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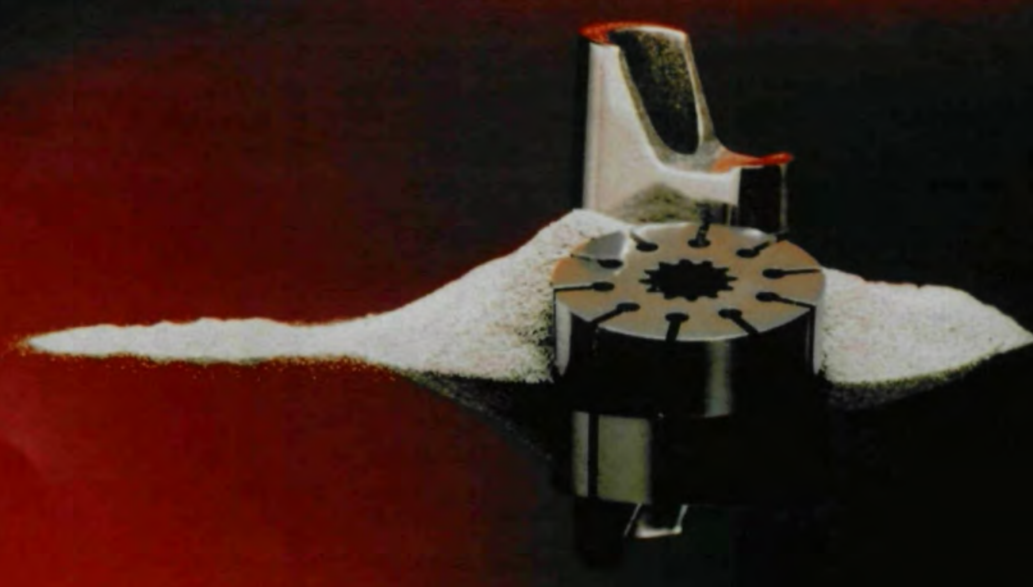

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CIRCLE 114

Timing is Everything

"Opportunities multiply as they are seized." – Sun Tzu, The Art of War

"Sow your seed in the morning, and at evening let not your hands be idle, for you do not know which will succeed, whether this or that, or whether both will do equally well" – Solomon, Ecclesiastes (11:6)

Although the cultures and areas of expertise of Solomon and Sun Tzu are worlds apart, the two offer similar opinions on the importance of seizing the moment. Their ancient wisdom may have increasing relevance to modern manufacturers in a global economy, particularly those contemplating whether now is the time to invest in capital equipment.

When is the best time to invest in extra manufacturing capacity? When should you upgrade to the latest technology? The answer, at least according to ancient wisdom, may be always.

But most of us have trouble with the idea of gambling hundreds of thousands or millions of dollars on a bet that we'll be able to use the extra capabilities a year or two down the road. Especially in times of economic uncertainty, the prudent thing seems to be to wait and see.

The U.S. economy has been steady and seems to be on track for continued growth with low unemployment and inflation, although the manufacturing sector still seems to be struggling. From March 1998 through mid-July 1999, U.S. manufacturing industries cut more than 488,000 jobs.

My sense from talking with gear manufacturers is that most of you are busy and that the manufacturing outlook is generally positive. But my sense is also that even though you're busy filling orders, you're also often competing with the deflated prices of your overseas competitors.

The past couple of years have been rough on Japan, the Far East and much of the rest of the world, and many currencies have fallen versus the dollar. This has made overseas manufacturers very price competitive in the United States while spurring growth in the U.S. trade deficit, which posted a record monthly high in May 1999.

This may be reason enough to invest now in capital equipment. The low inflation makes it difficult to raise your prices. Cutting your costs by becoming more efficient may be your only option for increasing profitability. The newest technologies can make you more productive and give you better quality, which can keep you competitive in any economy.

But a few sparks of life overseas may soon light flames under the economies of the world. Although Japan hasn't yet overcome its difficulties, other areas of the Far East are predicting strong growth for the end of 1999 and the year 2000. South Korea, Indonesia, Singapore and Thailand are expecting growth of 6–8% after their recent economic problems.

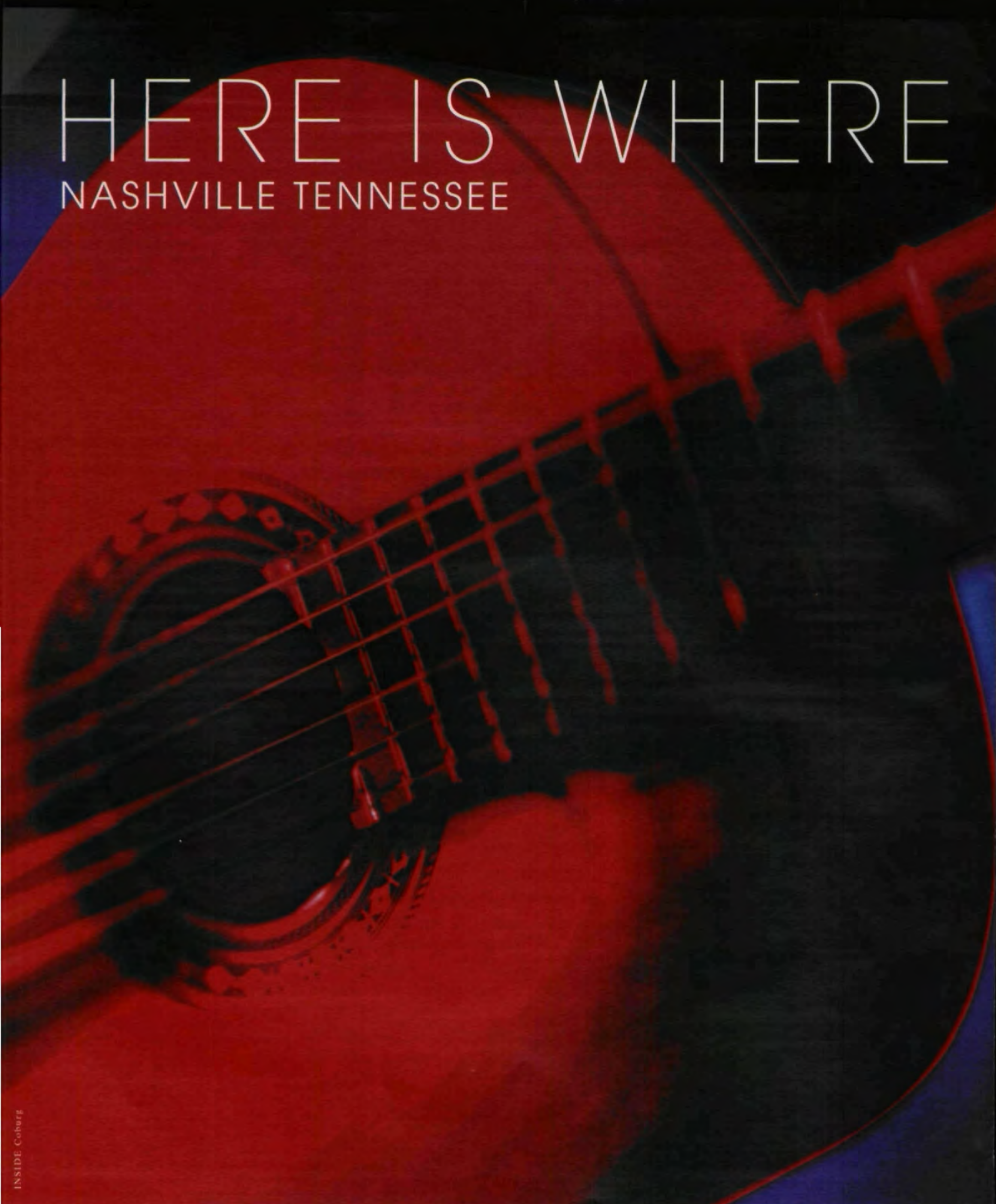
As these and other world economies begin to consume more of their own manufactured goods rather than relying on heavily discounted sales to the U.S., and as their currencies begin to rise, U.S. manufacturers may see price relief and increased demand for their products. Will your company be ready when this happens? Will your competitors?

As today's interest rates remain low, financing machine tool purchases is as cheap as you're likely to see it any time soon. If you wait six months or a year, what will it cost you?

Gear Expo 99 may be coming at exactly the right time for those who are interested in positioning their companies for a global economy that seems to be gaining momentum—and there are probably some good deals to be made for those who come with checkbooks in hand. In any case, you won't have a chance see a similar collection of the latest gear machinery and technology until IMTS 2000, and by then, it may be too late.

We'll be exhibiting at Gear Expo, and we invite you to come to visit us at Booth #618. But whether or not you plan to attend the show, it would be wise to consider the words of Sun Tzu and Solomon and the possibility that investing in your manufacturing capabilities today is the best choice. But don't think about it for too long.

Michael Goldstein, Publisher & Editor-in-Chief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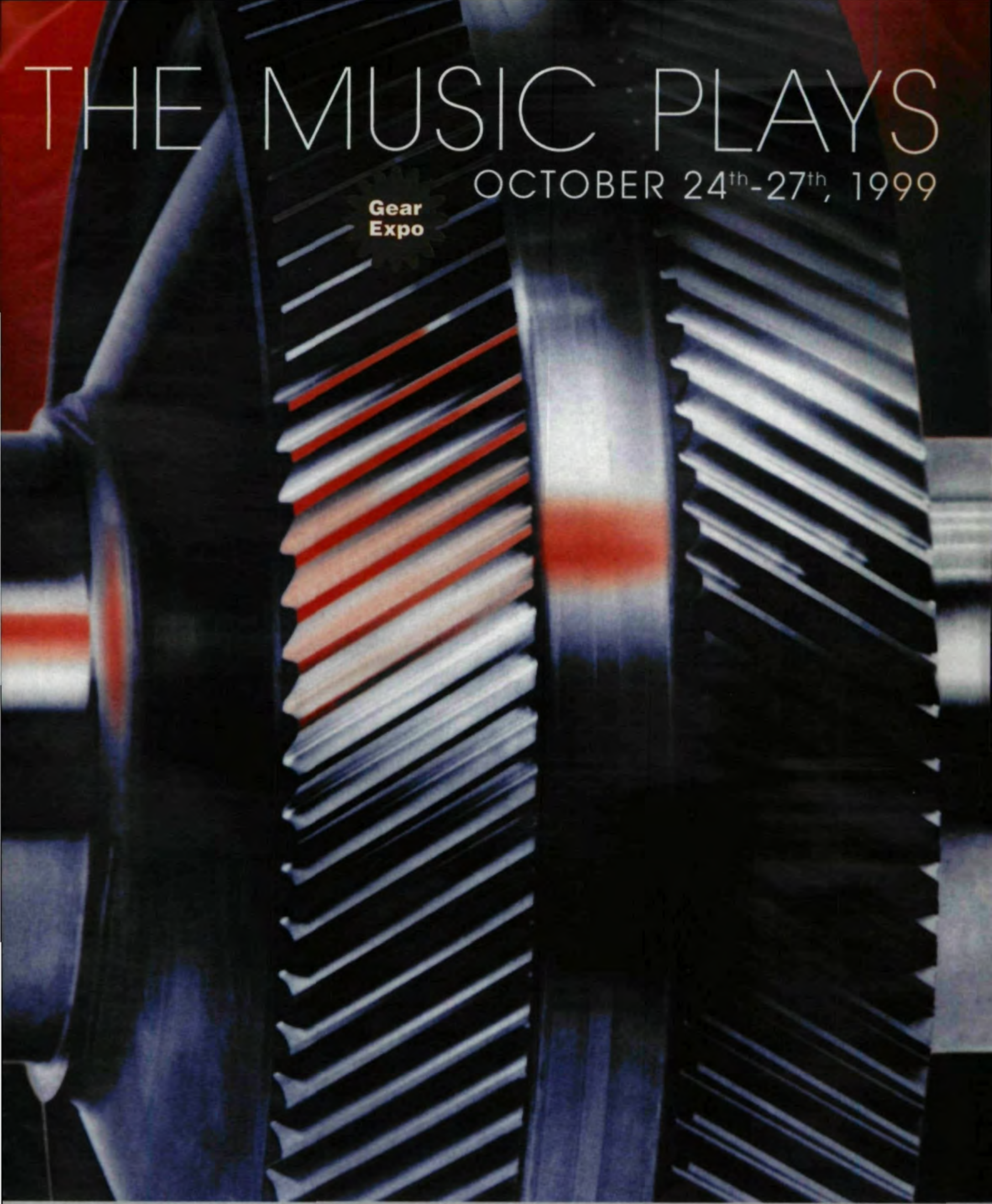
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Gear Drives Great and Small Part I: Micro Gearheads

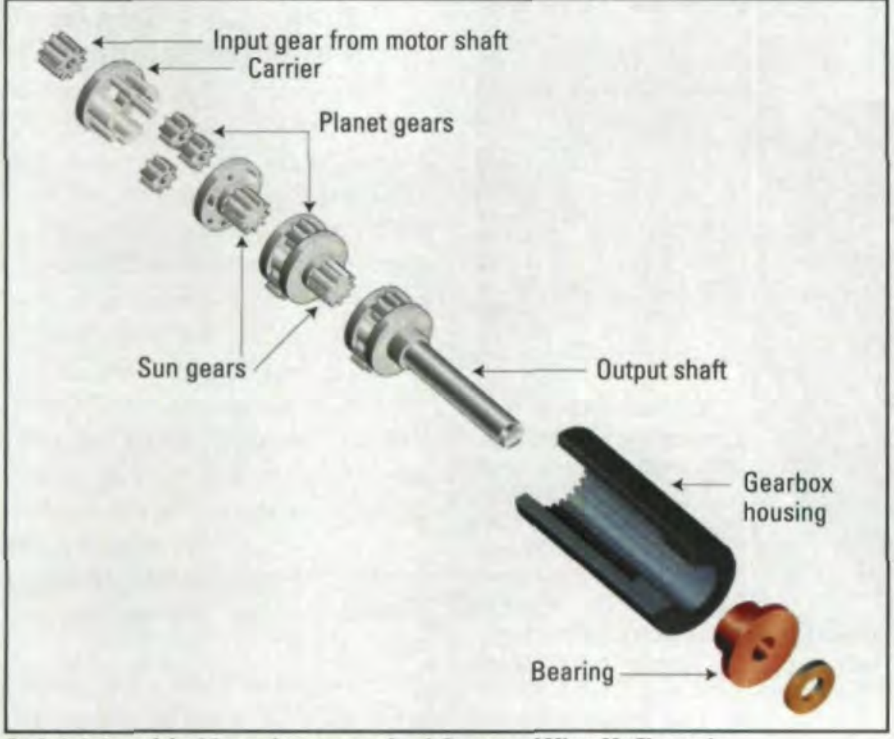
With many companies and researchers exploring the benefits of miniaturization, gears and gearheads are being designed and built to meet the requirements of increasingly tiny applications. Companies like Micro Mo Electronics are in the forefront of this effort. "We were interested in creating a very small gearhead that still had practical, real-world applications," said Steve O'Neil, the vice president of advanced research and planning. What Micro Mo developed is a planetary gearhead that is 1.9 mm in diameter. "This is considered an optimal size," said O'Neil, "because the unit can still generate useful power."

While the unit is not yet being used on a production basis, it is under consideration for a number of applications that call for precision miniaturized power transmission. "Right now," said O'Neil, "there are a number of beta projects going on that use these gearheads. Security, industrial hygiene and medical applications are being explored including minimally invasive surgical instruments and diagnostic technology."

The planetary gearhead is made using LIGA technology. LIGA is a German acronym for Lithography, Material Removal and Molding, a process similar to that used to make microchips. The difference is that the plastic gear material is injected into molds in the final part of the process.

The output statistics for this tiny gearhead are impressive. The unit can be ordered with ratios 3.6:1 to 47:1 depending on the needs of the application. At a 47:1 gear ratio, the gearhead's output torque for continuous operation is 150 µNm and 300 µNm during intermittent operation. The unit can take input speeds of up to 20,000 rpm continuous and 50,000 rpm intermittent with output of up to 100,000 rpm and can operate in temperatures ranging from –20°C to 60°C (–4°F to 140°F).

Circle 251



Exploded view of the 1.9 mm planetary gearhead. Courtesy of Micro Mo Electronics.

Gear Drives Great and Small Part II: Monster Gears

At the other end of the size spectrum stand the huge, steel-cast ring gears made by the Falk Corporation for the mining industry.

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.

Chile's Atacama Desert is home to the Escondida Copper Mine, the location of the world's largest horsepower driven ring gear drive. The custom-made, steel-cast gear is 43.27 feet in diameter and weighs 190,000 pounds. It is driven by two pinions and a pair of 9,000 horsepower, 176.5 rpm synchronous motors. With a reduction ratio of 17.48:1, the drive can produce 9.3 million ft-lbs. of output torque at a speed of 10.1 rpm.

The semiautogenous grinding (SAG) mill, built by Allis Mineral Systems and powered by this gear drive, is a recent addition to the Escondida Mine. The 36-foot diameter mill grinds large chunks of ore, some as large as a foot in diameter, into smaller, gravel-sized pieces. Until recently, operations such as Escondida's SAG mill had to rely on complex and expensive wrap-around motor configurations to drive the mill. Such systems were high maintenance given their vulnerability to dirt and debris. However, advances in large gear technology now permit mines and other heavy industrial operations to use the more reliable, lower maintenance and less expensive pinion/ring gear drive configurations.

"These advances," said Craig Danecki, mill products business unit manager for Falk, "include new materials and new ways to cast them. We use *full ring risers and fill the molds from the* bottom. The risers allow any dirt or debris that might be in the mold to float to the top while the excess steel feeds the center of the casting as the piece cools. We also use software to analyze the way steel will act within the mold. This is similar to the finite element analysis we apply to the gears as well."

Kalgoorlie, Australia is the site of another of Falk's giant ring gears, this time at the Fimeston Gold Mine. While *slightly smaller than the Escondida ring* gear, the 40-foot diameter ring gear manufactured for Fimeston shows just how quickly such a gear can be transported around the world.

"We usually ship by boat, but this was a breakdown emergency job," explained Danecki. "The mine was experiencing power failures due to extreme electrical storms. These power outages were damaging the gear they were already using because of the way the motors would *shut down when the power failed. If their* mill shut down because of a failed ring gear, they were looking at losses of nearly $60,000 per hour, so the insurance company approved the air freight."

These huge ring gears are made in quarters, cast from heavily alloyed chromium-nickel-molybdenum steel, normalized and then tempered. The pieces are then finish ground to AGMA 12 tolerances with surface finishes between 63 and 100 RMF. The gear sections have bolting flanges set at the same angle as the helical teeth. When the gear is put together, these flanges are locked into place with steel dowels and split locking pins. The pinions are made from forged ingots in a process that drives any defects into the center of the workpiece. The pinion is then rough cut, carburized and finished.

While 43 feet may be the largest gear Falk has made to date, there is an even bigger one in the works. "We're working on developing a 60-foot diameter gear for a shale-oil drilling company in Canada," said Danecki. "A test operation down in Australia has been using a 15-foot gear to work out the process, and now the full scale operation is being studied."

Circle 252

Putting a New Spin on Gear Manufacturing

For the makers of die cast metal and injection-molded plastic gears, there is a process that promises to cut costs and production time for small- to medium-sized runs. Called spin-casting, the method is also useful for rapid prototyping as well as the fast manufacturing of replacement parts. "With plastic materials such as polyurethanes we can achieve very high tolerances," said Sherif Nasser, technical sales and training manager for Tekcast Industries, Inc. "With metals, such as zinc alloys or aluminum—which is really only suitable for rapid prototyping because of the temperatures involved—the tolerances are slightly lower."

According to Nasser, the process begins with the model or prototype of the part you want to make. From this a

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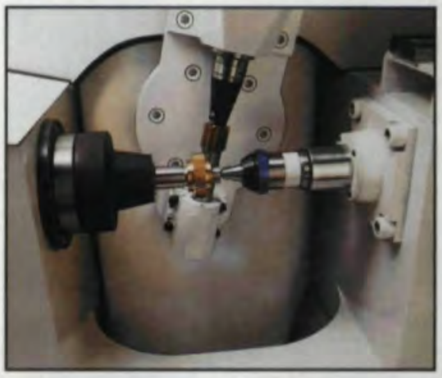

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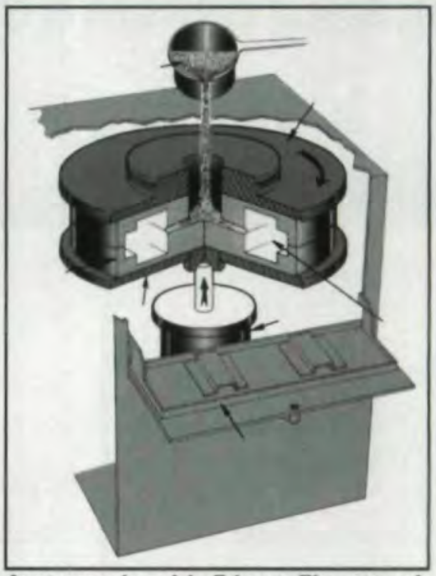
mold is made using a silicone rubber compound called Teksil that is highly temperature resistant. "This silicone mold has the exact cavities needed to duplicate the original," said Nasser, "and it can be anywhere from 9 to 30 inches across and up to 10 inches thick." Once the shapes are cut and molded around the model parts, the upper and lower halves of the mold are brought together around the model and the entire assembly is placed in a ring-shaped vulcanizing frame and put into an electrically heated vulcanizing press for curing. Hydraulic force clamps the mold frame shut between the heated platens, forcing the silicone into all crevices and around every detail of the model. The resulting mold is tough, resilient, dimensionally accurate to .008" and heat and chemically resistant. After vulcanization, the mold can be easily flexed to release the patterns (and later, parts) from the cavities—even patterns with a wide variety



A cut-away view of the Tekcaster™ courtesy of Tekcast Industries, Inc.

of undercuts. At this point, gates and vents can be cut into the mold with a sharp knife or scalpel. If the initial tests show the need for greater flow or more air venting, these gates and vents can be easily expanded on the spot.

