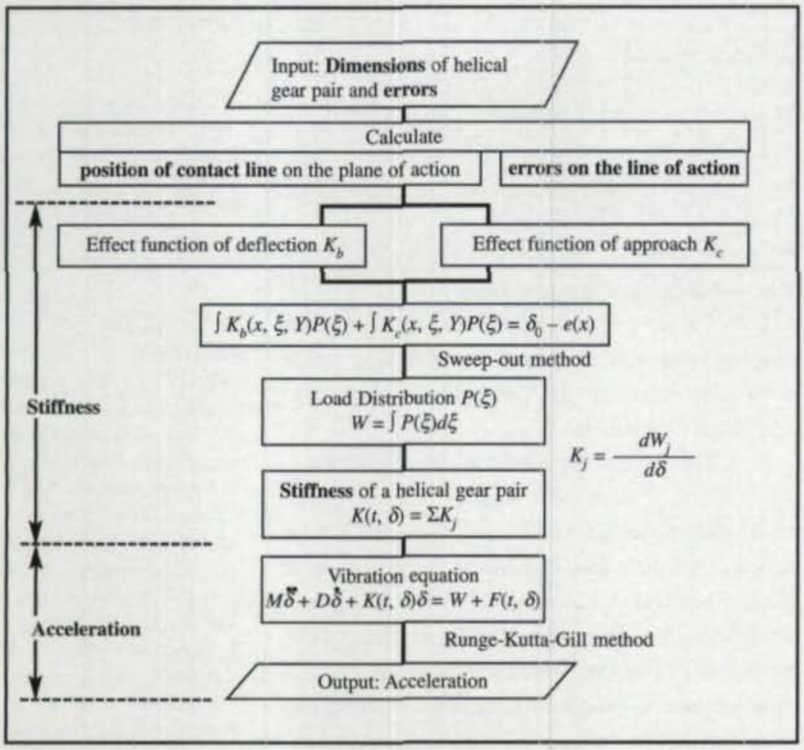

Fig. 6—Flow chart of the developed simulator on rotational vibration of a helical pair.

Where δ is the relative displacement along the line of action, M is the equivalent inertial mass of the gear pair on the line of action, D is the damping coefficient, $K(t,\delta)$ is the mesh stiffness of the gear pair; W is the static transmitting load, and $F(t,\delta)$ is the exciting force caused by profile modification or deviations $\bar{e}(Y)$.

Dimensionless acceleration. The motion equation of a pair expressed in Eq. (1) can be transformed into the non dimensional form,

$$\ddot{\chi}+2\zeta\sqrt{\kappa(\tau,\chi)}\dot{\chi}+\kappa(\tau,\chi)\chi=1+\phi(\tau,\chi)' \qquad (2)$$

Where $\kappa(\tau,\chi)=K_i(t,\delta)/K_{i,\,mean}$ is the dimensionless stiffness of a helical gear pair, $\chi=\delta/\delta_s$ is the dimensionless relative displacement, $\delta_s = W/K$ is the mean of the relative displacement, $\phi(\tau,\chi)=F(t,\delta)/W$ is the dimensionless exciting function, $\omega_n = \sqrt{K(t)/M}$ is the natural frequency of a pair, and $\tau=t\bullet\omega_n$ is dimensionless time. When the gear speed is represented by the parameter f_z/f_n (hereafter referred to as only "speed"), the nondimensional vibrational equation (Eq. 2) is solved by the use of equations shown in Figure 6.

Furthermore the dimensionless acceleration $\ddot{\chi}$ is expressed as follows,

$$\ddot{\chi} = \delta/(W/M). \qquad (3)$$

The value of the dimensionless acceleration indicates the performance of the pair related to vibration in RMS value of acceleration. This value is hereafter called "the vibration level," which is obtained uniquely at each point on the contact ratio domain.

The Developed Simulator

For solving the rotational vibration of a helical gear pair with narrow face width, a simulator was developed whose flow chart is expressed in Figure 6. It was developed especially for calculating the influence of tooth surface deviation. The input values required are only the dimensions of a helical gear pair, the distribution of deviations over the tooth face and the driving speed.

The simulator solves the differential equation with the Runge-Kutta-Gill method and outputs the vibration of the pair as either a wave form as shown in Figure 7, or a root-mean-square value of acceleration as shown in Figure 8.

Verification by Experiments. Calculated and experimental results under the 98 Nm of torque, at rotational speeds from 800 rpm to 2000 rpm, are shown in Figure 7. The gear pair has a normal module of 3.5, 30 teeth each, 20° pressure angle, 10 mm face width, and a 30° helix angle with a 10µm convex slope deviation at tip-side.

Agreement between the calculated results from the simulator and experimental results is good about the waveform, especially the change in the numbers of vibration cycles within one tooth meshing period T_z and about the behavior of amplitude as the rotational speed is increased.

The relation between vibration amplitude in RMS value and rotation speed is shown in Figure 8. This was developed using a good quality pair with deviations under 3μm, and whose dimensions are the same as those in Figure 7 except for the 25mm face width.

Nature of dimensionless stiffness. Figure 9 shows the stiffness behaviors along the line of action $K_i(t,\delta)$ of two helical pairs, (a) and (b). These are plotted at the same position on the contact ratio domain (black dot in the lower left figure).

Apparently stiffness behavior is different, especially with respect to the mean value of stiffness $K_{i,mean}$. However, the behavior of the dimensionless stiffness $\kappa(\tau,\chi)$, in which the actual stiffness is divided by the mean value of stiffness, is the same as shown Figure 9(c) from the viewpoint of how to synthesize the performance of helical gear pairs because the differences among the first order Fourier coefficients of each dimensionless stiffness are within 10 percent deviation on each pair belonging at the identical point on the contact ratio domain. The differences of the higher order Fourier coefficients are of the same level amplitude, and their values are smaller by one third than coefficients of the first.

Performance diagrams on vibration of helical gears. At each operating speed and under each deviation condition, the vibration levels were solved numerically by the simulator at 80 points in the contact ratio domain, where the transverse contact ratio (abscissa) was set at 8 points from 1.0 to 2.0 and the overlap ratio (ordinate) was at 10 points from 0.2 to 2.3. Consequently, the solved vibration levels were expressed as contour lines on the contact ratio domain.

Accounted deviations and modifications. Performance diagrams were produced on the seven kinds of pairs: the no error pair, the pair with crowned tooth face, and the pairs having, respectively, pressure angle (profile slope deviation in ISO), convex profile, concave profile, lead and pitch deviations, which are similar in manufacturing and assembling gear units. The performance diagrams calculated under the condition that the relative deviations between meshing driving and driven teeth are gathered apparently to only driven gear teeth, which have ideally the same figure and the same amount of deviations for every tooth in the gear. Therefore all teeth of the driving gear have ideally no error for calculation.

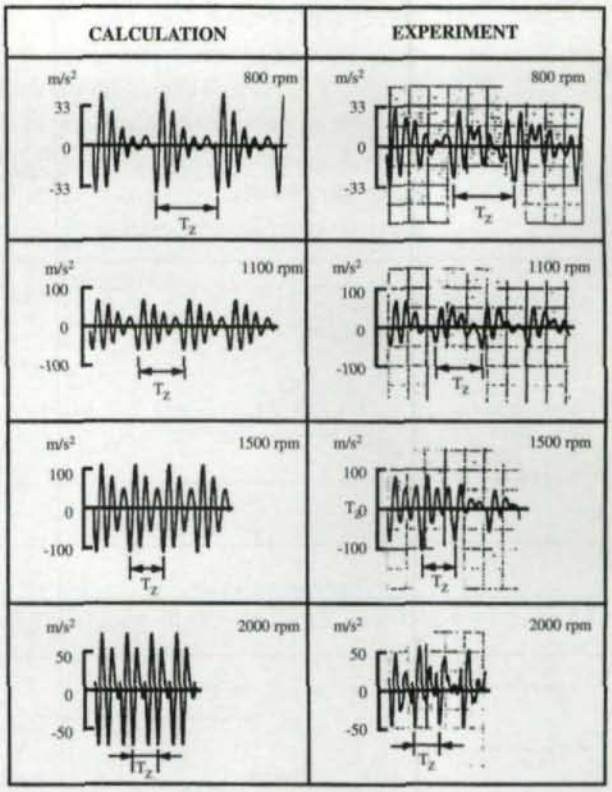

Fig. 7—Verification by experiments on the changing speed.

Performance diagrams on a non-error pair. The produced performance diagrams on a pair having no error at each speed f_z/f_n changing from a low value of 0.21 to a high value 0.98. The interval of vibration level between adjacent contour lines is a 0.025 vibration level. Generally, at each speed the vibration level becomes small according to an increase in overlap contact ratio, except for the 2nd resonance speed ($f_z/f_n = 0.49$) and the high speed region.

At low speed ($f_z/f_n \leq 0.35$). There is no difference in the vibration level of pairs belonging in this area by the scale 0.025. Clearly, choosing an overlap ratio over 1.0 lowers the vibration of a helical gear pair.

At middle speed ($0.35 < f_z/f_n \leq 0.7$). In the area $\varepsilon_\beta < 1.0$, the vibration level decreases when the transverse contact ratio $\varepsilon_\alpha = 2.0$. The contour lines trace along the band which is 45 degrees to each coordinate and where the total contact ratio ε_γ is 2.1. When designing a low vibration helical gear pair, the pair should be categorized into the upper side of this bank. On the middle speed, the vibration of a helical gear pair can be reduced by setting its total ratio over 2.1. The diagram of $f_z/f_n = 0.49$ showed complicated and dense contour lines because $f_z/f_n = 0.49$ is near the 2nd harmonic resonance speed.

At high speed $(0.7<f_z/f_n\leq1.0)$. In the area $\varepsilon_\beta<1.0$, the vibration level becomes large, especially around a transverse contact ratio of $\varepsilon_a=1.5\sim1.6$. It then decreases around $\varepsilon_a=2.0$.

In the area of $\varepsilon_\beta>1.0$, where vibration is weak at low and middle speeds, the vibration strengthens in the area of $\varepsilon_\beta=1.3$ and $\varepsilon_a=1.5$. Moreover, a strong vibration area extends around the total contact ratio $\varepsilon_\gamma=2.9\sim3.0$. This indicates that the vibration of a pair having no error is determined only by the behavior of the stiffness of a pair in Eq. 2. Therefore, the performance diagram at $f_z/f_n=0.91$ is very similar to the equi-amplitude contours of first order component of the Fourier series of stiffness. It is reasonable that the contour lines become dense and high at $f_z/f_n=0.98$ because it is near to the resonance speed.

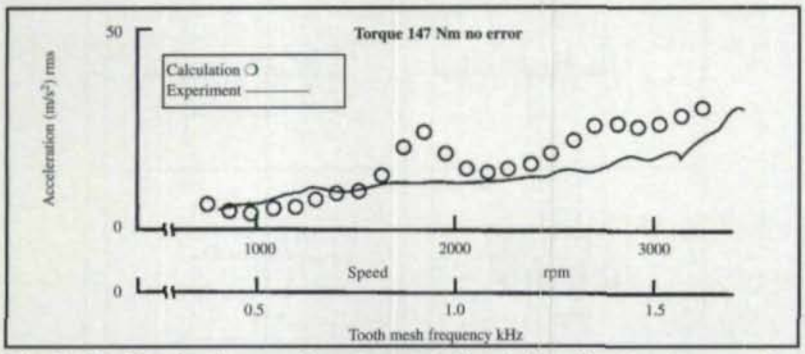

Fig. 8—Verification by experiments on rotational vibration (rms) vs. speed.

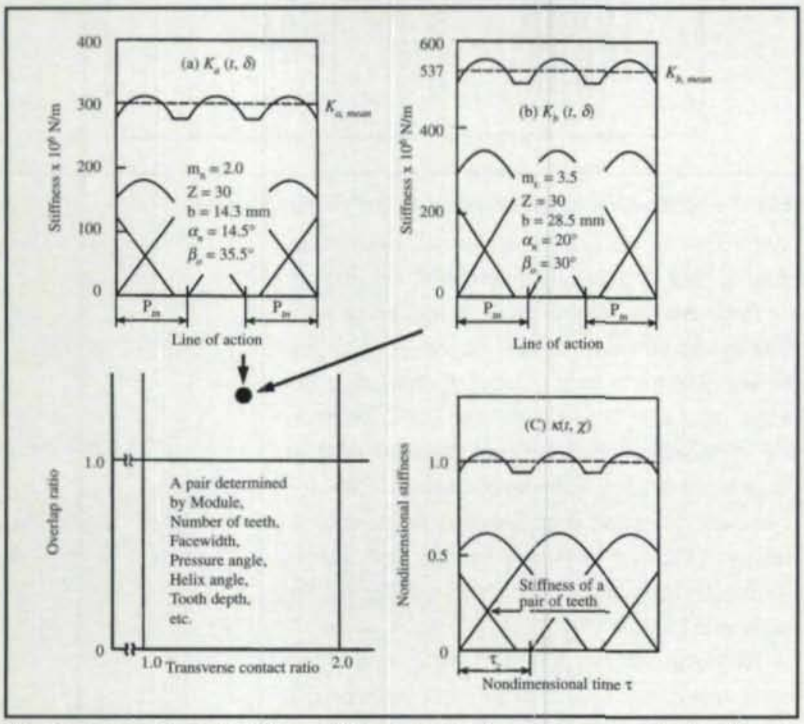

Fig. 9—The nature of stiffness of the pairs having the same contact ratio.

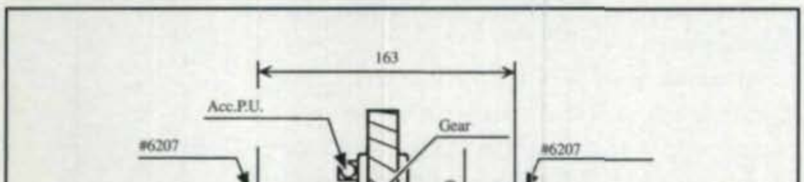

Fig. 10—Measurement points of laser Doppler velocimeter.

Performance diagrams on a pair having each kind of deviation. The performance diagrams on vibration were drawn at the speeds $f_z/f_n=0.63$ and $f_z/f_n=0.98$. Each diagram was calculated with every tooth on the driven gear having the same deviation, and the nondimensional deviation was 1.0. The maximum deviation is set to be the same as the mean deformation produced by the transmitting load.

At middle speed $(f_z/f_n=0.63)$. In the diagram on pitch error (single pitch deviation in ISO), the contour lines become parallel to the direction, 45 degrees to each coordinate, at which the total contact ratio is constant. The vibration does not increase much in the area of $\varepsilon_\beta>1.0$, almost regardless of the deviation. This feature is understood because the pitch deviation is assumed to be the same on every other tooth, so the load is always transmitted by the projecting area of every other tooth, therefore, apparently having little effect of pitch deviation. Increasing the total contact ratio of a pair weakens the influence of pitch deviation on increasing vibration.

At high speed $(f_z/f_n=0.98)$. In the high speed diagram, the contour lines generally become denser than those at the middle speed. Therefore, the vibration of a pair increases over all the area in the contact ratio domain.

On the pair having a convex profile, the vibration increases in the area of $\varepsilon_\alpha<1.4$. On the area of $\varepsilon_\alpha=1.4\sim1.6$ and $\varepsilon_\beta>1.2$, the vibration level decreases because the convex profile works as a profile modification.

