GEAR TECHNOLOGY

MARCH/APRIL 1999

The Journal of Gear Manufacturing

HEAT TREATING

- INNOVATIONS IN HEAT TREATING PARTS WASHING
- FATIGUE ASPECTS OF CASE HARDENED GEARS
- METALLURGY AND GEAR DESIGNS
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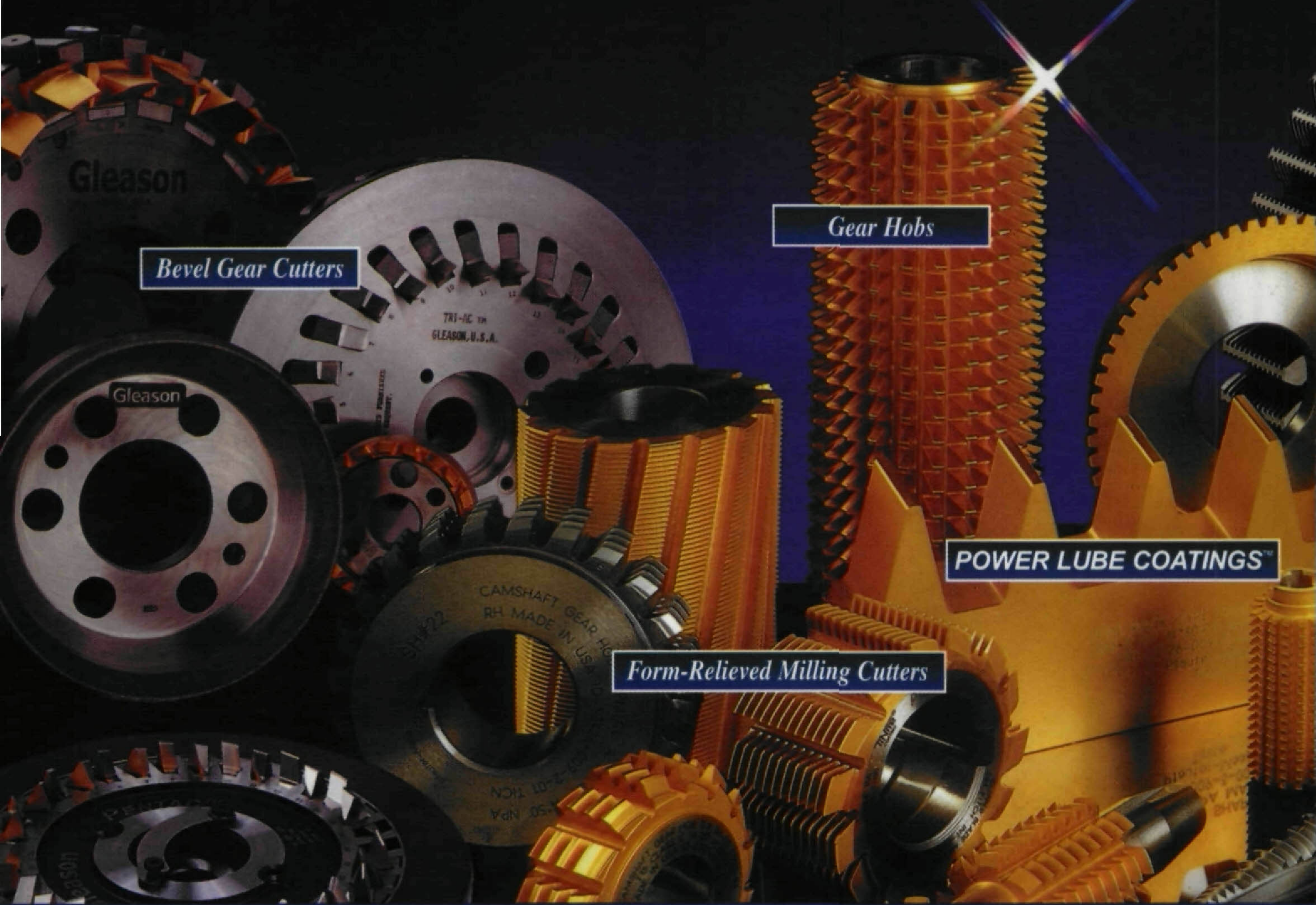

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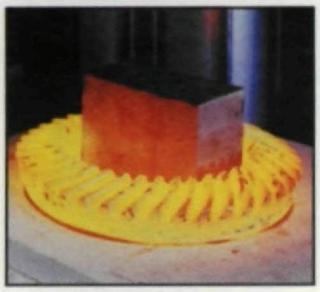
FEATURES

13

DIRECTORY

DEPARTMENTS

64



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CIRCLE 114

Navigating Uncharted Waters in Cyberspace

I'd like to share with you a vision of the future. It takes place in cyberspace, and it's coming soon to a computer near you. Whether you like it or not, and whether you're ready or not, the Internet is changing the way business is conducted.

My vision is filled not only with online information, but also with online transactions. By now we've all heard the success stories of cybersales pioneers such as *Amazon.com* and Dell Computers, who have capitalized on the Internet's ability to reach the masses. Today, however, this quick and easy way to reach the consumers of mainstream products such as books, CDs and videos is fast becoming the way to reach industrial buyers as well.

The question is whether manufacturers of industrial goods, such as gears, can follow the *Amazon.com* model and set up online purchasing systems through their Web sites. For some, the answer is still probably no. But there are a number of stocking distributors and manufacturers of catalog gears who have already added e-commerce to their sales repertoires. A case in point is the Web site of W. W. Grainger, Inc., the well-known catalog supplier of industrial goods including gears. The site at *www.grainger.com* offers online purchasing of any item found in the company's catalog.

However, a system that's simple and elegant for buying CDs or even stock gears breaks down when you're selling custom gears or other more substantial products. The kind of customer looking for these products will always need a more personal relationship with his supplier. He'll want to see what he's buying and meet the people he's buying from.

Many of you are this type of customer, especially when it comes time to buy major items like machine tools. Face-to-face contact is what makes trade shows like IMTS and the upcoming Gear Expo 99 so important. You can get important personal contact with many suppliers in one place. You can see the machines in action and judge one against the other.

Much of this personal side of the business will become easier to conduct electronically as computers become more powerful and our access to the Internet becomes faster. Instead of just reading about a new machine, we'll be able to see videos of it in operation. We'll be able to walk around a virtual version of the machine, press the buttons and make it go. Maybe we'll even be able to cut virtual gears online. Perhaps a real salesperson will be able to lead a whole team of us on a virtual tour of the machine and his company's manufacturing facility. We'll probably be able to see his face, and he'll see ours. We'll ask questions and he'll answer them in real time. We'll both save a lot of time and money.

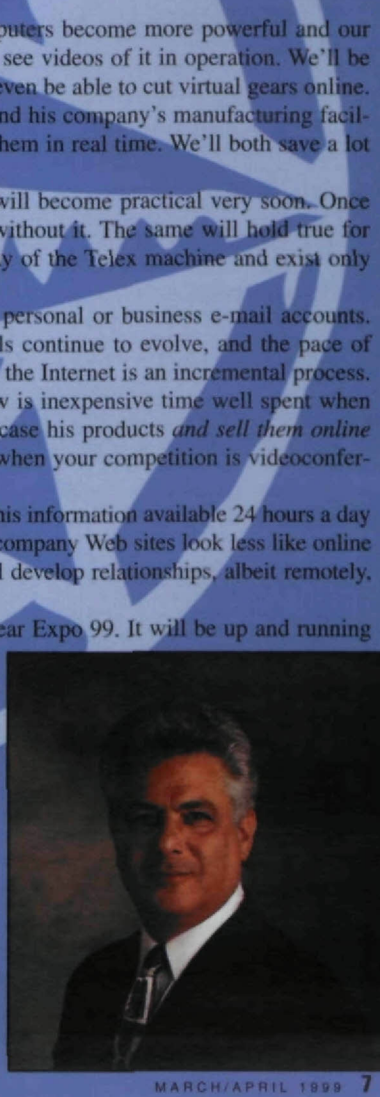
My vision includes all of this and much more. Most of these ideas are already possible. Some will become practical very soon. Once upon a time, even the fax machine seemed like an expensive toy. Now hardly a business survives without it. The same will hold true for much of this emerging Internet technology. Of course, some of these ideas will probably go the way of the Telex machine and exist only long enough to be replaced by something better.

E-mail and the Web have become the "something better" of today. By now, most of you have personal or business e-mail accounts. You've surfed the Web, and you've become familiar with the Internet. But the best of today's tools continue to evolve, and the pace of change, both in hardware and software, is faster than ever. Learning how your company can best use the Internet is an incremental process. Continually building on your knowledge and familiarizing yourself with the latest technologies now is inexpensive time well spent when you consider the possible long-term implications of a competitor who's using his Web site to showcase his products *and sell them online* without ever leaving his office. You don't want to be communicating with stone tablets and chisels when your competition is videoconferencing and leading virtual tours.

Most companies use their Web sites today as electronic versions of their printed materials. Having this information available 24 hours a day from anywhere in the world certainly has its advantages, but this is only the beginning. In my vision, company Web sites look less like online brochures and more like store fronts and showrooms, a place to do business. At your Web site, you'll develop relationships, albeit remotely, with far-flung customers, and you'll do more and more of your company's business.

We're investing considerable effort into this year's *Show Central*, our 3D version of AGMA's Gear Expo 99. It will be up and running at *www.geartechnology.com* by May 1. You'll have to download a small piece of software to fully explore *Show Central*, but we're confident that when you visit, you'll see how powerful an electronic showroom—or better yet, a whole shopping mall full of them—could be for buyers of machine tools. Experiencing *Show Central* as potential buyers will also give you some ideas about how you might be able to implement these technologies for **your** customers on geartechnology.com, powertransmission.com or your own Web site.

Show Central is not yet quite as advanced as my vision of the future, but our first step in that direction should show you enough that you and your company will be convinced to take the next step with us.



Sincerely,
Michael Goldstein, Publisher and Editor-in-Chief

Vector Gears

Take a herringbone gear, modify the usual V of the herringbone tooth into a smooth and gracefully rounded "U", add a little twist, and you have the gear that Flowdata Corporation is banking on being the state-of-the-art impeller for flow-metering and control—the Vector gear.

"We do a lot of work in the FDA-compliant industries—food, beverages and pharmaceuticals," said Dave Foran, Flowdata president. "We also sell to chemical, petrochemical and automotive markets. Because all of our products are based on impellers, our design engineers are very gear oriented."

Flowdata's products use pairs of gear-like impellers to measure fluids moving through various sized pipes and under various pressures. Previous designs were, however, limited in flow regardless of the applied pressure. The Vector impeller doubles the flow rate by incorporating large pockets between the gear teeth.

The teeth mesh so well that Flowdata engineers have been able to eliminate the external synchronizing gearboxes usually needed for these applications. This means that the functions the same regardless of the viscosity of the liquid the unit is metering.

A further benefit of this alignment accuracy is that it prevents gear abrasion, uneven wear and the passage of unmetered fluids.

Finally, the Vector's design eliminates the axial forces that push apart conventional paired gears when they are under pressure.

Although the Vector was designed by Flowdata, the actual machining of the gear was done by BPS Industries of Baltimore, MD. Creating the gear required a highly advanced 5-axis CNC machine tool working from a 3D solid modeling system. Flowdata used Parametric Technologies' Pro/Engineer to create the solid model, and BPS used the same system along with Pro/MFG to program their CNC machine tools and cut the metal.

Circle 254

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.

Above: A pair of Vector gears. Courtesy of Flowdata Corporation.

World's Slipperiest Solid

The *Guinness Book of World Records* lists a patented dry-film lubricant from General Magnaplate Corp. as the material with the lowest coefficient of friction (static and dynamic) of any solid.

HI-T-LUBE was invented in the 1950s for use in fighter aircraft. The lubricant was further developed for NASA in the 1960s to be applied to the mating surfaces of critical moving parts in space vehicles. Parts treated with HI-T-LUBE can operate in extreme temperatures (-360°F to +1000°F), vacuum and high radiation environments, maintaining a coefficient of friction of 0.03 while withstanding compression loads in excess of 150,000 psi.

HI-T-LUBE is made up of five layers of metals and alloys that are electrodeposited and permanently bonded to the substrate metal. It can be applied to steel, stainless steel, copper, copper alloys or aluminum. Typical applications include gears, rollers, bearings, pistons, engines and other moving parts.

The 1998 edition of *The Guinness Book* features an interview with HI-T-LUBE inventor Dr. Charles P. Covino, who describes how sometimes luck is better than design. "I put five materials together and composited them into a lubricant. And it worked the first time," Covino said.

Circle 251

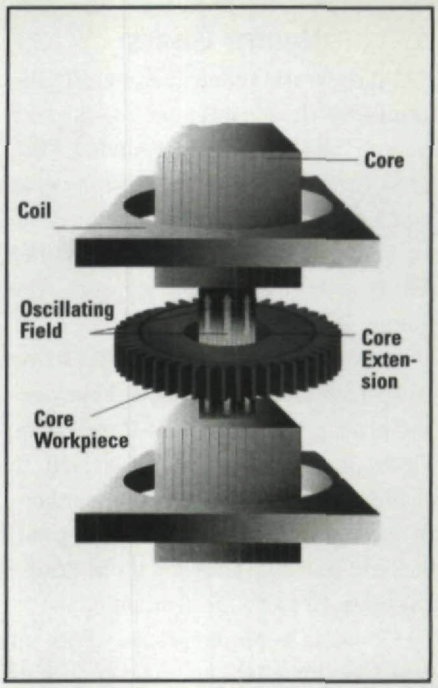
Gears and sprockets are protected against wear, sticking, and galling by General Magnaplate's Hi-T-Lube® synergistic coating.

Uniform Magnetic Heating

A new patented heat treating process that produces a rapid and uniform through-heating of metal components of varying shapes and mass may replace induction heating or furnace processing for some applications.

Both uniform magnetic heating and induction heating use coils to set up a linking of magnetic fields in the workpiece. Induction heating systems place the workpiece inside a heating coil. Eddy currents are generated on the surface of the component, creating a heating pattern on the outside that radiates or conducts inward toward the core.

Uniform magnetic heating uses two coils that are permanently fixed around the ends of a C-shaped laminated core. Because flux energy passes between



How uniform magnetic heating works. Courtesy of Mitsubishi International Corporation.

the ends of the core in a linear fashion, the energy is evenly distributed throughout the entire part. The result is a through-heating that doesn't rely on thermal conductivity to transmit heat from the surface to the center of the part.

Another benefit of uniform magnetic heating is that the same coils can run a wide variety of parts. The system's PLC can be programmed for a predetermined frequency level or voltage gain to automatically achieve the optimum power output and heating rates regardless of part size, shape or material.

Uniform magnetic heating is patented by the U.K.-based CoreFlux Systems International, Ltd., and is distributed worldwide by Mitsubishi International Corporation.

The CoreFlux process has been used successfully in lower temperature range applications such as the preheating of transmission gears for laser welding; tempering transmission couplings and drive shafts; shrink-fitting rotors, gears and bearings; and stress relieving of wheel hubs, gears and castings. Company officials expect to receive similar benefits in high-temperature applications such as through hardening of gears and bearings.

Circle 252

New Technology Helps Find Alloys of the Future

The Marshall Space Flight Center in Huntsville, Alabama has a containerless processing facility that will help materials researchers determine how atoms are arranged in molten mixtures, which could lead to the discovery of new, stronger and lighter alloys and metallic-electronic crystals with never-before-seen properties.

Called the Electrostatic Levitator or ESL (pictured above), the new machine was donated to Marshall's Microgravity Research Program by Space Systems Loral of Palo Alto, California. The ESL uses static electricity to levitate metal samples, which are then melted with a laser. This allows measurements of various thermal and physical properties including surface tension, viscosity, heat capacity, undercooling nucleation—how far below freezing a molten sample will stay liquid—and solidification rates without the metal touching the test container. Such contact could alter the test results, contaminate the alloy mixture, or damage the test container itself.

"The levitator provides important thermophysical property measurements," said Dr. Jan Rogers of Marshall's Space Sciences Laboratory. "By using hands-off measurements, we get an unhindered look at the effects different processing temperatures have on experimental samples. The internal structure of materials—like metals, alloys, oxides and semiconductors—are greatly influenced by heating and cooling rates. The levitator is helping us learn what structures and what unique material capabilities may result from manipulating various metal-alloy samples."

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A New Approach to Heat Treating Parts Washing

Rick Terrien

New innovations in the management of heat treating parts washers are yielding powerful, unexpected benefits. Simple, cost effective shop floor practices are being combined in new ways to deliver big quality improvements and significant help to the bottom line. Employing these steps early in the process can dramatically cut waste hauling expenses and greatly reduce environmental liabilities while continuously producing cleaner parts.

Typical heat treatment includes heating to some austenitizing temperature, then quenching in an oil bath to harden the steel. After quenching, the parts are washed and tempered to reduce residual stresses. The management of the parts washing step—after quenching and before tempering—is the subject of this article.

How Parts Washing Impacts Manufacturing

Poorly managed parts washing operations can affect manufacturing in many ways. Quality is perhaps the single biggest issue facing manufacturers using heat treating. Tim Hoefft, a heat treating engineer with Caterpillar, describes the problem: "Caterpillar continuously strives to increase quality throughout its operations. An ongoing evaluation showed that parts washing fluids used in heat treating operations could introduce quality problems when not managed properly. Parts washers covered with oil can cause poor quality washes and create other manufacturing problems downstream. Clean parts are particularly important in our gear manufacturing operations."

Fig. 1 — Treat-All Metals deployed a gravity separator above the parts washer conveyor line. Oily surface solution is pumped up from the wash tank by direct suction skimming. Oil and grit are removed in the separator (center, top). Clean, oil-free wash solution is continuously recycled back to the wash tank.

Parts washers heavily contaminated with oil contribute to quality problems. In poorly managed washers, clean parts are often sprayed with oily wash solution or pulled through a layer of surface oil and grit prior to tempering. Gears and other parts that are improperly cleaned carry oil out of the parts washer. These oils become baked-on contaminants during the tempering step. Removing baked-on oil residues typically requires shot blasting or other labor intensive reworking steps.

Oil dragged from the parts washers into the draw furnaces also raises significant environmental issues. Oil heated inside the furnaces creates a smoky environment for the workers in the plant as well as potentially prohibited levels of hydrocarbon emissions out of the stacks.

Oily parts washers also create significant long-term maintenance problems for furnace operators. Oil burning inside a tempering furnace degrades the fire brick lining. This leads to more frequent relining, an expensive step that keeps the furnace off line and unproductive.

In years past, quench oil was removed by solvent degreasing. However, environmental and safety concerns about solvents have recently led to a change to aqueous cleaners.

Early formulations of aqueous cleaners were aggressive, high pH surfactants designed to emulsify as much oil as possible. Oil that would normally rise to the surface was changed into an oil/water hybrid that was held in solution. This slowed the accumulation of oil on the surface of the washer, but it hid the problem in an ever dirtier bath. When the capacity of the bath to hold emulsified oils was used up, the bath lost its effectiveness. Spent baths must be hauled

Rick Terrien

is a managing partner with Universal Separators, LLC of Madison, WI. Universal Separators builds the SmartSkim™ line of suction skimmers and gravity separators for heat treating parts washers. Rick has managed parts washers for over 20 years and has designed and built separation systems since 1975. Universal Separators can be reached at www.smartskim.com.

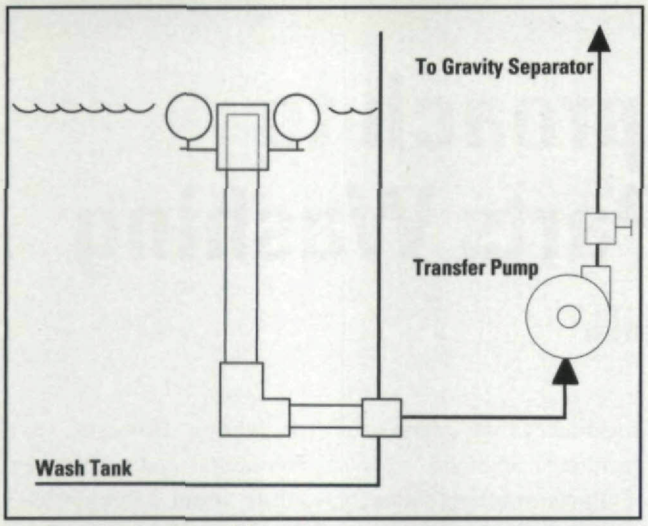

Fig. 2 — The SmartSkim™ direct suction skim head (patent pending) removes floating oil and other contaminants from the wash tank. A transfer pump sends the skimmed solution to a gravity separator, where oil and grit are removed.

