GEAR TECHNOLOGY

SEPTEMBER/OCTOBER 2000

The Journal of Gear Manufacturing

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Page 47

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CIRCLE 110

GEAR TECHNOLOGY

SEPTEMBER/OCTOBER 2000
The Journal of Gear Manufacturing

FEATURES

17

IMTS FOCUS

47

DEPARTMENTS

7

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CIRCLE 148

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CIRCLE 202

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CIRCLE 186

TRIUMPH OF PLANNING

"In preparing for battle, I have always found that plans are useless, but planning is indispensable." – General Dwight D. Eisenhower.

Normandy overwhelmed me when I first went there several years ago. I was sobered by the sea of white crosses in the cemeteries, I was inspired by the memorials and their tales of courageous soldiers battling impossible odds, and I was horrified by the visions of carnage that came to me as I stood on the scarred beaches of one of the most significant conflicts in human history.

I recently took my second trip to Normandy, and the experience was equally powerful, but for different reasons. Although the emotions were still a big part of the experience, I also began to see the Normandy Invasion from a more technical and intellectual perspective. As I learned more about the planning and resources that went into the operation, I was awed by the enormity of the enterprise that took place on those beaches and in the waters beyond in the summer of 1944.

On June 6, 1944, in the span of just one hour, roughly 135,000 men and 20,000 vehicles landed on five stretches of beach on the coast of France. The Allies chose one of the most inconvenient locations for their landing in order to gain the element of surprise. Over the next five months, another 700,000 soldiers, 200,000 vehicles and 725,000 tons of supplies were brought ashore. It's hard to fathom how the Allied forces were able get the right men and material, in the right quantities, to the right place at the right time.

Perhaps what's most amazing about the Normandy Invasion is that they did all of their planning using pencil and paper. They didn't have software or computers. They relied on manpower, brainpower and leadership to get the job done.

One of the biggest challenges facing the Allied commanders was getting huge quantities of men, material and supplies ashore in an area with no port. More than two years before D-Day, the Allies were already planning the invasion. It was then that Winston Churchill conceived the idea of a system of floating docks that would allow the unloading of material amid 20-foot tides and unpredictable weather in order to supply the fighting forces on the mainland. I find it remarkable that in Britain's darkest hour, when it was on its knees defensively, Churchill was thinking about the logistics of an invasion that might never have happened.

The Allies spent the next two years constructing the pieces for an artificial harbor. The British sank many large sections of the floating docks in the Thames River to hide them from enemy spies and surveillance. After D-Day, all the pieces were refloated and towed across the English Channel to a point off the coast of Arromanches, France. The floating harbor became one of the keys to the Allied success after they established the beachhead.

The artificial harbor consisted of a breakwater made up of sunken ships, four floating unloading docks, and a series of floating roadways to connect the docks to the shore. In effect, the Allies built a fully functional floating port in a matter of weeks. Under normal circumstances, it should have taken years to build a facility capable of off-loading as much material as the 7,000 tons per day that the artificial harbor at Arromanches handled.

Just as impressive as the manufacturing and design of the artificial harbor was the way it worked. The whole operation was set up in circles so that the trucks were always moving. One circle moved goods from the ships to the docks. As soon as a truck full of goods and equipment pulled away from the ship, an empty one on its return trip from the dock pulled up right behind it. Another circle of trucks moved the goods from dock to shore.

Many of the pieces of the artificial harbor are still there today. The system was a model of efficiency that reminded me of manu-

facturing cells and the way we try to set up our factories today. Getting the right material to the right place at the right time sounds an awful lot like the mantra of today's just-in-time manufacturing world. Today we've developed powerful tools to monitor and control the flow of material in our factories—tools that make us more efficient, profitable and successful.

I shouldn't be surprised that the Allies were able to coordinate such a huge effort without such tools. After all, the cost of failure would have been unthinkable, while monetary cost was of no object. They were willing to devote whatever resources were necessary to accomplish their task. "Give us the tools," Churchill said in 1941, "and we will finish the job."

Fortunately, we're not normally faced with such challenges. However, the story of the Normandy Invasion and the background behind it should serve as a model for enterprises of all sizes. On a much smaller scale, most of us must deal with the same logistical issues that faced the Allies.

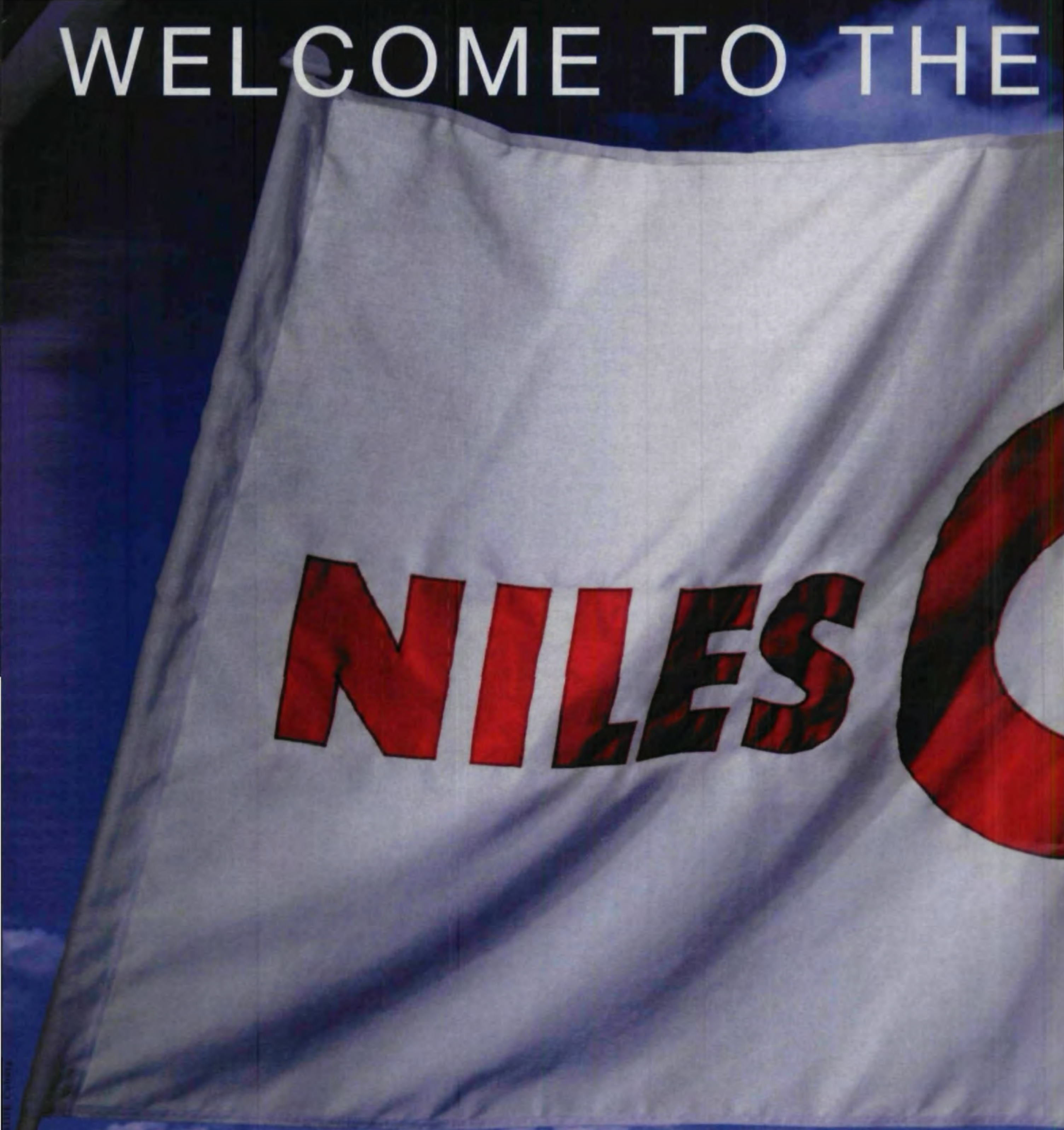
Today we have sophisticated computers and software to help us with our planning. We implement MRP systems, we invest in technology and we study our own efficiency. Despite these advantages, brainpower, manpower and leadership are still the drivers of success in any operation. In manufacturing, as in war, we need to make time for strategically important, long-range planning.

In particular, we're often faced with less than ideal situations. Business is sometimes bad. Competition is tough. But these are the *most important* times to prepare for the future.

When everyone thought Churchill and Britain were about to be defeated, he felt defeat was not an option. That was his strength. The plans he made and the leadership he displayed during those most trying times helped his country come back from almost insurmountable odds and achieve victory for the Allies. Ask yourself what victories you need to win. Whether you face unthinkable challenges or everyday obstacles, your planning today might make all the difference in your future.

Michael Goldstein

Michael Goldstein, Publisher and Editor-in-Chief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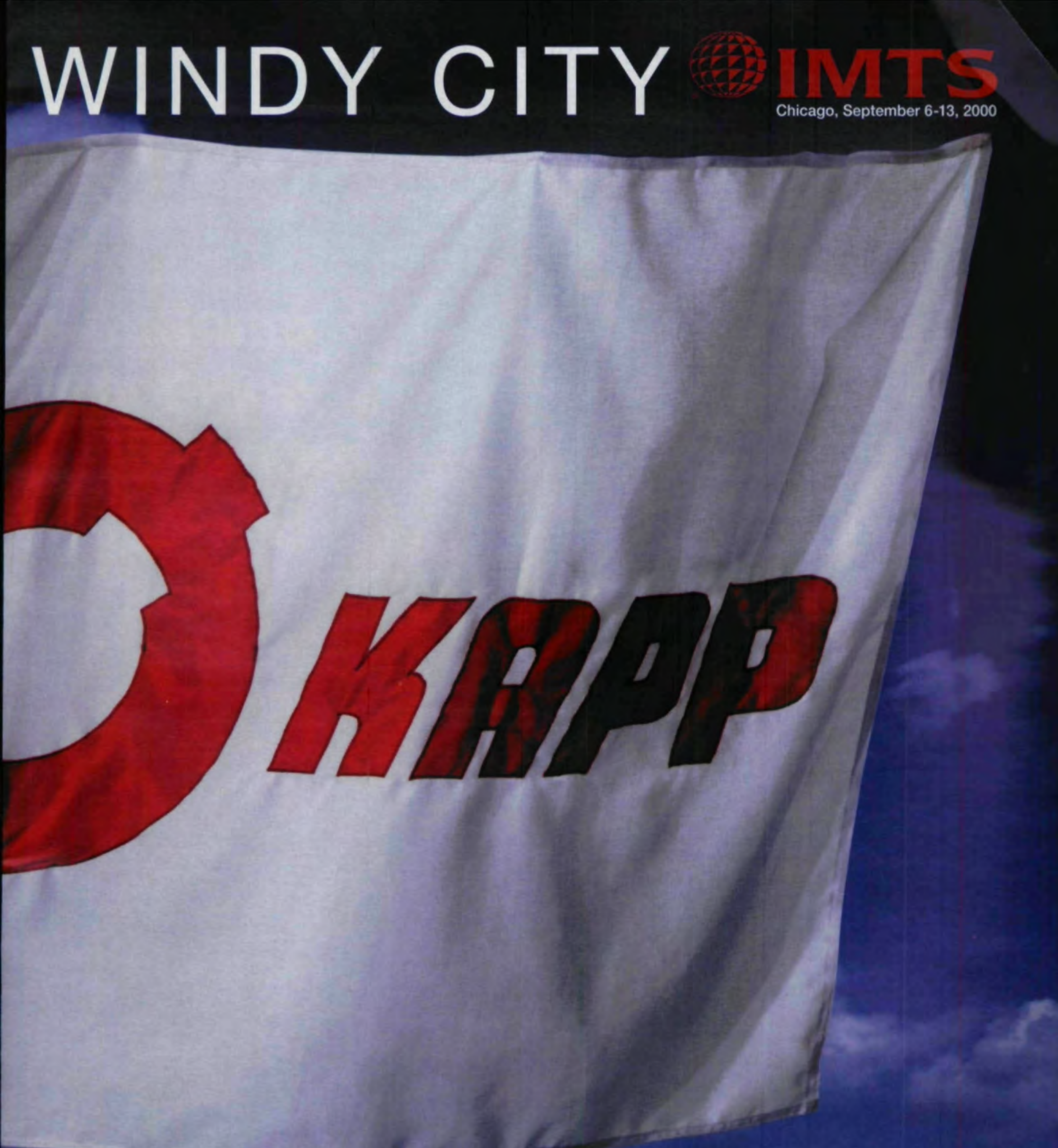
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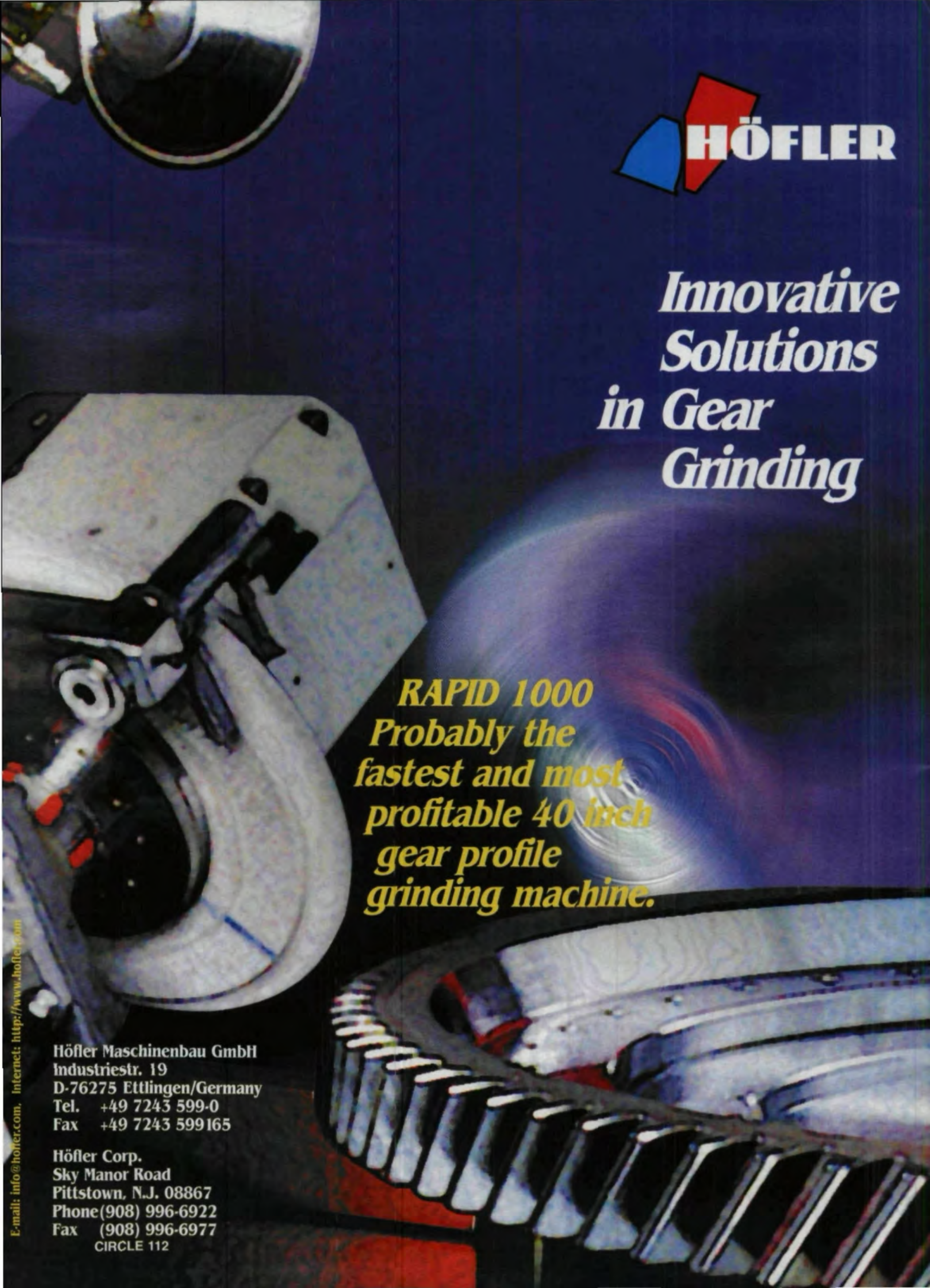
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Better Quality, Lower Cost Forged Gears

Today, near-net shape forged gears are produced with better quality than just a few years ago. Requiring only minimum finishing to meet specific tolerances, these gears can also be produced at significantly lower total costs than gears manufactured using other traditional techniques.

Near-net gears come from the forging press in almost the exact shape of the finished gear, with straight-from-the-die quality ratings as high as AGMA 6–7. Gear teeth are forged with an envelope of excess steel around the tooth profile, which is removed by either a single-pass grinding or hobbing operation. While only a handful of companies produce gears with this method, its popularity is growing, says Chris Carman, president and chief operating officer of Presrite Corporation, Cleveland, Ohio, which produces straight bevel, spiral bevel, helical and spur near-net gears in diameters up to 17" with stock allowances ranging from 0.1 mm to 1.5 mm.

Forging Near-Net Gears. The manufacturing process, which can take from 6 to 14 weeks depending on materials and design complexity, begins with steel bar stock that is usually turned and polished to improve the surface and then cut to the exact weight. This is critical since the steel must completely fill the die to complete the gear profile.

A near-net shape forged gear hot off the press. Courtesy of Presrite Corp.

Prior to forging, billets are heated in an electrical induction furnace, then, in a single stroke, mechanical forging presses, ranging from 1,600- to 6,000-ton, form near-net shape gears with the complete allowable material envelope, or stock allowance.

Finishing. After the raw forged gear is ejected from the die, it is allowed to atmospherically cool to ambient temperature. The gear is then ready for turning and a light-finish hob cut. If grinding is the final operation, a complete and consistent lower material envelope of grinding stock (0.1 mm to 0.3 mm per flank) is ensured by cold drawing the forged near-net gear through a finish sizing die. This operation is also capable of providing a finished protuberance and root configuration to the geometry supplied by customers, thereby eliminating requirements of grinding the root area. The cold drawing process is sometimes capable of producing a net tooth geometry, which eliminates gear finishing altogether.

Quality Control. A dedicated, climate-controlled gear lab, with responsibility for quality audits of the gears and dies, is essential to both the die design and the gear production process. Presrite recently improved its CMM capabilities with the addition of a new Mitutoyo Bright 910, running the latest proprietary gear software, to provide dimensional analysis of forged dies and gears. Dies are checked before and after press runs, and gears are checked during press runs to ensure quality.

"All of the machining equipment we've invested in is allowing us to produce near-net gears with lower profile stock allowances that are ready for our customers' final finishing processes," says Norman Fisher, Presrite's director of international sales. "Ultimately, we are helping our customers avoid capital equipment expenses, and at the same time we are providing them with higher quality parts."

Investing in Technology. Presrite has recently invested more than $30 million in technology for its near-net gear production process. This includes another state-of-the-art Solid Works 3-D CAD/CAM system to assist in precision tool design, and five CNC wire EDM machines to tighten repeatable die tolerances and reduce tooling costs.

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.*

Enhancements in equipment and tooling development have greatly reduced die set-up times, and advanced die materials now yield less forging scrap and greater production. Forging scrap rates have decreased from 20% to a current rate of less than 0.2%. "The changes we made to our die material and die design have resulted in extended die life, enabling us to produce more pieces per die," says Dale Debeljak, Presrite's technical services director. "And, in certain cases we've been able to cut die costs by as much as 50%."

Manufacturers Benefit. Manufacturers wishing to minimize capital expenditures and utilize their gear finishing areas for other manufacturing functions can benefit from using near-net shape forged gears. These gears exhibit less stress and last longer because of the consistent, unfractured grain structure of the integrally forged teeth. Near-net shaped forged gears can also cost less. Many manufacturers are eliminating rough hobbing, focusing instead on high-speed hobbing because of the benefits of working with near-net shape forged gears including increased productivity, reduced work-in-process, reduced expendable tooling costs and reductions in scrap rates.

According to Fisher, "We've had manufacturers tell us that they have experienced savings of up to 65% of hobbing time in certain conditions when working from a near-net shape configuration rather than a blank."

Circle 250

Recycling Comes to Abrasive Waterjet Operations

Abrasive waterjet, an alternative cutting process that utilizes abrasive particles in a highly directed, extremely high-pressure stream of water to cut metal and other materials without some of the drawbacks associated with other processes, has traditionally had some high waste and disposal

The Ward 24 Waterjet abrasive recycling system. Courtesy of Easijet, Inc.

costs associated with it. In fact, according to Richard Ward, president of EasiJet, Inc., of Tallmadge, OH, abrasive is the single largest consumable cost borne by all abrasive waterjet cutting customers. However, Ward and the folks at EasiJet think they have come up with an answer to those costs: their Waterjet Abrasive Recycling Dispenser, the WARD 24.

How It Works. The WARD 24 removes waste product from the tank in an abrasive waterjet cutting system. It separates the poor product into a container for removal and then washes and dries the remaining abrasive particles so they can be used again. The abrasive is removed from the tank using patented nozzles that have no moving parts. Even if they have been buried under the abrasive for several days, the nozzles can be activated to begin delivering the sludge to the WARD. The sludge is sent to the top of a series of vibrating screens where usable abrasive is separated. This recovered abrasive is then dried and readied for reuse. This results in two products: waste and recycled abrasive.

The waste is made up of sludge and fine particles. These waste products are typically well compacted and have very little water in them since the water used for washing the abrasive is returned to the tank. The recycled abrasive is washed and dried. It is then ready to be reused.

Maintenance Issues. In general, all alloys, steels and harder materials work well without clogging the machine. Test cutting of several plastics has also proven to work well. Small particles that found their way into the dryer were bonded, melted together with a grain of abrasive and removed during the final screening. This is not to say that clogging cannot happen. If materials being cut break down into frayed particles, these could cause screen clogging, which is easily fixed by removing and cleaning the clogged screen.