On the pair having a concave profile, over the entire contact ratio domain, the vibration level increases in comparison with the pair with no error. It is also especially large in the area $(\varepsilon_\alpha, \varepsilon_\beta)=(1.5, 1.5)$, where the vibration of the pair having the other deviations is small.

On the pair having a lead error (helix deviation in ISO), the vibration level increases around $\varepsilon_\alpha=1.5$ and also in several regions over $\varepsilon_\beta>1.0$ where the vibration is usually low. The nature is different from one of a pressure angle error, although the lead deviation and pressure angle deviation look the same as the projecting deviation at the beginning of the mesh process. However, they work differently along the line of contact of a helical gear and cause vibration.

When the tooth surface is crowned, vibration in the range of $\varepsilon_\beta \geq 1.0$ decreases in comparison with the pair with no error.

The simulator can depict vibration levels and waveform behavior precisely. The performance diagrams depicted the influence of deviation and operating speed on the vibration level of a pair in the contact ratio domain. Using these diagrams, a designer can select the best dimensions to lower the vibration of a newly designed gear to the lowest vibration or influence area by the use of deviations. Also, when an engineer has to improve a noisy gear, he can choose the most effective improvement by crossing to the contour lines of the diagrams.

Bias Modification

Finally, bias-in and bias-out modifications are discussed as they relate to shaft parallelism deviation with the use of the simulator on a helical gear unit (Ref. 23).

Among gear vibrations, rotational vibration is the most important. It can be approximated with a single-degree-of-freedom model. However, the effect of the thrust force from the helix angle of a helical gear complicates the vibration of a gear unit. To further reduce vibration, it is important to reveal the actual modal behaviors of the gear vibrations in every direction as well as the vibrations of the shafts.

The vibration of a helical gear unit as shown in Figure 10 with various gear ratios has been investigated. The dynamic response of transverse, rotational, tilting and axial vibrations of helical gears are measured by acceleration pick-ups mounted on the gear blank. Modal behavior is interpreted based on a modulation scheme due to shaft rotation. The modes of shafts and gears are measured precisely with a laser Doppler velocimeter. Then the simulation on a dynamic model, including transverse, rotational, tilting, and axial vibrations, is developed.

Modal Behavior. The locus of the transverse motion of the gears and gear shafts, measured with a laser Doppler velocimeter at resonance, are presented as q and Q in Figure 11. Circle marks are the points of instantaneous displacement when the rotation of the gear is such that the separation of the gears is the greatest along the line of action. Triangles are the spots of the opposite condition. Arrows indicate the direction of motion. Additionally, tilting motion of the gear is presented through the differentiation of two measurements at both shoulders (U and V in Figure 13) of the gear body.

Regardless of the ratio, the shaft of the bigger gear vibrates with an S-shaped mode. Each part whirls along a thin, elliptic locus with the mesh frequency. The major axis of this ellipse is not parallel to the line of action. At the bearing position, where the motion should be interpolated from the results of both sides, a low amplitude vibration exists, suggesting that the bearing positions are not constrained as simply supported pivots. The modal behavior is also unique to an individual gear-shaft-bearing assembly regardless of driving/driven conditions. Displacement of the pinion shaft at the slip ring side bearing is a little larger than at other bearing positions. This might be an individual feature of each bearing. Although the shafts are vibrating in an interesting manner, the gear itself is supposed to move in the direction of the line of action if we assume the vibration of the gear center by interpolating with outer vibration.

The simulator of 12-degree-of-freedom. To predict the vibration behaviors of helical gears as shown in Figure 14, the author proposes a 12-degree-of-freedom dynamic model that includes rotational, transverse, tilting, and axial motions. A gear is assumed to be a rigid body which can be vibrating in six directions in terms of equivalent stiffness and effective masses including the dynamic properties of gear, shafts and bearings. Tooth meshing springs of two coupled gears are modeled as two parallel springs that vary temporally with a certain phase relationship due to the helix angle.

Vibration analysis. Figure 12 shows that transverse vibration can be expressed by dynamic behaviors in the x and y directions. Rotational vibration can be expressed in the θ_z direction.

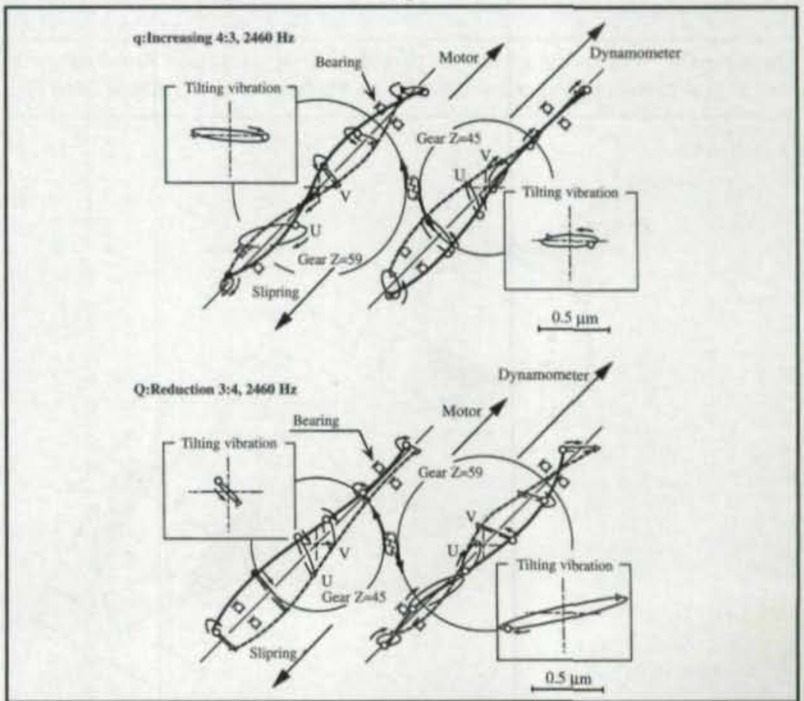

Fig. 11—Modal representation of the gear system by means of laser Doppler measurement. Gear ratio 3:4.

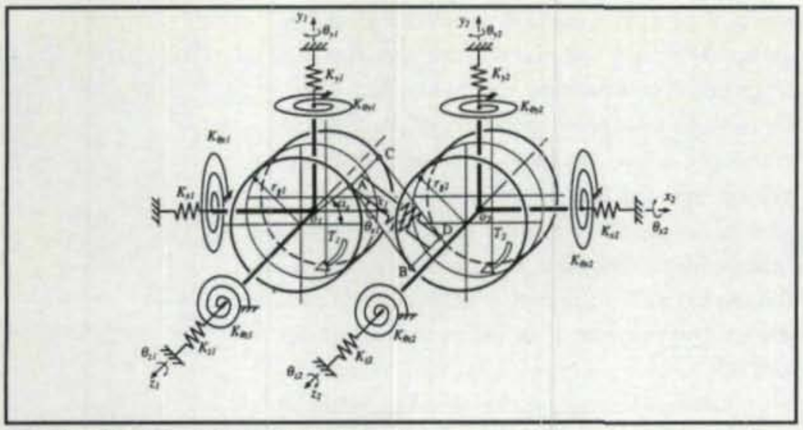

Fig. 12—Vibration model of helical gears.

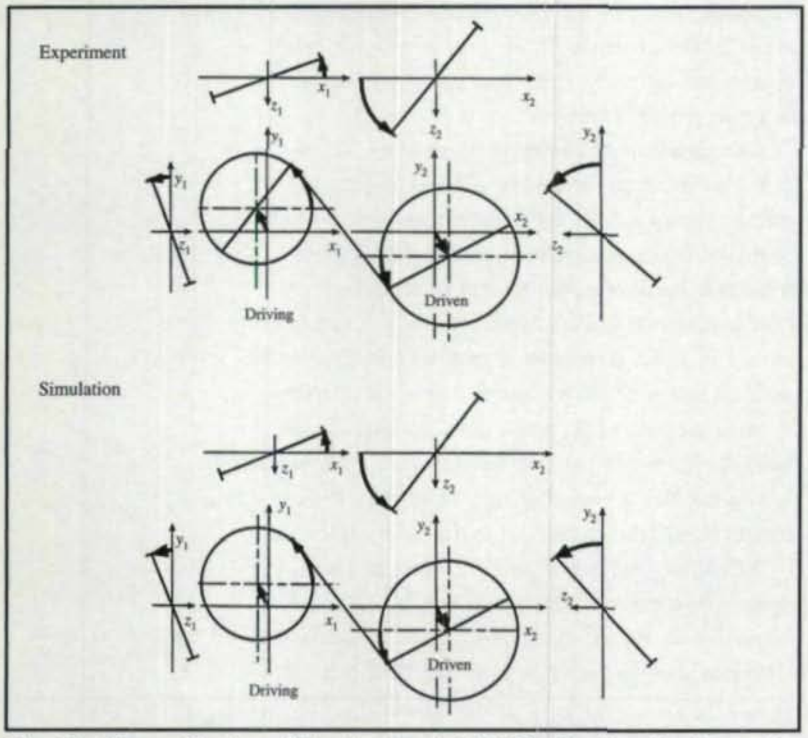

Fig. 13—The verification of the developed 12-DOF vibration simulator of a helical gear system by experiment modes under increasing 4:3, about 2460 Hz.

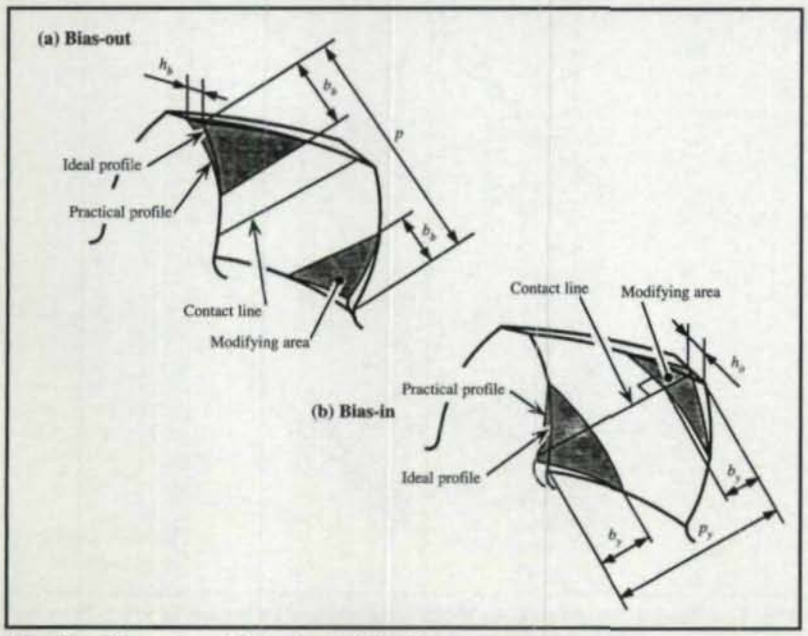

Fig. 14—Bias-out and Bias-in modification.

Tilting vibration can be expressed in the θ_x and θ_y directions, and axial vibration can be expressed in the z direction. In each direction, the equivalent stiffness and effective mass are determined by the gear, shaft, and bearings.

Angular displacement in the rotational direction θ_z is expressed in terms of tangential displacement along the base circle as $w = r_g\theta_z$. Angular displacements in the tilting directions θ_x and θ_y are also expressed along the base circle as $u = r_g\theta_x$, $v = r_g\theta_y$. The equations of motion can be expressed in the matrix equation

$$[m]\{\ddot{\delta}\}+[D]\{\dot{\delta}\}+[k]\{\delta\}=\{F\} \quad (4)$$

Where $\{\delta\}$ is a vector of displacements as

$$\{\delta\} = \{\, x_1 y_1 z_1 u_1 v_1 w_1\, x_2 y_2 z_2 u_2 v_2 w_2 \}^T \quad (5)$$

$[m]$ is a mass matrix, $[D]$ is a damping matrix, and $[k]$ is a stiffness matrix.

To verify the simulator with the use of the proposed formulation, experiments were performed for different ratios. The results agreed with the calculations (see Figure 13). The mode at resonance speed was found to be f_z = 2460 Hz when the gear ratio is 4:3.

The performance of a bias-modified helical gear pair. To decrease vibration, bias modification is often applied to the tooth surface. There are two methods in bias modification, bias-in and bias-out (see Figure 14). It is not clear which modification is better.

Using the vibration simulator of a 12-degree-of-freedom helical gear unit, the relationship between the performance of vibration level and misalignment is discussed on the bias-in and the bias-out modified helical gear pairs. These pairs have a high total contact ratio $\varepsilon = 3.81$ (usually used in automobile transmissions) to realize low vibration level. The gear data is: z_1 and $z_2 = 52$, $m_n = 2.0$, α=20° and $\beta_0 = 30°$, face width 30 mm and load 133 N/mm.

Misalignment is defined as positive when the axis inclines to the leading side bearing. On the bias-out modification with misalignment from –20μ to 10μm, amplitide factor contour maps have been developed in which the abscissa is the dimensionless modification length b_b/p, and the ordinate is the bias modification h_b[μm] (see Figure 14).

The contour lines in the maps show a ratio of rotational vibration to that of a non-modified helical gear pair at the resonance speed. The influence of the amount of bias-out modification and modification length on vibration can be obtained using the contour lines on each amplitude factor contour map. The influence of misalignment on vibration is realized by comparing the maps to each other.

Conclusion

The proposed classification of a parallel gear pair and contact ratio domain are verified to be useful in the design of a quiet gear pair.

Our research has shown that there is an asymmetrical relationship between vibration magnitude and the direction of each deviation (see Figures 4 and 5). For further noise reduction, the effects of shaft, bearing and gear-box on vibration are of great importance.

Finally, there is no new knowledge on how to design a quiet parallel gear. However, it is clear that surface deviation, as well as the direction of that deviation, can affect the vibration level of a gear pair. Gear engineers should see that their products turn in the right direction. They are very similar men who walk step by step carefully the narrow ridge between high mountains. ○

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"There is definitely a shrinking of demand for gears due to innovations and substitutions to replace gears. There are new drive techniques, for instance. You will see in a few years gear hobbing machines which manufacture gears but which do not have any gears within the machines. Conventional hobbing machines used to have more than 150 gears between the spindle drive of the cutter or the hob and the table, and today, if you count 5 to 10, this is the maximum, and it goes this way that one day there will be probably none. It is happening in the whole machine tool industry. Direct drives and the substitution of gear reducers due to more flexible drive systems."
—Peter Kozma, President, Liebherr Gear Technology, Inc.

Gear Manufacturing Past, Present & Future

Charles M. Cooper & William R. Stott

Roughly 100 years ago, Cornelius J. Brosnan of Springfield, Massachusetts, invented and received the first U.S. patent for a paper clip. At about the same time, his fellow inventors were coming up with such marvels as the zipper, the safety razor and the typewriter.

While these inventions seem mundane compared to the differential gear hobber or the gear shaping machine, sometimes it helps to put things in perspective, and the fact is, these inventions came at around the same time. Gear manufacturing, like most industries, has seen more change in the 20th Century than it has in all our previous history. But these changes didn't take place in a vacuum. They've been affected, influenced and driven by industry, war, politics and consumer demand.

