GEAR TECHNOLOGY

MARCH/APRIL 2000
The Journal of Gear Manufacturing

HEAT TREATING ISSUE

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GEAR FUNDAMENTALS: INDUCTION HARDENING

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A New Type of CVT, and Innovations in Plastic

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The Journal of Gear Manufacturing

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The Journal of Gear Manufacturing

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RANDALL PUBLISHING STAFF

President	Michael Goldstein
Vice President	Richard Goldstein
Controller	Patrick Nash
Accounting	Laura Manion
Art Consultant	Marsha Goldstein

Phone: 847-437-6604
E-mail: ***people@geartechnology.com***
Web: ***www.geartechnology.com***
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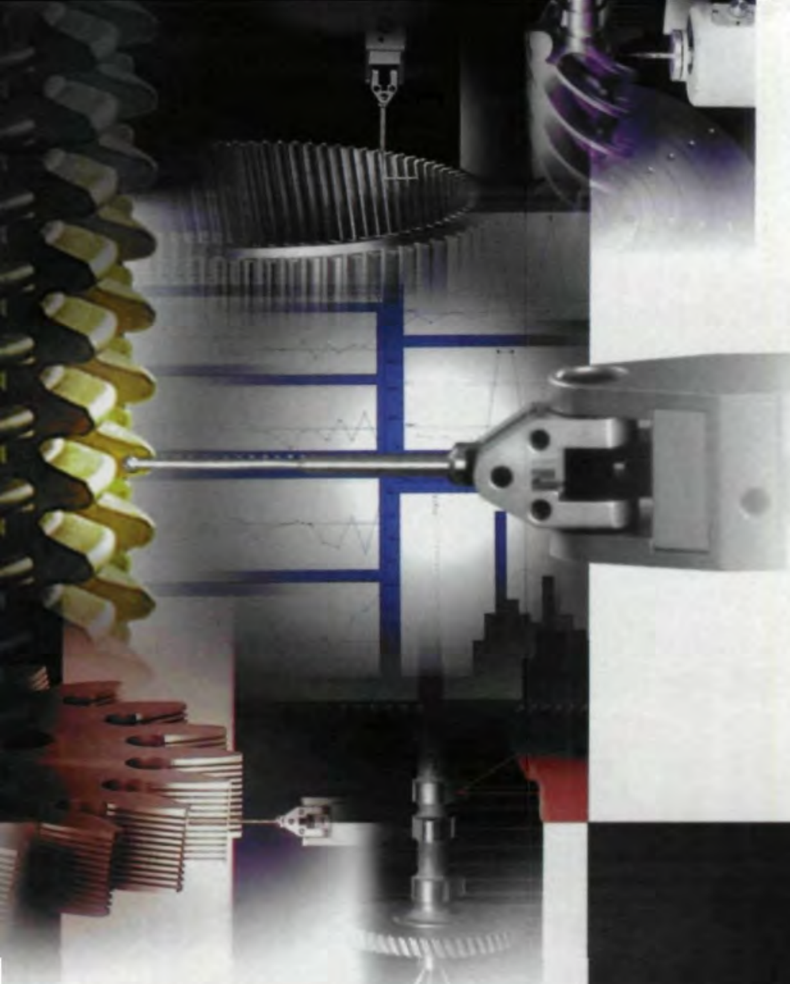


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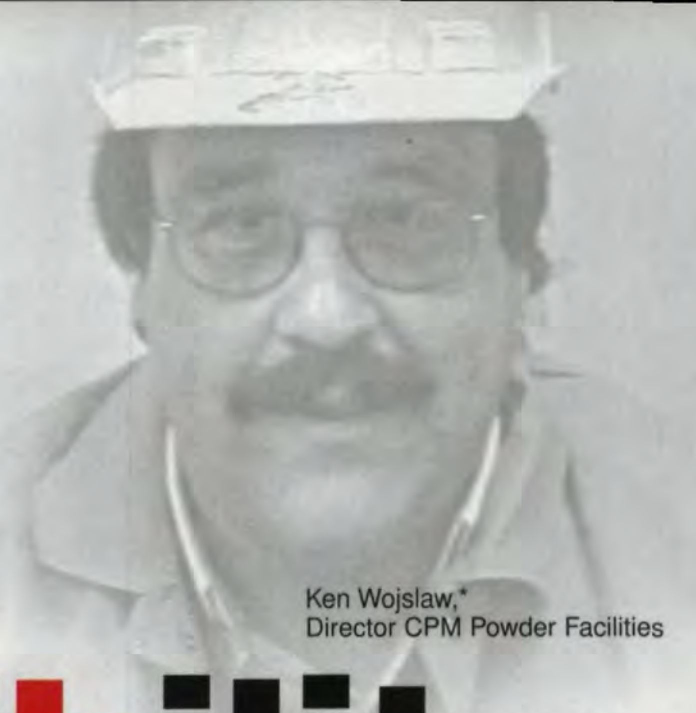

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CIRCLE 135

Goldstein's Paradox

—AND WHAT WE'RE DOING ABOUT IT

I just got off the phone with an associate of mine at a large gear manufacturing company. I was congratulating him on being awarded a new contract when he told me that they had just experienced a substantial downsizing.

As we went through the list of *Gear Technology* subscribers at his plant, I had to remove almost half the names, including a fair number of high-level engineering and management titles, because they were no longer there.

I shouldn't be surprised at the layoff, though. The shrinking of the manufacturing sector has been well publicized. For example, according to a recent *Business Week* article, manufacturing industries cut an average of 26,000 workers per month through the first 10 months of 1999.

