GEAR TECHNOLOGY

NOVEMBER/DECEMBER 2000

The Journal of Gear Manufacturing

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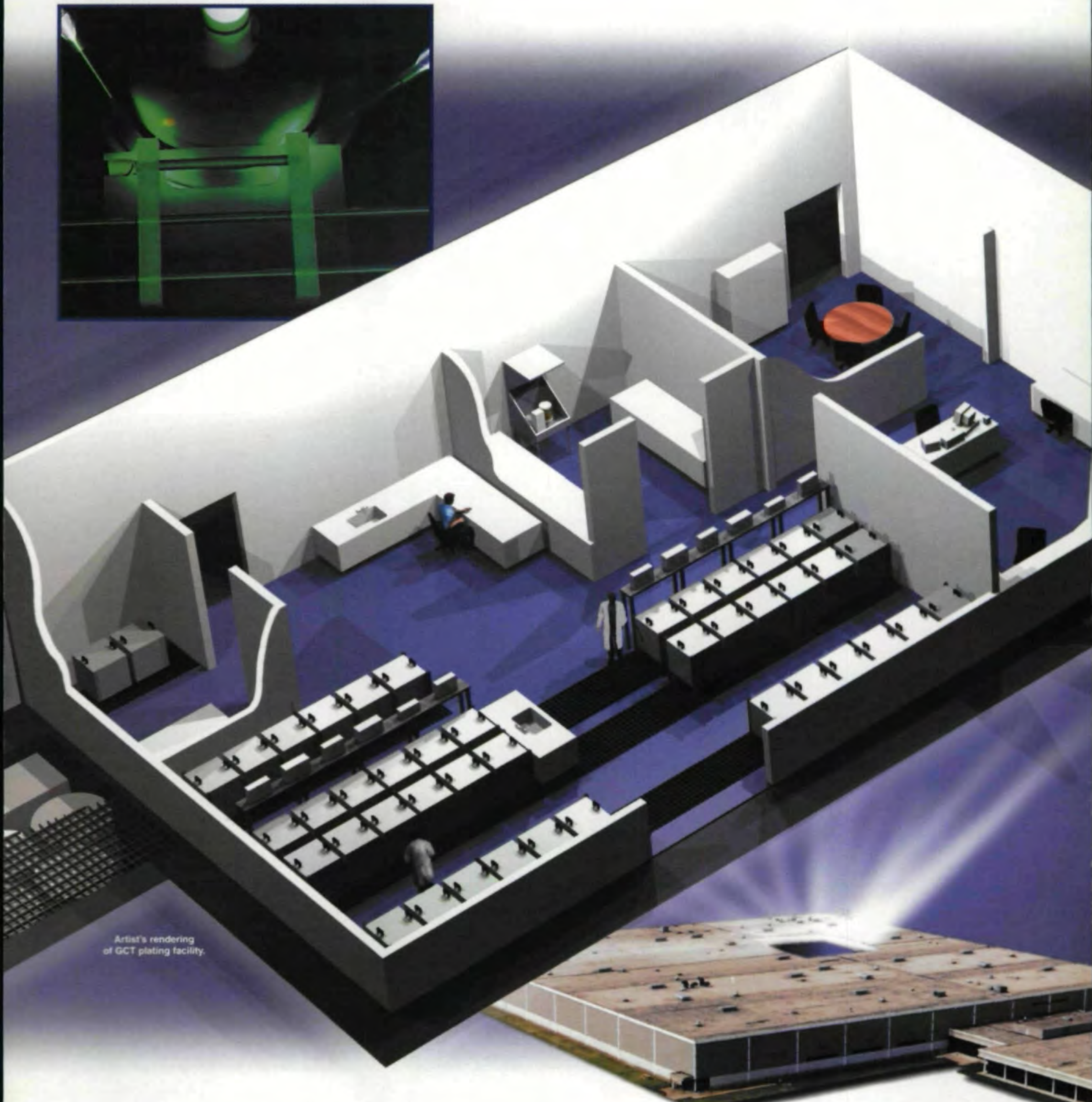

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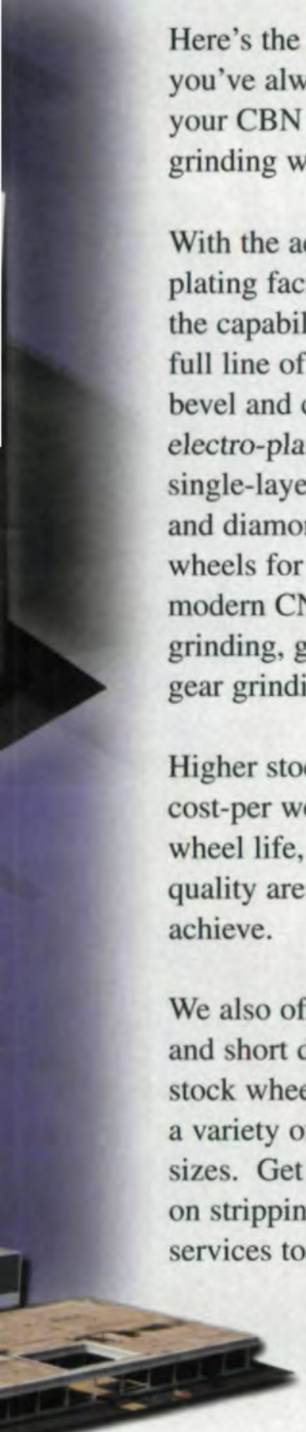

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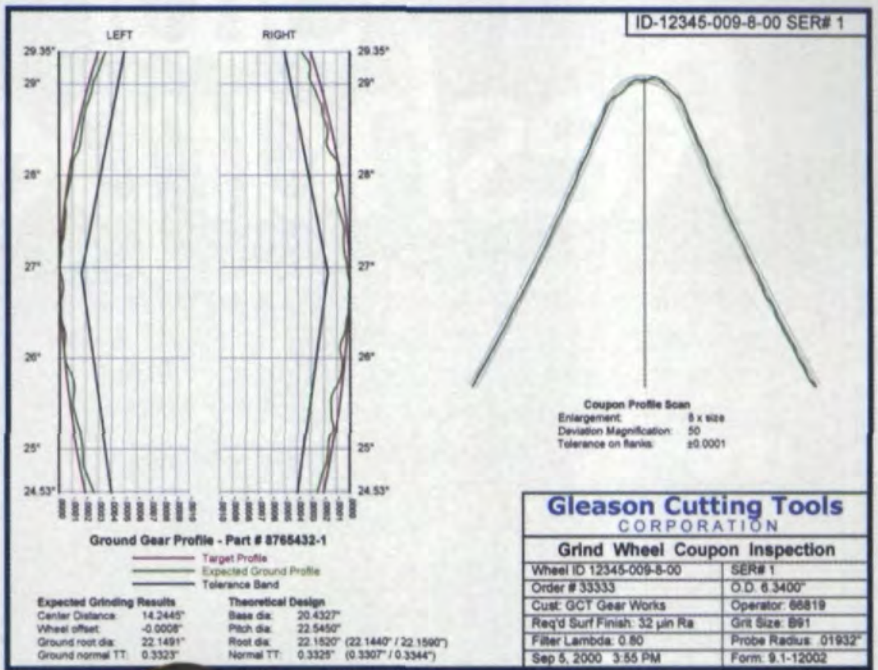

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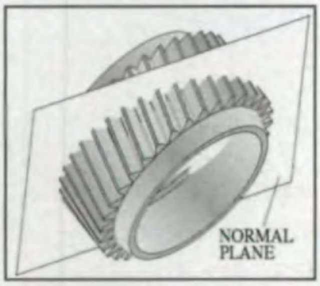
NOVEMBER/DECEMBER 2000 *The Journal of Gear Manufacturing*

FEATURES



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The Journal of Gear Manufacturing

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A PAUSE THAT Refreshes?

When you go to IMTS, you expect to see hoopla. The mass of machines and bodies gathered in one place should create an unmistakable level of energy and enthusiasm. IMTS 2000 seemed uncharacteristically quiet . . .

. . . In fact, it seemed to me that many of the exhibitors were just going through the motions. Sure, they shined up their best machines. They put on their show faces and wore their show suits. They had fresh brochures, new signs and impressive displays. Superficially, it was the same as any other IMTS. But as I walked around the Gear Pavilion and spoke with the exhibitors, it became clear that something was missing.

For the exhibitors, that something was the throng of buyers who usually come to IMTS. Many of these exhibitors spend hundreds of thousands of dollars to be at IMTS, and if they're not making sales, or at least generating good leads, it's easy to see why their level of enthusiasm might be down. Many gamely said that although the numbers were down, the quality of attendees was high. They put their best spin on the situation, but you could read in their faces how they really felt.

The scenario at IMTS is currently being played out at the national level. Industry in America seems to be in pause mode, as if we're taking a collective breath, waiting to see what's around the corner. A brief pause is typical around IMTS time, as manufacturers scale back their spending to see what technologies will be introduced at the show. The uncertainty in the world economy isn't helping, either. Although the U.S. economy seems to be continuing its steady growth, the strong U.S. Dollar is probably hurting overseas sales and contributing to dropping import prices. Add to these factors the political uncertainties of this big election year and you can begin to understand the lack of excitement at IMTS.

Well, IMTS is over, and soon the presidential election will be too. From what I've been hearing and reading lately, the economy may be ready for a new round of capital spending that should help boost the gear industry and the manufacturing sector in general.

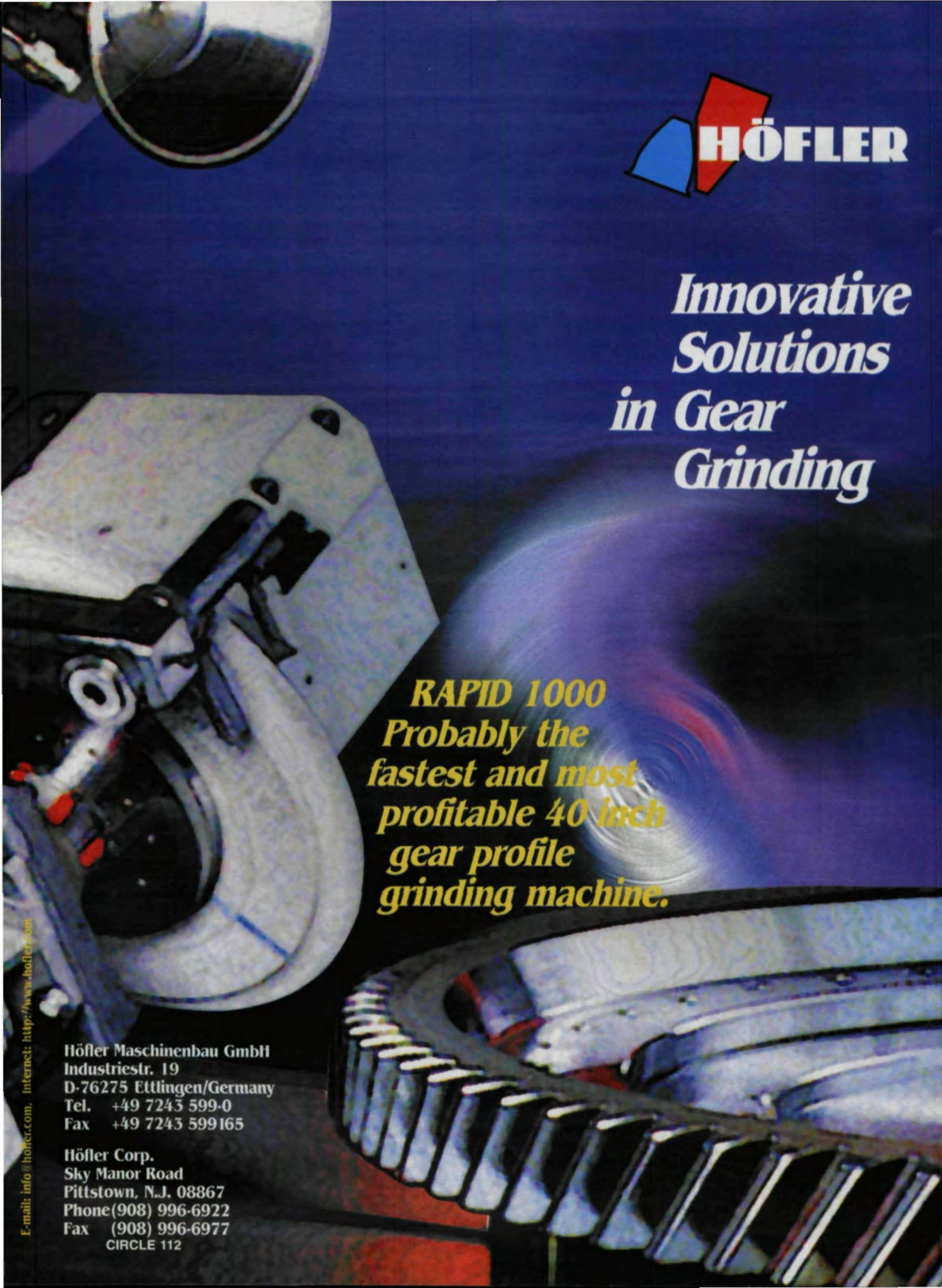
For example, economist Dr. Mike Bradley, whose column is featured in the AGMA News Digest, recently wrote that we may have reason to be positive about the outlook for the gear industry in 2001. According to Bradley, the overall economy saw a shift from consumer spending to capital goods spending in the first half of the year, with capital goods spending increasing in each of the months from March through June. This growth in capital goods spending, although slim, came at a time when the Federal Reserve was inching up interest rates. If the manufacturing sector can continue to withstand these increases, and if recent data on industrial production are any indication, the gear industry could see a positive 2001, Bradley says.

I, for one, am not going to worry about what I saw at IMTS. Even though the show lacked its usual energy and enthusiasm, there's no reason to panic. Like the rest of the manufacturing sector, we've got to wait and see what happens next. With any luck, some of the indicators we're seeing now will gain momentum and make 2001 a very strong year for the gear industry.

Who knows? By the time Gear Expo rolls around next October, we may even see smiles returning to the faces of the machine tool vendors.

Michael Goldstein

Michael Goldstein, Publisher and Editor-in-Chief



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SCRAM

According to its inventor, John Hammerbeck, the revolutionary thing about his Simple Continuous Ratio Adjusting Machine, or SCRAM, a new design in infinitely variable transmissions, is its belt. "Previous systems all use the interaction of differing diameters of wheels and/or belts to change speed," says Hammerbeck. "SCRAM uses the entirely new principle of an extendible belt constructed so that for a given input at the drive point, the belt will loop past the drive point in a fixed time however much the belt is extended. When the belt is extended, a greater length runs over an output wheel, making the output faster." One version of this system uses a tension coil spring as the belt, which is driven by lugs mounted within a hollow drive shaft and interacting between the windings of the coil. "Turning the shaft causes the lugs to propel the coil forward," says Hammerbeck. "It will be apparent, as the number of windings of the coil does not change, that for a given input RPM, the belt will pass the drive point in a fixed time."

According to Hammerbeck, this system has a number of distinct advantages over traditional gear drives and other "infinitely variable" systems as both a reduction mechanism and a speed control mechanism for both commercial and industrial applications. One of these advantages is that the technology depends on well-understood parts and processes. To the question of metal fatigue affecting the spring belt, Hammerbeck acknowledges the problem but answers, "Yes, but springs are studied and understood. The valve springs in your car do 500 million cycles while you drive 100,000 miles. Have you ever had a valve spring failure? The fatigue characteristics of compression springs are the same as extension springs." Other advantages include smooth, continuous ratio change while under power, a wide range of ratios, precise speed control, no backlash, little vibration, good heat dissipation, minimal lubrication and others. It is also easy to control, since there are no complex gear changing linkages, and easy to work on since there is no casing and no oil bath. The unit has a standard reduction of 25 to 1, which makes it suitable for high RPM input, but this can be modified to suit the application by specifying different springs or placing units in series. It can also buffer input energy, automatically storing it when output meets resistance instead of slowing the propulsion unit.

"SCRAM is an extremely cheap, light and effective ratio altering machine," says Hammerbeck, who came up with the initial idea while working to develop an accelerating moving sidewalk. "Its ability to take the most efficient, steady RPM from the power source and accelerate the system to high RPM without disengaging power gives it considerable advantages over previous systems, and its low cost will spawn new applications." Consumer applications for this technology include systems in both conventional and electric vehicles, household appliances, videotape machines, garden machinery, electric motors, bicycles and climate control. Industrial uses would include compressors and hydraulics, textile machines, machine tools, centrifuges, oil drills, lifts and conveyors, marine propulsion, wind generators and special vehicles. These last could include solar powered vehicles, lunar and amphibious vehicles, and human-powered flight. "Buffering of power could enable rowing action and, therefore, fuller utilization of body strength than cycling action," says Hammerbeck.

On the 28th of June, 2000, the Simple Continuous Ratio Adjusting Machine made its debut at the BBC Tomorrow's World Invention Fair in London, England. The two working proof-of-concept machines received what Hammerbeck calls a "tremendous response" from engineers in a variety of fields. Hammerbeck believes the range of applications for his invention is very wide because it makes continuous and automatic speed control very cheap. The unit itself has no casing and no gears to cut—just wire, plastic and fastenings. "I imagine that it might be used first in fun applications like Robot Wars," says Hammerbeck. "These devices are very easy to make, so I hope many amateurs will experiment with them."

Circle 301

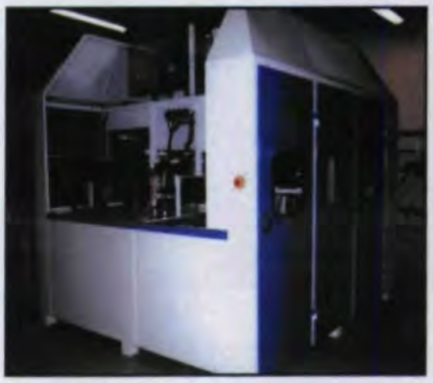
Welcome to* Revolutions*, the column that brings you the latest, most up-to-date and easy-to-read information about the people and technology of the gear industry.* Revolutions *welcomes your submissions. Please send them to* Gear Technology*, P.O. Box 1426, Elk Grove Village, IL 60009, fax (847) 437-6618 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.

New Currents in Deburring

Most metalworking processes leave burrs and other attached material residues that need to be removed before a part can be put into service. The more complex the part, the more difficult the task of finishing it. Now, from 3CD Gradningsteknologi AB, we have a deburring and polishing process that works with even the most complex and difficult to machine parts. Called the 3CD Process, this electrolytic polishing and deburring method promises to leave parts burr-free, with smooth edges and corners and a soft, clean surface with a lower Ra-value.

The Process. For simple workpieces, the part to be processed is connected to the machine as an anode (positive pole) in a direct current voltage circuit with a cathode (negative pole). An electrolyte solution (electrically conductive fluid) consisting of glycol and three different ammonium salts completes the circuit. This solution maintains a pH level of 6–7 and has a working temperature of 15–20° C.

According to Bo Magnusson, marketing manager for 3CD Gradningsteknologi AB, "In the electrolyte, there are free negatively charged chlorine and positively charged ammonia ions. When the current circuit is established, the chlorine ions move towards the anode and at the surface join the positvely charged iron ions, removing them from the work piece/anode. In the electrolyte, the molecule splits and the iron ions join free OH-ions



The 3CD deburring process.

and fall to the bottom as $Fe(OH)_2$. The OH-ions form as a result of the electron movement in the current circuit. At the cathode, water molecules are split into an H_2 gas and OH-ions. When the current circuit is established, the ions and the electrons move along current lines. These are most frequently located on the corners and edges of the workpiece, where you find more deburring activity."

After completing the deburring and polishing process, the part is then washed and rinsed. For more complex pieces, locally positioned auxiliary electrodes are used to direct the current. When deburring or polishing interior spaces on a part, such as intersecting holes, the process can be performed on a specially designed rig with auxiliary cathodes applied to the areas where deburring is to be carried out. In these cases, the electrolyte is routed to the area to be machined by means of a hose and drained via a collection pan into a pump-fitted system tank.

Material removal is directly proportional to the current strength and time. However, the material removal rate is also influenced by such parameters as the composition concentration, flow, temperature, electrolyte conductivity, the tendency of the metal to become passive, and the alignment and pulsation of the current. Still, the process is entirely safe for the workpiece, says Magnusson. "The electricity does not affect the work piece at all," he explains. "The deburring process can also offer the positive effect of removing cracks from the surface." The process is designed to handle burrs that are less than 2 mm in size and is capable of processing a part in 2–4 minutes when the burrs are about 1 mm in size.

Parts and Tooling. All parts can be treated. However the method is most profitable for parts with a certain value and with a high demand for burr-free surfaces. The size of the parts that may be treated depends on whether they must be placed in the electrolyte or not. Large surfaces demand more voltage, and the burrs on them tend to be less concentrated. Whether a hole can be treated depends on its depth, placement and diameter. Normally, holes with diameters of 2 mm or more can be treated. Threads on a part tend not to be a problem.

Different parts on a gear are usually deburred separately, although gear rings can be deburred all at once. "Any gear part can be deburred, but you have to use special cathodes/tools for different parts," says Magnusson. "Depending on the production method, you can transport the parts on a belt conveyor or pick-and-place robot into the deburring area, automatically apply the tools to the parts, deburr, remove the tools and then restart the conveyor or robot for the next part."

Materials and Tolerances. Any electrically conductive material, with the exceptions of titanium and zinc alloys, can be treated. Alloys with silicon and carbon can be processed; however each poses its own unique problems. The surface of alloys with silicon end the process covered with silicon oxide. Carbon content decreases the effectiveness of the process in proportion to its amount. In other words, the more carbon, the less effective is the process. Under normal circumstances, the metal removal rate for the process is 0.005 mm/min, a rate Magnusson says designers can count on when working out part tolerances.

The metal that is removed is discharged as hydroxide sludge. This could be environmentally hazardous if the machined components contain heavy or toxic metals. For this reason, sludge from the electrolyte bath and rinsing water must be separated before being discharged. 3CD Gradningsteknologi AB offers its customers solutions and equipment for this type of materials handling.

According to 3CD Gradningsteknologi AB, the flexibility of the 3CD process and its versatile range of use offer a high level of utilization, creating economic benefits for the user. This is regardless of whether the process is being used in a short-run job shop or on an automated production line. Other benefits stem from the energy-efficiency of the process and the long service life of the electrolyte solution.

Circle 302

Improved Diamond Dresser

Continuous gear grinding is one of the most important grinding processes for the manufacture of high precision gears. The grinding wheel, formed with a rack and tooth profile, is used as a cylindrical grinding worm. The involute profile of the grinding worm is formed and maintained by the profile of a diamond dresser disk.

The quality of the gear tooth flank depends on the accuracy of the involute

form of the grinding wheel. Advanced design gearboxes utilize special gear tooth forms to improve noise and operating qualities. Gear tooth modifications, such as tip and root relief created by a combination of two radii or a radius and straight line in addition to simple crowning, are formed in the grinding wheel by use of a profile form diamond dresser disk.

The lifetime of the diamond dresser disk is an important consideration in continuous gear grinding. Diamond dresser disks are available with a direct- or reverse-plated single diamond layer, or with a sintered single or multiple diamond layer. Sintered dresser disks offer a long life and have excellent corner wear characteristics. Sintered tools also utilize high dressing pressures and cannot produce as sharp a grinding wheel as can a direct plated diamond dresser disk. As a result of the excellent T.I.R and more aggressive diamond layer of the direct plated diamond dressers, the grinding wheel is more aggressive and free cutting. Direct-plated diamond dressers can be refurbished or modified by stripping and re-coating the diamond layer and/or regrinding the profile for a different tooth profile.

Sintered and direct plated diamond dresser disks can be re-lapped to restore the original involute profile; however sintered dressers cannot be re-plated.

A new generation of polycrystalline diamond (PCD) corner-reinforced, direct plated diamond dresser disks, designed and produced by Dr. Kaiser Diamond Tools, offers the advantages of both sintered and direct-plated dresser disks—high corner wear resistance and a free cutting grinding wheel. The combination of reinforcing PCD to counteract excessive edge wear on the outside diameter of the dresser disk, and direct-plated diamonds, improves gear grinding and dresser disk life equally. The direct-plated, PCD reinforced dresser disk can be stripped and recoated several times. Tooth form modifications such as tip relief or crowning, for example, can be built into the dresser disks.

The new generation PCD reinforced dresser can be utilized on all common dressing units. Small module applications offer a distinct opportunity for process improvement since the small width of the dresser disk can wear quickly. The PCD reinforcement leads to exceedingly long diamond dresser life, particularly if a separate root reliever cannot be utilized.