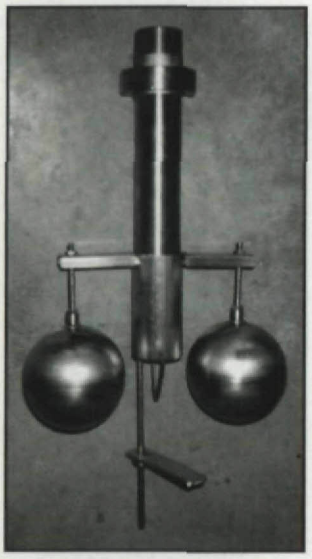

Fig. 3 — The all stainless steel SmartSkim™ skim head (patent pending) from Universal Separators.

away by licensed special waste haulers due to their high pH and high FOG (fats, oils and greases) count. The costs for these hauling services vary by region of the country. However, all add significant costs to the manufacturing process. Frequent hauling cycles also result in the need for expensive replacement cleaners.

Current Treatment Methods

Typical treatment methods for keeping parts washers clean have failed to take a comprehensive approach to the problem. Most employ tools borrowed from unrelated areas of fluid treatment. These typical treatments also rely on old assumptions about cleaners, resulting in an oily wastewater stream that is expensive and labor intensive to eliminate.

Typical methods currently in use include:

• **Drag-Out Systems**. These include oil belts, discs, drums and mops and have been the most common method in recent years. These devices have a component that rotates in and out of the parts washer. Many use an oil-attracting (oleophilic) material to attract oils from the surface. As these components rotate out of the washer, materials clinging to them are scraped off into a waste collection barrel. These devices typically drag out a waste stream that is about 50% oil and 50% wash solution, which is expensive to haul away and requires the continuous replacement of new wash solution and cleaners.

• **Coalescers**. These devices come in a wide variety of configurations, but most employ tightly packed beds of coalescing media. Oily washwater is pumped through the media, causing oil molecules to coalesce and grow larger, making them easier to remove. Coalescers were designed to work in pure oil-water solutions. Heat treating parts washers often contain a much wider variety of contaminants, such as grit, scale and soils. When operators attempt to pump these solids through the tight passageways of a coalescer, the coalescing media blinds over and becomes blocked. In heat treating applications, coalescers must be frequently taken off line and cleaned.

• **Off-Line Gravity Separation**. This method requires operators to pump out their washers into holding tanks for further separation over time. The large holding tanks take up otherwise productive floor space and frequent labor input is required to manage these fluid transfers. Emulsified oil is still held in suspension by emulsifying cleaners as there is no mechanism for readily separating the layers of oil from the aqueous cleaner. Because of this, an oily waste stream is still produced.

• **Barrier Filtration**. Bag and cartridge filters have been tested to solve the problem of oil and solids in the wash solution. These typically blind over quickly, and the cost of consumables becomes prohibitive.

• **Membrane Filters**. Membrane filters are devices that filter fluids down to a very tight micron rating (typically 1 micron and under). In washwater applications, they are designed to remove emulsified oil from the cleaners. Membrane filters quickly blind over with contaminants, particularly free oil. On the shop floor, membrane filters can become expensive maintenance headaches. Membrane filters also damage most cleaners by filtering out valuable cleaner components such as rust inhibitors and defoamers. Membrane filters can be avoided, however, with a simple change from emulsifying cleaners to oil-splitting cleaners.

Emerging Best Practices for Heat Treating Parts Washers

At Treat-All Metals, a commercial heat treating facility in Milwaukee, WI, a large batch washer equipped with a drag-out separation system was not able to keep up with the large volume of oil. It required frequent hauling of oily wastewater and replacement of the wash bath, according to maintenance director Ron Barnhart.

Treat-All tried several new methods before settling on a combination of oil-splitting cleaners, direct surface skimming of the oily wash solution from the wash tank, and separation of the oil from the wash using an in-line, open-channel gravity separator (Fig. 1).

The emergence of oil-splitting cleaners has been a great addition to the toolbox of heat treating managers. Oil splitters emulsify very little oil. Oils in these cleaners rapidly separate and rise to the surface, where they can be easily removed via direct surface suction (Figs. 2–3). Newer versions of oil splitting cleaners are moving toward pH neutral formulations, which contribute to improvements in worker safety.

Gravity separators exploit the difference in specific gravity between the oil and the wash solution. Oil separates from a fluid at a rate determined by Stokes Law. This formula predicts how fast an object will rise or fall through a heavier fluid based on the density and size of the object and the distance it must travel. Open-channel gravity separators exploit both variables of Stokes Law. Oil must rise only a very short distance before it is captured on the bottom side of closely spaced inclined plates inside the separator (Fig. 4).

Once separated from the flow, captured oil with very low water content can be removed from the gravity separator. This oil, which contains less than 5% water, is referred to as "dry" oil. While oily wastewater produced by other arrangements must be hauled away at the producer's expense, dry oil can typically be sold for a profit. Gravity separators discharge dry oil to a collection barrel without any moving parts. The clean wash water is returned to the wash tank.

Gravity separators also remove solids from heat treating parts washers. Difficult to remove, lightweight solids can easily contaminate the wash bath, causing significant quality problems. Those solids are typically made up of small particles of scale, grit, and stop-off paint, as well as a variety of other contaminants. Solids can be sprayed back onto the part from dirty wash solutions. Parts can

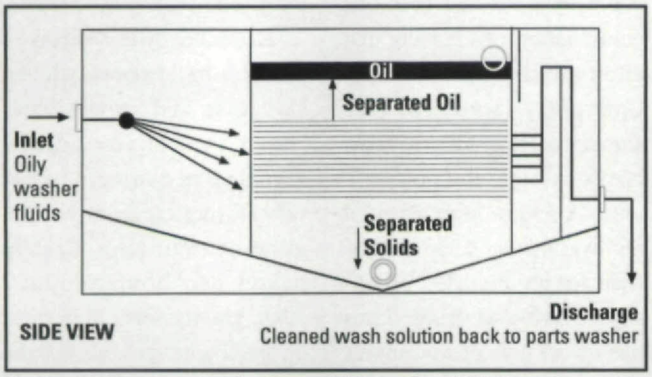

Fig. 4a — Side view showing flow of oily washer fluids through a gravity separator. Oily solution is continuously pumped from the washer surface across multiple separation plates. Oil and solids separate from the flow by gravity while cleaned wash solution is returned to the washer.

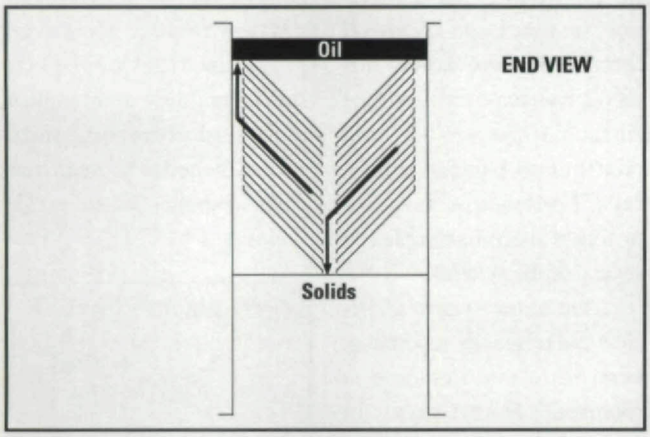

Fig. 4b — End view. Inclined plates inside a gravity separator capture and remove oil and solids simultaneously. Open channel separation pathways insure no clogging. Because there are no moving parts, separator management is greatly simplified.

also be recontaminated when they are dragged through grit held in the oil at the surface of these washers.

Removing these types of solids has been difficult and expensive. Coalescers have been tried but their filters are quickly blinded over by grit. Filtration devices such as cartridges or bags are sometimes used, but these require expensive replacement consumables to stay on line.

Gravity separators do not require any consumables and are not blinded over by solids. Treat-All Metals found that they don't notice any loss of separation efficiency until their gravity separators become half filled up (50% of the separator volume) with solids, which typically takes months.

Treat-All is not the only company which has tried this combination of cleaners and equipment. Tim Hoefft of *Caterpillar faced problems* similar to Treat-All's with his company's old drag-out system. "A review of existing oil removal methods showed the need for an upgrade," Hoefft says. "Belt and drum skimmers were not able to remove the continuous input of oil from the washers."

Caterpillar tested a surface suction system similar to the one in place at Treat-All Metals. "The test showed that all oil was removed from the surface of the washer on a continuous basis," Hoefft says. Following successful testing, Caterpillar deployed several of the systems.

"Due to the system's efficient use of gravity separation, very little maintenance is required," Hoefft says. "In fact, beyond the initial setup, our rule has been to 'leave them alone.'"

The Bottom Line

The combination in place at Treat-All Metals and Caterpillar offers significant benefits:

- Cleaner parts
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However, the switch to oil-splitting cleaners, suction *skimming and gravity separators* can require adjustments. For example, most oil-splitting cleaners are not good at removing already baked-on contaminants. Also, gravity separators must be sized appropriately for the job to be most effective. Small units can be overwhelmed by the treatment flows common to heat treat parts washing. However, given the right configurations, this new combination can yield powerful, unexpected benefits to heat treat parts washing operations.

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April 11–15. Metalform '99. Rosemont Convention Center, Rosemont, IL. Discover the latest innovative concepts and applications in the metalforming industry. There will be over 500 exhibits at this year's show, the largest number ever at a Metalform show. Sponsored by the Precision Metalforming Association. Call (800) PMA-SHOW (800-762-7469) or visit the Web site at *www.metalforming.com*.

April 13–15. Gleason Pfauter Hurth Advanced Gear Process Dynamics. Loves Park, IL. This is a three-day, high-intensity clinic on modern metal removal and measuring techniques for spur and helical gears. It is structured for manufacturing and process management with an in-depth look at modern methods, applications and hardware in gear manufacturing and measuring processes. It includes demonstrations of modern gear cutting and measuring techniques at the Gleason Pfauter Hurth Cutting Tools facility in Loves Park, Illinois. The course assumes all participants have a basic understanding of gear geometry, nomenclature, and some experience in gear manufacturing and quality assurance. Also runs October 5–7. For more information call (815) 282-3000 or visit *www.pfauter.com*.

April 19–24. Hannover Messe. Hannover, Germany. The Hannover Fair contains the world's largest concentration of electrical and mechanical power transmission, fluid power transmission and internal combustion engines. The show boasts over 7,500 exhibitors from 70 countries, with 1,280 in the power transmission sector alone. Contact Hannover Fairs USA at (609) 987-0092 or log onto *www.hfusa.com* for more information.

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April 28–May 2. Korea International Robot and Automation System Show '99 (KIRAS 99). Seoul Yoido Exhibition Center, Seoul, Korea. KIRAS 99 exhibitors will include the makers of industrial robots, automatic control and measuring systems, automatic storage systems, factory automation systems, automatic programming systems, FA peripheral equipment and other related items. Sponsored by the Korea Machine Tool Manufacturers' Association. Call +(82) 2-565-2721 or e-mail *komma@komma.org* for more information.

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

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Fatigue Aspects of Case Hardened Gears

G. P. Cavallaro & C. Subramanian

The efficient and reliable transmission of mechanical power continues, as always, to be a central area of concern and study in mechanical engineering. The transmission of power involves the interaction of forces which are transmitted by specially developed components. These components must, in turn, withstand the complex and powerful stresses developed by the forces involved. Gear teeth transmit loads through a complex process of positive sliding, rolling and negative sliding of the contacting surfaces. This contact is responsible for both the development of bending stresses at the root of the gear teeth and the contact stresses at the contacting flanks.

Gear Fatigue

In analyzing the stresses developed in the gear tooth, it is useful to begin with a brief description of the dynamics of tooth contact. Figure 1 depicts the cycle of contact and the contact path of the teeth of a spur gear. The path of contact begins on the tip (the addendum) of the driven gear tooth, goes through the pitch point and finishes on the tip of the driving gear tooth. The gear teeth are in contact along line C_1–C_5. At all points along this line, with the exception of the pitch point, the velocities of the contacting surfaces are different. Because of this, sliding will occur (Ref. 1). At the pitch point the velocities of the contacting surfaces are equal and there is pure rolling. The angular velocity of the driving gear tooth is then transferred to the driven gear by a complex process of positive and negative sliding and rolling. The bending stresses at the root of the gear tooth and the contact stresses on the contacting flanks are therefore generated by the loading conditions of the contacting surfaces. These stresses are responsible for the dual nature of gear fatigue failures (Refs. 2, 3).

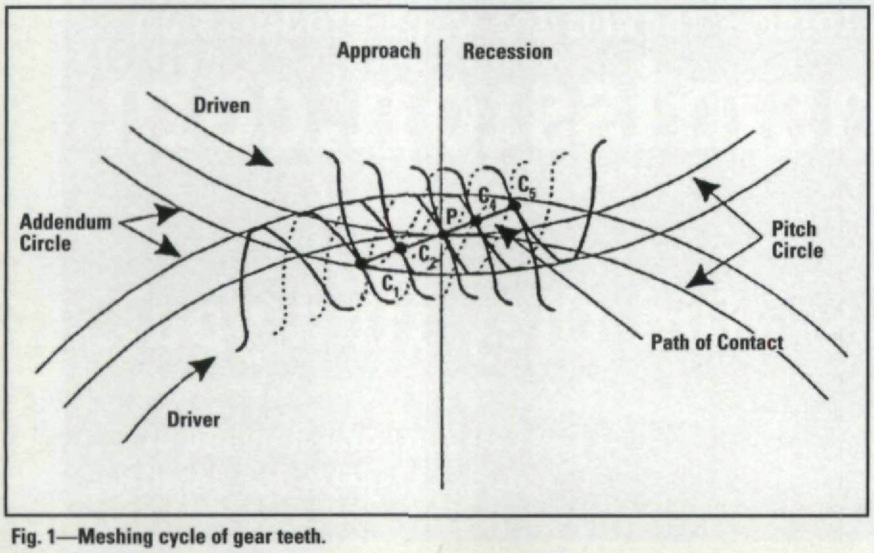

Fig. 1—Meshing cycle of gear teeth.

The bending stresses occurring at the root of the gear tooth arise due to the transfer of torque from one gear to another. The bending stresses, being cyclic in nature, can lead to fatigue crack initiation at the root of the tooth. This region acts as a stress concentrator and the fatigue cracks which develop here are classical fatigue fractures (Ref. 4).

The contact stresses arising in, and on, the contacting surfaces of the gear teeth are a consequence of the forces exerted by one surface on the other (Ref. 5). These forces create pressure distributions that are directly responsible for the development of shear stresses below the surface (Ref. 6). The magnitude and location of these stresses are dependent on the geometry of the gear tooth flank and the dynamic conditions under which the gear is operating (pressure distribution, involute radii, sliding velocities and coefficient of friction). The failures caused by these shear stresses are the typical pitting and spalling types.

The overall design of the gear must take into account these stress systems and minimize their effect on the integrity of the gear. While the material of the body of the gear tooth must display enhanced flexural ductility to counteract the bending stresses developed there (Ref. 7), the flanks of the gear tooth require a hard, wear-resistant surface with enhanced strength to some depth below the surface to resist the orthogonal shear stresses developed in that location.

Tooth Root Stresses. In 1892, Lewis (Ref. 8) made the first documented attempt to calculate the stresses developed in the root of a gear tooth. His approach was based on the analysis of a notched beam in bending mode, approximating the gear tooth shape by a parabola. This basic approach is still accepted as fundamentally correct, with the exception of the effects of what are now known as stress concentrators, investigated by Dolan and Broghamer (Ref. 9). There are a number of ways of calculating the stresses developed in the root of a gear tooth, from the two dimensional analysis adopted by Aida and Terauchi (Ref. 10) to the more sophisticated finite element models which were first introduced by Andrews (Ref. 11).

The bending fatigue of gears is principally governed by the geometry of the gear tooth, the loading conditions and the material properties at the root of the tooth. The authors show, to some extent, the importance of the geometry, but do not consider any of the factors which influence the material properties. These metallurgical factors depend on the material composition and heat treatments adopted, as well as their subsequent transformation products and/or residual stress distributions.

Contact Stresses. From the literature (Ref. 1) it can be seen that contact stresses developed during the contact of gear teeth can be approximated by rollers contacting under a known force, the sliding velocities of which reflect the dynamics of gear contact. From Figure 2 it can be seen that the rollers with a fixed sliding velocity will approximate the contact of gear teeth at certain points along the contact path. Figure 3 displays the semi-elliptical pressure distribution generated on the surface of contacting rollers.

The problems of contact stress, particularly the problems posed by contacting rollers, have been discussed by various authors. The pioneering work of Smith and Liu (Ref. 5), and more recently the work on the elastic shakedown of contacting surfaces by Johnson (Ref. 6) and the finite element modeling of such contacts by Hahn and associates (Refs. 12–14) deserve particular mention. However, the stress state which exists on the contacting surface layers can be significantly influenced by asperity interaction and can include tensile and compressive alternating cycles and shear.

Two different types of plastic zones are produced by rolling and sliding contact, as shown in Figure 4. The first layer is due to macro-contact width, usually between 1–10 mm. The second, which is much shallower, is due to micro asperities contact. This depth h is of the order of $0.5\mu m \leq h \geq 50\mu m$ and is obviously related to surface roughness. Therefore, depending on the friction developed between the contacting sliding surfaces, and the nature and strength of the material of the roller, failure will either initiate at the surface or subsurface or, in some conditions, in both.

Metallurgical Perspectives Relating to Fatigue Performance in Carburized Gears

While metallurgical factors such as oxidation, decarburization, supercarburization, carbide formation, grain boundary segregation, type and density of inclusions present, microcracks and residual stresses all significantly affect the fatigue performance of carburized gears, detailed treatment of these effects is well outside the scope of this discussion. However some of these aspects, such as

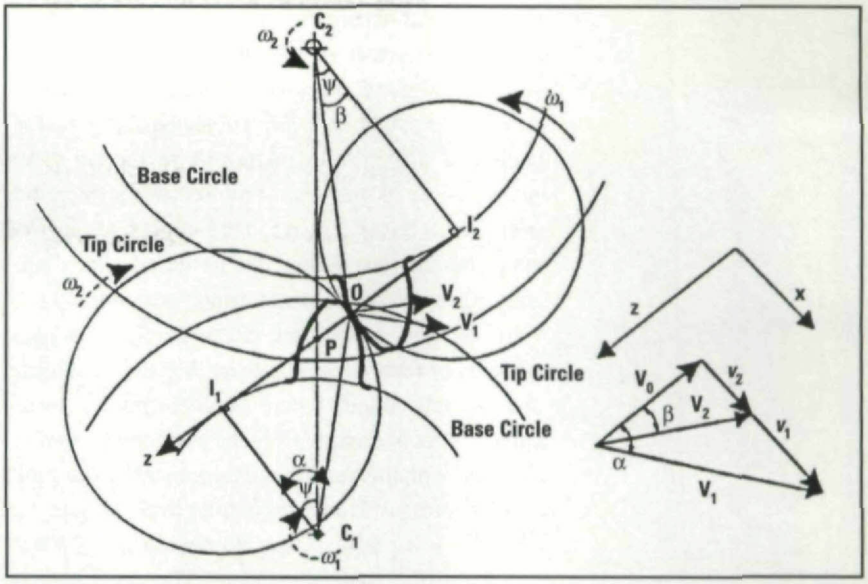

Fig. 2—Contact of involute spur gear teeth.

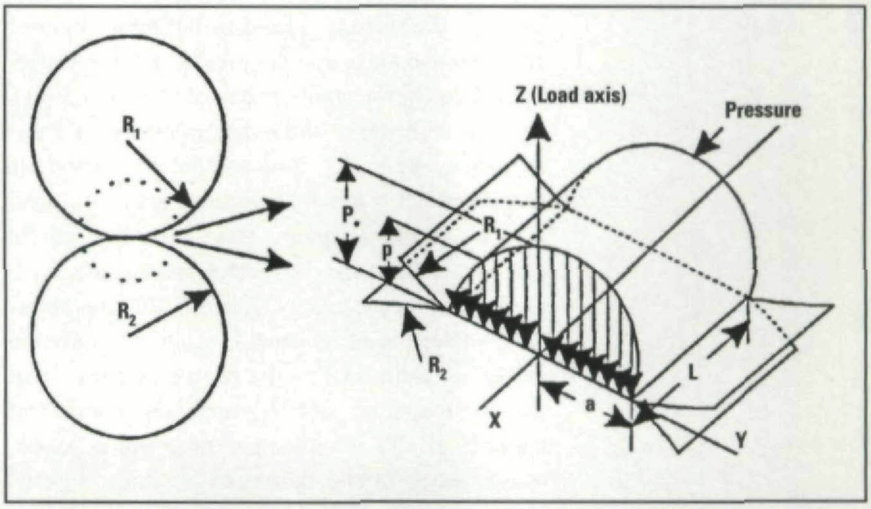

Fig. 3—Pressure distribution in contacting rollers, terminology adopted in Hertzian theory.

oxidation and carbide formation, will be discussed in relation to the case studies presented. The role of retained austenite will also be discussed in view of its highly controversial nature.