Despite this shrinkage of the workforce, manufacturing continues to grow in terms of sales volume and actual output. This is as true in the gear industry as in other manufacturing sectors. In its September/October newsletter, the American Gear Manufacturers Association published numbers from the 1997 U.S. Economic Census. These numbers indicate that open gear manufacturers employed just over 16,000 workers in 1997, compared to more than 25,000 in 1977. However, over the same time period, the value of annual product shipments rose from $2 billion to $2.4 billion (in 1997 dollars).

One set of numbers makes it look like the gear industry is doomed to fade away, while the other demonstrates its continued health. That's Goldstein's Paradox, Part I.

The explanation is really quite simple: We've gotten much more productive. I liken the situation to that of agriculture in our country's early history. With today's modern farming equipment, one worker produces far more wheat, corn or rutabagas than his predecessor of a century ago. What used to take the manual labor of many—ploughing, digging, planting and harvesting—is now accomplished by a few using equipment and technology.

Now we're seeing the same thing in our own industry. It wasn't so long ago that every gear machine had an operator standing by it. Today, because of increased automation, better tools and CNC controls, a single operator can run several machines. In addition, today's rigid machines and carbide tools are capable of cutting much faster than earlier models. We've become more efficient off the shop floor as well. Years of investment in computers, software and processes for CAD/CAM, just-in-time inventory control, order processing and business management have resulted in huge gains in productivity, and the Internet will likely provide even greater productivity in the years to come. The result is that we can produce far more gears with far fewer people.

However, the demand for skilled gear industry workers is still very high. You'd think that with layoffs like those my associate on the phone described, there should be a lot of skilled gear people available for hire. But one of the biggest complaints I hear from gear companies is that finding skilled people is becoming harder and harder. That's Goldstein's Paradox, Part II.

One explanation for this paradox is that changes in technology make it a constant job just to keep up. Gear manufacturing companies are forced to continually train and retrain their employees. Education is important, but *continuing* education is crucial.

A couple of weeks ago, I visited the AGMA Training School for Gear Manufacturing, where I was not surprised to learn that demand for gear training is as high as ever. The classes are held at the campus of Richard J. Daley College in Chicago, where instructors teach machinists, engineers and others the basics of gear manufacturing in a hands-on machine shop setting. Other gear-related seminars and classes on our technical calendar each issue seem to indicate that these types of programs are going strong as well.

Although the changing technology explains part of the paradox, another factor also plays a role. Although it seems logical that layoffs in the gear industry and a continual contraction of the workforce should provide for extra workers, unemployment in our country is at an all-time low. Most of those gear people are being absorbed by other industries.

It seems to me that our industry should do all it can to keep the skilled employees it already has. How does someone who's been downsized find a new job that takes advantage of his skills? How does a gear company know where to find the plant managers, gear engineers, operators, quality assurance people, sales engineers and others it needs? If we had some central place where the talent and the companies looking for it could communicate, we might be able to solve some of that problem.

That's why I've decided to announce something new being offered for free through *The Gear Industry Home Page™*. We've created an online service wherein qualified gear industry people who are out of work can post their qualifications and contact information at *www.geartechnology.com* at no cost. Managers at gear companies can locate the skilled workers they need, and employees who become the victims of downsizing or corporate restructuring can find employment that takes full advantage of the skills they've acquired.

This service is only for gear industry employees who have been laid off or have been given notice. A job seeker who wants to take advantage of our site must post the name of his previous employer and supervisor. We're not trying to create a situation where employees begin querying their companies' competitors for positions. We're trying to help recycle talent back into the industry.

This service can also be a benefit to the companies that are forced to cut staff. Very often, employees who get laid off are excellent, productive workers, who under other circumstances would still have their jobs. It's our hope that the managers or human resource departments of these companies will be able to help these workers find new jobs in the gear industry by making them aware of our free service and helping them post their information online.

Improving communications between employers and potential candidates will help solve part of the problem. By embracing the tools of the information age, we can help the gear industry build on the strength it already has.

Michael Goldstein

Michael Goldstein, Publisher and Editor-in-Chief

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.*

Heat Treating on a Grand Scale

The gear, a double helical with a 106" outside diameter and a 36" face, weighs 40,000 pounds. Destined for use as an intermediate drive gear for a hot strip mill in Latin America, the specifications called for an effective case depth of 0.250" and a nominal surface hardness of HRC 58–62 with a surface carbon content of 0.70–0.90%. The manufacturer turned to Metlab of Philadelphia, PA, to do the job.

According to James Conybear, one of the owners of Metlab, "We get orders from all over the world and heat treat two or three huge gears a month." His partner, Mark Podob, adds, "We carburize and nitride gears for mining equipment, mills, cement plants, ship drives, and the military. There is only one other furnace in the world that can accommodate the sizes we work with."

When working with such large workpieces, Podob and Conybear say that the real key is uniformity of heating. Without it, the process is imprecise and unrepeatable. Three major areas of concern determine the uniformity of the heating process: fixturing, quenching and process control. If these areas are not carefully watched, there can be problems. "With these big assemblies," says Conybear, "their weight will crush them. The material tends to sink into itself, almost self-forging, with the inside material moving toward the outside." That leads to distortion. "Most gear designers can design for dimensional change," says Podob, "so the key is to make the process precise and the results repeatable." That is accomplished by proper fixturing, quenching and process control.

Fixturing. "You have to make sure the part stays straight," says Podob. "With a big gear, you can pick it up with a three-point loading if, in the furnace, it is resting on a flat plate." With proper support, the slumping and tooth distortion effects of self-forging can be kept to a minimum. "With splines," adds Podob, "the easiest way is to support the tooth section and control the heating to minimize distortion.