Circle 303

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Old World Expertise

Dear Editor,

I am writing this in response to some articles appearing in your journal, but I want to take the opportunity, also, to express my thanks for all the good work your publication is doing. I always look forward to your next issue being in my mail slot. I know I will find timely technical articles relevant to our manufacturing situation here at Amarillo Gear Co., as well as thought provoking commentary on events and trends affecting our business. The Publisher's Page is always worth the reading.

I would like to comment about remarks made in your January/February and July/August issues by Mr. Joseph L. Arvin, President, Arrow Gear Company. Mr. Arvin is right on the mark concerning the loss of what he calls "old world machining expertise" in the gear industry.

I began working for my father in his automotive repair business when I was 8 years old. My first job was to keep the shop clean and make sure all the tools were accounted for and in the proper place. When I mastered that, I was allowed to clean parts for reassembly. Later, I was taught to disassemble, paying close attention to how the mechanism was put together. After that came hands-on reassembly. Finally, I began to learn about diagnosing problems and executing the repair.

Each new level of training was built on a necessary foundation of previously mastered skill and knowledge. First, I learned what the tools looked like, how they worked, how to pick the best tool for the job, and how to keep my work area clean and organized so I could get the job done. Then I learned what the parts looked like, what their names were, where they fit in the mechanism, how they contributed to its function, and what malfunction could be traced to a particular part. Only after all this was learned could I begin to understand how my father knew what was wrong with a vehicle and how to repair it.

I was 24 when I started my career here at Amarillo Gear Company, and the learning process is the same. "This is a spiral bevel gear, and this is how it differs from the hypoid gears you saw in your dad's shop. This is the convex side of the tooth and that is the concave side. This is called profile, and this is called bias. This is how lapping works, and this is why we lap gears in sets. This is called a tooth contact analysis. Can you see from this how the motion of the gear tooth in relation to the pinion tooth transfers the power? This is a face mill cutter. The machine moves the cutter in the same path the mating gear tooth will make as it passes through the tooth gap, thus generating the tooth gap as it cuts. These are proportional changes that you can use to adjust bias and profile to improve the bearing pattern. Now that you've mastered fixed setting method, we bought a new machine that does duplex cutting. We will finish both sides of the pinion at one cutting." Now comes face hobbing, CNC generators, power cutting, dry cutting, and who knows what else.

So what is "old world machining expertise" and where does it fit in today's world? I believe that old world expertise is a profound understanding of the manufactured part, and how it is physically (not just electronically) made. When you get right down to it, gears are still made by removing material from the gear blank to form the tooth gap. We use electronics now to put the blank where we want it and to put the cutter where we want it, and to move them both the way we want them to move. The successful gear technician on the plant floor is the one who knows why.

That level of expertise is a function of attitude(AT), aptitude(AP), opportunity(O), knowledge(KN), and time(T). If we were to look at it mathematically, it might look something like this:

$$((AT+AP+KN) \times O)/T = \text{expertise}$$

as time(T) goes from Day 1 to retirement.

We bring with us mechanical aptitude (not everyone is born with this), an attitude of continuous improvement (if you don't have it, get it), and we add knowledge (mine, yours, theirs, wherever we can get it). We apply that to every hands-on activity involved in gear manufacturing (opportunity), and over time (required!) we produce old world expertise within ourselves.

It becomes incumbent, then, that we as individuals share the expertise we have acquired with the next generation, that we as managers provide the opportunity for the acquisition of meaningful experience for employees, and that our companies nurture and retain expertise in the work force.

That sounds good, and no one would disagree that it is a noble goal, but it is not going to happen by itself. It will require a commitment from employee and manager alike to invest the time and energy to make it work. The dividends are well worth it. The future of gear manufacturing in this country depends on it.

Sincerely,
Bob Gerhardt
Gear Department Manager
Amarillo Gear Co.

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TECHNICAL CALENDAR

Nov. 5–10, 2000—ASME International Mechanical Engineering Congress and Exposition. Walt Disney World Dolphin Hotel, Orlando, FL. The theme of this year's conference is *Beyond Traditional Boundaries*. The event will provide one of the engineering industry's premier forums for industry, academia and government, with hundreds of technical presentations scheduled. Call ASME at (800) 843-2763.

Nov. 6–10, 2000—AGMA's Training School for Gear Manufacturing Basic Course. Daley College, Chicago, IL. The basic course is designed primarily for employees with at least six months of experience in set-up or machine operation. The five-day course is split into classroom and hands-on training sessions. Students will learn to set up machines for maximum efficiency, accurately inspect gears, perform gearing calculations and understand basic gearing. Call AGMA at (703) 684-0211.

Nov. 29–Dec. 1, 2000—Fundamentals of Gear Design, Part 1 of 2. University of Wisconsin-Milwaukee. This course features Ray Drago as instructor. The course content has been updated and expanded to provide a more comprehensive coverage of the important topics regarding the fundamentals of gear design. Part 1 includes history of gears, basic gear tooth nomenclature, types of gears, gear arrangements, theory of gear tooth action, and failure modes and prevention. The full course (Part 1 and 2) is specifically aimed at the designer, user, and beginning gear technologist. The main emphasis is on the proper selection, design application, and use rather than fabrication

Jan. 16–18, 2000—SME Advanced Productivity Exposition (APEX). Orange County Convention Center, Orlando, FL. This machine tool show is sponsored by SME, AMT-The Association for Manufacturing Technology, and AMTDA—The American Machine Tool Distributors' Association. Call SME at (313) 271-1500.

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Design Against Tooth Interior Fatigue Fracture

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Introduction

In a modern truck, the gear teeth are among the most stressed parts. Failure of a tooth will damage the transmission severely. Throughout the years, gear design experience has been gained and collected into standards such as DIN (Ref. 1) or AGMA (Ref. 2). Traditionally two types of failures are considered in gear design: tooth root bending fatigue, and contact fatigue. The demands for lighter and more silent transmissions have given birth to new failure types. One novel failure type, Tooth Interior Fatigue Fracture (TIFF), has previously been described by MackAldener and Olsson (Refs. 3 & 4) and is further explored in this paper.

Observations of TIFF

TIFF is characterized by a failure, approximately mid-height on the tooth, which distinguishes it from tooth root bending fatigue. Contact fatigue and/or spalling craters are not a prerequisite at the flank of a TIFF. In Figures 1 and 2, photos and a schematic of a typical TIFF can be seen.

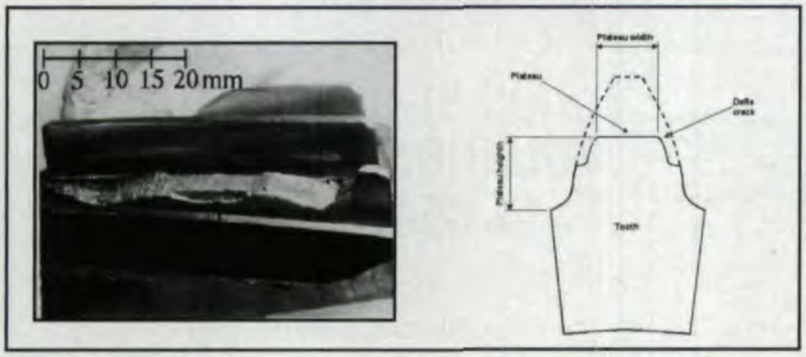

Fig. 1—A typical Tooth Interior Fatigue Fracture (TIFF) and a schematic of a TIFF.

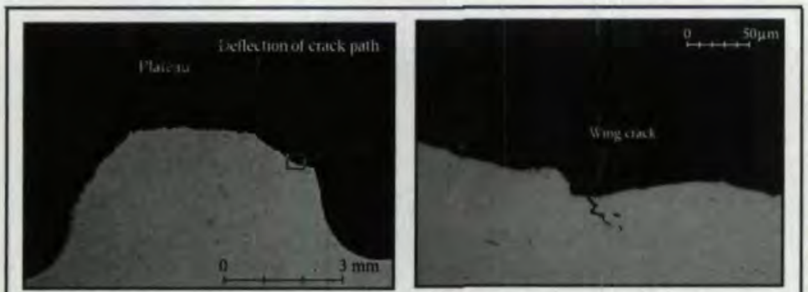

Fig. 2—Close-up of a cross-section of a TIFF. The wing crack indicates the propagation direction of the main crack (from the interior of the tooth towards the flank).

TIFF has been observed in case hardened idlers. A test series with idler wheels has been run. Out of 75 specimens, 20 were classified as TIFF. Tooth root bending fatigue or contact fatigue occurred in the other specimens.

TIFF Mechanism

TIFF is initiated in the interior of the tooth. Other known fatigue failures initiate at the surface. A failure type called Zahnkopfbruch in German, starting from spalling craters at the flank, has been reported by Shultz and Sauter (Ref. 5). Hence Zahnkopfbruch and TIFF are not the same type of failure, although they may appear similar. Alban (Ref. 6) described stress ruptures, which have a fracture surface similar to TIFF. However, stress rupture is not a fatigue fracture since the crack is formed during the hardening process.

TIFF is the result of: 1) constant residual tensile stresses in the interior of the tooth due to case hardening, and 2) alternating stresses due to the idler usage of the gear wheel.

Analysis

FE-model for mesh cycle simulation. To analyze the crack initiation process in the gear, a 2D FE-mesh was utilized. A plane strain 2D-mesh in the normal plane (perpendicular to the flank) was shown to give stress distributions in a cross-section of the tooth that is virtually the same as that of a 3D-mesh. Hence a 2D-mesh can be used for stress analysis of a complete mesh cycle. The FE-mesh is shown in Figure 3.

With a parametric model of the FE-mesh (developed in ANSYS, Ref. 7), an arbitrary position in the mesh cycle could be analyzed. The gear calculation program LDP (Ref. 8) computed the total force on one tooth as a function of position in the mesh cycle. The tooth force was divided by the width of the tooth and applied as torque.

The residual stress due to case hardening was found by applying an inelastic strain profile in accordance with residual stress measurements. The hardness penetration depth and its shape were obtained by hardness measurements.

Fatigue tests of the gear showed that shot peening increased the fatigue endurance limit by 36%.

Residual stress measurements of shot peened gear wheels showed that the shot peening increased the compression stresses to a depth of 0.1–0.2 mm.

Crack initiation criterion. In order to predict crack initiation in high cycle fatigue during multiaxial loading, Findley (Ref. 9) suggested a critical plane approach where the shear amplitude (τ_a) and the maximum normal stress ($\sigma_{n,max}$) during one load cycle are used to form the criterion. The criterion can be written

$$\sigma_F = \sigma_{crit} \quad (1)$$

where

$$\sigma_F = \tau_a + a_{cp}\sigma_{n,max} \quad (2)$$

is an equation for effective fatigue stress (Findley critical plane stress). The criterion states that crack initiation will occur if σ_F is greater than σ_{crit}. Here, σ_{crit} and a_{cp} are material constants that can be determined by combining the result of two fatigue tests. Here, σ_{crit} in the core was determined to be $\sigma_{crit,core}$ = 479.8 MPa while for the case, $\sigma_{crit,case}$ = 1090.0 MPa. The a_{cp} parameter was determined to be $a_{cp,core}$ = 0.37 and $a_{cp,case}$ = 1.00, respectively. Shot peening is considered in the FE-analysis by increasing the fatigue limit (σ_{crit}) 36% in the nodes of the model within 0.2 mm from the surface. The σ_{crit} and the a_{cp} parameter were taken to vary continuously between the case and core in the same manner as the hardness profile.

Numerical analysis. The FE-analysis is carried through in two stages: 1) calculation of the state of stress history in the tooth during one load cycle, including residual stresses, and 2) evaluation of the risk of crack initiation. The engaging gear teeth are analyzed in 19 different points of the mesh cycle, each point representing a "frozen" moment in the mesh cycle. The points included nine points with contact on each flank and one with the tooth unloaded. Results of the 19 analyses are combined to represent one load cycle (i.e. one revolution of the idler). The Findley critical plane stress is formed for every degree of plane inclination at each node of the cross-section of the loaded tooth. The maximum Findley critical plane stress at each node is stored for evaluation purposes.

Numerical results. In order to judge the risk of crack initiation, the crack initiation risk factor (CIRF) must be calculated. This is done by dividing the Findley critical plane stress by the σ_{crit} value at every material point. A contour plot of the CIRF of the gear can be seen in Figure 4b. It is also interesting to compare the CIRF for the studied gear used as an idler and in a single stage gear. The comparison can also be seen in Figure 4.

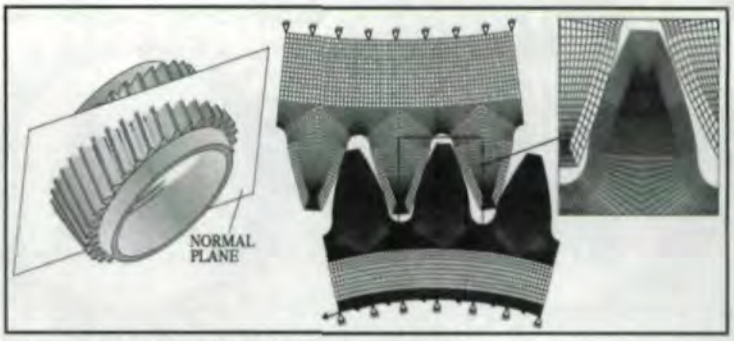

Fig. 3—Two-dimensional finite element mesh.

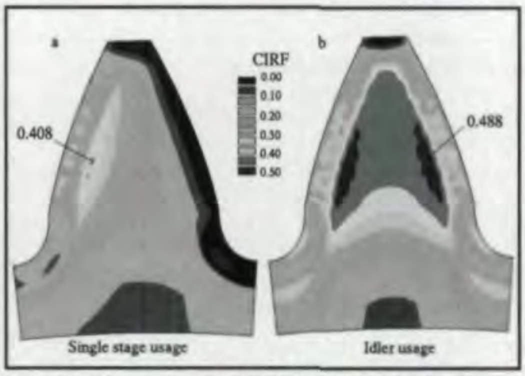

Fig. 4—Comparison of CIRF. a) the studied gear used as a single stage gear, b) the studied gear used as an idler.

The region with high CIRF is located approximately mid-height of the tooth and slightly below the case-core boundary. Thus, if a crack is developed in the interior of the tooth, it will initiate between the center-line and the case layer. The CIRF in the interior is increased by 20% if the gear is used as an idler instead of as a single stage gear. Moreover, the area (or volume) with high CIRF is larger in case of idler usage. Analysis of the risk of TIFF at different loads shows that, as the tooth load is increased, it is more likely to have a crack initiating in the root than in the interior. Thus, TIFF is a presumptive failure mode occurring at medium load, i.e. the load level is between the load at which contact fatigue is achieved and the load at with tooth root bending fatigue is obtained. This agrees well with the experience from the rig test of the idler gear.

Parameter Study

Crucial for a successful gear design is that the designer understands how different design parameters influence the response (certain properties) of the structure. Such knowledge can be gained by a factorial design. In contrast to a "one-factor-at-a-time" approach, the factorial design also gives information about interaction effects. For a detailed discussion on factorial design, see Box et al. (Ref. 10) or Montgomery (Ref. 11).

Here, a factorial design with five factors (A to E) was conducted. The parameters are the two material constants σ_{crit} (A) and a_{cp} (B), the slender-

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Fig. 5—The slender (left) and not-slender (right) geometry compared with the geometry of the original tooth (middle).

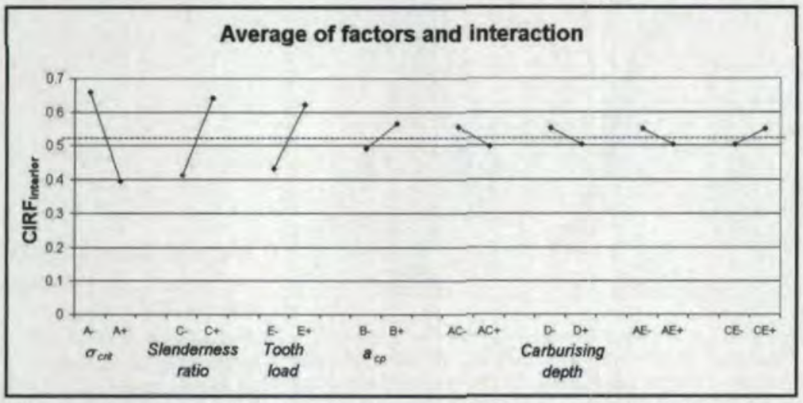

Fig. 6—The average of the factors with most influence on the CIRF in the interior. The overall mean is marked by the dashed line.

Table 1. The factors (parameters) and their levels.

Factor	Description	Low level (–)	High level (+)
A	σ_{crit} in core	359.85	559.75
B	a_{cp} parameter in core	0.28	0.46
C	Slenderness ratio	1.16	1.65
D	Carburizing depth	0.9 mm	1.5 mm
E	Tooth force	1238 Nm*	2064 Nm*

* Tooth force corresponding to torque on the idler in original design.

ness ratio, C (defined as the ratio between the height of the involute $((d_a-d_{Ff})/2)$ and the tooth thickness (s_{yn}) half-way between the transition from root fillet to involute (d_{Ff}) and the addendum diameter (d_a)), the carburizing depth (D) and the tooth load (E). For each factor, two levels were assigned, one low (marked with a minus sign) and one high (marked with a plus sign). The low and high level of each factor is set to approximately 75% and 125%, respectively, of the value of the original (previously analyzed) design of the studied gear. In Figure 5, the slender and not-slender gear design are compared with the geometry of the original gear wheel.

For details about the tooth geometry, see Table 3. The levels of the factors are given in Table 1.

Here, 32 experiments were conducted in accordance with an ordinary L32 orthogonal array. Each "experiment" in the array is represented by an FE-analysis determining the CIRF in the interior of the tooth.

Result of the parameter study. The result of the factorial design is the CIRF (response) in the interior of the tooth denoted y_i for the ith experiment (Table 4). Emanating from the results it is possible to estimate the main effect. The main effect should be interpreted as the change in response while changing the level of the factor from low to high. The main effect is given by

$$m_{N+} = \frac{1}{k^+}\sum_{i=1}^{k^+} y_{i+} - \frac{1}{k^-}\sum_{i=1}^{k^-} y_{i-} \qquad (3)$$

where k+ and k– are the number of times the factor appears at high and low level, respectively. The result of the factorial design is summarized in Table 2.

In Figure 6 the average of the factors regarded as significant is plotted. The main effect is the difference between the low (–) and high (+) level for each factor.

The greatest influence on the CIRF in the interior of the tooth comes from the factors A (σ_{crit}), C (slenderness ratio), E (tooth load) and B (a_{cp}) in that order. The influence on the CIRF in the interior from the factor D (the carburizing depth) is less than 5% but, somewhat unexpected, it is negative. This means that the lower the carburizing depth, the higher the risk of TIFF. It is also worth noting that the influence from the carburizing depth (factor D) is less than the interaction effect of σ_{crit} (factor A) and the slenderness ratio (factor C).

Since it is desirable to have as low a CIRF as possible, the optimal settings of the factors are A+, B–, C– and E–, meaning high σ_{crit} in the interior of the tooth, low slenderness, low tooth load and low a_{cp}.

Engineering Design Method

What so far has been shown in the present paper is that it is possible to predict and analyze TIFF by applying the FEM. However, this is time consuming and not appropriate in the design stage of gear development. Therefore, an "engineering design method" (EDM) was developed and implemented in MatLab.

A design method based on superposition of elementary solutions. Two basic assumptions are assumed for the EDM. These are:

i) The critical Findley plane is assumed to be perpendicular to the center-line of the tooth.

ii) Stresses in the tooth interior are expressed using elementary solutions of elasticity theory. Normal stresses are estimated by beam theory. Shear stresses are estimated with the half-space solution combined with beam theory.

Basically, three types of superimposed stress states, acting on the pre-assumed critical plane, need to be considered. These are i) residual stresses due to case hardening ii) normal tension stresses due to bending and iii) shear stresses.

Residual stress. A beam (or rod) with varying cross-section can approximate the tooth in the residual stress estimation. In a surface layer with thickness dc_{eqv}, a constant volume expansion ε_h is prescribed. A sketch of the simplified tooth can be seen in Figure 7.

The width of the tooth is b, the height is h and the varying tooth thickness as a function of the diameter d_y is given by $s_{yn}(d_y)$. The stress in the y-direction in the interior of the tooth can be neglected. By assuming that stresses are homogenous in case and core, respectively, and combining equilibrium and Hooke's law in the x- and z-direction of the tooth, the following expression of residual stress is derived:

$$\sigma_{x,core} = \sigma_{res}(\hat{d}_y) = 2E\varepsilon_h dc_{eqv} \frac{(s_{yn}(\hat{d}_y) - 2dc_{eqv} + b)}{s_{yn}(\hat{d}_y)b(1-v)} \quad (4)$$

Equation 4 is valid at the center line of the tooth, but FE-calculation has shown that the residual stress in the x-direction of the tooth is fairly constant over a region on both sides of the center line. Therefore, Equation 4 can be taken to hold for the interior of the tooth not only at the center line.

Normal stress due to tooth load. Consider a gear tooth as in Figure 8. Here, d_{ev} is the bottom diameter of the active flank, d_a is the addendum and d_y is an arbitrary diameter. $F(d_y)$ is the total tooth force as a function of the diameter. The maximum normal stress at a point P at diameter $\hat{d}_y$ a distance $\hat{z}_b$ from the center line is given by:

$$\sigma^P_{normal} = \sigma^P_{bend} - \sigma^P_{compr} = \frac{M^{max}}{I(\hat{d}_y)} \hat{z}_b - \frac{F_N(d_y)}{b \cdot s_{yn}(d_y)} \quad (5)$$

where

$$M^{max} = \max\left\{F_T(d_y)(d_y - \hat{d}_y)\frac{1}{2}\right\} \; d_y > \hat{d}_y \quad (6)$$

Table 2. The main effects of the factors for the response $CIRF_{interior}$.

Factor	Description	Main Effect
A	σ_{crit}	–0.264
B	a_{cp} parameter	0.072
C	Slenderness ratio	0.228
D	CD	–0.049
E	Tooth force	0.189

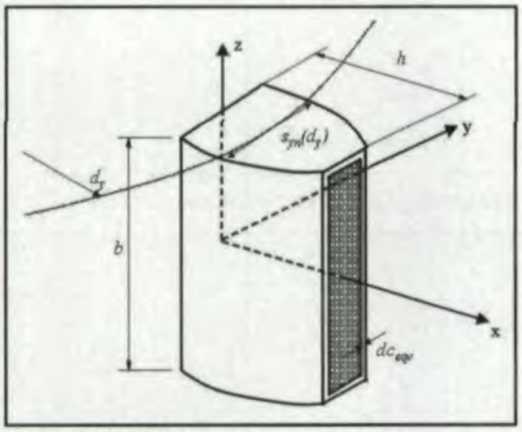

Fig. 7—Simplified tooth.

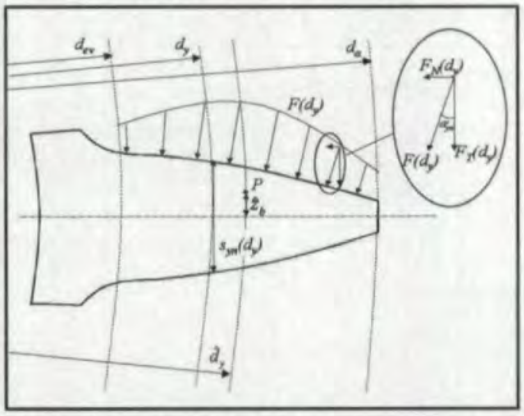

Fig. 8—Tooth load on gear tooth.

Shear stress. In estimating the shear stress amplitude at point P due to the tooth force, a pure beam analogy does not result in an acceptable estimate. The stress distribution, according to Johnson (Ref. 12), in an elastic half-space, as in Figure 9, due to a line load is given by

$$\tau_{xz}{}^{l} = -\frac{2F}{\pi b}\frac{xz^2}{(x^2+z^2)^2} \quad (7)$$

However, the half-space solution will result in stresses on the tooth boundaries (Ω_1 and Ω_2) that are not present in the real case (i.e. free surfaces are always stress free).

Since linear elasticity is assumed, superposition can be utilized and the error of the non-stress free boundaries can be compensated for. The method is to superimpose a stress state on the elastic half-space solution that eliminates the stresses at the boundaries (i.e. subtract boundary stresses). In order to simplify the computation,

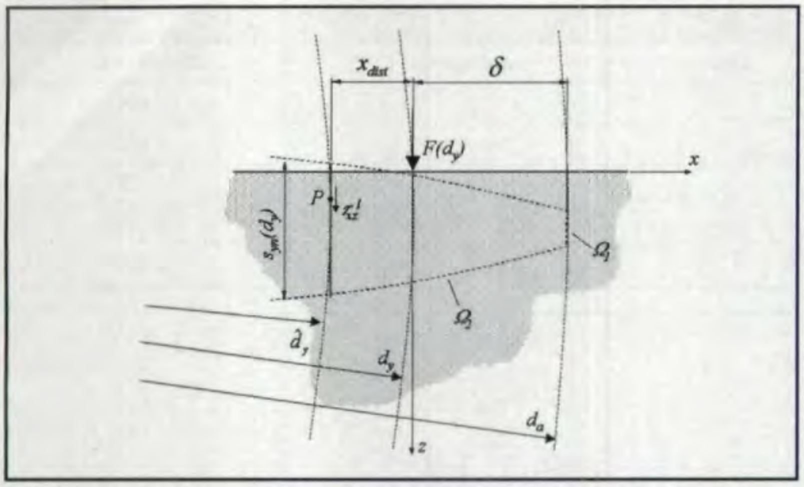

Fig. 9—Elastic half-space estimation of the contact problem in the tooth.