After the mold is made, it is placed in the spin-casting machine—a patented, front-loading unit called a Tekcaster™—and spun. Molten metal or plastic is then poured in. Centrifugal force pulls the liquid through the gates and into the molds, ensuring that the cavities are completely filled. With this method, metal castings are made at a rate of 50 to 60 cycles per hour. With plastic, the rate is typically 10 to 15 cycles.

According to Nasser, "With plastic we can make any kind of gear you can think of, bevels, spur, helical. With zinc alloys, we can do anything except helicals."

So what are some other reasons to consider spin casting? Cost and speed, according to Nasser. "With spin casting, if you have the model, the mold can be made for less than $100.00 and takes about three hours," said Nasser. "With spin casting you can go from prototype to production in a couple of days. With other methods it could be anywhere from one to four months before you start producing parts."

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Design for Silence: New Concepts and Techniques for Industrial Gears

Dr. Peter Flamang

Introduction

For a long time, relatively high noise levels have been generally accepted for industrial gear units in the 10–1000 kW power range. However, due to changing environmental awareness—both in and around industrial sites—customer expectations have moved drastically towards low noise as a key differentiating factor.

Gear drives, such as those used in cooling towers, water treatment plants and wind turbines, are frequently installed close to inhabited sites, and so low noise behavior has long been considered critical. More recently, however, noise is becoming a concern even in heavy industrial applications such as the large conveyor drives used in extraction and mining.

Not only are low noise expectations met in an increasing variety of applications, the accepted noise levels themselves are continuously decreasing. Severe low noise requirements in the past were met by using sound protection hoods over the installation, requiring extra expense, hampering installation and decreasing accessibility for maintenance and inspection. Customers' expectations have now often lowered acceptable noise levels down to the point where no protective hoods are needed, even for extreme applications.

The technologies available to meet these requirements have also changed, and so have the noise levels of state-of-the-art industrial gear units. Compared to the mid-eighties (VDI 2159, Ref. 5), the average noise levels of leading industrial gear products have decreased by 10 or more dBA. This is for standard drives without special-order modifications.

Design for Silence

In order to obtain these low values, a number of conditions have to be met. The literature describes the extensive research carried out in this field. In all cases, "accuracy under load" seems to be key in obtaining low noise behavior in gear units.

However easily defined, a lot of influences may counteract each other. The gear unit designer should meet the numerous requirements imposed by these influences in order to achieve the "total quality" of his design. Enabled by modern design and manufacturing technologies, a variety of measures can be taken. The challenge, therefore, has become making the right choices at the right time in the design process and carrying through with those choices in the manufacturing process.

"Design for silence" means that in order to meet today's low noise expectations, the designer has to make a series of consistent decisions, starting with the very concept, as exemplified in the following.

Accuracy Under Load

Manufacturing accuracy. Gear vibration, the root cause for generated noise, starts from the imperfect taking over of the contact between consecutive teeth. For example, this can be caused by a simple geometrical pitch error. The combination of pitch, lead and involute errors leads to transmission error, which can be measured on a single flank test machine (Refs. 1, 2, 3). Transmission error is defined as the difference between the real and the theoretical rotation of the gear when being driven by a uniform rotation of the pinion.

Aiming at lowest transmission error leads to excellent manufacturing accuracy of the gears. This is a primary condition for low noise behavior. For example, the limited curing effect of lapping on geometrical pitch errors can not sufficiently improve noise to meet today's requirements for industrial gear units (Ref. 1).

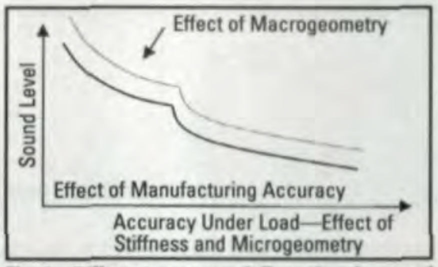

Fig. 1—Different measures influencing the sound level.

To achieve the required levels of accuracy in combination with the typical flexibility requirements in the manufacturing and logistics of industrial gear units, a first level decision is taken to grind all gears, both helical and bevel.

The manufacturing tolerances of the housings need to be in line with the high quality of the gears. In fact, a complete system of tolerances covering both the gears and the housing needs to be studied and implemented during the design phase of the new product. However, improving manufacturing quality can affect the noise level only up to a certain extent.

Dr. Peter Flamang

is the technical director of Hansen Transmissions International, a member of the Rexnord group of companies. He is responsible for gear technology in the group and has coordinated the development of a number of industrial gear products. He is a graduate of the University of Ghent, Belgium, where he obtained a Ph.D. in applied sciences. He also holds an MBA from the University of Antwerp.

This article was first presented at the 4th World Congress on Gearing and Power Transmission, organized by IET, the French Institute for Gearing and Transmissions. The Congress was held March 16–18, 1999 in Paris, France.

As described in the literature, Figure 1 shows that once manufacturing accuracy reaches a certain level, little or no further noise improvement can be obtained. This is due to the effect of load on the geometric accuracy of the gears. All of the components within the force flow deform under load. The gear teeth bend and the shaft deflects, as do the bearings and the gear unit's housing. It is clear that all of these act in a way similar to the geometric errors described above. In order to create the lowest possible transmission error, vibrations and noise, accuracy under load is the next consideration.

Stiffness is the key. In an ideal world, no deflection would exist. Obtaining the highest stiffness of all components in the power chain is, therefore, the closest thing a designer in the real world can aim for.

The typical construction used for standard, industrial gear units results from the need to easily machine the housing. In earlier days, this need led to the use of straight housing sides to support the shafts. As the dimensioning of the low-speed gear sets dictates the overall width of the unit, one of the disadvantages of the conventional design is that the narrower, high-speed gears are found on relatively long and flexible integral pinion shafts (A, Figure 2). Deflection under load will make optimization of these gear sets' noise behavior more difficult.

With the advantages offered by today's flexible machining centers, the housing sides can be designed and manufactured in such a way that the high-speed gears are supported by shorter bearing spans. This stepped housing is shown in Figure 3, and has additional advantages:

- Both the high-speed and intermediate-speed pinion shafts and gears can be standardized over all sizes where the same center distances are applied, irrespective of the number of stages in the respective units (Ref. 6). Note that integral pinion shafts, the key components of modern gear units, can not be truly standardized in a conventional gear unit. In Figure 2, the two intermediate pinion shafts B have different lengths in different housing sizes. In Figure 3 they are identical.

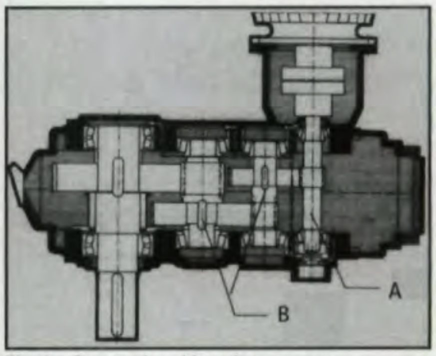

Fig. 2—Conventional housing concept.

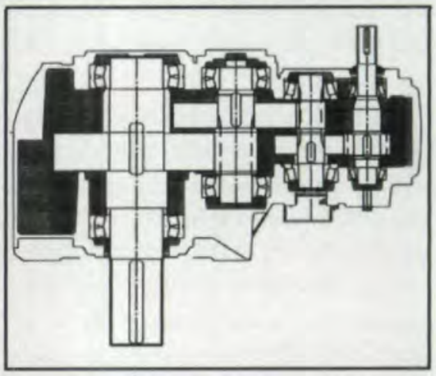
Fig. 3—Stepped housing concept.

- The standardized pinion shafts are those with the highest stiffness, as opposed to the more flexible, non-standard shafts, which need no longer be applied.
- Standardization allows cost-effective batch production of pinion shafts to the required manufacturing accuracies.
- Standardization allows the best optimization of corrections at the micro-geometry level in order to obtain the most uniform load distribution and lowest noise.
- The stepped housing design has an inherent stiffness that is beneficial to both the load contact pattern of the gears and to the sound emission behavior of the housing.
- Standardization works just as well for parallel as it does for right angle designs, which are even more critical in noise generation (Ref. 5).

Housing Design

Material. The use of cast iron for the housing offers significant advantages because the dampening qualities of cast iron are much greater than those of steel. The design flexibility of cast iron parts allows the designer to integrate the data and expertise gained from extensive studies such as those carried out by modal analysis of housing deformations and intensity analysis for minimal noise emission (Ref. 4).

Coping with external forces. External forces may deflect the housing and cause excessive noise and vibrations. The designer must consider these and minimize deflection, which distorts the contact patterns of the gears.

As an example, a finite element calculation can be used to limit deformations to the external side (mounting pad) of a gear unit, rather than distorting the internals of the housing.

Gear Geometry

Optimized macrogeometry. Referring back to Figures 2 and 3, it is clear that the presence of the shaft extension differentiates the high-speed integral pinion shafts from the intermediate-speed integral pinion shafts. Standardization between high- and intermediate-speed pinion shafts thus being impossible, the designer has a unique opportunity to optimize gear parameters such as module, face width, helix angle or contact ratio in different ways in order to meet different market needs. Indeed, the market needs for respectively high-speed and low-speed gear sets differ as follows:

- The low-speed gear set, being the largest gear set and therefore the highest cost factor in the gear unit, has to be designed for maximum torque in order to obtain the lowest cost for a given torque rating.
- The high-speed gear set, being the largest source of vibration and noise, needs to be optimized for lowest noise generation, because:
- For a given transmission error, the higher the rotational speed, the higher the generated vibrations.
- The human ear is less sensitive to very low frequencies, as reflected in the 'A' weighted spectrum. The most disturbing frequencies typically result from the mesh frequencies and harmonics of the higher speed gear sets.

The same applies *a fortiori* to bevel gear sets. These are always the high-speed gear sets in right angle gear units, and apart from the beneficial effect of being ground (Ref. 1), they also need to be optimized concerning low noise generation.

Microgeometry: the fourth level. State-of-the-art gears are corrected for deflections by profile and lead modifications. Sophisticated grinding techniques allow for the implementation of corrections, such as those calculated by Tooth Contact Analysis (TCA) software developed by Gleason or the Research Institute WZL-RWTH Aachen. However, as deflections are proportional with load, the applied modifications are optimal only for a given load situation.

Consider the straight tip relief correction as an example (Figure 4). This correction is the amount one has to take away from the mating gear tip in order to avoid interference with the driving pinion due to deformation under load.

The applied tip relief, however, is optimal for one load situation only. For other loads, the tip relief will be sub-optimal, resulting either in reduction of active profile or in tip interference.

Many gear units, however, are subject to a variety of loads. Figure 5 shows the amount of tip relief needed versus a given

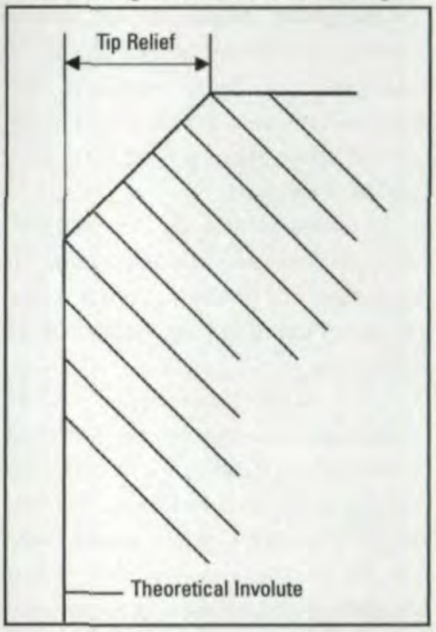

Fig. 4—Straight tip relief.

variation of load conditions for a certain high-stiffness design. This proves again how stiffness is key in the design:

- The level of corrections needed is lower. Consequently, there will be less reduction of active profile under low load conditions.
- For a given load spectrum, the mean deviation from the optimal correction is much lower.

Another approach to minimizing the effect of a load spectrum on the emitted sound is exemplified in Figure 7. By applying a modified tip relief geometry, which is enabled through the use of modern manufacturing equipment, the active profile gradually increases as the load increases. Therefore, the noise specifications can be maintained over a wider range of absorbed powers rather than only for the design power of the unit. The same principles are also applied for bevel gear sets, as exemplified in Reference 1, which discusses the measured noise behavior of a given gear unit over a variety of loads.

Results

Figure 7 shows sound power levels generated by a range of standard industrial gear units designed in line with the principles above. The sound levels, indicating

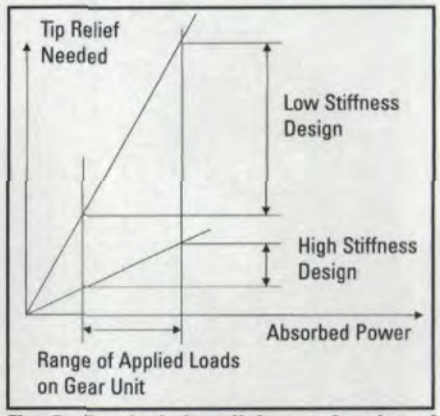

Fig. 5—Required tip relief as a function of absorbed power.

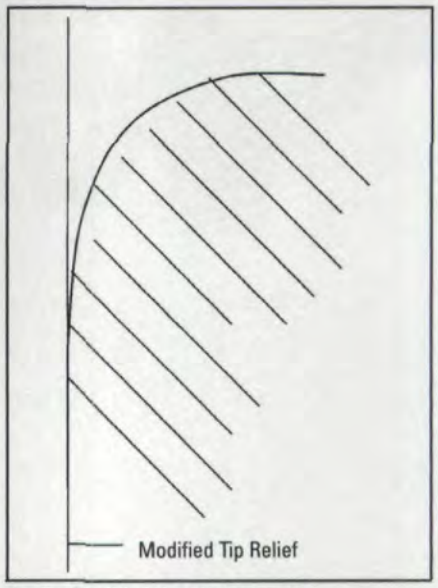

Fig. 6—Modified tip relief geometry.

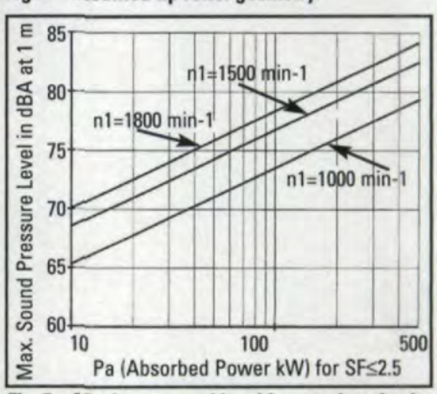

Fig. 7—Maximum sound level for a series of units designed according to the described strategy.

maximum rather than average values, are derived from a number of experiments on a variety of standard gear units, both parallel and right-angle, in a load range between 10 and 750 kW, without special modifications. The tests were carried out on in-house test benches, by means of intensity analysis. The horizontal axis on Figure 7 shows the absorbed power; the vertical axis shows the corresponding sound pressure level.

Conclusion

Low noise behavior in standard industrial gear units is becoming an important selection criterion for the customer, even in businesses that used to be considered "heavy industry." In addition, the accepted noise levels themselves are continuously decreasing. State-of-the-art machinery for manufacturing both housings and gears allows the designer to meet and even to exceed customer expectations. This presumes, however, that a number of careful and consistent design decisions are made from the very concept phase. The "Design for silence" strategy has been exemplified by describing this series of decisions as embedded in a range of standard industrial gear units. Results show the approach to be successful. ○

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6. United States patent Number 5680793.

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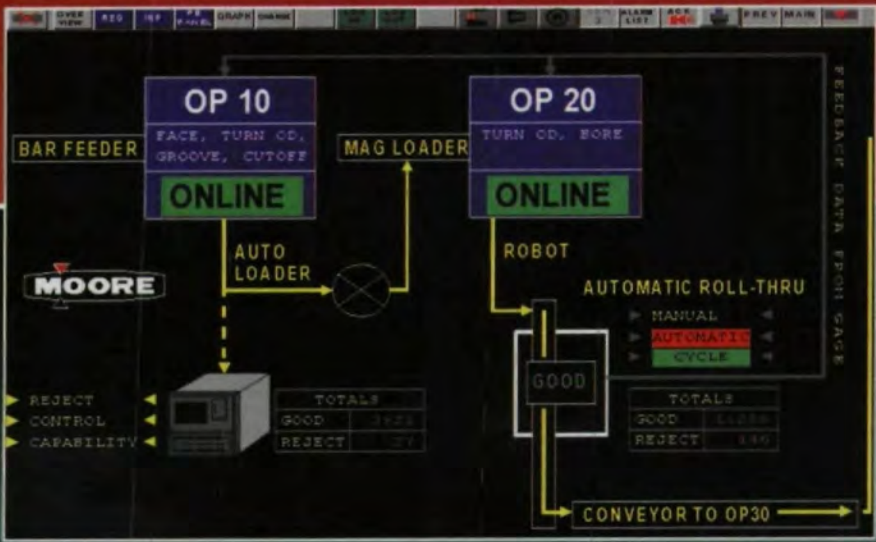

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CIRCLE 106

TECHNICAL CALENDAR

September 13–17. AGMA Gear Basic Course. Richard J. Daley College, Chicago, IL. This course is designed primarily for employees with at least 6 months of experience in setup or machine operation. The 5-day course includes basic gearing, efficient machine setup techniques, accurate gear inspection and gearing calculation. This course will also be offered November 8–12. For more information, contact AGMA at (703) 684-0211.

October 4–6. Functional Gaging: Geometric Dimensioning and Tolerancing. Manchester East Hotel, Milwaukee, WI. Sponsored by the Univeristy of Wisconsin—Milwaukee. Participants will learn the principles of functional gage design, dimensioning and tolerancing. They will also learn the major concepts of geometric dimensioning and tolerancing and how to analyze collected measurement data. This course is tailored to the needs of manufacturing, production and engineering managers; producibility engineers; QA professionals and product/process design engineers. For more information contact Richard Albers, program director, at (414) 227-3125 or Valerie Jordan, program assistant, at (414) 227-3167.

October 11–14. Gleason Pfauter Hurth Basic Fundamentals. Loves Park, IL. This four-day program is designed for those new to gear making who are seeking a basic understanding of gear geometry, nomenclature, manufacturing and inspection. Also offered November 15–18 and December 6–9. For more information call (815) 877-8900 or visit *www.pfauter.com*.

October 24–27. Gear Expo 99. Nashville Convention Center, Nashville, TN. Sponsored by the American Gear Manufacturers Association, this is the gear industry's premiere trade show, boasting 53,000 square feet of space for over 100 exhibitors representing all facets of the gear industry. For more information contact AGMA at (703) 684-0211, by fax at (703) 684-0242 or by e-mail at *gearexpo@agma.org*.

November 1–4. The 20th International Die Casting Congress and Exposition, Cleveland Convention Center, Cleveland, OH. The Congress and Exposition gives die casting industry professionals the opportunity to congregate and share the industry's latest technology and innovations. The Congress consists of 12 sessions, which provide valuable technology transfer, case studies, summaries of research projects and new process developments. The Exposition is a display of state-of-the-art die casting technology and ancillary equipment, supplies and services. For more information, contact Marie Frank at the North American Die Casting Association at (847) 292-3600, ext 321. For show information and a preliminary schedule visit NADCA's Web site at *www.diecasting.org/c&e*.

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THE CLEAN REVOLUTION.

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With the introduction of high-speed dry gear hobbing in 1993, Sigma Pool opened the door for the gear industry to make a giant first step in the direction of the 'clean' factory.
Dry cutting technology is now successfully used by Oerlikon customers to produce spiral bevel and hypoid gears, reducing cycle times for rings and pinions up to 50%. Oerlikon gear generating machines – designed to use all toothcutting methods – reduce costs and improve quality with ecologically responsible dry cutting technology. – Benefits start with: • Cycle times reduced up to 50%. • 95% or greater machine uptime. • 30% reduction in system cost. Fewer machines are required to meet production goals.
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World-wide, dry gear production is helping high-volume and small batch manufacturers meet head-on the economic and ecological challenges of the new millennium. The dry revolution is well underway.