Process Control. This covers the precise, uniform heating and cooling (quenching) cycle, as well as the atmosphere within the furnace itself. "This is very important because these gears are in the carburizing furnace for 8 to 10 days," says Conybear. "We have to know what is happening to them so we can make adjustments as the cycle continues." This is accomplished using samples of the same material as the workpiece as well as a standard sample that Metlab uses to gauge how well the process is working. According to Podob, throughout the cycle, these material samples are cut and inspected. Diffusion calculations are then performed to check the progress of the carburization process. In the case of the 40,000 pound gear mentioned above, the workpiece and samples were of 4320 steel and they underwent 200 hours (8.3 days) of carburization.


40,000 lb. double helical gear on its way to the quenching tank. Courtesy of Metlab.

Precise heat soak and quench control are important to minimizing tooth distortion. "The key is to minimize the differential temperatures within the part," says Podob. "If you heat big gears too fast, the inside moves to the outside." You also have to cool them down just as carefully, quickly moving the hot workpiece to the quench tank before it can begin to cool. "You need to have a large volume of quenching fluid, usually oil, with good circulation and temperature control," says Podob. "It also helps to have good material to begin with."

Not all materials are suitable for this kind of application, so making the right choice of material takes on added importance when designing very large gears. "We are often involved in the design stage," says Podob. "When you design one of these large components, you have to be more of a materials engineer to make sure that the workpiece will make it through the heat treating process with a minimum of distortion."

Circle 250

The SProcket Variable-Ratio Transmission

Say the words "continuously variable transmission" and most people familiar with the concept will envision V-belts and a split pulley. The ratio is changed by increasing or decreasing the split between to the two pulley halves. This works because the distance of the V-belt from the axis of rotation and the transmission ratio are proportional to the separation of the pulley halves.

Continuously Variable Transmissions Today. The problem with a belt-driven system is low torque capability, since torque depends on the frictional force that maintains the V-belt's contact with the pulley. This is solved by using corrugated belts and pulleys or chains and sprockets to provide positive, non-slip engagements. For such an arrangement to be truly continuously variable, a complex kind of corrugated pulley or sprocket with a continuously variable diameter and a constant rib pitch would be needed. While the advantages of using continuously variable transmission technology are very real, the drawbacks of present designs—limited torque, expense and complexity, size and weight, are problematic. What's more, according to Vince Bakulich, president of Revolution Industries of Santa Monica, California, many present designs are not really continuously variable at all. They adjust from one ratio to the next incrementally. Also, many designs are simply not practical or adaptable to everyday use. Recognizing the need for a simple, continuously variable transmission suitable for high-torque applications, Bakulich thinks he has come up with a better way.

The SProcket. Bakulich has designed the SProcket, a continuously variable gear or power transmission that operates at any discrete ratio within a finite range while constantly engaged and under load. Referred to as either an Infinitely Variable Transmission or a Continuously Variable Ratio Transmission (CVRT), the SProcket's corrugated belt maintains engagement while the gear circumference expands and contracts. "There is no slippage," said Bakulich. "You have a direct connection between the chain or belt and the driving member. Take a motorcycle. You have a chain and a sprocket—a solid connection." Bakulich then explained that in a motorcycle you have an internal transmission with three or four ratios. If, however, you could change the size of the sprocket, you could have an infinite number of ratios within a given range. Its ability to change the circumference of the gear is what permits variable speeds and power transmission. This change in circumference, called actuating the gear, can be accomplished in a number of ways, according to Bakulich, including hydraulically, mechanically, electrically or pneumatically. "It really depends on the application and the size and weight requirements." Then he added that the applications for this technology are very real and practical.

"Imagine getting in your car," said Bakulich, "and pressing the accelerator to get the engine up to 1,500 RPM, or whatever you need to provide enough power, and leaving it there at a constant speed. Then, you press a button up to go faster or down to go slower." Bakulich explained that with a conventional automobile, to go faster you have to accelerate the engine. In an automobile equipped with a CVRT, you would be adjusting the transmission instead of the engine speed.

CVRT Advantages. This example points out one of the main benefits of continuously variable transmissions—fuel efficiency and energy conservation. Other features of the SProcket design include precise gear ratio selection, continuous power transmission over the entire range of gear ratios with no belt slipping, high versatility and strong, simple construction. The prototype was built with readily available, off-the-shelf parts. Also, the speed at which gear ratios change can be altered allows the CVRT to go through its entire range of gear ratios as slowly or as quickly as necessary.

Applications and Response. According to Bakulich, the greatest use of conventional continuously variable transmissions is in the auto industry. Other applications include utility and constant velocity motors and HVAC units, bicycle chains and sprockets, motorcycle and electric vehicle transmissions, pumps, and wide variety of others. "The SProcket can be used on a wide variety of applications," said Bakulich, "but a unit would need to be designed to fit each one individually. We have had some interest from industrial and automotive manufacturers, but not too much response yet from Detroit."

Circle 251

Pushing the Envelope With Plastic

Achieving higher power density in an existing design space is one of the chief goals of today's gear designer. Because of the economic and design advantages offered by plastic materials, plastic gear engineers are developing some of the most innovative solutions.

Kleiss Gears, Inc., of Shoreview, MN, has developed some designs that promise increased torque capacity, reduction ratio and strength, says company president Roderick Kleiss.

Kleiss has worked with gear design-consultant Alex Kapelevich to develop a general purpose design for asymmetrical plastic gears. Although the designs haven't been used in production yet, they were developed as a possible solution for a lawn sprinkler manufacturer who had problems with broken gear teeth because of a rugged product assembly process.

Kleiss Gears actually worked on two designs to increase the strength of the gear teeth, the asymmetrical set and a beefed-up symmetrical set with increased pressure angle. According to Kleiss, both sets performed well in their

tests. "The asymmetrical set was obviously stronger than the symmetrical set," Kleiss says. However, the manufacturer chose to go with the standard gears because of the disadvantage of having to ensure the asymmetrical gears were going the right direction during assembly.