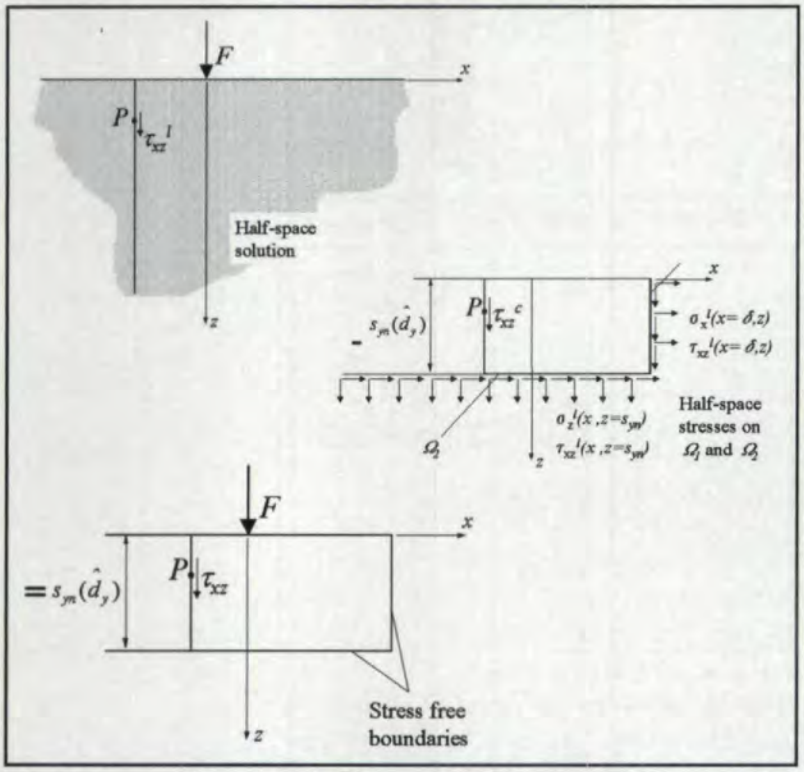

Fig. 10—Superposition of elastic half-space solution and compensating solution.

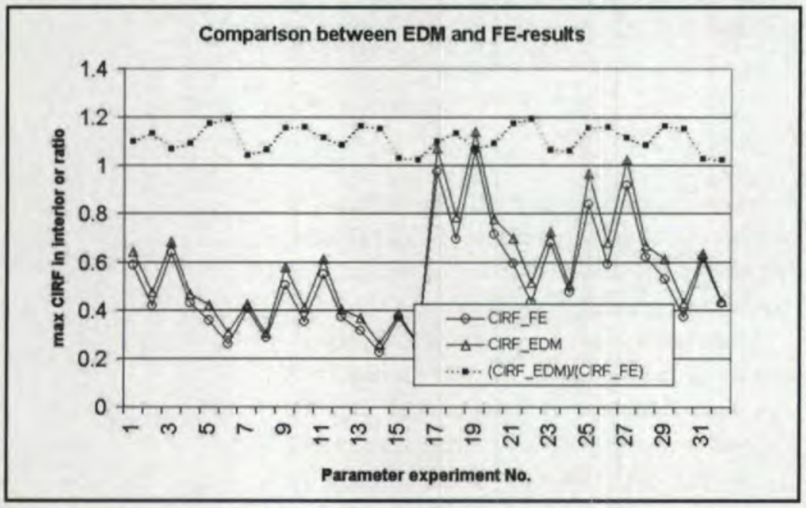

Fig. 11—Comparison of the CIRF calculated with the engineering design method and the CIRF according the FE-calculations in the parameter study.

the tapered tooth is approximated by a beam with constant thickness. The superposition technique is illustrated in Figure 10.

Consider the compensating solution (in Figure 10). The stresses on Ω_1 and Ω_2 in the compensating solution are given by the half-space solution (n Figure 10). After subtraction, stress free boundary conditions are fulfilled. The shear stress due to the line load on the half-space has been presented. The shear stress due to the compensation solution may be estimated by beam theory. The transverse force (T) on the studied plane in which point P lays is given by integrating the compensating solution along the boundaries Ω_1 and Ω_2. The latter integration should only be performed from the tooth tip to the studied plane in which P lays. The contributions to T from the two boundaries should be added to make up the transverse force. The transverse force at P is given by

$$T = T_1 + T_2 = \int_0^{s_{yn}} \tau_{xz}^{\ 1} (x = \delta, z) b dz + \int_{-x_{dist}}^{\delta} \sigma_z^{\ 1} (x, z = s_{yn}) b dx = \ldots =$$

$$= \frac{F}{\pi} \left[\frac{x_{dist}\, s_{yn}(\hat{d}_y)}{(x_{dist}^{\ 2} + s_{yn}(\hat{d}_y)^2)} - \arctan\left(\frac{s_{yn}(\hat{d}_y)}{x_{dist}} \right) \right] \tag{8}$$

where $x_{dist} = (d_y - \hat{d}_y)/2$ and $\delta = (d_a - d_y)/2$. The shear stress due to the compensating solution, estimated as bending shear stress due to the transverse force T, is then given by

$$\tau_{xz}^{\ c} = \frac{TS(\hat{z}_b)}{I(\hat{d}_y)b} \tag{9}$$

where $S(\hat{z}b)$ is the static moment given by

$$S(z_b) = \int_{\hat{z}_b}^{s_n(\hat{d}_y)/2} z_b b dz_b = b\left(\frac{S_{yn}(\hat{d}_y)}{2} - \hat{z}_b\right)\left(\frac{S_{yn}(\hat{d}_y)}{2} + \hat{z}_b\right)\frac{1}{2} \tag{10}$$

However, it should be noted that the compensating shear stress should only be subtracted if the tooth force is positioned outside the studied plane (i.e. $d_y > \hat{d}_y$). The resulting shear stress at point P in a plane at $\hat{d}_y$ is thus given by

$$\tau_{xz}^{\ P} = \tau_{xz}^{\ 1} - \theta(d_y - \hat{d})\, \tau_{xz}^{\ c} \tag{11}$$

where θ is the Heaviside's step function. However, in the Findley critical plane criterion, it is the shear stress amplitude rather than the shear stress itself that is used. Therefore, the maximum and minimum shear stress at each point is sought. It is not obvious when during the load cycle the maximum and the minimum occurs, respectively. By implementing the derived expressions in a computer program (here MatLab is used), it is possible to determine the maximum and minimum shear stress at all points in the tooth interior, and the shear stress amplitude can be formed by

$$\tau_a^{\ P} = \frac{\max\{\tau_{xy}^{\ P}\}_{loadcycle} - \min\{\tau_{xy}^{\ P}\}_{loadcycle}}{2} \quad (12)$$

Findley stress. The total stress in the radial direction of the tooth (or in the x-direction as in Figure 7) is the sum of the residual stress and the bending stress. Consequently, the Findley critical plane stress can estimated by

$$\bar{\sigma}_F^{\ P} = \tau_a^{\ P} + a_{cp,core}\,(\sigma_{res} + \sigma^P_{\ normal}) \quad (13)$$

The bar over the σ_F indicates that this is the EDM approximation of the Findley stress. By scanning through all plane diameters and all distances from the center line, the point in the interior of the tooth with maximum Findley stress can be determined.

Comparison with FEM results

The total tooth force as a function of contact force diameter is determined by the gear computation program LDP (Ref. 8). $F(d_y)$ is then approximated by a fourth-order, least-square fit to the calculated tooth force.

In order to verify the engineering design method, a comparison with an FE-analysis was conducted. Since an evaluation of the CIRF for different gear geometries is already made in the parameter study, it is possible to make a comparison for different geometries and parameter combinations. The previously conducted FE-analysis has shown that the area in the interior of the tooth with the highest Findley stresses is close to the case-core boundary (i.e. at depth CD). In the analysis, dc_{eqv} = 1.2 mm and ε_h = 0.000833 are used. In Figure 11, a comparison of the CIRF calculated with the engineering design method (CIRF_EDM) and the CIRF according the FE-computations (CIRF_FE) in the parameter study is shown.

It is clear from Figure 11 that the overall correlation between the CIRF calculated by the EDM and by FEM is good. It is noticed that the EDM overestimates the CIRF. The average discrepancy for all 32 investigated parameter configurations is 11% and never greater than 20%.

Discussion

The FE-analysis showed that the hypothesis of TIFF presented in this paper was strengthened. The parameter study surprisingly showed that the risk of TIFF was decreased as the carburizing depth was increased. This unexpected relation can be understood if the bending stress in the tooth is considered. The FE-analyses show that the region in the tooth with the highest CIRF is in the case-core boundary. Also, when the carburizing depth is low, the layer with the compressive stresses is thin and hence, the bending stress in the case-core boundary is greater due to the greater distance from the center line. The conclusion is that the effect of the bending stress is greater than the effect of the residual tensile stress in the interior of the tooth.

The parameter study also showed that the two factors having the greatest influence on the risk of TIFF are σ_{crit} in the interior of the tooth and the slenderness ratio. This highlights a new problem when it comes to gear design. When optimizing gears for noise, usually the slenderness ratio is increased, since slender gears allow higher contact ratio and potentially more silent gears. Therefore, TIFF has to be considered as a possible failure mode in future gear design.

Conclusions

In this work, the gear tooth failure mode TIFF is described and analyzed. In the analysis, FE-computations are utilized in conjunction with the Findley critical plane initiation criterion in order to predict crack initiation. It is shown that the TIFF cracks are initiated in the interior of the tooth. Other results are:

- The region where the interior crack will initiate is located approximately mid-height of the tooth and slightly below the case-core boundary.
- TIFF is a possibility at loads lower than the load where tooth root bending fatigue is achieved and at loads higher than the load where contact fatigue occurs.
- By using the gear wheel as an idler instead of as a single stage gear, the risk of TIFF is increased by 20%.

A parameter study was conducted in order to investigate which geometric and material parameters influenced the risk of TIFF. The parameter study was performed as a factorial design. The key results from the study are:

- The parameters influencing the risk of TIFF mostly are σ_{crit} in the interior, the slenderness ratio and the tooth load. The lower the σ_{crit}, the more slender the tooth and the higher the load, the greater the risk of TIFF.
- The influence from the a_{cp} parameter in the interior is small but positive, meaning the higher the a_{cp}, the greater the risk of TIFF.
- The influence of the carburizing depth on TIFF

Appendix—Gear data for gears in the factorial design.

The gear data of the two gear designs in the factorial design are given in the table below. For comparison, the gear data of the original design of the gear is given in Table 3. A sketch of the different gear designs is given in Figure 5. In Table 4, the crack initiation risk factors are presented as they were computed by FEM in the 32 experiments in the factorial design.

Table 3. Gear data of the slender (left) and not-slender (right) geometry compared with the geometry of the original tooth (middle).

	Slender gear design		Original gear design		Not-slender gear design	
	Pinion	Wheel	Pinion	Wheel	Pinion	Wheel
Modulus (mm)	2.34		3.06		3.75	
Pressure angle (°)	17.5		20		22.5	
Helix angle (°)	15		15		15	
Tooth width (mm)	43	35	43	35	43	35
Center distance (mm)	166.5		166.5		166.5	
Number of teeth	45	93	34	70	27	56
Addendum modification coefficient	0.270	–0.669	0.265	0.250	0.600	0.895
Diameter of addendum (mm)	116.5	230.6	116.5	230.6	116.5	230.6
Protuberance (mm)	0.060	0.095	0.060	0.060	0.60	0.060
Addendum for tool (mm)	4.850	3.900	4.350	4.350	4.350	4.800
Protuberance angle (°)	5.044	8.342	3.045	3.045	4.308	3.786
Radius of addendum for tool (mm)	0.45	0.85	1.20	1.20	1.75	1.45
Ratio	2.067		2.059		2.074	

Table 4. Crack initiation risk factors (CIRF) at the root and the interior of the tooth as they were computed by FEM in the factorial design.

Experiment	$CIRF_{root}$	$CIRF_{interior}$
1	0.757	0.586
2	0.449	0.417
3	0.752	0.640
4	0.437	0.429
5	0.206	0.358
6	0.105	0.259
7	0.203	0.408
8	0.100	0.285
9	0.757	0.503
10	0.449	0.353
11	0.748	0.550
12	0.437	0.372
13	0.206	0.317
14	0.105	0.224
15	0.203	0.371
16	0.100	0.257
17	0.720	0.976
18	0.380	0.695
19	0.780	1.066
20	0.390	0.715
21	0.206	0.596
22	0.105	0.432
23	0.203	0.681
24	0.100	0.476
25	0.690	0.839
26	0.430	0.589
27	0.750	0.917
28	0.430	0.620
29	0.206	0.529
30	0.105	0.373
31	0.203	0.619
32	0.100	0.428

is small, and the risk of TIFF is lower for a high carburizing depth than for a low carburizing depth.

An engineering design method (EDM) for design against TIFF was developed, implemented in MatLab and compared with the FE-calculations in the parameter study. The following results were found:

• It is possible to estimate the risk of TIFF by the EDM very quickly and with acceptable accuracy.

• The EDM overestimates the CIRF in the interior of the tooth compared to the FE-result by an average of 11%.

Acknowledgements

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CIRCLE 109

Failures of Bevel-Helical Gear Units on Traveling Bridge Cranes

J. M. Escanaverino

Introduction

Bridge cranes are among the most useful machines in many branches of modern industry. Using standard hooks or other specialized clamping devices, they can lift, transport, discharge, and stack a variety of loads.

Gear technology progress has always been influential to advances in bridge crane design, allowing lighter and more productive cranes. Many bevel-helical gear units are employed in the traveling drives of big industrial bridge cranes, as they form compact packages with couplings, brakes and electric motors that other gear units do not allow for.

A sketch of a typical individual wheel traveling drive is shown in Figure 1, with the electric prime mover (a) and the gear unit (b), with a usual hollow low-speed shaft (c). The gear unit is mounted on a floating base (d), common with the prime mover. All the aggregate pivots are on the low-speed shaft, which is vertically fixed at the other end to the crane framework by means of elastic blocks (e). The flexible coupling between the prime mover main shaft and the gear unit is a high-speed shaft that is usually combined with a drum brake (f).

In a number of cranes, frequent failures of travel bevel gears pose a difficult problem for maintenance. Open discussions have raised questions about the necessary service or application factor to avoid such failures and the associated downtime. Recommendations found in prestigious sources give application factor values from as low as 1.1 to as high as 3.0. In many gear unit catalogs, the crane traveling drive selection refers to the manufacturer, giving no other guidance to crane designers or plant maintenance engineers.

This paper focuses on the origin of the troubles experienced with the standard, general purpose bevel-helical gear units used in the traveling drives of medium and large size bridge cranes, according to the author's theoretical research and practical experience.

Nature of the Failures

Failures of crane traveling drives are usually of a catastrophic character, with the sudden fracture of one or several teeth in the bevel gear, ordinarily in the high-speed stage in the gear unit.

The above-mentioned failures are very difficult to anticipate, because time between failures (Ref. 2) behaves chaotically. Sometimes the gear works well for a relatively long period, in the order of several weeks, and sometimes the gear breaks down after a few minutes of work.

Such an irregular pattern of failure is usually associated with mechanical resonance. But even a detailed analysis of the bevel gear vibration behavior in crane bridge traveling gear units generally shows no resonance at all in the gear mesh. This fact may be highly misleading to an engineering researcher trying to find the origin of the above-mentioned troubles.

However, the bevel gear mesh is not the sole elastoinertial system related to the high-speed stage of the gear unit. Most important, according to our findings, is the elastoinertial system comprised of gear unit's high-speed shaft and half-coupling, including the brake drum (Fig. 2). For the sake of brevity, the elastoinertial system con-

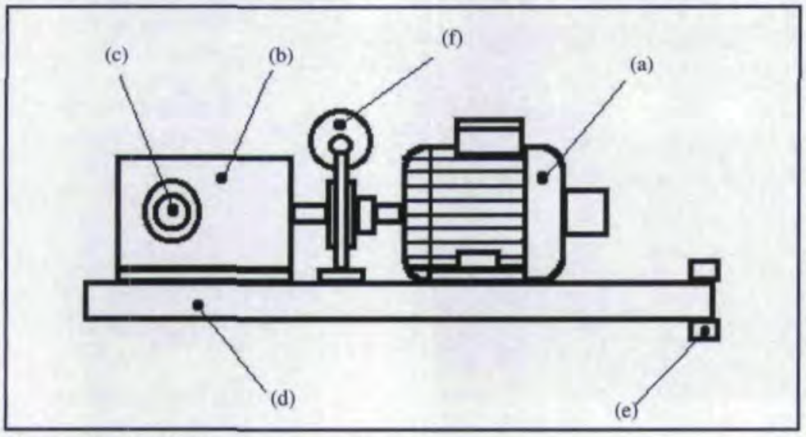

Fig. 1—Typical bridge crane traveling drive.

stituted by the gear unit's high-speed shaft and half-coupling with brake drum is referred to from now on as the shaft/coupling system.

In fact, almost all of the torsional elastic compliances of the shaft/coupling system belong to the shaft. This is because of the much bigger diameter and shorter axial length of the half-coupling and its attached brake drum. Therefore, it can be easily shown that

$$c_s = c_{sh} + c_{hc} \approx c_{sh} \qquad (1)$$

Where

c_{sh} is the shaft's elastic compliance.

c_{hc} is the half-coupling's elastic compliance.

All elastic compliances in (1) and after are given in rad/(N·m), according to the International System of units, SI.

On the other hand, almost all of the moments of inertia of the shaft/coupling system relative to its rotational axis belong to the half-coupling and its attached brake drum. This is due to the very small diameter of the shaft as compared with the brake drum. Therefore, it can be easily shown that

$$I_s = I_{sh} + I_{hc} \approx I_{hc} \qquad (2)$$

Where

I_{sh} is the shaft's moment of inertia.

I_{hc} is the half-coupling's moment of inertia.

All moments of inertia in (2) and after are given in kg·m^2, according to the International System of units, SI.

Being an elastoinertial system with almost lumped (concentrated) parameters, including only one elastic element and only one inertial element, the main proper frequency f_E of the shaft/coupling system can be assessed by the well-known expression

$$f_E = \frac{1}{2\pi}\sqrt{\frac{1}{c_s I_s}} \qquad (3)$$

Proper frequency in (3) and after is given in Hz, according to the International System of units, SI.

The resistive torque at the gear unit's high-speed pinion (Fig. 2) has a pulsation with a frequency equal to the mesh frequency of the high speed gear, given by the relation

$$f_z = n_m z_p \qquad (4)$$

Where

n_m is prime mover's rotational frequency.

z_p is high speed pinion's number of teeth.

Both mesh and rotational frequencies in (4) and after are given in Hz, according to the International System of units, SI. Meanwhile, the number of teeth is considered non-dimensional.

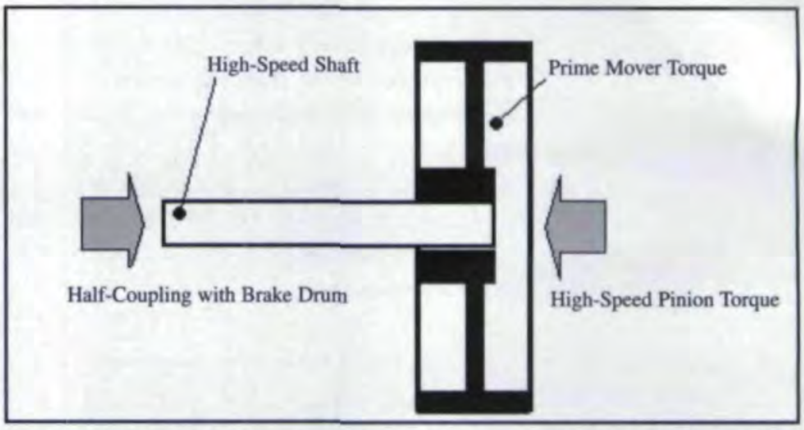

Fig. 2—Elastoinertial system comprised of a high-speed shaft and half-coupling.

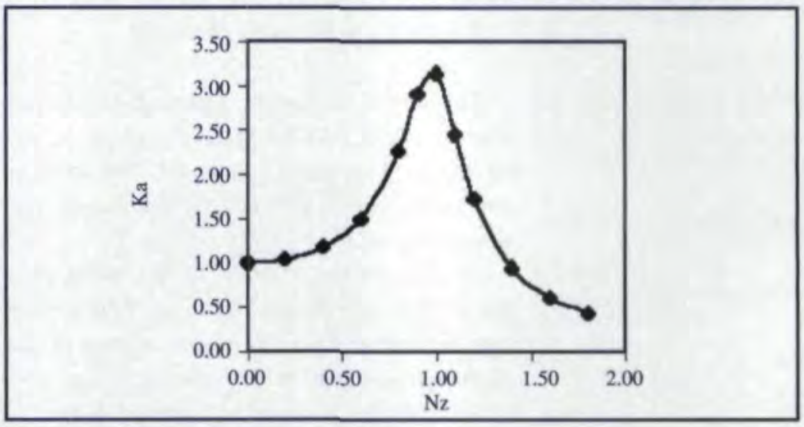

Fig. 3—Application factor for a bevel gear.

Under the excitation of the pulsating pinion torque, the shaft/coupling system develops torsional vibrations, which are superimposed on the otherwise smooth velocity profile of the gear unit high-speed shaft. The severity of such torsional vibrations is higher when the mesh frequency of the bevel gear approaches the proper frequency of the shaft/coupling system.

The degree of mutual approach of the above mentioned frequencies governing the vibratory process can be quantified by the tuning factor, given by the relation

$$N_z = \frac{f_z}{f_E} \qquad (5)$$

The tuning factor in (5) and after is a non-dimensional quantity, as long as both frequencies are given in the same units.

According to widely recognized practice (Refs. 3, 6), an elastoinertial system is in a state of resonance if

$$0.85 \le N_z \le 1.15 \qquad (6)$$

As the traveling drive operates under variable speed, the tuning factor of the shaft/coupling system sweeps a range of values. According to the commands given by the crane operator, the tuning factor stays stochastically in one or another value

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during a certain time.

If enough time is spent under condition (6), the amplitude of the pulsating torque can reach high values. Such high values can develop low cycle volumetric fatigue damage on the teeth of the bevel gear, leading to its quick fracture.

The overload imposed by the resonance effect can be expressed (Refs. 2, 3, 5) by means of an application factor

$$K_A = \frac{1}{\sqrt{(1 - N_z^2)^2 + \left[\frac{\beta N_z}{I_s f_E}\right]}} \quad (7)$$

Where

β is the factor of viscous damping.

The factor of viscous damping in (7) and after is given in (N·m)/Hz, according to the International System of units, SI. The application factor, as it is well known, is a non-dimensional magnitude.

There is a moderate degree of viscous damping due to oil film in the gear mesh and rolling bearings, as well as from the internal friction of the elastomeric element in the coupling. Therefore, critical damping in the shaft/coupling system is assumed. Such condition is the limit between light and heavy viscous damping. Critical damping is present when relation (8) holds

$$\frac{\beta}{I_s f_E} = \frac{1}{\pi} \quad (8)$$

The values of the application factor K_A under the assumption (8) are plotted as a function of the tuning factor in Figure 3. It is interesting to note that when the tuning factor equals unity, the application factor reaches its maximum value

$$K_{A\,max} = 3.14 \quad (9)$$

That is, the torque transmitted by the bevel pair of the gear unit can reach a value more than triple the nominal, enough to fracture its teeth if no ample strength has been left.

In conformity with this result, the service factor of 3.0 according to AGMA 6010-F97 (Ref. 1) appears adequate even when resonance is present. Therefore, to dimension a bridge traveling gear unit for a bulletproof quick design, or for an emergency overhaul, a service factor with the value of 3.0 could be used, but obviously at a cost.

On the Influence of Motor Controllers

Many of the failures in the high-speed bevel gears of crane bridge traveling drives appeared after the advent of the solid-state variable speed controllers for the electric prime movers. These controllers yield an almost constant torque at the prime mover main shaft during the starting period, suppressing the strong saw-tooth torque ripple characteristic of the prime movers under the older magnetic controllers.