Clogging is not the only potential problem associated with the WARD. A number of parts on the machine—all parts in contact with the abrasive—are considered consumables and need to be watched and replaced as needed.

Recovery Rates. A number of variables need to be taken into account when considering recovery rates of recycled abrasive. These variables include the material being cut by the waterjet, the speed and quality of the cut specified (this determines the amount of abrasive contacting the abrasive stream's cutting face), the type and mesh size of the abrasive used, the placement of the abrasive removal nozzles in the tank, and the amount of operator attention given to the machine. Given these variables, field tests have achieved recovery rates of up to 70% in a general job shop environment. This reduces costs associated with waste removal and hauling, saving users up to 40% of the cost normally associated with abrasive waterjet.

Circle 251

Ford's Outstanding Young Manufacturing Engineer

Jose R. Ruiz Ayala, a manufacturing/process engineer who contributed to the implementation of the helical gear honing process at Ford Motor Company's Automatic Transmission Organization, was named as one of six recipients of the John T. Parsons Outstanding Young Manufacturing Engineers award by the Society of Manufacturing Engineers. The honor is conferred on individuals 35 years of age or younger who demonstrate outstanding leadership and achievement in the field of manufacturing engineering.

Ayala is researching the honing process as the benchmark in gear noise. "We're using honing to control the frequencies of the gear noise," says Ayala. "Right now, we're applying it only at the Sharonville plant, but other units within the company are looking at it." Ayala also reduced tooling changeover time on two gear production lines through the redesign of tooling and equipment. According to Ayala, the original design of the machine, manufactured by Federal Broach, required the complete removal of six, 6-inch bolts to change two collets.

"This removal had to be done blind," Ayala says, "as did the reinstallation. We worked with Federal Broach to redesign the tools and the machine so that the collets could be removed by only loosening the bolts. This saved a great deal of time." Ayala's redesign reduced changeover time from 90 minutes to 15 minutes. He is now working to change the tooling at hard turning operations from diamond coated inserts to ceramic inserts, which cut tooling costs by half and extend the useful life of the tool. "With the diamond-coated inserts, which have two corners, tool life was 250 parts per insert," he says. "With the ceramic inserts, which have 4 corners and slightly longer life per corner, we can get approximately 720 parts per insert."

After earning a masters degree in mechanical engineering from the University of Michigan, Ayala, a former Exxon Scholar, joined Ford, participating in the Ford College Graduate Program. As a member of Ford's South American Ranger launch team at the Ford Pacheco plant in Buenos Aires, Argentina, he was able to work closely with vendors to address issues and was the liaison between the Pacheco launch team and the launch team at Dearborn, MI.

In addition to his work at Ford, Ayala is a member of the Society of Hispanic Engineers (SHPE) and has also worked with the Young Engineers and Scientists (YES) program, guiding students through presentations ranging from electricity and chemistry to resume writing.

Each year, the Outstanding Young Manufacturing Engineer Award is named after an SME member who is considered a role model for young engineers. This year's choice, John T. Parsons, is the retired founder and president of the John T. Parsons Company of Traverse City, MI. He has a 70-year history in manufacturing with contributions to the automotive and aerospace industries that include the development of Numerical Control (NC), which he worked on with a partner.

The awards were presented in May at the North American Manufacturing Research Conference (NAMRC), an international forum for the presentation and critical discussion of the results of basic and applied research in material forming, material removal, manufacturing systems and manufacturing controls. The other recipients were Matthew Davies, Ph.D., a mechanical engineer at the National Institute of Standards and Technology in Gaithersburg, MD; Hugh Jack, Ph.D., an assistant professor at the Padnos School of Engineering, Grand Valley State University, Grand Rapids, MI; Paul Schiebel, assembly engineering manager at Hutchinson Technology, Inc., Eau Claire, WI; Steven Schmid, Ph.D., CmfgE, PE, a professor and researcher at the University of Notre Dame, South Bend, IN; and W.R. Winfough, Ph.D., senior staff engineer at Ingersoll Milling Machine, Rockford, IL.

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Gear Up for Performance:
An Introduction to Synthetic Lubricants for Fractional Horsepower Applications

Jeffery Lay

Editor's Note: *The following article details the advantages of synthetic lubricants in certain applications. However, the user should be aware of certain design issues arising from the exact chemistry of the synthetic. For example, some synthetics may have low solvency for additives. Others may not be compatible with mineral oils or nonmetallic components such as seals and paints. Some synthetics may absorb water and may not have the same corrosion resistance as mineral oils. Finally, the user should consider biodegradability or toxicity before switching to any new lubricant. Many of these concerns are present in petroleum-based lubricants as well, so consult a lubrication specialist before specifying a lubricant.*

Introduction

DeWalt Industrial Tools, Towson, MD, was close to putting its new Northstar line of power hand drills into production when quality testing raised a red flag. Gear pinions were failing the rigorous 300-hour bench test. The problem wasn't the gear design, it was the grease.

Designed for the professional tradesman, Northstar drills are faster and more compact than DeWalt's previous models, and petroleum grease could no longer take the heat. When the power toolmaker switched to synthetic grease, a blend of light polyalphaolefin and ester oils, the Northstar gearboxes still ran flawlessly after 700 hours of testing. Because of the base oils' low viscosity and exceptional lubricity, the synthetic grease also reduced internal drag, optimizing motor speed and overall tool performance.

The DeWalt story is not unique. While petroleum-based lubricants are still the norm in the world of gearing, more and more OEMs are discovering—often out of necessity—that synthetic lubricants solve gearing problems and improve product performance, extending operating life.

A Synthetic Lubricant Primer

Petroleum or mineral oils will always have a place in the world of gearing. After all, they are much lower in cost than most synthetic lubricants on the market and work well in many gear applications. In spite of their higher cost, however, synthetic lubricants can be a viable choice—and in some cases the only viable alternative—for gear designers.

What are synthetic lubricants? The basic building blocks of any lubricating oil come from nature. Animal, vegetable, and mineral oils are harvested, refined, and sent to market. Synthetic oils undergo another step: They are manipulated at the molecular level to change and improve lubrication characteristics. For example, a synthetic hydrocarbon oil starts with ethylene, a petroleum product. The ethylene is resynthesized to purify the oil and to narrow its range of molecular weights. The result is a synthetic hydrocarbon oil that is much less volatile than petroleum or, in more practical terms, an oil that has a longer operating life and a broader operating temperature range. In short, each family of synthetic oils relies on Mother Nature for its raw materials, but their unique properties are the product of scientific invention and rigidly controlled chemical processes.

Compared to petroleum, synthetic oils can offer several intrinsic advantages. The best known advantage is broad temperature capability

Fig. 1—A Class N gear motor (rated at 200° C) by Autotrol Corporation uses a perfluoropolyether grease to meet its customers' 6,000 wear-cycle and 450° F temperature requirements.

Fig. 2—A sub-fractional horsepower electric gear motor by Autotrol Corporation powers the TEG® Coagulation Analyzer by Haemoscope Corp. Plastic gearing is lubricated with a light, thixotropic, synthetic hydrocarbon grease.

Jeffery Lay
is the Gear Industry Director at Nye Lubricants, Inc., Fairhaven, MA, a manufacturer of specialty lubricants since 1844. Jeff's e-mail address is jefflay@nyelubricants.com *if you have any questions or comments.*

(See Table 1: "Lubricant Temperature Ranges"). In fact, the ambient temperature of an application is the most common reason design engineers first turn to synthetic lubricants. It was the primary reason Autotrol Corporation of Crystal Lake, IL, specified one of the most expensive synthetic lubricants for their new Model 150, Class N gearmotor.

The Class N motors automatically lock oven doors when the temperature hits 450° F (232° C) during self-cleaning cycles. The motor then releases the door latch when the temperature drops below 450° F during the cool-down phase. Autotrol used a high-temperature, engineered plastic for the gearing; however, the gears did not meet the customer's 6,000-cycle wear requirement. External lubrication was needed and perfluoropolyether (PFPE) grease, which can easily withstand continuous temperatures of 250° C as well as even higher spikes, was the logical choice. While the cost may have seemed prohibitive—PFPEs can cost up to $100/lb.—a little goes a long way. For Autotrol, four cents worth of PFPE grease in each gearmotor is all it took to exceed customer specifications—and build a reputation for quality in high-temperature appliance applications.

In addition to surviving hotter temperatures, most synthetic lubricants have lower pour points than petroleum; that is, they do much better in cold environments as well—a key reason why synthetic oils and greases have replaced petroleum in

Table 1: Lubricant Temperature Ranges

SYNTHETIC BASE OILS	CHARACTERISTICS
Synthetic Hydrocarbons Temp. range: -60 to 125°C	• Excellent thermal stability • Good friction reduction and lubricity • Wide range of viscosities • Low-temperature serviceability • Good plastic and elastomer compatibility • Long and growing list of applications in many industries
Polyglycols (a.k.a. Polyethers) Temp. range: -40 to 180°C	• Non-carbonizing, no residue • Good lubricity and film strength • Wide range of viscosities • Unusually good elastomer compatibility • Good load-carrying • Only synthetic oils which include water-soluble versions • Good high-temperature stability with proper antioxidant • Commonly used in arcing switches, and particularly effective in large worm and planetary gears
Synthetic Esters (Includes diesters, polyolesters) Temp. range: -65 to 150°C	• Excellent oxidative and thermal stability • Low volatility • Excellent anti-wear properties • Outstanding lubricity • Good low-temperature properties • Minimal viscosity change with temperature • Excellent load-carrying ability for bearing applications
Silicones (Includes dimethyl, phenyl, halogenated) Temp. range: -70 to 200°C	• Excellent oxidative and thermal stability • Low volatility • Wide range of viscosities • Minimal viscosity change with temperature • Excellent plastic and elastomer compatibility • Good wetting capability • Commonly used with plastic and elastomer components, including gears, control cables, and seals. Higher viscosities provide mechanical damping.
Fluoroethers Temp. range: -90 to 250°C	• Excellent oxidative and thermal stability • Low volatility and vapor pressure • Nonflammable and chemically inert • Excellent plastic and elastomer compatibility • Resistant to aggressive chemicals and solvents • Commonly used in extreme-temperature environments and applications which require chemical, fuel, or solvent resistance
Polyphenylethers Temp. range: 10 to 250°C	• Highest thermal and oxidative stability of all oils • Excellent radiation, chemical, and acid resistance • Excellent lubricity • Excellent high-temperature stability • Non-spreading even in thin film • Traditional lubricant for noble metal connector applications; also used for high-temperature, specialty bearings
Multiply-Alkylated Cyclopentane Temp. range: -45 to 125°C	• Proprietary fluid distributed by Nye, that combines the low vapor pressure of a PFPE with the lubricity and film strength of a synthetic hydrocarbon

Table 2: Overview of Synthetic Lubricant Families

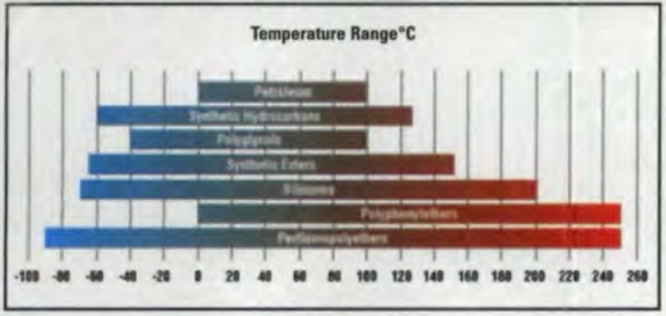

Fig. 3—In Bayside Control Group's precision gear set, even a film of lubricant can potentially be thick enough to cause a positioning error. A very light thixotropic grease not only passed rigorous life tests, it also lowered internal temperatures by five degrees.

Fig. 4—Special adherence and lubricity additives keep the synthetic grease on the gears and extend the operating life of Mallory's new Model 620 appliance timer.

Fig. 5—A new synthetic fluorocarbon gel on rack-and-pinion steering systems reduces wear, damps noise and eliminates the need for polishing racks after heat-treating.

most automotive components. Synthetic lubricants also last three to five times longer and do not form carbon deposits as readily as petroleum lubricants. They also have higher viscosity indices, the viscosity of the base oil showing greater consistency as temperatures change. Therefore, because there is less evaporative loss, you usually use less synthetic lubricant per part.

Each family of synthetic oils—there are six of them—also has its own unique, designed-in qualities (See Table 2: "Overview of Synthetic Lubricant Families"). A family consists of chemically similar oils in a variety of viscosities. Synthetic hydrocarbons, commonly known as polyalphaolefins (PAOs), are the most widely used synthetic lubricants for gears and gearboxes. They offer excellent cold-temperature performance (to −60° C) and are known for their oxidative stability. PAOs are compatible with many plastics, seals and paints used in gear applications. Compared with other synthetic fluids they are also relatively inexpensive. In addition, PAOs can be formulated for use as food-grade lubricants where toxicity issues such as contact with food products are of concern.

Synthetic esters are ideal for cut-metal and powdered-metal gearing, if proper seals are used. Due to their affinity for metal, especially steel and iron, esters provide maximum wear protection. Because esters can withstand temperatures as high as 180° C, they have become the clear choice for automotive supercharger gearing and other severe duty applications. A word of caution: esters, whether used alone or in combination with PAOs, have been known to attack certain nonmetallic components, i.e. plastics, elastomers, and paints.

Like esters, polyglycols have an affinity for specific metals, such as brass or phosphate bronze. Therefore, they are frequently used in worm gear applications to reduce friction and improve efficiency. In contrast to some of their mineral oil cousins and other synthetic fluid families, some polyglycols are biodegradable and non-toxic.

Silicones and PFPEs are compatible with nearly all gearing plastics. Both are suitable for broad temperature applications and have shown exceptional, low-temperature torque characteristics. PFPEs are also resistant to chemically aggressive environments and will not dissolve in the presence of fuel vapors or brake fluid. In addition, some PFPEs have very low vapor pressure, which is essential for vacuum chamber and aerospace applications where outgassing can be problematic. Both silicones and PFPEs have a low solvency for certain types of additives and as a result can have less corrosion resistance than other synthetic fluids or mineral oils.

Polyphenylethers (PPEs) are not widely used in gear applications. However, it is important to point out that these synthetic oils have high radiation resistance. In medical or dental applications, where radiation sterilization is mandatory, a PPE would be an ideal choice for gearing. (Note: Because of their radiation resistance they can not be exported to some countries for security reasons.)

In general, synthetic lubricants are simply new design materials that offer gear engineers an alternative to mineral oils or greases. They should be considered when mineral or petroleum lubricants can not meet operating conditions, such as extreme temperatures or the need for lifetime lubrication. Before replacing petroleum with a synthetic in an existing gearbox, always consult the gearbox manufacturer and do a cost-benefit anaylsis. When designing a new gearbox, weigh all options and consult with a synthetic lubrication specialist before specifying a lubricant.

So You're Designing a Gearset or Gearbox

Why would gears require lubrication? Simply stated, to make gears run smoother and last longer. Mechanically, a lubricant forms a protective film between the mating gear teeth and retards wear.

Selecting the best lubricant for an application is not always easy. The American Gear Manufacturers Association (AGMA) has developed an Industrial Gear Lubrication standard (ANSI/AGMA 9005-D94) to help engineers select an oil viscosity based on pitch line velocity of enclosed and open industrial gears. This standard references spur, helical, herringbone, straight bevel, spiral bevel, and cylindrical worm drives. However, there is no handy guide for the selection of greases or appropriate synthetic oils for gearing applications, which means the design engineer should have a basic knowledge of tribology and/or partner with lubrication engineers, especially for gearboxes that are "lubricated for life."

While the proper oil viscosity is important, choosing the right oil is the real key to getting the best lubricant for a specific application. All oils are subject to freezing and evaporation. In either state, they cannot lubricate, and the component fails. So matching the temperature range of an oil to the temperature extremes of the device is essential. Choosing the right oil is essential even when specifying a grease. Greases are made by mixing a powdered material or thickener—like lithium—with a base oil, but the oil is still the critical component. Greases can be thought of as a "sponge of oil." Moving parts, such as gear teeth, squeeze oil out of the matrix to prevent friction and wear. While many people are comfortable with a term like "lithium grease," it really tells little about the lubricant's properties. Lithium is only the "sponge." Lubricant behavior depends on the type of oil in the formulation.

What's better, grease or oil? When lubrication service intervals are part of the picture, oils generally get the nod. For example, oils are the norm in most large industrial gearing. Oil baths act as a cooling system and reduce operating temperature. They are also very effective in keeping wear debris suspended or out of the gear teeth mesh. The cooling and cleaning advantages of oil, however, have to be weighed against oil's tendency to leak. Seals add cost to the gearbox. Further, worn-out seals can pose safety and environmental hazards in an industrial setting as well as image and warranty issues in the consumer market.

When a gearbox is lubed-for-life, or if the orientation of the gearbox makes it prone to leakage, greases should be considered. Soft greases, those designed specifically for gears, not bearings, sometimes offer the best of both worlds. They will slump or flow back into the gear-teeth mesh like an oil while remaining gel-like to reduce leakage. Soft greases can be formulated to reduce internal operating temperatures. They also allow the addition of molybdenum disulfide (MoS_2) or polytetrafluoroethylene (PTFE), which do not suspend well in oil alone. These additives can dramatically reduce wear and friction under boundary lubrication conditions, where there are frequent changes in direction or sudden start/stops under load. Finally, a soft grease may reduce gearbox cost by eliminating oil seals and the manufacturing cost associated with seal designs.

Importantly, greases can be formulated light enough to accommodate even small gearmotors. For example, Autotrol designed a sub-fractional gearmotor for a medical device used to monitor the clotting ability of a patient's blood during surgery. Minimally, Autotrol needed a lubricant to protect against tooth wear and facilitate power transfer with minimal heat and noise. It also needed a plastic-compatible lubricant, since the gearmotor used plastic, brass, and steel components. A synthetic hydrocarbon grease with additives to minimize friction and start-up torque delivered the long, quiet life Autotrol's customer wanted.

Gear greases can be engineered soft enough to actually flow under shear and return to gel consistency when static. With their stay-in-place quality, these very light, thixotropic synthetic greases are a viable alternative to conventional gear oils, which are often automatically specified for low-torque applications.

Case in point: Bayside Motion Group, Port Washington, NY, designed a unique family of all-helical planetary gearheads with 30% more torque than other planetaries, backlash as low as 3 arc minutes, under 70 dB quiet operation, and over 92% efficiency.

Having pushed the laws of physics to the limit with its Helicrown gear tooth geometry and Plasma Nitriding, a computer-controlled hardening process, Bayside focused on the lubricant for further quality improvements. These gearboxes can see input speeds up to 10,000 RPM, so they require a robust lubricant to protect the tooth surface from wear and loss of profile accuracy. Compounding the task, in a precision gearset designed for servo motors, even a film of lubricant can potentially be thick enough to cause a positioning error. Lubrication engineers were able to formulate a very light, thixotropic synthetic grease whose flowability and durability assured continuous lubrication of the gears and bearings for the life of the gearhead. After a grueling, full-load, 300 hour/3,000 RPM life test, the gear teeth retained their original profile. In addition, the gearhead's operating temperature was 5 degrees cooler than with previously sampled greases.

Greases can be utilized in both high- and low-speed enclosed gear designs provided the housing or gearbox has been given proper consideration during the design process. The engineer must design the housing to reduce open spaces, where grease can become trapped and lead to lubricant starvation. In existing gearbox designs, engineers have incorporated plastic baffles to reduce the

A SYNTHETIC HYDROCARBON GREASE WITH ADDITIVES TO MINIMIZE FRICTION AND START-UP TORQUE DELIVERED THE LONG, QUIET LIFE AUTOTROL'S CUSTOMER WANTED.

amount of grease required to fill the box and to keep the grease where it is needed.

Plastic Gearing

Plastic gears are often "designed" to operate without lubrication—and they do. In the struggle to achieve maximum operating performance and life, however, many engineers are finding external lubrication dramatically improves plastic gear designs. In fact, it can be stated without exception that lubricated gears—even lightly loaded, low-speed, plastic gearing—will last longer and run quieter than the same gearset without lubrication. So the basic question is, How long and how quietly do the gears have to operate?

When selecting a grease for plastic gears, the base oil must be compatible with the design materials (See Table 3, "Materials Compatible with Synthetic Oils and Greases"). An engineer also needs to consider how well the lubricant will adhere to the gears. "Tackifiers," additives that improve a grease's ability to adhere to gear teeth, are usually recommended to reduce sling-off.

Mallory Controls of Indianapolis, IN, has a history of success with synthetic lubricants and plastic gearing. Recently, it set out to develop

Table 3 –Materials Compatible with Synthetic Oils & Greases (At Room Temperature)

	Synthetic Hydrocrbons	Esters & Polyglycols	Silicones (All Types)	Fluorinated Ethers
PLASTICS				
Acetals	A	A	A	A
Polyamides	A	A	A	A
Phenolics	A	A	A	A
Terephthalates	A	A	A	A
Polycarbonates	A	C	A	A
ABS resins	A	C	A	A
Polyphenylene oxide	A	C	A	A
Polysulfones	A	C	A	A
Polyethylenes	B	B	A	A
RUBBERS				
Natural Rubbers	C	C	A	A
Byna S	C	C	A	A
Butyl	C	C	A	A
Ethylene Propylene	C	B	A	A
Nitrile (Buna N)	A	B	A	A
Neoprene	A	C	A	A
Silicone	B	B	C	A
Fluoroelastomers	A	C	A	A

Legend: A=Usually OK; B=Be Careful; C=Causes Problems

Caution: *These compatibility ratings are intended to be guidelines for design engineers when selecting lubricants. Under high mechanical stress, high temperature, poor plastic/elastomerquality, or any combination of these conditions, compatibility can be compromised. Anysynthetic lubricant used with a plastic or elastomeric component should be tested to ensure compatibility in a specific application.*

the Model 620, a new longer-life timer for domestic clothes washers, dryers, and dishwashers.