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CIRCLE 180

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SIGMA POOL
The Gearing Partnership of Klingelnberg, Liebherr, Lorenz and Oerlikon.

Guide to Gear Expo

The world's largest collection of gear manufacturing technology comes to Music City U.S.A.

Thousands of gear industry professionals will converge October 24–27 in Nashville, TN, for Gear Expo 99, the industry's biennial collection of the latest in gear manufacturing technology. With nearly 50,000 square feet of exhibit space sold more than two months in advance of the show, this year's Gear Expo will offer visitors more opportunity for supplier comparison than ever before. As of July 20, 166 suppliers of equipment, tooling, services and precision gear products were scheduled to participate, with as many as 20 additional booths yet to be sold, according to AGMA vice president and Gear Expo show manager Kurt Medert. The largest previous Gear Expo was held in 1997 in Detroit, with 43,100 square feet of exhibit space and 161 exhibitors.

Photos courtesy of the Nashville Convention & Visitors Bureau.

GEAR EXPO 99 FACTS

Gear Expo 99
"The World of Gearing"
October 24–27, 1999
Nashville Convention Center,
Nashville, TN

Advanced Registration: $15
(open through October 11)
Call AGMA at (703) 684-0211
Or use your credit card to register online at *www.agma.org*
(Registration is also available at the show for $25)

Preview Gear Expo at *Show Central*, the world's first 3D online metalworking technology show.

www.geartechnology.com

TENNESSEE FACTS

1999 marks the first year that Gear Expo will be held in Nashville, Tennessee, and show organizers hope that this central location will attract many new gear industry professionals while still being close enough to the Midwest and the majority of the gear belt to keep the core of attendees it has always attracted. Tennessee is also part of a growing manufacturing belt in the South.

- Tennessee ranks behind only Michigan, Ohio and Illinois for passenger car production in the United States, with more than 450,000 units produced in 1998.
- Tennessee is home to more than 600 automotive industry suppliers.

Nashville offers plenty of entertainment options for visitors. Call the Nashville Convention and Visitors Bureau at (615) 259-4700 for a copy of the *1999 Music City Vacation Guide*, a 160-page directory of the city.

- Visit *www.nashvillecvb.com* for more information.

SME GEAR SEMINARS AVAILABLE AT GEAR EXPO 99

SME, IN COOPERATION WITH AGMA, WILL PRESENT THREE EDUCATIONAL PROGRAMS AT GEAR EXPO 99. EACH PROGRAM WILL BEGIN AT 8:00 A.M. AND END NO LATER THAN 1:30 P.M.

• HEAT TREATING AND HARDENING OF GEARS—October 25

A multi-speaker forum of industry leaders, led by George Pfaffmann, VP of Tocco, Inc. This panel will examine the basic concepts of heat treatment and hardening of gears as well as alternative methods. The seminar will address the status of induction hardening, alternative heat treating methods, process control and monitoring, fatigue and wear resistance, and distortion and scrap reduction.

Other speakers will include Loren Epler, Dynamic Metal Treating, Inc.; Charles J. Kuehmann, QuesTek Innovations LLC; Bill Bushchur, ibg NDT Systems Corporation; and additional speakers to be named later.

• GEAR METROLOGY—October 26

Edward Lawson, product manager of Mahr Corporation, will present this course on metrology and inspection issues unique to the gear manufacturing and processing industry. This one-day course is intended to give you a renewed interest, understanding and knowledge of how to improve your process and product.

• GEAR PROCESSING AND MANUFACTURING—October 27

This conference will provide a forum in which gear manufacturing professionals can openly discuss the trials and tribulations of processing and manufacturing high quality gears. This is your opportunity to hear how to overcome difficult procedures and to find new opportunities from colleagues and competitors. The forum will be led by Bill Maples of Star Cutter Co. The following industry experts are also scheduled to participate: Ed Tarney, Crucible Service Center; Dale Debeljak, Presrite Corporation; Thomas Schloz, Gleason Pfauter Hurth; Dennis Sine and Harvey Yera, National Broach & Machine Co; and Guenter Mikolelzig, Klingelnberg.

Register for these seminars by calling SME's customer service center at (800) 733-4763 or e-mail *albelyn@sme.org*.

The show's location is attracting many new exhibitors from different regions of the country, particularly the East coast, says Medert.

Much of the growth of the show also comes from the presence of gear manufacturers exhibiting at the show. At least 40 companies on the current roster are gear manufacturing companies, and they run the gamut from spur to spiral bevel, from plastic to powder metal, and everything in-between. So whether you are making gears or buying them, chances are good that you will find quality suppliers this October in Nashville.

Many exhibitors hope to generate excitement by unveiling new machines, models or processes at the show. For example, Chamfermatic, Inc. will demonstrate its new Model 1600 gear deburring machine. Mike Magee, president of Chamfermatic, wouldn't reveal any details about the machine, but he promises to unveil a new process that he hopes will revolutionize gear deburring.

Many other companies are offering new products at the show. You can read about many other exhibitors and what to expect at their booths in the listings on pages 29–44.

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For more information about Gear Expo, please circle **216.**

Don't Miss These Booths!

We've contacted many of the gear industry's leading suppliers to find out what they'll be showing at Gear Expo 99. Booth numbers are current as of July 31, 1999, but they are subject to change. A current list of exhibitors and booth information is available at the AGMA Web site at www.agma.org.

Acme Gear Company, Inc.—Booth #420. ACME Gear Company has over 70 years of specialized manufacturing experience in the prototyping and mass production of high quality precision ground or cut gears. They manufacture machine products as original equipment for machinery manufacturers, transit authorities, aerospace, defense and other related high-tech industries. They manufacture ground helical and spur gears up to 32.67" OD, 32–2.5 DP. Gears are manufactured up to AGMA class 13 for production and AGMA class 15 for prototypes. Acme also manufactures worms and worm gears, internal gears, involute and square splines, sprockets, ratchets and timing belt pulleys.

Amarillo Gear Company—Booth #514. Amarillo Gear Co. will exhibit a variety of spiral bevel gears, partially demonstrating the range of products available from their facility. Their catalogs of standard spiral bevel gears, right angle pump drives, and right angle cooling tower fan drives will also be available in the booth.

American Gear Manufacturers Association—Booth #602. The American Gear Manufacturers Association (AGMA), the sponsor or Gear Expo 99, is a trade association representing more than 400 manufacturers of gears and related gearing and coupling products, as well as suppliers and consultants to the industry. As secretariat of ISO technical committee 60, AGMA is the primary organization responsible for the development of gearing standards.

American Metal Treating Co.—Booth #622. American Metal Treating provides contour induction hardening services for the largest parts the gear industry is producing. American Metal specializes in just one method—precision induction hardening. For parts such as gears, shafts and sprockets, precision induction hardening is an ideal method for protecting those areas exposed to excessive wear. Induction-hardened parts retain their original characteristics because there is less distortion when compared with parts hardened by other heat treating methods. The parts treated with this method also perform better and last longer.

American Wera, Inc.—Booth #734. The WERA Deburr Machine KEM 500 CNC was developed in order to provide precise and defined workpiece edge deburring for bevel and special gears and other complex shapes. The WERA KEM 500 reduces the manual work required for deburring (especially bevel gears), is capable of machining a large number of different workpieces with simple tooling and has short change over times with high productivity.

Applied Process Inc.—Booth #1109. Applied Process is a world leader in the austempering process, a heat treatment that makes iron and steel parts tougher, stronger, quieter, lighter and more wear resistant than conventional heat treatments. Austempered irons and steels offer gear and shaft manufacturers the benefits of near-net shape and reduced machining cost. Also see how austempered ductile iron (ADI) is quietly outperforming steel. Applied Process has operations in Livonia, MI; Oshkosh, WI; Elizabethtown, KY; and licensees in England and Australia. Customers include General Motors, John Deere, Caterpillar, Dana, Meritor, Purolator, Eaton, Citation, Intermet, Thyssen/Budd, Freightliner, Ford Vermeer, Masco, Oshkosh Truck, Navistar, hundreds of other OEMs and first- and second-tier suppliers in 38 states and 5 Canadian provinces.

Arrow Gear Company—Booth #535. Arrow Gear Company is a privately held company that has been in business for 52 years. The company was started by James J. Cervinka and the late Frank E. Pielsticker in 1947. The company has since grown to 265 employees with approximately $35 million in sales. The main plant in Downers Grove, IL, has 124,000 square feet; Plant #2 has 24,000 square feet and Plant #3 in Lincoln, NE, has 56,000 square feet. Arrow Gear manufactures loose gears and enclosed gearboxes. Arrow Gear services the aerospace and high-precison commercial gear markets. The large aerospace sector of the business services such customers as Allied Signal, Allison Engine Company, Boeing Aircraft, Boeing Helicopter, Curtiss-Wright, Dowty Aerospace, FiatAvio, Inc., GEC Marconi, General Electric, Pratt & Whitney, Robinson Helicopter, Rocketdyne, Rolls-Royce, Schweitzer Helicopter and Williams International. The majority of Arrow Gear's work is in loose gearing. However, they also supply complete gearboxes. Johnson Gear Division of Arrow Gear, located in Lincoln, NE, has been in the complete enclosed gearbox business since 1905, serving the commercial gear industry worldwide, producing over one-half million gear drives for irrigation, cooling towers, printing presses, and centrifuge gearboxes for the medical industry. Arrow Gear has its own in-house heat treat capability and, to our knowledge, is still the first and only company in the world, according to The Gleason Works and Zeiss Hofler, to have under-roof a completely integrated, closed-loop system for the design, manufacture, electronic transfer and inspection of bevel gears.

Arte Corporation—Booth #723. With the motto of "a proud past, a productive relationship and a promising future," Arte Corporation has been in the manufacturing business since 1982. Arte is committed to providing its customers with defect-free products, as well as to continuously improving every process in the operation, according to specifications, at competitive prices. Arte is a member of AGMA and specializes in the plastic injection molding of precision gears up to 40 grams.

ATA Gears U.S.A. Inc.—Booth #517. ATA specializes in the production of spiral bevel gears and the manufacture of custom-designed gear units and water turbines. Based in Finland, the company has been producing gears for more than half of a century. Today more than 80% of ATA's output is exported, and gears are supplied to customers all over the world.

A/W Systems Co.—Booth #424. A/W Systems Company will be displaying an array of spiral gear cutting blades, hardware and bodies 5" to 9" in diameter, including Ridg-Ac®, Tri-Ac®, Helix® and Hard-AC®; straight bevel gear generating cutters; roughing blades for Ridg-Ac®, Wedg-Ac® and soft bodies 5" to 9" in diameter; finisher blades for Helix® bodies 5" to 9" diameter; and stick blades for Tri-Ac® bodies. (Ridg-Ac, Tri-Ac, Helix, Hard-Ac and Wedg-Ac are registered trademarks of Gleason Corporation).

B&R Machine & Gear Corp.—Booth #121. B&R Machine & Gear is a family owned and operated gear company founded in 1974. A custom job shop specializing in breakdown services, B&R manufactures gears to customer specifications or samples. They have their own material warehouse, gearbox repair facility and full in-house heat treating.

Balzers Tool Coating—Booth #1207. The focal point of Balzers' booth will be the new Balinit HARDLUBE Coating, which was recently developed to provide wear advantages in the wet, mist and dry machining of gears. The product is a combination of Balzers' TiAlN (a coating designed for excellent oxidation resistance) and Balzers' WC/C (designed to combat adhesive wear and seizure problems). This unique combination provides an extremely hard, thermally stable TiAlN coating with the sliding and lubricating properties of an outer WC/C coating. HARDLUBE coating is on tools such as hobs and shaper cutters used to manufacture gears, while WC/C coating is applied to the gears themselves to ensure continuous smooth operation. In addition to protecting cutting edges from wear, HARDLUBE also assures reliable chip evacuation. This results in improved reliability in drilling and tapping as well as the potential of dry-machining steel and aluminum alloys.

Barit International Corp.—Booth #529. Barit has been supplying the gear industry with tools since 1989. From either their manufacturing facility or on-the-shelf inventory, they can supply hobs, shaper cutters, broaches and shaving cutters. Visit the booth for more details.

Bourn & Koch Machine Tool Co.—Booth #705. Bourn & Koch will be exhibiting the 100H CNC 4-axis gear hobbing machine. The machine has incremental hob shift, full enclosure and 2500 hob spindle. It was designed to hob AGMA class 10 gears up to 5" in diameter and 30" in length with an optional bed extension.

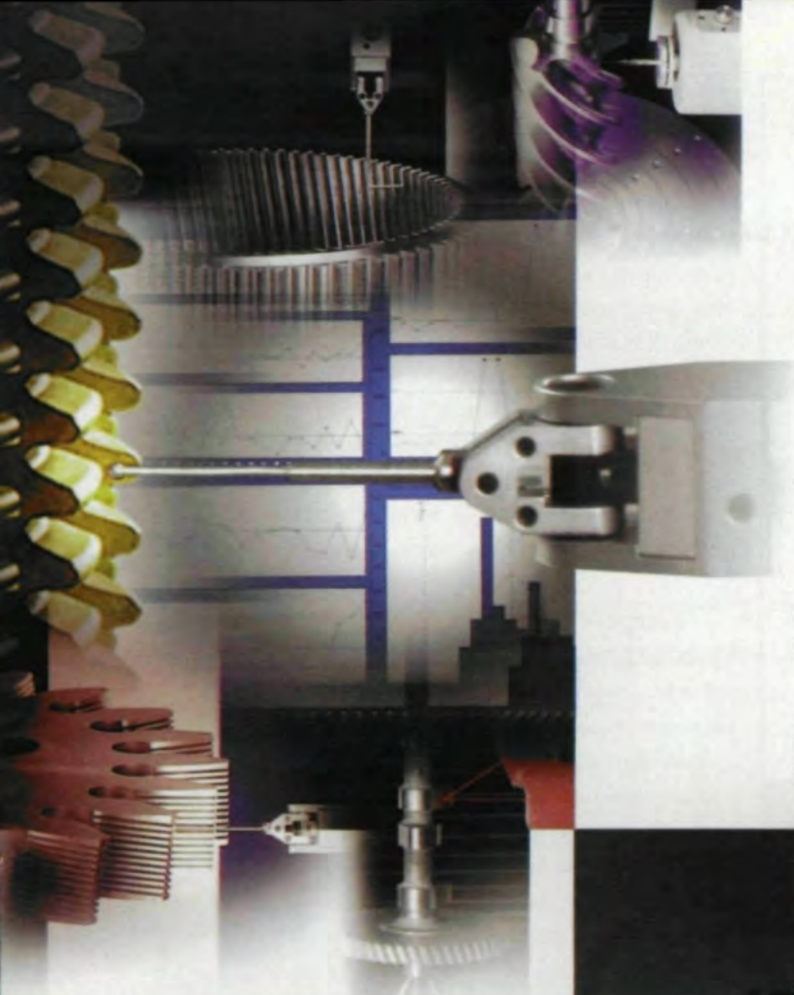
Chamfermatic Inc.—Booth #1042. Chamfermatic Inc. will be demonstrating their new concept in gear deburring. The model 1600 gear deburring machine uses carbide deburring, brushing or grinding wheels. This new technology will be seen for the first time at Gear Expo 99.

Cincinnati Gear Co.—Booth #715. Cincinnati Gear and BHS-Cincinnati are an international team of manufacturers specializing in high-performance gearboxes and power transmission components for industrial and marine applications. They will showcase couplings, turning gears, bearings and precision components for markets such as load gears and the automotive industry. On display will be an epicyclic gear set, a differential gear and TWINTORS diaphragm couplings.

Colonial Saw Company—Booth #1217. Colonial Saw will have on display the UTMA LC35-CNC NC tool grinder that can *sharpen end mills, milling cutters, shaper cutters and hobs. The* machine will handle straight or helical gashes, and it can sharpen high speed steel or carbide tools.

Crown Gear B.V.—Booth #1017. The Cylkro® angular face gear transmissions manufactured by the Dutch company Crown Gear B.V. have seen some significant additions and improvements in both technical features and applications since the show two years ago. The free choice of shaft angle, starting at 0°, has been widened from 110° up to 135°. The gear ratio to be realized in one stage is 20:1, for some applications even larger. Especially in the automotive and machine tools areas, several new designs were successfully completed using these new features. Visitors to the booth will be shown all new developments. Crown Gear welcomes visitors to bring drawings or designs to the booth to have a Cylkro layout drawn up.

Dura-Bar—Booth #1110. Dura-Bar is North America's only manufacturer of continuous cast iron bar stock and is the largest producer in the world. Dura-Bar is an engineered metal



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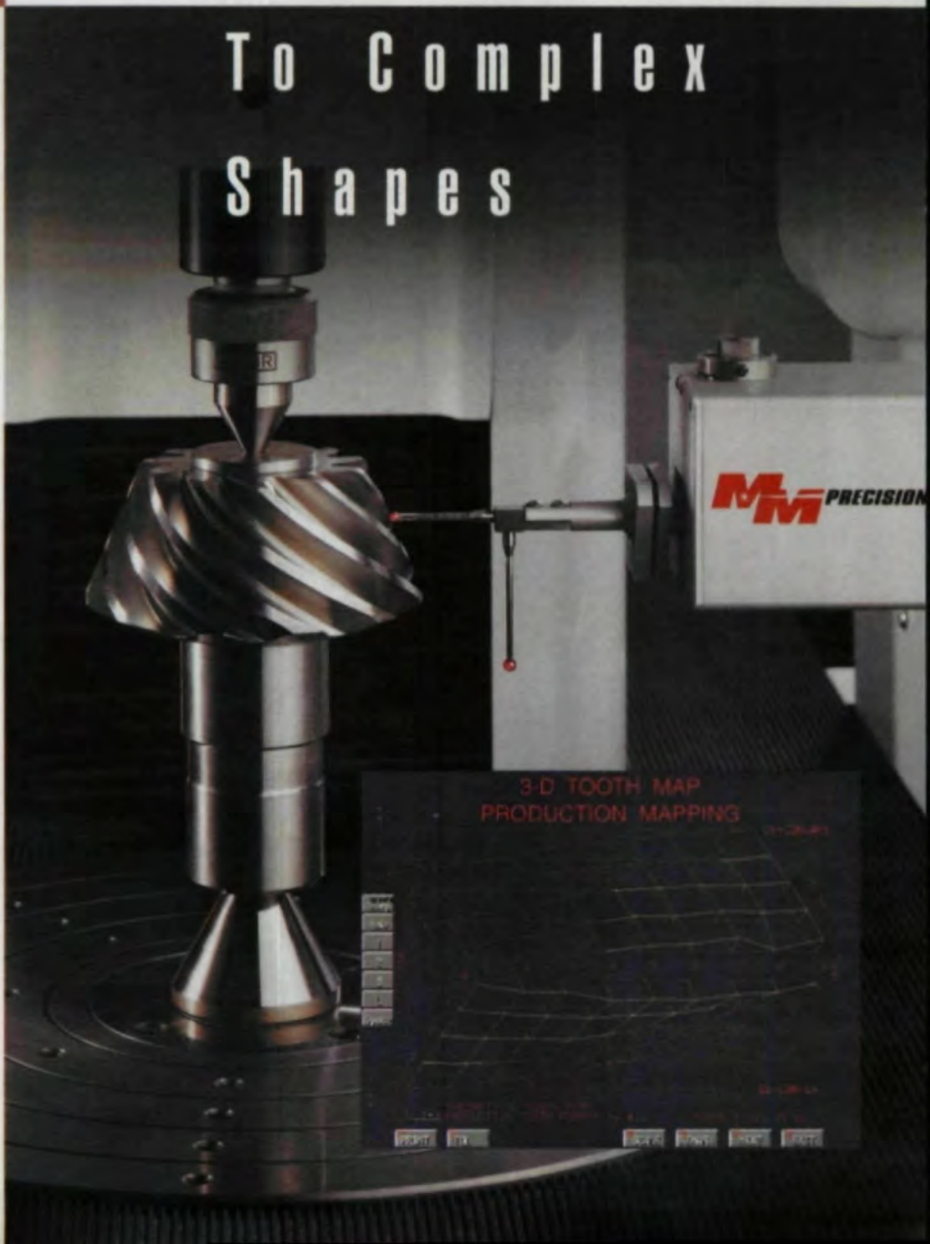

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with superior noise and vibration damping properties making it 3–10 times quieter than steel and 20–40% more machinable. This results in extended tool life. The continuous casting process produces a uniform, fine-grained microstructure. This eliminates the scrap from shrinkage, porosity, and tool-wearing inclusions that frequently occur in traditional castings. Dura-Bar can be austempered, through-hardened, flame-hardened, or induction hardened for added wear resistance. Dura-Bar is available in ductile, gray or special alloyed irons, in round bars from 5/8" to 20" diameters and lengths from 6' to 20'. It is also available in machined gear blanks. Dura-Bar, a division of Wells Manufacturing Company, has a nationwide network of distributors who maintain extensive inventories.