Apparently, a number of crane designers shortly after being acquainted with the new high-technology motor controllers, began to discard the old hydrodynamic clutches (the so-called hydraulic couplings) from the traveling drives of new design as an unnecessary piece of hardware. Consequently, the connection between prime mover and gear unit was effected by means of a simple flexible coupling, normally combined with a drum brake.

However, no flexible coupling has the strong viscous damping characteristic of hydrodynamic clutches, which do not allow for high values of resonance loads. Let the increase in viscous damping of the elastoinertial system due to the introduction of a hydrodynamic clutch be estimated conservatively as twofold. Then, as Figure 4 shows, the maximum value of the corresponding application factor will be under 1.7.

This result can justify the service factors from 1.5 to 2.0 given by certain manufacturers for bridge travel gear units, presupposing the use of hydraulic clutches. However, many times very similar values are recommended without any other necessary condition.

Therefore, to avoid unexpected problems, it is suggested that the replacement of hydraulic clutches with ordinary flexible couplings in drives with modern motor controllers should be

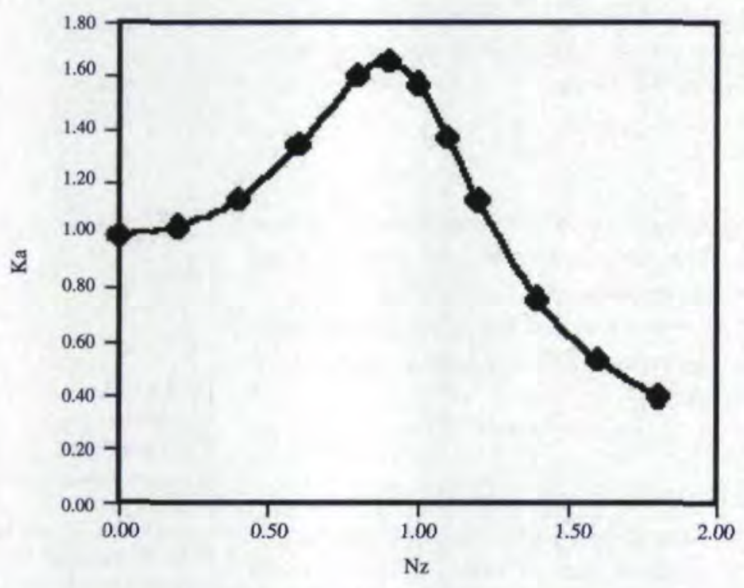

Fig. 4—Application factor for a bevel gear with a hydrodynamic clutch.

undertaken only after a dynamic analysis of the shaft/coupling system.

Suggestions to Manufacturers

AGMA standards point to the application engineer as responsible for an overall system design that avoids operation at resonance. Nevertheless, gear unit manufacturers can also take some basic measures to avoid near resonance operation of speed reducers equipped with standard drum brakes that are typical of crane traveling bridge drives.

There are two complementary characteristics in a non resonant-prone gear unit for crane travel drives: Minimum elastic compliance of the pinion shaft and minimum mesh frequency of the bevel gear.

Both characteristics tend to decrease the value of the application factor as given by (7). A shorter and oversize diameter high-speed shaft, allowed by an improved bearing design, seems to be a practical way to attain the first characteristic. A high-speed pinion with a smaller number of teeth, allowed by a special design of the bevel gear, seems to achieve the second characteristic.

Solutions for Existing Systems

On the user side, the installation of new gear units with a 3.0 service factor may be too costly and beyond the possibilities of existing travel drive systems without a major overhaul. However, there are three complementary modifications that can be done to an existing crane travel drive to improve its resonance behavior:

1. Minimize the compliance of the pinion shaft.
2. Minimize the mesh frequency of the bevel gear.
3. Minimize the moment of inertia of the high-speed shaft half-coupling.

All three modifications tend to decrease the value of the application factor as given by (7). The first and second modifications can be achieved by the same ways suggested in the former section, at only a fraction of the cost of a new gear unit. To minimize the moment of inertia of the shaft/coupling system, a simple solution is to invert the flexible coupling, as shown in Figure 5. This way, the high-speed shaft of the gear unit receives the smaller half-coupling (a), with a minimum moment of inertia, as it lacks the brake drum (b).

A Practical Example

A major industrial enterprise in South America has two special-purpose traveling bridge cranes, each with a total mass of 165 tons, working around-the-clock in a pit-furnace building. The bridge traveling drives for the individual motoring wheels of each crane were composed as follows:

Table 1—Dynamic data of the original drives.

Parameter	Value
c_s	$2.11 \cdot 10^{-5}$ rad/(N·m)
I_s	$3.77 \cdot 10^{-2}$ kg·m^2
f_E	178 Hz
n_m	from 0 to 20 Hz
z_p	11
f_z	from 0 to 220 Hz
N_z	from 0 to 1.24
K_A	from 1 to 3.14

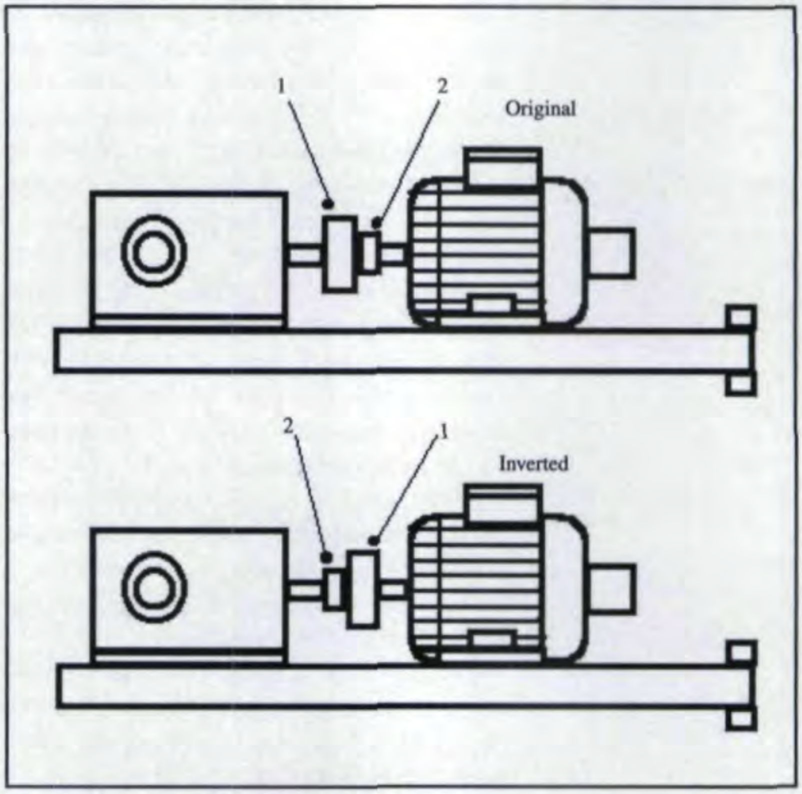

Fig. 5—Inversion of flexible coupling.

1. A slip ring AC induction electric motor with a nominal power of 25 kW at a rotational frequency of 19 Hz (1,140 min-1), under an operating regime S3 25%.
2. A solid-state electronic controller for the electric motor, which regulates speed and torque through stator tension and rotor resistance.
3. A bevel-helical three-stage gear unit, with a nominal ratio of 1:71, and a main stage center distance of 200 mm.
4. A flexible coupling between motor and gear unit combined with a drum brake. The gear unit half-coupling carried the brake drum.

The crane designers selected these gear units using a service factor of 1.5, as proposed in the

Table 2—Dynamic data of the modified drives.	
Parameter	**Value**
c_s	$1.44 \cdot 10^{-5}$ rad/(N·m)
I_s	$7.54 \cdot 10^{-3}$ kg·m^2
f_E	483 Hz
n_m	from 0 to 20 Hz
z_p	9
f_z	from 0 to 180 Hz
N_z	from 0 to 0.373
K_A	from 1 to 1.15

technical catalog of the manufacturer. However, just a few weeks after plant start-up, there were serious troubles with broken teeth in the high-speed stages of the gear units. Time between failures ranged stochastically from 15 days to 15 minutes. It made no difference if spare parts came from the original equipment manufacturer or from other sources.

After a series of attempts by different experts, the problem remained unsolved. The crane manufacturer proposed new gear units sized according to a 3.0 service factor. The author was subsequently called-in by the company as an independent advisor.

Under author's counsel, in-depth research into the dynamics of the original drives was performed. The most important results are given in Table 1. The methods and techniques used in this research are described above.

As can be seen in Table 1, the shaft/coupling system of the original gear units operated well deep in the conventional resonance zone, which covered no more than 24% of all the operating range of travel speeds. Consequently, the bevel gear received strong loads, up to 3.14 times the nominal, according to an unpredictable program that led to tooth fractures after a short period of time. The solution had a five-point strategy as follows:

1. A new bevel gear pair was designed and manufactured, with fewer teeth in the pinion, to lower the mesh frequency.
2. An optimum pinion design allowed a bigger diameter shaft to increase the system's proper frequency.
3. The brake drum was transferred to the motor shaft to increase the system's proper frequency.
4. The new bevel gear pair design was optimized for durability and strength (Refs. 4, 5, 7) using the same materials and within the same space.
5. A stronger taper roller bearing support for the high-speed pinion was devised to fit the same gear unit case without any change.

The dynamic data of the modified shaft/coupling system are found in Table 2, which shows that due to the reduction of the mesh frequency and the sharp elevation of the proper frequency, the tuning factor now covers a much smaller range. Therefore, the maximum value of the application factor has fallen to only 1.15.

Thanks to the reengineered high-speed state, the former high rate of bevel gear failures went to zero. This was accomplished at 20% of the cost of new, bigger gear units sized to operate with a 3.0 service factor. Now, after four years of field experience, the solution has proved its effectiveness. ○

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Gleason Technical Support Center, Novi, MI

Gleason Opens New Tech Support Center

Gleason Corporation has announced the opening of its new technical support center at 46850 Magellan Drive, Novi, Michigan. This facility will bring an array of gear manufacturing support services to customers in the Michigan and Western Ohio regions.

The new facility places many gear manufacturing solutions and services in close proximity to the important Detroit marketplace, and helps ensure that Gleason's customers will receive fast, hands-on responses to their needs. Gleason customers will have increased local access to comprehensive training resources; process and application engineering support; tool management including, in some areas, pick-up and delivery; spare parts inventories and on-site service personnel to help reduce repair and maintenance downtime.

West Industries Becomes United Gear and Assembly Inc.

On September 1, 2000, West Industries of Hudson, Wisconsin, a United Stars Company, became United Gear & Assembly Inc. (UGA), a world-class manufacturer of gears, shafts, assemblies and heat-treating operations. The company reputation was built on their responsiveness to customers, satisfying customer requirements and working successfully within narrow shipping windows. UGA meets specific market conditions by utilizing techniques that respond to customer orders with zero rejects and zero turn-around.

UGA has added new facility improvements and services available from a single source. With the ability and experience for additional value-added processes, UGA is committed to continuous improvement with their manufacturing system and with customers' parts and components. UGA offers a totally integrated supply source, including engineering, machining, heat-treating, plating, assembly and a quality assurance structure demanded by the marketplace.

Emerson Consolidates Gearing Brands Under EPT Operations

Emerson Power Transmission (EPT), of Ithaca, New York, has completed the consolidation of Emerson's gearing brands under the EPT organization. Effective September 1, 2000, EPT adds the US Gearmotor brand of gearing products to its already extensive gearing portfolio. Other brands include: Browning brand helical, bevel and planetary speed reducers and gearmotors, and Morse brand worm gear reducers and miter boxes.

According to Bill Boggess, vice president of strategic planning for EPT, "This will enable the US Motors organization to focus all its efforts on electric motors, and EPT to focus on all gearing and other power transmission products. Additionally, it enables Emerson to provide an enhanced support team to serve all of our gearing customers more efficiently."

National Broach & Machine Becomes Nachi Machining Technology

National Broach and Machine Co., the manufacturer of Red Ring® products, a world leader in broaching, gear manufacturing, roll forming equipment and tooling, is changing its name to Nachi Machining Technology Co. The Red Ring® trademark will be retained.

Nachi has worldwide manufacturing facilities and service support offices with over 6,800 employees. Beside broach and gear manufacturing tools and equipment, Nachi is also known for the manufacture of specialty steels, cutting tools, robotics, hydraulics, bearings, heat treatment equipment and specialty machines.

National Broach and Machine Co. has been a part of the Nachi family since 1991. Together, Nachi and National Broach and Machine share over 140 years of processing experience for customer broach and gear manufacturing needs around the world.

New Managing Director for Sumitomo Cyclo Europe

Worldwide power transmission specialist Sumitomo Heavy Industries has appointed Mike McCann as managing director at its European subsidiary, *Sumitomo Cyclo Europe*. The move is notable because it is the first time a European has taken full control since the Japanese gear giant bought the company from its former German owners in 1993.

McCann originally joined the company in 1998 as sales and marketing director, moving from UK competitor, David Brown Radicon. He takes over from Fuminori "Frank" Miyoshi, who is returning to Japan to take a senior position in Tokyo after seven successful years in Europe and six years previous to that with their American sister company in Chesapeake, Virginia.

Odds and Ends

ASI Machinery Company has been named the exclusive sales rep for Korean hobber manufacturer, Jeil Heavy Industries. • Steve K. Peterson is the new Vice President of Sales, Midwest Region, for SU America, Inc. • Arté Corporation has announced a joint venture with NN Inc. to manufacture plastic gears and components for office automation equipment and industrial applications in Guadalajara, Mexico. • Multi-Arc and Bernex are coming together under one name: IonBond, Inc., which will be a provider of PVD and CVD coating services and equipment.

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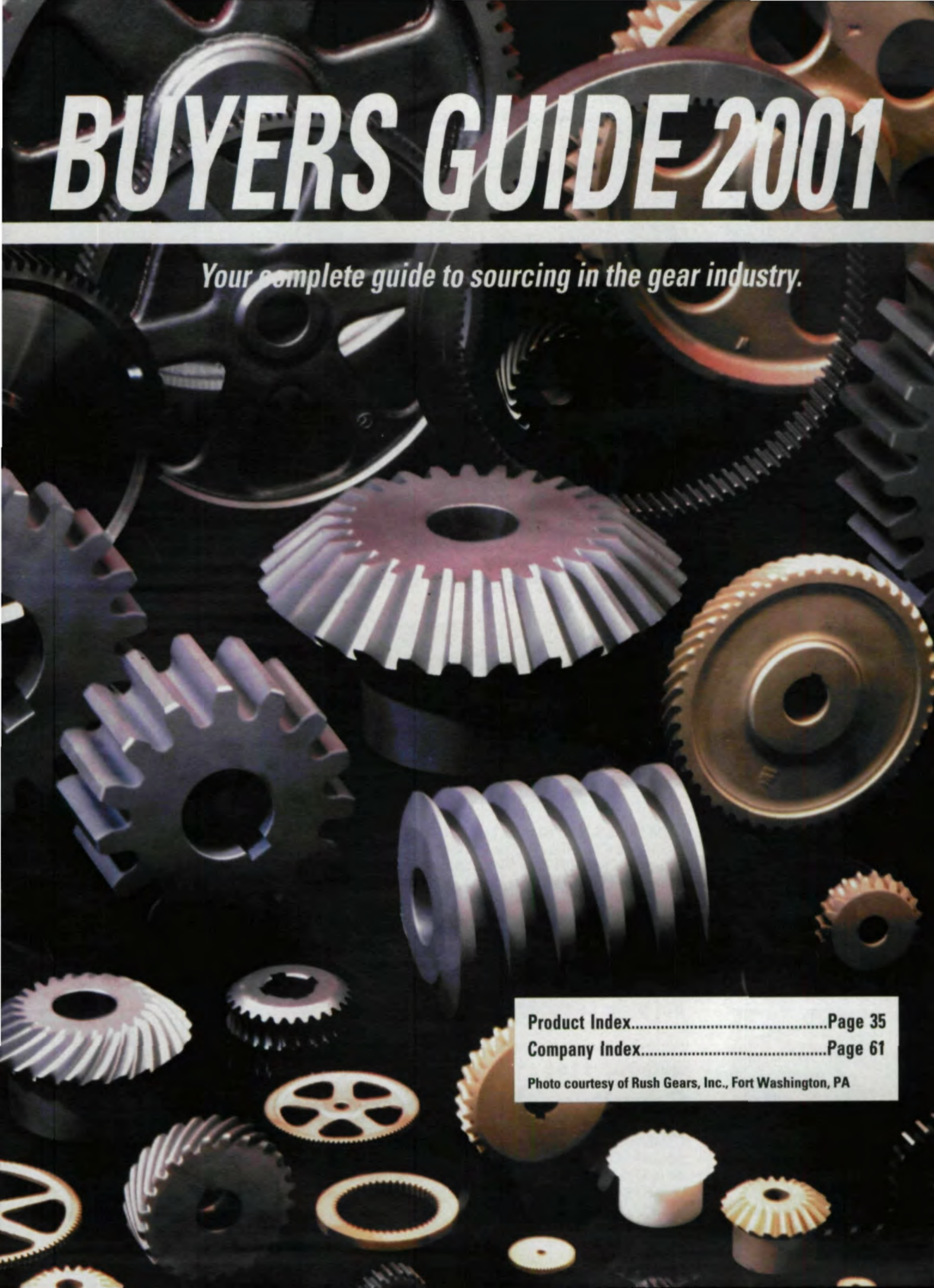

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Mitsui Machine Technology
Nachi Machining Technology Co.
Reishauer Corporation Sales Consultants
SU America
WMW Machinery

Honing Machines

Basic Incorporated Group
Bates Technologies
Belden Machine Corp.
Bluegrass Precision Machinery
Fässler Corp.
The Gleason Works
Great Lakes Gear Technologies
GTI Technologies
Kapp Technologies
Liebherr Gear Technology Co.
Micromatic Textron
Nachi Machining Technology Co.
Reishauer Corporation
Sidley Diamond Tool
SU America
Sunnen Products Co.

Inspection Machines

Alpha Precision Inc.
American Machinery & Engineering
ASI Machinery Co.
Basic Incorporated Group
Bluegrass Machinery
Cole Mfg. Systems, Inc.
Crown Powertrain
D.I.G.I.T., Inc.
Dyer Company
Fellows Corp.
FGT Gage & Systems

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PRODUCTS & SERVICES INDEX

Thread, Worm and Flute Milling Machines

Other Gear Manufacturing Machines

NON-GEAR MACHINES

Cutter Inspection/Setting Machines

Cutting Tool Sharpening Machines
American Broach & Machine Co.
American Machinery & Engineering
B.H. Jones Machine & Gage
Basic Incorporated Group
Colonial Saw Co.
The Gleason Works
Huffman Corporation
Interstate Tool Corp.
Klingelnberg Söhne
Mitsui Machine Technology
Mitts & Merrill L.P.
Oliver Instrument Co.
Russell, Holbrook & Henderson, Inc.
Star Cutter Co.
SU America

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

Form Grinders
American Machinery & Engineering
Eltech Inc.
The Gleason Works
Huffman Corp.
Kapp Technologies
Liebherr Gear Technology Co.
Oerlikon Geartec AG
SU America

Heat Treating Equipment
AFC-Holcroft L.L.C.
Ajax Magnethermic
ALD Vacuum Technologies
Basic Incorporated Group
Bluegrass Precision Machinery
Can-Eng Furnaces Ltd.
Capital Induction
Contour Hardening
ECM (USA) Inc.
Engineered Heat Treat
Fluxtrol Manufacturing
The Grieve Corp.
Inductoheat Inc.
K.H. Huppert Co.
Klingelnberg Söhne
Kowalski Heat Treating
Laser Machining Inc.
Lepel Corporation
McEnglevan Industrial Furnace
Midwest Thermal-Vac
Nachi Machining Technology Co.
Pacific Industrial Furnace
Pillar Industries
Quench Press Specialists
Radyne Corporation
Surface Combustion
TOCCO Inc.
Therm Alliance Co.
V.T.M. Co. Ltd.

Lasers
B.H. Jones Machine & Gage
D.I.G.I.T., Inc.
Huffman Corp.
Laser Machining Inc.
Process Equipment

Quenching Presses
American Machinery & Engineering
Klingelnberg Söhne
Kowalski Heat Treating Company
Liebherr Gear Technology Co.
Quench Press Specialists
Wabash MPI

Thread Grinders
American Machinery & Engineering
B.H. Jones Machine & Gage
Eltech Inc.
Great Lakes Gear Technologies
Holroyd
Huffman Corp.
Kapp Technologies
Klingelnberg Söhne
Leistritz
Liebherr Gear Technology Co.
Normac, Inc.
Reishauer Corp.
SU America

Tool & Cutter Grinders
Able Tooling
American Broach & Machine Co.
American Machinery & Engineering
B.H. Jones Machine & Gage
Eltech Inc.
The Gleason Works
Great Lakes Gear Technologies
Huffman Corp.
Klingelnberg Söhne
Liebherr Gear Technology Co.
Nachi Machining Technology Co.
Oerlikon Geartec AG
Oliver Instrument Co.
Star Cutter Co.
SU America
Wilton Machinery

Turning Machines
American Machinery
Bluegrass Precision Machinery
Eltech Inc.
Hermes Machine Tool
Miller Industrial Service
Sytec Corporation
WMW Machinery

Other Non-Gear Machines Tools
American Broach & Machine Co.—*CNC Broach Sharpeners*
American Machinery & Engineering—*Hob Sharpeners, Broach Grinders, Milling Machines*
Belden Machine Corporation—*Multi-spindle Drill Tap, Work Cells*
Bourn & Koch Machine Tool Co.—*Machining Centers*
COLDfire Chicago—

Cryogenic Treating Equipment
Eltech Inc. —*Boring Mills, Internal Grinders, OD Grinders, Milling Machines*
General Broach & Engineering—*Vertical Spline Rollers*
The Grieve Corporation—*Industrial Ovens*
Jamal Gear Machinery Ltd. —*Grinding Wheel Dressing Machines*
Huffman Corp.—*Abrasive Waterjet Machines*
Richel Inc.—*Abrasive Waterjet Machines*
Star Cutter Co. — *Broach Sharpeners*

GEAR MATERIALS

Bar Stock

Bunting Bearings Corp.
Charles E. Larson & Sons
Dura-Bar
Lovejoy Steel
Steel Industries, Inc.

Cast Iron

Advanced Cast Products
Dura-Bar
Ferry-Capitain Industries, LLC
Lovejoy Steel
Qualicast Corp.
Sales Consultants
Scot Forge
Wes-Tex Gear Inc.
Zhuhai Intercontinental Pulleys Ltd.

Gear Blanks

Able Tooling
Accurate Specialties
Adobe Precision Gear
Advanced Cast Products
Ann Arbor Machine
Arrow Gear Company
Bean Tool, Die & Engineering
Bengal Industries
Blanchat Machine Co.
Bunting Bearings Corp.
Cornell Forge Co.
Dabko Industries Inc.
Dura-Bar
East Point Foundry
Edgewater Steel Ltd.
Elmass North America
Ferry-Capitain Industries, LLC
Fisher's Gear & Machine Inc.
The Gear Works-Seattle
Gerhardt Gear Company Inc.
Horsburgh & Scott
Howard's Machine Shop
Lufkin Industries Gear Repair
McInnes
Milford Gear Works
Miller Centrifugal Casting Co.
Mobile Pulley & Machine
Moore-Addison
Nordex, Inc.
Orlandi Gear Co.
Penntech
PIC Design
Presrite Corp.
Process Industries
Pulley Manufacturers
Qualicast Corp.
Sales Consultants
Sinochem Jiangsu Wuxi
Spicer Industries Inc.
Steel Industries, Inc.
Trogetec Inc.
Union Gear & Sprocket
Wes-Tex Gear Inc.
Wiscon Products, Inc.
Wohlert Corporation
Worrall Grinding Co.

Plastics

Adobe Precision Gear
Arrow Gear Co.
Bengal Industries
The Gear Works-Seattle
Hoechst Celanese Corp.
Howard's Machine Shop
Intech Corporation
Moore-Addison
Performance Gear Systems, Inc.
Pulley Manufacturers
RTP Company
Seitz Corporation
Spicer Industries Inc.
Trogetec Inc.

Powdered Metals

Asco Sintering Co.
Bestmetal Corporation
Bunting Bearings Corp.
Burgess-Norton Mfg.
Capstan Atlantic
Carbon City Products
The Gear Works-Seattle
Major Gauge & Tool
Metal Powder Products
Spline Gauges Ltd.

Steels

Adobe Precision Gear
Arrow Gear Co.
Crucible Service Centers
Ferry-Capitain Industries, LLC
The Gear Works-Seattle
Latrobe Steel Company
Lovejoy Steel
Macsteel
McInnes
Pulley Manufacturers
Qualicast Corp.
Scot Forge
Steel Industries, Inc.
Trogetec Inc.
Wes-Tex Gear Inc.