Using its popular M–400 timer as a starting point, Mallory engineers upgraded the plastic gearing design. In initial prototype testing they used the M–400 grease, a plastic-compatible synthetic hydrocarbon with a wide serviceable temperature range that should have been suitable for the M–620. It did not meet cycle test requirements, falling short in the area of wear protection.

Because the M–400 grease was designed for small, slower-speed, plastic and metal gearing, the larger gears of the M–620 with their high pitch line velocity tended to sling off the M–400 grease. Without the cushion of grease between the gear teeth, friction exacerbated wear, which led to premature failure. Lubricant engineers recommended a similar formulation with special lubricity and adherence additives. Since a relatively light grease was needed to meet the unit's low-temperature, start-up torque requirements, a low-viscosity synthetic hydrocarbon base oil and lithium-soap thickener rounded out the chemistry. In cycle testing, this new lubricant dramatically reduced gear tooth wear, dampened acoustic noise, and substantially increased timing cycles.

Seitz Corp., Torrington, CT, manufactures precision-engineered, thermoplastic gears, gearboxes and components and is a recent convert to synthetic grease for plastic gears. Its latest actuated gearbox deploys and retracts canvas awnings on recreational vehicles. The gearbox incorporates both plastic and metal components that withstand output torques ranging from 140 to 220 inch-pounds under operating speeds from 30 to 14,200 RPM. The dry gears were noisy, which would have had a negative impact on the perceived quality of the product.

Seitz's lubrication supplier recommended a soft, clay-gelled, PAO grease with a tackifier for adhesion and PTFE to facilitate low-temperature start-up. When the gearset was loaded with the grease, it purred like a kitten. Subsequently, Seitz discovered a bonus to pass on to its customer. In wear tests, the greased gearset outlasted the dry gears by 300%.

One additional design note about lubricants for plastic gears: In cases where plastic gears have internal lubricants such as PTFE or silicone, the internal lubricant may interfere with the "wetting action" of some external lubricants, reducing the external lubricant's ability to provide an adequate film of oil between the gear teeth. Therefore, when selecting an external lubricant for plastic gearing, engineers should either choose gears without an internal lubricant or make certain that the internal lubricant works synergistically with the base oil in the external lubricant. Typically, if an external lubricant is used, no internal lubricant is required.

Heavy Metal

Some gear designs rely on mixed-film or boundary lubrication to prevent gear wear and failures. Visteon Automotive Systems' rack and pinion steering components, which are used in Lincoln, Thunderbird, and Mazda automobiles, were no exception.

Rack and pinion gears constantly change direction, and the potential for high shock-loading puts a great deal of stress on both the gears and the lubricant. Additionally, the Visteon system has a spring-loaded, yoke-to-rack mechanism, which keeps the rack mated to the pinion. Under mechanical shock-load testing, simulating pot holes and railroad tracks, the rack separated from the pinion, increasing wear and causing an annoying clunking sound—surely a warranty claim in the making. Visteon engineers needed a lubricant to reduce gear wear and the level of noise transmitted through the steering column, and their petroleum grease wasn't doing the job. They turned to lubrication experts for assistance on the project.

Synthetic lubricant formulators combined a newly developed, high-viscosity, synthetic base oil with a lubricious thickening agent and extreme pressure (EP) and antiwear additives. The grease was applied to the gear teeth as well as the spring-loaded, yoke-and-rack interface. It passed all gear and yoke wear tests while imparting a smooth, quiet, quality feel to the entire steering system.

Two other important benefits were realized. When Visteon switched from petroleum to synthetic grease, manufacturing costs decreased because less lubricant was needed per part. A bigger surprise, a manufacturing step was eliminated. Visteon typically hand-polished the back of the rack in some steering systems to reduce friction and wear between the spring-loaded yoke and rack. A lubrication engineer suggested that the new grease may eliminate the need to polish racks, without jeopardizing performance. In test runs, the unpolished racks lubricated with the synthetic grease actually outperformed the polished units lubricated with the petroleum grease.

Conclusion

Petroleum or mineral oils may always have a place in the world of gearing. However, synthetic lubricants are closing the gap. They are solving problems, reducing lubricant consumption, and making a real difference in the performance and life of demanding gearing applications. ○

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CIRCLE 142

TECHNICAL CALENDAR

September 6–13. The International Manufacturing Technology Show (IMTS). McCormick Place, Chicago, IL. The 2000 show features ten exhibit pavilions, Student Summit, keynote speakers and an expanded manufacturing conference. See our coverage on page 47. For additional details log onto *www.imts.org* or call (703) 893-2900.

September 10–13. 8th International ASME Power Transmission and Gearing Conference. Omni Inner Harbor Hotel, Baltimore, MD. Hear from top researchers from around the world as they present their latest work in the fields of gearing and power transmission. For information contact Neil Anderson, the conference chairman, at (248) 688-2369 or log onto the conference website at *www.enme.umd.edu/asme2000*.

September 26–27. Society of Manufacturing Engineers Conferences. Holiday Inn, Indianapolis, IN. SME's Conferencing Division is hosting two seminars. On September 26, SME will present "Understanding Gear Metrology." On September 27, SME will present "Manufacturing of Plastic Gears." To register for a program, or to get more information, contact SME at (800) 733-4763.

October 10–12. International Manufacturing Enterprise Technology Expo. Rosemont Convention Center, Rosemont, IL. IMET 2000 focuses on computers in manufacturing, enterprise systems, motion systems and industrial equipment and maintenance. For more information visit *www.imetexpo.com* or call (800) 964-9665.

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Gear Oil Micropitting Evaluation

A. B. Cardis & M. N. Webster

Introduction

During the last decade, industrial gear manufacturers, particularly in Europe, began to require documentation of micropitting performance before approving a gear oil for use in their equipment. The development of micropitting resistant lubricants has been limited both by a lack of understanding of the mechanism by which certain lubricant chemistry promotes micropitting and by a lack of readily available testing for evaluation of the micropitting resistance of lubricants. This paper reports results of two types of testing: (1) the use of a roller disk machine to conduct small scale laboratory studies of the effects of individual additives and combinations of additives on micropitting and (2) a helical gear test used to study micropitting performance of formulated gear oils.

Table 1—Factors Influencing Micropitting and Suggested Remedies.

Influencing Factor	Suggested Remedy
Gear Surface Roughness	Reduce to 0.3μm
Reduce Austenite Level	Retained Austenite
Lubricant Viscosity	Use Highest Practical Viscosity
Coefficient of Friction	Reduce the Coefficient of Friction
Speed	Run at High Speed (for a thicker EHL film)
Oil Temperature	Reduce Oil Temperature
Lubricant Additive Chemistry	Use Properly Selected Additives

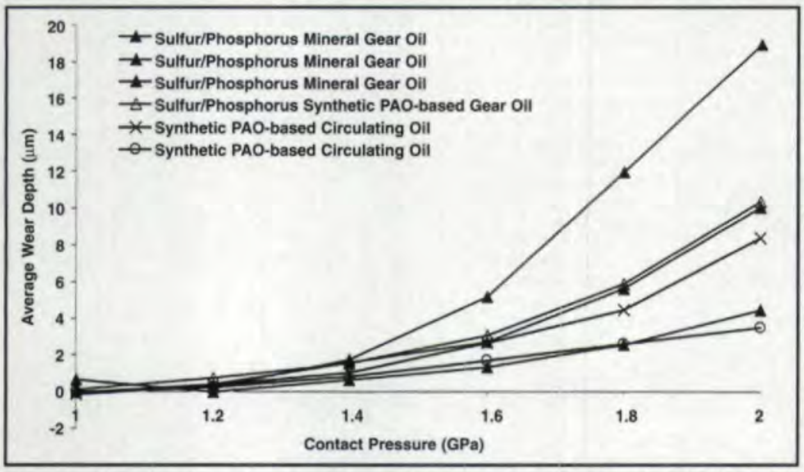

Fig. 1—Plot showing the progression of micropitting wear during Roller Disk machine experiments for various ISO VG 100 industrial gear and circulating lubricants.

Background

Micropitting is an unexpectedly high rolling contact fatigue wear phenomenon that is observed in combined rolling and sliding contacts operating under Elastohydrodynamic Lubrication (EHL) or mixed EHL/Boundary Lubrication conditions. Besides operating conditions such as temperature, load, speed, sliding and specific film thickness, the chemical composition of a lubricant has been found to strongly influence this wear phenomenon. Typically, the failure may start during the first 10^5 to 10^6 stress cycles with the generation of numerous surface cracks. The cracks propagate at a shallow angle to the surface forming micropits with characteristic dimensions of approximately 10μm. The micropits coalesce to produce a continuous fractured surface with a characteristic dull matte appearance that is variously called gray staining, frosting or micropitting when it is applied to gears. Micropitting is the preferred term. The terms peeling or general superficial spalling have also been used to describe this failure mode when it occurs on rolling element bearings. Micropitting is generally, but not necessarily exclusively, a problem associated with heavily loaded case hardened gears.

Unlike macropitting, micropitting is difficult to see, particularly under the conditions of field inspections. In the laboratory, with a clean gear mounted under a microscope with good directional lighting, micropitting takes on the appearance of etched glass. In the field, the tooth surface must be illuminated from various angles to see if the characteristic matte areas can be revealed.

Micropitting may occur almost anywhere on the gear tooth. However, research shows that micropitting is most likely to occur at local areas of high load, or areas associated with higher sliding during the gear tooth contact cycle. For this reason, micropitting is often found in the addendum and dedendum of the tooth profile and at the edge of the gear tooth if the gears are misaligned. It has also been observed that micropitting often tracks local high spots in the surface topography associated with high stresses.

The progression of micropitting may eventually result in macropitting. If pits form they often display a characteristic arrowhead or fan shape, with the pointed end at the edge of the micropitted area. There are also reported cases where the micropitting progresses up to a point and stops, sometimes described as a form of running-in or stress relief. Although it may appear innocuous, such loss of metal from the gear surface causes loss of gear accuracy, increased vibration, noise and other related problems. The metal particles released into the oil may be too small to be picked up by commonly used filters, but large enough to damage tooth and bearing surfaces (Ref. 1).

Micropitting Tests

The factors that are reported to influence micropitting (Ref. 2), along with suggestions for preventing the problem, are shown in Table 1.

The selection of properly additized lubricants is the most difficult parameter to determine. Ueno, et al. (Ref. 3) found in their testing that antiscuffing additives (often referred to as EP additives) in a GL-5 type lubricant caused micropitting to increase. Certain specification tests, such as the Timken OK Load Test, Four Ball EP Test and the FZG Scuffing Test require the use of such anti-scuffing additives.

There is no globally accepted test for determining the effect of the lubricant on gear micropitting. However, the test reported in the FVA (Forschungsvereinigung Antriebstechnik, the German Research Association for Drive Technology) Information Sheet No. 54/I-IV has gained widespread acceptance among gear builders and customers. In this test, the failure is determined by the degree to which micropitting causes a deviation from the original gear involute profile. If involute measurement equipment is unavailable, the micropitting can be tracked using a combination of micropitting area and weight loss, which is compared with tables and pictures characteristic of reference lubricants with different levels of micropitting protection.

Experimental Roller Disk Program

The FVA micropitting gear procedure can be used to screen the performance of various lubricant options. However, disk machines offer a more flexible platform on which to conduct tests to evaluate the influence of various operational and lubrication parameters on micropitting. Webster and Norbart (Ref. 4) have described the development of a roller disk test procedure that successfully reproduced many of the aspects of micropitting observed in gear testing. Significant findings from this preliminary work were:

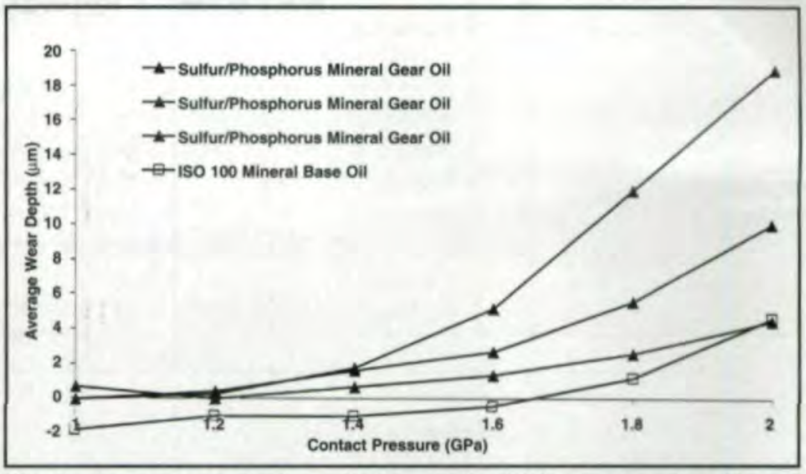

Fig. 2—Average wear depth results from Roller Disk tests show the effect of removing additives from an ISO VG 100 sulfur-phosphorus gear oil.

Table 2—Gear Design and Operational Variables for Helical Gear Micropitting Tests.

		Gear	Pinion
Number of Teeth		55	25
Normal Pressure Angle (deg)		25	25
Pitch Diameter (m)		0.297	0.135
Outside Diameter (m)		0.304	0.148
Helix Angle (deg)	19.75		
AGMA Quality Number	13		
Center Distance (m)	0.216		
Surface Roughness (rms)	0.81 mm		
Surface Hardness (HRC)	58–60		
Gear Material (carburized to 0.1016–0.1270 cm deep)	4820 Steel		
Face Width (m)	0.0286		
Gear Speed (rpm)	1000		
Power (kW)	625		
Oil Temperature (°C)	82		
Torque	5966 Nm		
Oil Viscosity		**Mineral**	**Synthetic**
Kinematic Viscosity at 40°C (cS)		68	68
Kinematic Viscosity at 100°C (cS)		8.5	10.4
Film Thickness (Lambda)	0.5 (approx.)		

- Under rolling/sliding conditions, the slower moving surface is more prone to micropitting.
- Increasing the specific film thickness (i.e. ratio of lubricant film thickness to combined surface roughness) from 0.92 to 2.32 moderately reduced micropitting damage versus the virtual elimination of micropitting with polished surfaces giving a specific film thickness of 5.62.
- Micropitting is drastically reduced at low, non-zero

Oil	Type	FVA Test Result
A	Mineral EP	Medium
B	Mineral EP	High
C	Synthetic AW	High
D1	Synthetic EP	Medium
D2	Synthetic EP	Medium
D3	Synthetic EP	Medium
D4	Synthetic EP	Medium
H	Synthetic EP	High

Table 3—Oils Used in the Helical Gear Test Program.

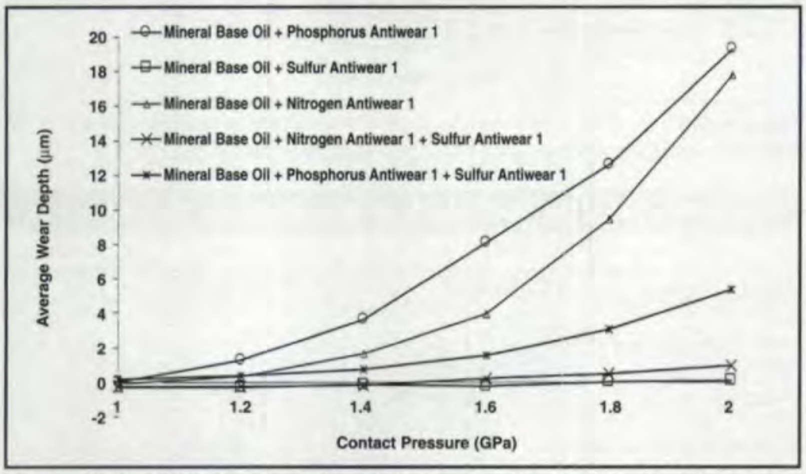

Fig. 3—Roller Disk Machine micropitting test results showing the influence of individual additive components from a typical ISO VG 150 sulfur-phosphorus-based gear oil package.

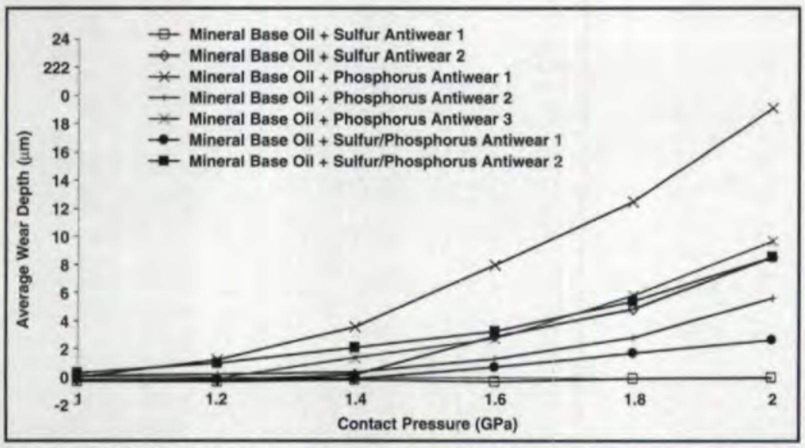

Fig. 4—Roller Disk Machine micropitting results for a range of alternative sulfur- and phosphorus-based antiwear additives blended into mineral base stocks.

slide to roll ratios (e.g. a slide to roll ratio of 0.0095).

The variable load method as described in reference 4 has been used to investigate the effect of lubricant composition on micropitting. Figure 1 shows results obtained from the tests conducted using a series of ISO VG 100 industrial gear lubricants. The two sulfur-phosphorus gear oils contain the anti-wear and anti-scuffing additives required to provide Timken OK load results greater than 60 lbs. The synthetic PAO based circulating oil was formulated to provide FZG fail stage 11 scuffing protection but does not provide a high level of Timken OK load protection. Despite the scatter associated with the mineral gear oils, the results show that both the mineral and synthetic based gear oils yield similar results. The results for the synthetic PAO circulating oil suggest that the use of less aggressive anti-wear additive systems provides directional improvement in micropitting performance. The results from these gear oil tests compare well with results obtained with the same lubricants using the FVA micropitting gear test and suggest a good correlation between the roller disk machine and FVA test methods.

To further investigate the influence of additives on micropitting, a test was conducted on the unadditized mineral base oil used in the mineral gear oil test. The results are compared with the fully formulated gear oil in Figure 2. The onset of micropitting is delayed and the final result corresponds to the lowest of the three fully formulated gear oil results. This result confirms the significant impact that lubricant additives can have on micropitting.

Obviously, gear oils must contain additives to meet various performance and specification requirements, not the least of which is to provide protection against the severe form of adhesive wear known as scuffing that can occur in gear tooth contacts. Thus, the challenge of developing next generation gear lubricants is to arrive at a base stock and additive composition that balances the various performance needs against the requirement to obtain good micropitting protection.

In order to gain an understanding of the impact of different component technology, micropitting tests were conducted on different combinations of additives and base stocks. In a first series of tests, individual components and combinations typically found in conventional sulfur-phosphorus gear oils were tested in ISO VG 150 mineral base stock. The results shown in Figure 3 indicate that the sulfur based antiwear additive 1 does not promote micropitting. Comparing against the mineral base stock results from Figure 2, we find that it may even improve upon base, stock-only performance. Both the nitrogen and phosphorus antiwear additives showed a significant tendency to produce micropitting. The addition of the sulfur antiwear to either of these two resulted in a significant improvement in performance. From these results it was concluded that sulfur additive 1 acts in some way to reduce micropitting damage. However, results from mixtures are not necessarily the sum of the results gained on individual components so the benefit from the use of sulfur additive 1 may not be reproduced when combined with additional additive technology.

In a second series of tests, the performance of a range of alternative sulfur- and phosphorus-based antiwear additives were evaluated and the results are shown in Figure 4. In this case, we see that there is a variation in the response within a general category of additive. For example, sulfur additive 2 resulted in a greater degree of micropitting than found for sulfur additive 1. Similar variations are found for the phosphorus and mixed sulfur/phosphorus additives tested. The results show that there is a large variation in the micropitting performance of the anti-scuffing additives that can be used to formulate gear oils. This variation is, no doubt, a function of the individual additive chemistry and it would be dangerous to assume, based on our limited testing, that any one class of additive has an advantage over another.

Helical Gear Test Rig

Following the roller disk machine experiments, a program was embarked upon to develop a micropitting resistant gear oil. The formulation effort made use of the FVA test as the primary tool for the evaluation of micropitting performance. However, additional testing was also conducted on larger gears more representative of commercial industrial gears. A test program was developed using an available four square gear test rig. In a further development, an automated machine vision system was employed to provide accurate and repeatable measurement of the micropitting areas on the test gears. Information about the gears and test conditions may be found in Table 2 and Figure 5. The test oils are listed in Table 3.

The machine vision system is based on light scattering by rough surfaces, as shown in Figure 6. Unworn areas appear dark to the camera because most of the incident light is reflected away from the camera due to the low angle of incidence of the inspection lights. Any micropitted areas on a gear tooth scatter light, in all directions due to the irregular roughness of the surface. Some of the scattered light is captured by the camera, causing the area to appear white. In the absence of other surface features that may scatter light, this approach gives an accurate assessment of the surface affected by micropitting. It thus provides an automated inspection system for following the progression of micropitting while avoiding the need for removing the gears from their shafts.

After initial runs to determine optimum conditions, the first test was run using the second side of the test development gear set with a mineral oil, designated Oil A, that had been rated fail load stage 9, medium, in the FVA test. Observations were made at 100-hour increments. Images were recorded and the amount of micropitting wear was calculated at 100 and 300 hours. The micropitting was concentrated in the dedendum and at the edges of the teeth. At 327 hours, the rig automatically shut down due to vibration in the slave box. At this time two large pits and a crack were found in Pinion Tooth #1 and a smaller pit in Gear Tooth #3.