Despite this, Kleiss believes the asymmetrical design shows great promise for future applications. "We expect to see a 15–30% increase in strength," Kleiss says.

Kleiss Gears has also developed an orbiting, or planocentric, gear design that promises to deliver high torque output and high reduction in a relatively small package. The company is exploring the possibility of using this design in several applications, including a trolling motor steering mechanism, Kleiss says.

According to Kleiss, this application is especially well suited for plastic. "Internal gears always face limitations with cut gearing," Kleiss says. With plastic, the designer can develop the teeth for maximum strength without having to worry about the tooth generating process. The high pressure angle in this set would be extremely unusual in cut metal gears, Kleiss says.

The orbiting design is still in the development phase. Kleiss is working on ways to overcome the uneven torque distribution on the carrier pins, and the company is developing an output coupler that will help to balance the bearing load.

An asymmetrical gear set. Courtesy of Kleiss Gears.

Planocentric gear set. Courtesy of Kleiss Gears.

Another issue that often concerns plastic gear designers is the heat generated by the drive system. "Heat is the killer," Kleiss says. Although the gear teeth in the orbiting gear set do not generate much heat, they have to be insulated from the heat generated by the motor, Kleiss says.

Kleiss sees much promise for this design. "I think this is just the beginning," he says. These gearsets will be ideal for developing a compound differential, Kleiss says, because they'll offer an extremely high reduction in a small package with good radial load output. ○

Circle 252

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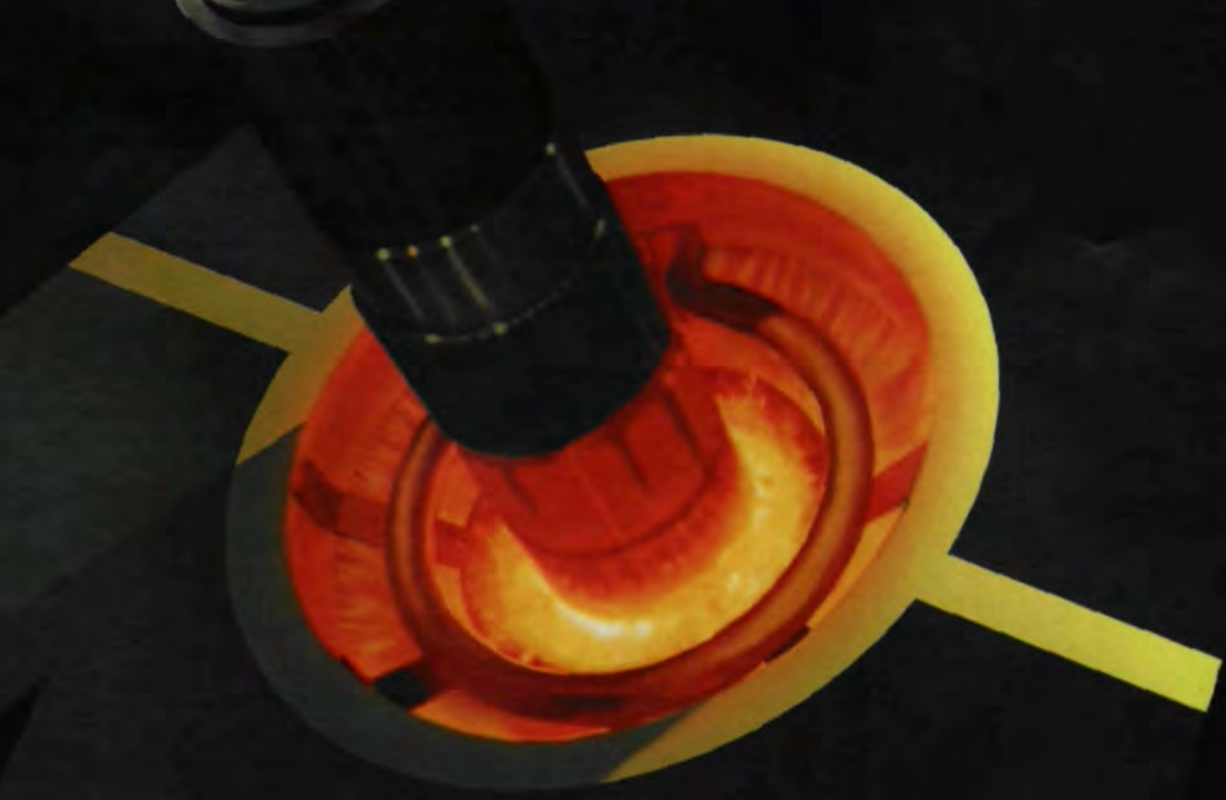