Other Materials

The A.B.A. Company—*Forgings and Castings*
Advanced Cast Products—*Austempered Ductile Iron*
Bunting Bearings Corp. —*Bronze Alloys*
Charles E. Larson & Sons—*Rolled Rings*
Crucible Service Centers—*High Speed Steel For Cutting Tools*
Intech Corporation—*Plastic/Metal Composite*
Keystone Threaded Products Div. —*Roll Formed Worm Stock*
Mc Innes—*Steel Forgings, Seamless Rolled Rings.*
Miller Centrifugal Casting Co. —*Worm Gear Blanks*
Moore-Addison—*Non-metallics/Laminates*
Portland Forge—*Steel Forgings*
Presrite Corp. — *Forged Tooth Gears*
Scot Forge—*Gear Weldments, Forged Rings & Hubs.*
SIFCO Selective Plating—*Brush Plated Stop-Off and Wear-in Coatings, Brush Plating Chemicals*
Steel Industries, Inc. —*Seamless Rolled Rings up to 160".*

Open Die Forgings up to 18,000 lbs.
Trogetec Inc. — *Nonferrous Metals*

GEAR SERVICES

Bevel Gear Manufacturing

ABA-PGT, Inc.
ACR Industries, Inc.
The Adams Company
Akron Gear & Engineering
Amarillo Gear Company
Arrow Gear Company
Ashot Ashkelon Industries
ATA Gears Ltd.
B&R Machine & Gear
Bevel Gears (India) Pvt.
C-B Gear & Machine
CGI, Inc.
Circle Gear & Machine
Curtis Machine Co.
Davall Gear Co. Ltd.
EMCO Gears
Emerson Power Transmission
Engranes Industriales Rivera
Foote-Jones/Illinois Gear
Franke Gear Works
Gajra Gears Ltd.
Great Taiwan Gear
Indiana Power Transmission Systems
ITW Spiroid
J&E Hofmann Engineering Pty. Ltd.
Midwest Gear & Tool
Moore Machine & Gear, Inc.
Nissei Corp. of America
Oliver Gear Inc.
Ondrives Ltd.
Overton Gear & Tool
Perry Technology
Precision Gear Co.
Progressive Engineering Co.
Reliance Gear Corp.
Rush Gears Inc.
Southern Gear & Machine Inc.
Stock Drive Products/Sterling Instrument
Suda International Gear Works
Tracey Gear & Machine Works
Union Gear & Sprocket
United Gear and Assembly, Inc
United States Gear

Broaching Services

Able Tooling
Accurate Gear & Machine, Inc.
Acme Gear Company
Action Gear & Broaching
The Adams Company
Akron Gear & Engineering
American Broach & Machine Co.
American Machine & Gear, Inc.
Ann Arbor Machine
Apex Broach & Machine Co.
Arrow Gear Company
Avon Broach and Production Co.
B&R Machine & Gear .
Biddle & Mumford Gears Ltd.
Brewer Machine & Gear Co.
The Broach Masters
Buckeye Gear Co.
CGI, Inc.
Chandler Machine Co.
Chicago Gear-D.O. James
Chicago Gear Works
Circle Gear & Machine
Colonial Tool Group
Columbia Gear Corporation
Commercial Gear & Sprocket Co. Inc.
Crankshaft Machine Group
Custom Gear & Machine Inc. (IL)
Custom Stock Gear & Machine
Davall Gear Company
Dayton Gear & Tool
Detroit Broach
Elmass North America
Fisher's Gear & Machine Inc.
Franke Gear Works
Gear Company of America
Gear Master Engineering Corp.
Geartronic Industries
General Broach & Engineering
Generated Gear & Machine Inc.
Gerhardt Gear Company Inc.
Harder Precision Components
J&E Hofmann Engineering Pty. Ltd.
Jack Dustman & Assoc.
Lawler Gear Corp.
Luoyang Zhongzhong GearBox Co.
Milwaukee Gear Co.
Mize & Associates Inc.
Moore Gear Mfg. Co.
Mr. Gears, Inc.
Nachi Machining Technology Co.
Nixon Gear Inc.
O'Brien Gear Company
Omni Gear & Machine
Ontario Drive & Gear
Orlandi Gear Co.
Oswald Forst Gmbh
Overton Gear & Tool
Pennsylvania Gear
Perry Technology Corp.
Precision Gear Co.
Precision Gear Inc.
Precision Gears, Inc.
Pulley Manufacturers
The Purdy Corp.
Rawling Gear Inc.
Raycar Gear & Machine Co.
Reliance Gear Corp.
Riley Gear Corp.
Rj Link International
Ronson Gears Pty. Ltd.
Rush Gears Inc.
Satellite Gear
Schafer Gear Works,
Southern Gear & Machine
Tracey Gear & Machine
Trojon Gear Inc.
Ty Miles Inc.
U.S. Broach & Machine
Unique Power Products, Inc.
United Gear and Assembly, Inc.
United States Gear
Wedin International,

Consulting

ABA-PGT, Inc.
Able Tooling
Action Gear &

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Broaching
Adobe Precision Gear
Advance Gear & Machine
Ann Arbor Machine
Aplus Engineering Inc.
Applied Mechaniques
Aston Metallurgical Services Co. Inc.
Axicon Technologies
Barit International
Becker Gearmeisters
Bourn & Koch Machine Tool Co.
Carbon City Products
C-B Gear & Machine
C-Dot Engineering
CETIM
CGI, Inc.
Ciateq, A. C.
The Cincinnati Gear Co.
D.L. Borden, Inc.
Dabko Industries Inc.
Davall Gear Company
Dayton Gear & Tool
Diamond Solutions
Drive Systems Technology, Inc.
Drivetrain Technology Center
EMCO Gears
Eversolv Software
Fairfield Mfg. Co.
Ferry-Capitain Industries, LLC
Fisher's Gear & Machine Inc.
Franke Gear Works
Gary P. Mowers, Inc.
Geartech
Geartech Ltd. - Tecnologia de Engrenagens
Generated Gear & Machine Inc.
GMI
Great Lakes Gear Technologies
Guy Crader Consulting
GW Plastics
Hi Tecmetal Group Inc.
HMC, Inc.
Holroyd
Horsburgh & Scott
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Impact Strategies Inc.
Involute Simulation Softwares Inc.
Intech Corporation
Interstate Tool Corp.
Ion Vacuum Technologies Corp.
J&E Hofmann Engineering Pty. Ltd.
Jack Dustman & Assoc.
James Reid Gear Services
Kowalski Heat Treating Company
Labeco
Luoyang Zhongzhong
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Mechanical & Structural Design & Software
Michigan Mfg. Technology Ctr.
Milburn Engineering,
Milford Gear Works
Milwaukee Gear Co.
moldedgear.com
Moore Gear Mfg. Co.
Moore Machine & Gear
Moore Measurement Solutions
Mostar Gear & Machine
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Nixon Gear Inc.
Oerlikon Geartec AG
Okubo Gear/Avon Gear
Ontario Drive & Gear
Overton Gear & Tool
Pacific Gauge & Machine Co.
Packer Engineering
Performance Gear Systems, Inc.
Powertrain Engineers
Precision Engineering
Precision Gear Inc.
Profile Engineering
Progressive Steel Treating
R. Cushman & Assoc.
R.E. Smith & Co.
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Riley Gear Corp.
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SBR Consulting
Schafer Gear Works,
Speedwell Industries
Spicer Industries Inc.
Spline Gauges Ltd.
Stork Technimet
Sussex Gear Company
Swiglo Metallurgical Consulting
Syntec Technologies
Taiga Engineering Group, Inc.
Thermotech
Trogetec Inc.
Ultron Incorporated
United States Gear
Van Gerpen-Reece Engineering
Web Gear Services
Wedin International,
Westech Gear
Wes-Tex Gear Inc.

Cryogenics

American Brazing
Best Engineering, Inc.
C-B Gear & Machine
COLDfire Chicago
Detroit Flame

Hardening Co.
Dynamic Metal Treating
Hauni Richmond, Inc.
Hi Tecmetal Group Inc.
Horsburgh & Scott
Hudapack Meta Treating–Elkhorn
Hudapack Meta Treating–Glendale Heights
Iron Bound Heat Treating
Jasco Heat Treating Inc.
Kowalski Heat Treating
Metlab
Midwest Thermal-Vac
One Cryo Inc.
Overton Gear & Tool
Paulo Products Company–Bessemer
Paulo Products Company–Memphis
Paulo Products Company–MurfreesborPaulo
Products Company–Peculiar
Paulo Products Company–St. Louis
Progressive Steel Treating
Sales Consultants
Sun Steel Treating Inc.
Xtek Inc.

Custom Gear Manufacturing

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Able Tooling
Accurate Gear & Machine, Inc.
Accurate Specialties
Acme Gear Company
ACR Industries, Inc.
The Adams Company
Aero Gear, Inc.
Akron Gear & Engineering
Albro Gear & Instrument Inc.
Allied Gear Co.
Amarillo Gear Company
American Machine & Gear, Inc.
Ann Arbor Machine
Arrow Gear Company
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ATA Gears, Inc.
B&R Machine & Gear
Bevel Gears (India) Pvt.
Biddle & Mumford Gears Ltd.
Bodine Gear Manufacturing
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Brewer Machine & Gear Co.
Buckeye Gear Co.
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Carnes-Miller Gear Co.
C-B Gear & Machine
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Channel Power Transmission, Inc.
Chardam Gear Co.
Chicago Gear-D.O. James
Chicago Gear Works
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Cunningham Industries
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Custom Gear & Machine (CA)
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Dearborn Gear & Tool Company, Inc.
Dee Kay Gears
Delroyd Worm Gear
EIMCO LLC
EMCO Gears
Emerson Power Transmission
Engranes Industriales Rivera, S.A. de C.V.
Ferry-Capitain Industries, LLC
First Gear Engineering & Technology
Fisher's Gear and Machine Co., Inc.
Forest City Gear Co.
Franke Gear Works
G&N Rubicon Gear
Gear Company of America
Gear Master Engineering Corp.
Gear Works, Inc.
GearTec, Inc.
Geartronic Industries
Generated Gear & Machine Inc.
Gerhardt Gear Company Inc.
Great Lakes Gear Technologies
Griffin Gear
Halifax Rack & Screw Cutting Co. Ltd.
HMC, Inc.
Holroyd
Indiana Power Transmission Systems
Invincible Gear Co.
ITW Spiroid
J&E Hofmann Engineering Pty. Ltd.
Jamal Gear Machinery
Klingelnberg Söhne
Kreiter Geartech
Lawler Gear Corp.
Linn Gear Co.
Luoyang Zhongzhong GearBox Co.
M.J.H. Gear & Tool
mG miniGears Inc.
Midwest Gear & Tool
Milwaukee Gear Co.
Modified Gear & Spline, Inc.
Moore Machine & Gear
Moore Measurement Solutions
Nissei Corporation of America
Nixon Gear Inc.
O'Brien Gear Company
Okubo Gear/Avon Gear
Oliver Gear, Inc.
Omni Gear & Machine
Ontario Drive & Gear
Orlandi Gear Co.
Overton Gear & Tool
P.H. Precision Products Corp.
Performance Gear Systems, Inc.
Perry Technology Corp.
Phillips-Moldex Co.
Precipart Corporation
Precision Gear Co.
Qualicast Corp.
Raycar Gear & Machine Co.
Reef Gear Mfg., Inc.
Reliance Gear Corp.
Richel Inc.
Rij Engineering Pvt.
Riley Gear Corp.
Robertson Mfg. Co.
Rush Gears Inc.
Russell Holbrook & Henderson
Satellite Gear
Schafer Gear Works,
Seitz Corporation
Selector Spline Products, Inc.
Sinochem Jiangsu Wuxi Corp.

Southern Gear & Machine
Speedwell Industries
Spicer Industries Inc.
Stackpole Ltd.
STD Precision Gear & Instrument, Inc.
Suda International Gear Works Ltd.
Suhner Mfg. Inc.
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Thermotech
Tifco Gage & Gear
Tracey Gear & Machine
Trogetec Inc.
Trojon Gear Inc.
Union Gear & Sprocket
Unique Power Products, Inc.
United States Gear
Wedin International
Westerman Companies
Wiscon Products, Inc.
Xtek Inc.

Cutting Tool Sharpening

Able Tooling
Acedes Gear Tools Ltd.
Action Gear & Broaching
American Broach & Machine Co.
American Machine & Gear, Inc.
Apex Broach & Machine Co.
Arrow Gear Company
B.H. Jones Machine & Gage
Bean Tool, Die & Engineering
Best Engineering, Inc.
C-B Gear & Machine
Colonial Tool Group
Custom Gear & Machine Inc. (IL)
Dayton Gear & Tool
EIMCO LLC
EMCO Gears
Fellows Corp.
Forest City Gear
Fubri s.r.l.
Gajra Gears Ltd.
Gear Company of America
Gerhardt Gear Company Inc.
Gleason Cutting Tools
The Gleason Works
Great Lakes Gear Technologies
Index Technologies Inc.
Interstate Tool Corp.
IonBond Inc.
Ion Vacuum Technologies Corp.
J&E Hofmann Engineering Pty. Ltd.
Jamal Gear Machinery
Koro Sharpening Service
Lawler Gear Corp.
Luoyang Zhongzhong GearBox Co.
Micromatic Textron
Mill Max Tools Pvt.
Mitsubishi Machine Tools
Mize & Associates Inc.
Moore Gear Mfg. Co.
Mr. Gears, Inc.
IonBond Inc.
Nachi Machining Technology Co.
Oerlikon Geartec AG
P.F. Markey, Inc.
Ply-Mar Tool Co.
Richter Precision Inc.
Ronson Gears Pty. Ltd.
Russell Holbrook & Henderson
Sales Consultants
Schafer Gear Works
Star Cutter Co.
SU America
Transmecanica
Trogetec Inc.
Universal Gear Co.
Wedin International

Fault Analysis

Adobe Precision Gear
Akron Gear & Engineering
Applied Mechaniques
Ashot Ashkelon Industries
Ashot USA Inc.
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Davall Gear Company
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Luoyang Zhongzhong GearBox Co.
Mechanical & Structural Design & Software
Milburn Engineering,
Modern Industries Inc.
moldedgear.com
Mr. Gears, Inc.
NASA Glenn Research Center
National Metrology
Overton Gear & Tool
Packer Engineering
Paulo Products Company–Peculiar
Philadelphia Gear Corp.–Houston
Powertrain Engineers
Progressive Steel Treating
R. Cushman & Assoc.
Reilly Engineering Inc.
Riley Gear Corp.
Speedwell Industries
Stork Technimet
Thermotech
Wedin International,
Westech Gear
Wes-Tex Gear Inc.

Gear Coatings

CGI, Inc.
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Diamond Black Technologies
Diamonex Incorporated
The Duffy Company
Dynamic Metal Treating
EIMCO LLC
Fellows Corp.
General Magnaplate
The Gleason Works
Great Lakes Gear Technologies
IonBond Inc.
J&E Hofmann Engineering Pty. Ltd.
Mitsubishi Machine Tools
Mize & Associates Inc.
Pacific Gauge & Machine Co.
Surface Technology
Trogetec Inc.

Gear Design

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Able Tooling
Accurate Specialties
Action Gear & Broaching
Adobe Precision Gear
Advance Gear & Machine
Aero Gear, Inc.
Akron Gear &

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Allied Devices Corp.
Ann Arbor Machine
Aplus Engineering Inc.
Applied Mechaniques
Arrow Gear Company
Arte Corporation
Ashot Ashkelon Industries
Ashot USA Inc.
ATA Gears, Inc.
Axicon Technologies
Barit International
Bevel Gears (India) Pvt.
Blanchat Machine Co.
Bodine Gear Manufacturing
Calicut Engineering Works Ltd.
Carbon City Products
Caterpillar Industrial Products Inc.
C-B Gear & Machine
C-Dot Engineering
CETIM
CGI, Inc.
Channel Power Transmission, Inc.
Chicago Gear-D.O. James
CIATEQ
The Cincinnati Gear Co.
CMD (UK) Ltd.
Columbia Gear Corporation
Contour Hardening
Crown Gear B.V.
Crown Powertrain
Curtis Machine Co. Inc.
D.L. Borden, Inc.
Davall Gear Company
Dee Kay Gears
Delroyd Worm Gear
Drive Systems Technology, Inc.
Drivetrain Technology Center
Dynamic Tool Grinding
EIMCO LLC
EMCO Gears
Emerson Power Transmission
Engranes Industriales Rivera
Estudio Ing. J.L. Piña
Eversolv Software
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Fellows Corp.
Ferry-Capitain Industries, LLC
First Gear Engineering & Technology
Fisher's Gear & Machine Inc.
Gear Works, Inc.
The Gear Works-Seattle
Gearesearch Assoc.
Geartech Ltd. - Tecnologia de Engrenagens
Generated Gear & Machine Inc.
Global Gear
Great Taiwan Gear Ltd.
GW Plastics
Harder Precision Components
HMC, Inc.
Horsburgh & Scott
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Insco Corporation
Intech Corporation
Involute Simulation Softwares Inc.
ITW Spiroid
J&E Hofmann Engineering Pty. Ltd.
Klingelnberg Söhne
Kreiter Geartech
Labeco
Lufkin Industries Gear Repair
Luoyang Zhongzhong GearBox Co.
McGinty Gear
Mechanical & Structural Design & Software
mG miniGears Inc.
Milburn Engineering,
Milford Gear Works
Milwaukee Gear Co.
moldedgear.com
Moore Machine & Gear
Mr. Gears, Inc.
Nixon Gear Inc.
Oerlikon Geartec AG
Okubo Gear/Avon Gear
Omni Gear
O'Neill Gear
Ontario Drive & Gear
Overton Gear & Tool
Packer Engineering
PC Enterprises
Pennsylvania Gear
Penntech
Performance Gear Systems, Inc.
Phillips-Moldex Co.
Power Engineering & Mfg. Ltd.
Powertrain Engineers
Precipart Corporation
Precision Engineering
Qualicast Corp.
R. Cushman & Assoc.
Reilly Engineering Inc.
Riley Gear Corp.
Rj Link International
Ronson Gears Pty. Ltd.
Santasalo North America
SBR Consulting
Seitz Corporation
Selector Spline Products, Inc.
Sokhi Heli-Worn Gears Pvt. Ltd.
Southern Gear & Machine
Speedwell Industries
Spicer Industries Inc.
Spline Gauges Ltd.
Suhner Mfg. Inc.
Sussex Gear Company
Syntec Technologies
Taiga Engineering Group, Inc.
Thermotech
Tifco Gage & Gear
Trogetec Inc.
UFE Incorporated
Van Gerpen-Reece Engineering
Von Ruden Mfg.
Wedin International,
United Gear and Assembly, Inc.
United States Gear
Web Gear Services
Westech Gear
Wes-Tex Gear Inc.
Winzeler Gear
Xtek Inc.

Gear Engineering

ABA-PGT, Inc.
Able Tooling
Accurate Specialties,
ACR Industries, Inc.
Action Gear & Broaching
Adobe Precision Gear
Advance Gear & Machine
Aero Gear, Inc.
Akron Gear & Engineering
Allied Devices Corp.
Ann Arbor Machine
Aplus Engineering Inc.
Applied Mechaniques
Arrow Gear Company
Arte Corporation
Ashot Ashkelon Industries
Ashot USA Inc.
ATA Gears, Inc.
Axicon Technologies
B&R Machine & Gear
Barit International
Bevel Gears (India) Pvt.
Biddle & Mumford Gears Ltd.
Blanchat Machine Co.
Bodine Gear Manufacturing
Calicut Engineering Works Ltd.
CETIM
Channel Power Transmission Inc.
Chicago Gear-D.O. James
CIATEQ
The Cincinnati Gear Co.
CMD (UK) Ltd.
Columbia Gear Corporation
Contour Hardening
Crown Gear B.V.
Crown Powertrain
Curtis Machine Co.
Custom Gear &

Machine (CA)
D.L. Borden, Inc.
Dabko Industries Inc.
Davall Gear Company
Dayton Gear & Tool
Dee Kay Gears
Delroyd Worm Gear
Drive Systems Technology, Inc.
Drivetrain Technology Center
Dynamic Tool
Grinding
EIMCO LLC
EMCO Gears
Emerson Power Transmission
Engranes Industriales Rivera
Fairfield Mfg. Co.
Federal Gear Corp.
Fellows Corp.
Ferry-Capitain Industries, LLC
First Gear Engineering & Technology
Fisher's Gear & Machine Inc.
Foote-Jones/Illinois Gear
Gear Company of America
Gear Research Institute
The Gear Works-Seattle
Gearesearch Assoc.
Gears & Drive Systems
Geartech Ltd.–Tecnologia de Engrenagens
Generated Gear & Machine Inc.
Global Gear
Harder Precision *Components*
HMC, Inc.
Horsburgh & Scott
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Insco Corporation
Intech Corporation
Involute Simulation Softwares Inc.
ITW Spiroid
J&E Hofmann Engineering Pty. Ltd.
Kreiter Geartech
Labeco
Lufkin Industries Gear Repair
Luoyang Zhongzhong GearBox Co.
Lyon Gear
Mechanical & Structural Design & Software
mG miniGears Inc.
Milburn Engineering,
Milford Gear Works
Milwaukee Gear Co.
Modern Industries Inc.
Moore Machine & Gear
Mostar Gear & Machine
Mr. Gears, Inc.
NASA Glenn Research Center
Oerlikon Geartec AG
Okubo Gear/Avon Gear
Omni Gear
O'Neill Gear
Ontario Drive & Gear
Overton Gear & Tool
Packer Engineering
Patterson Gear & Machine
Pennsylvania Gear
Penntech
Performance Gear Systems, Inc.
Perry Technology Corp.
Philadelphia Gear Corp.– Houston
Phillips-Moldex Co.
Power Engineering & Mfg. Ltd.
Powertrain Engineers
Precipart Corporation
Precision Engineering
Process Industries
Profile Engineering
Qualicast Corp.
R. Cushman & Assoc.
Reilly Engineering Inc.
Reliance Gear Corp.
Riley Gear Corp.
Rj Link International
Russell Holbrook & Henderson
Santasalo North America
SBR Consulting
Seitz Corporation
Selector Spline Products, Inc.
Southern Gear & Machine
Speedwell Industries
Spicer Industries Inc.
Spline Gauges Ltd.
Sussex Gear Company
Syntec Technologies
Taiga Engineering Group, Inc.
Thermotech
Tifco Gage & Gear
Trisys
Trogetec Inc.
UFE Incorporated
United States Gear
Van Gerpen-Reece Engineering
Vesta Works USA, Inc.
Web Gear Services
Wedin International
United Gear and Assembly, Inc.
Westech Gear
Wes-Tex Gear Inc.
Winzeler Gear
Xtek Inc.

Gear Grinding Services

Able Tooling
Acme Gear Company
ACR Industries, Inc.
Advance Gear & Machine
Aero Gear, Inc.
Allied Gear Co.
American Machine & Gear, Inc.
Ann Arbor Machine
Aplus Engineering Inc.
Arrow Gear Company
Ashot Ashkelon Industries
Ashot USA Inc.
B&R Machine & Gear
Blanchat Machine Co.
The Broach Masters
Calicut Engineering Works Ltd.
Caterpillar Industrial Products Inc.
C-B Gear & Machine
Channel Power Transmission Inc.
Chardam Gear Co.
The Cincinnati Gear
CMD (UK) Ltd.
Columbia Gear Corporation
Crown Gear B.V.
Custom Gear & Machine Inc. (IL)
Custom Stock Gear & Machine
Davall Gear Company
Dayton Gear & Tool
Dee Kay Gears
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Contact us for the latest data on gear noise.

CIRCLE 158

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Gajra Gears Ltd.
The Gear Works-Seattle
Gears & Drive Systems
Gerhardt Gear Company Inc.
Great Lakes Gear Technologies
Hamilton Gear
Hanover Gear Mfg. Co.
HMC, Inc.
Höfler Maschinenbau
Horsburgh & Scott
Insco Corporation
Invincible Gear Co.
Ion Vacuum Technologies Corp.
ITW Spiroid
J&E Hofmann Engineering Pty. Ltd.
Jamal Gear Machinery
Kreiter Geartech
Laser Machining Inc.
Lawler Gear Corp.
Lufkin Industries Gear Repair
Luoyang Zhongzhong GearBox Co.
Lyon Gear
Major Gauge & Tool
Merit Gear Corp.
mG miniGears Inc.
Midwest Gear & Tool
Midwest Gear Corp.
Milwaukee Gear Co.
Modern Industries Inc.
Modified Gear & Spline, Inc.
Nakanishi Gear
Niagara Gear Corp.
Nixon Gear Inc.
O'Brien Gear Company
Oerlikon Geartec AG
Oliver Gear, Inc.
Omni Gear
Overton Gear & Tool
Patterson Gear & Machine
Pennsylvania Gear
Penntech
Perry Technology
Philadelphia Gear Corp.–Houston
Precision Gear Co.
Precision Gear Inc.
Process Industries
Pro-Gear Company,
The Purdy Corp.
Raycar Gear & Machine Co.
Reliance Gear Corp.
Riley Gear Corp.
Riverside Spline & Gear
Ronson Gears Pty. Ltd.
Rush Gears Inc.
Satellite Gear
Seitz Corporation
Selector Spline Products, Inc.
Sinochem Jiangsu Wuxi Corp.
Sokhi Heli-Wom Gears Pvt. Ltd.
Southern Gear & Machine
Spline Gauges Ltd.
Tifco Gage & Gear
Trogetec Inc.
Unique Power Products, Inc.
Westech Gear
Wedin International,
Xtek Inc.