Retained Austenite. The mechanisms responsible for the retention of austenite on quenching have been reported in detail in the available literature (Refs. 15–18). It is clear that of all the alloying elements which influence the retention of austenite on cooling, carbon has the greatest effect. Quenching temperature and cooling rates have all been reported to affect the level of austenite retained (Refs. 15, 16).

The effect of the retained austenite on the fatigue resistance of carburized components has also been extensively dealt with in the literature. Nevertheless, some controversy still remains. In the past, the presence of retained austenite has been regarded as detrimental to the extent of adopting cryogenic treatments to reduce the amount present.

A more detailed picture has emerged from the investigations carried out by various authors, notably the work of Krauss (Refs. 19, 20) and Zaccone (Refs. 21–23). These authors have shown that there is a

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First presented at the Gear and Shaft Technology Seminar organized by the Institute of Materials Engineering Australasia.

possible relationship between fatigue performance and retained austenite, which can account for some of the continuing controversy and explain some of the high fatigue limits being published. The transformation of austenite to martensite at the tip of an advancing crack has been reported in the literature (Ref. 24) to be beneficial to the fatigue resistance of the carburized component due to the associated volume expansion of the transforming austenite.

It has been pointed out (Refs. 22, 23) that large amounts of retained austenite are beneficial in terms of low cycle fatigue where the large plastic strains induce strain hardening from the austenite to martensite transformation and the development of favorable residual stresses. However, in high cycle fatigue, the relatively low plastic strains do not allow any transformation of austenite to occur. The same authors found that the plastic strains needed to transform the austenite are directly related to the prior austenite grain size and the morphology and size of the austenite packets. In fine grain structures (ASTM 9.5–11), much lower levels of strains are necessary for transformation (Refs. 23, 24), so that in high cycle fatigue, which is usually associated with very small amounts of plastic strains, these structures will be *able to transform and resist crack propagation.*

Work by many authors (Refs. 15, 25, 26), points to the reduction of retained austenite by cryogenic means as detrimental to the fatigue properties and fracture toughness of the carburized component because of the development of residual tensile microstresses in the remaining austenite regions. However to this author's knowledge, no systematic investigation has yet been published outlining the nature, or indeed the magnitude, of these microstresses. The effect of cryogenic treatments on the bending and contact fatigue properties of carburized gears can be illustrated by results obtained from gear research conducted at the University of South Australia (Refs. 27–29). Figure 5 shows that the cryogenic treatment was detrimental to the bending fatigue properties of the gears tested.

The effect of the cryogenic treatment on bending fatigue properties can be explained by only three scenarios:

(a) If it is assumed that the retained austenite present in these gears can transform on straining, and that cryogenic treatment <u>only</u> reduced the levels of retained austenite, then the non-cryogenically treated gears have superior performance due to a higher amount of retained austenite, which can transform ahead of the propagating cracking tip.

(b) If it is assumed that the retained austenite present does <u>not</u> transform on straining, then the non-cryogenically treated gears have superior performance due to the cryogenic treatment imparting detrimental residual tensile microstresses in the remaining regions of untransformed austenite.

(c) If the retained austenite present does <u>not</u> transform on straining, and its presence is detrimental to the bending fatigue properties, then the cryogenic treatment has a greater detrimental effect on the fatigue properties of these carburized gears than the presence of retained austenite in the treated gears.

In all cases, these results point to a detrimental effect derived from the cryogenic treatment of these gears. Figure 6 displays the experimental results of contact fatigue tests carried out to determine the effect of cryogenic treatment. This figure shows that the adoption of cryogenic treatment has proven to be detrimental to the contact fatigue performance of En36A steel.

The role of cryogenic treatment on the contact fatigue behavior of the rollers tested is not as clear as it was in the bending fatigue section. This result follows the trend found in the literature, where the adoption of cryogenic treatment was found to be detrimental to the contact fatigue performance of carburized components. In particular, the experimental results of Kiessling (Ref. 31), Razim (Ref. 26) and Nakamura et al. (Ref. 32) have shown a direct relationship between high levels of retained austenite and high contact fatigue limits.

Case Depth and Core Strength Requirements. The determination of the appropriate case depth in carburized gears must reflect the stresses developed in and on the gear teeth, as discussed in the sections on gear

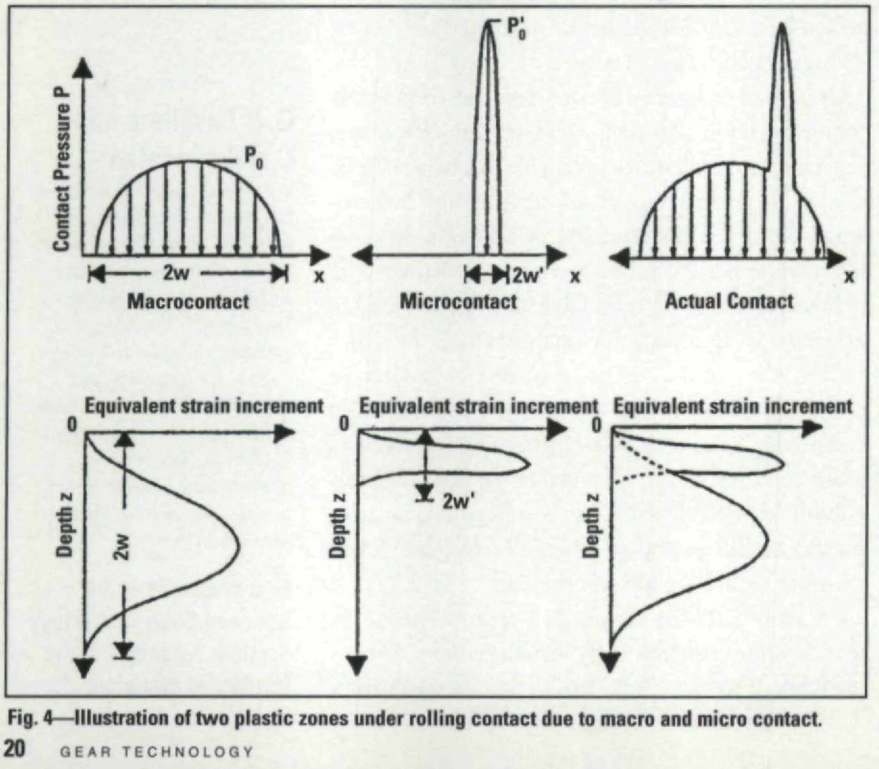

Fig. 4—Illustration of two plastic zones under rolling contact due to macro and micro contact.

stresses. The aforementioned duality of the stress system in gears places certain limitations, or at least conditions, which must be satisfied in the appropriate selection of the case depth. However, it has been discussed that the role of the hardened layer in the root of the gear tooth is fundamentally different than that required at the contacting flank. The literature, as expected, also displays this duality of role.

It has been known that a case depth selected on the basis of contact fatigue will not necessarily perform at its optimum in bending. This has been acknowledged by some authors. However in practice, the case depth requirements for maximizing bending fatigue resistance are usually overshadowed by the need for contact resistance. A great deal of controversy still surrounds the optimum case depth for bending/contact endurance.

The core strength is of significant importance in the fatigue resistance of the component. This is partly based on the core strength's influence on residual stresses, since the magnitude and indeed the polarity of the residual stresses developed are dependent on the difference in volume expansion of the case and core. The larger the difference, the higher the residual stresses, provided that the core material does not yield (Refs. 33, 34).

This simple criterion is, however, questioned by Ebert et al. (Refs. 35, 36) and McGuire et al. (Ref. 37), who proposed that a carburized structure is basically a two-component composite, and that each of these components will have significantly different elastic limits and plastic properties. At stress levels below the yield stress of both the case and core, the overall stress state will not differ from that anticipated in a homogeneous solid. However, as the load is increased and the stress level becomes higher than the yield stress of the core, the core will flow plastically while the case will still behave elastically. Because of the difference in the Poisson ratio for elastic behaviour (0.3) and plastic flow (0.5), the case and core will have different contracting tendencies. This creates transverse stresses normal to the applied stress in the case-core interface region. This is essentially a tensile biaxial state of stress.

The enhanced ductility of the carburized component, as compared to through hardened components, is derived by the development of compressive transverse stresses in the case, which help it resist the applied stresses. In carburized steels, the presence of retained austenite in the case can provide a further ameliorating effect if it can transform to martensite on straining. The volumetric expansion on transformation can reduce the biaxiality of the stress state in the case. This model highlights the importance of the core structure in the fatigue process, and it also defines the actual role of the hardened case. A deep case is seen as increasing the degree of biaxiality at the case-core interface while restricting the ductility of the case.

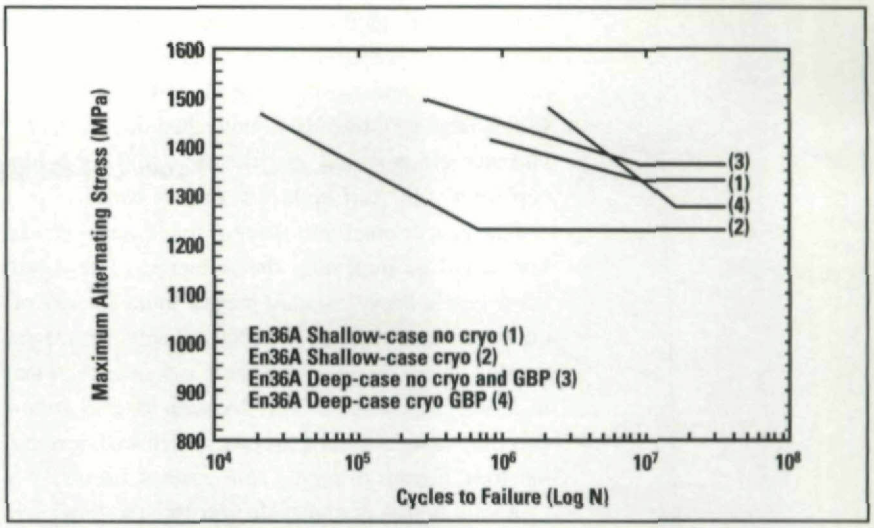

Fig. 5—The effect of cryogenic treatment on the bending fatigue of gears tested.

The effect of case depth on the fatigue properties of carburized gears is illustrated by the results obtained from tests carried out at the University of South Australia. They show that the shallow case depth consistently out-performed the thicker case depth, irrespective of the post-heat treatment process received (i.e. glass bead peening and/or cryogenic treatment).

The bending fatigue performance in relation to the case depth initially points to the various differences found between deep and thin cased gears (Ref. 30). Some of these differences were:

1. The hardness of the shallow-case samples were lower than the deep-case ones.
2. The retained austenite levels were higher in the shallow-case samples.
3. The microstructures developed in the case of the deep-case gears were different from those found in the shallow-case gears.
4. The crack initiation depth was deeper in the shallow-case samples.

The microstructural differences between the two types of samples were mainly in the degree of non-martensitic phases, which were primarly carbide networks. These carbides account for the higher hardness of the deep-case gears (point 1 above), and the higher amount of retained austenite in the thin-case gears (point 2 above) (Refs. 15, 38–40), since the carbon and the alloying elements, which are among the factors controlling the amount of retained austenite present, are not tied up in carbides in the thin-case gears and hence will increase the levels of austenite retained.

These non-martensitic features found in the case of deep carburized gears are mostly likely due to excessive carbon buildup in the outer layers. This problem, termed supercarburization by Razim (Ref.

26), has been suggested to be due to the adoption of a high carbon potential during carburizing. However, the reader is referred to the work of Goldstein and Moren (Ref. 41), who have shown that this supercarburizing effect could also be due to Chromium depletion of the surface layers (due to oxidation).

The deeper crack initiation of thin-cased gears is interpreted as indicating the influence of resolved stress (applied and residual) present in the interior of the gear tooth. Fatigue cracks can only initiate in regions where the resolved stress is higher than the material fatigue limit. This location is also influenced by defects and inclusions, which will develop localized regions of highly concentrated stress.

The initiation of cracks deep within the thin-case gears is the result of maximum resolved stresses developed in deeper areas below the tooth's surface as compared to deep-case gears. This is also explained by the higher solution carbon content of thin-case gears (Refs. 15, 35, 42), which will allow the development of compressive residual stresses of a higher magnitude. The enhanced performance observed in thin-cased gears can be explained by two separate mechanisms. The first is based on the model proposed by Ebert et al. (Refs. 35, 36) and McGuire et al. (Ref. 37) regarding the rheological reaction between case and core. The second is derived from the microstructural considerations discussed above.

Case Depth Requirements in Contact Conditions. Considering the stress distribution in contacting cylinders as outlined in the preceding sections, it is clear that an element of material in or on the gear flank will experience stresses according to its position, the radius of the roller, the applied load, the respective relative sliding velocity and the coefficient of friction. Failure of the material, irrespective of its nature, whether it is by excessive plastic deformation or fracture, is then a function of the parameters outlined above and the true strength of the material. If the material's strength is a constant throughout its depth (k) (this can include through-hardened components such as bearing races and/or austenitized components), then it is reasonable to conclude that failure will occur in locations below the surface where the shear stresses reach a maximum. If, however, the coefficient of friction is greater than about 0.3, signifying that these shear stresses reach a maximum on the surface, failure will occur on the surface (Ref. 5). However, in conditions where the material exhibits a strength gradient, as is the case for case hardened components, the problem of predicting failure locations becomes significantly more complex.

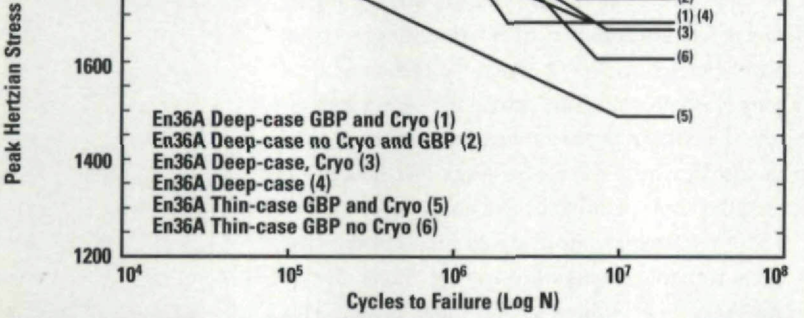

Fig. 6—The effect of cryogenic treatment on the contact fatigue performance of carburized rollers.

The need to accurately predict failure locations in case hardened components is a basic prerequisite in the establishment of case depth requirements. It can, therefore, be stated that the main role of the hardened layer in contact situations is to ensure that the core of the component is not subjected to shear stresses above its cyclic shear strength, and to increase the surface layer's resistance to asperity interaction. In view of the shear stresses developed under the contacting surface, it is clear that the hardened layer has to be of such a depth as to encompass not only the area of maximum shear stress, but also the area further into the interior where, even though the contact stresses are not at their maximum amplitude, they are still significant. The hardened layer should extend to a depth where the shear stresses decrease to a sufficiently low value so as not to pose a threat of crack initiation in the core.

The role of case depth in the contact condition cannot be ignored. Tests conducted at the University of South Australia show that rollers with a shallow case depth display significantly lower fatigue limits than their deep-case counterparts.

The model proposed earlier to account for the material strength in resisting contact damage explains the difference in the performance of rollers with different case depths, this being due to the deep case rollers having a higher contact fatigue resistant layer extending deeper into the roller.

Conclusions

The conclusions to be drawn from the results of the gear tests presented are as follows:

1. Gears with shallow case depths display higher fatigue limits than gears with deeper case depths.
2. Cryogenically treating the gears decreased both the bending and contact fatigue performance of the gears tested.
3. The contact fatigue performance of shallow case rollers was significantly inferior to the deep case rollers.

Recommendations

The bending fatigue strength of a gear tooth limits the amount of load applicable to the flank of the tooth. This, in turn, limits the maximum contact stresses developed. A deep case depth, which is specified to withstand high contact loads, is therefore not necessary if those loads cannot be reached by the bending properties of the gear. At the same time, a thinner case depth, which would increase the allowable bending stresses, does not impart the necessary resistance to contact that these stresses can generate. In the past a compromise was necessary in terms of choosing a case depth which would result in an acceptable fatigue life.

The maximum case depth in the root region should be optimized for maximum bending fatigue, while in the flank of the gear tooth, the case depth should be as deep as possible without running the risk of developing extensive carbides or other non-martensitic phases. One way to achieve this is to use a two step carburizing process, where the component is initially carburized to the case depth desired in the root, taken out, and a copper coating applied to the root region. The component is then recarburized to achieve the desired depth in the flank. This requires careful modeling of the diffusion of carbon in the masked region, as the carbon profile could become very flat due to inward diffusion. A more elegant method would entail a partial oxidation treatment in the root region to reduce the carbon intake in that region. If the controlled formation of Cr_2O_3 or even some type of SiO_2 could be encouraged in the surface of the root region, then the influx of carbon could be controlled to achieve the dual case depth suggested.

Investigation into novel heat treatment technologies should also be considered, especially in the light of the work carried out by Davies and associates at the Westland Helicopter Corp. (Refs. 43–47) dealing with duplex treatments. It should be pointed out that in the manufacturing of case hardened gears, the benefits expected from the best engineering practice and the highest level of accuracy do not materialize if the necessary metallurgical input into gear production is not given the necessary attention and emphasis. ○

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Redliner Charts and Gear Inspection

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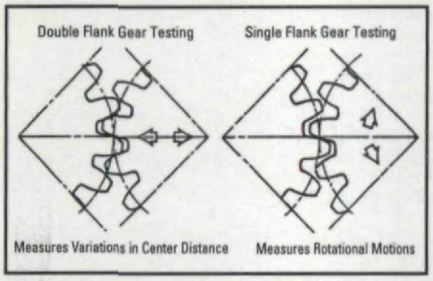

Fig. 1 — Types of composite gear inspection.

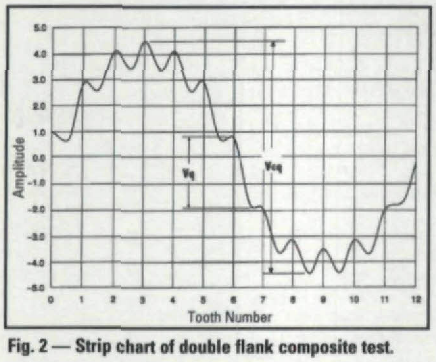

Fig. 2 — Strip chart of double flank composite test.

Question submitted by
Ramiro C. Salinas
Corpus Christi Army Depot
Corpus Christi, TX

Q: What are redliner charts, and who still does redliner charts?

Answer submitted by:
Robert E. Smith
R.E. Smith & Co.

A: For many years, the terms "red liner" and "red line charts" have been used by the Fellows Corporation in relation to their line of double flank composite testers. For example, they made the No. 4 Fellows Fine-Pitch Red Liner and the No. 12RL Red Liner. Double flank composite gear inspection is shown schematically in Figure 1. These instruments were in such common use that the term "red liner" became synonymous with double flank composite inspection.

The term "red line charts" apparently came from the fact that early recorders used pens that wrote with red ink. These were a constant maintenance problem, due to clogging and spatter. Later recorders used thermal writing pens and paper, thermal array printers, or even printers attached to PC computers. Double flank composite testers are made by many different companies and can use a variety of writing methods that do not produce a "red line" on the chart.

To compound the confusion even more, the term "composite" inspection has been taken to mean double flank composite inspection because it was in such common use. As can be seen in Figure 1, there is another type of composite inspection, called single flank composite, that can be used. Today, both types appear in gear quality standards such as AGMA and ISO.

Double and single flank composite testing results in charts such as that shown in Figure 2. However, they mean completely different things. As Figure 1 shows, double flank composite tests measure center distance variation as the gears roll through tight mesh. Single flank composite testing, however, measures rotational motion variation, as the gears roll through mesh at standard center distance, with backlash.