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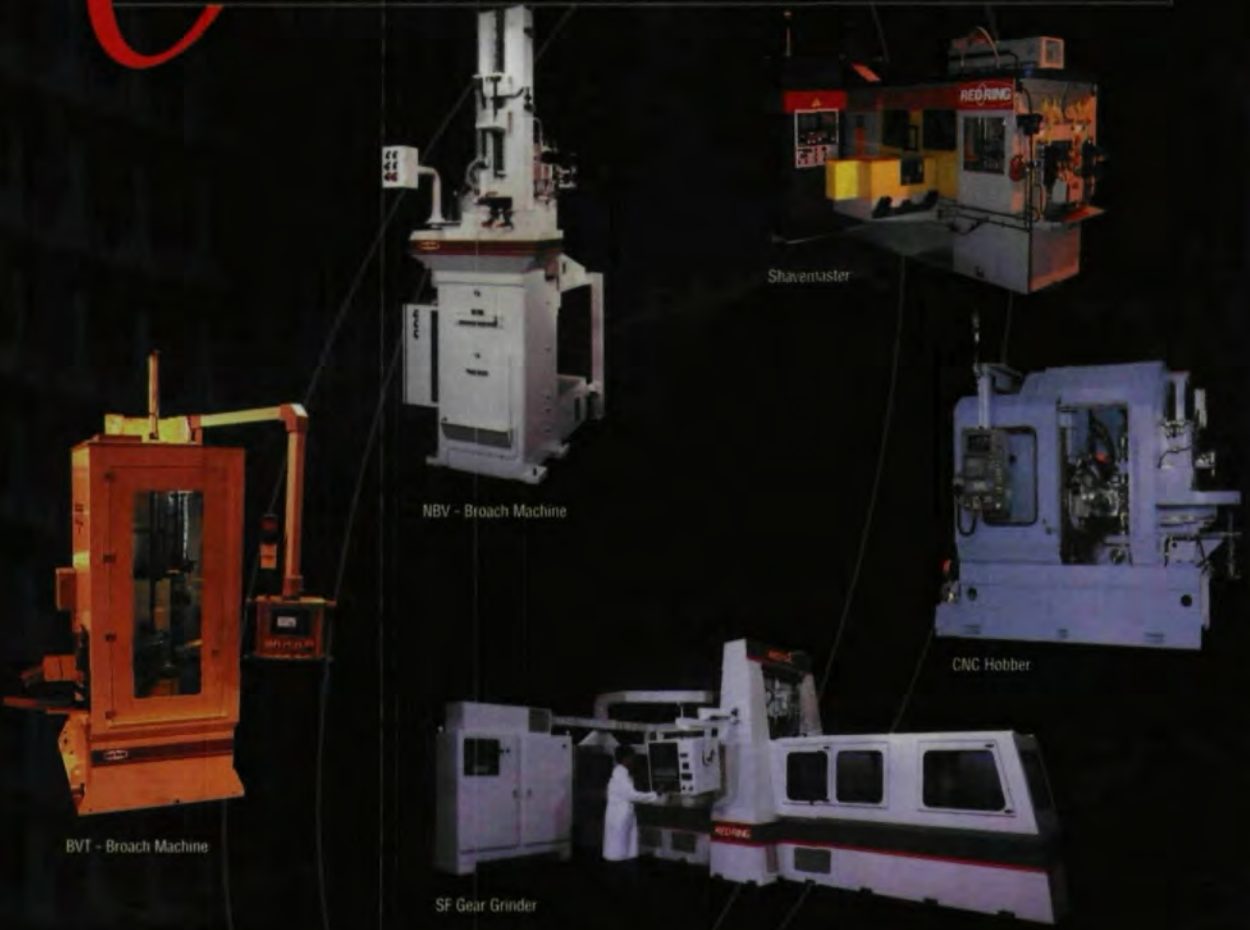

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Metlab Acquires Potero

Jim Conybear and Mark Podob, owners of Metlab, a commercial heat treating company with an emphasis on large components, deep case carburizing and nitriding, have purchased the assets and ongoing business of John V. Potero, Inc., specialists in atmosphere heat treating small to medium sized batches, induction hardening and black oxide processing. According to Podob, "The combination offered a true win-win business opportunity by strengthening the value offered to both customer bases. Metlab customers benefit from black oxide treatments and a well established pick-up and delivery service. Potero customers gain increased capacity to assure fast turnaround as well as the ability to handle larger parts and deeper case depths."

Gleason-Pfauter Italia S.p.A. Sale Completed

European Kinetic Systems (E.K.S.) B.V., a Dutch subsidiary company of Paritel S.p.A., an Italian corporation, has purchased Gleason-Pfauter Italia S.p.A. The terms of the agreement have not been disclosed. E.K.S. will change the name to DE.CI.MA. S.p.A and the newly acquired company will serve as a contract manufacturer to the parent for certain of the products currently produced at Gleason-Pfauter Italia's facilities.

Keough Named to Board of ASM Heat Treating Society

John R. Keough

John R. (Chip) Keough, owner and CEO of Applied Process, Inc., has been named to the ASM Heat Treating Society (HTS) board of directors. President and owner of Applied Process since 1992, Keough holds seven heat treating or foundry-related patents. He was recognized as an ASM Fellow in 1998 and was awarded the Wm. J. Grede Award by the American Foundrymen's Society that same year.

Two other HTS board members were also named: Daniel H. Herring, director of research and development at Ipsen International, and Ronald A. Wallace, chief technologist-modeling at Wyman Gordon Co. All of the new board members will serve three-year terms.

Cleveland Gear and PIV Sign Partnership Agreement

Cleveland Gear Company, a subsidiary of the Vesper Corporation, recently signed an agreement with PIV Antrieb Werner Reimers GmbH, of Bad Hombur, Germany. The agreement authorizes Cleveland Gear to manufacture and market the PIV Posired II series of enclosed drives to North American customers. Cleveland Gear will market these drives as their Redi II product line. The agreement includes Cleveland in PIV's global partnership network and enables Cleveland to provide complete drive systems employing PIV-designed drives in combination with a variety of mechanical power transmission components. "This partnership allows us to fully integrate Redi II drives into complete systems that are performance matched to meet customer requirements," said John Atkinson, Cleveland's vice president of Sales and Marketing.

"The Redi II drives complement our custom designed parallel shaft drives, providing our customers with a single source for their drive needs."

New Directors at Inductoheat

Inductoheat, Inc., a Madison Heights, Michigan, manufacturer of induction heating equipment and systems, has announced the following promotions:


Ed Haddad

Former project engineer Ed Haddad has been promoted to the position of Director of Mechanical Engineering. Haddad has been with the company for over 13 years and holds a BSME from Western Michigan University.