Emuge Corporation—Booth #1006. Emuge precision workholding/clamping technology products include mandrels, chucks, spindles, drawbars and diaphragm chucks. All are suitable for turning, grinding, hobbing, milling, drilling, lapping, balancing, centering, checking and assembling. They also offer mechanical clamping systems, mechanical-hydraulic clamping systems, hydrualic clamping systems, strain-gauge controlled clamping force and movement control, Emuge milling and threading tools, gear hobs, endmills, milling cutters, taps, tap holders, thread mills and thread gages.

Equotip Associates—Booth #1234. Equotip will be showing the ASTM-approved Equotip portable metal hardness tester, manufactured by Proceq S.A. They will also feature their Impact Device DL, which has an extremely slim and long front section (4 mm x 50 mm) for measuring hardness in hard-to-reach places like between gear teeth or on the teeth themselves.

Euro-Tech Corp./Frenco GmbH—Booth #1116. Euro-Tech will be exhibiting workholding and gaging products. Frenco is a German manufacturer of spline arbors and shop floor inspection gages for splines and gears. Product lines include the simple SPC compatible "Series V" indicating spline gages. The Universal Rotational Measurement (URM) gage simultaneously analyzes up to 8 individual shaft profiles (splines, gears, diameters, etc.) in an 8-second cycle time on the shop floor. Also displayed will be the Frenco dynamic spline gage system, measuring a complete internal or external toothed profile over its entire length. This system is capable of collecting 16,000 measurements per second over the entire length of the spline and feeding data into a PC utilizing Frenco dynamic gaging software, which displays complete profile and SPC charts and data. Euro-Tech will also display their line of hydraulic expansion chucks for quick change hobbing applications (arbor change in seconds), gear grinding arbors, gear hobbing arbors, gear shaving arbors, gear shaping arbors and gear inspection arbors. Typical runouts of these rupture-proof hydraulic expansion tools is less than .0001".

Power Integrated Pop-up™

Lift/Rotate Induction Heat-Treating System

Radyne's Power Integrated Pop-up™ heat-treat center is a self-contained system for hardening and tempering components in a lift/rotate, submerged quench method to meet the specific needs of the heat treater. A user-friendly machine interface panel and PLC control enable quick and easy setup and operation. An integrated, modern, efficient, transistorized inverter power supply can match a wide variety of heating coils with easy-to-change tuning capacitors and a multitap output isolation transformer.

The lift actuator assembly includes a ball bearing linear way mounted under a stainless steel sink through double lip wave seals. A chrome-plated stainless steel spindle is mounted on a tapered roller bearing, enclosed in a steel housing. The lift mechanism allows load/unload, heat and quench positions.

The Perfect Integration
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CIRCLE 139

Fairfield Manufacturing Co.—Booth #526. Fairfield Manufacturing Company, the largest manufacturer of gears and gear products in North America, will be displaying a wide range of gear types including spiral bevel gear sets, spur gears, helical gears, spur gear shafts, ring gears and several custom-designed gear assemblies. This display will be representative of their full range of capabilities including in-house heat treatment.

Fässler AG—Booth #328. Fässler will exhibit their all-new K-400-A gear honing machine with its new revolutionary force-controlled "Direct Honing"® process. Fässler claims this machine is setting new standards for stock removal, form geometry, gear durability and surface finish. Also on exhibit will be the unique HS-100 hard broaching machine used for improving or calibrating hardened internal splines and profiles.

Fellows Corporation—Booth #240. Fellows Corporation manufactures gear shaping machines, cutters, adapters and fixtures. The company offers full process integration and support. Complete Fellows machine remanufacture and retrofit is a specialty. A wide range of gear shaping machines stems from two basic lines: high performance Hydrostroke models, and traditional, crank-type 10-4 and 20-4 shapers. All are available with CNC control and equipment for fully automated production. Stock cutters and special designs are offered with competitive prices and deliveries.

GA-Heartland Machine Tool, L.L.C.—Booth #334. GA Heartland will display two models of high speed, dry hobbing gear cutting machinery: the XEROCUT 50H and 100H. Both models will be operational at the show. Notable features include a patent-pending chip disposal system that prevents the negative effects of heat buildup, minimal floor space, thru-the-spindle manufacturing capabilities, and built-in automation. The 50H will cut gears 3" in diameter, while the 100H will cut gears 5" in diameter. Both models will meet AGMA class requirements of 8 or greater. Additional information on these and other models will be available at the show.

GCTS, Inc.—Booth #716. GCTS represents the Swiss gear machinery manufacturers Lambert and Wahli AG. GCTS will bring three machines to the show. The Wahli 100 CNC is a new generation of high-speed gear hobbing machines developed for high precision pinion and face gear manufacturing with cutter rotation speeds up to 20,000 rpm. The Lambert 124 CNC is used in worm & thread milling shops around the world. Most of its benefits are in the flexible loading systems for high-volume, three-shift runs. The Lambert 7500 CNC is a flexible, fine pitch gear hobber with 8-axis control and a small footprint.

Gear Motions, Inc.—Booth #522. By combining a diverse group of specialized custom gear shops into one organization, Gear Motions offers its customers a broad range of solutions to their gearing problems. Nixon Gear offers state-of-the-art gear grinding on Reishauer and Gleason grinders as well as a commitment to continuous improvement. Nixon Gear is ISO 9002 registered. Oliver Gear manufactures large diameter, coarse pitch spurs, helicals, bevel gears, and racks. Reishauer gear grinding services now available. OEM and MRO services also available. Rawling Gear provides quick turnaround for short runs of commercial work. OEM and MRO services available.

Gear Technology—Booth #618. Stop by our booth for a chance to win a custom-made, one-of-a-kind gear clock. We'll tell you how *Gear Technology*, along with our Web sites, ***The Gear Industry Home Page™*** and ***powertransmission.com***, can help your company sell more of your products to your customers. No one else reaches the makers and buyers of gears like we do. We're the Gear Industry's Information Source.

Gleason Pfauter Hurth—Booth #100. Gleason Pfauter Hurth Worldwide Sales will exhibit a pair of new machines, the Gleason Pfauter GP130S gear shaper and a Gleason Honing Demo Module. A key focus of the exhibit will be a video wall with eight application videos focusing on wet and dry hobbing, optimizing the process, bevel gear Power Dry cutting and shaving in one-half the time on the new Hurth ZS130 T gear shaving machine.

GMI—Booth #500. GMI will feature carbide and HSS hobs, Maag cutting tools, bevel gear cutting tools, gear testers (flank rolling and over pins), hard turning machines, robotic deburring, robotic induction hardening, hob honing machines, hard gear finishing tools/wheels, diamond dressing gear forms, diamond dressing cylindrical forms, CBN tooth profile grinding wheels and gear deburring machines

Great Taiwan Gear—Booth #823. Great Taiwan Gear Ltd. will be showing the following products at Gear Expo 99: Gear heads for AC, DC, stepping, and induction motors; fine pitch gears with crown and skive hobbing after heat treatment to reduce noise and compensate for misalignment; gears for aerospace, automotive (transmission gears), machine tools, gear pumps and other power transmission applications; worm and worm gears for Hitachi elevators; gear reducing/increasing boxes; hobs and shaving cutters. They also produce bevel gears, coarse pitch gears, and herringbone gears.

Hermes Abrasives—Booth #608. Hermes Abrasives, Ltd. will be featuring a variety of precision grinding wheels specific to the gear industry. Continuous gear grinding wheels, as well as inner-toothed and outer-toothed honing rings, will be on hand for viewing. Technical product engineers will be on-site to discuss and recommend solutions to your grinding problems.

Höfler Maschinenbau GmbH—Booth #122. Höfler will introduce at Gear Expo in Nashville the completely new Helix 400 gear grinder for gears up to 16 inches in diameter. Höfler claims that the Helix is "most likely faster, more accurate, more flexible and more affordable than any other gear grinder."

Holroyd—Booth #217. Holroyd, part of Renold Precision Technologies, demonstrates its worm and thread milling/grinding capabilities with a display of precision components manufactured on Holroyd machines. Holroyd is also demonstrating its on-machine coordinate measuring systems—which eliminate the need for off-machine inspection—and its capabilities for sub-contract helical screw and worm gear manufacture. The company supplies helical screws from 0.3" to 33" diameter, screws for compressors and pumps, worm gears up to 41" centers, and adjustable backlash worm gears. Worm gear accuracies up to AGMA 14 can be supplied.

ITW Heartland—Booth #900. ITW has been a pioneer in the gear inspection industry since 1936. Today ITW Heartland remains a worldwide leader in functional gear inspection and gear burnishing. ITW Heartland builds a full line of functional gear inspection equipment from simple, hand-roll composite gear testers to high speed, fully automatic inspection machines.

At this year's Gear Expo, they will display the Model 2375 (course pitch) and Model 2306 (fine pitch) in-process gear inspection equipment. These units will demonstrate the latest developments in gear inspection software. In addition, ITW will be demonstrating the effectiveness of their burnishing process for improving the quality of the active tooth profile surface of the gear.

JRM International—Booth #314. JRM International is a customer driven, highly responsive supplier to the gear industry. They represent manufacturers that allow them to provide single-source standard solutions to your manufacturing challenges. Visit booth #314 to see Saacke hobs and hob sharpener machines, Kesel rack milling machines, Burka-Kosmos grinding wheels, and Schrem locking nuts.

Kapp GmbH—Booth #340. Kapp GmbH, along with affiliated companies Niles, Kapp Sales & Service and Kapp Tech, will display machine modules demonstrating external and internal gear and profile hard finishing. Kapp and Niles machines are capable of hard finishing gears and profiles using four technology concepts: form grinding with CBN profile grinding wheels; form grinding with dressable grinding wheels; form generation with dressable or non-dressable wheels; and coroning. Coroning is a unique, efficient, hard gear finishing process using non-dressable CBN coroning rings.

Koepfer America LLC—Booth #320. Since 1867, Jos. Koepfer & Sohne, GmbH, has provided quality machines and cutting tools for the parallel axis gear industry. The complete range of Koepfer cutting tools will be displayed, including hobs of high speed steel, powdered metal and carbide materials. The Koepfer Model MZ120 is a new CNC fine pitch hobbing and milling machine that offers total flexibility with the ability to hob gears as well as mill single or multi-start worms. A universal loading and unloading system will be fitted to the machine. The Koepfer Model 160 CNC hobbing machine offers high speed wet or dry hobbing. The Koepfer Model KFS100 CNC hob sharpening machine with four-axis control is suitable for straight gash hobs of high speed steel or carbide materials.

Liebherr Gear Technology—Booth #812. Liebherr Gear Technology Co. is your North American access point to Sigma Pool's broad range of technically advanced gear manufacturing technologies and processes, including your gear hobbing, generating, shaping, inspection and testing challenges. Liebherr is an ISO 9001 certified manufacturer of CNC gear cutting machines and material handling automation. They are also a Ford Q1 preferred supplier. At the booth you'll also find equipment from Liebherr's Sigma Pool partners, including Klingelnberg CNC Gear Measuring Centers, Lorenz CNC gear shapers and Oerlikon CNC spiral bevel gear manufacturing and testing equipment.

M&M Precision Systems Corp.—Booth #216. M&M Precision Systems will display a complete line of computerized analytical and functional gaging systems, plus the exclusive GearNet™ server that automatically shares data for SPC, remote analysis and archiving. M&M CNC Process Control Systems offers full four-axis flexibility, unsurpassed accuracy and up to 20% faster throughput. A wide selection of gear inspection software includes a bevel gear machine correction package.

Machine Tool Builders, Inc.—Booth #1236. Machine Tool Builders, Inc. will be displaying modular tooling designed to meet the needs of end users. The tooling on display will demonstrate the flexibility of modular tooling design. End users will be able to remove workpiece specific portions of the fixture and quickly adapt different fixturing specific to the individual workpiece with a minimal amount of setup time. MTB can offer tooling design consultation and will custom design fixturing to meet your needs. MTB has over ten years of automation design experience and can help you with your part handling and production requirements. MTB will have sample drawings on display exemplifying their capabilities in the tooling and fixture fields.

Macsteel—Booth #1120. Macsteel is an engineered bar producer headquartered in Jackson, MI, with world-class steel manufacturing plants in Jackson, MI, and Fort Smith, AR. Steel processing plants are located in Huntington, IN, and Pleasant Prairie, WI. Macsteel utilizes electric arc furnaces, ladle furnace refining, vacuum arc degassing, advanced rotary continuous casting, direct twist-free rolling, turning and grinding, and heat treating to produce engineered SBQ carbon and alloy hot rolled and bright cold finished seam-free® steel bar products. Macsteel customizes each batch of steel to specific end applications.

Mahr Corporation—Booth #206. Mahr's involvement in gear testing dates to 1923, when Carl Mahr developed the world's first involute profile instrument featuring variable adjustment of the base circle. Today, Mahr Corporation is an ISO 9001 certified supplier providing hand-held gear measuring tools including base pitch testers, snap gages and tooth span gages, plug gages, ball and anvil type bore gages, thread gages, PC-controlled double flank roll testers, CNC analytical gear and form testers, surface finish test equipment for gear tooth profiles, and their exclusive WinGear control and evaluation PC software. They also provide technical service, replacement parts and instrument calibration services.

Merit Gear Corporation—Booth #501. A full service gear producer, manufacturing custom powertrain components, specializing in spur and helical gears, splined shafts, couplings and sprockets. Capabilities include CNC ground gearing up to AGMA class 12 supported by a complete modern gear lab with state-of-the-art CNC gear inspection. Merit also offers a modern heat treating facility specializing in gear hardening with special attention given to distortion control and dimensional stability.

Milwaukee Gear Company—Booth #1124. Milwaukee Gear is a leading manufacturer of custom, high quality gearing. They offer an array of hobbed, shaved and precision ground gearing with a capability to produce up to AGMA class 14 ground gears in pitch diameters from .25" to 63". Using the latest, most sophisticated metallurgical testing equipment and personnel, Milwaukee Gear consistently achieves customer requirements with tighter control on production.

Mitsubishi Machine Tools USA Inc.—Booth #532. Mitsubishi Machine Tools will display their GN10 and GN20 "Super Dry" dry gear hobbing machines, which eliminate the need for coolant, double productivity and reduce production costs by 40% with a cutting speed twice as fast as standard hobbers. The Super Dry machines also extend tool life five times over wet cutting due to Mitsibushi's distinctive hob made of MACH 7 material and treated with a proprietary coating for sustained gear quality. Mitsubishi will also display their ST25CNC gear shaper, which eliminates the need for helical guides with a revolutionary mechanism that allows helical gears to be cut by setting the helix angle on the Windows-based CNC control.

Moore Measurement Solutions—Booth #941. Moore measurement solutions is a leading supplier of precision dimensional measurement systems for the gear industry, specializing in tight mesh (double flank) gear inspection equipment. Their preengineered solutions include fully automatic in-line gear checkers, semi-automatic operator-loaded gages, manual gear rolling fixtures, manual pitch diameter (over ball) gages, and automatic gear blank/bore size gages.

Multi-Arc, Inc.—Booth #701. Multi-Arc is a worldwide supplier of thin coating services and equipment with operations in North America, Europe and Asia. Their coatings provide increased wear resistance, corrosion resistance and performance to industrial cutting tools, metal forming dies, plastic molds, wear parts and medical devices. Multi-Arc coating centers offer the latest in thin film coatings and surface enhancement technology. Cathodic Arc PVD, enhanced arc PVD, unbalanced magnetron sputtering, chemical vapor depostion (CVD) and vacuum heat treatment services are available through Multi-Arc. In addition, many coating centers are equipped to provide edge conditioning, polishing services and tool grinding. Multi-Arc has also implemented coating standards at all ION BOND® centers worldwide. A first of its kind in the thin film coating industry, this program has established standards for hardness, adhesion, surface finish and color. Customers are assured of receiving consistent coating properties regardless of which Multi-Arc facility coats their parts.

National Broach & Machine Co.—Booth #300. National Broach & Machine Company will be demonstrating their latest low-cost internal & surface NBV broaching machines and their space saving high quality CNC gear shaving machine.

Also, they will demonstrate the latest in precision gear grinder enhancements. "Red-Ring"/Kashifuji hobbing machines will also be showcased in addition to all "Red-Ring" brand quality gear generating and finishing tools.

Nissei Corporation of America—Booth #1121. Nissei is a designer and manufacturer of precision fine pitch gears and gear assemblies supplying OEM customers. Visit the Nissei booth to see examples from the automotive, general industrial, hand power tool and electric motor marketplaces including steering, actuator, automation and armature shaft applications.

Nye Lubricants, Inc.—Booth #621. Nye Lubricants, Inc. is an engineering company dedicated to formulating high quality synthetic lubricants. Their gear greases and oils are specified in a full range of industries, including automotive, aerospace, appliance, textile, paperboard manufacturing, medical & dental equipment, power tools and recreation equipment. Founded in 1844, they maintain regional engineering offices throughout the United States, and they have agents and distributors around the world.

On-Line Services—Booth #135. Stop by the OLS booth to see the latest in deburring and chamfering. Highlights include information and examples on a variety of deburring processes for a wide range of parts. This year's focus will be on the use of brushes in gear deburring. OLS deburrs more than gears, and they'll be available to talk about your burr problems.

Perry Technology Corporation—Booth #908. Perry Technology Corp. advertises itself as "The Gear and Spline Experts." Their staff will be available to talk about your future gearing requirements and the design and manufacturing options for your product. View highlights of their state-of-the-art 50,000 square foot manufacturing facility and see samples of the various complex gear forms they produce.

Presrite Corporation—Booth #626. Presrite has invested millions of dollars to build a world-class gear forging plant, a dedicated facility equipped with a state-of-the-art gear lab, high-capacity presses and the latest in sophisticated machinery. Presrite hot forges gears to near-net shapes weighing as much as 300 pounds and measuring up to 450 mm in diameter. Little or no hobbing is required because of the tight tolerances achieved. The inherent strength of the forging is maintained while costly roughing and finishing operations can be eliminated.

Process Equipment Co.—Booth #1030. Process Equipment Company has been designing and manufacturing special machines for over 50 years. They will be displaying the ND 430 "Next Dimension"® gear measurement system. The ND 430 utilizes a Renishaw® 3-dimensional scanning probe head to measure tooth alignment, profile, index and root radius in its linearly and volumetrically mapped measuring envelope. Other products include their laser and capacitor discharge welding machines, which are used to join gears or other rotary components to like or dissimilar metals.

Profile Engineering—Booth #1005. Profile Engineering will unveil their newest model in double flank computer composite gear analyzing. The PC-8 Composite Gear Analyzer® will feature versatility of design for checking internal gears. The latest software will demonstrate automatic nick removal.

Quality Transmission Components—Booth #1137. Quality Transmission Components (QTC) has been the exclusive North American distributor for Kohara Haguruma Kogyo K.L. (KHK Co., Ltd.) of Saitama, Japan, since 1985. KHK (Kohara Gear) is the largest independent gear manufacturer in Japan, manufacturing over 3400 standardized coarse pitch metric gears and related items. Well equipped with the most up-to-date, sophisticated gear cutting and grinding equipment, KHK serves the gear needs of many Japanese OEM manufacturers. Their stock catalog includes spur gears, racks, bevel gears, internal gears, spiral bevel gears, helical gears, involute splines, pawls, ratchets, worms and worm wheels, ranging in sizes from module 0.5 to module 10. Quality Transmission Components is a leading supplier of metric gears throughout the United States, Mexico and Canada. They maintain a complete inventory of KHK's product line at their warehouse in New Hyde Park, New York, and require a minimal time to access the factory's inventory. In addition to the standardized QTC product line, QTC can also provide custom gearing with a minimum quantity of one and a maximum quantity of 500 per month.

Reishauer Corporation—Booth #138. Reishauer will be demonstrating the new RZ 300E, the machine that paved the way for one of the most popular and successful lines of continuous generating gear grinders on the market today. The RZ 300E is capable of grinding spur and helical gears to AGMA quality 15 economically and productively. In addition, the Richardon R200CNC hobbing machine will be on display, offering fast setup, large work envelope, high quality and excellent machining times.

Reliance Gear Corporation—Booth #619. Reliance Gear specializes in spiral bevel gears up to 33" in diameter with equipment that can produce, verify and chart through AGMA Class 13. They produce the "cut" gear using CNC 6-axis Gleason Phoenix Generators. Their CNC 463 and late model 463 Gleason Grinders produce the spacing and surface finishes that AGMA Class 13 tolerances demand. They are "on line" with The Gleason Works, allowing their setup men to have the very latest technological assistance at their finger tips. They can also produce straight, coniflex, hypoid and zerol bevel types. Parallel axis capabilities go to 26" and include spurs, helicals, splines, worms and worm gears. They produce most of their own gear blanks in a CNC lathe and machine center.