Our Recent History

"For sure, the biggest driver of change has been the mass production of automobiles," says Peter Kozma, president of Liebherr Gear Technology, Saline, MI. "Each part which goes into an automatic assembly line has to be exchangeable. Therefore, standards had to be developed, and standards such that every supplier could make the gears according to the standards and that they would fit into this mass production environment." Is it any wonder, then, that only eight years after Henry Ford introduced his Model T, the American Gear Manufacturers Association was formed?

1896 – *Invention of the Fellows Gear Shaper.*

1897 – *Robert Hermann Pfeuter invents the first gear machine capable of cutting both spur and helical gears. This machine included a horizontal workspindle on vertical ways, a hob swivel, and a hob carriage feed along horizontal ways along the bed of the machine. The hob feed was accomplished manually with a crank on the end of a feed screw.*

1900 – *Invention of the paper clip.*

1903 – *Orville & Wilbur Wright conduct the first powered flight at Kitty Hawk, NC.*

1906 – *Gould & Eberhardt produces its first gear hobbing machine.*

1907 – *Lees Bradner produces its first successful gear machine, the No. 5 Gear Generator.*

1908 – *Max Maag develops the geometry of nonstandard involute spur and helical gears using rack-type cutters.*

1908 – *Ford began producing the Model T using an assembly line. "The introduction of the automobile had a far-reaching effect upon the machine tool industry and machine tool design. The demand for high-grade materials capable of withstanding shocks and stresses of high-speed cars, made it necessary to design machine tools capable of working the metals at ecomonical speeds and feeds. These demands, in turn, showed weaknesses in machine tool design and construction. For example, it showed that cast-iron gears were entirely inadequate in many cases." – Machinery, September 1915.*

1910 – *Barber Colman ships its first hobbing machine, a No. 12 model*

1913 – *Maag grinding machines with saucer-shaped wheels are introduced. "This invention was important because it provided the first automatic compensation for the wear of the grinding wheel, making it the first and most famous automatic control system in the machine tool history." – from* Development of Gear Technology and Theory of Gearing, *by Faydor Litvin.*

1914-1918 – *World War I.*

1916 – *AGMA Founded.*

1916 – *Gleason invents a process for generating spiral bevel gears.*

Gary Kimmet, Vice President of Worldwide Sales for the Gleason Corporation, points to the 1970s oil embargo as having a big effect on gear manufacturers. It forced us to look at the fuel economy of our vehicles, and we saw a shift to smaller, front-wheel drive cars and away from rear-wheel drive gas guzzlers. For Gleason, this meant a significant decrease in the demand for the spiral bevel gears that drive rear axle differentials. But increased consumer demand for sport utility and 4-wheel drive vehicles reversed this trend in the early 1980s, Kimmet says.

Economic factors have certainly played a big role in the changes the gear industry has seen. In fact, the most important factor could be summed up in one word, says Bill Maples, marketing manager for Star Cutter Company. "Globalization," Maples says, pointing to the number of international corporate mergers and the number of major manufacturing companies moving their production locations outside the United States.

Joe Arvin, president of Arrow Gear Company, agrees. "The U.S. used to be able to sell because somewhere in the world they would buy our products." But in the 1970s, he says, foreign competition, particularly from Japan, began to challenge the ability of American companies to sell their products not only abroad, but at home as well. "They used to laugh at the Japanese products. It wasn't until the 80s that they realized what was going on," Arvin says.

A big factor in today's gear industry is the concern for the environment. "The changes in environmental requirements will definitely have an impact on the gear industry," says Liebherr's Kozma. We're seeing an increased demand for alternative energy sources, such as wind turbines, he says. "Environment also means to eliminate waste," Kozma says. "That means to increase efficiency, and this will also require transmissions in a different quality class."

The demand for energy saving, higher efficiency and increased power density have been the drivers of more and better gears as well as more economical ways of manufacturing them, says Dr. Hermann Stadtfeld, Vice President of Research and Development at Gleason Corporation. These demands have resulted in the 6-speed

"The basic trend will continue, and we will see a concentration in the gear industry. The remaining companies will be forced to modernize the equipment and update the technologies. The demand for gears will go down further. The typical example is the CVT gear box using less gears than a standard 5-speed gear box."
–Diether Klingelnberg, Chairman of the Board, Klingelnberg-Oerlikon Geartec Vertriebs GmbH.

"Gear makers in different parts of the world must learn from one another. European gear makers have a larger base of skilled people who understand the technology better because they can go to school for it and apprentice in it. The U.S. must concentrate on better educating its skilled workers."
—George Wyss, President of Reishauer Corporation

1919 – *AGMA publishes its first gear rating standard.*

1919 – *Lees Bradner develops the No. 10 Gear Tooth Grinder for grinding gears after hardening.*

1919 – *Barber Colman develops the No. 3 Hob Sharpening machine.*

1923 – *"The demand for high-performance spiral bevel gears grew at the beginning of this century as bevel gears began to be fitted in the powered rear axles of automobiles. The inventor Heinrich Schicht started to work in this field in 1907. In December 1921 he finally patented the simple method to produce spiral bevel gears using a helical hob. Klingelnberg took over the patent and employed the inventor Schicht, thus laying the foundation for his company's start in bevel gear hobbing technology. The first palloid hobbing machines were built from 1923 onwards." –Andreas Montag, marketing services, Klingelnberg-Oerlikon Geartec Vertriebs GmbH. Pictured at left is the 1923 Klingelnberg FK150 Universal Spril Bevel Gear Generating Machine.*

1923 – *Carl Mahr develops the world's first involute profile tester with variable adjustment of the base circle.*

1920s – *Lees Bradner develops its "rotary gear finisher," which pioneered the art of gear shaving.*

1922 – *Lees Bradner begins selling gear testers. These early instruments checked gear involute profile and tooth-to-tooth spacing.*

1929– *National Broach founded.*

1926 – *Ernst Wildhaber develops hypoid gearing at The Gleason Works.*

1932– *Rotary gear shaving introduced by National Broach.*

1937– *David Brown develops the Radicon worm gear drive.*

1919 – *Prohibition Ratified in the U.S.*

1927 – *The first working television is demonstrated.*

1926 – *Robert H. Goddard demonstrates the first liquid-fueled rocket.*

1929 – *U.S. Stock market crash.*

1930s – *Powder metal is first used to manufacture tungsten carbide cutting tools.*

1931– *Empire State Building completed.*

1933– *Prohibition Ends.*

1934– *Hitler comes to power in Germany.*

"We are ready for the challenges of the 21st Century. People are saying that the old-timers are leaving and the young upstarts don't know anything, and that's not true. You don't have to have the old school craftsmen with the computerized machines. We're better equipped in the U.S. than we were. The problem is being able to combat foreign competition."
—Joe Arvin, President, Arrow Gear

"I think that one of the biggest things that forced change in the United States is the influence of the Japanese manufacturing culture as it was perceived here. It's not that it was better, but it was truly perceived as being better. It revolutionized the thinking in the automobile industry, and accelerated changes through improvements."
—Bill Maples, Marketing Manager, Star Cutter Co.

manual automobile transmission, and the 5-speed automatic, he says.

Another big influence on the gear industry has been the emergence of computers and computing technology. Computers have allowed the development of tooth contact analysis, CNC controls, computer aided design and advanced metrology techniques, all of which continue to have a huge impact on the way gears are made.

The Turn of the Millennium

Today's gear industry is clearly very different from the gear industry of any other time. Machining gears out of metal was clearly the most common method 100 years ago. Today, this method of choice is being challenged by a far wider choice of materials—including, most notably, plastics and powder metals—and methods—including casting, forging, molding, grinding, EDM, stamping, sintering, fineblanking, laser and waterjet cutting. This is to say nothing of the choices we have today for improving a gear after it's initially formed, including the multitude of heat treating methods, coatings and finish machining processes.

"I think the industry is reinventing itself to adapt to the changes in technology," says Star Cutter's Bill Maples.

All of today's choices require the gear expert to obtain more and more education. "The gear industry requires a lot of technical skills to do a good job," says Gary Kimmet of Gleason. "It demands an ever-increasing movement in those technical skills. There is a continuing difficulty of having enough people who understand gears technically—how to design them so they are strong and quiet, and how to manufacture them."

"We don't see an overwhelming desire to go into the gear industry," Maples says. Parents would rather encourage their children to go into computers, medicine or law, he says. A career in manufacturing is not seen as one with promise. The AGMA has recently produced a video to promote the gear industry to young people deciding on a career path. The video is intended for high school and college guidance counselors, and according to Maples, it's the type of promotion the gear industry needs to do more of.

On the shop floor, at least, some see increases in machine tool technology as a way

1938 – *Gleason Formate method is invented by James Gleason.*

1938 – *du Pont researchers invent Nylon. Today, plastic gears are one of the fastest growing segments of the market.*

1939-1945 – *World War II.*

1939 – *The first digital computer.*

1942 – *The first controlled, self-sustained atomic reaction is conducted at the University of Chicago.*

1947 – *Dr. Edwin H. Land introduces the Polaroid camera.*

1949 – *China established People's Republic.*

1950s – *Powder metal is first used for gears.*

1950 – *Maag introduces spur and helical gear grinding by planar contact.*

1951 – *UNIVAC, the first commercial computer, is sold to the U.S. Census Bureau.*

1954 – *Darle Dudley publishes* Practical Gear Design.

1955 – *ITW introduces the Spiroid gear drive.*

1955 – *The first numerically controlled machine tools are on display at the National Machine Tool Show (precursor to IMTS).*

1956 – *Gear Honing introduced by National Broach & Machine.*

1957 – *Russians launch Sputnik, the first artificial earth-orbiting satellite.*

to offset the difficulty in finding expert gear makers. Many American workers are not as skilled as their European counterparts, says Ron Schomann, Vice President of LMT-Fette. "This costs American industry in terms of lower quality and broken tools. The development of electronic controls has allowed America to catch up because CNC machines are not as dependent on the operator to know as much as in the past. America has many unskilled people turning out good gears using this technology."

Joe Arvin of Arrow Gear agrees that machine tool technology can make a big difference. "People are saying that the old-timers are leaving and the young upstarts don't know anything." However, as the machines get better, we depend less on the skills of those old-timers, Arvin says. "You don't have to have old school craftsmen with the computerized machines."

But the rapid pace of change in today's technology requires an ever increasing need for continuing education. "The education we provide today to the next generation of specialists is the highest ever, and I believe that the learning phase in somebody's life will increase, not shorten. People will stay longer in the learning process," says Kozma.

The Next 1000 Years

"I cannot really tell you what sort of transmissions we will build twenty years from now," says Kozma. When you think what happened in the last 100 years, if you look back in the history books at how people were dressed and the tools they were using 100 years ago, and if you ask me to look forward 100 years from now, or even 50 years from now, and ask me how I think it will change, it's a very difficult question."

Kozma sees concern over the environment as being a key issue in the years to come. "In everything that we manufacture, we'll have to be focused on a higher environmental friendliness," Kozma says, "whether it's automobiles, whether it's mass transportation like airplanes or trains, or whether it's a refrigerator, and we have to consider when we're manufacturing it that there must be an environmental way of disposal. We cannot continue to make waste mountains, which have a tremendous negative impact on the environment."

"The gear industry requires a lot of technical skills to do a good job. It demands an ever-increasing movement in those technical skills. There is a continuing difficulty of having enough people who understand gears technically—how to design them so they are strong and quiet, how to manufacture them. The skill sets necessary to do a good job are not there. More training, something, has to be done to encourage people to go into the industry. The US is worse off than some countries, but the global trend is for less skilled people. It's going to lead us to having organizations providing those skills on an outsourcing basis."

—Gary Kimmet, VP Worldwide Sales and Marketing, Gleason

1961 – Development of Tooth Contact Analysis by Meriwether Baxter and Ernst Wilhaber at Gleason.

1964 – Darle Dudley publishes his Gear Handbook.

1968 – Pfauter introduces carbide hobbing.

1974 – Pfauter introduces first NC hobbing machine, incorporating the "Electronic Gear Box."

1966 – Sumitomo introduces the cycloidal gear reducer in the United States.

1963 – Earle Buckingham publishes Analytical Mechanics of Gears.

1976 – Kapp CBN hob sharpening introduced to the U.S. (by American Pfauter).

1963 – John F. Kennedy assassinated.

1973 – Oil embargo.

1969 – Apollo 11 astronauts land on the moon.

1960 – Invention of the laser.

1976 – Steve Wozniak and Steve Jobs build their first computer, the Apple I. "When my dad was writing the Manual of Gear Design, he calculated everything by hand from 15-place trig tables. He literally wore out an old hand-run calculator. Nowadays, you'd just do the whole thing on a computer."
– Eliot K. Buckingham, excerpted from a 1997 interview.

1961 – General Electric introduces cubic boron nitride (CBN).

"The development of electronic controls for gear machines has allowed America to catch up [in quality] because CNC machines are not as dependent on the operator to know as much as in the past. America has many unskilled people turning out good gears using this technology. We make up for low worker skills with high levels of technology."

—Ron Schomann, VP, LMT-Fette

This, our Millennium Outlook issue, has been one of the most interesting projects we've worked on in a long time. In our efforts, we've contacted many companies involved in the gear industry and asked them for help. We've tried to be as all-inclusive as possible, but we're sure we've overlooked some important people, processes or companies that should have been included. If we forgot you, we're sorry. Please send us a note, because we will continue to maintain and update our timeline of gear manufacturing achievements.

—The Editors

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Gary Kimmet adds that the trend toward globalization and increased competition will intensify. "I see consolidation of gear companies," Kimmet says. "The impact of globalization requires some level of critical mass in order to compete in the global market. That means trouble for some small gear companies."

Many predict that the automotive industry will continue to drive trends in gear manufacturing. Electric vehicles and CVT technologies will certainly have an impact in the decades to come, although the exact nature of that impact is still uncertain. Electric vehicles may eliminate geared transmissions altogether by using direct drive technology. Continuously variable transmissions will probably require more accurate, more efficient gear systems.

"We foresee in the next years to come tremendous changes in consumer behavior," says Kozma. "There will be new products on the market which we don't even think of today. When you think about the changes only in the last 20 years as far as the consumer market is concerned, the speed in going into different products will require from us that we stay absolutely alert, to look forward, to sense in which direction the next generation will go."

The consensus seems to be that there will almost certainly be gears in a diversity of products for many years to come. How they're made, and in what quantity and at what quality will be determined only by time.

"I don't want to be negative," Kozma says, "but the demand for gears on a worldwide basis will in quantity reduce, but has to improve in quality and performance. All the products coming in the future will definitely require a higher class of quality. There will be substitutions to the gears which have been traditionally manufactured. There will be gear making methods which maybe have not been invented. There will be technologies to come and tools which are not on the market today. But gears will be required in the future. But I cannot tell you to what extent new technologies will eliminate gears."