One can see that the continued use of the term "red line chart" is not a very good idea. The terms "double flank composite chart" or "single flank composite chart" would be more accurate and prevent confusion as to what the data means.

The second part of the question asks who still does redliner charts. Double flank composite inspection (to use the proper terminology) is very common in high volume applications, such as automotive transmission gears and fine pitch gearing made by cutting, molding, and powder metal processes. It is a good control of functional tooth thickness (size) and runout under certain conditions.

Double flank composite inspection can be a good control of runout before any subsequent finishing operations such as shaving and some grinding operations. However, after finishing, the chart may show very little runout, but the parts can still have a large accumulated pitch error that has all the ill effects of runout such as positional error or nonuniform once per revolution velocity. This is sometimes called "hidden runout." Single flank composite inspection will find these problems. See AGMA Tech-nical Paper 95FTM1, *Detection of Hidden Runout*, by R.E. Smith, et al.

Robert E. Smith
is the principal in R.E. Smith & Co., gear consultants of Rochester, NY, and one of Gear Technology*'s technical editors. He has over 50 years of experience in gearing and is the author of numerous papers and articles. He is also very active in AGMA standards development.*

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CIRCLE 158

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FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating Co.
General Heat Treating
General Metal Heat Treating Inc.
Grand Rapids Commercial Heat Treating Co.
H & S Heat Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
HI TecMetal Group —Cleveland
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Dallas
Hinderliter Heat Treating Inc.—Tarzana
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
HTG Commercial Induction
Hudapack—Elkhorn
Huron Metallurgical Inc.
Illiana Heat Treating Inc.
Impact Strategies Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ironbound Heat Treating
Jasco Heat Treating Inc.
JCS Engineering & Development
Lake County Steel Treating
Lawrence Industries Inc.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
Magnum Metal Treating
Merit Gear Corp.
Metal Improvement Co. —Columbus
Metal Improvement Co. —Lafayette
Metal Improvement Co. —McLean/Wichita
Metal Treaters Inc.
Metal Treating Inc.
Metal Treating & Research
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology
Metlab Co.
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Midland Metal Treating Inc.
Midwestern Machinery Co.
Modern Industries Inc.
Mountain Metallurgical
National Broach
National Metal Processing
Oakland Metal Treating Co.
Ohio Metallurgical Service
Paulo Products Co. —Bessemer
Paulo Products Co. —Kansas City
Paulo Products Co. —Memphis
Paulo Products Co. —Murfreesboro
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Shore Metal Technology
Southeastern Heat Treating
Specialty Heat Treating Inc. —Athens
Specialty Heat Treating Inc. —Elkhart
Specialty Heat Treating Inc. —Grand Rapids
Specialty Heat Treating Inc. —Holland
Specialty Steel Treating Inc. —Farmington Hills
Specialty Steel Treating Inc. —Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Pompano Beach
Suncoast Heat Treat, Inc. —Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Metal Treating Inc.
Thermal Treatment Center
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Tractech Inc.
Treat All Metals Inc.
Trutec Industries
Universal Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.

CARBURIZING

A.F.C. — Pifco
Abbott Furnace Company
ABS Metallurgical Processors Inc.
Accurate Steel Treating
Advanced Heat Treating
Advanced Metallurgical Technology
Advanced Thermal Technologies, Inc.
Albany Metal Treating
Alco Heat Treating Corp.
Alliance Metal Treating
Alpha Heat Treaters
American Heat Treating Inc.
American Metal Processing
American Metal Treating Inc.
AP Westshore
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating
Bodycote S.W. Inc.
Bodycote Thermal Processing—Dallas
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing (West)
Bomak Corp.
The Bowdil Co.
Braddock Metallurgical
Braddock Metallurgical —Alabama
Brite Metal Treating Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Central Kentucky Processing
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Clearing Niagara
Coleman Commercial Heat Treating
Commercial Steel Treating
Custom Heat Treating Co.
Delavan Steel Treating
Detroit Steel Treating Co.
Diamond Heat Treating Co.
Dixie Heat Treating Co.
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
Dynamic Metal Treating
East Carolina Metal Treating Inc.
East-Lind Heat Treat
Eckel Heat Treat
Edwards Heat Treating
Elmira Heat Treating Inc.
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Feinblanking Ltd.
Fenton Heat Treating
Flame Metals Processing
Fox Steel Treating Co.
FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating Co.
Gear Company of America
General Heat Treating
General Metal Heat Treating Inc.
Geo. H. Porter Steel Treating Co.
Gibson Heat Treat Inc.
Grand Rapids Commercial Heat Treating Co.
H & S Heat Treating
Hanson-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
HI TecMetal Group —Cleveland
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Hinderliter Heat Treating Inc. —Tulsa
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Horsburgh & Scott Co.
HTG Commercial Induction
Hudapack—Elkhorn
Huron Metallurgical Inc.
Illiana Heat Treating Inc.
Impact Strategies Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
Lake County Steel Treating
Lawrence Industries Inc.
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Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
M & M Heat Treat
Magnum Metal Treating
Master Heat Treating Inc.
Merit Gear Corp.
Metal Improvement Co. —Columbus
Metal Improvement Co. —Lafayette
Metal Improvement Co. —McLean/Wichita
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Metallurgical Inc.
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Metals Technology
Metlab Co.
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Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Midland Metal Treating
Midwestern Machinery Co.
Modern Industries Inc.
Mountain Metallurgical
National Broach
National Metal Processing
Oakland Metal Treating Co.
Ohio Metallurgical Service
P & L Heat Treating & Grinding
Partek Laboratories Inc.
Paulo Products Co. —Bessemer
Paulo Products Co. —Kansas City
Paulo Products Co. —Memphis
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
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Shore Metal Technology
Sonee Heat Treating Corp.
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Specialty Heat Treating Inc. —Elkhart
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Specialty Heat Treating Inc. —Holland
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Specialty Steel Treating Inc. —Fraser
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Suncoast Heat Treat, Inc. —Tampa
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Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Metal Treating
Thermal Treatment Center
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Tractech Inc.
Treat All Metals Inc.
Trutec Industries
Universal Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Westside Flame Hardening

CRYOGENICS

ABS Metallurgical Processors Inc.
Accurate Steel Treating
Advanced Thermal Technologies, Inc.
Alco Heat Treating Corp.
Alliance Metal Treating
Alpha Heat Treaters
American Brazing

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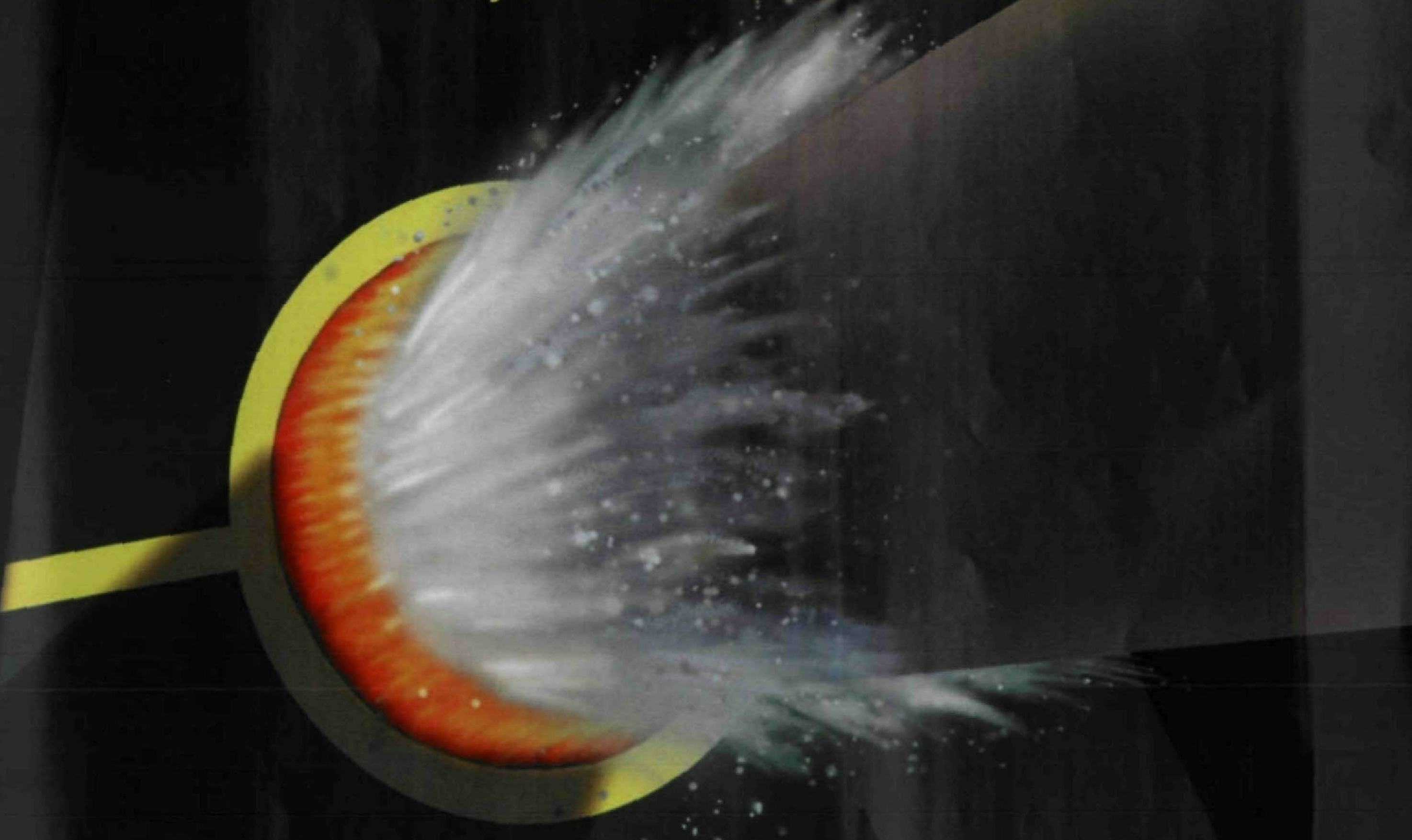

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CIRCLE 117

- American Cryogenics, Inc.
- American Heat Treating
- American Metal Treating Inc.
- Applied Cryogenics Inc.
- Beehive Heat Treating Inc.
- *Benedict-Miller Inc.*
- Bennett Heat Treating
- Bodycote S.W. Inc.
- Bodycote Thermal Processing—Dallas
- Bodycote Thermal Processing—Ft. Worth
- Braddock Metallurgical
- Braddock Metallurgical —Alabama
- Burbank Steel Treating Inc.
- Cal-Doran Division
- Carolina Commercial Heat Treating
- Century Sun Metal Treating
- Certified Heat Treating Inc.
- Certified Metal Craft
- Cincinnati Gear Co.
- Cincinnati Steel Treating
- City Steel Treating Inc.
- Delavan Steel Treating
- Detroit Flame Hardening
- *Detroit Steel Treating Co.*
- Dixie Heat Treating
- Drever Heat Treating
- Dynamic Metal Treating
- East Carolina Metal Treating Inc.
- East-Lind Heat Treat
- Edwards Heat Treating
- Elmira Heat Treating Inc.
- Engineered Heat Treat Inc.
- Erie Steel Treating Inc.
- Euclid Heat Treating Co.
- Fenton Heat Treating
- Flame Metals Processing
- Fox Steel Treating Co.
- FPM Heat Treating —Elk Grove
- FPM Ipsen Heat Treating
- FPM Milwaukee
- General Heat Treating Corp.
- General Metal Heat Treating Inc.
- Geo. H. Porter Steel Treating Co.
- Gibson Heat Treat Inc.
- Hanson-Balk Steel Treating
- Hauni Richmond Inc.
- Heat-Treating Inc.
- Heat Treat Corp. of America
- HI TecMetal Group —Cleveland
- Hinderliter Heat Treating Inc. —Anaheim
- Hinderliter Heat Treating Inc. —Dallas
- Hinderliter Heat Treating Inc. —Tarzana
- Hinderliter Heat Treating Inc. —Tulsa
- Hi-Tech Steel Treating Inc.
- Horizon Steel Treating Inc.
- HTG Commercial Induction
- HTG Hitech Aero Division
- Hudapack—Elkhorn
- Hydro-Vac
- Hy-Vac Technologies Inc.
- Illiana Heat Treating Inc.
- Impact Strategies Inc.
- Induction Metal Treating
- Industrial Metal Treating
- Industrial Steel Treating Inc.
- Ironbound Heat Treating
- Irwin Automation Inc.
- **Jasco Heat Treating Inc.**
- Kowalski Heat Treating Co.
- Lindberg Heat Treating Co. —Berlin
- Lindberg Heat Treating Co. —Houston
- Lindberg Heat Treating Co. —Melrose Park
- Lindberg Heat Treating Co. —Racine
- Lindberg Heat Treating Co. —Rosemont
- Magnum Metal Treating
- Master Heat Treating Inc.
- Metal Improvement Co. —Columbus
- Metal Improvement Co. —McLean/Wichita
- Metal Treaters Inc.
- Metallurgical Inc.
- Metals Engineering Inc.
- Metals Technology
- Metlab Co.
- Metro Steel Treating
- Met-Tek Inc.—Clackamas
- Midland Metal Treating
- Modern Industries Inc.
- Mountain Metallurgical
- Nitrex Metal Technologies Inc.—Burlington
- Nitro-Vac Heat Treating
- Ohio Metallurgical Service
- Paulo Products Co. *—Bessemer*
- Paulo Products Co. —Kansas City
- Paulo Products Co. —Memphis
- Paulo Products Co. —Murphreesboro
- Paulo Products Co. —Nashville
- Paulo Products Co. —St. Louis
- Penna Flame Industries Inc.
- Pennsylvania Metallurgical
- Peters Heat Treating Inc.
- Phoenix Heat Treating Inc.
- Pitt-Tex Inc.
- Progressive Steel Treating
- Racine Heat Treating Co.
- Rochester Steel Treating
- Rotation Products Corp.
- S.K.S. Heat Treating Inc.
- Shore Metal Technology
- Solar Atmospheres Inc.
- Sonee Heat Treating Corp.
- Southeastern Heat Treating
- Specialty Heat Treating Inc. —Athens
- Specialty Heat Treating Inc. —Elkhart
- Specialty Heat Treating Inc. —Grand Rapids
- Specialty Heat Treating Inc. —Holland
- Specialty Steel Treating Inc. —Fraser
- Steel Treaters, Inc.
- Steel Treating
- Sun Steel Treating
- Suncoast Heat Treat, Inc. —Pompano Beach
- Suncoast Heat Treat, Inc. —Tampa
- Superior Metal Treating
- Syracuse Heat Treating
- T. N. Woodworth Inc.
- Therm Tech of Waukesha
- Thermal Braze Inc.
- Thermal Metal Treating
- Thermal Treatment Center
- Thermet Inc.
- Thermo Electron Metal Treating Div.
- Tractech Inc.
- Treat All Metals Inc.
- Trutec Industries
- Universal Heat Treating
- Walker Heat Treating
- Washington Metallurgical Services
- Westside Flame Hardening

DIE QUENCHING

- A.F.C. — Pifco
- Beehive Heat Treating
- Benedict-Miller Inc.
- Bennett Heat Treating
- *Burbank Steel Treating*
- Caterpillar Industrial Products Inc.
- Century Sun Metal Treating
- Certified Metal Craft
- Cincinnati Gear Co.
- Cincinnati Steel Treating
- Detroit Steel Treating Co.
- Dynamic Metal Treating
- **Engineered Heat Treat Inc.**
- Euclid Heat Treating Co.
- **Fairfield Mfg. Co.**
- Fenton Heat Treating
- Fox Steel Treating Co.
- Franklin Steel Treating Co.
- General Metal Heat Treating Inc.
- Gibson Heat Teating
- **The Gleason Works**
- Grand Rapids Commercial Heat Treating Co.
- *Heat Treat Corp. of America*
- HTG Commercial Induction
- Hy-Vac Technologies Inc.
- Illiana Heat Treating Inc.
- Industrial Steel Treating
- Ironbound Heat Treating
- John V. Potero Co.
- Kowalski Heat Treating
- Lindberg Heat Treating Co. —New Berlin
- Lindberg Heat Treating Co. —Racine
- Lindberg Heat Treating Co. —Rosemont
- Metallurgical Inc.
- Metals Technology
- Metlab Co.
- Ohio Metallurgical Service
- Paulo Products Co. —Bessemer
- Paulo Products Co. —Kansas City
- Paulo Products Co. —Memphis
- Paulo Products Co. —St. Louis
- Phoenix Heat Treating Inc.
- Roboduction Thermal Processing
- Rotation Products Corp.
- Solar Atmospheres Inc.
- Specialty Steel Treating Inc.—Farmington Hills
- Specialty Steel Treating Inc.—Fraser
- Sun Steel Treating
- Therm Tech of Waukesha
- Treat All Metals Inc.
- Washington Metallurgical Services
- Westside Flame Hardening

FLAME HARDENING

- Alco Heat Treating Corp.
- American Heat Treating
- Beehive Heat Treating Inc.
- Benedict-Miller Inc.
- Bennett Heat Treating
- Bodycote S.W. Inc.
- Bodycote Thermal Processing—Ft. Worth
- The Bowdil Co.
- California Surface Hardening Inc.
- Calumet Surface Hardening
- Certified Heat Treating Inc.
- Chicago Flame Hardening
- Chicago Induction
- Cincinnati Flame Hardening Co.
- *Cincinnati Gear Co.*
- Cincinnati Steel Treating
- Clearing Niagara
- Cleveland Flame Hardening Co.
- Coleman Commercial Heat Treating
- Detroit Flame Hardening
- Detroit Steel Treating Co.
- Drever Heat Treating
- East-Lind Heat Treat
- Edwards Heat Treating
- Erie Steel Treating Inc.
- Flame Hardening Co. of California
- Fox Steel Treating Co.
- Franklin Steel Treating Co.
- Gibson Heat Treat Inc.
- Good Earth Tools
- Grand Rapids Commercial Heat Treating Co.
- Hansen-Balk Steel *Treating*
- Hauni Richmond Inc.
- Heat-Treating Inc.
- Hinderliter Heat Treating Inc.—Tulsa
- Hi-Tech Steel Treating Inc.
- Houston Flame Hardening
- Illiana Heat Treating Inc.
- Induction Metal Treating
- Industrial Metal Treating
- **Jasco Heat Treating Inc.**
- John V. Potero Co.
- Kowalski Heat Treating
- M & M Heat Treat
- Metal Improvement Co. —McLean/Wichita
- Metal Treating Inc.
- Metallurgical Inc.
- Met-Tek Inc.—Clackamas
- Met-Tek Inc.—Racine
- Michigan Flame Hardening
- Mid-West Flame Hardening
- Midwestern Machinery
- National Induction Heating
- Ohio Metallurgical Service
- Penna Flame Industries
- Pennsylvania Metallurgical
- Revas Engineering Co.
- Specialty Heat Treating Inc.—Athens
- Steel Treaters, Inc.
- Suncoast Heat Treat, Inc. —Orlando
- Suncoast Heat Treat, Inc. —Pompano Beach
- Suncoast Heat Treat, Inc. —Tampa
- Superior Metal Treating
- Syracuse Heat Treating
- Therm Tech of Waukesha
- Thermo Electron Metal Treating Div.
- Thermo Treaters Ltd.
- Westside Flame Hardening
- Wohlert Corp.