REM Chemicals—Booth #1138. Rem Chemicals is a provider of a specialized metal finishing process to reduce both friction and wear in moving parts such as gears, pistons, crankshafts and rocker arms. The chemically accelerated mass finishing process forms a smooth, randomly patterned surface rather than the ridge lines that are commonly left by standard mechanical finishing such as grinding. This type of isotropic finish has become the standard in aerospace manufacturing, reducing friction and heat on operating turbine compressor blades and other components.

Roto-Technology, Inc.—Booth #920. Roto-technology, Inc. will be introducing its newest CNC analytical automatic gear tester, the Model RC-400-16. This system will test gears, hobs, camshaft gears, worms, splines, ring gages, internal and external gears. This system utilizes a Pentium computer, an SVGA color monitor and a high speed laser printer. It is a new low-cost system that is easy to use and accurate. The tester is built on a granite base and steel stand with high frequency vibration pads, which makes it stable and durable. The linear axes, X,Y, and Z provide smooth and accurate movements and positioning for various types of inspection requirements. The basic system includes software to inspect index, pitch space variation, lead (TAV) and involute profiles on spur and helical gears. System sizes range from 6" up to 84". A line of CNC rotary tables will also be on display.

S.L. Munson & Co.—Booth #233. The S.L. Munson booth will feature Dr. Kaiser precision diamond products for gear dressing. Dr. Kaiser produces direct plated and sintered construction products in a full range of modules and pressure angles. Applications available for most dressing systems including Reishauer, Fässler, Gleason, Hodlund, Normac, G11, Liebherr, Csepel and Niles.

Seitz Corporation—Booth #722. QS-9000 certified Seitz Corporation provides design, development, production, and contract assembly for gear driven and linear-motion products. Seitz manufactures injection molds for high-tolerance complex products and assemblies and specializes in complete gear train design utilizing Pro/Engineer and UTS software. Seitz can also convert drive systems from metals to plastics for cost reductions and higher performance. Connecticut, Illinois and Colorado locations.

Speedgrip/Cameron, Inc./Madison Face Driver—Booth #1020. Speedgrip Chuck, Inc. offers a standard line of I.D. gripping collet chucks that provide .0005" accuracy as standard. When standard chucks or arbors won't do, Speedgrip's design & build capabilities can provide special workholding solutions with I.D. and O.D. collet chucks, diaphragm chucks, hobbing arbors, and other made-to-order designs to meet your gear processing needs. Cameron, Inc. provides high accuracy hydraulic workholding solutions to meet your gear machining and inspection needs when .0002" or better tolerance is an issue. Through the use of Cameron's sleeve design and grinding process, greater expansion and more accurate centralization can be achieved. Madison Face Driver provides "productivity solutions" with its line of hydraulic, elastomer and quick change face drivers. For hobbing applications, Madison uses a solid drive ring design to maintain rigid part position with no radial movement to ensure an accurate tooth form.

Star Cutter Company—Booth #800. Star Cutter Company will have the following on display: hobs, gun drills, gun reamers, milling cutters, diamond tools, carbide preforms, thin film coatings and solid carbide tools. They will also exhibit their UTG-1200 Universal Tool & Cutter Grinder, which grinds round broaches, flat broaches, hobs, and shaper cutters.

SU America—Booth #700. Samputensili (SU) employs 470 people worldwide. It is part of the Maccaferri Industrial Group, based in Bologna, Italy. Samputensili is present today in 11 different countries, 5 of which include manufacturing facilities for the production of gear cutting tools and machines. SU can design and build the entire gear cutting tool range, including solid hobs (HSS and carbide), shaper cutters, shaving cutters, chamfering tools, deburring tools and master gears, as well as provide several supporting services, including tool coating and resharpening, to meet all customers' needs. SU also provides CNC gear form grinders, CNC shaving cutter grinders and chamfering and deburring machines.

Ticona—Booth #936. Ticona is a leading supplier of high performance polymers used in gearing applications. With a broad product range and strong application development and technical support, Ticona helps customers worldwide realize the many benefits of using plastic gears, including cost, weight and noise reduction. Their product portfolio includes Celcon® acetal copolymer, Fortron® PPS, Celanese® nylon 6/6, Celanex® PBT, Impet® PET, Vectra® LCP and Celstran® long fiber reinforced thermoplastics.

Toolink Engineering—Booth #117. Toolink Engineering is the exclusive North American distributor of königdorn hydraulic arbors, chucks and other specialized work holding devices manufactured by könig mtm in Wertheim, Germany. For more than 30 years, könig mtm has manufactured tooling customized for each application. Applications include turning, milling, grinding, balancing, drilling, measuring and inspection.

TSK America—Booth #832. The Radiance Radial Measuring System (RMS) from TSK America, Pine Brook, NJ, is designed as a solution to complex rotary measuring challenges. The Radiance can complete a full radial scan of parts without probe changes or reorientation. The machine design allows unrestricted rotary scanning of parts such as gears, cones, cylinders and other solids with reduced cycle times and improved accuracy. The measuring range of the machine is one meter horizontal diameter and 0.6 m vertically. The machine occupies less than 2.5 square meters of floor space. The Radiance can measure all the features of a gear in a single setup such as teeth, shaft diameters, faces, and bolt hole circles, replacing the typical combination of coordinate measuring machine and gear checker. The machine can be supplied with proprietary gear software to facilitate complete, rapid, accurate gear inspection.

Unique Power Products—Booth #842. Unique Power Products, Inc. is a wholly owned subsidiary of Unique Mobility, Inc., a custom developer and manufacturer of brushless PM electric motors and controls, electronic assemblies, gears and gear assemblies for the automotive, industrial and aerospace markets. The UPPI Gear Division produces precision internal and external gears from AGMA 9–14 and has machine shop capabilities to manufacture complete parts or provide gear tooth or special form grinding on Kapp CNC gear grinders.

Universal Technical Systems—Booth #1113. UTS invites you to see GearLink, an easy and accurate means to create Pro/Engineer and AutoCAD models and engineering drawings of gears. Also being demonstrated are the latest versions of design and manufacturing software for metal and plastic gears. UTS is one of the leading providers of gear and other engineering software products.

Xtek, Inc.—Booth #503. Xtek custom designs, heat treats and manufactures spur, helical, double helical and bevel type gears. They are ISO 9001 certified and manufacture gears ranging from AGMA 6 to AGMA 12 quality levels. Their dimensional capabilities range from 10" to 216" in diameter and .375 to 16 DP. They will display their capabilities and distribute information at the show. ○

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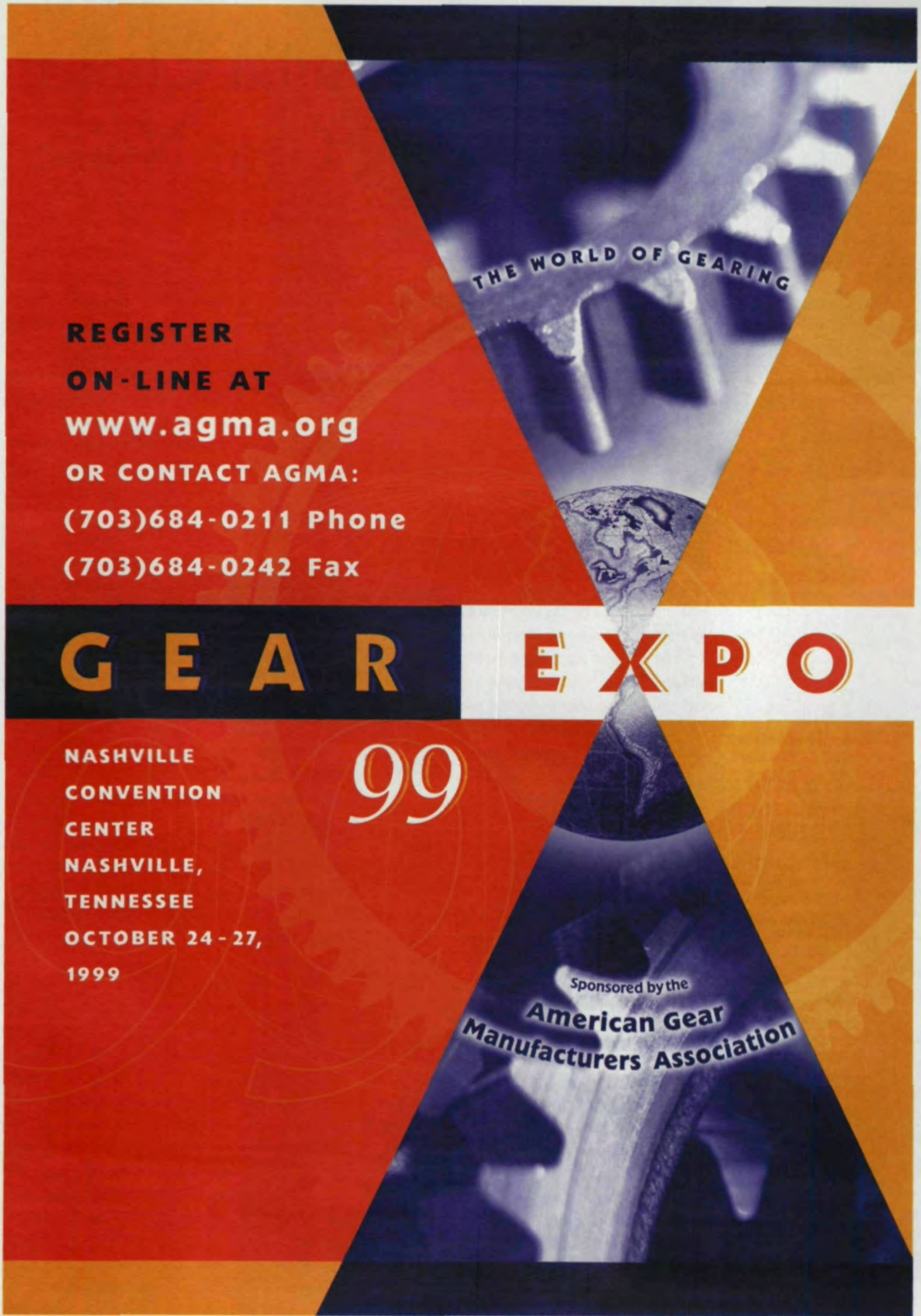
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CIRCLE 133

Cast Iron: A Solid Choice for Reducing Gear Noise

Robert O'Rourke and Matt Grander

Material selection can play an important role in the constant battle to reduce gear noise. Specifying tighter dimensional tolerances or redesigning the gear are the most common approaches design engineers take to minimize noise, but either approach can add cost to the finished part and strain the relationship between the machine shop and the end user. A third, but often overlooked, alternative is to use a material that has high noise damping capabilities. One such material is cast iron.

Cast iron is well known for being highly machinable, but it is often neglected as an engineering material because of the misconception that it is weak and brittle. While it's true that the gray irons are relatively brittle, ductile iron is not. Gray iron contains graphite in the form of flakes, while ductile iron contains graphite in the form of small, rounded nodules in a metal matrix. Ductile iron's mechanical properties are similar to those of carbon steels with a similar matrix:

	80-55-006 Ductile Iron 1141	Carbon Steel
Tensile Strength (psi)	80,000 (min.)	98,000 (typical)
Yield Strength (psi)	55,000	52,000
Elongation	6%	22%

NOTE:

- Ductile iron properties are minimum as specified in ASTM A536, grade 80-55-06.
- Carbon steel values are typical and not to be used for design purposes.
- Source for carbon steel values: *ASM Metals Reference Book.*

Cast iron's lack of use could also be attributed to the fact that many designers do not recognize the complex nature of the material or the wide number of applications for which it can be suitable. It is important to note that cast iron is not one material but a family of grades, each with its own characteristics. For example, tensile strengths range from 20,000 psi in the ferritic gray irons to 230,000 psi in the austempered ductile irons. Tensile strengths in steel gears typically will be higher than those found in cast iron. For comparison purposes, carbon steel has tensile strengths ranging from 100,000 psi to 250,000 psi, depending on the type of heat treat.

Cast iron's matrix structure resembles that of steel—the most commonly used gear material. Both are ferrous materials that are alloyed with carbon. Carbon combines with iron to form pearlite, which consists of alternating plates of hard iron carbide and soft ferrite. The carbon content controls the pearlite content in steel. High carbon steels contain more pearlite than low carbon steels. The pearlite content in cast iron is controlled by the cooling rate of the casting and the addition of pearlite stabilizing alloys. The balance of the matrix is pure iron ferrite. The pearlite-to-ferrite ratio influences strength, hardness and machinability in cast irons and steels.

Cast iron is a composite metal consisting of precipitated graphite in a metal matrix. The size and shape of the graphite particles influence most of the mechanical properties in a cast iron part. Ductile iron has spherical graphite and therefore has higher tensile strengths than gray irons that are made of flake graphite (Fig. 1). Graphite's ability to act as a natural chip breaker gives cast iron its desirable free machining characteristics.

Ductile and Gray Iron

Ductile and gray iron are the two types of cast iron most suitable for gear manufacturing. Ductile iron with a ferritic matrix has machining characteristics similar to 12L14 steel. Increasing the amount of pearlite improves wear resistance. A fully pearlitic ductile iron has optimal cast tensile strength (up to 100,000 psi) with a hardness of 302 BHN. Heat treating will increase strength to 120,000 psi when quenched and tempered, and up to 230,000 psi when austempered.

All types of cast iron—from gray to ductile—reduce noise because of the inherent sound

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damping properties of the metal. This is due to the graphite content of cast iron, which gives it optimal noise reduction capacity. Precipitated graphite particles absorb noise vibration; therefore, the relative damping capacity of ductile iron is twice that of steel. Gray cast iron has twice the damping capacity of ductile iron. The relative damping capacities of steel, ductile and gray iron are illustrated in Figure 2.

Ultimately, material selection for gears depends on what the application requires—the amount of damping desired and the required mechanical properties in the gear tooth. One example where cast iron was the best material choice involved the balance shaft in an automobile manufacturer's four-cylinder engine. Significant noise reduction was achieved after the gear material was changed from steel to ductile iron. No alterations to either the gear's design or dimensional tolerances were necessary to obtain these results. The switch to ductile iron also yielded a significantly lower machining cost.

Converting to ductile iron is not recommended in cases where added strength is required because of fatigue failures. Also, gears that are subject to high impact forces may not be suitable for ductile iron. It is important to understand the forces acting on the gear as well as the required safety factors before making a switch to ductile iron.

Despite its desirable noise reduction capabilities, the historic use of iron in gear manufacture goes back less than 30 years. Austempered ductile irons (ADI) began to be used as a material for gears in the 1970s when Kymi Kymmene Metall, a Finnish company, achieved excellent results after replacing forged steel with ADI. In 1977, General Motors converted a forged and case-hardened steel ring gear and pinion to ADI for its line of Pontiac rear-drive cars and station wagons. Another significant gain for iron came in 1983, when Cummins Engine Co. began using ADI for timing gears produced to AGMA Class 8 standards (Ref. 1).

ADI paved the way for steel conversions, but gray iron has been used for years in automotive applications. Distributor gears, oil pump gears and camshaft gears are made out of alloyed gray cast iron primarily because it is easy to heat treat and offers excellent wear resistance.

Cast iron, both gray and ductile, is easily heat treated because of the level of carbon present. Low carbon steels, such as 8620, must first be carburized, then quenched and tempered.

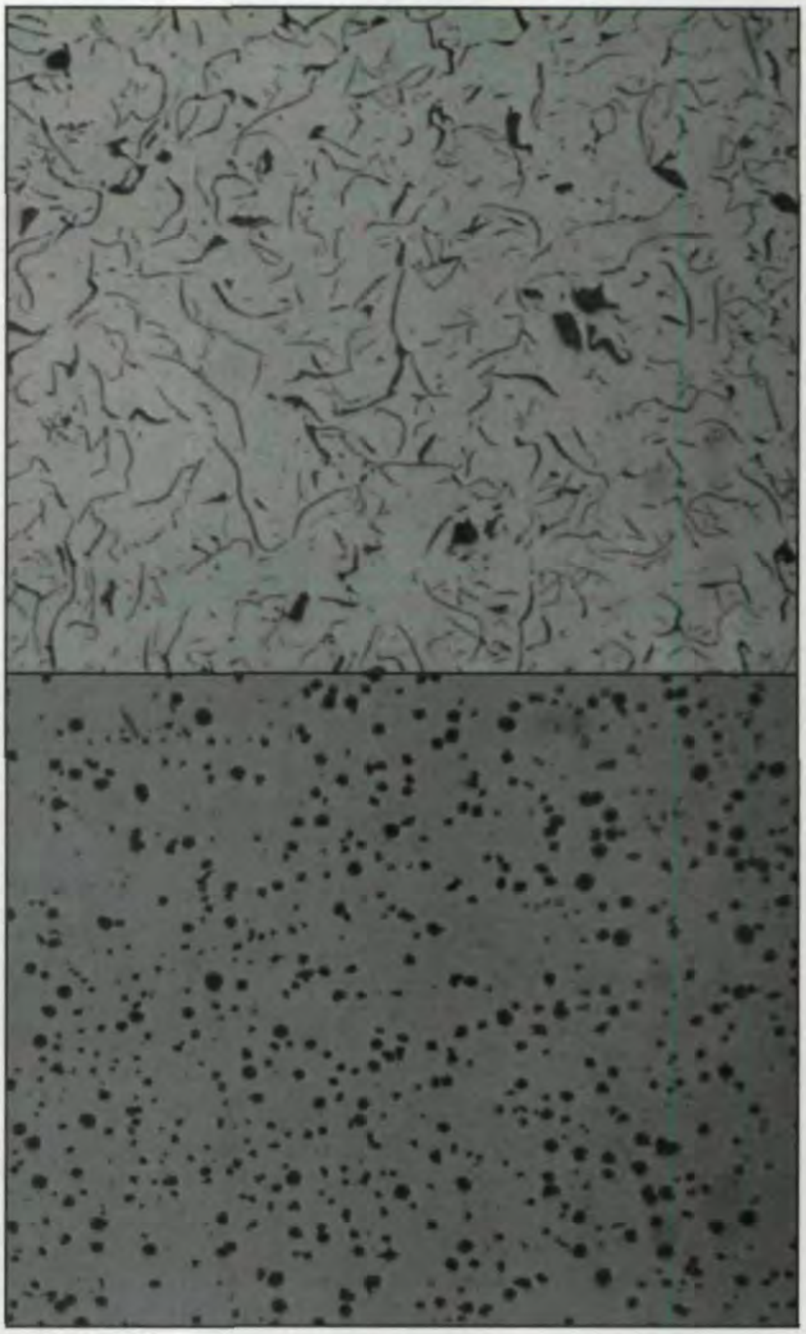

Fig. 1 — Flake (top) versus nodules (bottom) graphite cross sections.

EFFECT OF GRAPHITE SHAPE ON MECHANICAL PROPERTIES		
	Flake Graphite	**Nodular Graphite**
Tensile Strength (ksi)	20-50	60-230
Yield Strength (ksi)	n/a	40-185
Elongation (%)	n/a	2-18 (minimum)
Torsional Strength	50% of tensile strength	90% of tensile strength
Shear Strength	150% of tensile strength	90% of tensile strength
Impact Strength (ft-lbs)	1-5	10-25
Fatigue Strength (ksi)	20	40
Modulus of Elasticity (psi)	18 million	25 million
Vibration Damping (relative to carbon steel)	60 times	10 times

Source: *Iron Castings Handbook*

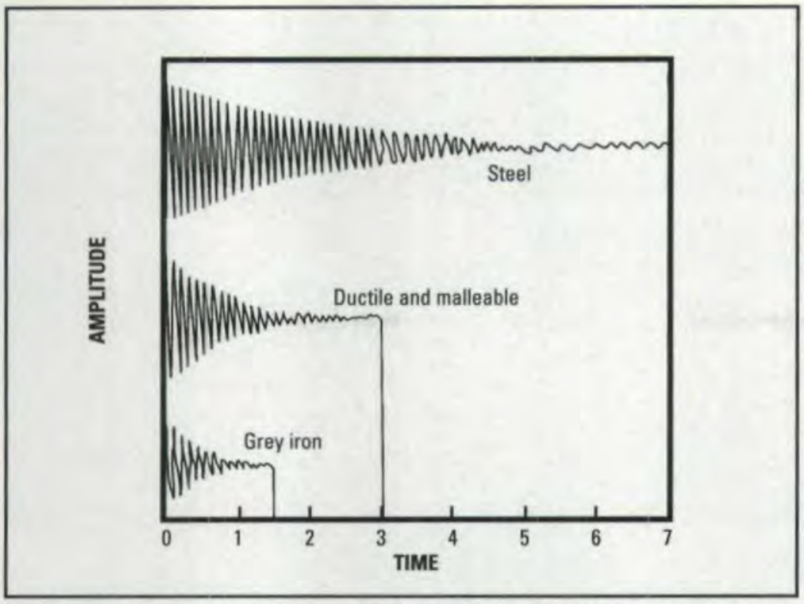

Fig. 2 — Relative damping behaviors of steel, ductile & malleable irons and grey iron.