Bill Maples puts a more positive spin on the industry's potential. "We haven't seen anything yet," he says. "I don't see why it's necessary to be anything but positive. The main thing people have to realize is that it's going to change." ○

1980 – *TiN coated gear tools introduced by Barber Colman, Star & Fette.*

1981 – *First CNC controlled combination lead/involute gear checkers introduced to U.S. (American Pfauter).*

1982 – *Kapp CBN plated wheel profile grinding introduced to U.S. & Canada (American Pfauter).*

1984 – Gear Technology *publishes its first issue.*

1987 – *Wafer Hobs are introduced by Pfauter-Maag Cutting Tools.*

1987 – *The First Gear Expo is held in Cincinnati, OH.*

1988 – *Opti-Gash Hobs are introduced by Pfauter-Maag Cutting Tools.*

1993 – *U.S. delegation becomes the secretariat to ISO TC-60.*

1994 – *Liebherr introduces dry hobbing.*

1994 – *Carbide Hobs introduced by Liebherr, Pfauter-Maag, Fette.*

1995 – *Harley-Davidson begins grinding transmission gears to reduce noise.*

1996 – *Launch of* **THE GEAR INDUSTRY HOME PAGE.**

1997 – *Gleason and Oerlikon debut dry cutting of spiral bevel gears.*

1999 →

1980 – *First Space Shuttle.*

1983 – *Compact Disk Debut.*

1980 – *The beginning of the rise of the sport utitlity vehicle. The greater demand for rear-axle differentials in 4X4 and SUV vehicles has a huge impact on the demand for spiral bevel gears.*

1989 – *Fall of the Berlin Wall.*

1990 – *Break-up of the Soviet Union.*

1989 – *Nelson Mandela elected president of South Africa.*

Gear Expo 99 Wrap-up

Many people seem to be counting this year's Gear Expo in Nashville as a resounding success. There were 180 American and international exhibitors occupying over 50,000 square feet of exhibit space in the Nashville Convention Center, with total attendance of 2,700. This figure is dramatically down from past shows but that doesn't seem to be an issue with the show organizers. According to Kurt Medert, vice president of AGMA's Administrative Division, even though attendance was off from the 1997 show, the exhibitors were pleased with the quality of the people who did come to the show. "This was an excellent show for us," said Marty Woodhouse, vice president of sales for Star Cutter Company and chairman of AGMA's Gear Expo committee. "Our customer base was there and they came to buy. It was very active."

Others were not so positive. At the show, the editors of *Gear Technology* heard from a number of exhibitors who were unsatisfied with the quantity and the quality of the attendees and the people who ran the registration. Still, these were quiet grumblings and they have not stopped AGMA from declaring Gear Expo 99 a great success.

While it is also true that there were fewer machines on the floor this year than in the past, the range of products on display was still impressive. Visitors saw everything from forging and blanking to surface enhancement, from testing to failure analysis, and from traditional cut gears to the latest technology in plastic, powder metallurgy, near-net and net-shaped gears. Machine tools, measurement systems, manufacturing accessories and a variety of services were also on display, occupying nearly every available foot of floor space in the Nashville Convention Center.

People came to Gear Expo from 45 states and 26 foreign countries (10% of the attendees) with the bulk of the show's attendance coming from the manufacturing belt—Ohio, Michigan, Indiana, Illinois and Pennsylvania. In total, 1,262 companies were represented at the show by 2,700 people, coming in either as exhibitors or as attendees. That is more companies but fewer people, a situation that Medert says may have more to do with the location and the economy than anything else. "In Detroit we get just as many solid attendees as we did in Nashville," said Medert, commenting on the numbers. "But we also get additional people and that adds to the numbers." With the economy being a little off, he added, companies are sending fewer people to the show. "A lot of companies were represented by just one person," he said.

One of the things AGMA learned this time around was the extent and importance of exhibitor-to-exhibitor contact at the show. "You've got the exhibitors selling to the people who attend, and you've got the exhibitors selling to each other," said Medert. "Gear Expo is a unique event as industrial trade shows go because of its special focus on gearing. It is two shows in one, Gear manufacturers on the one hand and suppliers to the industry on the other. There is as much buying and selling going on between exhibitors as there is between exhibitors and the people who attend the show. This reinforces the notion that the exhibitors are each other's customers."

Along with the show, the Gear Processing and Manufacturing Clinic, sponsored by the Society of Manufacturing Engineers, was held. The Clinic was actually a series of events covering topics from heat treating and gear hardening to gear metrology, gear processing and manufacturing. Under this last were lectures covering near-net vs. far-net shape gear applications, high-speed steel for gear cutting tools, shaving, broaching, honing and CNC gear inspection. "We had a registered attendance of about 150 people," said Lynn Albertson, the program administrator for SME's conferencing division. "Overall, we felt the Clinic went really well and that the exposition was extremely well done."

This excitement and overall approval of the show and the related events is reflected in the number of exhibitor reservations AGMA has already received for Gear Expo 2001. A month after the close of Gear Expo 99, AGMA has received commitments from 90 companies for 37,000 square feet of exhibit space in Detroit's Cobo Center for Gear Expo 2001. This is a 28% increase over the number of commitments made after the 1997 Gear Expo.

While this is a sign of growth in the show itself, the organizers would like to see more attendees as well. Gear Expo 2001 will be at in Detroit, and until recently, the 2003 show had been planned for Charlotte, North Carolina. That was the site discussed at the post-show exhibitor's meeting. However, according to Medert, there is only a letter of intent with Charlotte and AGMA is looking at other cities that are a little closer to the manufacturing belt, places like Milwaukee, Columbus and Pittsburgh. "Charlotte won't happen," Medert said, "too far East, too far South."

Gear Expo 2001 will run October 7-10, 2001. "Detroit is into a positive movement," said Medert, referring to the recent upgrades the city has made to its downtown infrastructure and facilities. "We are looking forward to going back." For more information about the show or to reserve booth space call AGMA at (703) 684-0211.

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For more infornmation about Gear Expo, please circle **204.**

Gear Expo 99 at the Nashville Convention Center.

Reverse Engineering of Pure Involute Cylindrical Gears Using Conventional Measurement Tools

Isaias Regalado & Rodrigo Lopez

Introduction

Designing a gear set implies a considerable effort in the determination of the geometry that fulfills the requirements of load capacity, reliability, durability, size, etc. When the objective is to design a new set of gears, there are many alternatives for the design, and the designer has the freedom to choose among them. Reverse engineering implies an even bigger challenge to the designer, because the problem involves already manufactured gears whose geometry is generally unknown. In this case, the designer needs to know the exact geometry of the actual gears in order to have a reference for the design.

Nomenclature	
MOB	Measurement over balls
N	Total number of teeth
N_s	Number of spaces in the span measurement
N_t	Number of teeth in the measurement over balls
OD	Outside diameter
OM	Outside measurement
P	Transverse diametral pitch
P_n	Normal diametral pitch
R	Theoretical pitch radius
R_2	Auxiliary radius during measurement over balls
R_b	Base radius
RD	Root diameter
RM	Root measurement
R_w	Radius of the wire (ball for helical gears)
SM	Span measurement
T	Transverse tooth thickness at reference radius R
ϕ	Theoretical normal pressure angle
ϕ_2	Auxiliary pressure angle during measurement over balls
ϕ_τ	Theoretical transverse pressure angle at reference radius R
ψ	Theoretical helix angle at reference radius R
ψ_β	Base helix angle

Using advanced measurement machines, the profile of the tooth can be checked and compared with a reference surface; therefore, using a trial and error scheme it is possible to approximate the actual geometry of the gears. Unfortunately, these machines are expensive and seldom available to the designer, so the need for a method using conventional measurement tools is justified, especially when the measurement has to be done in the field.

This article presents a methodology based on measurement over wires and span measurement to determine the geometry of a pure involute gear.

Background

For the complete specification of a cylindrical gear, it is necessary to know the following:

- Number of teeth
- Pressure angle at a reference diameter
- Outside diameter
- Root diameter
- Helix angle at a reference diameter
- Circular tooth thickness at a reference diameter
- Face width

It is well known that the operating surface of the tooth is uniquely defined by the base radius and the base helix angle. This surface is limited by the outside diameter, form diameter and face width. The tooth thickness is defined by the relative position of two symmetric tooth surfaces.

In order to define the geometry of a gear, it is useful to divide its characteristics into three groups. The first group includes characteristics that can be directly measured with conventional tools. The second group is integrated by properties that require special tools or procedures for their determination. The third one is formed by those properties which require some additional calculations for their determination. This division is shown in Table 1.

The proposed method is based on the measurement of the four properties in Group I and two in Group II (measurement over balls and span measurement).

The procedure to calculate measurement over balls and span measurement is available in the literature (Refs. 1–3). Fig. 1 shows the transverse plane of a gear; from this figure, it may be observed that given the transverse tooth thickness 'T' of the gear at a given radius 'R', the measurement over balls may be calculated as follows:

$$MOB = 2R_w + R_2\sqrt{2 - 2\mathrm{Cos}\left(\frac{2\pi N_t}{N}\right)} \quad (1)$$

Where:

$$R_2 = \frac{R_b}{\mathrm{Cos}(\phi_2)} \quad (2)$$

And ϕ_2 is calculated from:

$$\mathrm{Inv}(\phi_2) = \frac{T}{2R} + \mathrm{Inv}(\phi_t) + \frac{R_w}{R_b} - \frac{\pi}{N} \quad (3)$$

In the case of helical gears, the effect of the helix angle has to be considered, and Equation 3 becomes:

$$\mathrm{Inv}(\phi_2) = \frac{T}{2R} + \mathrm{Inv}(\phi_t) + \frac{R_w}{R_b\mathrm{Cos}(\psi_b)} - \frac{\pi}{N} \quad (4)$$

From Fig. 2, the span measurement for a given gear may be calculated by the equation:

$$SM = R_b\mathrm{Cos}(\psi_b)\left[\frac{T}{R} + \frac{2\pi N_s}{N} + 2\mathrm{Inv}(\phi_t)\right] \quad (5)$$

Again, in Equation 5, the base helix angle is included to compensate for the fact that in helical gears the measurement is actually performed in the normal plane. The number of teeth considered during the measurement (N_s) is limited by two conditions: contact of the caliper with the root of the teeth and contact of the caliper with the tip of the teeth.

Fig. 3 shows the limiting number of teeth for different numbers of teeth and pressure angles in standard spur gears. As may be observed, there is always a range of teeth numbers to use for the determination of the span measurement.

Tools

During the measurement process the following tools are required:

• A conventional caliper or micrometer of suitable size for the gear to be measured. If a digital caliper is available, it is recommended, although this is not strictly necessary.

• A set of pins for the measurement of gears. It is convenient to remember that helical gears must be measured with balls instead of pins. The recommended "standard" ball diameter is defined as 1.728/Diametral Pitch or 1.68/Diametral Pitch. If a set of "standard" pins is not available, a set of steel balls of nominal diameter close to the standard may be used instead.

• A set of disc calipers is desirable, although in most of the cases this tool can be replaced with conventional calipers.

• A calculator or a portable computer with the program for measurement. The computer is recommended only because the calculations can be done faster, but the procedure can be easily done with the calculator.

Group I (Directly Measured)	Group II (Requires Special Tools/Procedures)	Group III (Calculated)
Number of teeth	Chordal thickness & addendum	Pressure angle
Outside diameter	Measurement over balls	Diametral pitch
Root diameter	Span measurement	Helix angle
Face width		

Table 1 – Division of the geometrical characteristics in a gear

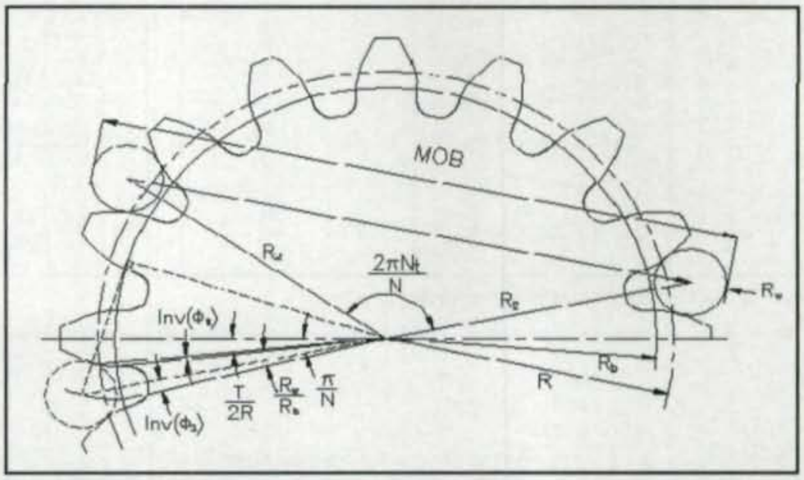

Fig. 1—Measurement over balls in a spur gear.

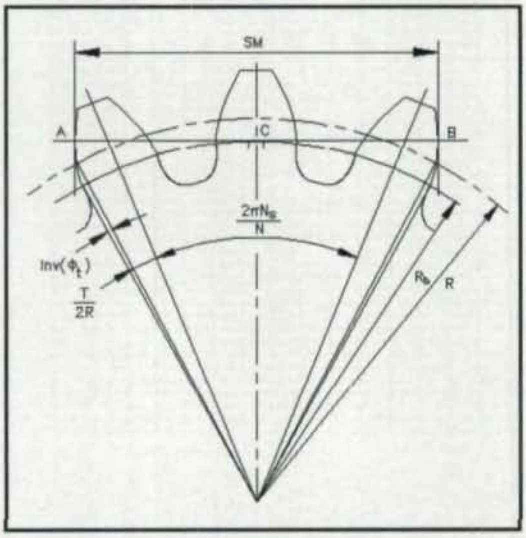

Fig. 2—Span measurement in a spur gear.

Dr. Isaias Regalado
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Dr. Rodrigo Lopez
is the director of the Mechanical Transmisssions Department at CIATEQ A.C.

Calculate / Given	ϕ	ϕ_t	ψ	R	P_n	P
ϕ	ϕ	$Sin^{-1}\left(\frac{Sin(\phi)}{Cos(\psi_b)}\right)$	$Cos^{-1}\left(\frac{Tan(\phi)}{Tan(\phi_t)}\right)$	$\frac{R_b}{Cos(\phi_t)}$	$\frac{N}{2RCos(\psi)}$	$P_nCos(\psi)$
ϕ_t	$Sin^{-1}(Sin(\phi_t)Cos(\psi_b))$	ϕ_t	$Cos^{-1}\left(\frac{Tan(\phi)}{Tan(\phi_t)}\right)$	$\frac{R_b}{Cos(\phi_t)}$	$\frac{N}{2RCos(\psi)}$	$P_nCos(\psi)$
ψ	$Sin^{-1}(Sin(\phi_t)Cos(\psi_b))$	$Cos^{-1}\left(\frac{R_b}{R}\right)$	ψ	$\frac{Tan(\psi) \cdot R_b}{Tan(\psi_b)}$	$\frac{N}{2RCos(\psi)}$	$P_nCos(\psi)$
R	$Sin^{-1}(Sin(\phi_t)Cos(\psi_b))$	$Cos^{-1}\left(\frac{R_b}{R}\right)$	$Tan^{-1}\left(\frac{RTan(\psi_b)}{R_b}\right)$	R	$\frac{N}{2RCos(\psi)}$	$P_nCos(\psi)$
P_n	$Sin^{-1}(Sin(\phi_t)Cos(\psi_b))$	$Cos^{-1}\left(\frac{R_b}{R}\right)$	$Sin^{-1}\left(\frac{NTan(\psi_b)}{2P_nR_b}\right)$	$\frac{N}{2P_nCos(\psi)}$	P_n	$P_nCos(\psi)$
P	$Sin^{-1}(Sin(\phi_t)Cos(\psi_b))$	$Cos^{-1}\left(\frac{R_b}{R}\right)$	$Tan^{-1}\left(\frac{NTan(\psi_b)}{2PR_b}\right)$	$\frac{N}{2P}$	$\frac{P}{Cos(\psi)}$	P

Table 2 – Calculation of the properties of a gear.