Heat Treating Services

Accurate Ion Technologies
Advanced Material Process Corp.
Aero Gear, Inc.
Aerocraft Heat Treating Co. Inc.
Ajax Magnethermic
ALD Vacuum Technologies
Alfe Heat Treating
Alfred Heller Heat Treating
American Brazing
American Metal Treating
Aplus Engineering Inc.
Applied Process Inc.
Arrow Gear Company
Ashot Ashkelon Industries
Ashot USA Inc.
B&R Machine & Gear
Blanchat Machine Co.
Calicut Engineering Works Ltd.
Caterpillar Industrial Products Inc.
CGI, Inc.
The Cincinnati Gear
The Cincinnati Steel Treating Co.
Commercial Steel Treating
Contour Hardening,
D.L. Borden, Inc.
Delroyd Worm Gear
Detroit Flame Hardening Company
Disston Precision Inc.
Drivetrain Technology Center
Dynamic Metal Treating
EIMCO LLC
Engineered Heat Treat
Edgewater Steel Ltd.
Euclid Heat Treating
Fairfield Mfg. Co.
Ferry-Capitain Industries, LLC
Fisher's Gear & Machine Inc.
Fluxtrol Manufacturing
Foote-Jones/Illinois Gear
FPM Heat Treating
Gear Company of America
General Surface Hardening
Generated Gear & Machine Inc.
Gleason Cutting Tools
The Gleason Works
Hamilton Gear
Hauni Richmond, Inc.
Hi Tecmetal Group Inc.
HMC, Inc.
Horsburgh & Scott
Hudapack Meta Treating–Elkhorn
Hudapack Meta Treating–Glendale Heights
Inductoheat, Inc.
Industrial Metal Treating Corp.
IonBond Inc.
Iron Bound Heat Treating
J&E Hofmann Engineering Pty. Ltd.
Jasco Heat Treating Inc.
Kolene Corporation
Kowalski Heat Treating Company
LAI East/Laser Applications, Inc.
LAI Midwest, Inc.
LAI Southwest, Inc.
Linn Gear Co.
Lufkin Industries Gear Repair
Luoyang Zhongzhong GearBox Co.
Merit Gear Corp.
Metal Improvement Company, Inc.
Metlab
mG miniGears Inc.
Midwest Thermal-Vac
Mill Max Tools Pvt.
Milwaukee Gear Co.
Modern Industries Inc.
Molon Gear & Shaft
Moore Gear Mfg. Co.
Mr. Gears, Inc.
Nachi Machining Technology Co.
Nitrex Metal Technologies Inc.
Overton Gear & Tool
P.H. Precision Products
Patterson Gear & Machine
Paulo Products Co.
Penn Machine Co.
Pennsylvania Gear
Penntech
Philadelphia Gear Corp.–Houston
Phillips-Moldex Co.
Precision Gear Co.
Progressive Engineering
Progressive Steel

Treating
Rex Heat Treating
Richter Precision Inc.
Rush Gears Inc.
Shore Metal Technology
Southern Gear & Machine
Speedwell Industries
Sun Steel Treating Inc.
Surface Technology, TOCCO Inc.
Trogetec Inc.
U. S. Axle Inc.
Unique Power Products, Inc.
Wall Colmonoy Corporation
Wedin International,
Welduction Corp.
United Gear and Assembly, Inc.
United States Gear
Westech Gear
Xtek Inc.

Inspection Services

Able Tooling
Action Gear & Broaching
Akron Gear & Engineering
Alfe Heat Treating
Allied Devices Corp.
Alpha Precision Inc.
American Stress Technologies, Inc.
Ann Arbor Machine
Aplus Engineering Inc.
Arrow Gear Company
Ashot Ashkelon Industries
Ashot USA Inc.
Aston Metallurgical Services Co. Inc.
Axicon Technologies
B&R Machine & Gear
Becker Gearmeisters
Best Engineering, Inc.
Blanchat Machine Co.
Bodine Gear Manufacturing
Bucyrus International,
Carnes-Miller Gear Co.,
C-B Gear & Machine
CETIM
CGI, Inc.
The Cincinnati Gear
Columbia Gear Corporation
Contour Hardening
Custom Gear & Machine Inc. (IL)
D.I.G.I.T., Inc.
Davall Gear Company
Delroyd Worm Gear
Drivetrain Technology Center
Edgewater Steel Ltd.
EMCO Gears
Euro-Tech Corp.
Fellows Corp.
Ferry-Capitain Industries, LLC
First Gear Engineering & Technology
Fisher's Gear & Machine Inc.
Forest City Gear
Fubri s.r.l.
Gear Company of America
The Gear Works-Seattle
Generated Gear & Machine Inc.
Gerhardt Gear Company Inc.
Harder Precision Components
Hi Tecmetal Group Inc.
HMC, Inc.
Höfler Maschinenbau
Horsburgh & Scott
Index Technologies Inc.
ITW Heartland
J&E Hofmann Engineering Pty. Ltd.
Kowalski Heat Treating Company
Krautkramer Inc.
Kreiter Geartech
Lufkin Industries Gear Repair
Luoyang Zhongzhong GearBox Co.
Lyon Gear
M&M Precision Systems
Manufactured Gear & Gage
Merit Gear Corp.
Milwaukee Gear Co.
Modern Industries Inc.
Moore Machine & Gear
Moore Measurement Solutions
Mr. Gears, Inc.
National Metrology
NewAge Testing Instruments Inc.
Niagara Gear Corp.
Nixon Gear Inc.
Okubo Gear/Avon Gear
Overton Gear & Tool
Packer Engineering
Patterson Gear & Machine
Paulo Products Company–Peculiar
PC Enterprises
Pennsylvania Gear
Penntech
Performance Gear Systems, Inc.
Perry Technology Corp.
Philadelphia Gear Corp.–Houston
Phillips-Moldex Co.
Precision Gage Co.
Precision Gear Co.
Precision Gear Inc.
Process Equipment Company
Process Industries
Profile Engineering
Pro-Gear Company
Progressive Steel Treating
R.E. Smith & Co.
Raycar Gear & Machine Co.
Reliance Gear Corp.
Riley Gear Corp.
Riverside Spline & Gear
Roto-Technology, Inc.
RTS Rework Inc.
Santasalo North America
Schafer Gear Works,
Scott Machine Tool Co.
Seitz Corporation
Southern Gear & Machine
Speedwell Industries
Spline Gauges Ltd.
Stork Technimet
SU America
Syntec Technologies
Thermotech
Tifco Gage & Gear
Trisys
Trogetec Inc.
Trojon Gear Inc.
Ultron Incorporated
Unique Power Products, Inc.
United States Gear Corp.
Wedin International,
Westech Gear
Wes-Tex Gear Inc.

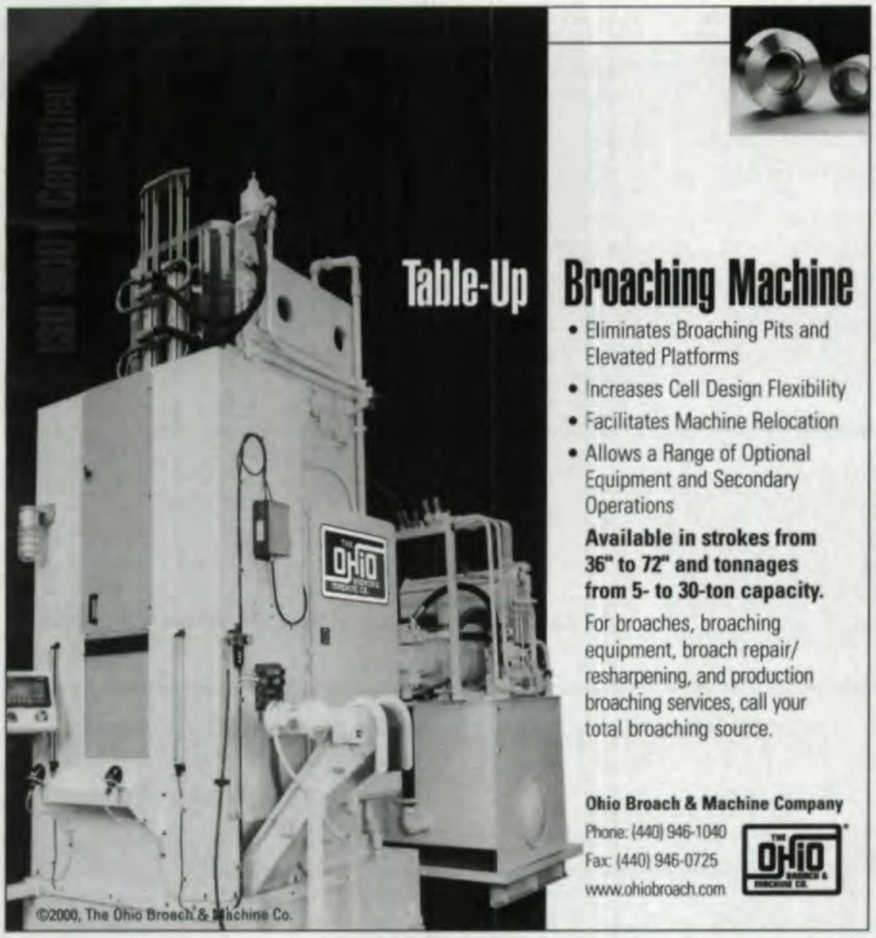
Shot Peening

Able Tooling
Advanced Material Process Corp.
Ashot ashkelon indus
Ashot USA Inc.
Blanchat Machine Co.
Edgewater Steel Ltd.
EIMCO LLC
Electronics, Inc.
Fairfield Mfg. Co.
Fisher's Gear & Machine Inc.
Generated Gear & Machine Inc.
HMC, Inc.
Hydro Honing
J&E Hofmann Engineering Pty. Ltd.
Kowalski Heat Treating Company
Metal Improvement Company, Inc.
Milwaukee Gear Co.
Moore Gear Mfg. Co.
Mr. Gears, Inc.
NASA Glenn Research Center
Overton Gear & Tool
Patterson Gear & Machine

Stock Gear Manufacturing

Tool Coating

Other Services



CIRCLE 144

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C-Dot Engineering
CETIM
Diamond Solutions,
Drive Systems Technology Inc.
Eversolv Software
Fisher's Gear & Machine Inc.
Gear Cutting Technology Systems
Gearesearch Assoc.
Gerhardt Gear Company Inc.
The Gleason Works
Hoglund Technology
I.S.P.J.A.E.
Involute Simulation Softwares Inc.
JobBoss Software
Locnar Software Engineering
M&M Precision Systems
Moore Measurement Solutions
Normac, Inc.
Pacific Gauge & Machine Co.
Richel Inc.
Romax Technology
Scott Machine Tool Co.
Software Engineering Service
Trogetec Inc.
Universal Technical Systems, Inc.
Van Gerpen-Reece Engineering
Web Gear Services

Gear Design Software

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Able Tooling
AGMA
Bluegrass Precision Machinery
C-Dot Engineering
CETIM
CIATEQ
Crown Powertrain
Dabko Industries Inc.
Drive Systems Technology, Inc.
Eversolv Software
Fairfield Mfg. Co.
Fisher's Gear & Machine Inc.
Gear Cutting Technology Systems
Gearesearch Assoc.
Geartech
Geartech Ltda.–Tecnologia de Engrenagens
Great Lakes Gear Technologies
GW Plastics
I.S.P.J.A.E.
Involute Simulation Softwares Inc.
Klingelnberg Söhne
Lemur Enterprises
Manufacturers Technologies, Inc.
Mechanical & Structural Design & Software
NASA Glenn Research Center
Oerlikon Geartec AG
Romax Technology
Software Engineering Service
Trogetec Inc.
Universal Technical Systems, Inc.
Van Gerpen-Reece Engineering
Web Gear Services

Gear Inspection Software

Alpha Precision Inc.
Bourn & Koch Machine Tool Co.
CETIM
D.I.G.I.T., Inc.
Diamond Solutions,
GW Plastics
Gearesearch Assoc.
Klingelnberg Söhne
Krautkramer Inc.
Lufkin Industries Gear Repair
M&M Precision Systems
Mahr Federal
Micro Gear
Moore Measurement Solutions
Nippon ITM Inc.
Pacific Gauge & Machine Co.
Precision Gage Co.
Profile Engineering,
Roto-Technology, Inc.

Scott Machine Tool Co.
Software Engineering Service
Spline Gauges Ltd.
Trogetec Inc.
TSK America
Web Gear Services
Worrall Grinding Co.

Shop Management Software

Bourn & Koch Machine Tool Co.
Diamond Solutions,
JobBoss Software
Kewill
Lilly Software Associates, Inc.
Scott Machine Tool Co.
User Solutions, Inc.

Other Software

American Gear Mfgrs. Assn. — *Gear Rating, Gear Capacity*
Best Engineering, Inc. —*Tool Crib Management Software*
Bourn & Koch Machine Tool Co. — *Change Gear/Setup Software*
DP Technology Corp. —*CAD/CAM Software*
Euro-Tech Corp. — *Spline Inspection*
Eversolv Software—*AGMA Load Rating Software*
Extrude Hone—*Surface Finish Measurement Software*
GB Gear Shop Tools—*Calculations*
Gearesearch Assoc. — *Gear Scoring Analysis*
Geartech—*Gear Life Analysis*
Geartech Ltda.–Tecnologia de Engrenagens—*Mechanical Design*
Gerhardt Gear Company Inc. — *Quality Rating*
Manufacturers Technologies, Inc. — *Cost Estimating Software*
Meccanic Nova Corp. —*Grinding Machine Software*
Mechanical & Structural Design & Software—*Strength & Fatigue Analysis Software*
NASA Glenn Research Center—*Bearing/Seal*
Radyne Corporation—*Quality Assurance*
Romax Technology—*RomaxDesigner Gearbox System Design Software*
Trogetec Inc. —*Cycloid Gear & Related Parts Mfg. Software*
Web Gear Services—*Excel Based Gear Design Software*

GEAR TOOLING & ACCESSORIES

Abrasives

Abrasive Technology
Bluegrass Precision Machinery
Clipper Diamond Tool
Engis Corp.
Ernst Winter & Son Inc.
Extrude Hone
Meister Grinding Tech.
Rex-Cut Products Inc.
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A/W Systems Co.
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Borazon/CBN Wheels

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Chamfermatic Inc.
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The Gleason Works
GMI
Kapp Technologies
Mize & Associates Inc.
Norton Abrasives
P.F. Markey, Inc.
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SU America
Universal Superabrasives
Wilton Machinery

Broaching Tools

American Broach & Machine Co.
Apex Broach & Machine Co.
Barit International Corp.
Best Engineering, Inc.
The Broach Masters
Crankshaft Machine Group
Detroit Broach
Elmass North America
General Broach & Engineering
Kingsford Broach & Tool
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Parker Industries Inc.
Reid Tool Service Inc.
Ty Miles Inc.
U.S. Broach & Machine
Universal Gear Co.

Cams

Able Tooling
Jamal Gear Machinery

Chamfering Tools

Able Tooling
Acedes Gear Tools Ltd.
A/W Systems Co.
Best Engineering, Inc.
Chamfermatic Inc.
The Gleason Works
GMI
Great Lakes Gear Technologies
Interstate Tool Corp.
Jack Dustman & Assoc.
LMT-Fette
P.F. Markey, Inc.
Reid Tool Service Inc.
Sales Consultants
Schenck Turner
SPF Specialties Ltd.
SU America
Transmecanica
Westgate Machine

Coatings

Able Tooling
Barit International Corp.
Diamonex Incorporated
Fellows Corp.
General Magnaplate
Gleason Cutting Tools

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Russell Holbrook & Henderson
SU America
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Klingelnberg Söhne
Oerlikon Geartec AG
P.F. Markey, Inc.

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Able Tooling
Acedes Gear Tools Ltd.
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A/W Systems Co.
B.H. Jones Machine & Gage
Barit International Corp.
Belden Machine Corporation
The Broach Masters
Crankshaft Machine Group
Emuge Corp.
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The Gleason Works
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Interstate Tool Corp.
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Jamal Gear Machinery
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Koepfer America, L.L.C.
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Oerlikon Geartec AG
Osborn International
P.F. Markey, Inc.
Parker Industries Inc.
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Reid Tool Service Inc.
Russell Holbrook & Henderson
SU America
Universal Gear Co.

Deburring Tools
Able Tooling
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Extrude Hone
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The Gleason Works
GMI
Great Lakes Gear Technologies
Jack Dustman & Assoc.
Osborn International
Redin Corporation
Reid Tool Service Inc.
Rex-Cut Products Inc.
Sales Consultants
Schenck Turner
SPF Specialties Ltd.
SU America
Sunnen Products Co.
Vesta Works USA, Inc.
Westgate Machine

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GMI
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Star Cutter Co.
SU America
Universal Superabrasives
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GMI
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Mize & Associates Inc.
Norton Abrasives
P.F. Markey, Inc.
Reid Tool Service Inc.
S.L. Munson & Co.
Tifco Gage & Gear
Universal Superabrasives

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Brighton Laboratories
Charmilles Technologies
Easco-Sparcatron
Extrude Hone
Hangsterfer's Laboratories
KGK International
Mecatool USA Ltd.
New Age Chemical Co.
P.F. Markey, Inc.
Perry Technology Corp.
Russell Holbrook & Henderson
Sales Consultants

Filtration Equipment
B.H. Jones Machine & Gage
Chamfermatic Inc.
Eltech Inc.
Great Lakes Gear Technologies
Jack Dustman & Assoc.
SPF Specialties Ltd.
Westgate Machine

Gages & Measuring Instruments
Able Tooling
Acedes Gear Tools Ltd.
Automated Precision
A/W Systems Co.
B.H. Jones Machine & Gage
Best Engineering, Inc.
The Broach Masters
Cole Mfg. Systems, Inc.
Comtorgage Corp.
D.I.G.I.T., Inc.
Dyer Company
Emuge Corp.
Euro-Tech Corp.
GMI
Invo Spline Inc.
Krautkramer Inc.
Kromhard Twist Drill Company
M&M Precision Systems
Mahr Federal
MTI Corporation (Mitutoyo)
Nachi Machining Technology Co.
Nippon ITM Inc.
Ono Sokki Technology,
Optical Gaging Products
Pacific Gauge & Machine Co.
Parker Industries Inc.
Paul W. Marino Gages

Precision Devices, Inc.
Precision Gage Co.
Profile Engineering
Reid Tool Service Inc.
Russell Holbrook & Henderson
Selector Spline Products, Inc.
Spline Gauges Ltd.
Sunnen Products Co.
Tifco Gage & Gear
Western Spline Gage

Grinding Wheels

Able Tooling
Abrasive Technology
A/W Systems Co.
B.H. Jones Machine & Gage
Best Engineering, Inc.
Bluegrass Precision Machinery
Bourn & Koch Machine Tool Co.
Chamfermatic Inc.
Clipper Diamond Tool
Dianamic Abrasive Products Inc.
Engis Corp.
Ernst Winter & Son Inc.
Gleason Cutting Tools
GMI
Hoglund Technology
JRM International, Inc.
Kapp Technologies
Lapmaster International
Meister Grinding Tech.
Norton Abrasives
P.F. Markey, Inc.
Redin Corporation
S.L. Munson & Company
SU America
Universal Superabrasives
Wendt Dunnington
Wilton Machinery

Heat Exchangers

Koolant Koolers Inc.
SPF Specialties Ltd.

Hobs

Able Tooling
Acedes Gear Tools Ltd.
American Machinery & Engineering
Barit International
Best Engineering, Inc.
CMH Tools Ltd.
Eltech Inc.
Emuge Corp.
Fubri s.r.l.
Gear Company of America
Gleason Cutting Tools
The Gleason Works
GMI
Great Lakes Gear Technologies
Great Taiwan Gear Ltd.
Index Technologies Inc.
Interstate Tool Corp.
Koepfer America, L.L.C.
Kromhard Twist Drill Company
LMT-Fette
Mill Max Tools Pvt.
Mize & Associates Inc.
Nachi Machining Technology Co.
P.F. Markey, Inc.
Pacific Gauge & Machine Co.
Parker Industries Inc.
Ply-Mar Tool Co.
Rebco Industrial Products
Reid Tool Service Inc.
Russell, Holbrook & Henderson, Inc.
Star Cutter Co.
SU America

Index Plates

Able Tooling
Ann Arbor Machine
Becker Gearmeisters
Bourn & Koch Machine Tool Co.
Mitts & Merrill L.P.
Nachi Machining Technology Co.
Parker Industries Inc.
Selector Spline Products, Inc.
Spline Gauges Ltd.
Tifco Gage & Gear

Injection Molds

ABA-PGT, Inc.
B.H. Jones Machine & Gage
Mize & Associates Inc.
Performance Gear Systems, Inc.
Russell, Holbrook & Henderson, Inc.
Seitz Corporation
Spicer Industries Inc.
Spline Gauges Ltd.
Syntec Technologies

Keyseat Cutters

Able Tooling
A/W Systems Co.
Best Engineering, Inc.
Colonial Tool Group
Elmass North America
GMI
Interstate Tool Corp.
Kromhard Twist Drill Company
Leistritz
Mitts & Merrill L.P.
Mize & Associates Inc.
Reid Tool Service Inc.
W. E. Litwin Assoc.

Lapping Compounds

Able Tooling
A/W Systems Co.
Brighton Laboratories
Dianamic Abrasive Products Inc.
Fuchs Lubricants Co.
Lapmaster International
Mize & Associates Inc.
Nachi Machining Technology Co.
Norton Abrasives
Universal Superabrasives

Lubricants/Coolants

Able Tooling
Abrasive Technology
American Refining Group
Apollo America
Bijur Lubricating Corp.
Brighton Laboratories
D. A. Stuart Co.
DoAll
Etna Products Inc.
Fuchs Lubricants Co.
General Magnaplate
Great Lakes Gear Technologies
Hangsterfer's Laboratories
Houghton International
Jack Dustman & Assoc.
Kluber Lubrication
Lubriplate
New Age Chemical Co.
Nye Lubricants, Inc.
Osborn International
Petronomics Industrial Products
Sunnen Products Co.
Tenaxol Inc.
Texaco Lubricants Co.

Master Gears

Able Tooling
Acedes Gear Tools Ltd.
Barit International
Best Engineering, Inc.
The Broach Masters
CMD (UK) Ltd.
The Cincinnati Gear
D.I.G.I.T., Inc.
Engelhardt Gear Co.
Fairfield Mfg. Co.
Fleet Tools Ltd.
Gajra Gears Ltd.
The Gear Works-Seattle
Gleason Cutting Tools
The Gleason Works
Interstate Tool Corp.
Invo Spline Inc.
ITW Heartland
ITW Spiroid

M&M Precision Systems
Nachi Machining Technology Co.
Nippon ITM Inc.
Pacific Gauge & Machine Co.
Parker Industries Inc.
Philadelphia Gear Corp.–Houston
Philadelphia Gear Corp.–King of Prussia
Ply-Mar Tool Co.
Precision Gage Co.
Profile Engineering.
The Purdy Corp.
Rebco Industrial Products
Reid Tool Service Inc.
Russell, Holbrook & Henderson, Inc.
Sales Consultants
Spline Gauges Ltd.
SU America
Tifco Gage & Gear
Transmecanica
Western Spline Gage

Shaper Cutters

Acedes Gear Tools Ltd.
American Machinery & Engineering
Barit International
Best Engineering, Inc.
The Broach Masters
CMH Tools Ltd.
Elmass North America
Eltech Inc.
Fellows Corp.
Fubri s.r.l.
Gajra Gears Ltd.
The Gleason Works
Gleason Cutting Tools
Interstate Tool Corp.
Kromhard Twist Drill Company
Nachi Machining Technology Co.
Pacific Gauge & Machine Co.
Parker Industries Inc.
Ply-Mar Tool Co.
Rebco Industrial Products
Reid Tool Service Inc.
Russell Holbrook & Henderson
Star Cutter Co.
Transmecanica
Tri-Wire, Inc.