FREE QUENCHING

- A.F.C. — Pifco
- ABS Metallurgical Processors Inc.
- Alliance Metal Treating
- AP Westshore
- Benedict-Miller Inc.
- Bennett Heat Treating
- Bodycote S.W. Inc.
- Bodycote Thermal Processing—Dallas
- Bodycote Thermal Processing—Ft. Worth
- Braddock Metallurgical
- Burbank Steel Treating
- *Cal-Doran Division*
- Carolina Commercial Heat Treating
- Caterpillar Industrial Products Inc.
- Certified Heat Treating
- Certified Metal Craft
- Cincinnati Gear Co.
- Cincinnati Steel Treating
- City Steel Treating Inc.
- Commercial Induction
- Commercial Steel Treating
- Detroit Steel Treating Co.
- Diamond Heat Treating
- East Carolina Metal Treating Inc.
- Edwards Heat Treating
- **Engineered Heat Treat Inc.**
- **Fairfield Mfg. Co.**
- Fenton Heat Treating
- Flame Metals Processing
- FPM Heat Treating *—Elk Grove*
- FPM Milwaukee
- Franklin Steel Treating Co.
- General Metal Heat Treating Inc.
- Gibson Heat Treat Inc.
- Hanson-Balk Steel Treating
- Heat Treat Corp. of America
- Heat-Treating Inc.
- Hinderliter Heat Treating Inc. —Anaheim
- Hinderliter Heat Treating Inc.—Tarzana
- Horizon Steel Treating Inc.
- Horsburgh & Scott Co.
- Huron Metallurgical Inc.
- Illiana Heat Treating Inc.
- Induction Metal Treating
- Industrial Metal Treating
- Industrial Steel Treating
- Kowalski Heat Treating
- Lake County Steel Treating
- Lawrence Industries Inc.
- Lindberg Heat Treating Co. —Berlin
- Lindberg Heat Treating Co. —Houston
- Lindberg Heat Treating Co. —Melrose Park
- Lindberg Heat Treating Co. —New Berlin
- Lindberg Heat Treating Co. —Racine
- Lindberg Heat Treating Co. —Rosemont
- Merit Gear Corp.
- Metal Improvement Co. —Lafayette
- Metal Improvement Co. —McLean/Wichita
- Metal Treating Inc.
- Metallurgical Inc.
- Metals Technology
- Metlab Co.
- Met-Tek Inc.—Racine
- Midland Metal Treating
- Mid-West Flame Hardening
- **National Broach**
- National Induction Heating
- Nettleson Steel Treating
- Ohio Metallurgical Service
- P & L Heat Treating & Grinding
- Phoenix Heat Treating Inc.
- Pitt-Tex Inc.
- Progressive Steel Treating
- Rotation Products Corp.
- S.K.S. Heat Treating Inc.
- Scot Forge
- Sonee Heat Treating Corp.
- Specialty Steel Treating *Inc.—Farmington Hills*
- Specialty Steel Treating Inc.—Fraser
- State Heat Treat Inc.
- Sun Steel Treating
- Suncoast Heat Treat, Inc. —Pompano Beach
- Superior Metal Treating
- Syracuse Heat Treating
- T. N. Woodworth Inc.
- Thermal Treatment Center
- Thermo Electron Metal Treating Div.
- Treat All Metals Inc.
- Walker Heat Treating
- Westside Flame Hardening
- Wohlert Corp.

HOT OIL QUENCHING

- A.F.C. — Pifco
- Abbott Furnace Company
- ABS Metallurgical Processors Inc.
- Advanced Metallurgical Technology
- Advanced Thermal Technologies, Inc.
- Alco Heat Treating Corp.
- Alpha Heat Treaters
- American Heat Treating
- Atmosphere Annealing
- Beehive Heat Treating Inc.
- Benedict-Miller Inc.
- Bennett Heat Treating
- Bodycote S.W. Inc.
- Bodycote Thermal Processing—Ft. Worth
- Bomak Corp.
- Burbank Steel Treating
- Carolina Commercial Heat Treating
- Central Kentucky Processing
- Century Sun Metal Treating
- Certified Heat Treating Inc.
- Certified Metal Craft
- Cincinnati Gear Co.
- Cincinnati Steel Treating
- City Steel Treating Inc.
- Clearing Niagara
- Cleveland Flame Hardening Co.
- Commercial Steel Treating
- Custom Heat Treating Co.
- Detroit Steel Treating Co.
- Disston Precision Inc.
- Dixie Machine & Heat Treating Inc.
- Drever Heat Treating
- East Carolina Metal Treating Inc.
- Eckel Heat Treat
- Elmira Heat Treating Inc.
- **Engineered Heat Treat Inc.**
- Erie Steel Treating Inc.
- **Fairfield Mfg. Co.**
- Feinblanking Ltd.
- Fenton Heat Treating
- Fox Steel Treating Co.
- FPM Heat Treating —Elk Grove
- FPM Ipsen Heat Treating
- FPM Milwaukee
- Franklin Steel Treating
- General Heat Treating
- General Metal Heat Treating Inc.
- Gibson Heat Treat Inc.
- Hansen-Balk Steel

Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
HI TecMetal Group —Cleveland
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
Horsburgh & Scott Co.
HTG Commercial Induction
Huron Metallurgical Inc.
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Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating
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Kowalski Heat Treating
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Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
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Metal Improvement Co. —McLean/Wichita
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Metals Technology
Metlab Co.
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Met-Tek Inc.—Racine
Midland Metal Treating
Mid-West Flame Hardening
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Rochester Steel Treating
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S.K.S. Heat Treating Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
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Specialty Steel Treating Inc. —Fraser
Sun Steel Treating
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Pompano Beach
Syracuse Heat Treating
Therm Tech of Waukesha
Thermal Treatment Center
Thermo Treaters Ltd.
Treat All Metals Inc.
Washington Metallurgical Services
Weiss Industries, Inc.

INDUCTION HARDENING

Advanced Heat Treat Corp.—Waterloo
Advanced Heat Treating
Ajax Magnethermic Corp.
Alco Heat Treating Corp.
Alpha Heat Treaters
American Metal Treating Co.
American Metal Treating Inc.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating
Bodycote Induction Processing
Bodycote S.W. Inc.
Bodycote Thermal Processing—Ft. Worth
Braddock Metallurgical
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Central Kentucky Processing
Century Sun Metal Treating
Certified Heat Treating Inc.
Chicago Induction
Cincinnati Gear Co.
Cincinnati Steel Treating
Clearing Niagara
Coleman Commercial Heat Treating
Commercial Induction
Contour Hardening Inc.
Delavan Steel Treating
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
East Carolina Metal Treating Inc.
Edwards Heat Treating
Elmira Heat Treating Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Flame Metals Processing
Fluxtrol Manufacturing Inc.
Franklin Steel Treating Co.
Gear Company of America
General Heat Treating
Gibson Heat Treat Inc.
Good Earth Tools, Inc.
H & S Heat Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
HI TecMetal Group —Cleveland
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
HTG Commercial Induction
Hudapack—Elkhorn
Illiana Heat Treating Inc.
Impact Strategies Inc.
Induction Services Inc.
Induction Metal Treating
Induction Heat Treating
Inductoheat Inc.
Industrial Metal Treating
Industrial Steel Treating Co.
International Induction Inc.
Ironbound Heat Treating
Jasco Heat Treating Inc.
John V. Potero Co.
Lawrence Industries Inc.
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
Mannings U.S.A.
Master Heat Treating Inc.
Merit Gear Corp.
Metal Treating & Research
Metal Improvement Co. —McLean/Wichita
Metal Processing Co.
Metal Treaters Inc.
Metal Treating Inc.
Metal Treating & Research
Metallurgical Inc.
Metals Engineering Inc.
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Met-Tek Inc.—Racine
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Midland Metal Treating Inc.
Modern Industries Inc.
Molon Gear & Shaft
National Induction Heating
National Metal Processing
O & W Heat Treat Inc.
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Paulo Products Co. —Memphis
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Pitt-Tex Inc.
Precision Heat Treating
Racine Heat Treating Co.
Revas Engineering Co.
Roboduction Thermal Processing
S.K.S. Heat Treating Inc.
Southeastern Heat Treating
Specialty Heat Treating Inc. —Elkhart
Specialty Heat Treating Inc. —Grand Rapids
Specialty Heat Treating Inc. —Holland
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Suncoast Heat Treat, Inc. —Pompano Beach
Suncoast Heat Treat, Inc. —Tampa
Superior Metal Treating
Syracuse Heat Treating
Thermal Braze Inc.
Thermal Metal Treating Inc.
Thermal Treatment Center
Thermet Inc.
Thermo Electron Metal Treating Div.
Tocco, Inc.
Treat All Metals Inc.
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Welduction Corporation
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Advanced Heat Treat Corp. —Waterloo
Advanced Metallurgical Technology
AMT Monroe Inc.
Century Sun Metal Treating
Cincinnati Gear Co.
Fox Steel Treating Co.
FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
HI TecMetal Group —Cleveland
HTG Commercial Induction
Ionex, Inc.
Lindberg Heat Treating Co.—Rosemont
Magnum Metal Treating
MPT America
Progressive Engineering
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Sun Steel Treating
Thermal Treatment Center

LASER HARDENING

Cincinnati Gear Co.
Laser Machining, Inc.
National Metal Processing
Weiss Industries Inc.

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Advanced Heat Treating
Advanced Metallurgical Technology
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
Alliance Metal Treating
Alpha Heat Treaters
American Metal Treating Inc.
Benedict-Miller
Bennett Heat Treating
Bodycote S.W. Inc.
Bodycote Thermal Processing—Dallas
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing (West)
Burbank Steel Treating
Century Sun Metal Treating
Certified Metal Craft
Cincinnati Steel Treating
Delavan Steel Treating
Detroit Steel Treating Co.
Dixie Heat Treating
Dynamic Metal Treating
East-Lind Heat Treat
Elmira Heat Treating Inc.
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Flame Metals Processing
General Heat Treating
General Metal Heat Treating Inc.
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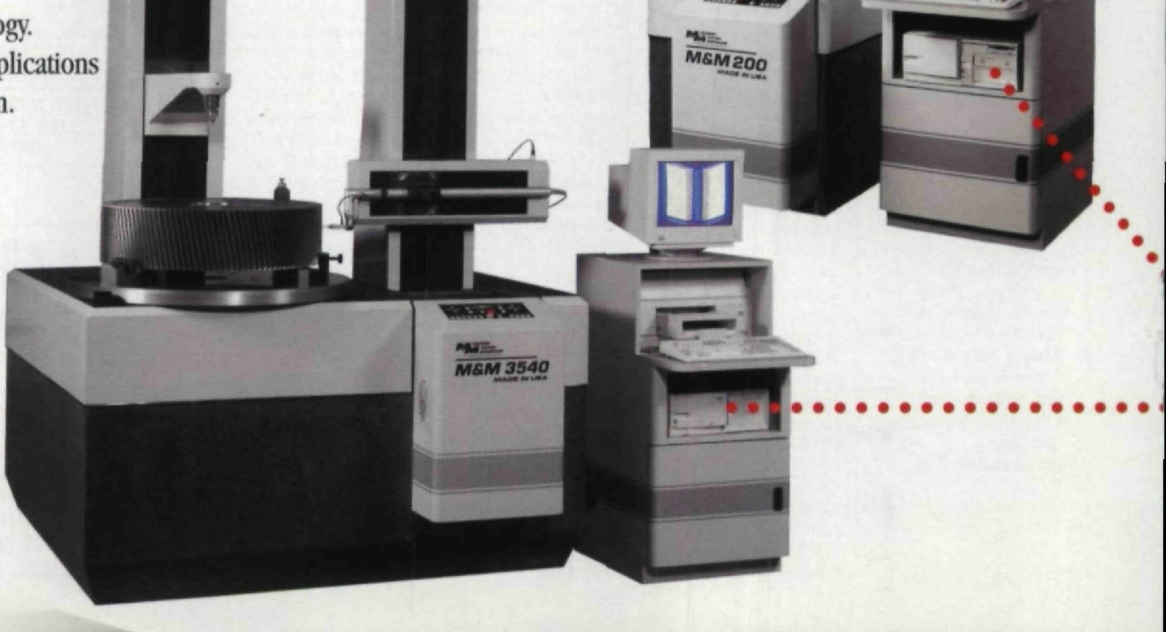

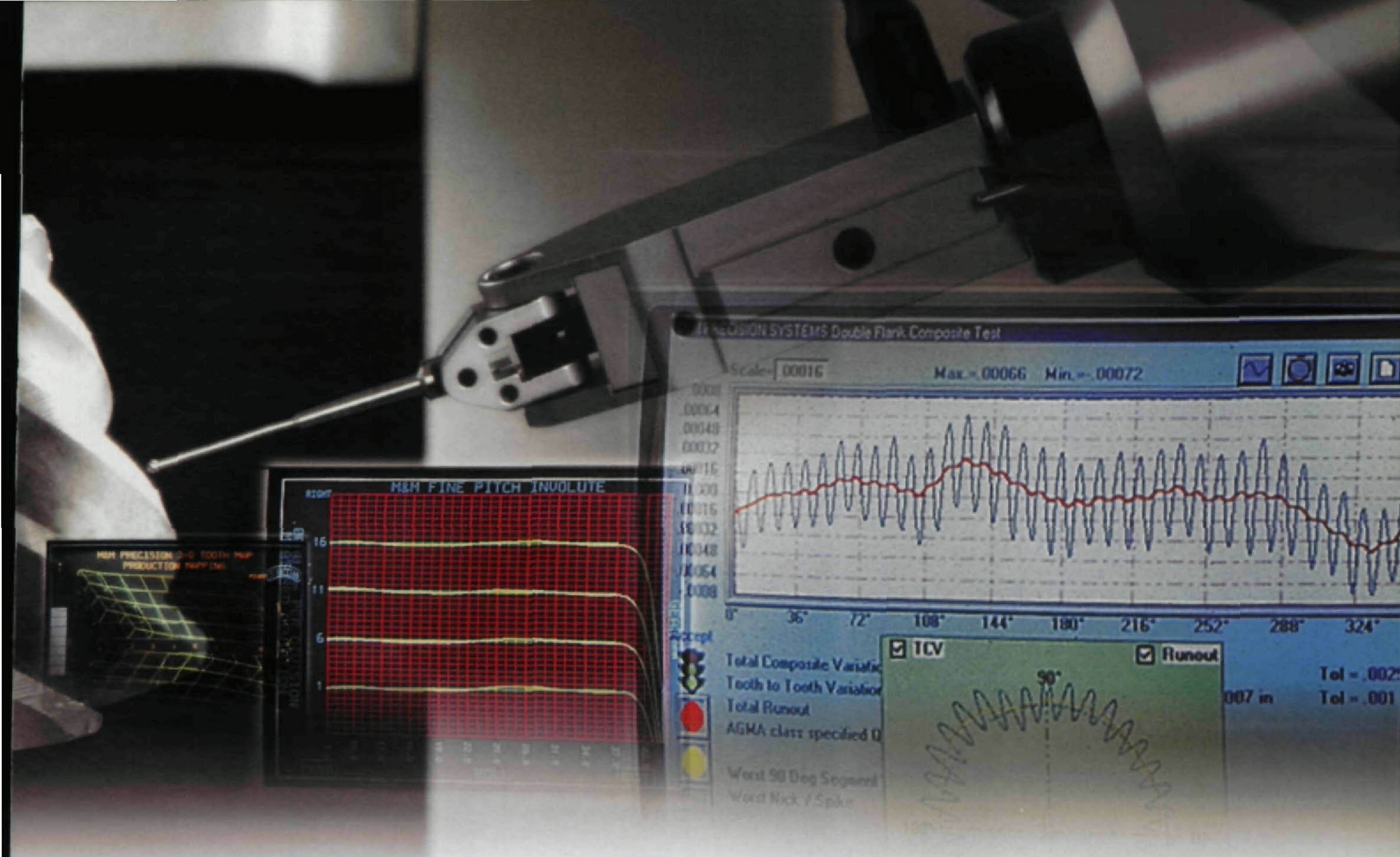

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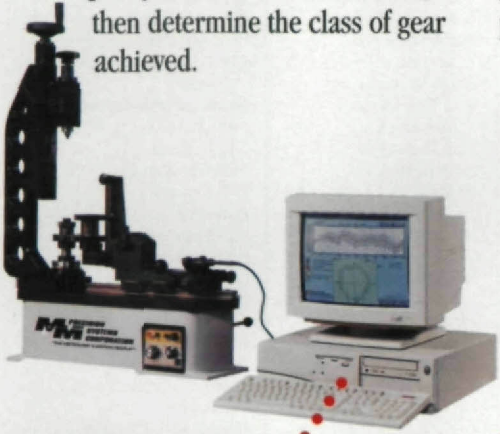

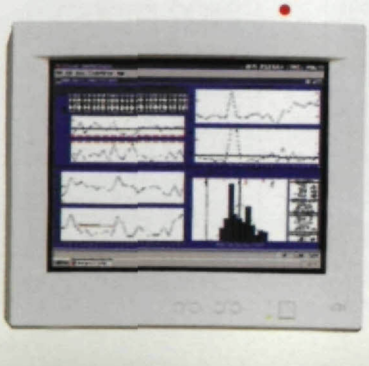

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FPM Ipsen Heat Treating
FPM Milwaukee
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Hinderliter Heat Treating Inc.—Tarzana
Hinderliter Heat Treating Inc.—Tulsa
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Cincinnati Gear Co.
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Delphi Engineering
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Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
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Lindberg Heat Treating Co. —St. Louis
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Met-Tek Inc.—Racine
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National Broach
National Metal Processing
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Nitro-Vac Heat Treating
Oakland Metal Treating
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Rochester Steel Treating
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Scot Forge
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating Inc. —Athens
Specialty Heat Treating Inc. —Elkhart
Specialty Heat Treating Inc.

—Grand Rapids
Specialty Heat Treating Inc. —Holland
Specialty Heat Treating Inc. —Farmington Hills
Specialty Heat Treating Inc. —Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
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Suncoast Heat Treat, Inc. —Orlando
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Universal Heat Treating
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Fairfield Mfg. Co.
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General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
The Gleason Works
Heat Treat Corp. of America
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Kowalski Heat Treating Co.
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
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Metals Technology
Metlab Co.
Mountain Metallurgical
Ohio Metallurgical Service
Phoenix Heat Treating Inc.
Roboduction Thermal Processing
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Engineered Heat Treat Inc.
Flame Metals Processing
Fox Steel Treating Co.
H & M Metal Processing
HI TecMetal Group —Cleveland
Illiana Heat Treating Inc.
Induction Metal Treating
Lake County Steel Treating
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
Metal Treaters Inc.
Metals Technology
Met-Tek Inc.—Clackamas
National Broach
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Trutec Industries
Walker Heat Treating
Wear-Ever Surface Treating
Weiss Industries Inc.