Valery Rudnev

Dr. Valery Rudnev has been promoted from chief scientist to Group Director, Science and Technology. Dr. Rudnev holds an MS in electrical engineering and a Ph.D. in induction heating. He holds 14 patents and has published 92 scientific engineering and research articles. He has been with the company for over 6 years and in the induction heating industry for 24 years.


Peter Dickson

Peter Dickson, former manager of Research and Development, has been promoted to Director of Research and Development. He has been with Inductoheat for 15 years and holds a B.Eng. from Gippsland University in Australia.

Mihelick Nominated to Gear Research Institute Board

Joseph Mihelick, PE, has been nominated to the Gear Research Institute board of directors to fill the 2000-2002 Class A Trustee vacancy created with the departure from the board of Mr. Gary Kimmet. Mihelick is president of Gears Plus, Inc. and has 38 years experience in the development, design and manufacturing of enclosed industrial gearing. He is a mechanical engineering graduate of the University of Cincinnati and holds an MBA from Xavier University. Mihelick has three patents, has authored technical papers for both AGMA and ASME and has served on various gear and engineering-related boards. Gears Plus, Inc, is a consultancy that offers engineering services with an emphasis on gearing.

New Patent for Alfe Heat Treating

Alfe Systems, Inc., a division of Alfe Corporate Group, has received a patent for their new Double Level Furnace. The new heat treating furnace, described as a flexible, cost effective high production heat treating system, has multiple transport systems within the same furnace. This enables multiple heat treating cycle times using the same control temperatures to be run simultaneously. The furnace minimizes temperature variations by operating two discharge doors independently from each other. ○

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Insco Corporation	146	53
ITW Heartland	116	10
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Modern Industries, Inc.	166	39
National Broach & Machine Co.	186	14
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Star Cutter Co.	100, 157	2, 70
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Toolink Engineering	172	55
United Tool Supply	170	69

The Effect of Material Defects on Gear Performance—A Case Study

Raymond J. Drago, P.E. and Alejandro Font Filax, Ph.D.

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Abstract

The quality of the material used for highly loaded critical gears is of primary importance in the achievement of their full potential. Unfortunately, the role which material defects play is not clearly understood by many gear designers. The mechanism by which failures occur due to material defects is often circuitous and not readily apparent. In general, however, failures associated with material defects show characteristics that point to the source of the underlying problem, the mechanism by which the failure initiated, and the manner in which it progressed to failure of the component.

In this case study, the authors examine the failure of a medium-sized pinion used in a mining application. The mode of failure was rather catastrophic in nature but did not follow any of the typically understood mechanisms such as tooth bending, surface distress, wear, etc. Often, as was the case for the subject pinion, material defects do not manifest themselves in these more typical tooth oriented failure modes, though the initial presentation of the failure often suggests more classical origins.

A complete shaft fracture was the ultimate cause for the pinion's removal from service. Initial inspection of the failed pinion indicated the presence of cracking in the toothed area. This cracking appeared to have progressed through the pinion and resulted in the shaft fracture, which caused the pinion to cease transmitting torque. In order to avoid a recurrence of the problem in this very critical application, it was very important to fully understand the failure including its cause and progression mechanism.

This paper presents a summary of the failure, its investigation, and the methods proposed for its resolutions. The data is presented in tutorial format so that the basic effect of the identified material defects can be better understood and used in future designs.

Fig. 1—Distress observed on ball mill pinion during 1994 visual evaluation.

Fig. 2—Close view of distress observed on ball mill pinion during 1994 inspection.

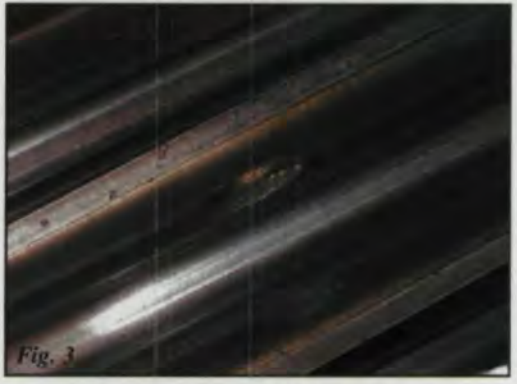

Fig. 3—Currently installed ball mill #2 pinion showing region (near midface) which has been ground out to remove pitting and surface cracks and then restarted.

Introduction

In 1992, two new single helical gear sets were installed as part of a new mill system at a mine site. The pinion and gear sets are used to drive essentially identical ball mills used for processing ore from the mine.

After some relatively minor start-up problems, the gear sets were placed into normal service and performed without significant incident until some pitting was discovered during a visual examination conducted late in 1994. At that time, we noted only very minor surface distress, as Figures 1 and 2 show. The distress was located at about the middle of the face width and had been slightly ground out at the time of my November 1994 visit.

The pinion shown in Figures 1 and 2 was in service until its removal in August 1995 because of severe surface damage. It was reinstalled in mid-1998 and failed catastrophically in 1998, approximately three working years after start-up. The number of cycles accumulated by the pinion at the time of failure was lower than 3×10^8. This, therefore, was certainly not a low cycle failure, but it was only one-third of the total design life.

The failed pinion was replaced and the mill restarted. During a visual inspection conducted in early 1999, the new replacement pinion was found to be exhibiting pitting very similar in both extent and location to the pitting in the original pinion. This pitting was hand dressed out and was found to have not progressed significantly during a visual inspection, which was conducted during April 1999, as Figure 3 shows.