The gear and pinion were analyzed to identify the type of damage and the cause of pitting. It was determined that the initiation of the failure was due to rolling contact fatigue, not adhesive wear. There was also evidence of movement and/or alignment problems with the gears. The photograph in Figure 7 shows a fan-shaped area starting in the micropitted area and terminating with macropits at the pitch line. This result appears to support field observations that have linked the onset of macropitting to areas that have previously been damaged by micropitting.

The second test was conducted using Oil B, for which a good rating in the FVA micropitting gear test had been obtained. This oil ran for the entire 1000 hours and had a much lower pinion micropitting rate compared to the previous test. Data for these two tests are graphically compared in Figure 8. Note the repeated pattern in the wear results, which exactly match the non-hunting tooth engagement pattern for the 25/55 pinion/gear tooth configuration. The nominal surface finishes recorded before and after the test are found in Table 4.

It was encouraging to find that the helical gear tests appeared to track the FVA test results. However, the small degree of micropitting resulted in anomalies in the machine vision measurement system that required improvements prior to starting the third test. A hard mount was fabricated to replace the universal fixture previously used

Table 4—Surface finish for Oil B.

Surface Finish, µm, rms.	Before	After
Pinion	0.51	0.23
Gear	0.47	0.23

Table 5—Surface finish for Oil C.

Surface Finish, µm, rms.	Before	After
Pinion	0.64–0.76	0.20–0.25
Gear	0.64–0.76	0.20–0.25

Table 6—Failure Modes and Hours to Failure.

Test	Test Duration	Cause
Oil D1	760 hours	Cracked tooth
Oil D2	36 hours	Broken tooth
Oil D3	30+ hours	Broken tooth
Oil D4	148 hours	Broken tooth
Oil H	534 hours	Broken tooth

Fig. 5—Pictures showing the 55-tooth gear and 25-tooth pinion used in the helical gear testing.

A. B. Cardis

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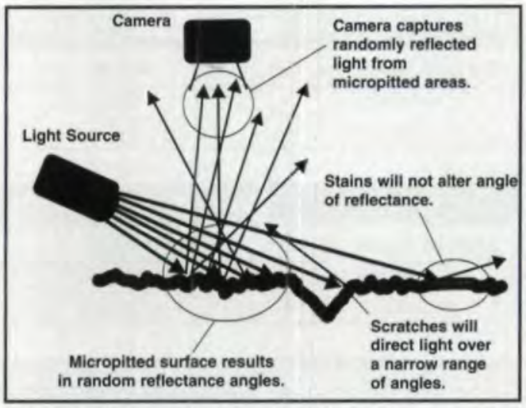

Fig. 6—Schematic showing the light-scattering characteristics from various surface features of the gear tooth under inspection.

Fig. 7—Pitted gear tooth from the helical gear tests on Oil A. Note that the pit appears to have started from within the micropitted area.

to locate the camera with respect to the gear under inspection. This eliminated the need to adjust the lighting to compensate for shifts in the location of the camera. Additionally, post processing vision algorithms, which use an adaptive rather than a fixed threshold to discriminate between worn and unworn areas of the gear tooth, were employed.

In the third test, the same procedure was employed using a synthetic oil, designated Oil C, that rated fail load Stage >10 high in the FVA test. A report file was generated containing the estimated percent micropitting relative to the total tooth contact area. A reference data set was recorded after run-in to be used to correct inspections made during the test for anomalies present at the start, which were not related to micropitting and which would not be expected to change during the test. Data for the 100-hour inspection period are not available due to a problem with the data acquisition system.

As expected, there was a very low level of micropitting wear. Since we have a quantitative measure of micropitting throughout the test, it is possible to estimate wear rate as a function of test time. In comparing Oil B with Oil C, we found that the progression of micropitting wear was quite different. In the case of Oil B, the rate was consistently low at 0.2%/100 hrs up to 700 hrs, at which point the rate increased sharply. Between 700 and 900 hours, the rate increased to 0.7%/100 hrs and between 900 and 1000 hours, the rate was 0.9%/100 hrs. The overall rate for the test was 0.5%/100 hrs. For Oil C, the overall rate was slightly greater at 0.61%/100 hrs, however, the greatest amount of wear occurred in the first 300 hours (1.57%/100 hrs) with a very low rate of wear, 0.17%/100 hrs, thereafter. For Oil C, the nominal surface finishes were recorded before and after the test as shown in Table 5.

The difference in micropitting wear rate was unexpected, since both oils had the same performance level in the FVA Test. However, it is interesting to note that the high initial rate found in the Oil C tests corresponds to gears with higher initial roughness. This result matches well with observations that gear tooth surface roughness has a significant impact on the initiation of micropitting.

The low level of micropitting, as well as the changes in appearance of the worn surfaces, posed additional problems for the illumination/imaging system. Individual gear teeth showed different localized levels of both micropitting and macropitting. Under these conditions, the intensity based feature recognition system was not always able to successfully separate brightness due to a micropitted area from the brightness of the non-micropitted portion of the tooth. One possible solution to this problem would be to replace the incandescent light with a laser based system. However, this upgrade has not been implemented.

The next run was made with Oil D, a synthetic oil that was rated fail load stage 9, medium, in the FVA test, using the second side of the gear set which had been used for Oil C. This oil had a similar progression of wear to that of Oil C with most of the wear occurring in the first 300 hrs and with very low incremental wear thereafter. The test was stopped at 760 hrs due to vibration caused by a cracked tooth. The surface finishes before and after testing were the same as for Oil C.

Figure 9 compares the results at 300 hours for the first set of test oils. The mineral oils are rated in the same order as the rating in the FVA test and the synthetic oils are not. These differences may well be related to manufacturing and surface finishing variations between the test gears.

A further series of tests were conducted using a new batch of test gears. The first of these tests was conducted with Oil D. From early observations it became clear that this test was yielding a different result from the first test using Oil D with the previous batch of test gears. Mild scuffing was observed on several of the pinion teeth after only a few hours of run-in. This test terminated after 36 hours with a broken tooth. A repeat of this test ended with a similar result. Following modifications to the torque system, a further repeat test was initiated (denoted as Oil D4). This test was terminated at 148 hours due to a broken tooth and also showed signs of mild scuffing. During this test it was observed that the unworn tooth area had taken on a mottled appearance. However, the vision system did successfully exclude these from the micropitted area. It was also noted that some of the initial micropitting was removed as the test progressed. The test was terminated at this point due to uncertainties in the validity of the micropitting measurement under these circumstances.

Following our disappointing experience using Oil D with the second batch of test gears, we elected to try a different oil. Oil H had been developed as a micropitting resistant oil based on the earlier Roller Disk Machine results and had achieved a high rating in the FVA test. In this test, significant micropitting (7.8%) appeared during run-in and the first 5 hours at the test load. An additional 7.0% had accumulated by the 100-hour inspection.

Thereafter, the micropitted area appeared to decrease in a similar fashion to that in the last test of Oil D. Once again the test was stopped because of a broken tooth, at which point micropitting covered 14.37% of the pinion active flank area. Table 6 summarizes the failure modes and hours to failure for the tests conducted on the second batch of gears.

Conclusions

Despite the mixed experience with the gear test, several instructive lessons were gained from the earlier roller disk machine experiments and the large-scale gear tests.

• Results from both the roller disk machine and the FVA gear test have confirmed that if all other variables are held constant, the composition of the gear oil has a direct influence on micropitting.

• Additives commonly used in gear oils to provide anti-scuffing performance can have a negative influence on micropitting.

• There is a wide variation in the micropitting performance of the anti-scuffing additives that can be used to formulate gear oils.

• An automated machine vision system can be applied to *in situ* gear inspections to track the progression of micropitting.

• Gear manufacture and finishing has a significant influence on micropitting, which highlights the need for close tolerances on these variables in order to obtain a consistent test.

• Batch to batch variations between gear sets suggest that it is good practice to plan any test series on one batch of gears. One gear set from the batch should be run with a reference oil.

• Variation in results between the helical gear and FVA tests confirms that micropitting responds to many gear manufacturing, operational and lubricant characteristics.

• Gear oils can be formulated using new additive systems balanced to meet the combination of providing anti-scuffing requirements while reducing the risk of micropitting. ○

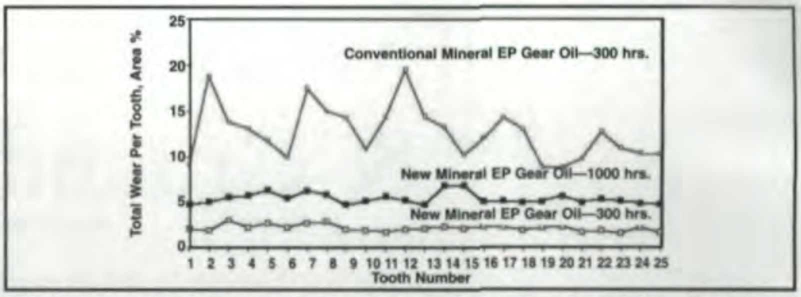

Fig. 8—Micropitted area measured on individual pinion teeth for different lubricants and test times. Note the repeated pattern observed for the conventional EP gear oil corresponds to gear contacts associated with the non-hunting 25/55 gear ratio.

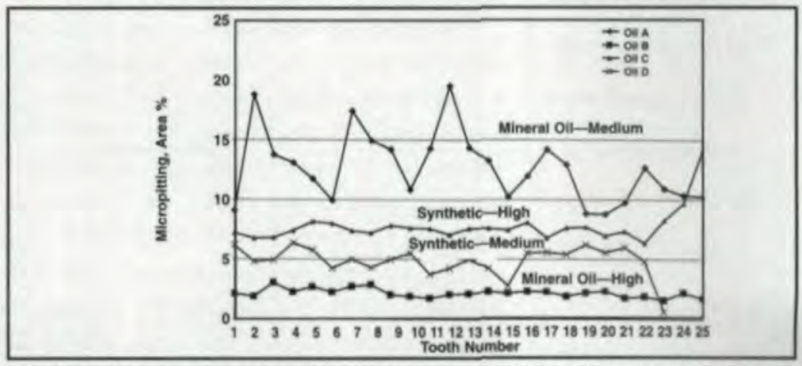

Fig. 9—Micropitted area at 300 hours for oils exhibiting different FVA gear test micropitting performance.

Acknowledgements

The authors would like to acknowledge the work of E. E. Shipley and R. W. Gamache of Mechanical Technology Incorporated (MTI) who were responsible for the helical gear testing and development of the machine vision system respectively. We would also like to dedicate this paper to our friend and colleague, E. E. Shipley, who sadly passed away soon after the completion of the large-scale gear test program.

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Evaluation of Caburized & Ground Face Gears

Dr. David G. Lewicki, Dr. Robert Handschuh, Gregory F. Heath and Vijay Sheth

This article was first presented at the 55th Annual Forum of the American Helicopter Society, May 25–29, 1999, in Montreal, Canada. Reprinted with the permission of AHS International—The Vertical Flight Society.

** Editor's Note: Crown Gear B.V., the manufacturer of Cylkro® face gears, has been working with Kapp GmbH and Reishauer AG to develop grinding machines and technology capable of producing AGMA 13-14 quality Cylkro® gears for the aerospace and automotive industries and presented its first ground Cylkro® gear at Gear Expo in October 1999.*

Introduction

Designers are constantly searching for ways to reduce rotorcraft drive system weight. Reduced weight can increase the payload, performance, or power density of current and future systems. One example of helicopter transmission weight reduction was initiated as part of the United States Army Advanced Rotorcraft Transmission program. This example used a split-torque, face-gear configuration concept (Ref. 1). Compared to a conventional design with spiral-bevel gears, the split-torque, face-gear design showed substantial weight savings benefits. Also, the use of face gears allows a wide range of possible configurations with technical and economic benefits (Ref. 2).

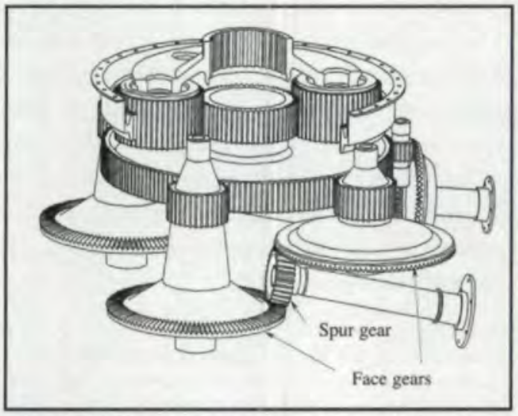

Fig. 1—Split-torque, face-gear transmission from the ART program (Ref. 1).

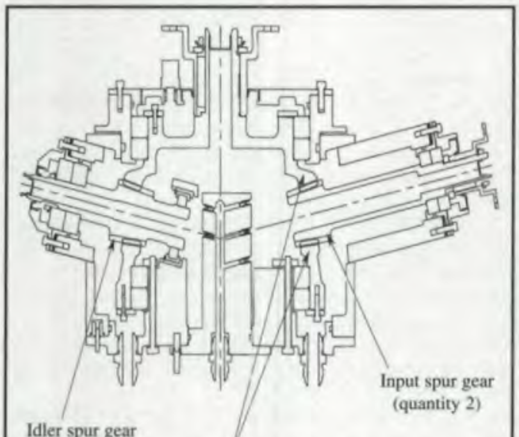

Fig. 2—Split-torque, face-gear transmission from the TRP program (Ref. 12).

Historically, face gears have been used to transfer light loads or angular motion between intersecting shafts (usually at right angles) such as in positioning mechanisms. Standards (Ref. 3) as well as examples of research contributions (Ref. 4) exist for this type of application. There is, however, a lack of experience with respect to design guidelines, allowable stress, and manufacturing capabilities for face-gear use in high-speed, high-load applications such as helicopter rotor drive systems. Recent studies have been performed to advance the analytical capabilities relating to face-gear design (Refs. 5–8). These studies considered face-gear geometry, size limitation factors, tooth contact analysis, kinematics and transmission error analysis. Experimental testing has also been performed to demonstrate the feasibility and investigate the failure modes of shaper-cut face gears (Refs. 9–10). These studies identified the need for face gears made from high-strength, carburized steels in order to obtain the required durability when subjected to a high-speed, high-load environment. When using carburized steels, there is a requirement to grind the gears to compensate for heat treatment distortion in order to obtain high-accuracy tooth geometry. However, there is currently no machine available that will grind face gears.*

A new initiative has begun in Europe to investigate and advance the use of face gears in aerospace transmissions (Ref. 11). In the United States, a Defense Advanced Research Projects Agency (DARPA) Technology Reinvestment Program (TRP) was established to further enhance face-gear technology. The objective of the DARPA program is to develop a grinding procedure for face gears as well as design and demonstrate the proof-of-concept of a concentrically-arranged split-torque, face-gear transmission configuration (Ref. 12). A grinding procedure was developed based on a continuous grinding method using a worm grinding wheel. Prototype carburized and ground AISI 9310 steel face gears were fabricated as part of this program.

The objective of this work is to describe the preliminary results of the experimental tests performed on the carburized and ground AISI 9310 steel face gears. Face gears were tested in the NASA Glenn spiral-bevel-gear/face-gear facility. Basic face-gear design, test facility, setup procedures, testing procedures, and test results are described.

Face Gear Applications in Helicopter Transmissions

Figure 1 shows the split-torque, face-gear transmission developed during the U.S. Army Advanced Rotorcraft Transmission (ART) program (Ref. 1). For this configuration, an involute spur gear, drives both an upper face gear and lower face gear. These face gears are connected to spur gears, which drive a large bull gear. By splitting the power flow in these two paths, smaller components can be utilized, which leads to reduced weight. Compared to spiral-bevel gears, face gears allow the use of a simpler, less expensive, involute spur pinion. In addition, the pinions do not produce axial forces and have less axial misalignment restrictions than spiral-bevel gears. It was estimated that a 40-percent weight reduction resulted from the split-torque, face-gear design compared to a conventional design. The conventional design weight used for comparison above was based on a parametric upscale of transmission design technology existing at that time. A design configuration which can be installed in existing aircraft much more readily than the preceding ART design is shown in Figure 2. This is a concentric, split-torque, face-gear design developed during the DARPA Technology Reinvestment Program (Ref. 12). This reduced-scale test gearbox will be used in proof-of-concept test evaluations. For this concept, an involute spur gear also drives a pair of face gears and the power flow is split in two. For the upper face gear, the power flow is direct from the input spur gear to the face gear. For the lower face gear, however, the power flow is from the input spur gear through the lower face gear, to an idler spur gear, and then the upper face gear. This configuration allows a large power capacity in a relatively small package. Assuming a full size production design, this concept has an estimated weight savings of 25-percent compared to a modern technology conventional design. These two examples show the potential benefits for the use of face gears in helicopter transmissions.

Test Facility

The experiments reported in this article were performed in the NASA Glenn spiral-bevel-gear/face-gear test facility. An overview sketch of the facility is shown in Figure 3a and a schematic of the power loop in shown in Figure 3b. The facility operates in a closed-loop arrangement. A spur pinion drives a face gear in the test (left) section. The face gear drives a set of helical gears, which in turn, drive a face gear and spur pinion in the slave (right) section. The pinions of the slave and test sections are connected by a cross shaft, thereby closing the loop. Torque is supplied in the loop by a thrust piston which exerts an axial force

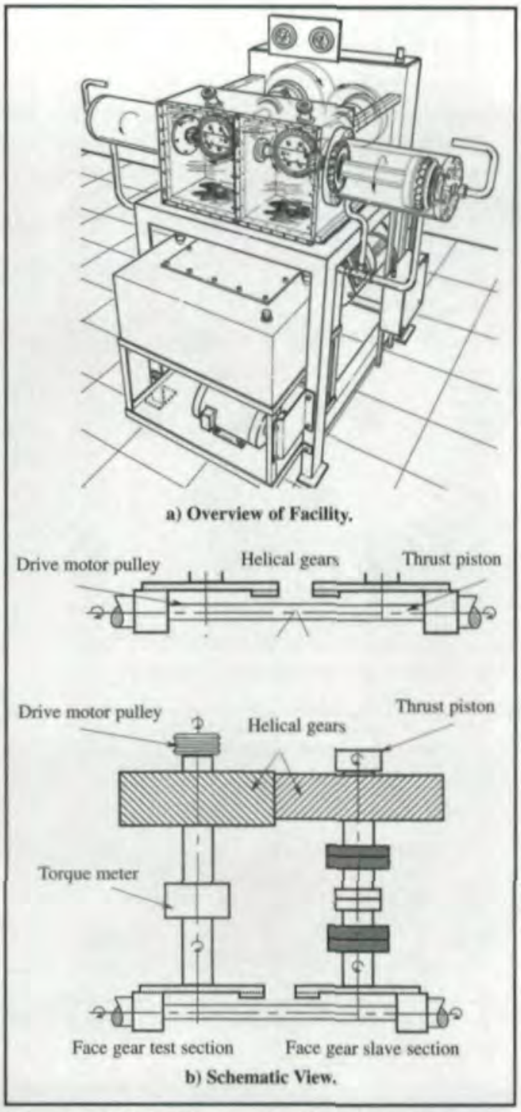

Fig. 3—NASA Glenn spiral-bevel-gear/face-gear test facility.

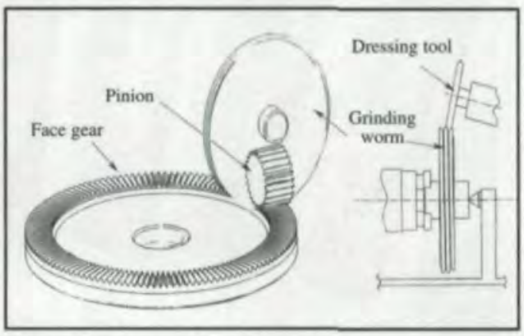

Fig. 4—Face-gear grinding setup.

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on one of the helical gears. A 75-kW (100-hp) DC drive motor, connected to the loop by V-belts and pulleys, controls the speed as well as provides power to overcome friction. The facility has the capability to operate at 560 kW (750 hp) and

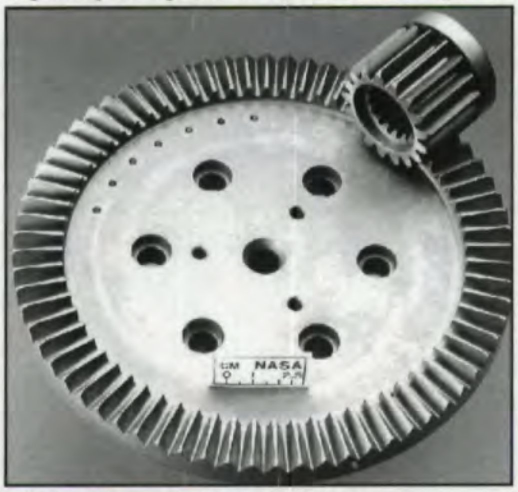

Fig. 5—Test spur pinion and face gear.

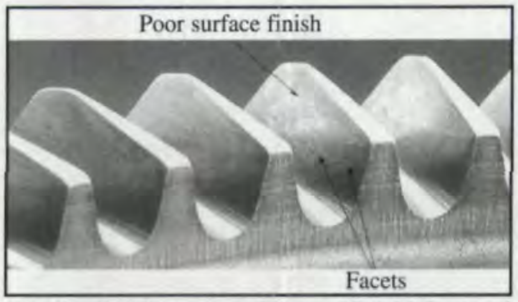

Fig. 6—Development problems with initial ground face gears.