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Jasco Heat Treating Inc.
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Paulo Products Co. —Memphis
Superior Metal Treating
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Modern Metal Processing
Pennsylvania Metallurgical
Progressive Steel Treating
Solar Atmospheres Inc.
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Specialty Heat Treating Inc.—Elkhart
Specialty Heat Treating Inc.—Grand Rapids
Specialty Heat Treating Inc.—Holland
Suncoast Heat Treat, Inc. —Pompano Beach
Syracuse Heat Treating
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Gleason Pfauter Hurth Cutting Tools
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HTG Commercial Induction
Industrial Metal Treating
Kowalski Heat Treating Co.
Metlab Co.
Solar Atmospheres Inc.
Sun Steel Treating
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Bennett Heat Treating
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Bodycote Thermal Processing (West)
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Cincinnati Flame Hardening Co.
Cincinnati Steel Treating
Clearing Niagara
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Engineered Heat Treat Inc.
Erie Steel Treating Inc.
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Flame Metals Processing
Gleason Pfauter Hurth Cutting Tools
Grand Rapids Commercial Heat Treating Co.
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
Horsburgh & Scott Co.
Houston Flame Hardening
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Kowalski Heat Treating
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
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Metal Treating Inc.
Metlab Co.
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Racine Heat Treating Co.
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Ajax Magnethermic Corp.
Albany Metal Treating
Alco Heat Treating Corp.
Alliance Metal Treating
Allread Products
Alpha Heat Treaters
American Brazing
American Heat Treating
American Metal Treating Inc.
AMT Monroe Inc.
Atmosphere Annealing
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating
Bodycote S.W. Inc.
Bodycote Thermal Processing—Dallas
Bodycote Thermal Processing—Ft. Worth
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Bonal Technologies Inc.
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Brazing & Metal Treating —Cleveland
Brazing & Metal Treating of Kentucky
Brazing & Metal Treating of Minnesota
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Brite Metal Treating Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Central Kentucky Processing
Century Sun Metal Treating
Certified Heat Treating Inc.
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Chicago Flame Hardening
Cincinnati Flame Hardening Co.
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Clearing Niagara
Cleveland Flame Hardening Co.
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Commercial Induction
Commercial Steel Treating
Cooperheat Inc.
Custom Heat Treating Co.
Delavan Steel Treating
Delphi Engineering
Detroit Flame Hardening
Detroit Steel Treating Co.
Diamond Heat Treating
Disston Precision Inc.
Dixie Heat Treating Co., Dixie Machine & Heat Treating Inc.
Drever Heat Treating
Dynamic Metal Treating
East Carolina Metal Treating Inc.
East-Lind Heat Treat
Eckel Heat Treat
Edwards Heat Treating
Elmira Heat Treating Inc.
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Fairfield Mfg. Co.
Feinblanking Ltd.
Fenton Heat Treating
Flame Metals Processing
Fluxtrol Manufacturing
Fox Steel Treating Co.
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General Metal Heat Treating Inc.
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Hinderliter Heat Treating Inc.—Tulsa
Hitech Metallurgical Co.
Hi-Tech Steel Treating Inc.
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Hudapack—Elkhorn
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Hydro-Vac
Hy-Vac Technologies Inc.
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Impact Strategies Inc.
Induction Metal Treating
Induction Services Inc.
Inductoheat Inc.
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Ironbound Heat Treating
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Kowalski Heat Treating
Lake County Steel Treating
Lawrence Industries Inc.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
M & M Heat Treat
Magnum Metal Treating
Mannings U.S.A.
Master Heat Treating Inc.
Merit Gear Corp.
Metal Improvement Co. —Columbus
Metal Improvement Co. —Lafayette
Metal Improvement Co. —McLean/Wichita
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Metal Treaters Inc.
Metal Treating Inc.
Metal Treating & Research
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology
Metal-Tec Heat Treating
Metlab Co.
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Michigan Flame Hardening
Michigan Induction Inc.
Midland Metal Treating
Midwest Flame Hardening
Midwestern Machinery
Modern Industries Inc.
Modern Metal Processing
Mountain Metallurgical
National Broach
National Induction Heating
National Metal Processing
Nettleson Steel Treating
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Oakland Metal Treating
Ohio Metallurgical Service
Partek Laboratories Inc.
Paulo Products Co. —Bessemer
Paulo Products Co. —Kansas City
Paulo Products Co. —Memphis
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Penna Flame Industries
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating

Racine Heat Treating Co.
Roboduction Thermal Processing
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shanafelt Mfg. Co.
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating Inc. —Athens
Specialty Heat Treating Inc. —Elkhart
Specialty Heat Treating Inc. —Grand Rapids
Specialty Heat Treating Inc. —Holland
Specialty Heat Treating Inc. —Farmington Hills
Specialty Heat Treating Inc. —Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Sun Steel Treating
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Pompano Beach
Suncoast Heat Treat, Inc. —Tampa
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Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Metal Treating
Thermal Treatment Center
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Tocco, Inc.
Tractech Inc.
Treat All Metals Inc.
Trojan Heat Treat Inc.
Trutec Industries
Universal Heat Treating
Vacu Braze
Walker Heat Treating
Wall Colmonoy Corp.
Washington Metallurgical Services
Weiss Industries Inc.
Western Stress Inc.
Westside Flame Hardening

TEMPERING

A.F.C. — Pifco
Abbott Furnace Company
ABS Metallurgical Processors Inc.
Accurate Steel Treating
Advanced Heat Treating
Advanced Metallurgical Technology
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
Albany Metal Treating
Alco Heat Treating Corp.
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Bodycote Thermal Processing—Ft. Worth
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The Bowdil Co.
Braddock Metallurgical
Braddock Metallurgical —Alabama
Brazing & Metal Treating—Cleveland
Brite Brazing
Brite Metal Treating Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Calumet Surface Hardening
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Central Kentucky Processing
Century Sun Metal Treating
Certified Heat Treating Inc.
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Chicago Flame Hardening
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Cincinnati Flame Hardening Co.
Cincinnati Gear
Cincinnati Steel Treating
City Steel Treating Inc.
Clearing Niagara
Cleveland Flame Hardening
Coleman Commercial Heat Treating
Commercial Induction
Commercial Steel Treating
Custom Heat Treating Co.
Delavan Steel Treating
Delphi Engineering
Detroit Flame Hardening
Detroit Steel Treating Co.
Diamond Heat Treating Co.
Disston Precision Inc.
Dixie Heat Treating Co.
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
Dynamic Metal Treating
East-Lind Heat Treat
East Carolina Metal Treating Inc.
Eckel Heat Treat
Edwards Heat Treating
Elmira Heat Treating Inc.
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Fairfield Mfg. Co.
Feinblanking Ltd.
Fenton Heat Treating
Flame Metals Processing
Fluxtrol Manufacturing Inc.
Fox Steel Treating Co.
FPM Heat Treating —Elk Grove
FPM Milwaukee
Franklin Steel Treating Co.
Gear Company of America
General Heat Treating
General Metal Heat Treating Inc.
Geo. H. Porter Steel Treating Co.
Gibson Heat Treat Inc.
Gleason Pfauter Hurth Cutting Tools
Grand Rapids Commercial Heat Treating Co.
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H & S Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
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HI TecMetal Group —Cleveland
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Dallas
Hinderliter Heat Treating Inc.—Tarzana
Hinderliter Heat Treating Inc.—Tulsa
Hitech Metallurgical Co.
Hi-Tech Steel Treating
Horizon Steel Treating
Horsburgh & Scott Co.
Houston Flame Hardening
HTG Aerobraze
HTG Commercial Induction
HTG Hitech Aero Division
Hudapack—Elkhorn
Hudapack—Glendale Hts.
Huron Metallurgical Inc.
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Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Impact Strategies Inc.
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Induction Services Inc.
Inductoheat Inc.
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Industrial Steel Treating Co.
Industrial Steel Treating
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Irwin Automation Inc.
Jasco Heat Treating Inc.
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Lake County Steel Treating
Lawrence Industries Inc.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —New Berlin
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
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Magnum Metal Treating
Master Heat Treating Inc.
Merit Gear Corp.
Metal Improvement Co. —Columbus
Metal Improvement Co. —Lafayette
Metal Improvement Co. —McLean/Wichita
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Metal Treating Inc.
Metal Treating & Research
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology
Metlab Co.
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
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Michigan Induction Inc.
Midland Metal Treating
Midwest Flame Hardening
Midwestern Machinery
Modern Industries Inc.
Modern Metal Processing
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Mountain Metallurgical
National Broach
National Induction Heating
National Metal Processing
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O & W Heat Treat Inc.
Oakland Metal Treating
Ohio Metallurgical Service


HEAT TREATING

P & L Heat Treating & Grinding
Partek Laboratories Inc.
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Paulo Products Co. —Kansas City
Paulo Products Co. —Memphis
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
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Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Richter Precision Inc.
Roboduction Thermal Processing
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating Inc. —Athens
Specialty Heat Treating Inc. —Elkhart
Specialty Heat Treating Inc. —Grand Rapids
Specialty Heat Treating Inc. —Holland
Specialty Heat Treating Inc. —Farmington Hills
Specialty Heat Treating Inc. —Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Sun Steel Treating
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Pompano Beach
Suncoast Heat Treat, Inc. —Tampa
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Syracuse Heat Treating
T. N. Woodworth Inc.
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Thermal Metal Treating
Thermal Treatment Center
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Thermo Electron Metal Treating Div.
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Treat All Metals Inc.
Trutec Industries
Universal Heat Treating
Vacu Braze
Walker Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Westside Flame Hardening
Wohlert Corp.

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Alliance Metal Treating
Allread Products
American Brazing
American Heat Treating
American Metal Treating Inc.
Beehive Heat Treating
Benedict-Miller
Bennett Heat Treating
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Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing (West)
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Cal-Doran Division
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Certified Metal Craft
Certified Heat Treating
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Drever Heat Treating
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East-Lind Heat Treat
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Fenton Heat Treating
Flame Metals Processing
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Hanson-Balk Steel Treating
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Hinderliter—Dallas
Hitech Metallurgical Co.
Hi-Tech Steel Treating Inc.
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Irwin Automation Inc.
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Kowalski Heat Treating Co.
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Metlab Co.
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Nitrex Metal Technologies Inc.—Mason
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O & W Heat Treat Inc.
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Paolo Products Co. —Kansas City
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Racine Heat Treating Co.
Richter Precision Inc.
Solar Atmospheres Inc.
Speciality Heat Treating —Grand Rapids
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
Suncoast Heat Treat, Inc. —Orlando
Superior Metal Treating
Syracuse Heat Treating
Thermal Braze Inc.
Universal Heat Treating
Washington Metallurgical Services

OTHER

American Metal Treating Inc.—*6-Bar Program Quenching*

Beehive Heat Treating—*Neutral Salt Hardening*

Benedict-Miller—*Nitemper*

Bennett Heat Treating—*Vertical Carburizing or Hardening to 80"*

Bodycote Thermal Processing—Dallas—*Hydrogen*

Bodycote Thermal Processing (West)—*Marquenching*

Century Sun Metal Treating—*10- and 12-Bar Vacuum Treating*

Cincinnati Gear Co.—*Electron Beam Hardening*

Cincinnati Steel Treating—*Sub-Zero*

Contour Hardening—*Metallurgical Services*

Delphi Engineering—*Portable H.T. on site*

East-Lind Heat Treat—*Air, Oil, Water Hardening*

Engineered Heat Treat Inc.—*Lab Services, NAD-CAP Approved*

Erie Steel Treating Inc.—*Plug Quenching*

Euclid Heat Treating Co.—*Grit Blasting*

Flame Hardening of California—*On-Site Work*

Fox Steel Treating—*Select Hole Quenching*

H & S Heat Treating—*Neutral Hardening*

Heat Treating Network—*Heat Treating Training*

Hinderliter-Anaheim—*Kool Kase —FNC—*

Hitech Metallurgical Co.—*Welding*

HTG Commercial Induction—*TiN-TiC CVD Coatings*

HTG Hitech Aero Division—*CVD Hard Coatings*

Hundapack—Glendale Hts. —*Automated Salt to Salt Austempering and Marquenching*

Impact Strategies Inc.—*Consulting & Lab Work*

Induction Services—*Bonding Heat*

Industrial Steel Treating Inc.—*Magnetic Particle Inspection; Tensile Testing*

Ironbound Heat Treating—*Lab Work*

Jasco Heat Treating Inc.—*Large Salt Bath Lines*

Kowalski Heat Treating—*20 Bar Quenching*

Merit Gear Corp.—*NATCO Gear Hardening*

Metal Improvement Co.—Milwaukee—*Magnetic Particle Inspection*

Metals Technology Corp.—*Hyperannealing, Bright Hardening*

Michigan Induction Inc.—*Consulting on Induction*

Midland Metal Treating Inc.—*Turnkey Induction Heat Treat Systems with Metallurgical Services and Product Development*

National Metal Processing Inc.—*Continuous Belt Furnace*

Paulo Products—Kansas City—*Inspection*

Paulo Products Co.—Murfreesboro—*Zinc & Phosphate Plating*

Phoenix Heat Treating Inc.—*Copper Plating*

Progressive Steel Treating Inc.—*Grit Blasting*

Rebco/Rolock/MTech—*Sales Engineer*

Sun Steel Treating—*Salt Bath Hardening*

Suncoast Heat Treat, Inc.—Orlando—*Malcomizing*

Syracuse Heat Treating—*Ultrasonic Cleaning*

Thermal Braze Inc.—*Induction Brazing*

Thermal Metal Treating Inc.—*Fe-Mn-2 Phosphate Coating*

Westside Flame Hardening—*Vibra Hardening, Vibratory Stress Relieving*

HEAT TREAT EQUIPMENT & SUPPLIES

A.F.C. — Pifco—*Batch & Continuous Heat Treat Systems for Steel, Aluminum and Brass Components*

Abbott Furnace Company—*Continuous Belt Furnaces*

Ajax Magnethermic Corp.—*Induction Heat Treating Equipment*

American Cryogenics, Inc.—*Cryogenic Processors*

Can-Eng Furnaces Ltd.—*Continuous Furnaces, Batch Furnace Systems, Mesh Belt Furnaces, Fluidized Bed Furnaces, Atmosphere Furnaces for Annealing, Austempering, Carbonitriding, Carburizing, Normalizing, etc.*

The Duffy Company—*Condursal Stop-Off Paints for Carburizing and Nitriding*

Holcroft—*Standard and Custom Heat Treat Furnaces, including Batch, Pushers, Rotary Hearths, Vacuum Furnaces, Atmosphere Generators and More*

IHS, an Inductotherm Co.—*Induction Heating Equipment*

Inductoheat Inc.—*Induction Heating Equipment*

Ionex, Inc.—*Plasma Ion Nitriding & Ion Implantation Systems*

Laser Machining, Inc.—*Laser Heat Treating Systems*

Macdhui Probe of America—*Carbon Probes*

Nitrex Metal Technologies Inc.—Mason—*Technologically advanced gas nitriding systems (furnaces, process control hardware/software, exhaust neutralizing options, metallurgical consulting and technical support services)*

Nitrex Metal Technologies Inc.—St. Laurent—*Technologically advanced gas nitriding systems (furnaces, process control hardware/software, exhaust neutralizing options, metallurgical consulting and technical support services)*

Pillar Industries—*Induction Equipment*

Radyne Corporation—*Induction Heat Treating, Annealing, Tempering and Brazing Equipment*

Surface Combustion, Inc.—*Wide Variety of Batch & Continuous Furnaces for Atmosphere, Vacuum and Non-Atmosphere Heat Treating*

Thermet Inc.—*Induction Systems*

Welduction Corporation—*Induction Heat Treating Equipment and Related Supplies*

INDUSTRY REPORT

Study Predicts Modest Growth in Gear Manufacturing

Gears, a new 192-page study from The Freedonia Group (Cleveland, OH), projects U.S. demand for gears to increase 4.3 percent annually through 2002, when shipments are predicted to reach $25.7 billion.

The automotive industry will continue to be the largest source of gear demand, comprising about two-thirds of total sales. However, growth in the sales of automotive gears will be the slowest among major industry sectors, the study says.

The reasons for the expected slowdown include a saturation of key gear-powered accessories such as power windows, the ongoing development of belt-driven and other continuously variable transmissions and the slowdown of the overall economy.

Demand for gears in equipment and machinery is also likely to slow down because of the overall economy, while marine applications should exhibit the best growth prospects because of a projected continued demand for recreational boats, the study says.

Individual gears accounted for about 60 percent of total shipment value in 1997. However, growth in gear assembly shipments is expected to rise faster than that of individual gears through 2002. Most of this is expected because of growth in the gearmotor market.

Gear Demand By Market & Origin (million dollars)

Item 1987	1992	1997	2002	2007	
Durable Goods Shipments	1229	1456	2050	2582	3247
$ gears / 000 $ durable goods	10.4	10.4	10.4	10.2	10.2
Gear Demand	**12770**	**15125**	**21405**	**26380**	**33165**
By Market:					
Motor Vehicles	8720	10070	14700	17820	22010
Machinery & Equipment	2800	3355	4905	6120	7845
Other	1250	1700	1800	2440	3310
By Origin:					
OEM	11425	13495	19225	23660	29735
Captive	8120	9435	13635	16570	20535
Merchant	3305	4060	5590	7090	9200
Aftermarket	1345	1630	2180	2720	3430

Gears is available for $3,300 from The Freedonia Group, Inc., 767 Beta Drive, Cleveland, OH 44143-2326.

Tell Us What You Think . . .
If you found this article of interest and/or useful, please circle **206**.

If you'd like more information about **The Freedonia Group**, please circle **207**.

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CIRCLE 115

Welcome to the Company Index of the 1999 *Gear Technology* Directory of Heat Treating Services. Use this index to locate the complete contact information for each company listed in the Services Index. *Gear Technology* advertisers are shown in boldface type. To find the pages on which their ads appear, see the Advertisers Index on page 48.

While we have made every effort to ensure that company names and addresses are correct, we cannot be held responsible for errors of fact or omission. If your company was not listed in this directory, and you would like to be included in the next one, please call 847-437-6604.

A

A.F.C. — Pifco
49630 Pontiac Trail
Wixom, MI 48393
248-624-8191
Fax: 248-624-3710
E-mail: *sales@afc-pifco.com*
Web: *www.afc-pifco.com*

Abbott Furnace Company
1068 Trout Run Road
Saint Marys, PA 15857
814-781-6355
Fax: 814-781-7334
E-mail: *abbsales@penn.com*
Web: *www.penn.com/abbottfurnace*

ABS Metallurgical Processors Inc.
4313 E. Magnolia St.
Phoenix, AZ 85034
602-437-3008
Fax: 602-470-0309

Accurate Ion Technologies
10010 S. Miller Way
South Gate, CA 90280
562-928-1868
Fax: 562-927-8591
E-mail: *jbs3ait@earthlink.net*
Web: *www.heattreaters.com*

Accurate Steel Treating
10008 Miller Way
South Gate, CA 90280
562-927-6528
Fax: 310-927-8591

Advanced Heat Treat Corp.
1625 Rose St.
Monroe, MI 48162
734-243-0063
Fax: 734-243-4066
Web: *www.ahtweb.com*

Advanced Heat Treat Corp.
2839 Burton Avenue
Waterloo, IA 50703
319-232-5221
Fax: 319-232-4952
E-mail: *mkt@ion-nitriding.com*
Web: *www.ahtweb.com*

Advanced Heat Treating Inc.
Trout Run Rd.
St. Marys, PA 15857
814-781-3744
Fax: 814-781-3230
E-mail: *cherry@ncentral.com*

Advanced Metallurgical Technology
212 Page Ave.
Fort Worth, TX 76110
817-921-5100
Fax: 817-921-5372
E-mail: *amtsmith@earthlink.net*
Web: *www.heattreaters.com*

Advanced Thermal Technologies, Inc.
P.O. Box 875
3668 East U.S. 6
Kendallville, IN 46755
219-347-1203
Fax: 219-347-3568

Ajax Magnethermic Corp.
1745 Overland Ave.
Warren, OH 44482
330-372-8511
Fax: 330-372-8608
E-mail: *ajaxsales@ajaxmag.com*

Albany Metal Treating
400 S. Dowden Ave.
Albany, IN 47320
317-789-6470
Fax: 317-789-6839

Alco Heat Treating Corp.
130 Verdi St.
Farmingdale, NY 11735
516-249-1660
Fax: 516-249-7889

Alliance Metal Treating
P.O. Box 68
Eola, IL 60519
630-851-5880
Fax: 630-851-0733
E-mail: *almt@ix.netcom.com*

Allread Products
22 S. Main St.
Terryville, CT 06786
860-589-3566
Fax: 860-589-3566

Alpha Heat Treaters
270 Emig Rd.
Emigsville, PA 17318
717-767-6757
Fax: 717-764-0129

American Brazing
4428 Hamann Pkwy.
Willoughby, OH 44095
440-946-5900
Fax: 440-946-3091
E-mail: *jerwin@paulo-us.com*

American Cryogenics, Inc.
203 Travis Lane
Waukesha, WI 53189
414-513-0486
Fax: 414-513-0485
E-mail: *jim@americancryogenics.com*
Web: *www.americancryogenics.com*

American Heat Treating
1346 Morris Ave.
Dayton, OH 45408
937-461-1121
Fax: 937-461-1166

American Metal Processing Co.
22720 Nagel
Warren, MI 48089
810-757-7337
Fax: 810-757-8232

American Metal Treating Co.
1043 E. 62nd St.
Cleveland, OH 44103
216-431-4492
Fax: 216-431-1508
E-mail: *bruce@americanmetaltreating.com*
Web: www.geartechnology.com/copage/amtc.htm

American Metal Treating Inc.
P.O. Box 4157
High Point, NC 27263
336-889-3277
Fax: 336-889-7950
Web: *www.amerimetal.com*

AMT Monroe Inc.
615 Harbor Ave.
Monroe, MI 48162-5601
734-242-1733
Fax: 734-242-0993
E-mail: *amtsmith@earthlink.net*
Web: *www.heattreaters.com*

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4000 State Hwy. 91
Oshkosh, WI 54904-9217
920-235-2001
Fax: 920-235-2701
E-mail: *adiapw@aol.com*
Web: *www.appliedprocess.com*

Applied Cryogenics Inc.
1191 Chestnut St.
Newton, MA 02164
617-969-6490
Fax: 617-969-6266

Applied Process Inc.
12238 Newburgh Rd.
Livonia, MI 48150-1046
734-464-2030
Fax: 734-464-6314
E-mail: *jkeough@appliedprocess.com*
Web: *www.appliedprocess.com*

Atmosphere Annealing Inc.
1300 Industrial Dr.
N. Vernon, IN 47265
812-346-1275
Fax: 812-346-4534

B

Beehive Heat Treating Inc.
132 Water St.
S. Norwalk, CT 06854
203-866-1635
Fax: 203-855-9327

Benedict-Miller Inc.
Marin Ave. & Orient Way
Lyndhurst, NJ 07071-0912
201-438-3000
Fax: 201-438-3137
E-mail: *info@benedict-miller.com*
Web: *www.benedict-miller.com*

Bennett Heat Treating
690 Ferry St.
Newark, NJ 07105
973-589-0590
Fax: 973-589-6518

Bodycote Thermal Processing
10543 Doric Street
Dallas, TX 75220
214-904-2438
Fax: 214-904-2433
E-mail: *llance@bodycote-na.com*
Web: *www.bodycote-na.com*

Bodycote Thermal Processing
2005 Montgomery St.
Fort Worth, TX 76107
817-737-6651
Fax: 817-377-9610
E-mail: *truglic@bodycote-na.com*
Web: *www.bodycote-na.com*

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8468 Ronda Dr.
Canton, MI 48187
734-459-8514
Fax: 734-459-8795
E-mail: *ehutton@bodycote-na.com*
Web: *www.bodycote-na.com*

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1240 N. Harvard Ave.
Tulsa, OK 74115
918-834-0855
Fax: 918-836-4162

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Tarzana, CA 91356
818-344-0216
Fax: 818-609-9372

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Metallurgical Aspects to be Considered in Gear and Shaft Design

M. G. Conyngham

Introduction

In his *Handbook of Gear Design* (Ref. 1), Dudley states (or understates): "The best gear people around the world are now coming to realize that metallurgical quality is just as important as geometric quality." Geometric accuracy without metallurgical integrity in any highly stressed gear or shaft would only result in wasted effort for all concerned—the gear designer, the manufacturer, and the customer—as the component's life cycle would be prematurely cut short. A carburized automotive gear or shaft with the wrong surface hardness, case depth or core hardness may not even complete its basic warranty period before failing totally at considerable expense and loss of prestige for the producer and the customer. The unexpected early failure of a large industrial gear or shaft in a coal mine or mill could result in lost production and income while the machine is down since replacement components may not be readily available. Fortunately, this scenario is not common. Most reputable gear and shaft manufacturers around the world would never neglect the metallurgical quality of their products.