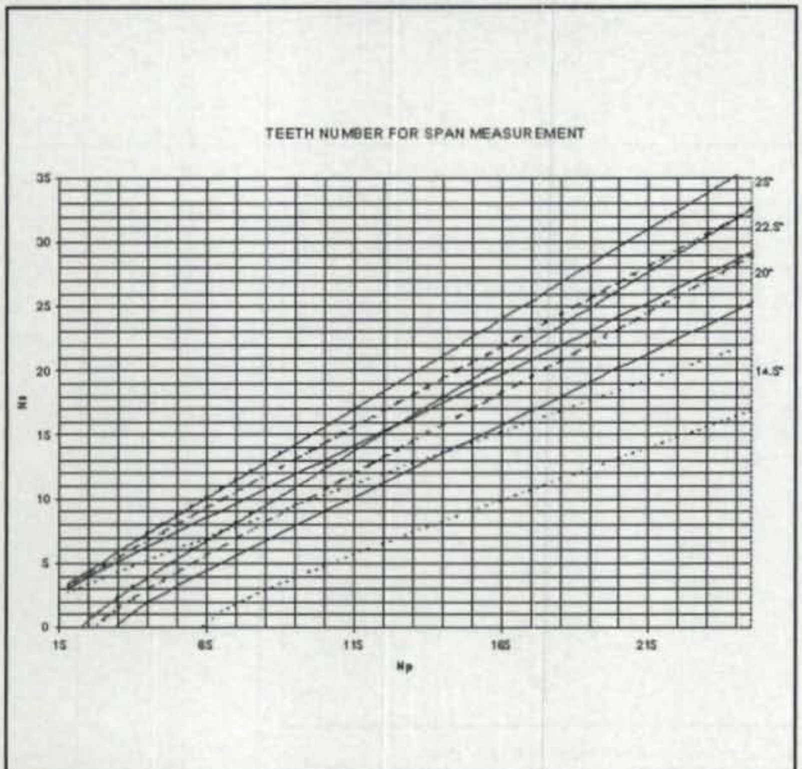

Fig. 3—Limiting number of teeth for span measurement.

Procedure

The proposed procedure assumes it is possible to take at least two span measurements. These measurements will be called SM_1, SM_2, etc. and are obtained considering N_{s1}, N_{s2}, etc. spaces. The geometry of the gear is calculated as follows:

1. Determine the number of teeth in the gear.
2. Determine the outside diameter of the gear.

From Fig. 4, if the number of teeth is even, the outside diameter corresponds to the outside measurement of the gear OD=OM. If the number of teeth in the gear is odd, or there are some missing teeth, the outside diameter may be calculated using Equation 6:

$$OD = OM\sqrt{\frac{2}{1-Cos\left(\frac{2\pi N_s}{N}\right)}} \tag{6}$$

Where N_s is the number of spaces considered when performing the measurement (see Fig. 4a).

3. Determine the root diameter of the gear, taking into account the same considerations as in the outside diameter, RD=RM for even number of teeth and for odd number of teeth:

$$RD = RM\sqrt{\frac{2}{1-Cos\left(\frac{2\pi N_t}{N}\right)}} \tag{7}$$

Where N_t is the number of teeth considered when performing the measurement (see Fig. 4b).

4. Determine the face width of the gear.
5. Select a suitable ball diameter.
6. Determine the measurement over balls of the gear.
7. Determine at least two span measurements in the gear registering the number of spaces used for every measurement.
8. Perform the following calculations:

Assuming two measurements are available, then from Equation 5 a constant K_1 may defined as:

$$K_1 = R_bCos(\psi_b)$$

$$= \frac{(SM_2 - SM_1)\,N}{2\pi(N_{s2} - N_{s1})} \tag{8}$$

Because of the fact that the tooth thickness is the same for all the teeth, it is possible to define a constant K2 as:

$$K_2 = \frac{T}{R} + 2Inv(\phi_t) = \frac{SM_1}{K_1} - \frac{2\pi N_{s1}}{N} = \frac{SM_2}{K_1} - \frac{2\pi N_{s2}}{N} \quad (9)$$

Then from Equation 3:

$$Inv(\phi_2) = \frac{K_2}{2} + \frac{R_w}{K_1} - \frac{\pi}{N} \quad (10)$$

And from Equation 1,

$$R_2 = \frac{MOB - 2R_w}{\sqrt{2 - 2Cos\left(\frac{2\pi N_t}{N}\right)}} \quad (11)$$

Then, from Equation 2:

$$R_b = R_2 \cdot Cos\ (\phi_2) \quad (12)$$

If it is possible to measure with balls of different radius, the value of R_b would be the average of the individual values obtained applying Equations 10–12 for each ball diameter.

Using the definition for K_1, it is possible to obtain ψ_b by:

$$\psi_b = Cos^{-1}\left(\frac{K_1}{R_b}\right) \quad (13)$$

It is well known that it is possible to manufacture a gear with a given pressure angle at a reference diameter using a hob with different pressure angle by properly pulling or pushing the hob during the manufacturing process. Based on this, it is possible to assign an arbitrary value to any one of the following properties and determine the rest of the parameters in the gear.

ϕ	Normal pressure angle
ϕt	Transverse pressure angle
ψ	Theoretical helix angle
R	Theoretical pitch radius
Pd_n	Normal diametral pitch
Pd_t	Transverse diametral pitch

The equations relating these parameters may be found in References 2 & 3. Six cases are possible, and the equations for each of them are listed in Table 2. Once these parameters have been defined, the tooth thickness may be calculated applying Equation 9 as:

$$T = R \cdot [K_2 - 2Inv(\phi_t)] \quad (14)$$

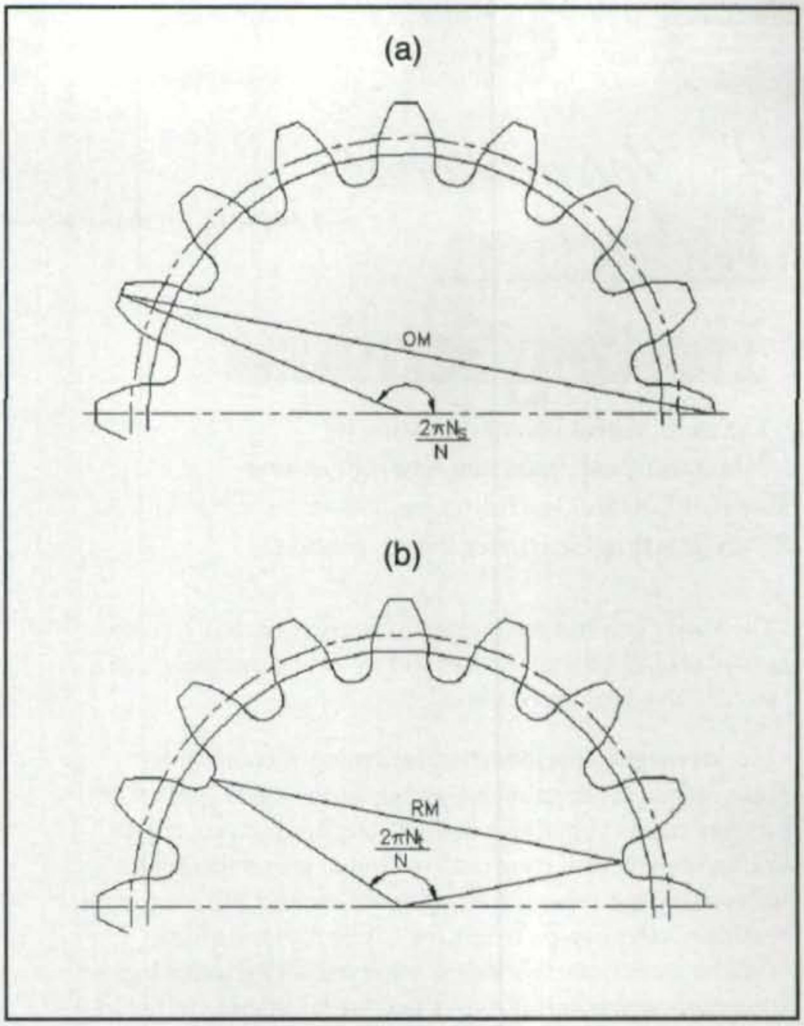

Fig. 4—Outside and root measurement for a gear with odd or missing teeth.

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2 Dudley, Darle W. "Dudley's Gear Handbook," McGraw-Hill, 1991.

3 American Gear Manufacturers Association. "ANSI/AGMA 2002-B88; Tooth Thickness Specification and Measurement," 1988.

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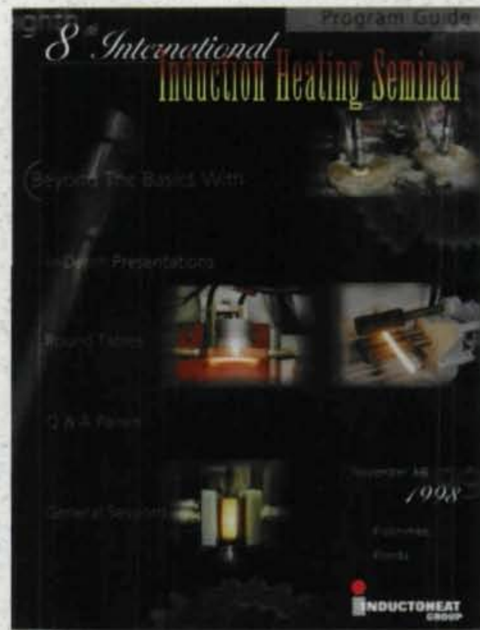

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Shop Floor Safety—Things to Think About

Charles M. Cooper

It should be a point of pride that the gear industry is actually safer than most other metalworking industries.

However, accidents do happen. A review of OSHA inspection reports for the gear manufacturing industry (SIC 3566) from January, 1990, through November, 1999, showed a total of 247 violations for which OSHA sought fines, including one fatality. These violations ranged from hazard communication and control of hazardous energy-lockout/tagout procedures at the high end (36 and 30 violations respectively) down to electrical training and arc welding and cutting procedures at the low end (1 violation each).

Because of the nature of the business, gear shops attract a higher caliber of skilled worker than other kinds of shops, and this goes a long way to creating a safe workplace. "From the shops that I have seen, they are very well set up," said John Coniglio, vice president of OSEA, the Occupational Safety and Environmental Association, Inc., an industrial safety consulting firm. "I find them in good order, neat and clean, with good accident records. If they have a problem, you normally see hand and finger injuries or eye injuries." These are things that the proper use of machine guards, lockout/tagout procedures and personal protective equipment used as part of a company-wide safety program can effectively prevent.

A safety program can do other things for your business as well. Such a program can improve your bottom line by lowering the costs associated with health insurance and worker's compensation; by raising employee morale and productivity; and by reducing the scope and occurrence of regulatory fines and penalties.

What elements go into such a program? Shop floor safety arises from a combination of factors, all of which you can control—environment, equipment, training and supervision. When these factors are in place and working together properly, your shop floor will be a safe and productive place to work.

Safety from the Top Down

Safety in the workplace does not begin with technology, but rather with the mindset, participation and leadership of management determined to make safety part of their company's corporate culture. This is important, because without support from the leadership, no safety initiative will last.

According to Coniglio, "Companies need to recognize, in a business sense, that safety is no more or less important than anything else that they do. They turn out a quality product. They turn out a product that's safe. They need to recognize that if they have good safety people, they do because the safety person is looking at the cost per hour and the cost of goods impact that safety and health have. The best resource they have is the people who work in the plant, and that resource needs to be protected because of the return on investment." Coniglio then explained that companies need people in safety positions who can tell the board of directors what the cost impact is, not only in terms of losses, but also in terms of productivity and product improvement. These factors all tie together to improve the company's bottom line. "The company that has an effective safety and health program," said Coniglio, "will absolutely be better off than their competitors."

It is the job of management to develop the overall safety strategy for the company and to provide adequate training to both workers and supervisors. This strategy should tell management how and when to use engineering or administrative controls to limit worker exposure to hazards. It should also tell workers and their supervisors where hazards exsist and how to implement these safety directives to abate them. The strategy should also include audits and surveys to allow management to track the success or failure of the program as well as a way for workers and supervisors to suggest changes and improvements.

Environment, equipment, training and supervision are the factors that come together on the shop floor to create a safe work environment, and the strategy ought to reflect that. These broad categories include many obvious things like machine guarding, goggles and gloves, proper electrical maintenance, clean and dry floors and air quality. They also include obscure things—temperature, ergonomics, noise, the way storage areas are set up, stress, violence—the list goes on. It is up to you to go through your plant and try to see it as an OSHA inspector would. Try to

"COMPANIES NEED TO RECOGNIZE, IN A BUSINESS SENSE, THAT SAFETY IS NO MORE OR LESS IMPORTANT THAN ANYTHING ELSE THAT THEY DO."

—JOHN CONIGLIO, V.P., OSEA.

see what kinds of hazards exist in your plant and figure out how to abate them.

Environmental Safety Issues

This covers your facility as a whole and includes air quality, temperature, noise, surface contamination, lighting, and building structures such as floors and stairs, railings, sprinkler systems and door signs. All of these factors must be taken into account, but a lot of it is just common sense. Floors must be kept clean and dry, walkways should be well marked and clear, and places where workers could fall should be guarded in some fashion. Any hazards in these areas should be either guarded or fixed. These guards and fixes don't have to be very complicated, either. It could be as simple as swapping out one kind of floor covering for another. "Sometimes the best results come from the simplest fixes." Coniglio says.

Other things to consider are that ladders should not be used where a permanent staircase would be appropriate, work areas should be well lit, sprinklers should function, exit doors should be well marked and open easily from the inside. Dealing with items such as these, which are covered under OSHA standards, would be a good start to any safety program. However, there are three shop floor environmental issues that should be looked at closely since they can have long term effects on your employees—fluids, temperature and noise.

"SOMETIMES THE BEST RESULTS COME FROM THE SIMPLEST FIXES"

— JOHN CONIGLIO
V.P., OSEA.

Metalworking/Machining Fluids. Chemical contamination is becoming a major issue for American industry and labor. According to OSHA, millions of workers building automobiles, farm equipment, aircraft, heavy machinery, and other equipment are exposed to machining fluids. Studies have shown that occupational exposure to these fluids has resulted in cancers of the esophagus, stomach, pancreas, colon, rectum and other sites; respiratory problems ranging from respiratory irritation and asthma to bronchitis, lipoid pneumonia and hypersensitivity pneumonitis; and skin problems including irritation and dermatitis. There is evidence of impaired health at levels well below the Permissible Exposure Limit (PEL) for oil mists (5 mg/m^3 time weighted average (TWA)) and the "nuisance dust" exposure limits applicable to all other machining fluids (15 mg/m^3 TWA for total particulate).