MECHANICAL PROPERTY COMPARISON Steel v. Continuous Cast Iron				
Steel Grade	**Tensile (psi)**	**Yield (psi)**	**Elongation (%)**	**Machinability Rating (based on 1212 = 100%)**
1018	61,000	47,000	37	70%
1045	85,500	54,300	28	60%
1141	99,000	61,000	25	67%
12L14	78,000	60,000	17	180%
Dura-Bar Grade				
65-45-12	65,000	45,000	12	150%
80-55-06	80,000	55,000	6	100%
100-77-02	100,000	70,000	2	80%

Reference only, not typical or minimums Source: *ASM Metals Reference Book*

Fig. 3 — Mechanical Property Comparison, steel versus continuous cast iron.

Fig. 4 — Continuous cast iron production.

Cast iron has plenty of carbon available and is easy to heat treat.

In metallurgical terms, "heat treat" means the matrix must be transformed to austenite prior to quenching in order to achieve the required hardness. The solubility of carbon in austenite is 2%. The higher the carbon in austenite, the higher the hardness when quenched.

Since carbon makes up only 0.20% of 8620 steel, there is not nearly enough to maximize the quench hardness. Additional carbon is introduced into the matrix by a diffusion process called carburizing. The carburized depth determines the hardness depth after heat treating. The rule of thumb is that it costs about $0.01 per 0.001" depth of hardness, and you haven't paid for the heat treat yet.

So, to heat treat to 0.100" depth, carburizing would cost $1.00, and quenching and tempering would cost the same as it does in iron. Cast iron—both gray and ductile—does not have to be carburized prior to heat treating because it is made up of at least 2.5% carbon.

However, cast iron is still not widely accepted as a suitable material by many gear manufacturers. Manufacturers who are set up to machine steel bar stock may be reluctant to change to cast iron for several reasons. The initial pattern cost is one reason. Castings are made in sand molds, and patterns are required to produce the shape of the mold cavity. Iron is poured into the cavity to make the part. Patterns can cost up to $20,000 each to produce. In addition, manufacturers set up to machine bars have bar feeders and machining centers designed to handle bars, not cast slugs. Therefore, switching to iron castings means having to retool the machining center. Manufacturers may also be reluctant to switch because of typical quality problems associated with statically cast iron blanks, such as sand and slag inclusions, hard spots, shrinkage and porosity. Cast iron can also be dirty to machine because of its graphite content.

Continuous Cast Iron

There is an alternative to sand-cast iron blanks that overcomes many of these obstacles. Cast iron also can be produced through continuous casting, a unique process that produces a material that is almost perfectly suited for gear manufacturing. Figure 3 compares the properties of continuous cast iron with those of steel.

Continuous cast bar stock eliminates issues associated with pattern and retooling expenses. Manufacturing this highly machinable material involves a water-cooled graphite die mounted on the base of a refractory lined crucible. Molten iron enters the die and a solid skin begins to form around the perimeter of the bar. As the bar is pulled through the die, the solid skin becomes thick enough to support the molten iron core. The only part of the bar that is solid immediately outside of the die is the rim.

Heat from the molten iron core re-heats the rim above the critical temperature, and the entire bar cools in still air, eventually to room temperature (Fig. 4). The reheating of the rim and uniform cooling create a homogenous, consistent structure throughout the cross section. This eliminates the cracking and porosity problems commonly encountered with sand casting.

The die/cooler system is mounted on the bottom of the bar machine. Slag, dross and tool wearing inclusions float to the top of the crucible, well away from the entrance end of the die. The ferrostatic head from the molten metal in the bar machine crucible feeds iron under pressure into the die and eliminates microshrinkage that can have a detrimental effect on fatigue properties in the gear teeth. The clean, fine grain microstructure makes continuous cast iron an excellent starting material for gears, as it shares the same optimal noise damping capabilities as other types of cast iron.

Although machining continuous cast iron is still "dirty" because of the presence of graphite, which turns into fine dust during machining, any machine shop with good dust collection and coolant management will not have a dirt problem. Machining cast iron is no more dirty or hazardous than machining leaded steels or any other free machining grade that has solid, precipitated particles introduced as chip breakers. Graphite is black, which makes it appear dirtier, but it is not nearly as hazardous as lead.

Final Considerations

Cast iron may not be a viable substitute for steel in all gear applications. For example, high-speed gear sets will benefit from the damping properties of iron more than low-speed gears. However, both high and low speed gears can take advantage of the growth consistency in austempered ductile iron.

Heat treat distortion occurs in carburized gears because of the inconsistency in the depth of the diffusion layer attained during carburizing. Also, the matrix in rolled carbon steel is not homogenized, and residual stresses are present as a result of the rolling process.

Continuous cast iron is stress free because it is not rolled and does not require carburizing. In other words, there is no heat treat distortion, and its growth consistency is uniform throughout the material. Iron and steel grow when heat treated because of the volume change in the atomic structure. However, growth is predictable; it's the distortion that causes problems.

Heat treat distortion should also be taken into consideration in gear material selection because it is one of the largest contributors to noise and early fatigue failure in steel gears. Less heat treat distortion means quieter gears and, possibly, longer life.

The cost of continuous cast iron bar stock is typically 5–15% higher than rolled carbon steel. It can also be 5–15% cheaper than forgings. Usually, material cost is higher when continuous cast iron is used for gears less than 4" in diameter and lower when used for gears greater than 4".

Overall, cast iron can be an economical solution for problems created by noise and vibration, especially in applications where a slight decrease in strength is a workable tradeoff. The free machining characteristics of cast iron offer an environmentally friendly alternative to leaded steels, and its wide range of properties allows the design engineer to select the best-suited grade for an application. O

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Gear Grinding With Dish Wheels

Dr. Evgueni I. Podzharov

THIS ARTICLE ANALYZES THE POSSIBILITIES FOR THE SELECTION OF TOOL ADJUSTMENTS TO REDUCE TOOTH PROFILE ERRORS AND RUNNING DISTANCE AND TIME DURING GRINDING OF GEARS WITH DISH WHEELS. THE SELECTION OF PARAMETERS WAS BASED ON THE ANALYSIS OF A GRID DIAGRAM OF A GEAR AND A RACK. SOME FORMULAS AND GRAPHS ARE PRESENTED FOR THE SELECTION OF THE PRESSURE ANGLE. GRINDING OF EXPERIMENTAL GEARS CONFIRM THE THEORETICAL ANALYSIS.

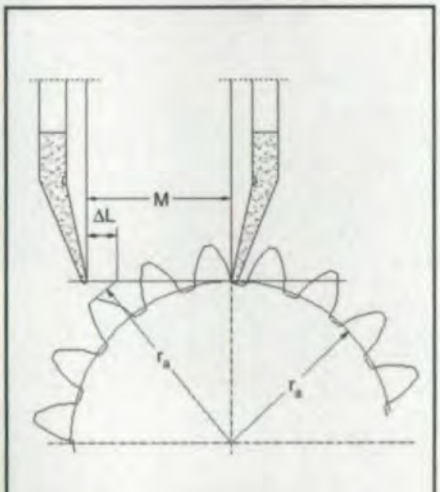

Fig. 1—0-degree method of gear grinding.

Introduction

The grinding of gears with dish wheels (Maag type grinding machines) is widely viewed as the most precise method of gear grinding because of the very short and simple kinematic links between the gear and the tool, and also because the cutting edges of the wheels represent planar surfaces. However, in this grinding method, depending on the parameters of the gears and one of the adjustments (such as the number of teeth encompassed by the grinding wheels), so-called overtravel at the tip or at the root of the teeth being ground generally occurs. When this happens, machining with only one wheel takes place. As a result, the profile error and the length of the generating path increases while productivity decreases.

Analysis of Grinding Gears With Dish Wheels

The 20-degree method of gear grinding with dish wheels was examined in a previous article (Ref. 1). In that method, the blades of the dish wheels represent part of a 20-degree rack.

Here we shall consider the process of grinding gears with dish wheels using the 0-degree method (Fig. 1). This is more productive than the 20-degree method because of the shorter running distances involved. However, because of the overtravel, the formation of a step form profile error is possible. In Figure 1, ΔL is the overtravel at the tooth tip, which enlarges the running distance. During this overtravel, a step is formed near the tooth root.

Consider this problem using the grid diagram of gear-tool engagement (Fig. 2a). The grid diagram is constructed for a spur gear with the following parameters: pressure angle $\phi = 20°$, module m = 3.5 mm, number of teeth N = 19, addendum modification coefficient x = +0.5, outside diameter d_a=76.78 mm, distance between grinding wheels M = 28.0 mm, which is equal to the span measurement. The coordinates of the grid diagram are described as follows: The ordinate axis represents the actual radius of curvature ρ of the tooth profile; the abscissa axis represents the corresponding length $S=\varphi r_b$ of the arc along the base circle of radius r_b, φ – arc angle. The inclined lines on the diagram denote the motion of the points of contact of the grinding wheels with the right and left profiles. Here, ρ_a, ρ_m and ρ_l are the radii of curvature on the outside diameter, at the points of contact with the wheels during symmetric positioning relative to the

Dr. Evgueni I. Podzharov

is a professor of engineering mechanics at Guadalajara University in Guadalajara, Mexico. After graduating in 1972 with a Ph.D. from the Moscow Peoples Friendship P. Lumumba University, he began his gear manufacturing career as senior research engineer in the machine tool building factory "Krasnyi Proletarii" in Moscow, where he was responsible for reducing the gear noise of the machine tools. He continued his work in gear noise as associate professor at the Moscow Textile Institute, where he worked from 1975-1995 and where he earned a Doctor of Science degree in 1995. He has published more than 40 articles related to gear manufacture, gear noise and vibration. Dr. Podzharov also works as a consulting engineer with Molinos y Maquinaria, S.A. de C.V., helping them to design and manufacture gear transmissions for agave mills for the tequila industry.

axis of the centers and at the boundary point of the tooth profile respectively.

Figure 2b shows plots of the normal components of the cutting forces for the right and left profiles, which, as in a previous article (Ref. 2), were proportional to the width of the contact area of the wheel with the tooth being machined. As a result of the effect of normal cutting forces and the deformation of the elastic system, the gear rotates, causing a deviation in the profile. Figure 2c shows this deviation of tooth profile by the addition of the lines in Figure 2b.

As we can see in the diagram of the tooth profile (Fig. 3), which was obtained after grinding such a gear in a Maag-type grinding machine, a step was formed at the root of the teeth. We can see from the diagrams in Figure 2c and Figure 3 that the experimental and theoretical curves are very similar to each other and that the step at the tooth root is caused by the overtravel.

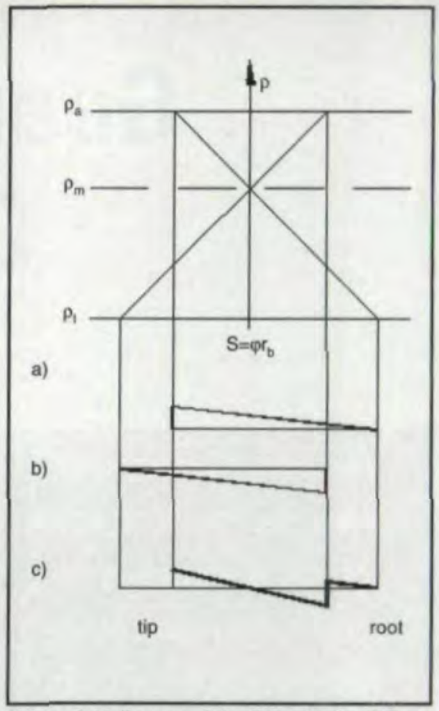

Fig. 2—Grid diagram of the dish wheels. a) Gear teeth engagement, b) Construction of the profile error, c) Theoretical tooth profile error.

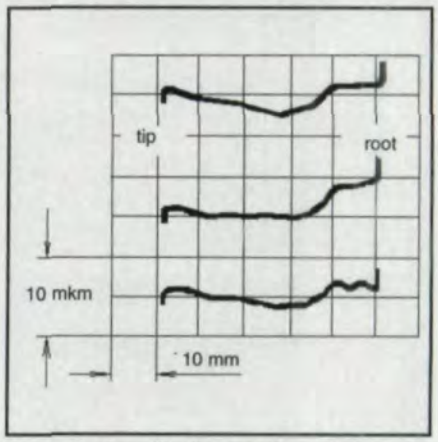

Fig. 3—Tooth profile diagram after grinding by 0-degree method.

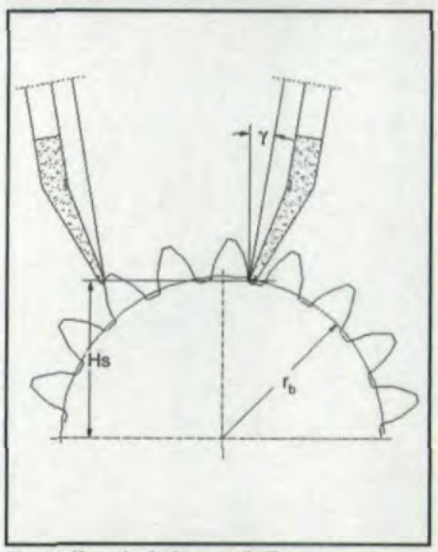

Fig. 4—K-method of gear grinding.

In order to eliminate the problem overtravel during grinding, the Maag Co. (Switzerland) developed the K-method of grinding (Ref. 3). Using the K-method, during overtravel of the tips, the lower edge of the wheels is placed above the axis of the centers at height $H_S < r_b$. During overtravel of the roots, the lower edge of the wheels is placed at height $H_S > r_b$. Quantity H_S was chosen so that at the end of the generating stroke both wheels simultaneously complete grinding on the tips and roots of the teeth. In the first case, the wheels also rotate by a certain angle γ in order to complete the grinding of the root section of the tooth.

A shortcoming of this method is that the obtained profile (either a lengthened or shortened involute) differs from the theoretical. Therefore, a mechanism is needed to correct the profile (Ref. 4).

The mentioned shortcomings of the K-method can be eliminated if grinding is carried out using a generating roller with a corrected diameter and an angle of machine tool engagement α_{0t} in the transverse plane. The angle α_{0t} must be determined from the condition of evenness of the number of contacts during gear grinding or a symmetry of the grid diagram (Ref. 5). From the symmetry of this diagram (Fig. 2a) with respect to the line corresponding to the radius of curvature ρ_m of tooth profile we have

$$\rho_a + \rho_l = 2\rho_m \quad (1)$$

From Figure 5 we can find the quantity of ρ_m as

$$\rho_m = 0.5\,(M / \cos\psi_b - d_b\,\alpha_{0t}) \quad (2)$$

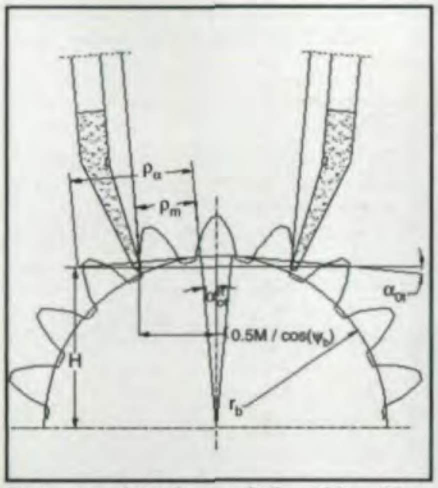

Fig. 5—α-method of gear grinding with positive angle of engagement.

where M = span measurement of the teeth encompassed between grinding wheels. ψ_b = base helix angle and d_b = base diameter.

Substituting equation (2) in equation (1) we can get

$$\alpha_{0t} = [M / \cos\psi_b - (\rho_a + \rho_l)] / d_b \quad (3)$$

Figure 5 shows a diagram of grinding according to the proposed method. Let us call it the α-method when $\alpha_{0t} > 0$. Figure 6 shows the α-method when $\alpha_{0t} < 0$. The axes of the grinding wheels are also inclined at an angle α_{0t} to the horizontal axis, and diameter D of the generating roller is determined from the condition of equality of the meshing intervals of the part being machined and the imaginary tool rod according to the known formula

$$D_r = 2r_b / \cos\alpha_{0t} - \delta \quad (4)$$

where δ is the thickness of the generating strip in mm.

The points of contact of the wheels with the teeth move in the planes of meshing tangent to the base cylinder and inclined at angle α_{0t}. For this reason, the length of longitudinal travel of the part during machining by this method is somewhat greater than during machining by the K-method.

It is apparent from Figure 5 that when $\alpha_{0t} > 0$ the wheels must be lowered in comparison with their position during grinding according to the 0-degree method. The setting height of the lower points of the grinding wheels above the axis of the centers is found by considering the diagram in Figure 5

$$H = r_b \cos \alpha_{0t} - \rho_a \sin \alpha_{0t}$$

In similar fashion, when $\alpha_{0t} < 0$ we can find from Figure 6

$$H = r_b \cos \alpha_{0t} + \rho_l \sin \alpha_{0t}$$

We must note that during grinding with positive α_{0t} (Fig. 5), in order to ensure the emergence of the edge of the wheel at the tooth root, it is desirable to carry out undercutting at the tooth roots (filleting), since deeper cutting of the tooth root is required. However, in many cases machining is possible without filleting, since the radial clearance is adequate for emergence of the edge of the grinding wheel.

The proposed method of tooth grinding was checked on the same model

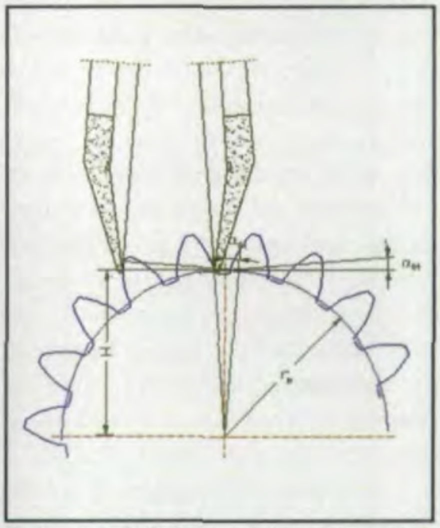

Fig. 6—α-method of gear grinding with negative angle of engagement.

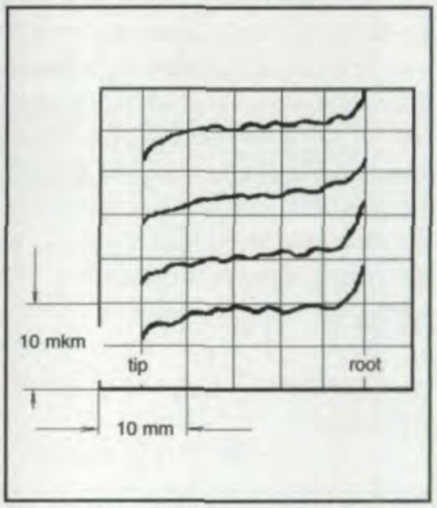

Fig. 7—Tooth profile diagram after grinding by α-method.

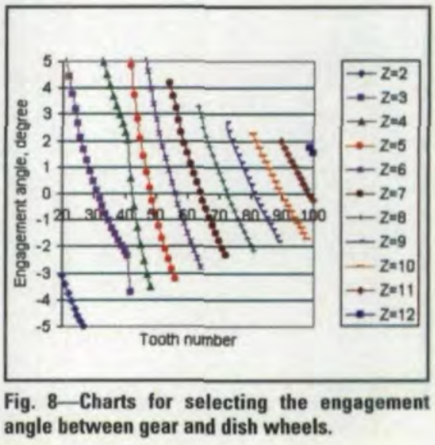

Fig. 8—Charts for selecting the engagement angle between gear and dish wheels.

machine tool as the 0-degree method. A gear with the same parameters as above was ground. The calculated parameters were: angle of engagement $\alpha_{0t} = -4.29°$; span measurement $M = 17.6$ mm for the number of teeth $Z = 2$, encompassed between the grinding wheels; generating path $L = (\rho_a - \rho_l) \cos \alpha_{0t} = 22.3$ mm. This was 4.7 mm less than in the 0-degree method of gear grinding in which $L = 2\rho_a - M = 27.0$ mm (in case of 2 teeth between the wheels) and $L = M - 2\rho_l = 28.0$ mm (in the case of 3 teeth between the wheels).

Figure 7 shows diagrams of tooth profiles of the indicated gear, ground according to the proposed method. In this case, the profile error does not have a step at the tooth root.