Additionally, there exists today a wide range of sophisticated and reliable control equipment available to the gear industry to ensure that all of the metallurgical processes in gear making are adequately quality assured.

New Opportunities for Manufacturers

In the automotive industry, customers have always demanded lighter, cheaper and quieter gears that carry higher loads at increasing speeds. It is only through an increased knowledge and understanding of the metallurgical aspects of gear and shaft design that these demands can be satisfied.

For many years, industrial gear manufacturers have followed the larger automotive gear companies in introducing processes such as gas carburizing for their small to medium sized gears. Surface hardening techniques such as flame hardening and contour induction hardening are frequently used to improve the endurance or load carrying ability, allowing reduced weight and cost. Gears and shafts manufactured for mining machines, for example, have been surface hardened using techniques that include gas carburizing, nitriding, induction hardening and shot peening. In all of these cases, customer demands can be fully met by an intimate knowledge of the metallurgical changes occurring before, during and after manufacturing. This includes material selection, machining, heat treatment processing, shot peening, grinding, chemical treatment and subsequent lubrication.

Design Engineer's Role

The design engineer has overall responsibility of the engineering specifications of new gears and shafts used to transmit torque, change rotational speeds or drive machinery. This responsibility includes calculating the geometric or dimensional specifications and ensuring that the loads can be transmitted smoothly and safely without breakage or seizure. The designer makes use

> "THE BEST GEAR PEOPLE AROUND THE WORLD ARE NOW COMING TO REALIZE THAT METALLURGICAL QUALITY IS JUST AS IMPORTANT AS GEOMETRIC QUALITY."
> — *DARLE W. DUDLEY*

of various gear standards, handbooks, and computer software to aid in this process. He will utilize tables and charts in these references to obtain the load carrying properties of various materials or, more likely, to compare the surface load and bending endurance limits of the available materials. The most commonly tabulated metallurgical property shown in these tables and graphs is Brinell hardness, which is directly related to ultimate tensile strength, as are all indentation hardness tests (Ref. 2).

These charts apply to normalized or hardened and tempered steel gears up to a maximum of about 400 Brinell hardness. Metallurgical factors such as sur-

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is a metallurgist and a thirty-year veteran of the gear industry. He is a member of the Engineering faculty at the University of Wollongong, New South Wales, Australia, where he coordinates postgraduate education with the Cooperative Research Center for Materials Welding and Joining. His research interests and areas of expertise include gear process technology and surface engineering.

face microstructure, grain size and steel cleanliness can have a major influence on gear and shaft endurance limits, but they are typically ignored. Such factors are not easily expressed numerically and are difficult for the design engineer to use directly in his calculations. It is probable that the designer may consult tables giving the full mechanical and physical properties of specific materials and rate them on performance in areas such as impact strength, ductility, fatigue life, or surface load and bending endurance limits if these figures are available. In reality, it is implied that the vast majority of vital metallurgical factors must be correctly dealt with by the material supplier or process provider, who must ensure that metallurgical integrity and the optimum balance between strength and toughness properties are achieved in the final product.

Materials Engineer's Role

In larger gear and shaft companies, it is the responsibility of the materials engineer to ensure the metallurgical integrity of the final product. This includes selecting the correct materials and thermal processing, as well as quality assurance of all the vital production processes that could change the properties of the final gear or shaft. Many metallic and nonmetallic materials have been successfully used to manufacture gears (Ref. 6). A wide variety of steels, cast irons, nonferrous alloys, phenolic resins, thermoplastics and sintered irons are available, but by far the greatest number of highly stressed gears and shafts are made from steels because of their high strength to weight ratio and relatively low cost. Additionally, ferrous materials gain their wide acceptance from the fact that their structural properties can be modified by heat treatment, and their surface chemistry can be changed by diffusing carbon or nitrogen into their surfaces. It has been estimated, for example, that steels account for about ninety percent of all gears and shafts produced in Australia. There are also a wide range of surface hardening options to select from, so specialist knowledge and material test equipment is required. It is in this area that most materials engineers receive their training.

Mechanical and materials engineers work together in their differing roles to arrive at the correct design and manufacturing route to make better and cheaper gears and shafts that will not fail prematurely.

Materials and Process Selection

In general, the design engineer will consult with the materials engineer to discuss all of the available options before selecting the final materials and heat treatment processes that satisfy the design requirements for a particular gear or shaft as well as fulfill the economic requirements of the business in an increasingly competitive environment. In Australia there are a limited number of steels and process options available (Ref. 6), so the right decision at the design stage is essential. For example, an automotive transmission shaft may be made from a low carbon alloy steel and carburized and quenched, or it could be satisfactorily made from a cheaper plain carbon steel and induction hardened. The final decision will depend on the configuration and type of gear or shaft being considered as well as the location, magnitude and duration of stresses that are likely to be present. Also vital are the capability, reliability and cost of the metallurgical processes available at the time.

At this stage, the materials engineer must consider metallurgical problems such as distortion during heat treatment processing, the likely impact and fatigue loads that may be encountered during service, and the added costs related to ensuring metallurgical quality. The two engineers must be able to apply theory and experience to the particular application in question so as to arrive at the desired result—a precision product at a competitive price to satisfy the customer.

Considerable experience and knowledge of existing successful designs is normally required. Discussion of the precise application needs and requirements may reveal that special problems exist with lubrication or overheating. Impact loads are normally impossible to estimate accurately and some metallurgical factors may not be known precisely. For the most highly loaded gears and shafts, this uncertainty may affect the final factor of safety in the design calculations. The gear design standards may mention certain metallurgical factors to be considered, but they may not give precise answers regarding what can be tolerated. Finally, confusion may exist between the different standards regarding how they should be applied.

These problems are of major concern to smaller gear companies that cannot afford an in-house materials engineer and do not possess in-house heat treatment facilities.

Gear Tooth Loading

Any discussion of the metallurgical aspects of gear design must begin by looking at basic gear tooth loading. Regardless of the gear type, whether spur, bevel, helical, hypoid or worm, in highly loaded mechanical gear trains, the forces acting on the mating gear teeth when they engage to transmit power will produce high surface contact stresses on the loaded flanks of the mating teeth and high bending stresses at or near the root of those teeth. Differences exist in the magnitude and depth of the shear stress as well as in the thrust direction and amount of sliding that occurs in the different gear types, but these differences will not be considered at this point.

Surface stresses. Surface fatigue is a frequent cause of gear failure. Although wear and scoring can be related to poor lubrication or surface roughness, pitting fatigue and subsequent breakage can be related to metallurgical factors.

The surface and near surface stresses developed between two steel surfaces under load have been studied by the 19th century German engineer Hertz, who developed formulae to aid in rating pitting resistance. However, these Hertzian equations are correct only for static loads on isotropic homogeneous materials. Because of the complex stress patterns existing in modern gears, where sliding and rolling take place above and below the pitch line, more recently developed relationships are available. However, these too are of limited value as the effect of lubricants was not considered (Ref. 4).

Initial wear or "wearing in" may be normal, and unless cracks develop in the tooth surface, it will generally not lead to pitting. However, pitting fatigue is progressive and leads to the destruction of the tooth profile.

A combination of rolling and sliding takes place both above and below the pitch line. The sliding motion plus the coefficient of friction tends to cause additional surface and subsurface stresses. Compressive stresses are present just ahead of the contact zone in the direction of sliding. Just behind this zone, there are tensile stresses. Beneath the contact zone are shear stresses. The depth of the point of maximum shear stress is about one third the width of the contact band. For any given load, the magnitude of these stresses is dependent on the length of the contact band and the action of the lubricant present.

As already mentioned, gear design tables and standards make use of the strong relationship that exists between indentation hardness, ultimate tensile strength, the surface stress factor (Sc) and the bending stress factor (Sb) for static loads. But as the majority of gears and shafts fail by fatigue at loads well below the ultimate tensile strength, then such tables are only useful in determining the steel's behavior under static loads. They are of little help in predicting the material's behavior under cyclical loading. It is at this point that the influence of residual stresses on fatigue must be discussed.

It has been well documented that processes introducing residual tensile stresses into the surface of a cyclically loaded specimen decrease its fatigue life. Processes that introduce residual compressive stresses into the surface of a specimen increase its fatigue life (Ref. 3). Because indentation hardness does not indicate the sign or magnitude of residual stresses existing at or below the surface, load tables based on hardness are of little help in designing fatigue resistant, highly loaded gears and shafts. It has also been well documented that the presence of surface abnormalities in the microstructure, or inclusions in the base material, can initiate fatigue cracks that eventually lead to failure. In addition, cracks can initiate at the surface of high hardness gears and shafts if high impact loads are present. Therefore, in order to know more about improving the fatigue life of gears and shafts, and so be able to build lighter and cheaper gears and shafts that give longer service, we must concentrate on knowing more about:

1. processes that introduce high residual compressive stresses into the surfaces of gears and shafts where fatigue failure is likely,
2. the metallurgical factors controlling impact toughness,
3. the factors affecting the cleanliness of the steel.

Residual Compressive Stresses. High surface contact loads can produce unfavorable tensile stresses in the tooth surface. These stresses eventually produce cracks that lead to failure of the surface by pitting and breakage. The introduction of residual compressive stresses into the tooth surface opposes the tensile stresses and prevents the initiation of fatigue cracks. It is well documented that manufacturing processes such as carburizing, carbonitriding, nitriding, induction hardening and shot peening considerably increase the residual compressive stress level at the surface of ferrous components. Also, thermal, mechanical and chemical processes can be used together as in the case of automotive planetary gears which are carburized, acid treated and shot peened with hardened steel shot. (This process produces the most fatigue resistant gears that the author is aware of.) It is extremely important that all such processes be precisely controlled if maximum residual compressive stress levels are to be consistently achieved.

Thermal Processing of Gears and Shafts

Carburizing. Case hardening processes have been known to impart high residual compressive stresses at the surface of a gear or shaft. It is these beneficial internal stresses that give the gear or shaft the improved endurance properties that allow the components to carry higher loads without failing.

Carburizing has been used for many years to case harden gears and shafts to improve wear resistance and load carrying ability. The process has come a long way from the early years of pack and salt bath hardening to modern controlled atmosphere furnaces that use sophisticated gas measuring devices and computers. The process, when correctly carried out, produces very high residual compressive stresses at the surface and underlying cased region. This results in improved surface endurance and wear resistance, as well as improved bending fatigue life and impact resistance. The metallurgical requirements (in the tooth contact zone) to achieve these benefits can be stated briefly below as:

1. surface carbon level to achieve the eutectoid composition for the particular steel used:
2. absence of excessive retained austenite after quenching:
3. absence of cementite networks (carbides) at or near the contact face:
4. absence of sub-surface oxides:
5. absence of intermediate transformation products. 100% martensite or mixtures of martensite and lower bainite being the aim (no pearlitic or upper bainitic skins):
6. fine grain size throughout the case.

The above requirements can only be achieved by precise control over

1. furnace temperature and carbon potential of the furnace atmosphere at the desired level:
2. use of the optimum quenchant and quench conditions (oil type, agitation, and oil temperature):
3. fine grain steel of the correct hardenability to ensure the gear or shaft meets the requirements for surface hardness, effective case depth, and core hardness:
4. optimum heat treatment cycle to produce the required case depth (carbon gradient) and microstructure.

The above requirements become difficult to achieve if the carburizing furnace load contains gears or shafts made from carburizing steels of different composition, or the furnace is overloaded to the extent of reducing either gas circulation or subsequent quench oil circulation. For example, a plain carbon manganese carburizing steel such as YK1320H will require a higher carbon potential than a high nickel carburizing steel such as X3312H.

Residual surface stresses must now be considered in relation to the commonly available gear heat treatment operations. By far the greatest quantity of highly stressed gears are carburized. These gears are made from low carbon, low alloy steels which, in and of themselves, lack surface durability. However, after raising the surface carbon of these gears to about 0.8–0.9% carbon, they exhibit the most desirable combination of surface endurance, bending endurance and toughness. Extremely precise control of all variables is required during carburizing and subsequent quenching to achieve the highest quality, lowest distortion gears.

Whether the gear designer requests direct quenching or reheat quenching after carburizing will depend on the known applications of the gears. Direct quenching has been used for many years with automotive gears where extremely fine grained, automotive quality steels are specified. However, the reheat method for more precise gears such as turbine gears has been said to produce better metallurgical structures and more assurance that the gears can run satisfactorily for a much higher number of cycles.

Induction hardening. Induction hardening has long been used to harden plain carbon automotive axle shafts. Surface hardening shafts using induction techniques also develops residual compressive stresses at the surface and in the hardened zone (Ref. 7). The exact pattern of these stresses depends on the process conditions and the composition of the material being hardened.

Apart from delaying the initiation of fatigue cracking in service, these residual compressive stresses are known to delay the process of stress corrosion cracking. Gears can also be induction hardened using different inductors and fixtures. The method best suited to large gears, where the profile and root area can be hardened without embrittling the tip of the tooth, involves using an inductor shaped to fit between the teeth. Modern techniques use dual frequencies in order to achieve the deeper case depths required by larger gears. Shafts are induction hardened using a scanning-type machine, which progressively moves the shaft through the inductor, heating and then quenching a small moving zone. The depth of the induced currents that heat the steel shaft or gear are related to the frequency of the induction hardening unit. Case depths for small shafts require higher frequencies (RF), while larger shafts require low frequencies (AF).

Automotive axle shafts are hardened using motor alternator units with a frequency between 3 and 10 Khz. The resulting hardened depth, measured to 40 HRC, is approximately 2.5 mm. Smaller solid state units operating at radio frequency 450KHz can harden small shafts within seconds to a depth of 0.7 mm.

Mechanical Processing

Shot Peening. The automotive industry uses dynamometers, driven by either electric motors or gasoline engines, to carry out precise life tests on finished transmission assemblies. These tests have proven that carburized automotive gears and shafts can achieve significantly improved fatigue life after peening with hardened steel shot, precisely carried out. The shot peening process is expensive but has allowed automotive companies to upgrade the ratings of automatic and manual transmissions without the need to make expensive dimensional changes to their gear trains. The peening operation induces beneficial residual compressive stresses in the flank and root area of the teeth under strictly controlled conditions. Compressive stress prevents or limits failure in gearing due to fatigue failures at the fillet and pitting failure at the pitch line.

Rolling. In some applications, work hardening of a component surface by rolling can induce residual compressive surface stresses and improve the surface finish, but care must be taken not to produce fine surface cracks that may initiate fatigue.

Common Failure Modes of Gears and Shafts

Fatigue Considerations. In regard to surface stresses, the limiting load for wear depends upon the surface endurance limits of the material, which in turn depends on geometric as well as metallurgical factors. Surface endurance limit values appear to be related consistently to a Brinell hardness number up to approximately 400 Brinell hardness (Ref. 2). When the Brinell hardness is over 400, the steel does not

TABLE 1
Spur and helical Gears (Ref. 2)

Brinell Hardness HB	Surface Endurance Limit (psi)
200	70,000
300	110,000
400	150,00

TABLE 2—For steels over 400HB (Ref. 2)

Brinell Hardness	Surface endurance limit (psi)			
HB	1 X 10^6	2 X 10^6	5 X 10^6	10^7
450	188000	170000	147000	132000
500	210000	190000	165000	148000
550	233000	210000	182000	163000
600	255000	230000	200000	179000

When the Brinell hardness is over 400

appear to have a definite endurance limit. Values for the surface endurance limit for steels over 400 Brinell are given in the table above.

The focus up until now has been on uniform loading, but in reality many gear systems experience fluctuating loads ranging from moderate to heavy shock. The sensitivity of the gear or shaft material to notches or sharp corners is a major consideration. In addition, most gears and shafts fail by fatigue at loads well below their yield strength. Although Tables 1 and 2 above are comparatively useful to design engineers in calculating load carrying capacity, they do not impart any information about the toughness or impact properties of the material, nor can they shed any light on the materials' fatigue strength. The often quoted "rule of thumb" that the fatigue strength is about 50% of the yield strength is probably very conservative. More information about the metallurgical factors that influence toughness and fatigue life is needed so that the engineer can confidently reduce the weight and hence the cost of a drive system. Research work to date points clearly at factors such as steel cleanliness, alloy combinations present, heat treatment condition, grain size and grain flow and the nature of micro-constituents present at or near the surface. Of critical importance is the steelmaking practice and the processing route used to make the components. Two steels with the same Brinell hardness could vary dramatically in impact and fatigue properties, particularly in the presence of small stress concentrators such as machine tool marks or subsurface defects.

Impact Properties

The selection of the correct material and heat treatment process for steel must be considered to be a compromise between strength and ductility. Although through hardened gears with a surface hardness over 400 Brinell can give excellent wear properties, they may lack the toughness for many applications. Tempering will reduce the hardness and wear resistance but will increase the toughness. The balance between strength and toughness, developed after quenching and tempering, is a critical consideration for the materials engineer.

The only processes where both strength and toughness increase together are those involving grain refinement. This is achieved by making micro-alloy additions to steel and thermo mechanical processing. Heat treatment processes involving the diffusion of carbon, or carbon and nitrogen combinations, into the surface of a low or medium carbon steel can result in the production of wear resistant gears and shafts that are also tough. The resulting high hardness is at the surface of the case where it can improve wear and fatigue strength, while the core is softer and more ductile, giving high toughness properties. The core, however, must not be too soft as the case needs adequate support to prevent case crushing (Ref. 4).

Importance of Flow Lines

The impact properties of steel castings, plates, and forgings are not uniform in all directions, but are related to the flow line direction. Charpy tests indicate that the impact strength across the flow lines can be up to 50% lower than tests where the test piece is parallel with the flow lines. Since any inclusions and microsegregation will follow these flow lines, they must not be parallel with the base of the gear teeth in highly stressed gears (Ref. 4).

Importance of Composition

During the eighties, research was completed on the impact properties of alloy steels with higher molybdenum content using instrumented Charpy testers. Although the early results indicated that molybdenum steels were tougher than nickel steels, it was later shown that certain combinations of the two alloys gave the best results. The instrumented Charpy tests gave the researchers valuable information regarding the initiation of the propagation of cracking that could not be obtained otherwise.

Conclusions

Many workers have generated a wealth of metallurgical knowledge and information about the surface fatigue resistance and impact resistance of various materials. There is also considerable information about the metallurgical factors affecting those thermal and mechanical processes used to improve the life of highly stressed gears and shafts. Much of this information is available for the designer to consider and apply in order to achieve metallurgical and geometric quality and meet customer demands for precision gears and shafts at minimum costs. ○

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This paper was first presented at the Gear and Shaft Technology seminar organized by the Institute of Materials Engineering Australasia.

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Mitsubishi Machine Tools Opens New Tech Center

MHI Machine Tool U.S.A., Inc., has announced the opening of its new Southeastern Technical Center. Located in Greensboro, North Carolina, the new Technical Center showcases the latest product developments for Mitsubishi's entire line of machining centers, turning centers, cylindrical grinders, gear production machinery, Flexible Manufacturing Systems (FMS) and more.