Because of this evidence, there are those in industry who do not believe these standards go far enough. "The United Auto Workers are involved in looking at worker exposure to oil mist in the air," said Coniglio. The UAW even had a hand in a 1992 report called "Health Effects of Exposure to Machining Fluids." According to the authors of the report, "Results from both the respiratory morbidity study and the mortality study suggest associations between machining fluid exposure and respiratory disease or cancer that are consistent with an interpretation of causality. Our initial dose-response analyses suggest that an exposure level of 0.5 mg/m^3 would minimize any adverse health effect of worker exposure to machining fluids." This study and others have led to calls from both labor and business for a lowering of PELs for metalworking and machining fluids.

Because of these acknowledged health dangers, OSHA has designated metalworking and machining fluids to be a priority for comprehensive rulemaking. The agency is in the process of working with businesses and labor to develop these rules. In the meantime, some of the immediate steps you can take today to lower the risk associated with these fluids include protective clothing and equipment, mechanical splash guards and enclosures, local exhaust ventilation, marking any hand tools used in contaminated areas to prevent chemical contamination from spreading, and a good program of preventative maintenance.

Ambient Noise. Noise in the workplace is another environmental hazard that should be addressed. In high-noise environments, hearing can deteriorate over time, beginning in the higher frequency ranges and progressing down into the low frequencies to deafness. OSHA regulations state that in work areas where the noise level is 85 dB(A) or above, hearing protection must be provided, but it is up to the worker to use it. At 90 dB(A) or higher, the use of such protection is mandatory.

Ambient noise issues can be addressed administratively or mechanically. Administrative controls can include restricting the amount of time a worker is exposed to the noise and/or mandating the use of personal protective equipment such as earplugs or muffs.

These devices carry noise reduction ratings (NR) that were developed by ANSI. The higher the rating, the more noise is muffled. Care should be taken to get the right NR rating for your work environment. For example, an NR rating of 6 or better is needed to cope with noise levels of 96 dB(A) or higher.

Mechanical methods of dealing with excessive noise include noise reducing baffles, compartmentalization, the use of noise reducing gears or the installation of rubber pads underneath machinery.

Heat. Temperature can be a problem when it leads to heat stress, a term that covers such disorders as heat stroke, which can lead to brain damage; heat exhaustion, which includes such symptoms as extreme weakness, fatigue, dizziness, nausea, headache, vomiting or unconsciousness; heat cramps, painful muscle spasms due to salt loss from sweating; fainting; or transient heat fatigue, which is a temporary state of discomfort and mental strain caused by prolonged exposure to heat.

Heat stress can be dealt with in a number of ways. Minimizing the heat within the workplace is one of the best ways to do this; however, there are circumstances where that is simply not practical. Giving workers time to gradually adjust to the heat, or lessening the amount of work and exposure by allowing adequate rest periods are other ways to fight heat stress.

You can also isolate the worker from the heat source by mechanizing some or all of the work procedures or providing heat shielding and ventilation. Protective clothing is also useful; however, it is necessary to know if the clothing will interfere with sweat evaporation.

Equipment

This is another broad category that covers a variety of items ranging from machine tools to fire extinguishers to ladders to personal protective equipment (PPE) such as hard hats, work gloves and boots. While fire extinguishers and ladders are among the many things looked at in an OSHA inspection, it is with machine tool safety and personal protective devices that most people on the shop floor are concerned.

Machine Guarding. This refers to the mechanical means by which a worker is protected from the actions of the machine tool he is operating. The subject is covered in some depth in Subpart O of 29 CFR of the OSHA regulations. According to Part 212 of the regulations: "One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks." The regulations require that manufacturers and owners of machine tools prevent you from putting your hand—or any other part of your body—where it might be injured or removed while the machine is in operation. Often, however, in shops where safety is not a big part of the corporate culture, these safeguards are bypassed or disabled.

"A company puts a light curtain on a machine because someone says they have to have a guard on that," said Coniglio. "They spend three-, four- or even five-thousand dollars to have it there. It looks good, but because it is, in somebody's mind, hindering their operations, instead of figuring it out, they just defeat the light curtain and take a chance. It's out of sight, out of mind. They say 'this guy knows how to do it, I'll just sit back and not look at it and hope nothing happens.' That's the reality of the situation."

That is what happened at a major Illinois heavy vehicle and equipment manufacturer. Following a 1993 inspection of their facility, the Secretary of Labor cited the company with two violations of OSHA's machine guarding standard, one as willful and one as serious. A willful violation is one where the company has been cited before and has not abated the hazard, while a serious violation is a new one that could result in serious injury or death. In the case of the willful violation, workers were bypassing the guards on a 700-ton LVD hydraulic press. Employees were in the habit of disabling the light curtain, reaching into the machine's work area and manipulating the workpieces while the press was in operation. The second citation dealt with workers being able to load workpieces into a track press while the machine was indexing. This created a hazard by permitting workers to put their hands in the machine's work area while the machine was in operation.

By the time of the final hearing on the matter, this second hazard had been abated. These two violations cost this company $22,000 in penalties and could have cost a machinist his hand, arm or life.

Lock-out/Tag-out. Sometimes it is necessary for an operator or some other trained individual to bypass the guards and get into the machine, usually when the machine needs to be serviced. When this happens, it is necessary to control the hazardous energy of the machine. This energy—mechanical, electrical, thermal, hydraulic, pneumatic, gravitational or chemical—can come from a variety of sources depending on the design and function of the machine. The key to controlling this energy is to properly shut down and fully deenergize the machine in question and to make sure that it stays that way until it can be returned to service. This is the purpose of a lockout/tagout program.

Once it has been determined that a machine should be locked or tagged out, all of the employees affected by this decision should be notified that the machine will be offline. This is followed by a normal shutdown of the machine. All of the controls and valves should then be placed in their off or closed positions. Place the lockout/tagout device, such as a breaker lock, hasp, chain or valve cover so that the controls cannot be accessed. Now, release any stored energy from capacitors, springs, raised parts, rotating flywheels and hydraulic, air, gas or steam systems. This energy has to be released or restrained by grounding or repositioning. This is done blocking or bleeding the system. Verify that the equipment has been locked or tagged out and that it has been successfully isolated and de-energized by trying a normal startup. If this startup fails, you may now proceed with the work.

When you are done, inspect the work area for parts, tools, missing guards and make sure that the equipment is ready to operate. Clear the area and make sure everyone knows the machine is going to be restarted. Remove the locks and tags, and restart the machine.

The primary elements of a lockout/tagout program include documenting the program itself and developing procedures for each machine in the inventory, employee training and the distribution of standardized locks and tags to authorized personnel (the only employees permitted to lock or tagout a machine). These locks and tags should be dedicated to the lockout/tagout program, and they should identify the employee to whom they were issued. Only the person who placed the lock should be allowed to remove it.

Personal Protective Equipment (PPE). These are devices worn by the worker to protect him from hazards specific to the job he is doing when engineering controls such as machine guards are not practical or applicable. Depending on the job and the circumstances, these devices can include hard hats, eye protection, ear protection, boots and gloves, respirators, cool suits, and more. When it has been determined that the use of personal protective equipment is required, it should be provided by the company.

According to OSHA Section 1910.132 general requirements, the employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall:

- Select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified in the hazard assessment.
- Communicate selection decisions to each affected employee.
- Select protective equipment that properly fits each affected employee.

In the general requirements, OSHA mentions four basic areas of personal protection—head, face/eye, hand and foot.

Head protection ranges from lightweight, minimally protective bump caps or skull guards, to various classes of helmets, which provide impact and penetration resistance. Class A and B helmets also offer protection from electricity. Class C helmets do not. Where falling object hazards are present, or if working on exposed, energized conductors, the appropriate helmet must be worn.

Face and eye protection includes a variety of spectacles, goggles, face shields and welding shields. The choice is based on the nature of the hazard being faced (see tables).

Hand protection is needed when the worker's hands may be exposed to chemicals and other toxic substances, fire, extreme temperatures, cuts or lacerations, punctures or abrasions. There are gloves available that can protect against multiple hazards. However, a single type of glove cannot protect against all hazards. These hazards are classified under four broad categories: chemicals, abrasions, cutting and heat.

With chemicals, the chief concerns are chemical burns and the absorption of toxic substances through the skin. These can be minimized by using gloves made for this type of work, rinsing them before carefully removing them after use, and replacing them regularly. Replacement is very important because all glove materials are eventually penetrated by chemicals. The rate of replacement is based on the application, the frequency of contact with the chemicals and the glove material.

Abrasion, heat (and cold), and cutting hazards also require the proper type of glove. They should be insulated for temperature extremes and made of tough, resilient materials to protect the hands from cuts, punctures and abrasions when handling sharp or rough objects.

One place where gloves are not recommended is around moving machinery, since the glove can actually make it easier for a worker's hand to be caught and injured. Here, protection is to be supplied by machine guards and lockout/tagout procedures.

Foot protection is necessary when workers are in areas where their feet are exposed to falling, rolling, piercing or electrical hazards.

Safety shoes and boots are built to offer both impact and crush protection. Some also provide puncture protection as well while others offer electrical protection. The type of safety shoe or boot you need is based on the type of work you will be doing (see table).

PPE Training. OSHA rules also cover training standards for workers learning to use personal protective equipment. This includes new hires as well as established employees. According to Section 1910.132, employers are to train any employee whose job requires the use of personal

TABLE 1—FACE AND EYE PROTECTION BY HAZARD. SOURCE: OSHA.

SOURCE	HAZARD	PROTECTION
IMPACT—Chipping, grinding machining, masonry work, woodworking, sawing, drilling, chiseling, powered fastening, riveting, and sanding.	Flying fragments, objects, large chips, particles, sand, dirt, etc.	Spectacles with side protection, goggles, face shields. For severe exposure, use face shield.
HEAT—Furnace operations, pouring, casting, hot dipping, and welding.	Hot sparks, splash from molten metals, high temperatures.	Face shields, goggles, spectacles with side protection. For severe exposure use face shield. For splash from molten metals, use a face shield worn over goggles. For high temperature exposure, use screen face shields or reflective face shields.
CHEMICALS—Acid and chemicals handling, degreasing, plating.	Splash	Goggles, eyecup and cover types. For severe exposure, use face shield. For irritating mists, use special-purpose goggles.

TABLE 2—FACE AND EYE PROTECTION FOR LIGHT AND RADIATION HAZARDS. SOURCE: OSHA.

Welding: Electric arc	Optical radiation	Welding helmets or welding shields. Typical shades: 10-14.
Welding: Gas	Optical radiation	Welding goggles or welding face shield. Typical shades: • gas welding 4-8 • cutting 3-6, • brazing 3-4
Cutting, Torch brazing, Torch soldering	Optical radiation	Spectacles or welding face-shield. Typical shades: 1.5-3.
Glare	Poor vision	Spectacles with shaded or special-purpose lenses, as suitable.

TABLE 3—FOOT PROTECTION BY HAZARD. SOURCE: OSHA.

TYPE OF PROTECTION	HAZARD
Impact Protection	Carrying or handling materials such as parts or heavy tools, which could be dropped, and for other activities where objects might fall on the feet.
Crush Protection	Activities involving skid trucks, bulk rolls, heavy pipes or any heavy objects that could roll over a worker's feet.
Puncture Protection	Anywhere sharp objects such as metal scraps, nails, wire, etc. could be stepped on.

TO LEARN MORE

There are a number of places where employers and employees can go to learn more about workplace safety and health. Here are a few:

U.S. Government
ANSI American National Standards Institute
11 West 42nd Street , New York, New York 10036
Phone: (212) 642-4900, Fax: (212) 398-0023

FEMA Federal Emergency Management Agency
500 C Street, SW , Washington, D.C. 20472

NCIPC National Center for Injury Prevention and Control
Mailstop K65, 4770 Buford Highway NE, Atlanta, GA 30341-3724
Phone: (770) 488-1506, Email: *OHCINFO@cdc.gov*

NIOSH National Institute for Occupational Safety and Health
Hubert H. Humphrey Bldg., 200 Independence Ave., SW , Room 715H
Washington, DC 20201
Phone: (202) 401-6997
CDC Emergency Response Phone Number: (770) 488-7100
NIOSH Technical Inquiries 1-800-35-NIOSH (1-800-356-4674).

OSHA U.S. Department of Labor Occupational Safety & Health Administration
Office of Public Affairs - Room N3647
200 Constitution Avenue , Washington, D.C. 20210
Phone: (202) 693-1999
If you have an EMERGENCY and need to report a *fatality* or *imminent life threat* contact 1-800-321-OSHA (6742) immediately.

Associations
American Board of Industrial Hygiene
6015 West St. Joseph, Suite 102 , Lansing, MI 48917-3980
Phone: (517) 321-2638, FAX: (517) 321-4624 , E-mail: *abih@abih.org*

The American Society of Safety Engineers Customer Service
1800 E Oakton St, Des Plaines, IL 60018
e-mail: *customerservice@asse.org*,
Phone: (847) 699-2929 between 8:30 to 5:00 CST
Fax: (847) 768-3434 24 Hours

ONLINE RESOURCES

www.abih.org
This is the Web site of the American Board of Industrial Hygiene. Offers industrial health and safety-related information as well as information about the Board's programs.

www.asse.org
The Web site of the American Society of Safety Engineers. Contains safety-related information as well as information on the Society, its aims and its programs.

www.cdc.gov/ncipc/ncicphm.htm
This is the official Web site for the National Center for Injury Prevention and Control. It contains information and statistics on injuries ranging from unintentional home accidents to workplace injuries to criminal violence.

www.niosh.gov
This is the official Web site for the National Institute for Occupational Safety and Health. It contains information on health and safety issues affecting American workers.

www.osha.gov
This is the official Web site for OSHA, containing information on standards, procedures, statistics (including findings on individual companies) and much more.

www.safetyinfo.com
This site is one of the most comprehensive safety resources available. It is a free service and is owned by:
Safety Engineering, PO Box 477,Blount Avenue, Guntersville, Alabama, 35976
Phone: (256) 583-6321

protective equipment in the use of that equipment. That includes learning when PPE is to be used and what kind is necessary, how to properly put on, remove, adjust, and wear the equipment, its care and maintenance, the limitations of the equipment, its useful life and proper disposal. The trainee must be able to demonstrate that he understands these elements before being allowed to do work that would require the use of PPE.

Under the rules, those who cannot demonstrate such an understanding are to be retrained. Some of the circumstances where retraining is necessary include:

- Changes in the workplace render previous training obsolete.
- Changes in the types of PPE to be used render previous training obsolete.
- Inadequacies in an affected employee's knowledge or use of assigned PPE indicate that the employee has not retained the requisite understanding or skill.

Finally, the employer is to verify the training through a written certification, which should contain the name of each employee trained, the date(s) of training, and the subject of the certification.

The Role of the Supervisor

Once the program is in place, the engineering and administrative controls are working and the people on the floor are trained, then it is up to the supervisors to make sure that things go smoothly and according to plan. Like management, the supervisors are responsible for following all safety program requirements and making sure that their charges on the shop floor do likewise. Would that company in Illinois have received the penalties it did if a supervisor had caught and corrected the press operator's mistake? Probably not.

OSHA has drawn up its own safety and health program, in which they have delineated the responsibilities of supervisory personnel.