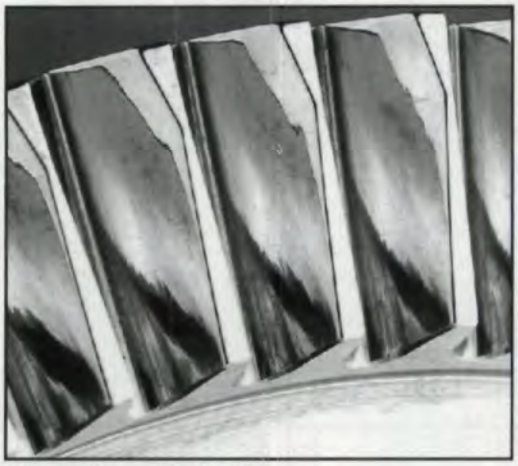

Fig. 7—Super-finished face gear.

Fig. 8—Typical tooth contact pattern checks from loaded static roll tests during installation.

20,000 rpm pinion speed. A torque meter in the loop measures torque and speed. The facility is also equipped with thermocouples, oil flow meters, pressure transducers, and accelerometers.

The gears and bearings of the facility are lubricated and cooled by a pressurized oil system. The lubricating fluid used was a synthetic base helicopter transmission oil conforming to the DOD-L-85734 specification. The test pinions and face gears were lubricated by jets which radially directed oil into the roots of the teeth on both the into-mesh and out-of-mesh sides. The nominal oil supply pressure was 552 KPa (80 psi) and the nominal flow rate was 2.6 l/min (0.7 gpm) for both the test section and slave section. Oil inlet temperature was set at 74° C (165° F). In addition, the oil system was equipped with a chip detector as well as a three-micron filter.

Face Gear Grinding Setup

The face gears used in the current tests were precision ground using a true generating method. The goal was to produce face gears having a quality of American Gear Manufacturers Association (AGMA) Class 12 or better. The method used employed a worm thread grinding wheel to generate the face gear teeth in a setup similar to that shown in Figure 4. The worm wheel rotational axis was located perpendicular to the face gear axis at an offset distance. During grinding, the worm rotated about its axis as it translated across the face gear teeth along a nearly radial line. The translation was at a small angle to the true radial line and related to the lead angle of the worm. The face gear work piece also rotated slowly during grinding so that all teeth were generated synchronously after multiple turns of the face gear as the grinding worm slowly translated inward. An effective method of redressing the grinding wheel (without tooth undercutting) during the above process was also developed.

The face gears were ground on a four-axis machine incorporating the basic setup described above. The first development gears experienced grinding burns as process parameters were being adjusted. Other difficulties included tooth facets and rough surface finishes. Eventually, face gears of AGMA Class 11 quality were made for the tests. The experience with the setup used validated the process but indicated that a better machine is required to obtain the gear quality needed. Deficiencies encountered included limited machine grinding speed, excessive machine deflections, and control-loop errors inherent in older vintage machines. The machine capability for making larger face gears (desired for aerospace use) was limited as well. Current work is underway to develop a full CNC five-axis grinding machine for face gears.

Test Gears

The design parameters for the pinions and face gears used in the tests are given in Table 1. A photograph of the test specimens is shown in Figure 5. This set was a hybrid between the ART program design and the TRP design. The set had a module of 2.54 mm (diametral pitch of 10 teeth/in) and a reduction ratio of 4.059:1. The face width of the face gears was 15.7 mm (0.620 in). The face width of the spur pinions was 32.6 mm (1.285 in). The shaft angle was 90° to accommodate the facility. The pinions were made from carburized and ground AISI 9310 steel using standard aerospace practices. The face gears were made from the same material and manufactured using the grinding procedure previously mentioned.

The 100-percent design torque for the face gears was defined as 377 N-m (3340 in-lb). This produced the same magnitude of contact stress as the face gears of the TRP concentric, split-torque transmission configuration at its 100-percent design load (Ref. 12). For the test gears, the calculated contact stress at 377 N-m torque was 1170 MPa (170 ksi) based on Hertz theory. The calculated pinion bending stress at 377 N-m torque was 210 MPa (30 ksi) based on standard AGMA calculations and using an effective face-gear face width. The allowable stresses stated in the table are those commonly accepted for AISI 9310 carburized and ground spur gears.

Due to the manufacturing problems previously mentioned, the face gears actually produced by the grinding procedure described above were not up to aerospace quality standards. The teeth had a relatively poor surface finish as well as faceted areas (Figure 6). In order to improve the surface finish, the teeth were subjected to a super-finish process (Ref. 13). In this process, the gears were immersed in a container of small zinc chips, water, and aluminum oxide powder. The container was vibrated for a number of hours and the grade of oxide powder was increased in fineness in several stages. Figure 7 shows a face gear after such a process. Although actual surface roughness measurements for the face gears tested were not available at the time, it was reported (Ref. 13) that a four- to six-times improvement in surface finish was achieved on those specific gears studied.

Test Gear Installation Procedures

Although not as stringent as for spiral-bevel gears, proper pinion and face gear installation is crucial for successful operation. The installation procedure for the gears tested was as follows: First, the test-side pinion and face gear were installed in the facility (with no cross shaft connected to the pinion). The pinion was locked to ground and backlash measurements were taken for the mesh. A dial indicator was installed at the center of the face gear tooth, the face gear was manually rotated back and forth, and the backlash was recorded. After completion, marking compound was applied to the pinion and face gear teeth. No-load contact pattern checks were performed by manually rotating the pinion/face-gear assembly. If necessary, the shim located behind the face gear, which moves the face gear in the axial direction, was adjusted to achieve the proper backlash and contact pattern. This process was then repeated for the slave-side pinion/face-gear mesh. After proper shimming was achieved, the cross shaft was installed. Marking compound was then re-applied to all the pinions and gears and a loaded static roll test was performed. This was done by applying a moderate torque in the loop,

Table 1—Test Gear Design Data

AGMA quality; desired, achieved	12, 11
Number of teeth; pinion, face gear	17, 69
Module (mm)	2.54
Pressure angle (deg)	27.5
Shaft angle (deg)	90
Face width (µm); pinion, face gear	32.6, 15.7
Hardness (Rc); pinion and face gear	58–62
RMS surface finish (µm)	0.4
AGMA pinion bending stress (MPa); index, allowable	210, 450
AGMA contact stress (MPa); index, allowable	1170, 1380
Material	Carburized and ground AISI 9310

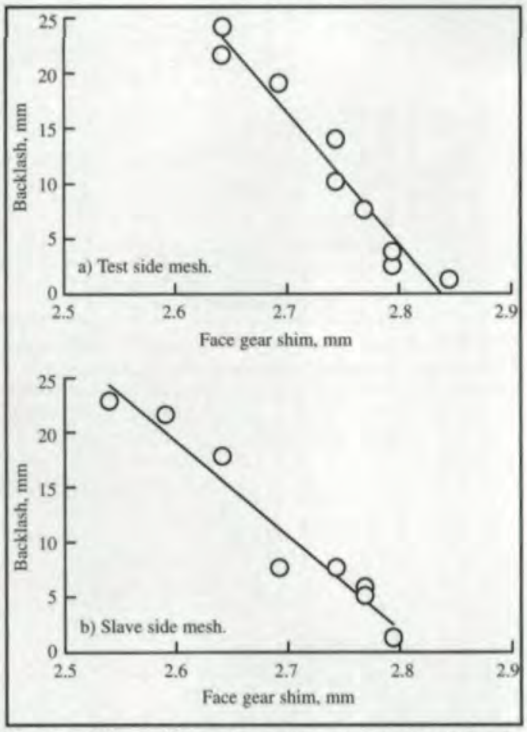

Fig. 9—Effect of face-gear shimming on tooth backlash.

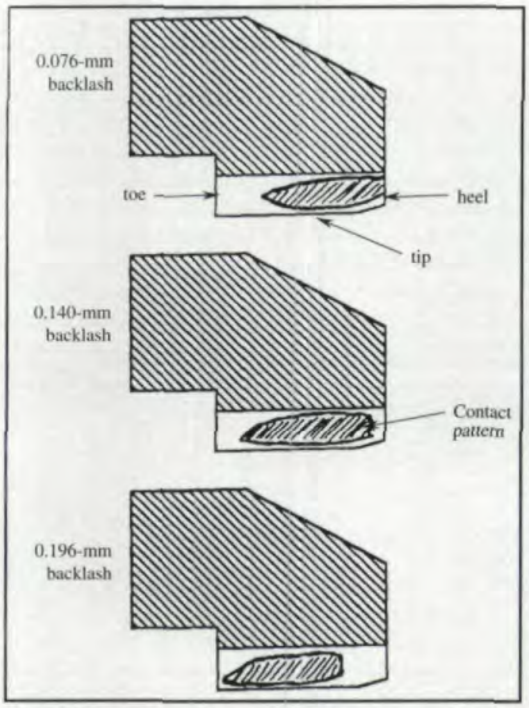

Fig. 10—Effect of face-gear shimming and backlash on tooth contact pattern (test side face gear).

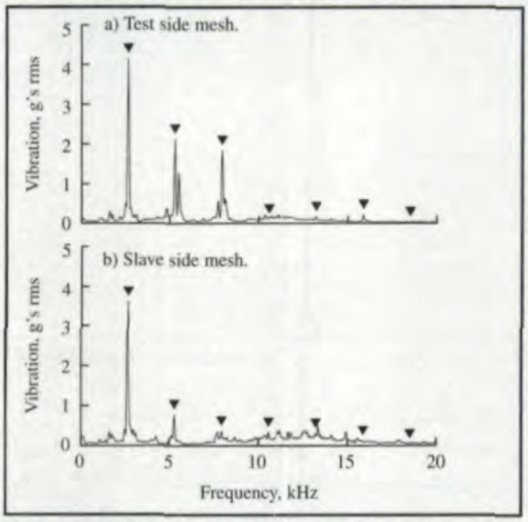

Fig. 11—Vibration spectrum at 10-million face-gear cycles at 424 N-m torque and 2300 rpm (triangles denote pinion/face-gear meshing and harmonic frequencies).

manually rotating the complete assembly and photographing the contact patterns. Figure 8 shows a typical example of a tooth contact pattern check for a loaded static roll test. Again, the objective of this procedure was to ensure the proper shimming to produce a tooth contact pattern that was centered on the pinion and face-gear teeth in order to avoid edge loading.

At the start of the project, the proper shim value to produce the required backlash and contact pattern was unclear. To gain experience, a study was conducted to determine the effect of shimming on backlash and contact pattern. Here, various shims were installed while backlash and pattern checks were measured for the test and slave sections using the procedure described above. Figure 9 documents the effect of shimming on backlash. It should be noted that there was some variability in the backlash measurement. Overall, there appeared to be a linear relationship between shimming and backlash for the selected range presented. Figure 10 shows the effect of backlash on tooth contact pattern. The results depicted are for the test side, but a similar trend resulted for the slave side also. Note that the figure contains hand-drawn sketches of the contact pattern. The purpose is not to quantitatively define the required magnitude of backlash, but to show an important trend in the installation process. If the backlash is too loose (higher number), the tooth contact approaches the inner-diameter edge of the face gear, possibly leading to edge contact. If the backlash is too tight (lower number), the tooth contact approaches the outer-diameter edge of the face gear, again possibly leading to edge contact. In addition, the clearance between the pinion and face gear could be critically reduced when the gears reach operating temperature if the backlash is too tight. This could result in jamming, coast-side contact, or scoring failure. From the experience of the tests performed, backlash in the range of 0.178 to 0.254 mm (0.007 to 0.010 in) produced acceptable tooth contact patterns.

Test Procedure

A total of five endurance tests are reported in this work. The test operating conditions are listed in Table 2. The objective of the tests was to demonstrate that carburized and ground face gears would achieve the required durability when subjected to high-load helicopter transmission conditions. At the start of the project, extensive modal surveys of the test facility were conducted as well as speed sweeps with the test hardware installed. From these studies, a face gear speed of 2300 rpm was selected as the test condition to avoid any speeds that could contain facility-resonant dynamic loads. Test gear loads of 64, 76, 88, 100, and 112-percent design torque were run for ten-million face-gear cycles each. The same test-side face gear was used for all of the runs (serial number (S/N) 2-2). Similarly, the same slave-side face gear was used (S/N 2-4). These were carburized, ground, and super-finished face gears. Since the pinions accumulated over four times the number of cycles as the face gears, the pinions were replaced after each higher load condition to minimize the chance of a pinion failure causing face-gear tooth distress. Based on this, the pinions for both the test and slave sides were replaced after the 88- and 100-percent load tests. The original

Table 2—Test Operating Conditions.								
					Test section		Slave section	
Test No.	Face-gear speed (rpm)	Face-gear torque (N-m)	Pinion, million cyc	Face-gear, million cycs	Pinion S/N	Face-gear S/N	Pinion S/N	Face-gear S/N
1	2300	242 (64%)	40.6	10.0	L5-12	2-2	L5-5	2-4
2	2300	287 (76%)	40.6	10.0	L5-12	2-2	L5-5	2-4
3	2300	332 (88%)	40.6	10.0	L5-12	2-2	L5-5	2-4
4	2300	377 (100%)	40.6	10.0	L5-11	2-2	L5-9	2-4
5	2300	424 (112%)	40.6	10.0	1	2-2	2	2-4

pinions (S/N's L5-12 and L5-5) were carburized, ground, and super-finished, while the subsequent ones used were only carburized and ground.

At the start of each test, the gears were installed as discussed in the previous section. They were then run for a break-in period, which consisted of a gradual increase in speed and torque. After the break-in, the gears were visually inspected then run per the specified test condition. Facility parameters such as speed, torque, oil flow, oil pressure, temperatures, and vibration were monitored throughout the test. After completion of ten million face-gear cycles, the gears were removed from the rig, inspected (visual and magnetic particle), and photographed.

Results and Discussion

Figure 11 shows typical vibration spectrums from the tests. The spectrums were produced from high-frequency piezoelectric accelerometers mounted on top of the pinion housings near the pinion/face-gear meshes. One was mounted on the test side and one on the slave side. The accelerometers had integral electronics, a typical sensitivity of 10 mV/g, and a resonance frequency of 90 kHz. From the spectrum, the major sources of vibration were from the pinion/face-gear fundamental meshing and harmonic frequencies.

Figure 12 gives the maximum vibration as a function of run time for all the tests. The maximum vibration is defined as the maximum value of the spectrum, and usually occurred at the pinion/face-gear fundamental meshing frequency. Note that the vibration was rather sporadic during the tests. This is not uncommon for vibration of high-speed machinery. Also, there appeared to be no definite trend of vibration with torque. This is consistent with previous studies performed on helicopter transmissions (Refs. 14, 15). From Figure 12b, a significant reduction in vibration for the slave side occurred at 20 million cycles. This was probably due to the replacement of a failed pinion shaft support bearing at the end of Test 2. Also, significant changes in vibration occurred at 30 and 40 million cycles for both the test and slave sides (Figures 12a and 12b), probably due to the replacement of pinions for Tests 4 and 5.

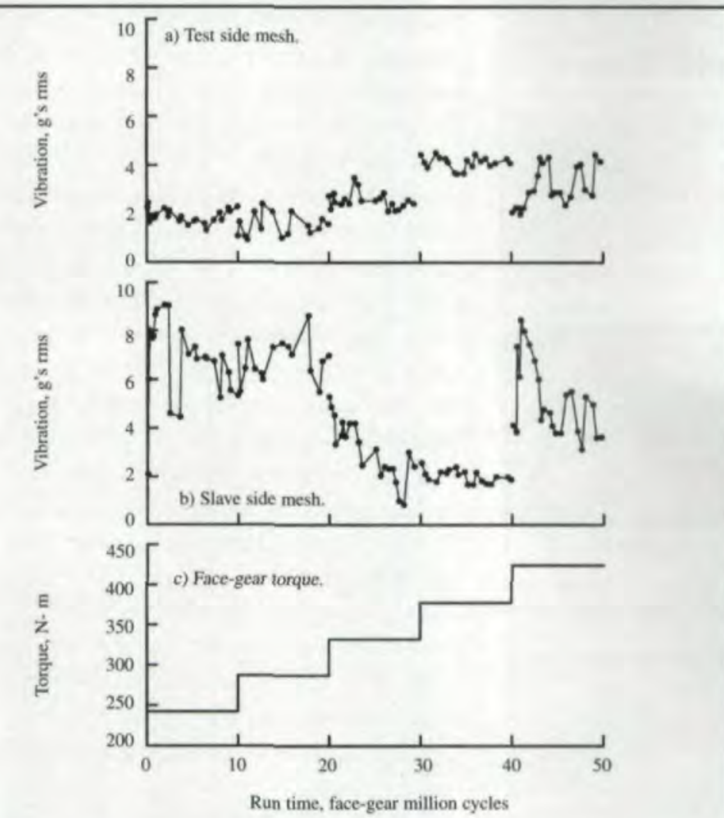

Fig. 12—Maximum vibration of spectrum as a function of run time.

At the end of Tests 1 and 2 (242 N-m, 64-percent design torque, and 287 N-m, 76-percent design torque, respectively), there was no noticeable wear on any of the spur pinions or face gears. At the end of Test 3 (332 N-m, 88-percent), the pinions had very light wear but the face gears exhibited no noticeable wear. The pinion teeth on the slave side had wear lines where the pinion meshed with the face-gear outer-diameter region. This was possibly caused by debris from the pinion shaft support bearing failure.

At the end of Test 4, the replacement pinions had a slight increase in the amount of wear compared to the pinions from Test 3. Concentrated wear on the pinion teeth was noticed as diagonal lines on the teeth corresponding to the location of the pitch line. The face gears, however, had less noticeable wear than the pinions. Slight wear lines were noticed that appeared to correspond with the edges of the facets on the teeth.

a) Pinion, test side.

b) Face gear, test side.

c) Pinion, slave side.

d) Face gear, slave side.

Fig. 13—Pinion and face gear teeth after Test 5 (424 N-m, 112-percent design torque).

At the end of Test 5 (424 N-m, 112-percent), the replacement pinions had again a slight increase in the amount of wear compared to the pinions from Test 4. This was expected due to the increased applied load. Slight wear lines were apparent near the pitch line as well as edge lines where the pinion meshed with the face-gear inner-diameter and outer-diameter regions. The marks corresponding to the face gear outer-diameter region were attributed to a few burrs on the face-gear outer-diameter edge, probably caused during hardware assembly. Slight scratching appeared at the tooth tips. Overall, however, relatively little wear was noticed. The face gears had even less noticeable wear than the pinions. As stated before, slight wear lines were noticed that appeared to correspond with the edge of the facets on the teeth. At this time, the effect of the facets on durability and performance are not known. Also, minor scratching was exhibited on the face gears near the outer-diameter tip region. Figure 13 depicts the wear after Test 5. Aside from minor wear line situations, the pinions and, especially the face gears, had no significant wear problems or failure modes. (Note that the wear of the pinions in Figure 13 is just the removal of the black-oxide.) Thus, from the tests, the carburized and ground face gears demonstrated the required durability when subjected to up to 112-percent design torque. Further tests are planned to increase the applied torque and determine the load capacity of the face gears.

Conclusions

Experimental durability tests were performed on carburized and ground AISI 9310 steel face gears. The tests were conducted in the NASA Glenn spiral-bevel-gear/face-gear test facility. Tests were run at 2300 rpm face gear speed and at loads of 64, 76, 88, 100, and 112-percent of the design torque of 377 N-m (3340 in-lb) at ten million face-gear cycles each. The following conclusions were made:

1) Carburized and ground face gears demonstrated the required durability when run for ten million cycles at loads of 64, 76, 88, 100, and 112-percent of the design torque. Other than wear lines caused by isolated situations, the spur pinions and face gears had no significant wear problems or failure modes.

2) Proper installation was critical for the successful operation of the spur pinions and face gears. Backlash that was too high produced tooth contact patterns that approached the inner-diameter edge of the face-gear tooth. Backlash that was too low produced tooth contact patterns that approached the outer-diameter edge of the face-gear tooth. Measured backlashes in the range of 0.178 to 0.254 mm (0.007 to 0.010 in) produced acceptable tooth contact patterns.

3) From spectrum readings taken during the tests, the major source of vibration was from the pinion/face-gear fundamental meshing frequency and harmonics. Also, there was no definite trend of vibration with torque. ○

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Samputensili Acquires Hurth Modul

The Italian-based gear manufacturing machine tool maker Samputensili S.p.A. has acquired the German company Hurth Modul, a manufacturer of hobbing machines. The move positions Samputensili to offer a complete range of products, adding spur and bevel hobbing machines to its existing production range. The acquisition also brings Samputensili closer to its goal of internationalization, creating an integrated worldwide network for the production and sales of its products. The plant in Chemnitz will be integrated into Samputensili's production facilities abroad in Brazil, USA, France, Japan and South Korea.

This acquisition completes a process of integration between the two companies, which started on a commercial level in 1998 when the two companies first started targeting the main industrial markets together. According to Stefano Salmi, general manager of the Samputensili Group, "The synergies developed by Hurth Modul and Samputensili enable our worldwide customers to find the ideal supplier for machines, tools and services for gear manufacturing in our companies."

Bodine Electric Announces New Gear Manufacturing Unit

Bodine Electric Company, a manufacturer of fractional horsepower electric gearmotors, announced the formation of a new strategic business unit, Bodine Gear Manufacturing, to produce fine pitch open gears.

Bodine Gear Manufacturing is focused on manufacturing high precision, fine pitch, parallel axis spur and helical gears and pinions. The normal DP ranges from 64 to 8. Gear diameters go up to 6 inches. Worms and wormgears, as well as involute and straight-sided splines, are also produced. Unique Bodine Gear process capabilities include skiving to eliminate heat treat distortions without expensive secondary gear finishing.

Employing modern CNC gear hobbing machinery, Bodine Gear is at the leading edge of carbide hobbing technology. Bodine Gear has developed a proprietary database covering every single aspect of carbide hob usage. This technology has revolutionized and reduced tool costs per gear by a factor of three. Both Bodine Gear Manufacturing and its customers are the beneficiaries of this technology.