Shaving Cutters

Acedes Gear Tools Ltd.
Barit International Corp.
Best Engineering, Inc.
Eltech Inc.
Fubri s.r.l.
Gajra Gears Ltd.
The Gleason Works
Micromatic Textron
Nachi Machining Technology Co.
Parker Industries Inc.
Ply-Mar Tool Co.
Rebco Industrial Products
Reid Tool Service Inc.
SU America
Transmecanica
Tri-Wire, Inc.

Spline Rolling Racks

Acedes Gear Tools Ltd.
Cold Forming Technology, Inc.
Colonial Tool Group
General Broach & Engineering
Great Lakes Gear Technologies
Great Taiwan Gear Ltd.
Micromatic Textron
Nachi Machining Technology Co.
Pacific Gauge & Machine Co.
Ply-Mar Tool Co.
Selector Spline Products, Inc.
Spline Gauges Ltd.

Wheel Truing & Dressing Devices

Able Tooling
B.H. Jones Machine & Gage
GMI
Mize & Associates Inc.
Normac, Inc.
Oerlikon Geartec AG
Tifco Gage & Gear Universal
Superabrasives
Wilton Machinery

Worm Milling Cutters

Best Engineering, Inc.
The Gleason Works
Rebco Industrial Products
Reid Tool Service Inc.
Russell Holbrook & Henderson

Other Tooling & Accessories

Acedes Gear Tools Ltd. *—Maag Rack Cutters, Sunderland Rack Cutters, Hurth Milling Cutters, Form-Relieved Milling Cutters*
American Refining Group*—Quench & Gear Oil*
A/W Systems Co. —*Cutter Bodies and Blades*
Bates Technologies—*Honing Tools*
Becker Gearmeisters—*Spare Maag Parts*
Bijur Lubricating Corp. *—Lubricating Equipment*
CMH Tools Ltd. — *Spline Milling Cutters*
Detroit Broach—*Broaching Tool Holders*
The Duffy Company—*Heat Treat Stop-off Paints*
Dyer Company—*Dimensional Gaging*
Etna Products Inc. — *Heat Treating Quenchants*
Euro-Tech Corp. — *Spline Gage Certification*
Fubri s.r.l. *—Special Milling Cutters*
General Broach & Engineering Co., Inc. *—Gear Rolling Tools*
Gleason Cutting Tools—*Form Cutters*
Hermes Machine Tool—*Tooling Packages for Specific Machine Tool Purchase*
Interstate Tool Corp. — *Matched Herringbone Cutters*
Invo Spline Inc. — *Spline Gages*
ITW Heartland—*Burnishing Dies*
Koolant Koolers, Inc. *—Chillers*
Krautkramer Inc. — *Hardness Testers*
Major Gauge & Tool Co. *—Powder Metal Tooling*
Mastertech Diamond Products—*CBN Inserts*
Mayfran International—*Filtration Equipment, Conveyors, Chip Processing Equipment*
Mill Max Tools Pvt. Ltd. *—Profile Milling Cutters, HSS Tool Bits*
Nachi Machining Technology Co. — *Roll Dies*
New Age Chemical Co.

—Cleaners, RPs & Vibe Compounds
NewAge Testing Instruments Inc. — *Hardness Testers*
Optical Gaging Products—*Non-contact Measurement & Inspection Equipment*
Osborn International—*Brushes*
Parker Industries Inc. —*Spline Gages*
Pitch Templates, Inc. — *Pitch Template Inspection Racks*
Rebco Industrial Products—*Involute Milling Cutters*
S.L. Munson & Co. — *Rotary Diamond Dressing Tools*
Sensor Products, Inc. —*Film used to detect pressure distribution and magnitude for measuring gear tooth contact.*
SIFCO Selective Plating—*Brush Plating Equipment & Solutions*
SPF Specialties Ltd. — *Wash & Dry Systems*
Star Cutter Co. — *Bevel Gear Stick Blades*
Tenaxol Inc. —*Polymer Quenchants*
Universal Gear Co. — *Shank & Disc Cutters*
Universal Superabrasives—*Dressing Equipment*
Wendt Dunnington—*Diamond Dressing Rollers, Dressing Equipment*

GEAR WORKHOLDING & FIXTURING

Arbors

Able Tooling
A.G. Davis/AA Gage
Alpha Precision Inc.
B.H. Jones Machine & Gage
Bean Tool, Die & Engineering
Best Engineering, Inc.
Bluco Corp.
Bluegrass Precision Machinery
Bodine Gear Manufacturing
Bourn & Koch Machine Tool Co.
The Broach Masters
Cameron Hydraulic Workholding
D.I.G.I.T., Inc.
Emuge Corp.
Fellows Corp.
Gear Cutting Technology Systems
The Gear Works-Seattle
Gleason Cutting Tools
The Gleason Works
Great Lakes Gear Technologies
Hermes Machine Tool
HPI–Heartech Precision
Index Technologies Inc.
Jack Dustman & Assoc.
Jamal Gear Machinery
LeCount Inc.
M&M Precision Systems
Manufactured Gear & Gage
Nachi Machining Technology Co.
Oerlikon Geartec AG
P.F. Markey, Inc.
Precision Devices, Inc.
Profile Engineering
Redin Corporation
Reid Tool Service Inc.
Russell, Holbrook & Henderson, Inc.
Schunk, Inc.
Selector Spline Products, Inc.
Speedgrip Chuck-Cameron Workholding
Spline Gauges Ltd.
SU America
Tifco Gage & Gear
Toolink Engineering
Universal Gear Co.
W. E. Litwin Assoc.
Western Spline Gages
Wilton Machinery

Chucks

Able Tooling
A.G. Davis/AA Gage
Alpha Precision Inc.
B.H. Jones Machine & Gage
Best Engineering, Inc.
Bluco Corp.
Bluegrass Precision Machinery
Bourn & Koch Machine Tool Co.
Cameron Hydraulic Workholding
D.I.G.I.T., Inc.
Emuge Corp.
Gear Cutting Technology Systems
The Gleason Works
Great Lakes Gear Technologies
Hermes Machine Tool
HPI–Heartech Precision
Index Technologies Inc.
Jack Dustman & Assoc.
Jamal Gear Machinery
LeCount Inc.
M&M Precision Systems
Manufactured Gear & Gage
Oerlikon Geartec AG
P.F. Markey, Inc.
Paul W. Marino Gages
Precision Devices, Inc.
Production Dynamics
Redin Corporation
Reid Tool Service Inc.
Schunk, Inc.
Speedgrip Chuck-Cameron Workholding
Spline Gauges Ltd.
Star Cutter Co.
Sytec Corporation

Tifco Gage & Gear
Toolink Engineering
W. E. Litwin Assoc.
Wilton Machinery

Collets

Able Tooling
B.H. Jones Machine & Gage
Bluco Corp.
Bourn & Koch Machine Tool Co.
D.I.G.I.T., Inc.
Emuge Corp.
Gear Cutting Technology Systems
Gleason Cutting Tools
The Gleason Works
HPI–Heartech Precision
Jack Dustman & Assoc.
Jamal Gear Machinery
M&M Precision Systems
Oerlikon Geartec AG
P.F. Markey, Inc.
Production Dynamics
Reid Tool Service Inc.
Redin Corporation
Selector Spline Products, Inc.
Spline Gauges Ltd.
Sytec Corporation
Wilton Machinery

Modular Fixtures

Alpha Precision Inc.
B.H. Jones Machine & Gage
Bluco Corp.
Bluegrass Precision Machinery
CD Miller & Associates
Colonial Tool Group
Crankshaft Machine Group
D.I.G.I.T., Inc.
Emuge Corp.
Gear Cutting Technology Systems
The Gleason Works
Hermes Machine Tool
Jack Dustman & Assoc.
LeCount, Inc.
Mize & Associates Inc.
P.F. Markey, Inc.
Paul W. Marino Gages
Schunk, Inc.
Scott Machine Tool Co.
Sytec Corporation
W. E. Litwin Assoc.

Toolholders

Able Tooling
A.G. Davis/A.A. Gage
Alpha Precision Inc.
B.H. Jones Machine & Gage
Best Engineering, Inc.
Bluegrass Precision Machinery
Crankshaft Machine Group
Emuge Corp.
Gear Cutting Technology Systems
General Broach & Eng.
The Gleason Works
Hermes Machine Tool
HPI–Heartech Precision
Jack Dustman & Assoc.
Miller Industrial Services
Mize & Associates Inc.
P.F. Markey, Inc.
Production Dynamics
Reid Tool Service Inc.
Santasalo North America
Schunk, Inc.
Speedgrip Chuck-Cameron Workholding
Toolink Engineering
W. E. Litwin Assoc.

Other Fixturing & Workholding

Apex Broach & Machine Co. — *Broach Fixtures, Holders, Pullers & Tools*
Bean Tool, Die & Engineering—*Custom Tooling*
Bluco Corp. — *Expanding Mandrels*
Cameron Sabertooth Mandrel—*Mandrels & Workholding Devices*
CD Miller & Associates—*Hydraulic Workholding Fixtures*
HPI–Heartech Precision Inc. —*Tool Presetters*
JRM International, Inc. —*Hydraulic Locknuts*
Madison Face Driver—*Face Driving Centers*
Precision Devices, Inc. —*Gaging Fixtures*
Redin Corporation—*Special Tooling*
Schunk, Inc. — *Automation Components*
Speedgrip Chuck/Madison Face Driver—*Face Drivers*
SPF Specialties Ltd. — *Pick & Place Systems*
Standard Steel Specialty—*Key Stock*
Sytec Corporation—*Pitch Diameter Locating Fixturing*
Ty Miles Inc. —*Broach Fixturing*
Universal Gear Co.—*Tapered Spline Arbors*

MACHINERY/ EQUIPMENT DISTRIBUTORS

American Machinery—*Liebherr, Lorenz, Hoefler, Klingelnberg, Oerlikon, Apex Broach, Colonial Saw, Kanzaki, Kingsbury, Ransohoff.*
American Wera Inc. — *Wera Werk, Hurth Modul, Samag.*
Ashot USA Inc. — *Ashot Ashkelon Industries.*
Ataka Engineering—*Saikuni Mfg. Co., Ltd.*
Basic Incorporated Group—*Wolf Gear Machines*
Best Engineering, Inc. —*ITW Heartland, Redin.*
Bluegrass Precision Machinery—*Mitsubishi.*
Caledonian Midwest Sales, Inc. —*Ernst Gröb*
Channel Power Transmission—*Speed Reducers, Gears*
Eltech Inc. —*Kapp, Niles, SU America, MGF GmbH.*
Gear Cutting Technology Systems Inc. —*Lambert Fine-Pitch Gear Hobbing and Worm/Thread Milling Machines, Wahli Fine Pitch Hobbers*
Geartech Ltda. - Tecnologia de Engrenagens—*Hexagon Software.*
Great Lakes Gear Technologies—*Fässler Gear Honing Machines, Höfler Gear Grinding Machines, Ernst Gröb Spline Rolling Machines, Escofier Gear Burnishing Machines, Sanyo Gear Chamfering Machines, Hoffmann Filtration Equipment, StarGear Software*
Jamal Gear Machinery

Ltd. —*Grinding Wheel Dressing Machines*
Kapp Technologies—*Kapp GmbH and Niles Berlin.*
Miller Industrial Service—*Tornos Technologies.*
National Metrology—*Metronics.*
Ohio Broach & Machine—*Tesa Measurement Systems, UVA Machine Company.*
Pacific Gauge & Machine Co. — *Lorenz, Liebherr, Vermont Machine, Star, Klingelnberg, Invo Spline Gaging Ply-Mar Tool Co. Sigma Pool, including Liebherr Hobbers and Grinders, Lorenz Shaping Machinery, Oerlikon Gear Cutting Machines & Grinders, Klingelnberg Cutting, Grinding & Inspection Machinery, and Kanzaki Gear Shavers; ITW Heartland Gear Inspection and Burnishing Equipment*
Precision Gage Co. — *Vari-Roll gear testers.*
Reid Tool Service Inc. —*Fellows Corp.*
Toolink Engineering—*König MTM.*
Trisys—*Rhf KG (Germany).*
V & R Associates—*Laschet & Partner.*
W.E. Litwin Assoc. — *Speedgrip Chuck-Cameron Workholding Chuck Professional Tool Grinding*
Wes-Tex Gear Inc. — *American Pumping Units*

TRAINING & EDUCATION

Colleges/ Universities

Drivetrain Technology Center
I.S.P.J.A.E.
Mississippi State Univ.

Gear Schools

AGMA
Aplus Engineering Inc.
Best Engineering, Inc.
Bourn & Koch
Machine Tool Co.
Cole Mfg. Systems, Inc.
Drive Systems Technology, Inc.
Educational Systems Workshops
Euro-Tech Corp.
Eversolv Software
Fellows Corp.
Geartech
Gleason Cutting Tools
The Gleason Works
Hane Industrial Training
Hy-Mech Systems Inc.
I.S.P.J.A.E.
Koepfer America, L.L.C.
Lufkin Industries Gear Repair
M&M Precision Systems
Nachi Machining Technology Co.
Philadelphia Gear Corp.
Salem Company
Trogetec Inc.
Web Gear Services

Research Institutions

CETIM
CIATEQ
Drivetrain Technology Center
Gear Research Institute
Gearesearch Assoc.
I.S.P.J.A.E.
Lambda Research
Michigan Mfg. Technology Ctr.
Mississippi State Univ.
NASA Glenn Research Center

Trade Associations

AGMA
ASM International
IMTS–International Mfg Technology Show
Metal Powder Industries Federation
The Society of Mfg. Engineers

Other Training & Education

Electronics, Inc. —*Shot Peening Training*
Michigan Manufacturing Technology Center—*Manufacturing Training & Consulting*

For years, *Gear Technology's* readers have relied on the annual buyers guide as the best resource for finding gear industry suppliers. Next year we would like to supply this directory in an easy-to-use electronic format.

YOUR OPINION COUNTS! VOTE TODAY!

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YES! I want the buyers guide on CD-Rom next Year!

Circle 359
NO! Leave it the way it is!

COMPANY INDEX

Welcome to *Gear Technology's* Buyers Guide 2001, the definitive guide to the gear industry for the 21st century. Use this index to locate contact information for companies listed in the Buyers Guide 2001 Products & Services Directory. We have tried to ensure that company names and addresses are correct. However, we cannot be held responsible for errors of fact or omission. If your company is not listed and you would like to be included in the next directory, please e-mail *people@geartechnology.com*, call (847) 437-6604 or fax (847) 437-6618, and we will be pleased to add your company to our mailing list.

GIHP indicates companies whose pages can be found on *The Gear Industry Home Page™* at *www.geartechnology.com.* PTHP indicates companies whose pages can be found on *The Power Transmission Home Page™* at *www.powertransmission.com.* Companies advertising in this issue of *Gear Technology* are indicated by boldface type.

Apollo America Corporation
2000 Town Center
Suite 1450
Southfield, MI 48075
Ph: 248-355-0666
Fax: 248-355-9337

Applied Mechaniques
12 Tallarook Close
Toronto NSW 2283
Australia Ph: (61) 49593573
Fax: (61) 49504538

Applied Process Inc.
12238 Newburgh Rd.
Livonia, MI 48150-1046
Ph: 313-464-2030
Fax: 313-464-6314
jkeough@appliedprocess.com
www.appliedprocess.com

Arrow Gear Company
2301 Curtiss Street
Downers Grove, IL 60515
Ph: 630-969-7640
Fax: 630-969-0253
gllynn@arrowgear.com
www.arrowgear.com
PTHP

Arte Corporation
1111 Foster Avenue
Nashville, TN 37210
Ph: (615) 254-6691
Fax: (615) 254-6656
tarun@artecorp.com
www.artecorp.com

Asco Sintering Co.
2750 S. Garfield Ave.
Commerce, CA 90040
Ph: 213-723-5121
Fax: 213-888-9968

Asco Sintering Co.
635 Park Meadow, Road #102
Columbus, OH 43081
Ph: 614-882-7460
Fax: 614-882-7396
elw614882@aol.com

Ashot Ashkelon Industries
Gear Systems Division
P.O. Box 21
Ashkelon 78100
Israel
Ph: (972) 767-21581
Fax:(972) 767-21711
joseph.barkan@ashot.co.il

Ashot USA Inc.
485 Madison Ave.
14th Floor
New York, NY 10017
Ph: 212-223-4050
Fax: 212-223-4156

ASI Machinery Company
516-D River Highway #200
Mooresville, NC 28117
Ph: (704) 881-0790
Fax: (704) 881-0851
asimachinery@conninc.com
www.seokyung.co.kr

ASM International
Materials Information
Materials Park, OH 44073
Ph: 216-338-5151
Fax: 216-338-4634
mem-serv@po.asm-intl.org

Aston Metallurgical Services Co. Inc.
4201 N. Ravenswood Ave.
Chicago, IL 60613
Ph: 773-528-9830
as@astonmet.com
www.astonmet.com

ATA Gears, Inc.
19885 Detroit Rd.
Rocky River, OH 44116
Ph: 440-356-0289
Fax: 440-356-0289
www.ata-gears.fi
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PTHP

Ataka Engineering Co., Ltd.
2-218 Kamiyashiro Meito-Ku
Nagoya Aichi
Japan
Ph: (81) 52-772-0690
Fax: (81) 52-772-0692
ataka@mxb.meshnet.or.jp

Automated Precision, Inc
7901-C Cessna Ave.
Gaithersburg, MD 20879
Ph: 301-330-8100
Fax: 301-990-8648

Avon Broach & Production Co.
1089 John R. Road
Rochester, MI 48307
Ph: 248-689-0800
Fax: 248-651-7250
avonbroach@ix.netcom.com
www.avonbroach.com

Avon Gear Co.
2770 Research Drive
Rochester Hills, MI 48309
Ph: 248-853-6500
Fax: 248-853-1437
avon@agcoa.com

A/W Systems Company
612 E. Harrison
P.O. Box 1344
Royal Oak, MI 48067
Ph: 248-544-3852
Fax: 248-544-3922

Axicon Technologies, Inc.
2857 Banksville Road, Bldg #3
Pittsburgh, PA 15216-2815
Ph: 412-531-7500
Fax: 412-531-7035
mwyeth@axicontechnologies.com
PTHP
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B

B&R Machine and Gear Corp.
4809 U.S. Highway 45
P.O. Box 536
Sharon, TN 38255
Ph: 901-456-2636
Fax: 901-456-3073
brgear@aeneas.com
www.brgear.com
PTHP

B.H. Jones Machine & Gage
95 Rte. 17-A
P.O. Box 586
Drewsville, NH 03604
Ph: 603-835-9033
Fax: 603-835-9033
bhjones@fmis.net

Balzers Tool Coating,Inc.
661 Erie Ave.
N. Tonawanda, NY 14120
Ph: 716-693-8557
Fax: 716-695-1995

Barit International Corp.
3384 Commercial Ave.
Northbrook, IL 60062
Ph: 847-272-8128
Fax: 847-272-8210
sales@barit.com
www.barit.com
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Basic Incorporated Group
Basic Machine Tools
P. O. Box 36276
Los Angeles, CA 90036
Ph: 323-933-7191
Fax: 323-933-7487
wolf@basicmachinetools.com
www.basicmachinetools.com
GIHP

Bates Technologies, Inc.
9059 Technology Dr.
Fishers, IN 46038-0213
Ph: 800-331-6778 or 317-841-8805
Fax: 317-841-9443
www.batestech.com

Bean Tool, Die & Engineering
1107 East Main
Clarksville, AR 72830
Ph: 501-754-2217
Fax: 501-754-8592

Becker Gearmeisters, Inc.
235 Harrison Ave
Miller Place, NY 11764-3108
Ph: (800) 423-2537 or (516) 821-3967
Fax: (631) 821-3870
EGB4Gears@aol.com

Belden Machine Corporation
2500 Braga Drive
Broadview, IL 60153
Ph: 708-344-4600
Fax: 708-344-9321
info@beldenmachine.com
www.beldenmachine.com
PTHP

Bengal Industries Inc.
11346 53rd St. North
Clearwater, FL 33760
Ph: 727-572-4249
Fax: 727-573-2428

Best Engineering Co., Inc.
5600 S. Westridge Dr.
P.O. Box 510797
New Berlin, WI 53151-0797
Ph: 414-784-2200
Fax: 414-784-2541

BestMetal Corp.
925 Dieckman St.
Woodstock, IL 60152
Ph: 800-277-5800
Fax: 815-337-8803
jim@bestmetal.com
www.bestmetal.com

Bevel Gears (India) Pvt. Ltd.
17(b) Sadaramangala Industrial Area
Whitefield Road
Bangalore, Karnataka 560 048
India
Ph: (91) 8410239
Fax: (91) 8410185
jamalgrp@vsnl.net.in
www.jamalgears.com

Biddle & Mumford Gears Ltd.
8-18 Kings Place
Buckhurst Hill, Essex IG9 5EB
United Kingdom
Ph: (44) 208515-4615
Fax: (44) 208505-3718

Bijur Lubricating Corporation
50 Kocher Drive
Bennington, VT 05201
Ph: 802-447-2174
Fax: 802-447-2174
bijur@worldnet.att.net
www.bijur.com

Blanchat Machine Co.
3323 Maple
Wichita, KS 67277-2290
Ph: 316-943-4257
Fax: 316-943-0005

Bluco Corp.
509 Weston Ridge Drive
Naperville, IL 60563
Ph: 800-535-0135
630-637-1820
Fax: 630-637-1847
info@bluco.com
www.bluco.com

Bluegrass Precision Machinery
442 Three Springs Rd.
Bowling Green, KY 42104
Ph: 502-842-7201
Fax: 502-842-7242

Bodine Gear Manufacturing
2500 West Bradley Place
Chicago, IL 60618
Ph: 773-478-3515
Fax: 773-478-3232
pmr@bodine-electric.com
www.bodinegears.com
GIHP

Bodine Electric Company
2500 West Bradley Place
Chicago, IL 60618
Ph: 773-478-3515
Fax: 773-478-3232
info@bodine-electric.com
www.bodine-electric.com
PTHP

Bourn & Koch Machine Tool Co.
2500 Kishwaukee St.
Rockford, IL 61104
Ph: 815-965-4013
Fax: 815-965-0019
bournkoch@worldnet.att.net
www.bourn-koch.com
GIHP

Brewer Machine & Gear Company
2820 Clark Ave.
St. Louis, MO 63178
Ph: 314-534-4021
Fax: 314-534-4026
info@brewertensioner.com
www.brewertensioner.com

Brighton Laboratories
1100 Old U.S. 23
Howell, MI 48843
Ph: 810-632-3045
Fax: 810-632-3052

The Broach Masters Inc.
1605 Industrial Drive
Auburn, CA 95603
Ph: 530-885-1939
Fax: 530-885-8157
sales@broachmasters.com
www.broachmasters.com

Buckeye Gear Co.
5130 Richmond Rd.
Bedford Hts, OH 44146
Ph: 216-292-6424
Fax: 216-292-6454
skidmore@earthlink.net
www.buckeyegears.com

Bunting Bearings Corp.
1001 Holland Park Blvd.
P.O. Box 729
Holland, OH 43528
Ph: 419-866-7000
Fax: 419-866-0653

Burgess-Norton Mfg. Co.
737 Peyton Street
Geneva, IL 60134
Ph: 630-232-4100
Fax: 630-232-3790
www.burgessnorton.com

Burlytic Systems
100-1 Crawford Street
Leominster, MA 01453
Ph: 508-466-9495
Fax: 508-466-9499
www.burlytic.thomasregister.com

C

Caledonian Midwest Sales, Inc.
5497 Daniel Drive
Brighton, MI 48114
Ph: 810-227-3977
Fax: 810-227-4771
cms-grob@msn.com

Calicut Engineering Works Ltd.
26A, Camac Street
P.O. Box 9119
Calcutta, West Bengal 700 016
India
Ph: (91) 33-2475693 or 33-2401979
Fax: (91) 33-2476072
calicut@cal3.vsnl.net.in

Cameron Hydraulic Workholding
859 E. Whitcomb Blvd.
Madison Heights, MI 48071
Ph: 248-588-0215
Fax: 248-588-4570
speedgrip@tlh.net
GIHP

Cameron Sabertooth Mandrel
859 E. Whitcomb Blvd.
Madison Heights, MI 48071
Ph: 248-588-0215
Fax: 248-588-4570
speedgrip@tlh.net
GIHP

Can-Eng Furnaces Ltd.
P.O. Box 235
Niagara Falls, NY 14302
Ph: 905-356-1327
Fax: 905-356-1817

Capital Induction
6505 Diplomat Dr.
Sterling Heights, MI 48314
Ph: (810) 254-2740

Fax: (810) 254-1951

Capstan Atlantic
10 Cushing Dr.
Wrentham, MA 02093
Ph: 508-384-3100
Fax: 508-384-3196
capstan2@aol.com

Carbon City Products
150 Ford Rd.
St. Marys, PA 15857
Ph: 814-834-2886
Fax: 814-834-9091
jrb@carboncity.com
www.carboncity.com

Carnes-Miller Gear Co., Inc.
13879 Browns Hill Road
P.O. Box 268
Locust, NC 28097
Ph: 704-888-4448
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dan@cmgear.com
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General Surface Hardening Inc.
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Generated Gear & Machine Inc.
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Gerhardt Gear Co.
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Merit Gear Corp.
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Ph: 516-437-6700
Fax: 516-326-8827 GIHP
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Redin Corporation
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Wison Products, Inc.
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WMW Machinery Company
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Ph: 517-485-3750
Fax: 517-485-0501
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Ph: 916-365-4565
Fax: 916-365-9560
wgc@snowcrest.net
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www.sunrising.com/zic.htm

PTHP

Parallel Axis Gear Grinding: Theory & Application

Roger Burdick

This article was originally presented at the Society of Manufacturing Engineers' Gear Design and Manufacturing Seminar, January, 2000.