The staff at the new Mitsubishi Southeastern Technical Center will be available to answer design and manufacturing questions and to assist in developing innovative solutions. The center is located in the Deep River Business Park, 7860 Thorndike Road, Greensboro, North Carolina.

Mahr Promotes Hochwart to President, Parker to Vice President

Thomas Keidel, Chairman of the Board of Mahr GmbH, Germany, announced the promotion of Edgar Hochwart to President of Mahr's North American operations and Donald Parker to Vice President. Hochwart, a 13-year Mahr employee, has been Executive Vice President and General Manager for North America since November 1997. Parker formerly served as National Sales Manager.

About the promotions, Hochwart said, "Mr. Parker and I pledge to continue the strengthening of Mahr customer support we began one year ago. In that time we've added more applications, engineering and other after sales support personnel to our Cincinnati headquarters. We also opened additional Measurement Resource Centers in North Carolina and California, and increased our presence in Mexico and Canada—all with the goal of delivering exceptional customer service along with our industry-leading measurement products."

PresMet to Double Production Capacity

The PresMet Corporation has announced the purchase of two additional buildings to meet current and anticipated production demands for powder metal parts. The company's $10 million investment includes the cost of the buildings and the new equipment that will be housed in them. When completed, the new site will double the company's manufacturing operations. The new facilities add 60,000 square feet of production space.

"Work will begin immediately on these facilities and we expect to be operational by the second quarter of 1999," said Julia E. Gwinn, President of PresMet. "The ever-expanding acceptance of powder metallurgy as a viable metal forming process has increased the demand for the high-performance, high-tolerance parts we produce. This is especially evident in the automotive industry where it is anticipated that the use of metal powder will increase anywhere from 20 to 30 percent by 2002. PresMet anticipates it will exceed those industry growth figures for that time frame."

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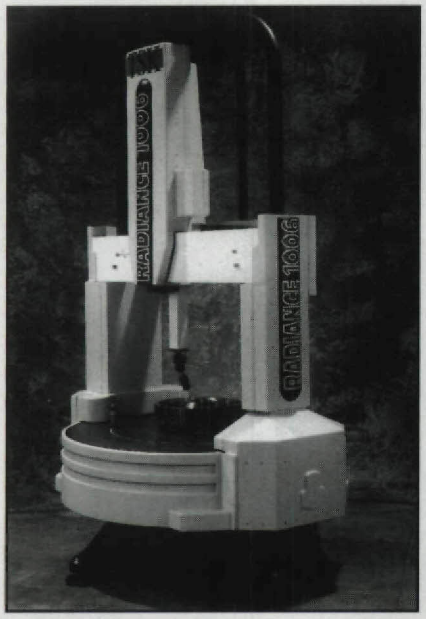
Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.



New TSK Measuring System Performs Continuous Radial Scanning

TSK America has unveiled its Radiance Radial Measuring System (RMS), a solution for complex rotary measuring challenges. The all-new RMS permits unrestricted rotary scanning of parts such as gears, turbine blades, cones and other shapes with reduced cycle times and improved accuracy for complex measurements. The measuring range of the RMS is 1 m in diameter and 0.6 m vertically, yet the machine occupies less than 2.5 m^2 of floorspace.

The Radiance Measuring System allows manufacturers to collect information quickly and accurately. Linear accuracy in the X and Z axes is 2 microns; the U2 (X and Z axes) is 2.0 + L/500 microns. Angular accuracy is 3 arc-seconds. Acceleration is 1000 mm/s^2 along the linear axes (X and Z) and 250 mm/s^2 along the Y (round) axis. Measuring speeds are up to 250 mm/s. "The main advantage to the Radiance is that for the first time ever, users can complete a full radial scan of a nonrotating part without probe changes or reorientation," said Jack Epstein, TSK product manager and developer of the Radiance concept. For more information, contact TSK America Advanced Metrology Division at (800) 247-9875.

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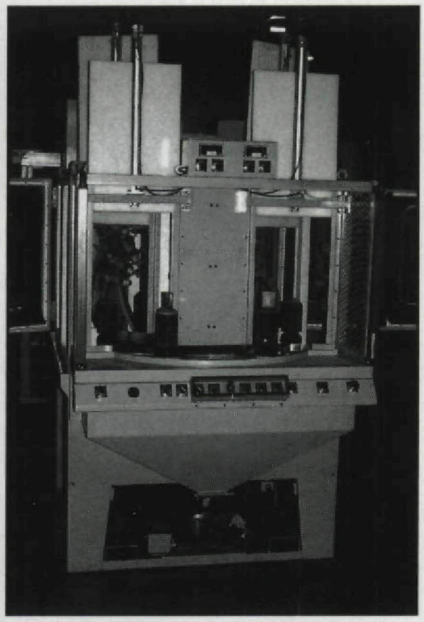

Guyson Introduces New Rotary Indexing Blast System

Guyson Corporation announces the introduction of the Model RXS-1000 indexing spindle-blast machine. This midsized system is applicable to a wide variety of impact treatment operations such as shot peening, deburring, cosmetic finishing, etching and surface preparation, in which 360-degree coverage is required on components that must be handled and blasted individually.

Up to 12 component-holding spindles are located around the perimeter of the machine's 42" diameter indexing table. Components more through separate entry, blast and airwash chambers within the blast cabinet before returning to the front load/unload position. Vertical sliding doors, actuated by pneumatic cylinders, are available to seal the blast enclosure and isolate dust and noise from the work environment. The overall dimensions of the blast cabinet are approximately 72" high by 55" wide by 80" deep (183 cm x 140 cm x 203 cm). A full depth door with abrasion-protected view windows on each side of the cabinet enables full access for inspection, adjustment and maintenance. For more information contact John Carson, Guyson Corp., at (518) 587-7894 or via e-mail at *jccarson@guyson.com.*

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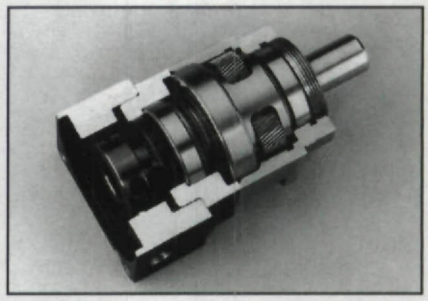

Thomson Industries Introduces the UltraTRUE Planetary Gearhead

The UltraTRUE Planetary Gearhead has the highest radial load capacity, up to 8,500 lbs., of all the Thomson Micron planetary gearheads. This ultra-precise gearhead was designed for the high torque performance requirements of tool changers and plasma and waterjet cutting equipment. The UltraTRUE has two important features: a standard 4-arc-minute backlash and crowned helical carburized steel gears that are hardened to a minimum of HRC 60 and flank-finished after heat treating for ultra smooth performance. The UltraTRUE provides lifetime lubrication and features a self-aligning RediMount system that speeds mounting to virtually any motor. For more information, contact Thomson at (516) 467-8000 or send E-mail to *gearheads@thomsonmail.com*

Circle 302

New Small Parts Washer from Cincinnati Industrial Machinery

Cincinnati Industrial Machinery introduces its small parts washer with a unique 360° rotation and separation design. The washer features a special S-shaped track to guide round parts from side to side to ensure complete and proper cleaning. Parts remain separated throughout the wash and blow off stages via stationary slots. The brass drying trays prevent the parts from marring, which occurs with other metal trays.

For more information, contact Keith Williams, industrial systems sales manager, at (513) 769-0700 or by fax at (513) 769-0697.

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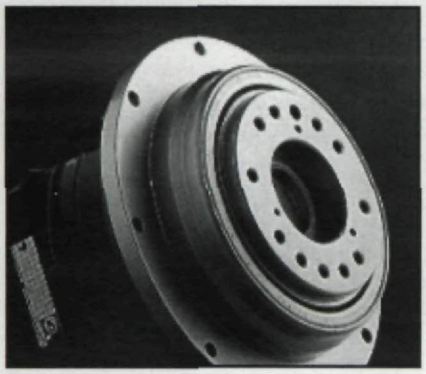


Alpha Introduces TP Low-Backlash Planetary Gear Reducer

Alpha Gear Drives, Inc., has announced the introduction of the TP Low-Backlash Planetary Gear Reducer.

The new TP gear reducer features a minimum backlash of less than 1-arc-minute, which is the lowest of any gear reducer currently available. The unit also offers an advanced motor mounting system that provides unparalleled motor shaft thermal expansion compensation. The TP ensures high-torsional rigidity due to its output flange and optimized planetary gear train. This creative design ensures maximum torque transmission, high efficiency (>95%), and the least audible noise. Because of its superior engineering, the Alpha TP is guaranteed to have the longest service life available today. For more infomation call Alpha at (847) 439-0700.

Circle 304

ShapeGrabber Computer-Aided Inspection System Released

Vitana Corporation has announced its new ShapeGrabber Computer-Aided Inspection system for Part-to-CAD verification and inspection.

The tightly integrated ShapeGrabber includes the scanning head, translation stage, acquisition and inspection software, training, and even the PC. The system was developed for speed, accuracy, ease-of-use, and affordability. In particular, the system introduces new technologies to simplify fixturing, to streamline scan alignment, and to reduce noise. For more information contact Joel Bisson, president, at (613) 749-4445 or via e-mail at *joel.bisson@vitana.com.*

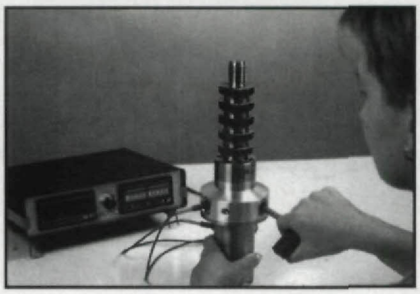
Circle 305

Grieve Introduces New Electric Walk-in Oven

Grieve Corporation announces the introduction of its new No. 822 500°F electric walk-in oven. Workspace dimensions inside this unit measure 72" wide by 96" deep by 78" high. 60 kW power is installed in Incoloy sheathes tubular heating elements while a 6000 CFM, 5 HP recirculating blower provides a combination airflow, which sweeps around the workload, traveling upward to a return duct.

This Grieve walk-in oven features an aluminumized steel interior and exterior, double doors at each end and a removable top-mounted heat chamber. Operat-ing and safety equipment on this unit includes a digital indicating temperature controller, manual reset excess temperature controller with separate heating element control contactors, recirculating blower airflow safety switch and a fused disconnect switch. For more information contact Frank Calabrese, national sales manager for Grieve at (847) 546-8225 or by fax at (847)546-9210.

Circle 306



New Digital Readout for Hydraulic Expansion Arbors

MyTec GmbH (Germany) has introduced a new digital readout system to monitor and control internal arbor/chuck pressures. Advantages of the new system include better expansion control when working with thin-walled parts and confirmation of full pressurization. Uniform clamping, especially in gear grinding and advanced aerospace applications, is another benefit. For more information contact Eurotech at (414) 781-6777 or via e-mail at *eurotech@execpc.com.*

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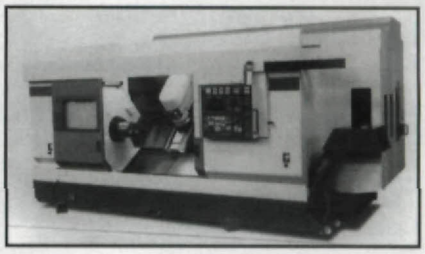

Mori Seiki Develops New Lathe and Machining Center

Mori Seiki introduces the MT-250, a lathe and machining center combination that reduces fixturing, increases product flow and gives greater accuracy on very complex work pieces.

"The MT-250 is the new standard in integrated machining and is the ultimate machine for parts requiring multiple processes," said William Jones, National Sales Manager for Mori Seiki. "We have gone beyond the conventional level of technology to create a machine that integrates full-scale turning and milling. Combining the lathe operations and machining center allows for more accurate work pieces and the elimination of extra handling in the shop."

The MT-250 features headstocks on both the left and right sides, making setup time shorter and promising high precision machining. The spindle design features the turning range from -90 degrees to +90 degrees, making oblique machining possible. The MT-250 also has an automatic tool changer that carries 20 tools attached to the saddle. The automatic jaw changer eliminates setup hassles when work pieces vary or require multiple machining. For more information, contact William Jones at (972) 929-8321 or by fax at (972) 929-0730.

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ITW Heartland, a division of Illinois Tool Works, Inc., has locations in Chicago, IL, Detroit, MI, and Alexandria, MN, along with a worldwide network of sales and service offices. ITW has manufactured and serviced gear inspection and burnishing equipment since 1936. To learn more about our products and services, visit our Web site.

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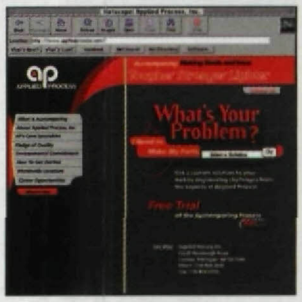
Applied Process is the world leader in austempering, a heat-treating method that produces steel and iron parts that are **stronger, tougher, lighter, quieter, more wear resistant** and have greater dimensional repeatability than conventionally heat-treated parts. AP has advanced this technology for heavier stampings, forgings and castings.



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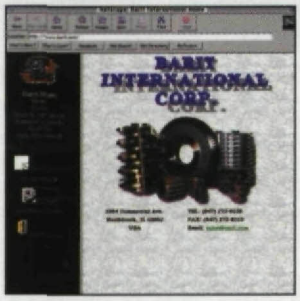

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LeCount expanding mandrels are designed to grip the inside diameter of parts to be inspected. Place your part on the mandrel, load it between centers and you're ready to inspect. Our mandrels are distributed in Europe, Asia and the United States. For a brochure or the name of a representative in your area, please visit our Web site for further information.

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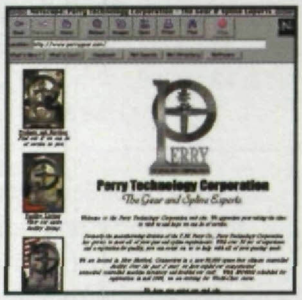

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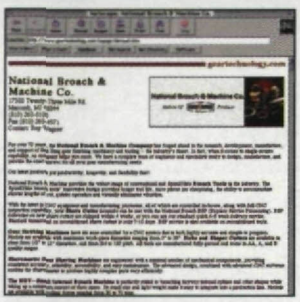

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BOURN & KOCH

Bourn & Koch is a manufacturer of OEM gear hobbers, gear shapers, specialty gear machines, dial machining centers, extrusion milling machines, specialty machines, turning centers, machining centers, grinders, boring machines and more. Visit their Web site for more information about their product lines and services.

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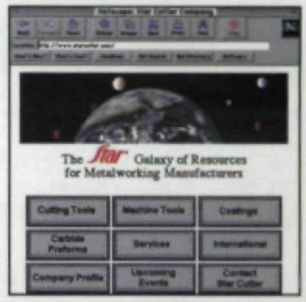

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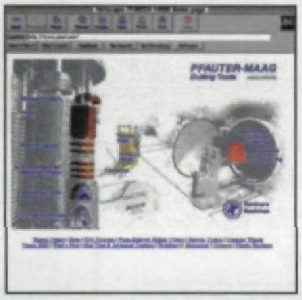

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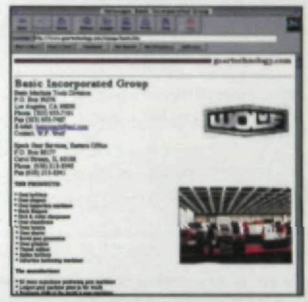

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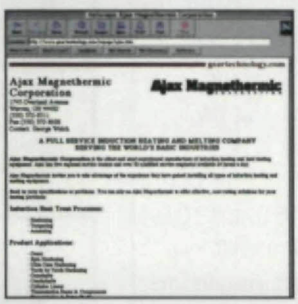

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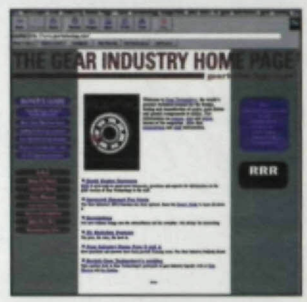

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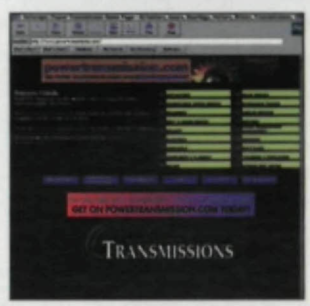

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The Gallery of Fame: A Tribute to Gear Pioneers

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

The Gear Research Laboratory of the University of Illinois at Chicago is home to a unique tribute to gear pioneers from around the world, the Gallery of Fame. The gallery is the brainchild of the laboratory director, Professor Faydor L. Litvin. The Gallery was begun in 1994 and is a photographic tribute to those gear company founders, inventors and researchers who devoted their careers to the study and development of gears.

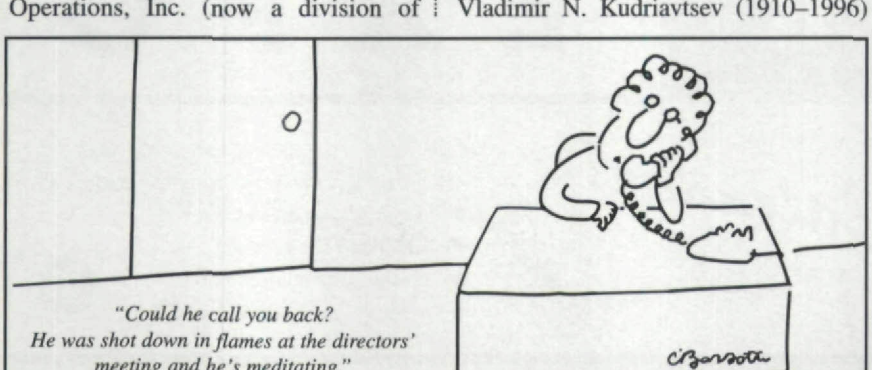
According to Prof. Litvin, "this collection is unique because retrieving items and information for the gallery was a difficult task. Time had destroyed documents and memories of the many contributors who were deceased, requiring much detective work." He created the gallery to give these innovative people the credit they deserve for their valuable contributions. "I consider creativity a driving force in human life," said Litvin. "I also consider Fame a very capricious goddess who doesn't reward in a proper time, or doesn't reward at all, people who deserve it."

One example of the difficult detective work involved was the case of Samuel I. Cone, founder of the Cone Drive Company and the inventor of the double enveloping worm gear drive. When Litvin approached Cone Drive Operations, Inc. (now a division of Textron) for a picture and biography, he was given the latter but told that the former was missing and that the company would be obliged if he could find one. Litvin discovered a reference in Cone's biographical materials to work at the Norfolk Navy Yards, the place where he invented his double enveloping worm gear drive in 1909. Litvin then contacted the Secretary of the Navy, and with his help Litvin was able to find Cone's living relatives. He was given the photograph of Samuel I. Cone by Cone's granddaughter, Mrs. Mary Bell Kluge.

The Gallery of Fame is dedicated to all gear scientists, not just those from the West. Litvin also pays tribute to those who worked in the Soviet Union. To sum up his feelings about the old Soviet communist system, Litvin quoted Bertolt Brecht's couplet about life in East Germany: "To the Descendants. I live in dark times indeed!" Litvin's admiration for Russian and Soviet gear scientists is every bit as deep as his disgust over the communism they were forced to live and work under. They are well represented in the Gallery by Dr. Chaim I. Gochman (1851–1916), the founder of the analytical theory of gearing, Dr. Chrisanf F. Ketov (1887–1948), Nikolai I. Kolchin (1894–1975), Dr. Mikhail L. Novikov (1915–1957), Dr. Vladimir N. Kudriavtsev (1910–1996) and Dr. Lev V. Korostelev (1923–1978), who Litvin credits as the developer of the theory of gearing in Russia. "Dr. Korostelev belonged to the second generation of scientists who developed the theory of gearing in Russia," said Litvin.

Above: Samuel I. Cone
Left: Dr. Chaim I. Gochman

The Gear Research Laboratory performs its research in cooperation with aerospace and industrial giants like Ford, Bell Helicopter, Sikorsky, The Gleason Works and U.S. Government agencies such as NASA and the U.S. Army. The Gallery of Fame, the faces of the great men—and a couple of great women—from the world of gearing, looks down upon Litvin and his researchers as they meet to discuss their work and theories. As for adding new names and photos to the Gallery in the future, Litvin says: "The space is not closed. We can always start the second row." Only time will tell who'll be next.



"Could he call you back? He was shot down in flames at the directors' meeting and he's meditating."

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