Goodfellow Named to Axicon Technologies Board

David W. Goodfellow

Axicon Technologies, Inc. announced that David W. Goodfellow has joined its Board of Directors. Goodfellow is the former president of American Pfauter LP, the former president and chairman of the board of Pfauter Maag Cutting Tools LP, and the former managing director of Pfauter Group Worldwide. He also served on the Board of Directors of the American Gear Manufacturers Association (AGMA) from 1992–1997.

"Mr. Goodfellow is a significant leader in both the domestic and international gear manufacturing industry," said Axicon CEO Mark T. Wyeth. "Axicon is extremely fortunate to have someone of Mr. Goodfellow's experience and industry knowledge serving on its Board of Directors."

Milwaukee Gear Announces New Director of Product Development


Ed Hahlbeck

Milwaukee Gear, a Midwest manufacturer of custom gears and gear drives, announced that Ed Hahlbeck has rejoined the company as Director of Product Development. Hahlbeck is a state-licensed Professional Engineer and a Certified Manufacturing Engineer. He was vice president of engineering when he left the firm in 1995 to pursue consulting opportunities. According to Milwaukee Gear president Rick Fullington, "Ed will be focusing on our company's expanded effort to obtain more opportunity in enclosed drives. He will also provide support to our Sales and Marketing group for our loose gearing business."

Wall Colmonoy Appoints New Director of Sales and Marketing


Dr. S. Rangaswamy

Dr. S. Rangaswamy has been promoted to director, marketing and sales, of Wall Colmonoy Corp., Madison Heights, MI. Rangaswamy joined the company in 1996 as brazing products sales manager and most recently held the position of director, technical services. Rangaswamy received his Ph.D. in materials science from State University of New York. During his 20 years in the brazing and coatings industry, he has published many technical articles and has been awarded several patents.

Falk Renew Opens New Facility

With its new 42,000 square-foot facility in New Berlin, WI, Falk is staying true to its motto, "Service is Personal."

The building houses a 35,000 square-foot repair and rebuild shop, the field service group and a 7,000 square-foot office that includes classroom space for the company's Falk School, a four-day course intended for Falk gear drive users. The course outline is designed to familiarize working maintenance mechanics with field-practical, factory-approved installation, alignment, maintenance and failure analysis procedures for Falk gear drives and couplings. "We designed the facility with input from our employees," says Brian Halverson, general manager of Falk Renew. "We wanted to focus on customer service, quality and speed of repair, and who knows those elements the best but our employees?"

Falk Renew is a program that repairs, replaces or restores Falk and competing gear drives and fluid couplings to improved or original specifications. The Falk Corporation established Falk Renew as a separate business unit in 1997. Since then, the program has repaired and rebuilt more than 2,000 units. "Falk Renew actually goes back to the roots of The Falk Corporation," explains Halverson, "where repair and rebuild started."

Fowler Appoints New District Manager for the Southeast


David J. Martin

The Fred V. Fowler Company, a major supplier of measuring instruments used in quality control by the manufacturing industries, announced that David J. Martin of Marietta, GA, has been appointed regional district manager for the southeastern states. His territory includes all of the southeastern United States and Arkansas. He will be managing the sales of Fowler's diverse line of height gages, bore gages and other precision measuring tools, primarily for the metalworking industries in his region of coverage.

Integrated Manufacturing Technology Establishes Board

The Integrated Manufacturing Technology Initiative (IMTI), a non-profit organization aimed at bringing industry and government together to identify key needs and deliver solutions to increase the productivity and competitiveness of U.S. industry, announced the formation of its Board of Directors, launching an unprecedented research and development collaboration focused on strategic challenges facing the U.S. manufacturing sector.

The IMTI launch is an outgrowth of the recent Integrated Manufacturing Technology Roadmapping (IMTR) project, sponsored by the U.S. Departments of Energy, Defense and Commerce; the National Science Foundation, and more than 100 U.S. companies and industrial organizations.

The IMTI Board named Jack Harris, of Rockwell Collins, as interim chairman; and Richard E. Neal as executive director responsible for day-to-day operations. Harris is the director of Technology Applications for Rockwell Collins, Cedar Rapids, IA. Neal was most recently project manager for IMTR-related projects at Lockheed Martin Energy Systems.

Odds and Ends

Dr. Faydor L. Litvin, director of the Gear Research Center at the Univeristy of Illinois—Chicago, has been named Engineering Distinguished Professor Emeritus by the University. •**Wall Colmonoy** has moved its products group to a new, 55,000 square-foot plant in Los Lunas, NM. •**Ametek Specialty Metal Products** (SMP) has completed its $1.75 million plant expansion at Eighty Four, PA, increasing its stainless steel production capacity by 30%. •According to **UCIMU-SISTEMI PER PRODURRE**, the Italian Association of Machine Tool, Robot and Automation manufacturers, in 1999 the Italian machine tool industry increased production by 8.3% to overtake the United States to become the world's third largest producer of machine tools behind Japan and Germany. •**Falk Corporation** has been presented with a Key Supplier Award by Motion Industries in recognition of Falk's product quality and service as a supplier partner. •**Milacron Marketing Company** has named Briggs-Weaver as its new Southwest distributor for its Cimcool® metalworking fluids and Cimform® grinding wheel lines. ○

Tell Us What You Think . . .

If you found these items of interest and/or useful, please **circle 217.**

If you did not care for these items, **circle 218.**

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

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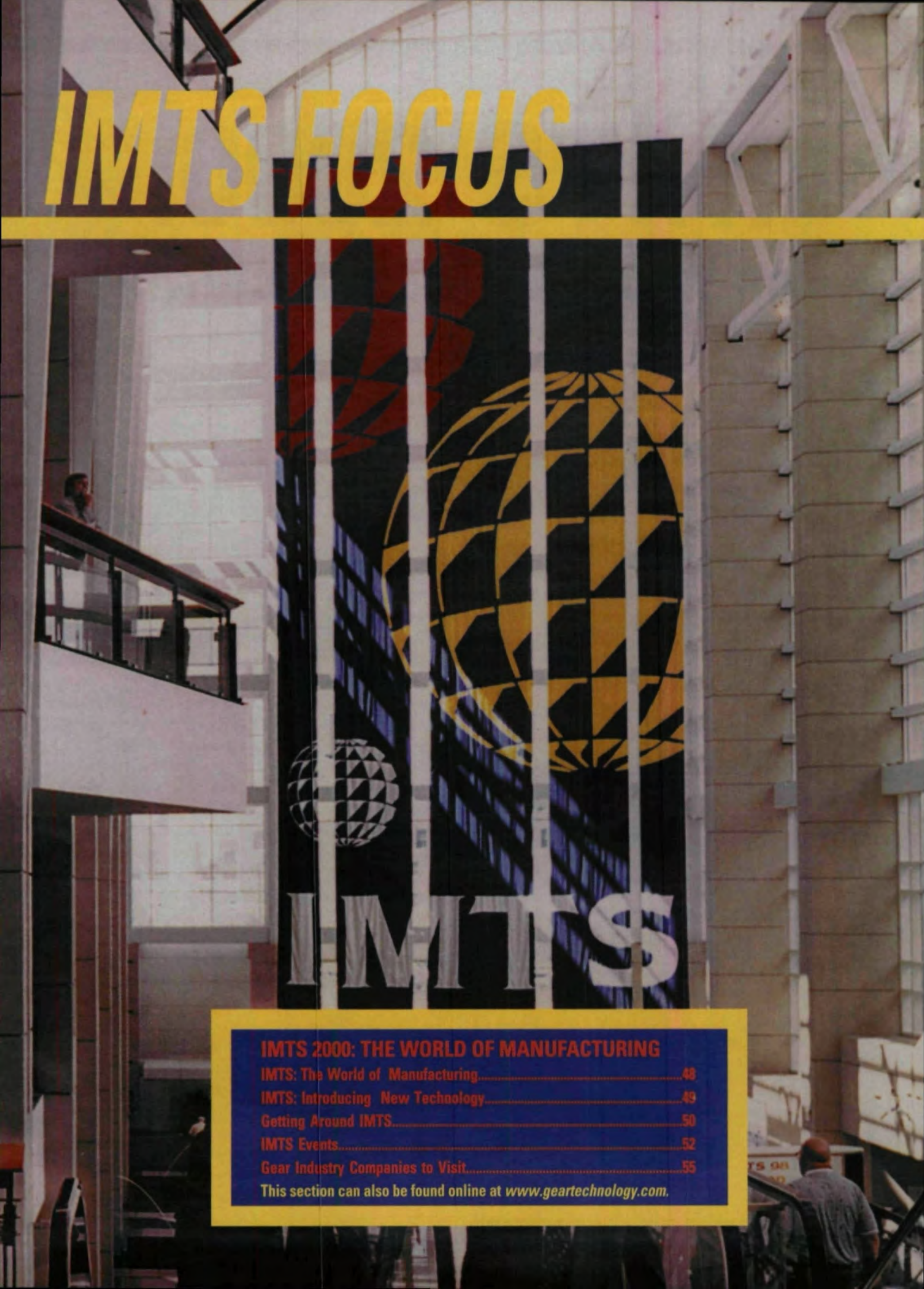


IMTS 2000: THE WORLD OF MANUFACTURING

This section can also be found online at *www.geartechnology.com.*

IMTS 2000:
The World Of Manufacturing

For eight days every other year, the sponsor of the International Manufacturing Technology Show (IMTS), the Association for Manufacturing Technology (AMT), strives to turn Chicago's McCormick Place into a "productivity marketplace," the largest and most complete display and demonstration of manufacturing technology ever seen in the Americas. If the growth of the show is any indicator, that effort has been very successful indeed. With over 1.4 million square feet of exhibit space taking up all five levels and all three exhibit halls of McCormick Place, each level would rank as one of the nation's 200 largest trade shows. That wasn't always the size or scope of the show. Its inception, while impressive for the time, was humble by today's standards.

DATES • LOCATIONS • TIMES • DATES • LOCATIONS • TIMES • DATES

SHOW DATES: September 6–13, 2000

LOCATION: McCormick Place, Chicago, Illinois, USA

EXHIBIT HALL HOURS:
- Lakeside Center and North Building, Hall C: 9:00am to 5:00pm
- South Building and North Building, Hall B: 10:00am to 6:00pm
- Hours for Sunday, September 10, All Buildings: 10:00am to 4:00pm

TECHNICAL CONFERENCE DATES AND LOCATION:
September 6–13, 2000
McCormick Place South, Level 4–5

CONTACT AND OFFICE LOCATIONS:
Additional IMTS information is available by calling (800) 322-IMTS or by logging-on to *www.imtsnet.org*. At the show, if you have a question or need assistance, help is available. There are Show Offices located in the South Building (S400), the North Building (N229) and the Lakeside Center (E250). If you are an exhibitor wishing to drop off press materials, the Press Office is on the Main Concourse, Room N426. For international visitors, the International Center is in the North Building, Rooms N226–N228. Security Offices can be found in the Lakeside Center (E250), the South Building (S103) and in the North Building (N132). Exhibitor Registration Offices are located in the Lakeside Center (E256), the North Building (N229) and in the South Building (S103). Finally, Contractor Service Centers are located in the Lakeside Center (E253), the North Building (N230) and the South Building (S406).

The Birth of IMTS. The first Machine Tool Show, sponsored by AMT's predecessor, the National Machine Tool Builder's Association, opened for a five-day run at the Public Auditorium in Cleveland, Ohio, on September 19, 1927. This precursor to IMTS was heralded as a neutral forum where engineers, product users, distributors and producers could freely discuss questions of mutual interest and seek solutions to manufacturing problems. The show's 12,000 visitors and 184 exhibitors filled the Public Auditorium to capacity. Helping to bring in the visitors, the Society of Automotive Engineers, the Machine Tool Congress, the Association of Woodworking Machinery Manufacturers, the Associated Machine Tool Dealers, the Foundry Equipment Manufacturers Association, the Screw Machine Products Association and the Power Transmission Association all held meetings in conjunction with the show. IMTS was born.

IMTS Today. Over the last 73 years, IMTS has grown, setting more and more records for attendance, exhibit space, the number of exhibitors, the number of pavilions and other growth measurements like the amount of sales conducted on the show floor. In fact, since its inception, the show has steadily evolved into a major selling event, with millions of dollars in business being conducted right on the show floor every day. In 1998, sales on the show floor exceeded $1 billion. That was a 20% increase over the previous record. Sales averaged over $715,000 for each of the 1,443 exhibitors at the 1998 IMTS, or almost $15 million per hour for the entire eight-day run of the show.

IMTS 2000 offers ten pavilions with more than 1,800 exhibiting companies from around the world slated to attend. As in previous years, each pavilion is a highly focused "show-within-a-show," designed to allow visitors to find the products and services they need quickly so they spend their time at the show more efficiently. Also returning are the SME Technical Conferences, where engineers and other industry professionals can meet to discuss the latest in technology and processes, and the Student Summit, which is held to introduce high school and college students to the world of manufacturing.

INTRODUCING NEW TECHNOLOGY. . .

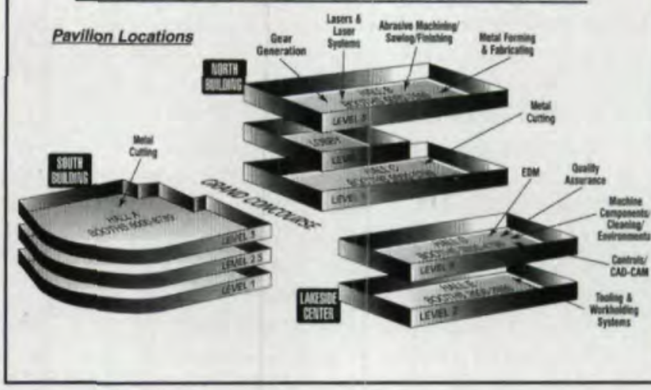
. . . has always been a big part of IMTS, so much so that during World War II, the show was closed because the organizers feared that the introduction of new models would slow America's mobilization efforts! After the war, however, IMTS was the place where new models, products and technology were unveiled.

Technology and Products Introduced at IMTS. In 1947, the Cincinnati Milling Machine Company introduced its new synthetic cutting fluid, Cimcool, a shocking pink fluid that the company provided to all the machine tool exhibits. Since the machines themselves were all the same "machine tool gray," the pink color really stood out, making for a great promotion. At the 1955 show, the first Numerical Control (NC) systems were introduced. These systems relied on a number of control inputs including punch cards and paper tape. The 1970 show saw the introduction of an operational Direct Numerical Control (DNC) system. In this demonstration, a General Electric mainframe computer situated at Navy Pier fed programs to the NC controllers on 70 different machine tools installed at the International Amphitheater. Two years later, Computer Numerical Control was introduced at the show with several U.S. companies showing production model CNC controllers for the first time. In 1994, the big product news was the unveiling of the startling hexapod machine design technology with the Variax, by Giddings and Lewis, Inc., as well as a smaller version of these six-legged machine tools by Geodedics, Inc. Concepts in open architecture machine tools were also widely discussed as a way to make it easier to tailor CNC machines to specific applications. By 1996, the new technology star at IMTS was linear motion, with one horizontal machining center able to reach axis travel speeds of 3,000 inches per minute and acceleration as high as 1.5 g.

New Technology at IMTS 2000. This year's IMTS will showcase a variety of new products, processes and technologies. You will see new grinding machines from **Bryant Grinder Corporation (Booth A-8531)** and **Overbeck Corporation (Booth B2-7530)**. The Bryant *Ultraform UF2* is an external form grinder for use on precision-ground components such as gears and bearings. The machine offers greater speed and precision thanks to improved stiffness characteristics. Overbeck will exhibit the *IRC-400*, their newest generation of universal internal grinding machine for bores, faces, angles and generating radius with a cylindrical wheel. Another grinder, the *Blanchard/Reform Model AR-6000 Type 13 Heavy Duty Traveling Head Production Surface Grinder*, can be seen at the **Motch/Cone-Blanchard booth (Booth A1-8343)** along with the new *Conomatic Tri-Turn 383 CNC Multiple Spindle Bar Machine* and several others. **Leistritz Corporation (Booth C-5315)** will be demonstrating their new *PW200 Whirling Machine*, the first in a series of newly engineered thread-producing machines. **National Broach and Machine Company (Booth B-7048)** will be showcasing their latest roll-forming technology with the new *PMF-610 Red Ring NC Precision Vertical Roll Forming Machine*. **Sentry Company (Booth C-5737)** will introduce their new *MP-2000 Multipurpose Heat Treating Furnace*, a 2000 °F open hearth furnace designed for tool hardening. **Balzers, Inc. (Booth E-2748)** is set to unveil their new *Diamond-Like Carbon (DLC)* tool coating.

These are just a few of the many new machines, processes and technologies that will be on display and, in many cases, on sale at IMTS 2000. See "Places to Visit" on page 55 for descriptions of the booths of many gear-related suppliers.

IMTS: INTRODUCING NEW TECHNOLOGY • IMTS: INTRODUCING NEW TECHNOLOGY • IMTS: INTRODUCING NEW TECHNOLOGY



GETTING AROUND IMTS 2000

Within the pavilions you will find companies involved in all aspects of manufacturing, but how do you find the pavilion you want with all these different halls and levels? The map above shows you precisely where everything is located. The ten pavilions and one service area of IMTS 2000 are:

Abrasive Machining, Sawing and Finishing Pavilion (North Building, Hall B, Level 3)

This pavilion will feature various types of grinders and abrasive cutoff machines; band, circular and hack saws; and machines for buffing, polishing, vibratory finishing and lapping. Deburring and marking equipment will also be featured.

Business Services (North Building—Concourse Lobby)

This is the place for industry-related publications as well as government and other non-manufacturing organizations.

Controls & CAD-CAM (Lakeside Center, Hall D, Level 3)

This pavilion features CIM/CAD/CAM systems, CNC controls, automation management systems, communications systems and LAN, software development services, computers and software, instruments, controls and systems integration services.

EDM (Lakeside Center, Hall D, Level 3)

The EDM Pavilion will include wire EDM, ram type EDM, EDM filtration systems and supplies, metal disintegrators and die sinking machines.

Gear Generation (North Building, Hall B, Level 3)

Manufacturers of gears and related equipment will find gear hobbing, shaping, shaving, skiving, rolling, grinding, lapping and measurement systems in this pavilion. See "Places to Visit" for a listing of gear industry vendors you do not want to miss.

Lasers & Laser Systems (North Building, Hall B, Level 3)

This pavilion will feature a wide range of applications including metal cutting, marking, scribing, drilling, cladding, trimming, engraving, welding, heat treating and measurement.

Machine Components/Cleaning/Environmental (Lakeside Center, Hall D, Level 3)

This pavilion features equipment; machine components; engineering services; environmental protection services; services for air, water and oil filtration and purification; safety guards and mats.

Metal Cutting (South Building Hall A, Level 3 and North Building, Hall C, Level 1)

The Metal Cutting Pavilion will feature over 600,000 square feet (almost as large as the entire 1978 Machine Tool Show) of machining and turning centers as well as machines for milling, rolling, boring, drilling, transfer, broaching, skiving/roller burnishing and whirling.

Metal Forming & Fabricating (North Building, Hall B, Level 3)

This pavilion will house straight-side, OBI and hydraulic presses; water jet cutting equipment, CNC turret punch presses, tube and pipe benders, press brakes, roll benders, shears, hand welding and robotic welding equipment, hot and cold forming technology, spinning machines, wire forming, forming cells and systems, foundry/casting and, investment casting equipment, plasma cutting, friction welding, stress relief equipment, coil and sheet handling equipment and plate benders.

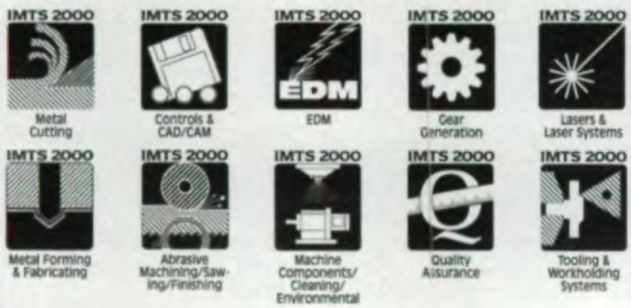
Quality Assurance (Lakeside Center, Hall D, Level 3)

This pavilion will include precision measuring machines, coordinate measuring machines, precision gaging, automated gaging, laser measurement, in-process gaging, tool condition monitoring equipment, measurement software, and quality and environmental management software.

Tooling & Workholding Systems (Lakeside Center, Hall E, Level 2)

From angle brackets to z-axis fixturing and everything in between, the Tooling & Workholding Systems Pavilion includes boring bars, cutters, drills, endmills, fixturing systems, gun drilling tools, hobs, inserts, jigs, keyseating tools, lapping tools, magnetic chucks, NC tables, over spindle adaptors, plates, quick change dies, reaming tools, screw thread inserts, tool storage equipment, universal fixturing, vises, and workholding systems.

Pavilion Icons



IMTS takes place Sept. 6–13 at McCormick Place, Chicago, IL.

IMTS EVENTS

IMTS is more than just the largest manufacturing exhibition in America. It is a place where industry professionals can share ideas and learn from each other. It is also a place where young people can come and see, first hand, what modern manufacturing is all about and whether it is a career path they should consider.

THE IMTS 2000 MANUFACTURING CONFERENCE

The Society of Manufacturing Engineers (SME) and the Association for Manufacturing Technology (AMT) have teamed up to create the most comprehensive educational conference in the manufacturing community for IMTS. "We've realigned the conference with the attendee in mind," said John McEachran, SME conference director. "We've added high-level keynote luncheons addressing strategic manufacturing practices, free interactive technology forums on capital expenditures, and a new conference format allowing attendees to participate in the conference while attending the show."