According to the OSHA plan, the supervisor will be responsible for enforcing safety and health rules, regulations and standards. Supervisors are to instruct employees in safe practices and methods of operation and give full support to the Occupational Safety and Health Program. They are to conduct regular safety and health inspections, correct whatever unsafe and unhealthful conditions and practices are noted, obtain medical attention for injured or ill employees, and encourage and promote employee suggestions on how to improve safety and health. Finally, supervisors are to work with the Safety Officer in investigating accidents, completing appropriate compensation and accident prevention forms and submitting them through proper channels on a timely basis.

The roles assigned by OSHA to its own supervisory personnel are not too different from similar roles in companies across the country. All recognize that the supervisor is management's eyes and ears on the shop floor in many ways and for many initiatives, safety included. ○

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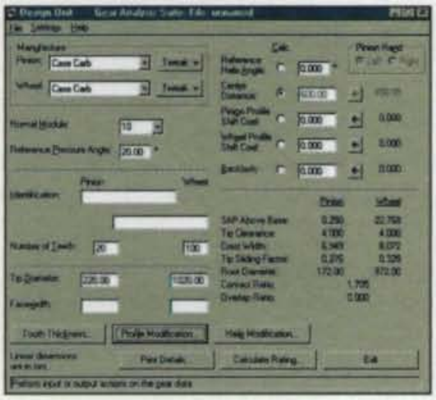
Software Bits

Our New Products Special Edition



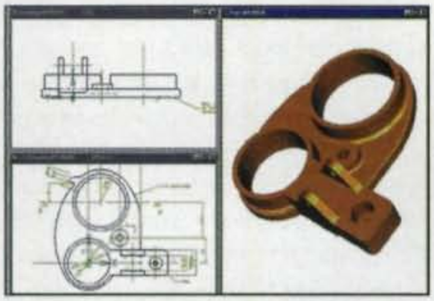
Gear Design and Details Software

The Newcastle design unit (DU)/Gear Research Foundation's (GRF) Gear Analysis Suite has been created to provide designers and specifiers of spur and helical involute gearing the latest in gear design standards. The Gear Rating module, used for the calculation of gear tooth contact and bending stresses in accordance with the procedures specified in BS/ISO 6336, was tested by the ISO 6336 Project Committee of the GRF. It is based on the format used for the popular DU436 software suite. The Gear Details module, for drawing data in accordance with the British Gear Association's Codes of Practice, is an improved and updated version of a widely used software package. Both sections are Y2K compliant. Together, the two modules allow:

- Gear design data to be saved and retrieved.
- Standard gear design and manufacturing information to be saved and retrieved.
- Input data that causes out of limits outputs to be flagged.
- Easy access to a QuickHelp menu at every stage, and on each data entry box and button.
- Specification of internal gear wheels and epicyclic (planetary) configurations.
- Specification of profile modifications such as crowning and tip/root relief.
- Detailed data output.

These modules are available separately or together. GRF and BGA members are eligible for substantial discounts when purchasing the Ratings section. For further information on the Gear Rating module and Gear Details module, log on to *www.staff.ncl.ac.uk/e.j.myers*.

Circle 300

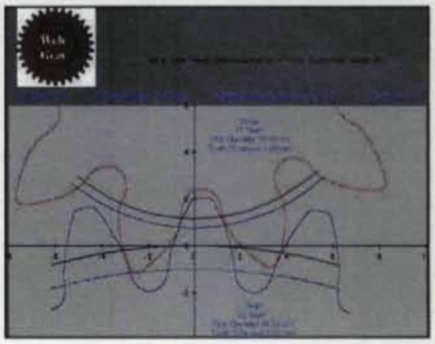


3D Designs for 2D AutoCAD Users with Helix Capture

Microcadam, Inc., announces the release of Helix Capture, a new option for Helix Design System mainstream CAD/CAM software that enables design engineers to create solid models based on 2D AutoCAD drawings. "Helix Capture is the fastest way to bring 2D users into the world of solid modeling with all its downstream benefits," said David J. Arens, director of product marketing for Microcadam. The vast majority of CAD data is stored in 2D AutoCAD drawing archives, representing a huge investment in time and resources. "Helix Capture releases this stored equity, allowing AutoCAD users to produce 3D designs in as little as five minutes."

Starting with the AutoCAD program, users are simply prompted to select views for 3D generation. These views are automatically transferred into Helix Modeling, which creates solid models using powerful AutoSOLID™ and Gen3D™ functions. AutoSOLID uses intelligent algorithms to build models from geometric information in the 2D drawing. If cross-view inconsistencies are detected, Gen3D takes over to complete the model. In some cases, a model can be completed manually. "It's a win-win for the 2D user," says Arens. "Helix Capture not only creates a solid model for you, but also checks drawing accuracy. For additional information log on to *www.helixcapture.com*.

Circle 301



Web Gear

Web Gear is a gear design software package for use with Microsoft Excel that offers full geometric mesh analysis, plotted mesh views, quick design analysis and immediate calculation results, easy variable input and hard copy output of your data. Three packages are available: spur gears, helical meshes (crossed axis helical and worm gears) and internal meshes.

For more information and demos contact *rei@golden.net* or log on to *http://homepages.msn.com/corporateway/webgearsoftware/webgear.htm*.

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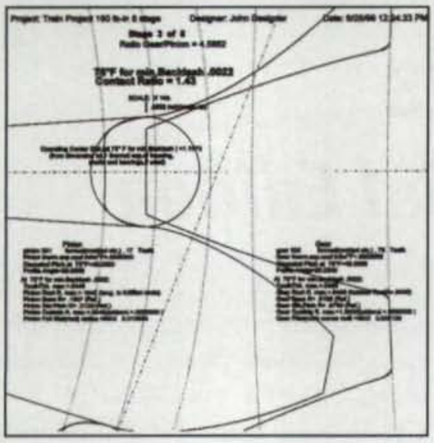


GearDyn: Gear Dynamic Analysis Program

Originally developed by NASA, GearDyn, from Partners in Scientific Computing, Inc., is a powerful analytical tool that can aid you in designing gears with lower dynamic loads and reduced noise without requiring the purchase of either software or hardware. All you need is a pentium class PC and access to the Internet.

GearDyn can determine detailed geometry, dynamic loads, Hertz and bending stresses and surface damage factors. The software can also analyze a variety of epicyclic and single mesh systems with spur or helical gear teeth including external, internal, buttress tooth forms and high contact ratio gears. GearDyn allows the designer to input various types and amounts of profile modifications, crowning and tooth spacing errors and determines the effect they have on the dynamic loads. GearDyn also gives you options for flexible carrier, flexible ring gear, floating sun gear, a natural frequency option and a finite element compliance analysis for helical gear teeth. It also provides for synchronous or phased meshing for epicyclic or star systems.

GearDyn generates tabular data and plots for dynamic loads for each mesh in the system. You will be able to generate dynamic Hertz and bending stresses, flash temperature, pressure velocity, natural frequencies and spectral analysis. Log on to *www.pscico.com* for more information.

Circle 303

GearTrax

Camnetics' GearTrax for SolidWorks 99 allows you to create all types of gears and sprockets inside SolidWorks. Your gears will be created to industry standards with true involute tooth profiles. Some of the features available include worm, bevel, internal and external spur and helical gears; timing belt/V-belt pulleys and chain sprockets; precise specification of backlash or tooth clearance, auto-draw hubs, bores and keyseats; set screw holes and customized diametral pitch and pressure angle. GearTrax's three modeling options are: create a tooth profile using straight line segments, create a three-segment tooth for "Quick Draws," and create a true involute tooth profile.

Log on to *www.camnetics.com* for more information, to download the full version for a free trial, or to request a CD that also contains drawings of racks, belts and tapered bushings with nearly 500 different bore configurations.

Circle 304

cymex Software Sizes and Selects Servo Motors and Gear Reducers

cymex (Cyber Motion Explorer) software from alpha gear drives, Inc., simplifies servo system design and analysis, allowing engineers to more accurately design and specify high-performance systems in less time and at a lower cost.

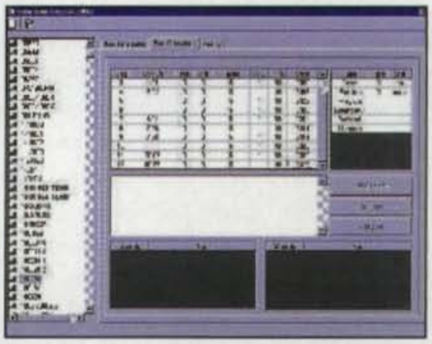
cymex has a Windows-type graphical interface that guides the user through the program in a simple, intuitive manner, allowing the user to define path/time, path/speed and time/speed in any combination or sequence. Using this data, the software calculates the complete motion profile of the system including component inertia based on object type, dimensions and distance from the axis of rotation.

cymex also incorporates the gearbox into the servo system calculations. All the specifications needed to select a suitable motor and gear reducer for an application are stored in the database. Tables and graphics in the program help the user select a gear reducer with the correct properties.

Once the optimum design has been finalized, cymex will list geometrically equivalent motors and automatically select the correct adapter plate and bushing. It can also print out relevant data sheets, output a DXF file that can be imported into drawings and generate orders with the correct part numbers and order codes. If a gear reducer from alpha gear drives is selected, cymex can also print maintenance, mounting and operating information. After calculations are performed, the system configuration can be stored for use in later projects.

For more information on cymex (Cyber Motion Explorer) servo design software, call alpha at 847-439-0700.

Circle 305



ShopWerks—From Purchase Order to Packing Slip

Team Research has introduced ShopWerks, a complete manufacturing management system that runs production and order processing more efficiently, while maximizing net profit and return-on-investment with real-time, activity-based cost accounting.

ShopWerks determines profitability job-by-job, eliminating guesswork by calculating the actual cost of materials, machines and labor. It automatically tracks labor, machine and material use, rewarding productive workers for multitasking by automatically splitting work time between the jobs, painting a more precise picture of real labor costs. The software also complements accurate cost accounting and automated data recording by providing optimized, load-balanced production scheduling with a visual, calendar-type interface. The program offers four configurable build strategies: by sales order, economical build quantity, calendar period or number of days.

ShopWerks also streamlines interdepartmental communication. Online, up-to-date information, such as production scheduling, is freely available on the network. Also, ShopWerks provides sales staff with the timely, accurate information they need to close sales and groom customers for repeat sales. Sales people can now pull up orders, look at parts and view the production schedule right from their desktops.

For additional information about ShopWerks, call (800) 619-2055 or visit their Web site at *www.teamresearch.com*.

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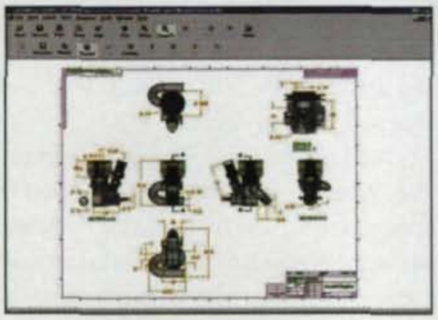


SolidWorks Announces eDrawings

eDrawings is a new type of compressed electronic drawing file that enables users to create, view, send and receive mechanical design drawings via e-mail. Each eDrawings file includes a self-contained viewer, enabling recipients to start using the drawing information immediately. The eDrawings Publisher is available for existing users of SolidWorks, AutoCAD and any other CAD system outputting a DXF or DWG file.

eDrawings break down the communication, software incompatibility and drawing interpretation barriers by allowing engineers and designers to easily create compressed electronic drawings and e-mail them to anyone. In addition, the small file size enables fast delivery of eDrawings.

For information, contact SolidWorks 800-693-9000 or visit their Web site at *www.solidworks.com.*

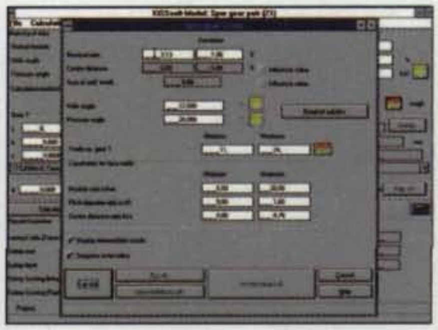
Circle 307

Easy 5

Easy 5 is a family of software tools used to model, simulate and analyze dynamic systems containing hydraulic, pneumatic, mechanical, thermal, electrical and digital subsystems. Developed by Boeing, Easy 5 is a commercial product sold and used world wide.

Easy 5 software includes a complete set of control system modeling, analysis and design features. Systems are quickly modeled with functional blocks (summers, dividers, wave generators, integrators, etc.) and/or with predefined components representing physical elements (pumps, gears, engines, etc.), as well as user-defined FORTRAN or C. If required, a virtual prototype of an entire system can be constructed via links to other CAE software used for multibody and structural dynamics, controls, controller code generation, integrated circuit design and others. Source code is automatically generated to support real-time simulation. For more information, log on to *www.boeing.com/assocproducts/easy5.*

Circle 308



KISSsoft

KISSsoft has been developed for engineers and design engineers. It is interactive software for the layout, calculation and optimizing of machine and joining elements, shafts, axles, bearings, gears and gearwheels. The software calculates according to standards (ISO, DIN, VDI, AGMA, etc.) and accepted standard literature.

The software was developed to meet the data retention standards of the ISO-9000 quality system and it is constantly being updated and adjusted to the latest calculation methods. Designed with the user in mind by Kissling, a Swiss precision gear manufacturer, KISSsoft is easy to use with just a few hours of training. Also, it has many interfaces to CAD and NC programs, making it an important part of the CAD-CAE-CAM chain. For more information contact KISSsoft at +41-1-308-97-77 or send e-mail to *info@KISSsoft.ch.*

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If you found this article of interest and/or useful, please circle **222**.

ZF Builds New Tech Center, Finalizes Joint Venture with Meritor

ZF Friedrichshafen AG, a leading global manufacturer of driveline, steering and axle systems, has established a new 152,000 sq. ft. corporate engineering technical center on a 10-acre site in Northville Township, a western suburb of Detroit, MI. The new center further strengthens the company's commitment to the North American market and will support its line of automotive products.

The new center, with 95,000 sq. ft. of office space and 57,000 sq. ft. of prototype building and testing space, will be home to more than 200 technical, engineering and sales personnel. It will provide state-of-the-art technical capabilities that will support the development and testing of new products as well as adaptation of existing ZF products for the North American markets. The new center will be ready for occupancy by July, 2000.

ZF has also announced a joint venture with Meritor Automotive Inc., forming ZF Meritor LLC. The new company, based in Laurinburg, NC, will produce technologically advanced medium- and heavy-duty transmission components and systems for original equipment manufacturers and the aftermarket in the United States, Canada and Mexico. ZF Meritor LLC will begin operations immediately.

According to Meritor chairman and CEO, Larry Yost, "Meritor's joint venture with ZF supports our long term business strategy to provide our customers with new and technologically advanced products. This partnership also supports Meritor's aim to lead in the markets we serve, increase our customer base and achieve our global growth goals."

Richard Martello will serve as president of ZF Meritor LLC. He was previously general manager of Meritor's transmission, clutch and driveline business.

Philadelphia Gear Signs Record Contract

Philadelphia Gear Corporation has reached an agreement with FastShip, Inc. to supply sophisticated transmission equipment for the company's high-speed transatlantic fleet. The $35 million order is the largest in Philadelphia Gear's 100-year history and will bring more than 100 jobs to the area.

Philadelphia Gear will supply 20 gearboxes—five in each of FastShip's initial four vessels—plus one spare gearbox as well as additional parts and a 10-year service and maintenance package. These components will help generate power for these vessels that is 2.5 times that of a jumbo jet.