To determine the angles α_{0t}, the charts shown in Figure 8 can be used. Here the values of α_{0t} are plotted as a function of the number of teeth of the gear being ground and the number of teeth Z, encompassed between the grinding wheels. The calculation was made using Equation 3 for standard gears of 20-degree pressure angle, full tooth height and without addendum modification and rounding at the tooth root. From these charts one must select the smallest angle possible, either positive or negative, because of limitations of angle in some models of machine tools with dish wheels and also for shorter length of longitudinal travel. A smaller number of teeth encompassed between grinding wheels gives negative angle and larger number gives positive angle of engagement between gear and grinding wheels. ❍

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TEXTRON ACQUIRES ALSTOM GEARS

Textron Inc. has announced the recent acquisition of U.K.-based Alstom Gears, part of Alstom, a leading supplier of components, systems and services to the world's energy and transportation infrastructure markets. Alstom Gears is a manufacturer of gears and gearboxes, including high-speed epicyclic and parallel shaft gearboxes, for the industrial, rail and marine industries. The acquisition will be fully integrated into Textron's power transmission products business, part of the company's fluid and power systems group. For the fiscal year-ended March 1999, Alstom Gear's revenues were approximately $10 million. Terms of the transaction were not disclosed.

"Textron's acquisition of Alstom Gears further strengthens our power transmission capabilities, adding a range of technologically advanced gearbox systems to our existing product brands, including David Brown, Cone Drive and Textron Industrial Gears," said Textron Fluid and Power Systems president Bob Geckle. "Furthermore, the acquisition establishes a multiyear preferred supplier agreement for Textron with Alstom for power transmission products."

EUROPEAN PATENT OFFICE RULES ON GLEASON'S PHOENIX PATENT

In July, 1999, the Opposition Division of the European Patent Office, based in Munich, Germany, upheld in modified form The Gleason Works' European patent No. 0-374-139. The patent, which continues to cover CNC multiaxis gear generating machines and processes that produce some of the most complex gears in use today, was challenged by two competitors of The Gleason Works. The decision can be appealed.

The Gleason Works also owns a corresponding United States patent, No. 4,981,402, which is the subject of patent infringement litigation filed in U.S. federal court by The Gleason Works against Oerlikon Geartec AG and Liebherr-America, Inc. In that suit, The Gleason Works seeks damages and a permanent injunction preventing the defendants from selling or using any infringing machine in the United States during the remaining life of the patent, which expires in 2008.

David J. Burns, president and chief operating officer of Gleason Corporation, stated that "We are extremely pleased by this ruling in the European Patent Office. The Gleason Works remains adamant that our basic Phoenix technology, which embodies the subject matter of the patent challenged in Munich and the corresponding U.S. patent, is technology that remains proprietary to our company. We are gratified that the Opposition Division of the EPO recognized the validity of our patent."

In a response to the ruling and the patent infringement suit, Oerlikon Geartec AG has issued the following statement:

"On July 7th, 1999, the European Patent Office (EPO), after rejecting 117 original patent claims of the European Patent Application of 0-374-107 filed by The Gleason Works, confirmed the patentability of 8 patent claims of limited scope. The Klingelnberg-Oerlikon bevel and hypoid gear cutting machines C22 and C28 do not infringe the remaining claims. Nonetheless, we will appeal this decision on the basis of prior art published many years ago by Professor Segal, who has been our technical advisor for some years.

"The decision of the EPO reducing the scope of protection in the European Patent Application also increases (bodes well for) our chances of successfully defending the patent infringement litigation concerning U.S. Patent 4,981,402 filed by The Gleason Works in a Federal District Court in the United States. We are pleased by the success and acceptance of our C22 and C28 around the world." ○

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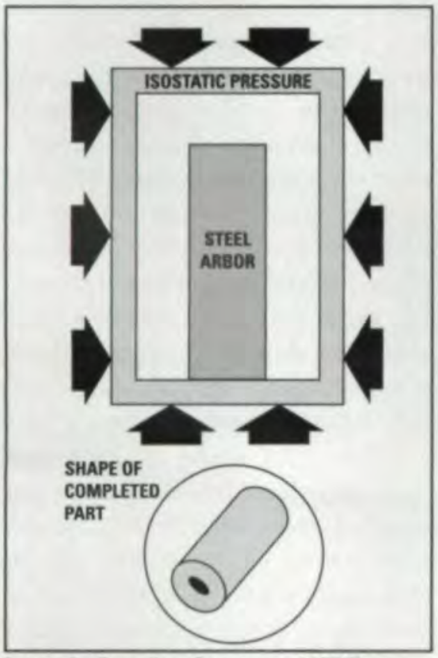
Powder Metallurgy Innovations

New materials, processes and standards are making powder metal a viable alternative to wrought metals in the gear industry. Here's what's new and what you can expect.

Charles M. Cooper

Powder metal. To gear makers today, the phrase conjures images of low power applications in non-critical systems. As powder metal technology advances, as the materials increase in density and strength, such opinions are changing. It is an ongoing, evolutionary process and one that will continue for some time. According to Donald G. White, the executive director of the Metal Powder Industries Federation, in his State-of-the-P/M Industry—1999 report, "The P/M world is changing rapidly and P/M needs to be recognized as a world-class process—national, continental and even human barriers and prejudices must be eliminated—we must join forces as a world process—unified in approach and goals."

According to Todd Olson, marketing manager for Burgess-Norton Manufacturing Co., this kind of unification is already happening. "Overall, the powder metal industry is moving toward consolidation. Historically, the industry has been very fragmented. However, the late '90s have witnessed a wave of mergers and acquisitions, which is allowing major powder metal players to optimize economies of scale and provide customers with a full range of products and services."



Isostatic Pressing. Courtesy of MPIF.

There is a greater use of powder metal in gear manufacturing, on both the tooling side and the workpiece side, today than ever before. In fact, a number of gear applications won awards in the 1999 P/M Design Competition (see sidebar, page 61). Major automakers are increasing the amount of powder metal they use in their transmissions and engines, and many of these gears are being made with new high speed steel alloy cutting tools. Part of the credit for this goes to new alloys being developed, while the rest goes to the new powder metal processing methods, which are designed to increase the material density to improve its mechanical qualities.

According to Philip Krupp, president of P/M Krupp Technologies, Inc., this drive toward heavier density in powder metal parts is of great importance to the powder metal industry because, as he said, "They've done all that can be reasonably achieved with varying chemistry and heat treat, and higher density is pretty much all that is left."

P/M Technology: The Quest for Density

According to Krupp, "Current P/M gear capabilities are very good in regard to shape complexity and tolerances, but fall short on high strength and hardness. For that, higher densities will be needed." This need for higher densities has led to the development of processing methods that promise near-fully dense powder metal products. Near-fully dense means that the part has less than 1% residual porosity. These processes also use different compacting methods, enhanced sintering techniques and work primarily with high alloy materials. Four of the most promising processes are powder forging, isostatic pressing, metal injection molding and spray forming.

Powder Forging. This method begins with the creation of a "green compact" (a workpiece that has been pressed into shape at room temperature) called a "preform." The preform is then sintered as usual, producing a near-net shape workpiece. This workpiece is then placed in the forge and restruck until the final density is reached. Powder forging is currently used in the mass production of powder metal steel parts with wrought steel properties. These parts are primarily used by the automotive industry and include gears, transmission parts and engine parts.

Isostatic Pressing. This method is primarily used to produce powder metal parts to near-net sizes and shapes of varying complexity. The biggest difference between isostatic pressing and other methods of compaction is that isostatic pressing is performed in a pressurized fluid. The powder mass is contained in a flexible, sealed container, which provides a pressure differential between the powder and the pressurizing fluid.

There are two types of isostatic pressing—hot and cold. Hot isostatic pressing is carried out using an inert gaseous atmosphere, usually argon or helium, contained within the pressure vessel. Usually, both the pressurized atmosphere and the part to be pressed are heated by a furnace within the vessel.

The powder being processed is hermetically vacuum-sealed within a shaped mold that will deform plastically at high temperatures. The powder metal is then simultaneously pressed and sintered within the heated vessel. Common pressure levels reach 15,000 psi at temperatures as high as 2,300°F. The mold is then removed from the finished near-net shaped part by chemical leaching, machining or some other mechanical method. Hot isostatic pressing allows densities in the 7.2–7.4 g/cm^3 range. While this is a notable improvement over the results of other methods, it is still not dense enough for many gear applications.

According to Krupp, "The tolerances are roughly equivalent to those of investment casting. It is suitable for more complex shapes that have the economic room for finishing operations to bring dimensions into line."

Cold isostatic pressing is carried out at room temperature and uses a liquid pressure medium rather than a gas. The pressures in this method often reach 60,000 psi. Packed into complex shaped rubber or elastomeric molds, the powder metal achieves a higher and more uniform density than could be obtained from regular cold die compaction. The resulting green preform is then sintered.

Metal Injection Molding. This method allows for the mass production of complex powder metal parts. Here, fine metal powders are mixed with thermoplastics, waxes or other ingredients, which serve as binding materials. The resulting feedstock is then fed into a conventional injection molding machine. Once the green preform is made, most of the binding material is removed either thermally or chemically, or by some combination of the two. The precise method is based on the binding material being used. The part is then sintered at temperatures that normally exceed 2,300°F, eliminating the remaining binding material. This process offers final relative densities in excess of 96% with interconnected porosity being less than 0.2%.

Injection molding permits parts with curved sides, external undercuts and threads. A wide variety of alloys can be processed with this method including alloy and stainless steels, soft magnetic alloys and tungsten carbide.

Spray Forming. This is not a process used to create a single workpiece. Rather, it is used to create billets, tubes and sheet/plate that are then used to make other products. The spray forming process consists of sequential stages of liquid metal atomization and droplet consolidation at deposition rates from 0.5 to 5.0 pounds per second. This produces a near-net shaped product that is close to full density with a fine, even grain structure and mechanical properties that meet or exceed those of ingot processed alloys.

P/M Technology: Alloys

There are a number of new powder metal alloys that will be of interest to gear manufacturers as both gear and tool materials. They include the various types of high speed steel bridge alloys as well as more exotic beryllium, titanium alloys and aerospace superalloys.

Bridge Alloys. When it comes to cutting tools, gear manufacturers have traditionally had a choice between high speed steel and carbide. High speed steel is economical and tough, but it is not hard enough for some of today's applications, such as dry cutting. Carbide allows dry cutting because it can take higher speeds and temperatures, but it is also far more expensive than high speed steel tools and far more fragile. Today, a third alternative is available, a material that many believe takes the best of both high speed steel and carbide and brings them together into one tool material.

In the cutting tool industry it is called Super High Speed Steel, a high speed steel tool material that provides many of the benefits of carbide but at a far lower price. To the powder metal industry, it is simply called a bridge alloy. "This is a new super high speed steel being developed that bridges the gap between high speed steel and carbide," said Robert Carnes, a staff specialist with the Technical Services division of Carpenter Specialty Alloys.

This material is made both possible and practical because of some of the unique properties of powder metals. "The material is much more uniform, without the segregation of the alloy material you often find in alloy ingots," said Carnes, who explained that with alloy ingots, you often find concentrations of different alloy components in different parts of the ingot. "Each particle in the powder metal mix is a microingot. That means you can create heavier, more consistent alloys with fine, uniform microstructures." This uniformity offers some specific benefits in terms of finishing and machining. According to Carnes, "The more uniform the alloy, the more uniform will be the response to heat treating and the more predictable will be the hardness and movement. Also, the material will be more readily machined." This means a tool material that is tougher than regular high speed steel and hard enough to handle jobs traditionally left to carbide tools.

Titanium and Beryllium. These lightweight metals are often alloyed and

A BRIDGE ALLOY IN THE MAKING

One example of the new bridge alloys being made today comes from Carpenter Specialty Alloys. Called Micro-Melt®, the material's manufacture begins with the nitrogen atomization of molten metal to produce prealloyed metal powders. These powders are then blended, screened, and poured into mild steel canisters. The powder is then hot isostatically pressed into ingots of 100% theoretical density.

The resulting powder metal ingots are then finished. This process includes forging on rotary forges, hot rolling and cold finishing into product forms, which include round or flat bar and plate.


Atomizing


Blending


Screening


Filling


Hot isostatic pressing


Hot working


Hot rolling


Cold finishing

1999 P/M DESIGN AWARDS

Gears and other power transmission products were big winners in the 1999 P/M Design Competition, sponsored by the Metal Powder Industries Federation. According to the MPIF, these "outstanding examples of powder metallurgy (P/M) eclipse competitive forming processes such as casting, extrusion and screw machining."

The Ferrous Grand Prize went to Stackpole Ltd. of Mississauga, Ontario, Canada, for the P/M steel helical balancer gears they make for DaimlerChrysler. The gear set, which replaced ductile cast iron, includes a balancer drive gear and a driven gear and operates at up to 13,000 rpm in a Chrysler 2.4L engine, twice the crankshaft speed. The AGMA Class 8/9 gears are selectively densified on the flanks to 7.8 g/cm^3 while the core region, which does not experience the high stresses of the tooth region, remains at 7.0 g/cm^3. The parts are vacuum carburized and hardened to 70 HRA. The mechanical properties include an ultimate tensile strength of 125,000 psi and a minimum yield strength of 120,000 psi. More than 2 million of these gears have been made.

The Stainless Steel Grand Prize goes to Keystone Powdered Metal Company of St. Mary's, Pennsylvania, for the AGMA Class 7 output gear they make for Eaton Corp., Lectron Products, Rochester Hills, Michigan. The output gear, used as an actuator in an automobile engine manifold, is a net-shape part that meets critical tolerances; inside diameter 4.80–4.85 mm and measurement over wires was 15.44 mm/15.31 mm. The part, which replaced a hobbed steel gear, has a density of 6.4 g/cm^3, an ultimate tensile strength of 43,000 psi and a minimum yield strength of 30,000 psi. Its hardness is measured at 61 HRB. More than a million such output gears have been produced.

Ferrous Awards of Distinction were given to two companies this year for entries from the gear and power transmission industries.

The first was given to the Burgess-Norton Mfg. Co., of Geneva, Illinois for a coupler assembly they make for Caterpillar, Inc., Peoria, Illinois for use in Caterpillar's backhoes. Made from MPIF material FLC-4608-80HT, the mating parts transfer power from the diesel engine to a high pressure hydraulic pump, which powers the backhoe loader as it digs ditches and trenches.

The adapter is formed to a minimum density of 6.9 g/cm^3 and has an ultimate tensile strength of 90,000 psi. The critical dimension over wires on the larger external spline is 107.1 mm/106.8 mm. The dimension between wires on the internal spline is 23.2 mm. The hub is made to a density of 6.7 g/cm^3 and has an ultimate tensile strength of 110,000 psi. It is machined and heat treated.

The second Award of Distinction went to Cloyes Gear and Products, Paris, Arkansas, for a reductor wheel they make for the General Motors Mark VI V-8 engine. The application is an assembly of two pieces brazed together during sintering. The 48-tooth part is produced as a net shape except for grinding to establish the separation groove, burnishing to qualify the bore and shot peening to remove grinding burrs. Necessary tolerances include holding the maximum total runout of both rows of teeth to <0.1295 mm to the bore; flatness of the mounting hub is held to less than 0.0787 mm. The teeth have a minimum density of 7.0 g/cm^3.

The Overseas Award of Distinction went to an assembly of a block crank, counterweight and eccentric gear for a jig saw made by MG miniGears S.p.A., Padova, Italy, for Porter Cable Professional Power Tools, Jackson, Tennessee. The complex parts are made from diffusion alloyed steel, MPIF material FD-0205-120HT. The parts are fabricated to a density range of 6.85–6.95 g/cm^3 and have a minimum ultimate tensile strength of 120,000 psi.

Grand Prize Winners. Courtesy of MPIF.

Award of Distinction Winners. Courtesy of MPIF.

used in aerospace applications including gears. Beryllium processing is usually begun with cold isostatic pressing followed by hot pressing or hot forging. Hot isostatic pressing can be substituted for the hot pressing step. However, titanium can be either conventionally processed or hot isostatically pressed, which for titanium means that the material will exceed the minimum wrought alloy specifications. Also, the near-net shape of the preforms makes the use of powdered titanium or beryllium more economical than cast, forged and machine processing.

Superalloys. Materials that fall into this category are found most often in the production of near-net shapes and forging preforms for aircraft turbine engines. Economic benefits have been the driving force behind the use of powder metal for the manufacture of these costly alloys.

Processing of these alloy powders is either through hot isostatic pressing followed by thermomechanical processing to enhance the mechanical properties and/or microstructure, or hot extrusion of the atomized powder. Lower costs are realized due to the alloy's homogeneous microstructure and near-net shape configuration. Today, over 10,000,000 pounds of superalloy components are in civilian and military aircraft worldwide.

P/M Technology: Gears

So what is driving all these advances? Look to Detroit. According to Krupp, "Automotive is probably the biggest driving force behind the quest for higher density, since the potential is very large. Transmission gears require higher strength and fatigue properties that are currently unavailable in conventional powder metal processing."

While that may be true, the trend toward the use of powder metal gears is certainly pointing to continued growth. "In today's marketplace, there are very few industries that don't take advantage of powder metal gear technology. Powder metal gears can be found in applications from automotive and agriculture to laser printers and lawn/garden equipment. As strength and tolerance characteristics continue to improve, we expect a continued proliferation of powder metal gear acceptance," said Olson.

Powder metal gears. Courtesy of Burgess-Norton Mfg. Co.

AGMA standards. According to Glen Moore, Burgess-Norton's director of engineering, those strength and tolerance characteristics are being addressed by AGMA, which is moving forward on classification standards for powder metal gears. Like the standards for their cut gear counterparts, these new standards will permit tighter tolerances and more uniform strength data, which will facilitate the overall design and product selection process. "This is important because it will allow customers of powder metal gears to easily make objective decisions about what product is best suited to their application," added Olson.

In November of 1998, AGMA published its first standards covering powder metal gears created by conventional powder metallurgy processes. *Specifications for Powder Metallurgy Gears*, ANSI/ AGMA 6008-A98, gives the powder metal gear purchaser the detailed information that needs to be included in the gear specifications he submits to the gear producer. Detailed specifications for gear tooth geometry are described in the standard for external spur, helical and straight bevel gears. There are also discussions on the specifications needed for gear drawings and gear material data. "The powder metal people grossly lacked a way of communicating with their customers," said Charlie Fischer, manager of AGMA's technical division. "This standard allows them to do that. It's not a technical standard; it covers what needs to be communicated." Fischer then went on to say that AGMA's Powder Metal Committee is now working on developing an information sheet that deals with the strength of powder metal gears, as well as their materials and configurations, but added that the information sheet won't be out for a year or two.

The application suitability is going to become very important as powder metal gears become more economically competitive with traditional cut gears. "Through increased densification, powder metal gears have made their way into applications, which were once the sole domain of cut gears," said Moore. "Certainly, there will continue in the foreseeable future to be applications that can only be served by cut gears. However, because of the efficiency of the powder metal process, powder metal gears continue to offer economic advantages over cut gears."

According to Krupp, the benefit of a powder metal preform is its ability to eliminate manufacturing steps, since the more you can eliminate, obviously, the more economical the process becomes. "Near-net shape offers two key advantages over machining a blank," said Tom Stockwell, field sales manager for Burgess-Norton. "First and foremost, the density of the part will be "true." Second, the inherent physical properties of a near-net shape part will be much closer to the final production part. This eliminates surprises and facilitates the component finishing process."