During an inspection in April 1999, we did not observe any cracks on this pinion (we were unable to dye check it). However, the pinion was reported to have some cracks in the pitted region which were discovered during a previous dye check inspection. The cracks were ground out and the pinion was returned to service. At the time of our inspection, it appeared that only minor progression of the pitting was occurring.

The Second Helical Gear Set

As noted above, there are two identical mill gear systems on line at this site. The second mill was running at the time of our visit and we were unable to shut it down for a good look at the teeth. We examined the teeth through the inspection port with the aid of a strobe, which allowed the pinion and gear rotation to be "stopped" artificially. As Figure 4 shows, this pinion exhibited moderate surface distress in the form of pitting.

We could not detect any cracks on the surface of this pinion; however, it would be almost impossible to do so under the conditions of this inspection. The regions of pitting observed were similar in size to those observed on the first (failed) mill pinion, but they were in a somewhat different location along the face width. In the profile direction, the pitting was located near the pitch line on both mill pinions.

Fig. 4—Pitting distress on second mill pinion teeth.

Fig. 5—Ball mill pinion #1 teeth, which exhibit no surface distress.

Fig. 6—Failed pinion removed from #2 ball mill in August 1998.

Fig. 7—Pinion fracture face. The light area at the top of the pinion is the crack propagation area. The dark area at the bottom of the pinion is the area that was cut after the failure.

Lubricant distribution on both gear sets appeared to be adequate and uniform across the face width. There was no indication of any lubrication-related distress on any of the pinions or gears examined.

The distress is located about 2/3 of the face width from the motor end of the face width. While Figure 4 shows typical distress, it is important to note that not all pinion teeth exhibit this distress. Figure 5 shows another group of pinion teeth on

Raymond J. Drago, P.E.

leads a double life. He is a senior technical fellow of the Boeing Company specializing in gear technology. He is also chief engineer of Drive Systems Technology, Inc., a gear engineering consulting company he founded in 1976.

Alejandro Font Filax, Ph.D.

is a professor with the Department of Mechanical Engineering at the University of Chile in Santiago.

Fig. 8—Pitting observed on fractured pinion. Note the ground out condition of the pitted area and the lack of new progression.

Fig. 9—Fractured tooth surface, suggestive of a subsurface flaw.

Fig. 10—Cracks progressed from the tooth roots.

the same pinion which exhibit virtually no distress at all.

The Failed Mill Pinion

The pinion, which failed in August 1998, was available for our visual examination; however, as Figure 6 shows, it was quite rusted. Still, our visual evaluation provided valuable clues regarding the cause of the failure.

It was apparent that a crack propagated through the pinion. The crack was on the divided face width at about the 2/3–1/3 point. The crack propagated through about 75% of the shaft thickness (Figure 7) but did not completely sever the pinion.

This failure was discovered during normal maintenance and no problem had previously been noted during operation. At shut down, maintenance personnel found a piece missing from one tooth and noted the crack extending about 75% around the circumference of the pinion.

It was reported that this pinion had been run in both directions and that the contact apparent on the tooth flanks confirms this. It was also reported to me that this pinion had been running in one direction only for "…many years…." The pitting observed was reported to have occurred generally at four locations, positioned about 90 degrees apart. The pitting which I observed on this pinion (Figure 8) was not sufficient, of and by itself, to account for this massive crack propagation failure. Note also that this level of pitting is not very different from that which I observed on this same pinion when I last visually evaluated it during my November 1994 visit (see Figures 6 and 7 above). Close examination of Figure 8 clearly shows that there was no real progression of the pitting distress and that the fracture does not appear to originate in the pitted region.

The surface characteristics of the failure, as shown in Figure 9, suggest the presence of a subsurface defect, which initiated the crack that propagated to failure. Despite the rusted nature of the fracture face, it is still relatively smooth in appearance. It is clear that multiple crack branches have propagated in the region of the fracture. This topography is suggestive of a fatigue crack propagation mechanism. Scanning electron microscopy of this region showed crack growth rates of 10^{-4} mm/cycle, that is, 80 mm in 3 days of operation.

Based on the view of the fracture face shown in Figure 10, it appears that the original failure had multiple origins and that it spread from the tooth root area down into the shaft section.

Current Pinion Condition

The conditions of the pinions and gears currently installed in both mills are very similar to each other. At this time neither pinion exhibits any critical problems; however, the overall condition of the pinions are very similar to the condition of the fractured pinion which failed in 1998. This is, of and by itself, some cause for concern.

The pitting which is apparent on these pinions is somewhat unusual in both its location and its appearance. The fact that the pitting is largely mid-face indicates that it will not be practical to realign the gear sets to favor the undamaged tooth surfaces. The appearance of the pitting suggests an over crowned condition on either the pinions or their mating gears or, perhaps, both. I have no indication of the actual geometry of these pinion and gear sets (i.e., lead and profile inspection charts or other similar measurements) which might identify the specific cause. Considering the experience of the failed pinion, however, and the similarity of the appearance of the pitting on all three pinions, it is quite possible that the two currently installed pinions also exhibit some of the material anomalies which affected the failed pinion and, as described below, ultimately led to its fracture.

If this pitting is the result of material anomalies as was the fractured mill pinion described below, dressing the pitted area will lower the stress level in the region where the inclusions appear to be prevalent, thus reducing the possibility that they will cause a crack initiation and progression mechanism similar to that which led to the failure.

Failed Pinion Shaft Analysis

The fracture failure of this pinion shaft is an extreme example of the highly deleterious effects of material anomalies on the load capacity, reliability and life expectancy of large gears. The specific mode of failure experienced was via initiation of cracks near the top of one tooth with propagation occurring across approximately 75% to 85% of the shaft cross section, as Figures 11 and 12 clearly indicate. The cross hatched areas in these figures show the region which was cut to expose the fracture faces while the unhatched regions show the region over which the cracks progressed. Note especially the origin of the failure in the tooth top at the top of both figures and the extensive, branched crack network below the origin.