Introduction

The goal of gear drive design is to transmit power and motion with constant angular velocity. Current trends in gear drive design require greater load carrying capacity and increased service life in smaller, quieter, more efficient gearboxes. Generally, these goals are met by specifying more accurate gears. This, combined with the availability of user-friendly CNC gear grinding equipment, has increased the use of ground gears.

Some of the first gear grinding machines were manufactured between 1910 and 1920, by both American and European machine builders. Improvements in machine design followed, so that by the late 1930s, extremely accurate gears were being ground. The equipment in use at that time, and for many years after, required operators having a very high level of skills.

While the same basic principles have been in use for gear grinding for many years, recent developments in CNC machines employing digital drives and sophisticated software have significantly changed the nature of the equipment used.

Advantages of Ground Gears

For many applications where gears transmit power at low speeds, or where loads are low and positional accuracy is not an issue, shaped, hobbed, or shaved gears will be adequate to meet the design requirements. As operating conditions become more demanding, gears of higher quality levels will be specified.

Hardened gears have increased strength and wear resistance, making it possible to reduce the size of the gears while increasing the load carrying capacity. This offers benefits in both economy and efficiency. Grinding is generally the preferred finishing method for hardened gears, particularly those which may have significant distortion due to heat treatment.

Gears manufactured from difficult-to-machine materials, such as high-temperature alloys, are frequently ground, abrasive machining often proving to be more economical than finishing by shaping or hobbing. In some cases, the gears or splines are ground from solid.

In addition to having accurate lead and involute profile, good quality ground gears have excellent tooth spacing: both pitch (tooth-to-tooth spacing), and index (cumulative spacing). Minimizing spacing errors provides better load sharing between teeth, resulting in greater bending fatigue resistance and lower noise.

Gear Grinding Methods

There are two basic methods of gear grinding—formed wheel grinding and generating grinding.

Formed Wheel Grinding. This method may be employed to finish either spur or helical gears (see Figure 1). If helical gears are to be ground, the machine will have a provision for setting the grinding wheel spindle to the helix angle of the gear and will be equipped to impart a slight rotary motion to the gear as it is ground. The grinding wheel is accurately dressed to the shape of the gear tooth space, the part is reciprocated axially past the wheel, and as the gear is ground, it is indexed to each tooth space. With appropriate equipment, formed wheel grinding machinery can be used to grind internal gears. Also, formed wheel grinding may allow the use of small diameter wheels to grind gears that are located near shoulders or other features that preclude the use of larger standard wheels.

Generating Grinding. In the generating method of gear grinding, the shape of the gear tooth is the result of the com-

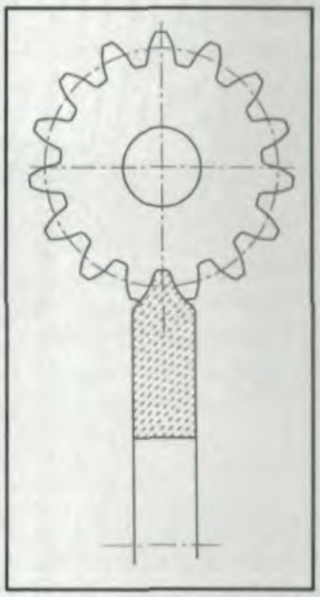

Fig. 1—Gear tooth form development by formed wheel grinding.

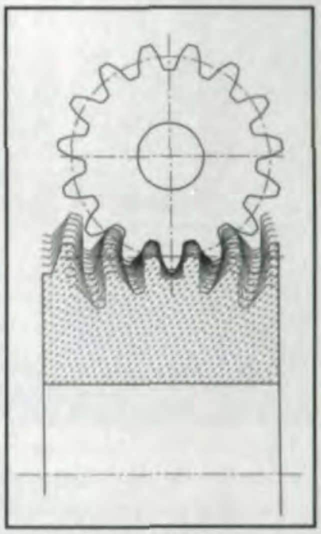

Fig. 2—Gear tooth form development by continuous generating.

Roger Burdick
has been involved in gear manufacturing for 30 years. He is a project engineer for Aero Gear Inc. (Windsor, CT) and is a member of the AGMA Aerospace Gearing Committee.

bined movements of the work piece and the grinding wheel, which is usually dressed to the shape of a rack tooth. Generating grinding is done by one of the following systems:

• Continuous generating gear grinding is done on a machine using a grinding wheel with a threaded rack tooth form similar to a worm (see Figure 2). The gear rotates continuously as it moves axially past the grinding wheel, which is fed in at the end of each stroke. The mechanics of the operation are analogous to hobbing.

• Single index generating involves grinding with a double-tapered wheel, which is dressed to the shape of a rack tooth (see Figure 3). The wheel is reciprocated as one tooth space is ground, while the work table feeds back and forth slowly at right angles to the gear's helix angle. After one tooth space is ground, the work indexes, the next space is ground, etc. Very large gears are usually ground using this method.

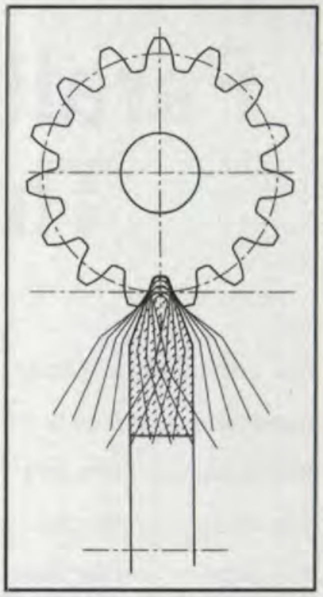

Fig. 3—Gear tooth form development by single-index generating.

Gear Grinding Technology

Grinding Wheels. Regardless of the type of machinery used, selection of the appropriate grinding wheel is of utmost importance. Wheels are either aluminum oxide, ceramic (seeded gel), or cubic boron nitride (CBN). In addition to abrasive type, the grit size, wheel hardness and structure must be selected to produce an acceptable tooth form and surface finish without burning.

Traditionally, gear grinding has been done using aluminum oxide wheels; they are readily available in a variety of grades and sizes, and are easily dressed. In recent years, it has become more common to use ceramic wheels. Though they are somewhat more difficult to dress, their structure makes it possible to dress much less frequently. CBN wheels are either plated or dressable, with the plated wheels being much more commonly used. Disadvantages of CBN wheels are cost, particularly in situations where part volume is low, and the lead time required for wheel manufacturing.

Grinding wheel balancing is critical, particularly for larger size wheels. The wheels may be balanced on a dynamic balancing machine before mounting on the gear grinder. Alternatively, some grinders are equipped with automatic balancing equipment that maintains the balance of the wheel as it is in use.

Wheel Dressing. For many years, wheel dressing on any type of gear grinder was done using mechanical dressers equipped with single-point diamonds. Diamond tool setting was critical and diamond wear had to be very carefully monitored. Selecting the proper diamond traverse speed was crucial to produce the required surface finish. Successful wheel dressing was dependent upon the skill and experience of the machine operator. Currently available machinery is equipped with CNC dressing equipment, designed to use rotary diamond dressing rolls with either plated or hand-set diamonds. These combine the advantages of longer life with greater accuracy. Wheel dressing parameters have to be carefully developed to give both the gear tooth form and surface finish required. Software is available not only for involute gears and splines, but also for non-involute forms.

Tooling. One very important element in gear grinding is the workholding tooling used. No matter how accurate the grinding machine is, or how carefully the parts are processed, if the workholding or driving tooling is not properly designed, built and maintained, it will be impossible to consistently grind parts to the quality levels required.

Grinding Fluids. Coolants of various types are used to keep the grinding wheel clean and free-cutting and to prevent localized overheating or burning of the work, particularly on carburized and hardened gears. Carburized gears for critical applications are generally inspected after grinding by nital etching to reveal burning.

Gear grinding is most often done using petroleum-based oils. As grinding wheel speeds have increased, particularly in applications where CBN wheels are employed, current trends are toward the use of less viscous oils. This reduces foaming and allows the use of refrigeration units to chill the oil, maintaining a constant temperature to reduce thermal expansion of both the work piece and the machine. In some cases, special oils have been developed specifically for gear grinding. For some applications, grinding may be done using water-based grinding fluids. Fluid maintenance has also become much more critical, generally using textile or paper filter media to remove abrasive and metallic fines from the fluid to help produce better surface finishes.

One of the things that requires operator attention is the correct placement of the grinding fluid supply lines. It is advantageous to have them placed as close as possible to the grinding wheel, positioned so that the rotation of the wheel will tend to carry the fluid into the grinding zone. As the wheel is dressed, it is necessary to occasionally reposition the nozzles.

A frequent source of environmental concern has been the airborne oil mist caused by oil being thrown from the

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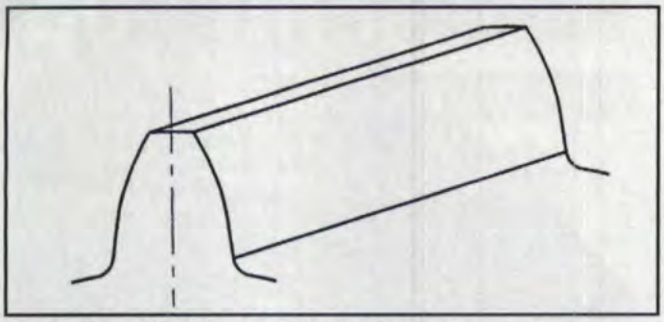

Fig. 4—Unmodified spur or helical tooth form.

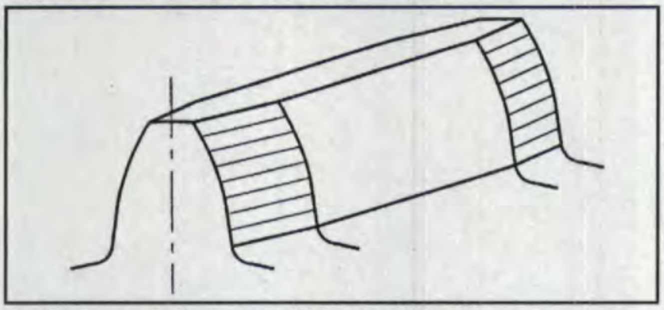

Fig. 5—Spur or helical tooth with lead modification.

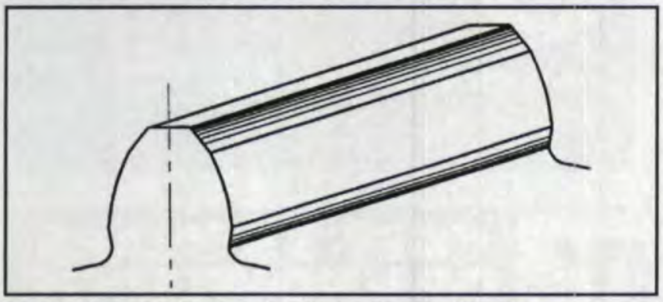

Fig. 6—Spur or helical tooth with involute modification.

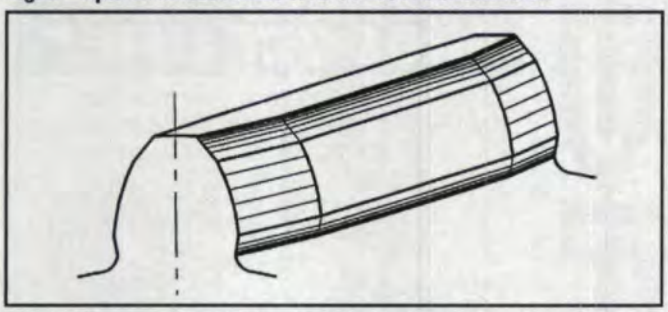

Fig. 7—Spur or helical tooth with both lead and involute modification.

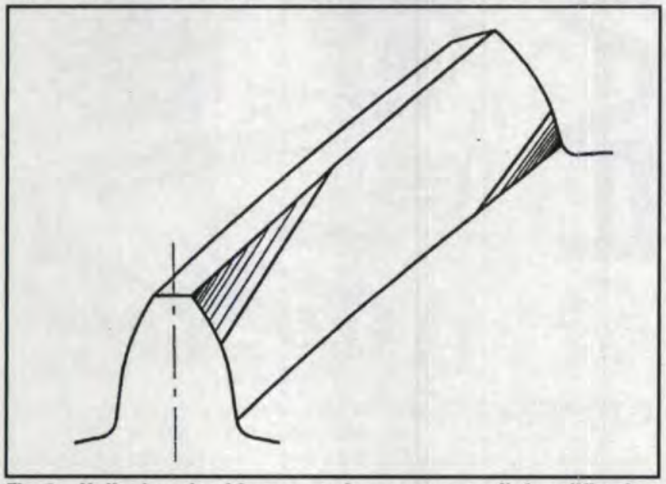

Fig. 8—Helical tooth with generated engagement relief modification.

grinding wheel at operating speeds. Machines now being built generally utilize an enclosure that helps contain the mist, combined with a recirculating air filtration unit.

Electronic Stock Dividing. One of the features of many recently-built gear grinders is automated equipment for locating the center of the tooth space before the grinding operation begins. This may be done by probing the tooth faces on one or more teeth, or by using a proximity detector. Accurate stock dividing allows equal stock to be removed from both flanks of the teeth. This is particularly useful in grinding carburized and hardened gears, where case depth is an important requirement. Some machine manufacturers have taken this a step further by identifying the widest space and dividing the stock at that point.

On-Machine Inspection. Another recent development is on-machine gear element inspection after grinding, sometimes including the capability of generating machine corrections automatically. Inspection is accomplished while the part is still mounted in the machine, using a probing system similar to a CMM with appropriate software. This is a particular advantage on larger workpieces, where work piece handling and fixturing are time consuming.

Gear Tooth Modification

Traditionally, gear tooth modifications on either spur or helical gears have been limited to involute modifications, removing a small amount of material at the tip and/or at the form diameter to compensate for tooth deflections under load, thereby providing more gradual tooth engagement (see Figure 6). This may sometimes be combined with a slight amount of lead modification (or crown), removing material at each end of the tooth face, to assure that the forces on the teeth are not concentrated at the ends of the teeth (see Figures 5 and 7). The negative effects of these strategies are that loads are distributed over smaller areas of the tooth surface, thereby increasing the contact stresses and the chance of surface fatigue failures.

Machines are currently available that allow topological grinding, thereby modifying the tooth flank profile on helical gears to allow gradual engagement and disengagement of each tooth pair, reducing noise and vibration and making possible smaller, more compact gearboxes. However, conventional profile and lead

ANOTHER RECENT DEVELOPMENT IS ON-MACHINE GEAR ELEMENT INSPECTION AFTER GRINDING, SOMETIMES INCLUDING THE CAPABILITY OF GENERATING MACHINE CORRECTIONS AUTOMATICALLY. INSPECTION IS ACCOMPLISHED WHILE THE PART IS STILL MOUNTED IN THE MACHINE, USING A PROBING SYSTEM SIMILAR TO A CMM WITH APPROPRIATE SOFTWARE.

modifications are still the only choice for spur gearing, as tooth engagement occurs along the entire face width simultaneously.

The tooth engagement dynamics of helical gears are different. Initial contact occurs at the upper corner of each tooth, and the line of contact is diagonal to the tooth face. Therefore, it would be appropriate to introduce a modification that offers relief at the initial point of contact and runs parallel to the line of contact on the tooth (see Figure 8). At the American Gear Manufacturers Association 1996 Fall Technical Meeting, W. Kiess and S. Price of Höfler Maschinenbau presented a paper entitled, "Noise Reduction Through Generated Engagement Relief Modifications." Höfler is a German builder of gear grinding machinery. Recent advances in machines and controls have made possible the grinding of helical gears with this sort of tooth modification on single index generating-type machines. By allowing additional material to be removed from the tooth only at the points of engagement and disengagement, a larger tooth flank area is maintained and Hertzian contact stress is minimized. It is reported that helical gears modified in this manner have less measured vibration than unmodified gears, allowing designs that require less volume and weight. The results of research on the advantages of modified helical gears was presented by the late Dr. Eng. Kiyohiko Umezawa at the AGMA's 1998 Fall Technical Meeting in a paper entitled, "Low Vibration Design on a Helical Gear Pair" (see *Gear Technology*, Jan/Feb 2000). Topographic inspection equipment is available to monitor the engagement relief modification that is produced.

Conclusion

Gear grinding equipment has been available for over eighty years, providing a means of finishing high quality gears. Gear grinding may provide substantial savings in gear finishing costs. The machines that are currently available have features that reduce reliance on operator experience and skill while economically and consistently producing high quality gears in a way never before possible. ○

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3. Townsend, D., Ed. "Dudley's Gear Design Handbook," McGraw-Hill, 1992.
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If you would like more information about **Aero Gear, Inc., circle 318.**

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New Honing Machine from Mitsubishi

Mitsubishi introduced its new ZS25A CNC Gear Honing machine at IMTS 2000. The machine is designed to perform finishing operations for hardened gears and is aimed at mid-volume automotive applications where quality of the final tooth geometry is essential.

The ZS25A uses a synchronous technology to deliver superb index accuracy while improving lead and involute characteristics.

For more information, contact Mitsubishi Heavy Industries America, 1250 Greenbriar Drive, Suite B, Addison, IL 60101-1065 or call (630) 693-4700.

Circle 325

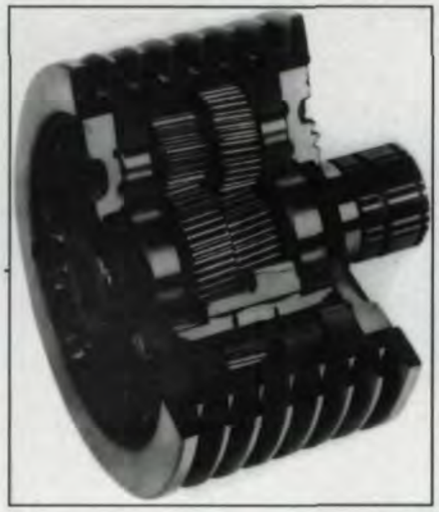
Direct Drives Update Liebherr's LC80 Hobbers

Liebherr Gear Technology Co. demonstrated the newest generation of its model LC80 dry hobbing machines at IMTS 2000. The high-speed hobbing machine now comes equipped with direct drives for cutter and table spindles.

The direct drives permit higher hob and table speeds (9,000 rpm and 800 rpm, respectively) and reduce the number of mechanical transmission components in the machine, improving reliability and maintainability.

For more information, contact Liebherr Gear Technology, 1465 Woodland Dr., Saline, MI 48176 or call (734) 429-7225.

Circle 326



Andantex Announces Space Saving Epicyclic Drive

Andantex USA, Inc. has introduced their compact, Type SA epicyclic drive, which can be used as a differential to control web tension, correct register and balance speed and torque. It can also be used as a speed reducer with ratios from 2:1 to 260:1.

The differential consists of three elements, the case-planet carrier, the torque arm sleeve sun-gear and the central bore sun-gear, which are mechanically connected by gears and therefore impart a definite speed and torque relationship on one another.

Precise speed adjustment is achieved by driving one element at constant speed, one element at variable speed, and outputting on the third element. Register control or phase-shifting is achieved with one constant-speed input and one intermittent input. It is also possible to balance torque and speed between two mechanically connected cylinders by inputting one element of the differential and outputting on the other two.

Industries using the SA include machine tools; pulp, paper and printing equipment; wire and steel manufacturing; textile processing; fiber optics manufacturing; film processing; food machinery; and web handling equipment.

For more information, contact Andantex USA at 1705 Valley Road, Wanamassa, NJ 07712 or call (800) 713-6170.

Circle 327

Fellows Introduces New Gear Shaper

The new High Performance Universal gear shaping machine was introduced at IMTS 2000. The new machine comes with a uniquely designed "live upright."

The live upright design is a nested configuration that results in minimum spindle overhang compared to alternate arrangements. The resulting increased spindle stiffness allows higher metal removal rates with premium surface finish and shape qualities. Standard features also include hydrostatic spur guide, hydraulic fixture clamping and through-hole chip flow, rear exit chip conveyor, totally enclosed guarding and HSK quick-change cutter interface.

The new High Performance Universal gear shaper accepts workpiece diameters up to 300 mm (11.75") and face widths up to 127 mm (5").

For more information, contact Fellows Corporation, Precision Drive, P.O. Box 2001, Springfield, VT 05156-2001 or call (802) 886-8333.

Circle 328

Alpha Introduces V-Drive Gearhead

Alpha Gear Drives, Inc., has introduced its V-Drive series of high-precision, right-angle gearheads for economy servomotor applications. The compact right-angle design is intended for use in applications where space is at a premium.

The V-Drive is currently available in sizes ranging from 50 mm to 100 mm and ratios from 4:1 to 40:1. It also offers six output styles, including flange mount, hollow shaft smooth, hollow shaft keyed, shaft mount smooth, shaft mount keyed and a spline shaft option for rack and pinion applications.

The V-Drive incorporates a specially designed, optimized tooth profile that promotes longer life due to less friction. Additional benefits of the tooth design include greater torque capabilities and higher precision. According to the manufacturer, the V-Drive boasts efficiencies as high as 95% and comes with a backlash rating of 3 arc minutes or less.

For more information on the V-Drive series, call Alpha Gear Drives at (847) 439-0700.

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THE NAME GAME

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

"What's in a name? That which we call a rose By any other name would smell as sweet." —William Shakespeare, Romeo and Juliet (act ii, sc. 1)

"A good name is better than riches." —Miguel de Cervantes, Don Quixote (Ch. xxxiii)

The addendum team has just returned from IMTS 2000, and we were surprised to see several new names among the gear industry suppliers at the show.

Perhaps most notable for the gear industry was National Broach & Machine Co.'s announcement that they have changed their name to Nachi Machining Technology Company. Those familiar with National Broach know that the Macomb, Michigan based company has been owned for almost 10 years by the Nachi Corporation of Japan, a leading manufacturer of machine tools, antifriction bearings, precision cutting tools, hydraulic equipment and specialty steel, with customers worldwide in a variety of industries.

The name change is a formal recognition of the global reach and technical expertise of the combined companies, says Raymond Wagner, Vice President of Marketing & Sales. "Nachi has already invested over $40 million in our Macomb, Michigan facility so we can provide world-class products," says Wagner. "We've also expanded our product line. In addition to broach tools, gear shaving tools and related machines, we now offer hobs, shaper cutters and precision roll form racks. Our machine technology has benefited from Nachi's background as well. From CNC broach machines to CNC vertical roll forming machines, we now have advanced machining solutions for every market."

Together, National Broach and Nachi have more than 140 years of combined experience in the manufacture of broaching and gear manufacturing equipment and tools.

Nachi Machining Technology Co. will retain the familiar trade name "Red Ring," which is present on all of its products.

Another company taking on a new identity at IMTS was IonBond Inc., formerly known as Multi-Arc Inc. The supplier of thin-film coating services and equipment merged with Bernex in 1997 and this year adopted one of its most popular trade names as the overall company name.

Finally, Kapp Sales and Service and Kapp Tech, formerly separate companies, have announced that they have jointly formed Kapp Technologies. The new partnership represent Kapp GmbH and Niles GmbH by providing machine sales, parts and service as well as CBN wheel engineering, manufacturing and replating, according to a press release issued at IMTS. Kapp Technologies will continue to operate out of the Boulder, CO facility the two companies previously shared.

We apologize to any companies who have been left out of this short list. Any omissions were purely unintentional and should be blamed on the short attention span of the addendum staff. However, if your gear-industry company has recently changed names, or if you know of any others, please let us know. We consider it our duty to inform the public, so we're posting a scorecard on our website to help everyone keep track of who is who, now that they're no longer who they once were, even in cases when they're still who they've always been. Visit us at *www.geartechnology.com.*

Nachi Machining Technology (Formerly National Broach & Machine).

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