The first luncheon keynote, "Manufacturing for Customer-Driven Organizations," will be held on Thursday, September 7, from 12:00pm to 1:30pm. A panel of Blue Chip companies will address the shifting paradigms and philosophies steering companies to become customer-driven organizations. The second keynote, "Small and Mid-sized Manufacturers: Making E-commerce a Reality," will be held on Monday, September 11, from *12:00pm to 1:30pm. This presentation will cover the many* options available to small and mid-sized manufacturers wanting to sell directly to customers over the Internet.

Leading equipment manufacturers will participate in several Interactive Technology Forums dealing with capital expenditures, which will be followed by question and answer sessions with the panel members. These forums include "Comparative Coatings for Cutting Tools," Wednesday, September 6, 9:00am to 11:00am; "Software for Job Shops,", Wednesday, September 6, 9:00am to 11:00am; "Maintenance Management," Friday, September 8, 9:00am to 11:00am; and "Environmental Compliance," Tuesday, September 12, 9:00am to 11:00am.

To allow attendees to participate in the conference while attending IMTS, the conference has been designed with half- and full-day sessions. Over 60 technical sessions are available with 10 new half- and full-day sessions available including the Machining and Grinding Series, the Forming Series, the Plastics Series, the Management Best Practices Series, the Factory Automation Series, the Design Engineering Series, Computer Technologies Solutions, the Green (Environmental) Series, the Leadership Development Series, and the Precision Machine Design Workshop (a special two-day intensive workshop).

To register for the IMTS 2000 Manufacturing Conference, contact SME customer service at (301) 694-5243 or (888) 346-8925. For more information log onto *www.sme.org/imts*.

IMTS 2000 STUDENT SUMMIT

One of the toughest issues facing American industry is recruitment, educating today's young people about the reality of working in manufacturing. That is what the Student Summit program is all about. Students get a pragmatic, hands-on look at a wide variety of rewarding job and career opportunities in today's sophisticated, high-tech manufacturing industry. Junior high through graduate level college students will be exposed to the latest manufacturing products, services and processes of more than 1,800 exhibitors.

The majority of teachers responding to a survey from the 1998 IMTS Student Summit indicated that students acquired a greater understanding of the industry and experienced a positive change in their perceptions of careers in manufacturing technology. More than 4,000 students from approximately 240 high schools, post-secondary technical schools and colleges across the United States attended the IMTS 98 Student Summit. Even more are expected this year as the industry attempts to reach out to students in order to change misconceptions that are keeping some of them from considering manufacturing careers.

The program demonstrates what's hard to depict in the classroom—a close-up view of the latest machine tools and related technology being offered as well as the opportunity to meet experts in the field who are demonstrating this technology. Most groups visit for one full day or more. For more information, *visit www.imtsnet.org*.

Tell Us What You Think . . .

If you found this article of interest and/or useful, please **circle 219**.

If you did not care for this article, **circle 220**.

If you would like to respond to this or any other article in this edition of *Gear Technology*, please fax your response to the attention of Charles Cooper, senior editor, at 847-437-6618.

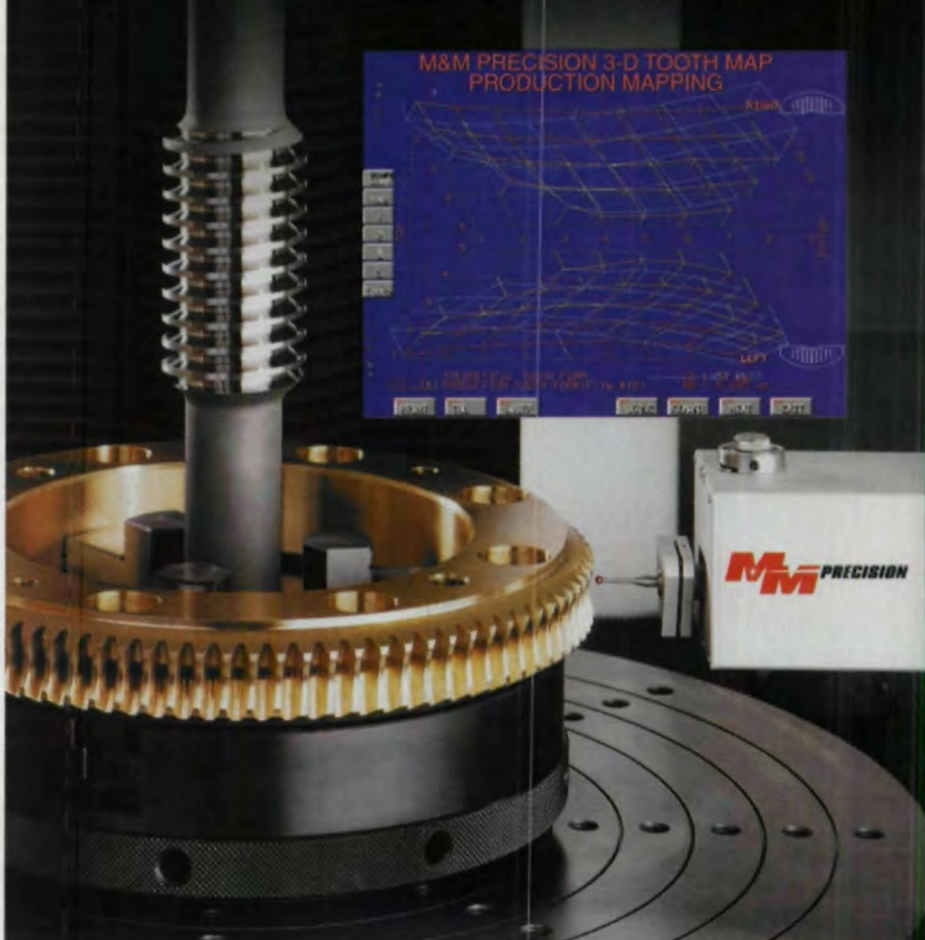
CIRCLE 136

CIRCLE 147

M&M Solutions...

Worm and Worm Gears

The Simple Solution To Right Angle Gear Analysis



With M&M, A,N,I and K-type worm and worm gear inspection and analysis is not only easy, it also lowers your development cost and reduces set-up time on every job.

Multiple Inspection Methods: Measure against theoretical forms based on an easy-to-use cutting simulation. Or compare to a master artifact automatically scanned by your M&M Gear Inspection System. You can even inspect from your own coordinate files.

Process Simulation: "Virtual cutting" lets you see the effect of machine tool settings on your PC and make corrections *before* you begin cutting.

No Programming Required: All you need are M&M's tailored, application-specific software and correction modules to meet your inspection, analysis and process control needs. (Be sure to ask about M&M's straight and spiral bevel and hypoid gear packages, too.)

To talk with one of our experts, please call: (937) 859-8273. Or fax: (937) 859-4452; e-mail: info@mmprecision.com. Visit us on the web at www.mmprecision.com.

PRECISION SYSTEMS CORPORATION

"THE METROLOGY & MOTION PEOPLE"®

CIRCLE 165

See Us At IMTS Booth #7132

Guide To The Booths

Bourn & Koch Machine Tool Co.
(Booth B-7056)
2500 Kishwaukee Street
Rockford, IL 61104
(815) 965-4013
Fax (815) 965-0019
bournkoch@worldnet.att.net
www.bourn-koch.com

Bourn & Koch has manufactured precision machine tool products since 1975. Their Rockford, IL plant offers 130,000 square feet of climate controlled working space and a staff of highly skilled engineers and technicians.

Bourn & Koch offers a complete line of new equipment that includes gear hobbing machines, gear grinding machines, rotary transfer machines, extrusion milling machines, specialized machining centers, machining units and speciality machine tools designed around a customer's needs.

Colonial Saw Company, Inc.
(Booth B-6465)
122 Pembroke St.
P.O. Box A
Kingston, MA 02364
(781) 585-4364
Fax: (781) 585-9375
sales@csaw.com
www.csaw.com

Colonial Saw will feature its line of cutting tool sharpening machines, including their 4-Axis NC gear hob sharpener, flat surface grinders, and cold saw sharpening machines.

Colonial Tool Group, Inc.
(Booth C-5635)
1691 Walker Road
Windsor, Ontario N8W 3P1
Canada
(519) 253-2461
Fax: (519) 253-5911
www.colonialtool.com

Colonial Tool Group will be demonstrating its complete product line, including rolling racks for involute splines, helical splines, tapered splines and threads; spindles; broaches; and vertical and horizontal broaching machines.

D.C. Morrison Company
(Booth C-5650)
201 Johnson Street
P.O. Box 586
Covington, KY 41011
(859) 581-7511
Fax: (859) 581-9642
RVBBJ@juno.com
www.dcmorrison.com

Visitors will see the latest Morrison keyseaters, Schauer speed lathes and Burke/Morrison milling machines.

Emuge Corporation
(Booth E-2844)
104 Otis Street
Northborough, MA 01532
(800) 323-3013
Fax: (800) 393-1302
emuge@emuge.com
www.emuge.com

Emuge's full line of precision workholding devices will be on display, including taps, tap holders & adapters, high speed milling products, thread milling products, and precision clamping products.

The Gear Generation pavilion is one of 10 "shows within the show".

Chicago's McCormick Place.

Fellows Corporation
(Booth B-8531)
P.O. Box 2001
Springfield, VT 05156-2001
(802) 886-8333
Fax: (802) 886-2700

This booth is shared with Bridgeport Machines, Inc., Bryant Grinder Corporation, Harig Products Division, J&L Metrology and Jones & Lamson Machine. Visitors will be able to see the complete line of Fellows gear manufacturing and testing machines, cutting tools and services.

Gleason Corporation
(Booth B-6931)
The Gleason Works
1000 University Avenue
P.O. Box 22970
Rochester, NY 14692-2970
(716) 473-1000
Fax: (716) 461-4348
sales@gleason.com
www.gleason.com

Gleason's giant video wall will be the center of attention this year. Visitors will be able to see the entire Gleason product range in action on the giant screens. Even more importantly, visitors who stop by to see the show will be able to take the experience home with them, because Gleason will be handing out the presentation on CD-ROM as well. In addition, Gleason will bring a number of machine tools for live demonstrations. These include the Gleason 175 HC Power Dry Cutting CNC Bevel machine with robot; the Gleason Pfauter GP200S CNC Gear Shaper; the Gleason Pfauter GP130 CNC Hobbing Machine with autoload; the Gleason Hurth ZS130T Power Honing Machine with automation; and the Gleason Pfauter P60 CNC Horizontal Hobbing Machine with automation. Visitors will also have the opportunity to see and ask about the comprehensive range of Gleason cylindrical and bevel cutting tools.

Gold Star Coatings (Booth E-2701)
P.O. Box 376
Farmington, MI 48332-0376
(248) 474-8200
Fax: (248) 474-9518
www.goldstarcoatings.com

This division of Star Cutter Co. will feature its line of wear resistant thin-film coatings for cutting tools and wear parts.

Great Taiwan Gear Ltd./Luren
(Booth B-7139)
108 Collier Lane
Greer, SC 29650
(864) 322-1266
Fax: (864) 609-5268

Visitors will be able to learn about Great Taiwan Gear's gear manufacturing capabilities, including fine- and coarse-pitch spur, helical, bevel, spiral bevel and worm gears, splined shafts and speed reducers. Also on hand will be a selection of gear cutting tools, including hobs and shaper cutters.

H.B. Carbide (Booth E-2700)
4210 Doyle Drive
P.O. Box 538
Lewiston, MI 49756-0538
(517) 786-4223
Fax: (517) 786-4494
www.hbcarbide.com

This division of Star Cutter Co. will feature its line of carbide preforms, including fluted preforms, special rod blanks, special extruded shapes, cold heading dies and bushings, round rods, flat blanks, gundrill blanks and special tooling.

Holroyd (Booth B-6917)
Division of Renold Precision Technologies
Harbour Lane North, Milnrow
Rochdale OL16 3LQ
United Kingdom
(44) 1706-526590
Fax: (44) 1706-353350
paul.hannah@holroyd.com
www.holroyd.com

Holroyd will show its line of thread grinding and thread milling machines; worm gears; compressor rotors; pump screws; vacuum screws; cylindrical and surface grinding machines; and machining centers. This booth is shared with Jones & Shipman and Edgetek.

Kapp Tech (Booth B-6950)
2870 Wilderness Place
Boulder, CO 80301
(303) 938-1130
Fax: (303) 447-1131
info@kapp-usa.com
www.kapp-usa.com

This booth features Kapp GmbH, Niles GmbH and Kapp Sales and Service. Visitors will be able to see the Kapp KX1 Gear Center with automation, the Niles ZP12 Profile Grinder, the VAC65 Coroning system, the VAS55P Dressable Grinding system, GA5 External Grinders and Niles Internal Grinders.

Klingelnberg Söhne GmbH—
See Sigma Pool

Koepfer America
(Booth B-6938)
635 Schneider Drive
Elgin, IL 60177
(847) 931-4121
Fax: (847) 931-4192
sales@koepferamerica.com
www.koepferamerica.com

Koepfer will feature its line of precision gear hobbing machines, cutting tools and services.

Laser Machining, Inc. (Booth B-6748)
500 Laser Drive
Somerset, WI 54025
(715) 247-3285
Fax: (715) 247-5650
tbenson@lasermachining.com
www.lasermachining.com

Laser Machining, Inc. will feature a display of deep penetration laser weldings to 18 mm, high speed selective laser heat treating and an array of special applications, including cutting utilizing both CO_2 and Nd:YAG lasers.

LMI's technical staff will be on hand to duscuss the company's laser process development program and to give visitors the knowledge they need to take their ideas from "concept to product." This unique program provides prototypes, short-run or long-run production and ultimately, a laser system suited to the manufacturer's operation.

Special attention will be provided to laser gear welding, hydraulic cylinder laser welding, selective heat treating and laser lap welding for sheet metal applications.

Leistritz Corp. (Booth C-5315)
Machine Tool Division
165 Chestnut Street
Allendale, NJ 07401
(201) 934-8262
Fax: (201) 934-8266
jross@leistritzcorp.com
www.leistritzcorp.com

The PW200 Whirling Machine is the first in a series of newly engineered thread producing machines from Leistritz. With its broad work range of 1/2" to 4" diameters, and cycle times 3 to 4 times faster than other methods, the PW200 is the fastest way to produce precision gear worms available, says the manufacturer.

The PW65 Whirling Machine from Leistritz is not only the smallest, but also the fastest machine in the manfuacturer's inventory. The PW65 has a workpiece diameter range of .187" to .625". This compact, yet sturdy machine is capable of whirling at 12,000 rpm.

Liebherr Gear Technology—
See Sigma Pool

LMT-Fette, Inc. (Booth E-2765)
18013 Cleveland Parkway
Suite 180
Cleveland, OH 44135
(216) 377-6130
Fax: (216) 377-0787
www.fette.com

Visit LMT-Fette for more information on their line of precision metalworking cutting tools.

M&M Precision Systems Corp.
(Booth B-7132)
300 Progress Road
West Carrollton, OH 45449
(937) 859-8273
Fax: (937) 859-4452
info@mmprecision.com
www.mmprecision.com

M&M Precision Systems Corporation manufactures CNC analytical gear inspection systems for parallel and crossed-axis gears as well as a full range of gear and spline gages and testing instruments. On display will be three complete CNC metrology systems, including one configured for spiral bevel gear inspection; the GRS-2 double-flank gear roller system; the ODM-8 dimension over pins gage; as well as M&M spline gages and master gages.

Mahr Federal Inc.
(Booths D-4417 & D-4501)
1144 Eddy Street
P.O. Box 9400
Providence, RI 02940

(401) 784-3100
Fax: (401) 784-3246
info@fedprod.com
www.mahrfederal.com
Mahr Federal will demonstrate two measurement systems for gear manufacturers. The quick and easy-to-use DF1-898B is a modular, field-proven double-flank gear roll tester, which comes with or without encoded glass scale for accurate radial center distance pre-setting. The DF1-898B is controlled by Mahr Federal's popular *WinGear*® Pro Series PC Test and Evaluation software for Windows™ 95/98/NT environments. The combined system offers a common and flexible platform for data collection, evaluation and SPC data transfer for gear roll testing, letting you determine total composite, tooth-to-tooth, radial runout and other errors with a single mouse click.

The Primar MX4 is Mahr Federal's latest advancement in analytical measuring technology. The Primar is a universal inspection system, which is based upon generative testing principles. Primar offers users capabilities for conducting high accuracy measurements on both polar and linear form and generative gear testing (two-axis scanning), and 3-D polar measurements all in one system. This system is ideal for a variety of cylindrical components—gears, splines, camshafts, crankshafts, pistons and more.

Manufacturing Technology, Inc.
(Booth B-6005)
1702 West Washington Street
South Bend, IN 46628
(219) 233-9490
Fax: (219) 233-9489
info@mtiwelding.com
www.mtiwelding.com
Manufacturing Technology, Inc. will be showing many friction welded samples that have previously been welded on MTI friction welding equipment. Applications include aerospace, aircraft, agricultural, automotive, bimetallic, cutting tools, oilfield, trucking and waste canisters.

MTI's show booth will have an 18-foot-long by 9-foot-high photographic mural of the world's largest friction welder, specifically made for Rolls-Royce, with 2,000 ton welding force. MTI will also show an informational video of the friction welding process. Booth personnel will be available to answer friction welding questions.

Mitsubishi Heavy Industries, Inc.
(Booth A-8260)
Machine Tool Division
1250 Greenbriar, Suite B
Addison, IL 60101-1065
(630) 693-4700
Fax: (693-4710
www.mhi-mmt.com
The Mitsubishi booth will feature the following machine models: Horizontal Machining Centers M-H60EN and M-H5BN; Vertical Machining Center M-V70E-FM; Cylindrical Grinding Machine PD32-50; Gear Cutting Machines ST40, GN20A, and ZS25A; and Turning Machine TM4-20.

Multi-Arc Inc.(Booth E-2554)
200 Roundhill Drive
Rockaway, NJ 07866
(973) 625-3400
Fax: (973) 625-2244

Multi-Arc Inc. is announcing that the company is changing its name to IonBond Inc. at IMTS 2000. IonBond Inc. is a leading provider of coatings for cutting tools and wear parts.

National Broach and Machine Co.
(Booth B-7048)
17500 Twenty-Three Mile Road
Macomb, MI 48044-1103
(810) 263-0100
Fax: (810) 263-4571
sales@redringproducts.com
www.redringproducts.com

Visitors to National Broach and Machine Company in the gear pavilion will view the exciting new Red Ring brand products for the new millennium. Red Ring's 70 years of global experience in the entire gear manufacturing process will be demonstrated. From surface broaching on the NBV flexible, compact, internal broaching machine to the Red Ring/Kashifuji KA 100 hobbing ma-chine, followed by gear shaving on the Red Ring Shavemaster 200 with its innovative bed design for optimum quality and efficiency. The inspection of the demonstrated parts will be on both the Red Ring precision CNC Gear Inspection Machine, the CLP-35, and the Red Ring Gear Rolling Tester, GTR-PC.

Visitors will also be able to see the newest developments in roll forming—with the new Red Ring NC Precision Vertical Roll Forming Machine, the PFM-610.

Complementing the Red Ring gear finishing machines will be the high quality Red Ring brand tools featuring tool development for broaching, shaving, hobbing, honing and roll form finishing.

Also, a major announcement by National Broach & Machine Company will occur at the show.

Niles GmbH (Booth B-6950)—
See Kapp.

Oerlikon—See Sigma Pool.

The Ohio Broach & Machine Tool Co.
(Booth A-8675)
35264 Topps Industrial Parkway
Willoughby, OH 44094
(440) 946-1040
Fax: (440) 946-0725
www.ohiobroach.com

Ohio Broach & Machine offers extensive capabilities in broaches, broach sharpening, broaching machines and broaching production.

Optical Gaging Products, Inc.
(Booths E-2524 and D-4500)
850 Hudson Avenue
Rochester, NY 14621-4896
(716) 544-0400
Fax: (716) 544-0131
sales@ogpnet.com
www.ogpnet.com

Optical Gaging Products designs and manufactures non-contact inspection systems that provide solutions for the measurement of machine parts used by manufacturing industries worldwide. For over 50 Years OGP has been at the forefront of innovation with the development of such technologies as automatic edge detection for optical comparators, low-cost, high-value video measuring systems, and programmable LED illuminators.

Production Dynamics (Booth E-2527)
2351 Industrial Drive
Valparaiso, IN 46383
(219) 464-7938
rja@productiondynamics.com
www.productiondynamics.com

Visitors will be able to see Production Dynamics' full line of collet chucks, shrink-fit toolholder systems and I.D. workholding systems.

Reishauer Corporation
(Booth B-7033)
1525 Holmes Road
Elgin, IL 60123
(847) 888-3828
Fax: (847) 888-0343
dennis.richmond@reishauer-us.com
www.reishauer.com

Visitors can stop by to learn about Reishauer's line of CNC gear grinding, thread and worm grinding, honing and automatic tap grinding machines, as well as the Richardon line of CNC gear hobbing machines.

Samputensili/SU America
(Booth B-7047)
8775 Capital Avenue
Oak Park, MI 48237
(248) 548-7177
Fax: (248) 548-4443
sales@suamerica.com
www.samputensili.com

Samputensili will present its enhanced product line, now inclusive of gear hobbing machines and bevel gear generators thanks to the acquisition of Hurth Modul GmbH. On display there will be the WF 160 model hobber and the KF 250 model bevel gear generator.

Emphasis will also be put on the complete line of gear cutting tools and related resharpening services offered by SU worldwide.

Additionally, the new TWIN 400 Gear Grinding Machine will be displayed (work area only) featuring 5 controlled axes, CBN or ceramic wheel capabilities, form or generation grinding and honing. CBN electroplated wheels will be exhibited also as part of Samputensili's latest manufacturing program.

Sigma Pool (Booth B-7040)
1465 Woodland Drive
Saline, MI 48176
(734) 429-7225
Fax: (734) 429-2294
info@LGT.Liebherr.com

This booth features Klingelnberg, Liebherr, Lorenz and Oerlikon A full range of CNC gear hobbing, CNC gear inspection, CNC gear shaping, bevel gear generation and material handling systems will be on display.