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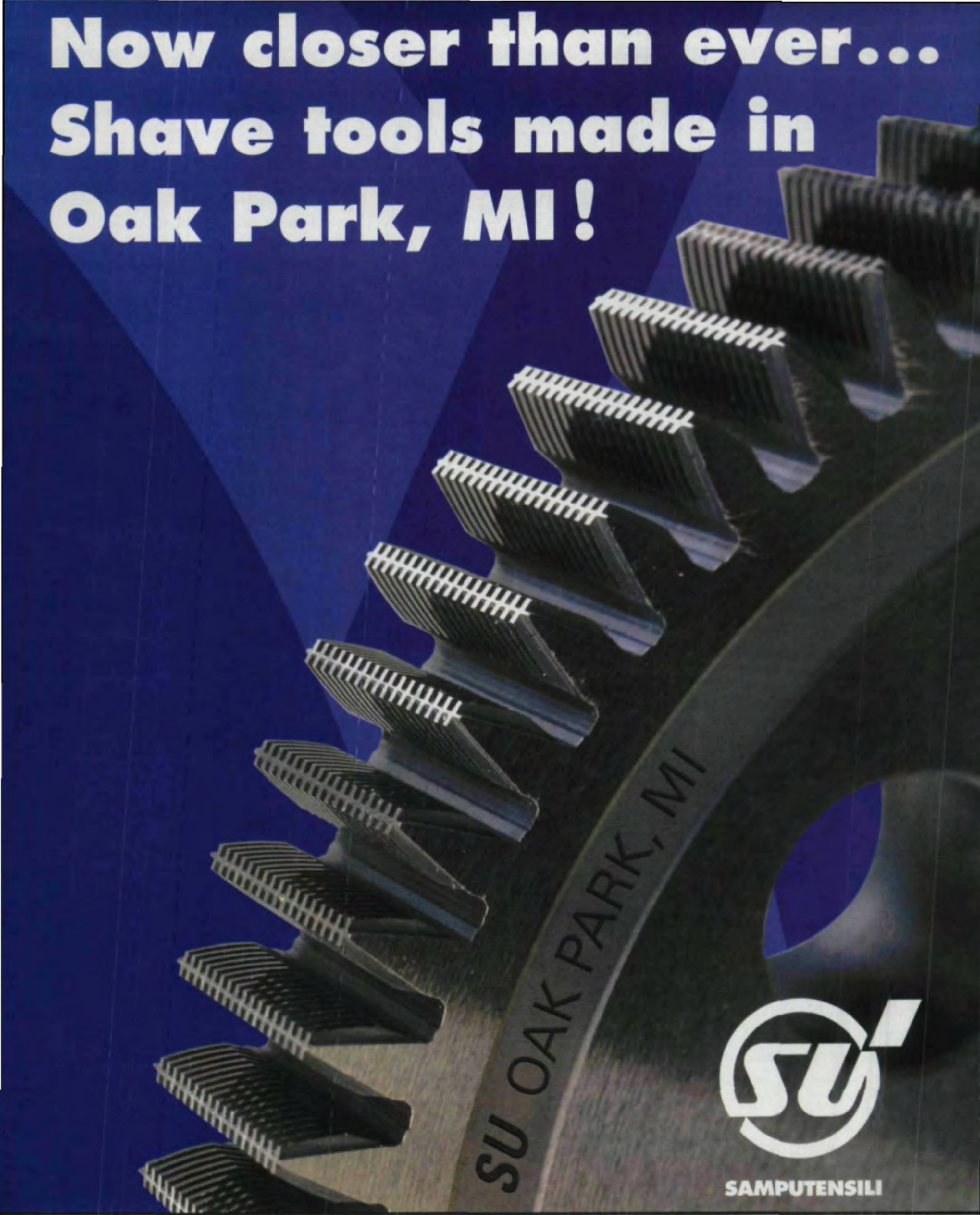
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Calculating SAP and TIF

Dan Thurman

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Question submitted by G. Lueck
Dalton Gear Co., Minneapolis, MN

Q: Are there any simpler formulae for S.A.P. & T.I.F.? Are there any not involving the mating part?

Answer submitted by Dan Thurman

A: Start of Active Profile (SAP) is defined as the lowest point on the gear tooth where contact with the mating gear tooth tip can occur. On gears without tooth tip chamfers, it will be determined by the maximum outside diameter of the mating gear. It is usually expressed in degrees of roll above the base diameter. There is a diameter called the form diameter (D_f), associated with this roll angle, which can be calculated.

True Involute Form diameter (TIF) is defined as being the point on the gear tooth where the involute form must begin. It is not necessarily the same diameter as the form diameter determined by the SAP. For example, it is possible for a SAP to occur in an undercut area, but the TIF diameter to be at a higher point on the tooth profile.

SAP is dependent on the mating gear outside diameter and the operating center distance.

Figure 1 contains the equations for calculating SAP, Form Diameters, and mating gear outside diameters. Any combination

Terms and Definitions

N	Number of teeth in gear (specify as minus if an internal gear)
N_m	Number of teeth in mate (specify as minus if an internal gear)
P_n	Normal diametral pitch
D_o	Outside diameter of gear (inside dia. if gear is internal)
D_{om}	Outside diameter of mate (inside dia. if mate is internal)
D_b	Base circle diameter of gear
D_{bm}	Base circle diameter of mate
D_f	Form diameter
OD/ID	Outside diameter/Inside diameter
SAP	Start of active profile
TIF	True involute form
m_c	Profile contact ratio
ϕ_n	Normal pressure angle
ϕ_t	Transverse pressure angle
ϕ_t'	Operating transverse pressure angle
ψ	Helix angle (zero if spur gear)
θ_o	Roll angle at gear OD/ID
θ_{om}	Roll angle at mating gear OD/ID

Calculating Transverse Pressure Angle

$$\phi_t = \text{atan}\left(\frac{\tan(\phi_n)}{\cos(\psi)}\right) \quad (1)$$

Calculating Operating Transverse Pressure Angle

$$\phi_t' = \text{acos}\left[\frac{(N + N_m) \cdot \cos(\phi_t)}{2 \cdot P_n \cdot CD \cdot \cos(\psi)}\right] \quad (2)$$

Calculating Base Circle Diameter of Gear

$$D_b = \left[\frac{N \cdot \cos(\phi_t)}{P_n \cdot \cos(\psi)}\right] \quad (3)$$

Calculating Base Circle Diameter of Mating Gear

$$D_{bm} = \left[\frac{N_m \cdot \cos(\phi_t)}{P_n \cdot \cos(\psi)}\right] \quad (4)$$

Calculating Pressure Angle at OD/ID of Gear if Mating Gear OD/ID is Given

$$\phi_{om} = \text{acos}\left(\frac{D_{bm}}{D_{om}}\right) \quad (5)$$

Calculating SAP if Form Diameter is Given

$$SAP = 180 \cdot \frac{\sqrt{\frac{D_f^2}{D_b^2} - 1}}{\pi} \quad (6)$$

Calculating Pressure Angle at OD/ID of Mating Gear if SAP is Given

$$\phi_{om} = \text{atan}\left[\frac{(N + N_m) \cdot \tan(\phi_t') - \pi \cdot N \cdot \frac{SAP}{180}}{N_m}\right] \quad (7)$$

Calculating Start of Active Profile

$$SAP = 180 \cdot \frac{(N + N_m) \cdot \tan(\phi_t') - N_m \cdot \tan(\phi_{om})}{\pi \cdot N} \quad (8)$$

Calculating OD/ID of Mating Gear

$$D_{om} = \frac{D_{bm}}{\cos(\phi_{om})} \quad (9)$$

Calculating Pressure Angle at SAP of Gear

$$\phi_f = \text{atan}\left(\frac{\pi \cdot SAP}{180}\right) \quad (10)$$

Calculating Form Diameter at SAP of Gear

$$D_f = \frac{D_b}{\cos(\phi_f)} \quad (11)$$

Calculating Pressure Angle at OD/ID of Gear

$$\phi_o = \text{acos}\left(\frac{D_b}{D_o}\right) \quad (12)$$

Calculating Roll Angle at OD/ID of Gear

$$\theta_o = 180 \cdot \frac{\tan(\phi_o)}{\pi} \quad (13)$$

Calculating Profile Contact Ratio

$$m_c = \frac{|\theta_o - SAP| \cdot |N|}{360} \quad (14)$$

*** Note: quantities enclosed in vertical bars are absolute values.**

Fig. 1 — Equations.

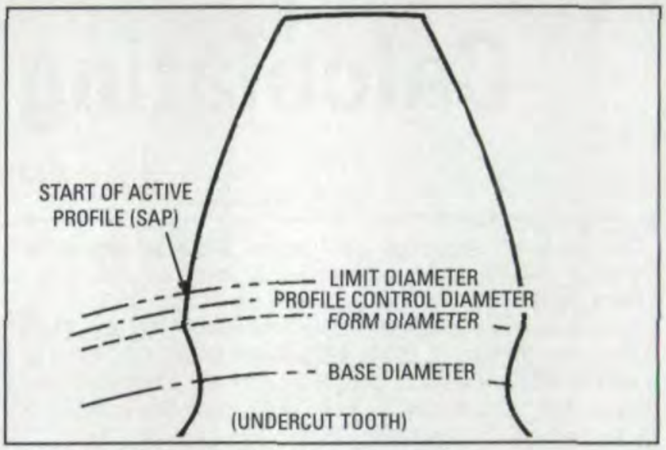

Fig. 2 — Start of Active Profile and Form Diameter.[1]

of SAP, Form Diameter or mating gear outside diameter may be given. (Note: Use negative numbers to specify number of teeth on internal gears.)

Extended Example

The following example uses the formulas presented above and a sample gear set (see Fig. 3 for sample specifications) to calculate SAP.

Using formula (1), we can calculate the transverse pressure angle based on the values given for normal pressure angle and helix angle in the example:

$$\phi_t = \text{atan}\left(\frac{\tan(\phi_n)}{\cos(\psi)}\right)$$

$$\phi_t = \text{atan}\left(\frac{\tan(20)}{\cos(0)}\right)$$

$$\phi_t = 20 \text{ deg}$$

From this, we can calculate the operating transverse pressure angle using formula (2) and the given values for the center distance, the normal diametral pitch, the helix angle and the number of teeth in gear and mate:

$$\phi_t' = \text{acos}\left[(N + N_m) \cdot \frac{\cos(\phi_t)}{(2 \cdot CD \cdot P_n \cdot \cos(\psi))}\right]$$

$$\phi_t' = \text{acos}\left[(21 + 18) \cdot \frac{\cos(20)}{(2 \cdot 7.7915 \cdot 2.64 \cdot \cos(0))}\right]$$

$$\phi_t' = 27.0221166 \text{ deg}$$

N=21
N_m=18
CD=7.7915
P_n=2.64
ϕ_n=20 degrees
ψ=0 degrees (spur gear)
D_o=9.177
D_{om}=8.159

Fig. 3 — Sample Gear Set for Extended Example.

We will also need the base circle diameter of the mating gear, which can be determined using formula (4):

$$D_{bm} = N_m \bullet \frac{\cos(\phi_t)}{P_n \bullet \cos(\psi)}$$

$$D_{bm} = 18 \bullet \frac{\cos(20)}{2.64 \bullet \cos(0)}$$

$$D_{bm} = 6.4069951$$

Finally, we'll use formula (5) to calculate the pressure angle at the OD of the mating gear based on the given outside diameter:

$$\phi_{om} = \text{acos}\left(\frac{D_{bm}}{D_{om}}\right)$$

$$\phi_{om} = \text{acos}\left(\frac{6.4069951}{8.159}\right)$$

$$\phi_{om} = 38.2546016$$

Using the calculated and given values, we can now calculate SAP using formula (8):

$$SAP = 180 \bullet \left[\frac{(N + N_m) \bullet \tan(\phi_t') - N_m \bullet \tan(\phi_{om})}{\pi \bullet N}\right]$$

$$SAP = 180 \bullet \left[\frac{(21 + 18) \bullet \tan(27.0221166) - 18 \bullet \tan(38.2546016)}{\pi \bullet 21}\right]$$

$$SAP = 15.55 \text{ deg}$$

The calculated SAP is given in degrees of roll above the base circle diameter. It can be converted to a corresponding form diameter (D_f) as follows:

$$D_b = N \bullet \frac{\cos(\phi_t)}{P_n \bullet \cos(\psi)}$$

$$D_b = 7.4748277$$

$$D_f = D_b \bullet \sqrt{\left(\pi \bullet \frac{SAP}{180}\right)^2 + 1}$$

$$D_f = 7.7451$$

Many times we will be starting with an existing gear where we already know the form diameter (D_f) or the corresponding roll angle (θ_f) where the involute begins, and we want to find the outside diameter of the mating gear which will reach that point on the involute. In that case, the following equations apply:

Given the Form Diameter (D_f) from the example above:

$$D_f = 7.7451$$

$$SAP = 180 \bullet \frac{\sqrt{(D_f^2 - D_b^2)}}{\pi \bullet D_b}$$

$$SAP = 15.55$$

$$\phi_{om} = \operatorname{atan}\left[\frac{(N + N_m) \cdot \tan(\phi'_t) - \pi \cdot N \cdot \frac{SAP}{180}}{N_m}\right]$$

$$\phi_{om} = 38.2546462 \text{ deg}$$

$$D_{om} = \frac{D_{bm}}{\cos(\phi_{om})}$$

$$D_{om} = 8.159$$

By definition, calculation of start of active profile requires knowledge of the mating gear. However, it is possible to calculate SAP without knowing anything about the mating gear except for the profile contact ratio.

$$\theta_o = 180 \cdot \frac{\sqrt{D_o^2 - D_b^2}}{\pi \cdot D_b}$$

$\theta_o = 40.8088321$ degrees roll angle at outside diameter of gear

$m_c = 1.4736$ (Contact Ratio Between Gear and Mate)

$$SAP = \theta_o - \frac{360 \cdot m_c}{N}$$

SAP = 15.55 degrees

It is sometimes helpful to be able to calculate the corresponding roll angle (θ_{xm}) on a mating gear, given a known roll angle on gear one. For example, from our original external mesh:

SAP = 15.55 degrees

$$\theta_{xm} = 180 \cdot \frac{(N + N_m) \cdot \tan(\phi'_t) - \pi \cdot N \cdot \frac{SAP}{180}}{\pi \cdot N_m}$$

$\theta_{xm} = 45.175$ degrees

Any roll angle can be converted to a diameter according to the following relationship:

$$D_x = D_b \cdot \sqrt{\left(\pi \cdot \frac{\theta_x}{180}\right)^2 + 1}$$

For more information about SAP and TIF, see ANSI/AGMA 115.01 *Basic Gear Geometry* and ANSI/AGMA 1012-F90 *Gear Nomenclature, Definitions of Terms with Symbols.*

References

1. Fig. 2 extracted from ANSI/AGMA 1012-F90, *Gear Nomenclature, Definitions of Terms with Symbols*, with the permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Virginia 22314.

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Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.

New Drives from BNA

Bonfiglioli North America (BNA) has introduced its new F-Series shaft mount helical drives and gearmotors as well as a new series of mechanical planetary adjustable speed drives and its new A-Series right angle bevel gear drives.

The new F-Series helical drives and gearmotors are designed to increase the efficiency that is available with hollow shaft mounting capabilities. Allowing for simple compact drive applications, these drives have a torque range between 670 and 25,700 in-lbs. and offer ratios from 6.4:1 to 545.3:1.

Designed for retrofitting fixed speed applications to change over to adjustability, BNA's new line of mechanical planetary adjustable speed drives are available in C-face or IEC input or output. They can also be used as components within complete drive packages with virtually any reducer or motor combination. The sealed planetary design running in oil makes them ideal for explosion proof applications or where overloads or shock loads are encountered. With a 6.5:1 stepless speed range, they can accept both high efficiency or explosion-proof motors.

The new BNA A-Series (pictured above) offers efficiency approaching that of helical gears but at a lower cost than many other bevel gear drives on the market. Outstanding drive mounting flexibility results from the unique symmetrical housing design and universal mounting faces. In addition, they provide nearly 50% greater two-stage reduction, as high as 100:1, resulting in greater economy and reduced maintenance costs. Torque ranges from 650 to 25,000 in-lbs. and ratios from 5:1 to 400:1 are available, as are hollow or solid output shafts.

For more information about these or other BNA products, contact Joel Camunias, BNA technical sales, at (905) 738-4466 or visit their Web site at *www.bnagear.com.*

Circle 300

New High Performance CBN Grinder with Small Footprint

The extreme stiffness of the new 950 Series Compact Multiaxis CBN Grinders from Campbell Grinder Company allows higher feed rates, increased productivity and longer wheel life.

The Campbell 950 is a 3-axis form grinder with strokes of X=18", Y=18" and Z=18". Axes are driven by AC servomotors directly coupled to precision preloaded ballscrews. The 20 HP liquid-cooled motorized spindle has an HSK 80 mount for quick and accurate wheel changes. The one-piece, polymer concrete-filled frame totally encompasses the machine axes, providing stiffness, vibration dampening and thermal stability. A stiff and stable grinding platform allows higher feed rates for greater productivity and maximizes wheel life. With a dressable CBN wheel, the Campbell 950 can hold tolerances of .0001" and surface finishes of 16 RMS or better on a production basis.

The 950 Series comes equipped with Fanuc's new 21i Series CNC, which can be upgraded to Fanuc's Windows NT-based 210i open architecture CNC. Other customer options include a 30 HP spindle, high-speed spindles, rotary axes, mist collectors, coolant filters, fixturing and automation. For more information contact Norman Campbell, president, Campbell Grinder Company, at (616) 733-2674 or visit their Web site at *www.campbellgrinder.com.*

Circle 301

Conveyor Blast System from Guyson

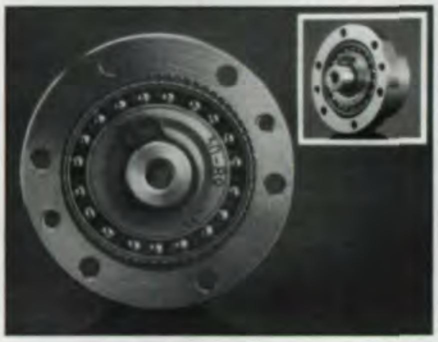
Guyson Corporation has introduced an expanded through-feed conveyor blast system for continuous in-line cleaning, surface preparation and impact treatment operations. The Model TR-900 is now available with a belt width of up to 17 inches.

Equipped as either a pneumatic suction-blast system with up to 12 guns, or a direct pressure system with media delivery by multiple pressure nozzles, the TR-900 can utilize the full spectrum of dry blast media. According to the manufacturer, the system's compatibility with all types of media, from nonabrasive plastic bead to metallic, glass or ceramic shot and the most aggressive mineral grit, makes it useful for a broad range of applications. These include cleaning, deflashing, deburring, cosmetic or decorative surface finishing, descaling, etching and profiling.

The TR-900 blast machine can be fitted with a rubber conveyor belt or a honeycomb mesh belt capable of moving in continuous or indexed motion at controlled and variable speed from 0 to 20 feet per minute. The blast nozzles are pre-positioned at the correct angles and distances on multi-adjustable brackets. When required for total coverage with the minimum number of nozzles and the lowest compressed air usage, synchronized movement of the blast nozzles can be oscillating, linear or rotary. The media delivery system is completed by a cyclone separator-reclaimer connected by ducting to an efficient cartridge-type dust collector.

For additional information, contact John C. Carson, Guyson's marketing manager, at (518) 587-7894.

Circle 302



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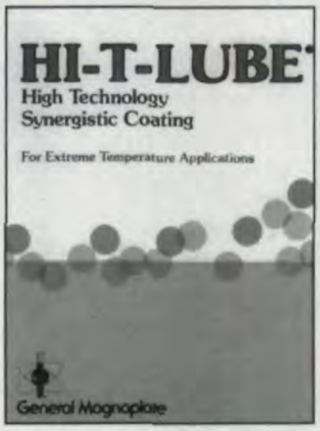

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If He Builds It, Will They Come?

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

Richard Spens has been rebuilding antique machine tools for nearly a decade. He is drawn to the ornate architecture and fascinated by the open design that allows you to see inside a machine as it operates. "Working with machines has been a lifelong thing with me," said Spens, now a design engineer. "I started building steam engines when I was 10 years old." What he's working on now, however, is bigger than any steam engine or machine tool. In rural Livonia, Michigan, Spens is converting an old dairy barn into an accurate recreation of a turn-of-the-century, belt-driven gear shop. It's an outgrowth of his interest in antique machine tools and, he feels, a way to stem the tide that is costing America so many manufacturing and skilled trade jobs.

"I see America losing its industrial base and hands-on skill," said Spens. "I think it's important to keep up the interest in the young people." He is hoping that his antique gear shop will be able to do just that by introducing children to machine tools that they can see into, watch in operation, and even operate themselves. Ideally, they could create something that they could take away as a souvenir. It was an idea Spens got while visiting the Henry Ford Museum's machine shop exhibit. "People were lined up to take a turn making a little candlestick at a turret-lathe they had set up. A machinist—an old timer—would take them through the procedure, and they came away with the candlestick they made themselves. I thought it was great."

According to Spens, one of the real jewels of his collection, and the most operational gear machine he has, is a Chase and Sloane machine built in the 1880s. A tabletop machine with its own motor, it was used to cut the tiny gears that went into the foot-powered dental drills of the day. According to Spens, "It was one of the most accurate gear cutters of its time. To make the drill as quiet as possible, it had to be."

The Massey Harris Gear Plant, Racine, WI, 1945.

Some of the other gear machines that will one day adorn his shop include another Chase and Sloane, this one with a three-spindle head that gashes, rough-cuts and finishes the tooth before the manual index moves the blank to its next position. There are also a pair of Adams gear hobbers (circa 1910) with fully open architecture and several smaller gear cutters used for watch making. Spens is also restoring an interesting pair of Gould and Eberhardt vertical hobbers, dated 1909 and 1912 respectively. These machines demonstrate the changes in machine architecture that G&E implemented during that time.

The project itself has been a long and difficult one right from the start, with humidity problems encouraging rust as well as problems with powering the shop. Spens' long-term goal is to erect a hit-or-miss single piston gas engine to operate the belt. This, in turn, would power the belts going to the machines. However, those machines that already have motors, such as the gear machines, will not be converted in order to keep them operational. Other machines will be belt-driven to give visitors a taste of what a belt-driven factory was like.

So, will the shop be open to the public? Yes, answered Spens. "It'll start out as a kind of private exhibit people can visit on a one-on-one basis. My ultimate goal, however, is to make it a museum to educate teens and young adults and interest them in careers in industry."

If you can help, Spens wants to hear from you. If you have an antique machine for sale or donation, or if you are interested in acquiring antique machine tools, write to him at:

Richard Spens, 28515 W. 7-Mile Rd.,
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