"Our contract with FastShip further establishes us as a global competitor in the supply of high-tech power transmission equipment," said Gerry Rooney, president of Phildelphia Gear Corp. "Our aggressive investment in new technology and equipment, as well as our efficiency guarantee, positions us perfectly to thoroughly serve FastShip's cutting-edge transmission needs."

The contract means 100 jobs for Philadelphia Gear and its vendors, including securing or adding 70 full-time jobs over the next two years at Philadelphia Gear's King of Prussia, PA, facility.

Bison Names Kopp Continuous Improvement Manager


Marty Kopp

Marty Kopp has been named continuous improvement manager at Bison Gear and Engineering, St. Charles, IL. This is a new position. Kopp, who joined Bison in 1996, was most recently TQM facilitator for the manufacturer of fractional horsepower gearmotors, motors and reducers for the global market. According to George Thomas, vice president of operations, "A commitment to improve our products and processes is inherent in maintaining Bison leadership."

Kopp will now be responsible for total quality management, coordinating Bison's program for ISO-9000 certification, overall management of all Bison service and repair operations, and joint programming with the Bison Engineering department on the assembly area auditing process, to work towards error-free, zero-defect performance. Prior to joining Bison, Kopp was at Argonne National Laboratories.

New Venture Gear Expands

New Venture Gear, a joint venture between DaimlerChrysler AG and General Motors Corp., will expand its East Syracuse, NY, New Process Gear plant by 100,000 square feet, creating 300 new jobs. This 20% increase in capacity will allow the company to increase its production of 4-wheel drive transfer cases to about 500,000 per year.

Sport utility and pickup truck vehicles continue to sell at record volumes," said New Venture president and CEO Fred Hubacker. "This plant expansion gives New Process Gear the ability to meet our commitment to our customers for transfer case production."

Inductoheat Promotes Director of Engineering


Randy Minnick

Inductoheat, Inc., Mass Heating Division in Ray Township, MI, has promoted Randy Minnick to the position of director of engineering. His previous position was engineering manager. Minnick has been with Inductoheat for six years and holds a BSME from Saginaw Valley State University.

Mitsubishi Appoints New Senior VP of Sales and Marketing


Thomas D. Poyser

Mitsubishi Machine Tools has appointed Thomas D. Poyser senior vice president of sales and marketing for North America. Prior to coming to Mitsubishi, Poyser held both general and sales management positions at Westinghouse Electric Corp. and Hurco Companies, Inc. He has a BSEE from Purdue University and an MBA from Indiana University. Poyser assumes the duties formerly held by the recently retired Donald Chabot.

Mitsubishi Opens New Headquarters and Hob Recoating Facility

Mitsubishi Machine Tools has moved its headquarters from the company's former location in Itasca, Illinois, to a larger facility in neighboring Addison. The new address, 1250 Greenbriar Drive, will house both corporate offices and a production area, and cover 38,250 sq. ft.—14,000 sq. ft. larger than the Itasca site. The new facility will house a showroom for Mitsubishi products, as well as a one-of-a-kind facility dedicated to the restripping, resharpening and recoating of hobs used in high precision gear production, representative of Mitsubishi's large investment in cutting technology.

The strategic placement of a recoating facility in the Midwest is expected to increase the sales of gear cutting tools by providing an economical alternative to shipping hobs overseas for recoating.

ASME and SME Mutually Cease Merger Exploration

The American Society of Mechanical Engineers (ASME International) and the Society of Manufacturing Engineers (SME) have mutually ceased exploration of a possible merger.

ASME International President Robert E. Nickell and SME President Cecil W. Schneider, in jointly making this announcement, observed that the investigation phase was conducted in an extremely positive and professional manner and involved many volunteer and staff members from both organizations.

These two societies will continue as separate organizations, and where possible, will continue to conduct joint activities and look for additional opportunities to work together in the future.

Balzers Announces New Tech Development Center

Balzers Tool Coating, Inc., a leader in thin-film tool and precision component coatings, has opened a new technical development center in Amherst, NY, adjacent to Balzers' existing coating center. The new center was built to develop new coatings and evaluate cutting-edge technologies that will solve a variety of customer needs.

"Our customers are the true beneficiaries of this expansion," stated Balzers president Peter Bjorkman. "Not only are we increasing physically, but we are expanding our advanced technology problem solving, our customer service and our ability to interface with larger corporate customers."

The new technical center will house an expanding staff of engineers, including a number of rotating resident scientists from Balzers facilities around the world and from the company headquarters in Liechtenstein. The facility also incorporates the Balzers Knowledge Management Center, which provides resources and technologies for Balzers technicians worldwide to help them service their customers' specific coating requirements.

Tell Us What You Think . . .
If you found this article of interest and/or useful, please circle **221**.

UNBEATABLY FAST

Höfler's HELIX gear profile grinders, the most economical way to grind gears. HELIX 400 for 16" diameter and DP 50-2.5. HELIX 700 for 28" diameter and DP 25-1.6. Now introducing the completely new RAPID 1000 profile grinder for gears up to 40" in diameter.

For more information fax to 011(49)7243-599-165.

CIRCLE READER SERVICE #147

INDUCTION FIXTURES

The LR-PAK data sheet describes induction lift rotate fixtures useful for heat treating parts such as transmission O.D. races, I.D. cams, hubs, spindles, C.V. joints and gears. LR-PAKs are completely assembled and interconnected.

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Warren, OH 44482
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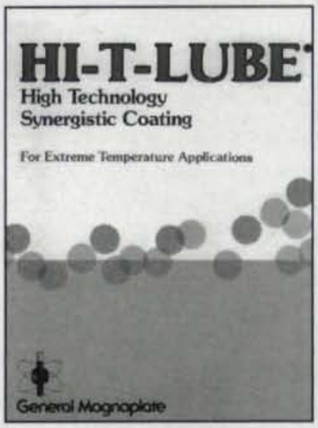

WORLD'S SLIPPERIEST SOLID LUBRICANT PREVENTS WEAR

HI-T-LUBE® dry-film lubricant solves wear, galling and fretting problems for gears, bearings and other metal parts, even at high and low operating temperatures. Works under high compression loads, in a vacuum and in high radiation environments.

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AUSTEMPERING IMPROVES MATERIAL TOUGHNESS

Our 8-page brochure is an information-packed guide to the Austempering process, a high performance heat treatment for ductile iron, gray iron, and steel for improved toughness, wear resistance, and fatigue strength. Learn how to boost product performance, and reduce costs.

Call Applied Process, Inc.,
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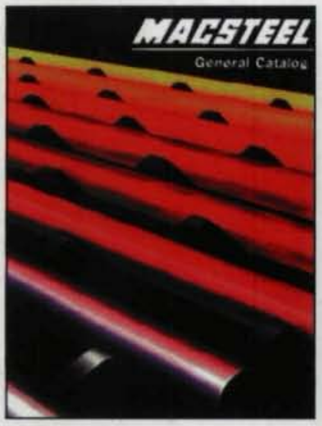

MACSTEEL® – ENGINEERED CARBON AND ALLOY STEEL BARS

A new full color catalog details the complete products and processes of MACSTEEL®, including specialty bar products like MACGOLD®, MACPLUS®, NITROSTEEL®, NITRO100® and specialized heat treated bars and tubes. Domestic and international specification tables are also provided.

Visit *www.macsteel.com*
or call 800-876-7833.

CIRCLE READER SERVICE #137

GLEASON PFAUTER HURTH CUTTING TOOLS CORPORATION

A full color brochure showing the product capabilities of our Loves Park, Illinois facility. We manufacture high-speed steel and carbide hobs, shaper cutters, form cutters, CBN wheels and thin film coatings. Heat-treat, resharpening and recoating services are available.

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Telephone 815-877-8900
E-mail: *sales@gphct.com*

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METRIC GEARS

NEW 456–page catalog features technical specs for over 3400 standardized metric gear components: spur, helical and internal gears, straight and helical racks, straight and spiral bevel gears, worm and worm gears, and more in modules 0.5-10.

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New Hyde Park, NY 11042
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WEB: http://www.qtcgears.com

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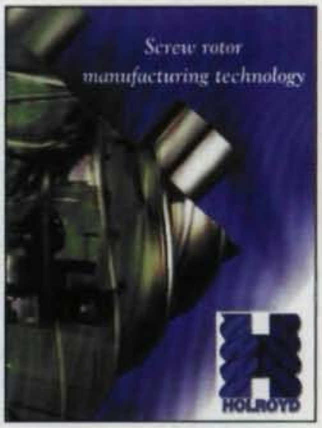

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Holroyd is the world leader in the production of the most comprehensive range of machines to produce profiles on screw compressor rotors for every application, ensuring production of first class quality components at competitive prices.

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LITERATURE MART

GLEASON PFAUTER HURTH INTRODUCES THE GP SERIES:

a new line of gear hobbers, shapers and grinders that share a "common platform" and use standard modules to greatly simplify the traditional processes of machine design, assembly and maintenance. They're designed to take advantage of the latest tool technologies available—wet or dry. Call us at (815) 877-8900 to request this brochure.

CIRCLE READER SERVICE #148

WRITER'S GUIDELINES

Learn what it takes to be a *Gear Technology* author. Earn the respect and admiration of your peers as you enhance the technical credibility of your company. Send for our free writer's guidelines or visit *www.geartechnology.com* to download a copy from our Web site.

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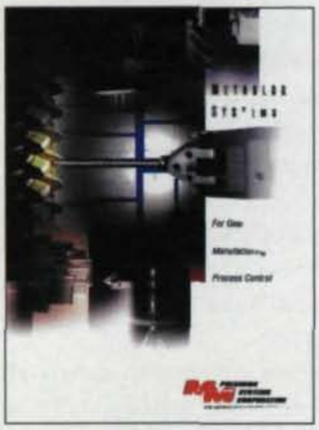

METROLOGY SYSTEMS

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

CIRCLE READER SERVICE #169

SELL GEARS ONLINE

The Power Transmission Home Page™ is the Web's leading directory of power transmission manufacturers and suppliers. Hundreds of buyers visit ***www.powertransmission.com*** each day to find the right manufacturers for their jobs. Call (847) 437-6604 to find out how inexpensive and effective Internet marketing can be. Mention this ad and receive a FREE bonus page of advertising with your order!

CIRCLE READER SERVICE #230

CLARIFICATION

Some of our readers have expressed confusion over our article "CMM and the Gear Industry," which appeared in the November/December 1999 issue. Although this article was about coordinate measuring machines, it was not our intention to slight the capabilities of generative gear testers. It should be understood that generative gear testers can also measure bevel gears, and that the machines of most major manufacturers perform measurements according to AGMA, DIN and ISO standards. In addition, many generative gear testers also possess coordinate measuring capabilities.

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

Bison Servo Duty Reducers

Bison Gear and Engineering has introduced a new line of servo duty gear reducers for stepper and brushless DC motors in precision applications. The new Bison reducers, the MultiTech series, are designed to be used with NEMA 23 and 34 mounts. A one-piece pinion mounts easily onto the motor shaft. The gear cases are permanently lubricated and the gear boxes can be used with the motor of the customer's choice.

Bison offers eight ratios in each frame size, ranging from 3:1 to 100:1. Torque ratings range from 40 to 399 in-lbs., with peak torque capacities up to 798 in-lbs. Backlash specifications are held to less than one degree.

For further information log on to Bison's Web site at *www.bisongear.com* or call Bison at (800) AT-BISON.

Circle 310

Harmonic Drive Technologies Introduces New Zero-Backlash Actuator

Harmonic Drive Technologies has introduced the PowerHub robotic actuator, a high-powered, zero-backlash, compact brushless actuator with a hollow shaft.

The PowerHub actuator has the same compactness, configuration and performance of a direct drive and the low cost and controllability of a geared actuator. However, unlike most geared servo actuators, the PowerHub's hollow middle allows vacuum lines, wiring, etc. to be run through its center to external devices including end-effectors or wafer paddles. The PowerHub is available in three sizes—50, 100 and 200 watts—and offers sub arc-minute accuracy.

For further information call (800) 921-3332 or visit Harmonic Drive Technologies' Web site at *www.harmonic-drive.com.*

Circle 311

NORD Gear Corp. Launches New Gear Motor Line

NORD has launched a new line of compact, high-performance helical gear motors. Called the NORDBLOC line, these new gear motors offer customers a choice of seven compact case sizes, each with two or three stages. NORDBLOC units range in horsepower from 1/6 HP to 50 HP and generate maximum torque ranging from 730 in-lbs. to 26,660 in-lbs. They are also customizable to the customer's needs. Options include alternate shaft sizes, heavy duty output bearings and special lubricants for specific work environments. Motor options, including 230, 460 and 575 volt motors, single and three phase, a full range of brakes, temperature monitors, auxiliary blowers for slow speed inverter duty and feedback encoders are also available.

Circle 312

New PM High Speed Tool Steel from Crucible

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GEARS ON ICE

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

Saginaw, Michigan, may be home to the only gear operation in the world that requires the use of a Zamboni® machine. It may also be the only place in the world where teeth on the Gears are optional.

The Saginaw Gears are a professional hockey team in the United Hockey League.

The history of the Gears in Saginaw goes back to the early 70s, according to Mark Thompson, director of media relations and the team's radio play-by-play broadcaster. The Saginaw Gears were originally a team in the International Hockey League from 1972–1982, during which time they won two Turner Cup championships and became very popular with the fans.

The original team got its name through a contest in which the fans voted for their favorite name. The Gears won, and the name stuck, says Thompson.

The original Gears changed their name in the 1980s and eventually left Saginaw. For a while, there was no professional hockey in town, until the Chatham Wheels crossed the border from Ontario to become Saginaw's franchise in what was then the Colonial Hockey League, precursor to today's UHL.

Gearilla, Mascot of the Saginaw Gears.

After stints as the Saginaw Wheels and the Saginaw Lumber Kings, the team changed owners. The new owners wanted to try to capture some of the old excitement, Thompson says. After the 1997–98 season, the team changed its name to the Gears.

Although the name change hasn't brought much success in terms of the team's record, they've certainly captured the enthusiasm of the fans. "It really hasn't been a great run for the Gears over the past two years," Thompson says, "but the fans just won't let it go."

The Gears have struggled because of the loss of their goalkeeper, Darren Madeley, a former NHL goalie, due to an injury at the beginning of this season. As of the first week in December, the team was 6-15-2, in last place by a wide margin.

But the hockey is still fun to watch, Thompson says. The United Hockey League includes players with a wide variety of age and experience, including the young players just coming up out of junior hockey along with many players filtering back down from the IHL and NHL ranks.

Information on the Saginaw Gears is available on their Web site, including full team statistics, schedules and highlights, as well as pictures Gearilla, the team mascot. You can also order tickets online or shop for Gears jerseys, hats or other merchandise. Visit *www.saginawgears.com* or call (517) 753-4801 for more information. O

TEAMS IN THE UHL

You can see the Gears in action in these UHL cities.

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Fort Wayne Komets, Fort Wayne, IN
Muskegon Fury, Muskegon, MI
Port Huron Border Cats, Port Huron, MI
Saginaw Gears, Saginaw, MI

Western Division

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Missouri River Otters, St. Charles, MO
Quad City Mallards, Moline, IL
Rockford Ice Hogs, Rockford, IL

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