S.L. Munson (Booth B-6865)
401 Huger Street
Columbia, SC 29201
(803) 252-3211
Fax: (803) 929-0507
kstone@slmunson.com
S.L. Munson is the distributor of Dr. Kaiser diamond dressing products, IMT America spindles, Campbell Grinders, DWH vitreous diamond wheels and balancing systems from an Italian manufacturer.

Star Cutter Co. (Booth B-6953)
23461 Industrial Park Drive
P.O. Box 376
Farmington, MI 48332-0376
(248) 474-8200
Fax: (248) 474-9518
sales@starcutter.com
www.starcutter.com
Visitors will see CNC sharpening and tool grinding machines, hobs, form relief milling cutters, pressure coolant drills & reamers, non-pressure coolant drills & reamers, PCD tooling, Gold Star thin-film, wear resistant coatings, carbide preforms, shaper cutters, shaving cutters, solid carbide tools and single- and two-flute gun drills.

Suhner Industrial Products Corp.
(Booth E-2633)
Low Cost Automation Division
Highway 411 S. Suhner Drive
P.O. Box 1234
Rome, GA 30162-1234
info@suhnerusa.com
www.suhnerusa.com
Suhner will demonstrate its line of drilling and tapping components, as well as multi-head systems.

Sunnen Products Co. (Booth B-7301)
7910 Manchester Ave.
St. Louis, MO 63143
(314) 781-2100
Fax: (314) 781-2268
www.sunnen.com
Sunnen produces a line of high-performance, modular bore-sizing and finishing machines featuring Sunnen's MHS Krossgrinding® system.

TSK America (Booth D-4717)
Advanced Metrology Division
20 Chapin Road #1003
P.O. Box 838
Pine Brook, NJ 07058
(800) 247-9875
www.tsk-metrology.com
The TSK booth will have on display the Radiance radial measuring system for gears.

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

If you did not care for this column **circle 222.**

If you would like to respond to this or any other article in this edition of *Gear Technology*, please fax your response to the attention of Charles Cooper, senior editor, at 847-437-6618 or send an e-mail message to *Charles@geartechnology.com.*

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GEAR INDUSTRY BUYERS GUIDE 2001 FREE LISTING FORM

If you provide a product or service to the gear industry, list your company in *Gear Technology's* annual **Buyers Guide**. This guide is designed to be the definitive directory of products and services for the gear industry. It will be mailed out to 14,000 of your potential customers with the November/December 2000 issue.

THE BEST NEWS IS THAT BUYERS GUIDE LISTINGS ARE ABSOLUTELY FREE!

Company Name ______________________

Division Name ______________________

Street Address ______________________ P.O. Box ________

City ______________ State ________ Zip/Postal Code ________ Country ________

Phone ______________ Fax ______________

E-mail ______________ Web Site Address ______________

PRODUCTS & SERVICES YOU SELL

Select from the list below. Indicate any products or services not listed in the blanks marked "Other."

NEW GEAR MACHINES YOU MANUFACTURE

- ❑ Bevel Gear Generators
- ❑ Bevel Gear Lapping/Testing Machines
- ❑ Broaching Machines
- ❑ Burnishing Machines
- ❑ Chamfering Machines
- ❑ Deburring Machines
- ❑ Gear Cutting Machines
- ❑ Gear Grinding Machines
- ❑ Gear Inspection Machines, Analytical
- ❑ Gear Inspection Machines, Functional
- ❑ Gear Roll Forming Machines
- ❑ Gear Roll Testing Equipment
- ❑ Hard Gear Finishers
- ❑ Herringbone Generators
- ❑ Hobbing Machines
- ❑ Honing Machines
- ❑ Keyseating Machines
- ❑ Rack Millers and Cutters
- ❑ Shaping Machines
- ❑ Shaving Machines
- ❑ Spline Grinding Machines
- ❑ Spline Milling Machines
- ❑ Spline Rolling Machines
- ❑ Thread, Worm and Flute Millers
- ❑ Other ________

OTHER NEW MACHINE TOOLS

- ❑ Abrasive Waterjet
- ❑ Coordinate Measuring Machines
- ❑ Cutter Inspection/Setting Machines
- ❑ Cutter Sharpeners
- ❑ EDM Machines
- ❑ Form Grinders
- ❑ Heat Treating Equipment
- ❑ Lasers
- ❑ Powder Metal Presses
- ❑ Quenching Presses
- ❑ Thread Grinders
- ❑ Tool & Cutter Grinders
- ❑ Other ________

NEW MACHINERY/EQUIPMENT DISTRIBUTOR FOR:

____

____

GEAR TOOLING AND ACCESSORIES YOU SELL

- ❑ Borazon/CBN Wheels
- ❑ Broaching Tools
- ❑ Chamfering Tools
- ❑ Coatings
- ❑ Cutter Bodies/Straight & Spiral Bevel
- ❑ Cutting Tools/Straight & Spiral Bevel
- ❑ Deburring Tools
- ❑ Diamond Wheels
- ❑ Dressing Diamonds
- ❑ EDM Tooling and Supplies
- ❑ Filtration Equipment
- ❑ Gages & Measuring Instruments
- ❑ Grinding Wheels
- ❑ Heat Exchangers
- ❑ Hobs
- ❑ Index Plates
- ❑ Injection Molds
- ❑ Keyseat Cutting Tools
- ❑ Lapping Compounds
- ❑ Lubricants, Coolants & Oils
- ❑ Master Gears
- ❑ Shaper Cutting Tools
- ❑ Shaving Cutters
- ❑ Spline Rolling Racks
- ❑ Wheel Truing & Dressing Devices
- ❑ Other ________

GEAR MATERIALS YOU SELL

- ❑ Bar Stock
- ❑ Cast Iron
- ❑ Coatings
- ❑ Gear Blanks
- ❑ Plastic Resins
- ❑ Plastic Stock Forms
- ❑ Powdered Metals
- ❑ Steels
- ❑ Other ________

GEAR SERVICES YOU SELL

- ❑ Bevel Gear Manufacturing
- ❑ Broaching Services
- ❑ Calibration Services
- ❑ Consulting
- ❑ Cryogenics
- ❑ Custom Gear Manufacturing
- ❑ Cutting Tool Sharpening
- ❑ Fault Analysis
- ❑ Gear Coating Services
- ❑ Gear Design
- ❑ Gear Forging Services
- ❑ Gear Grinding Services
- ❑ Heat Treating
- ❑ Inspection Services
- ❑ Shot Peening
- ❑ Stock Gear Manufacturing
- ❑ Tool Coating
- ❑ Other ________

FIXTURING AND WORKHOLDING YOU SELL

- ❑ Arbors
- ❑ Chucks
- ❑ Collets
- ❑ Modular Fixtures
- ❑ Toolholders
- ❑ Other ________

SOFTWARE YOU SELL

- ❑ Gear Design
- ❑ Gear Inspection
- ❑ Shop Management
- ❑ Custom Software
- ❑ Other ________

EDUCATION AND TRAINING

- ❑ We are a college/university
- ❑ We provide a gear school
- ❑ We are a research institution
- ❑ We are a trade association

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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.

The Next Dimension in Gear Metrology

Process Equipment Company has announced the release of the ND430 Next Dimension™ Gear Measurement System, which can perform both generative and coordinate measurements including index, tooth alignment, involute profile, root radius, diameters, planes, true position, tooth thickness and dimension over pins. "Our goal was to develop a machine where the accuracy could be known throughout the measuring zone so that related part features could be measured in relation to traditional gear features," says Brian Slone, Business Unit Manager for Process Equipment Co. Since both generative and coordinate measurements are made on the same machine, operating expenses are reduced. Data collection and analysis can be done using AGMA, DIN, ISO or user-defined standards.

"With customer specific software, the ND430 can inspect any type of gear once the geometry is defined," says Slone. "If the gear geometry is undefined, the ND430 can scan the component and give numerical information that can be loaded into a special analysis package for review. Customers can also write their own software modules so that customer proprietary part designs can be protected in house."

The ND430 can handle parts up to 430 mm (16.9") in diameter, 762 mm (30.0") in length, and 400 lbs. The machine is designed for an accuracy of 1.73 microns anywhere in the measuring envelope with repeatability to NIST-traceable masters in the sub-micron range. For information contact Process Equipment Company at (937) 667-7105.

Circle 300

Two New Machines From Kinefac

The **MC-300 Kine-Roller**, with a radial die load capability in excess of 600,000 lbs., is an ultra-high capacity, two-cylinder die rolling machine that uses the Kinefac enclosed force concept to achieve high rolling force with high-precision and minimal asymmetrical deflection. Consequently, the MC-300 is ideally suited to performing high precision, infeed and single-revolution, thread rolling, worm rolling and roll sizing.

This compact machine handles dies up to 15 inches in diameter with a 10-inch operating face. Ultra-precision, rotary match is achieved by a continuously variable rotary coupling between the two gearboxes, allowing angular die match within increments of 1/2 minute. Radial die penetration is achieved by a direct-acting cylinder. This accurately controls final penetration by direct contact at the end of its stroke, against a stop surface in the high stiffness, symmetrical stress frame. Penetration rate is controlled through an electro-hydraulic, proportional, directional-flow control valve. A linear position transducer monitors the position of the die head, allowing variable penetration rates depending on die head position.

Originally developed primarily for hollow shaft spline rolling, the **MC-6-FTF Kine-Roller** is cost effective for the production of splines on virtually any type of solid and hollow shafts up to 3 inches in diameter. The three cylindrical dies automatically center the part and are directly synchronized by a phasing plug, assuring precise angular location of the die teeth as they contact the blank. The dies are driven through a unique new torque sharing system that eliminates any rotational die error that may come from the individual die drivelines. The dies are held in the rolling position by a massive hydraulic actuation ring. The effects of spring or backlash in the spindle and actuation system are minimized by a preload ring, which operates directly on a cylindrical area on the dies. With this system, maximum spacing errors of .001" are achievable with a typical MOW tolerance range of .002".

This compact, rugged Kine-Roller occupies only about half the floor space of a typical horizontal rack-type spline roller. Because of the simple setup, high-productivity, low-cost and small machine footprint, it is well suited to the production of automotive, steering and transmission shafts, washing machine shafts and similar torque transmitting machine elements. For information on either of these machines, contact Kinefac Corporation at (508) 754-6891 or by email at *sales@kinefac.com.*

Circle 301

Diaform Dressing System

The CNC Diaform grinding wheel profiling system by Engis Corporation brings sub-micron precision, consistent performance and flexibility to form-wheel dressing and grinding operations. The system features a full 3-axis dressing capability, which brings highly accurate and repeatable precision to the production of deep and complex forms. Designed specifically for grinding by grinding specialists, the Diaform can be fitted to most types of surface, cylindrical and centerless grinding machines, as well as special purpose grinders and wheel-forming machines. By converting grinders into multi-axis form grinders with full CNC control, the system enables production engineers to change forms fast and efficiently, run dressing and grinding operations and create stand-alone wheel dressing systems to feed multiple grinding stations.

Controlled by a powerful processing unit, the Diaform automatically converts conversational-type data entries into internationally accepted ISO machine code. Input data can be in either metric or English measurements. The system accepts remote programming as well, via both diskette and RS-232 network links. For further information contact Engis Corporation at (800) 99-ENGIS or visit *www.engis.com.*

Circle 302

New Parallel Shaft Gearmotors from Bodine

Bodine Electric Company's new Pacesetter™ fractional horsepower, parallel shaft AC gearmotors are designed for extended life in inverter-driven applications. They offer adjustable speed to increase adaptability and the productivity of industrial machinery without the limitations normally associated with adjustable speed brush-type DC gearmotors.

The Pacesetter™ line of inverter duty gearmotors is comprised of nine models in two frame sizes (34 and 42), from 1/6 to 3/8 HP, with up to 341 lb-in of output torque. These gearmotors are designed for 230 V, 3-phase input and rated for constant torque output with drive frequencies varying from 10 to 90 Hz. For cool operation, they feature fan cooling and finned aluminum center rings for high thermal efficiency. For information, contact Bodine Electric Company at (800) 7BODINE (800-726-3463) or visit *www.bodine-electric.com.*

Circle 303

Hommel America Adds New Line

Hommel America, a manufacturer of surface roughness, form and gear testing measurement equipment has recently added the Steinheil-Kontur by Jenoptik to its product line. The Steinheil-Kontur is a dimensional/form-measuring machine for round components. The machine measures dimensional characteristics including diameter, length, reference rotation position, angular displacement, tapers, grooves, radii and chamfers. In addition, the machine can also measure form deviations such as run-out and roundness. It operates using live centers to hold the workpiece vertically, scanning the profile using an opto-electric sealed CCD array camera. The profile is then loaded into a Windows NT-based editing program, which then measures the features in seconds without contacting the measured part. For more information contact Hommel America, Inc., at (860) 827-8500 or visit their website at *www.hommelamerica.com.*

Circle 304

New Microhardness Test System

The Wilson division of the Instron Corporation has introduced the Series 2100 Modular Computerized Test System, a Micro/Vickers hardness test system that includes a high-resolution video camera and a choice of three operating modules. Users can configure a system for PC-based manual testing, add a Windows® X-Y auto-traversing stage system for semi-automatic operation, or perform fully automatic image analysis measurements under complete software control.

Providing microscopic images on a computer monitor in all operational modes, the Series 2100 eliminates operator fatigue caused by microscope viewing. Users can manipulate the specimen manually with a joystick or by on-screen commands, and 756x576 pixel resolution assures the ability to detect and measure indents as specified by ASTM E-384. For more information contact Instron at (800) 695-4273 or log onto *www.instron.com.*

Circle 305

New Toolholder Designed for "Power Shrinking"

The concept of "Power Shrinking" is expanded with the use of the Tribos toolholding system from Schunk, Inc. Unlike other systems that require a labor and time intensive heating or cooling process to achieve maximum clamping force, the unique geometric clamping technology of Tribos distributes uniform clamping force to three areas on the toolholder I.D. using the elastic deformation of steel (no wear).

The precise, tri-lobe symmetrical profile makes the Tribos system ideal for high speed machining applications such as tool and die, gear housings and mold making. The slim design enables maximum clearance of the cutting tool and extreme accuracy and concentricity (within 3 microns) resulting in extended tool life and improved surface finishes. For more information contact Schunk, Inc. at 919-572-2705 or send e-mail to info@schunk.de.

Circle 306

New Directory of Casting Sources

The American Foundry Society (AFS) has completed its new Casting Source Directory and Reference Issue 2001 (10th Edition). Available free to purchasing and engineering officials involved with the design and/or specification of metal components, the 370-page directory is the industry's only casting reference book. In addition to 75-plus pages of process and property data, it contains capability information on 3,000 foundries, die casters and investment casting suppliers in the United States, Canada and Mexico. For a copy of the book, or more information, contact AFS at (847) 824-0181.

Circle 307

Send your new product releases to:
***Gear Technology*, 1401 Lunt Avenue,**
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Fax: 847-437-6618.

Tell Us What You Think . . .

If you found this column of interest and/or useful, please **circle 232**.

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NACHI MACHINING TECHNOLOGY CO.

New Gear Shaving Machine brochure contains technical data on the Shavemaster 200 series. The Shavemaster 200 provides superior rigidity and unequalled finishing quality while requiring minimal floor space. A 30° slant bed makes part loading and unloading easy. Contact Dennis Sine at Nachi Machining Technology Co. (810) 263-0100 or E-mail *sales@nachimtc.com* for further details.

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

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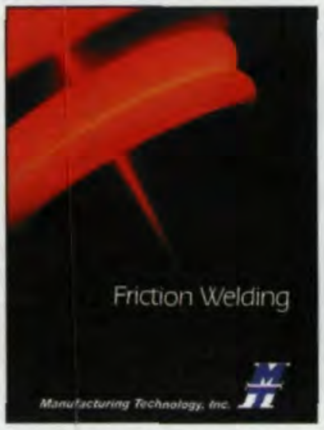

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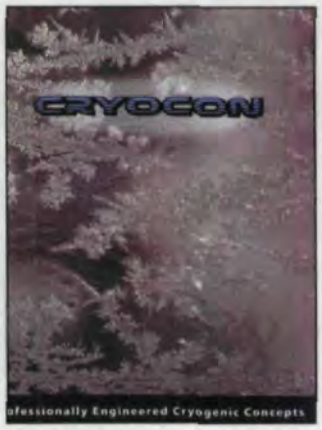

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CIRCLE 179

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LIEBHERR IS SEEKING QUALIFIED PEOPLE FOR THE FOLLOWING POSITIONS:

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Minimum requirement: 2 year technical degree in engineering (manufacturing preferred). Ideally, the successful applicant will have 2 to 5 years experience in the field of gear processing and an understanding of the gear hobbing, shaping, shaving and grinding processes. Training and an excellent opportunity for growth will be given to a motivated person. Responsibilities include quotation processing, time study calculation and engineering support for the sales staff.

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Qualifications include an engineering degree and a minimum 5 years experience in the field of project engineering. Responsibilities include project management and coordination of machine assembly for gear cutting machines for the automotive industry. Good people skills are a must. The successful applicant will have a proven record for a systematic approach to their work with good organizational skills and an understanding of gear processing.

SERVICE ENGINEER
The successful applicant will have a 2 year electrical technical degree or equivalent experience. Mechanical aptitude will be a plus. Extensive travel, Monday through Fridays within the USA, is required for this position. Gear processing knowledge such as hobbing, shaping, shaving and grinding would be an advantage. Responsibilities include servicing, installing and training the array of SIGMA POOL gear cutting equipment.

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Gear Rhymes

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

We'd like to thank our friends down at Sanderson Brothers Pty. Ltd., Thomastown, Australia, for bringing the work of Capt. S. Bramley-Moore to our attention. So, without further ado, we offer you the following poem to help you keep your gear formulae straight.

Those who belong to the Trade Engineering,
and wish for success must understand gearing.
Wherever you go where machinery's fixed,
you are bound to find gear wheels, all sizes, all mixed.

Diameters then shall be called letter D.
It shortens the word, so I hope you agree.
Big D is measured right over the teeth,
Pitch D is measured a little beneath.

From one tooth to the next, if measured it be,
Along the Pitch Circle and not on Big D.
Will give us the Circular Pitch of the gear,
A word you will probably frequently hear.
The number of teeth in a gear wheel, you see,
Depends on the Circular Pitch and Pitch D.

If two are but known, you can find out the third
With the help of a rather peculiar word.
PI it is called, it's a valuable key,
Three point one and four one and six it must be.

If you're given the Circular Pitch and the teeth,
Put these on top and put PI underneath.
Work out this fraction and you will obtain
The answer, Pitch D. Now let me explain
That if you require any other relation,
It's easily got from this simple equation.

If Pitch D and PI are both multiplied,
To get Circular Pitch, by teeth you divide.
Reverse the last two, and the answer will be
The number of teeth in the gear wheel, you see.

The height from Pitch D to the top of the tooth
Is called the Addendum, it's really the roof.
To reckon addendum you just specify
The Circular Pitch and divide it by PI.

With this information Big D can be had,
Just twice the Addendum to Pitch D you add.
The opposite part is Dedendum, you know.
It's the height of the teeth, not on top but below.

At bottom of tooth a space is left empty,
Take Circular Pitch and divide it by twenty.
This space, known as Clearance, will plainly become
The whole depth of tooth, adding twice Addendum.

Now the Circular Pitch should not be confused
With a more simple method more frequently used.
Diametral is better than Circular Pitch,
The figures are shorter, no chance of a hitch.
Let us call it DP, it saves waste of time,
It's not only correct but it is easier to rhyme.
It gets over the use of those troublesome PIs;
Moreover its value at once signifies
The number of teeth for each inch of Pitch D.
Large DP means size of the teeth becomes wee.

The number of teeth—over DP—will at once
Give the answer Pitch D, unless you're a dunce.
The other way round, teeth over Pitch D,
Will obviously give you the answer DP.

For number of teeth, now kindly take heed,
Use Pitch D and DP, it's their product you need.
For Addendum you take one, and divide by DP.
From this you can easily work out Big D.
If it is the Clearance you're anxious to know,
Write point one five seven, with DP below.

To convert DP into circular measure
Is so easily done that it's really a pleasure.
Divide PI by DP, that is all you need do.
The thing is so simple it hardly seems true.

If you want to convert these the other way round,
The answer is quickly and easily found.
Divide PI by the Circular Pitch and you then
Get the answer DP with the stroke of a pen.

Now that's what we call literature! Any other budding gear poets out there are encouraged to send in their work. Send it by fax to Charles Cooper, senior editor, *Gear Technology* magazine, at (847) 437-6618 or by e-mail to *Charles@geartechnology.com.*

Tell Us What You Think . . .

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


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ANSI-RAB
National Accreditation Program
Perry Technology Corporation
The Gear & Spline Experts
(Please visit our Website for a complete listing of capabilities, facility listing and virtual tour)
CIRCLE 134

Gleason Cutting Tools

We're The Right Choice for Service

Did you know that many of the same resources used to develop and manufacture the world's most productive gear-cutting tools are available to you? Our customers can choose any or all of the following services:

- *Advanced coatings*, to improve the performance of everything from gear tools to taps to wear parts.
- *High-performance heat treat*, with new vacuum furnaces that ensure better gear consistency and reduced variation in tool life.
- *Factory regrinds and recoatings*, to bring tools back to their original factory condition.
- *An on-site metallurgical lab*, to help put new coatings, materials, and designs to work.
- *GCT Express*, the door-to-door pickup and delivery service that gives you fast delivery on the complete range of services.

For more information on these and other Gleason Cutting Tools services, contact:

The Right Choice

See us at
Booth B 6931

The Vital Manufacturing Show
IMTS
Chicago, September 6-13, 2000

Gleason Cutting Tools
CORPORATION

ISO 9001 Registered

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