Despite this extensive propagation, no indication of the failure of the shaft was observed during normal operation of the mill. The fracture was only noted during a maintenance check. This crack propagation took place in less than three months of operation.

The condition of the tooth flanks and location of the fracture (almost mid-face) also indicated that the problem was not related to alignment. Further, the nature of the crack initiation and early progression indicates that the failure was not due to an overload condition, either one time or repeated. These factors point to problems with the material or manufacture of the pinion.

Based on the appearance of the fracture surface, a material anomaly is the primary suspect. In order to investigate this possibility, a detailed metallurgical evaluation was required.

The relatively good condition of the teeth over most of the face width combined with the large piece which was fractured away from one tooth near the middle of the face from just below the pitch diameter of the tooth tip very strongly suggests a localized anomaly. Pitting failures due to overloading or overall material insufficiency (e.g., low hardness, etc.) will manifest themselves relatively uniformly on all or most teeth while pitting failures due to misalignment-induced overloading will occur in a localized region of the face width, biased to the more highly loaded end but also uniformly dispersed on most or all teeth. The surface failures observed on this pinion were highly localized, as Figure 13 shows.

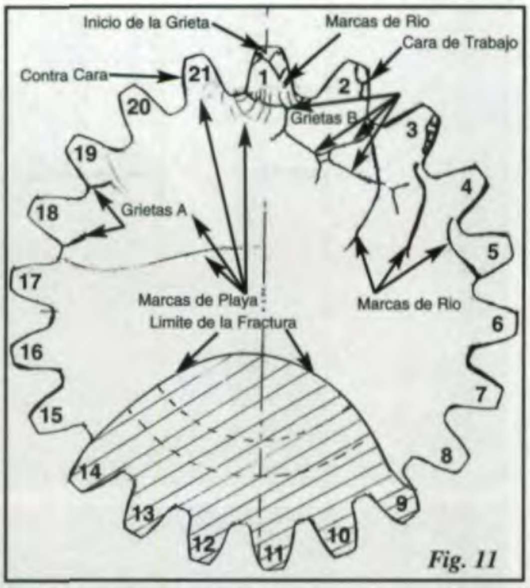

Fig. 11

Fig. 11—Pinion fracture face. Mating surface shown in Figure 12.

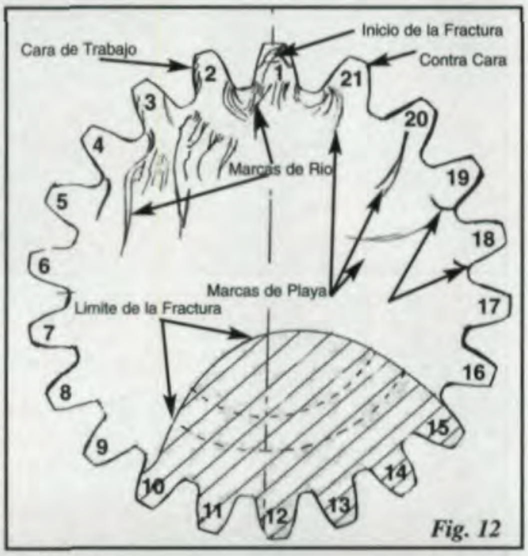

Fig. 12

Fig. 12—Pinion fracture face. Mating surface shown in Figure 11.

Fig. 13

Fig. 13—Fractured pinion after removal. Note the large piece fractured from one tooth.

The pinion was cut through the remaining shaft section to render the fracture faces visible. Figures 14 and 15 show the fracture faces after shaft sectioning. In Figure 14, the darker region in the upper right of the photograph is the section that was cut through to reveal the fracture face, which

Fig. 14

Fig. 14—Pinion fracture face corresponding to Figure 12.

Fig. 15

Fig. 15—Pinion fracture face corresponding to Figure 11.

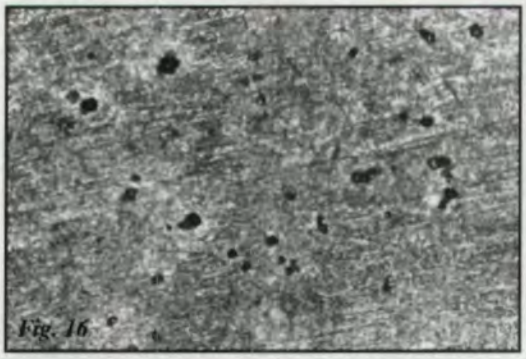

Fig. 16

Fig. 16—Inclusions that were found in the fracture origin region.

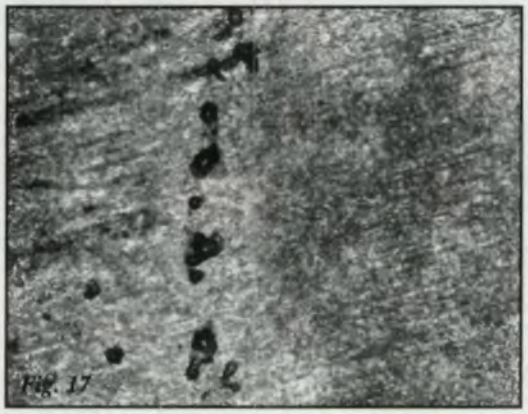

Fig. 17

Fig. 17—Inclusions clustered in a longitudinal pattern.

is the smoother surface at the lower left of this photograph. It is clear from these figures that the origin of the crack network is in the tooth region identified by the arrows shown in Figure 15.

Metallurgical Evaluation

In order to better understand the nature of the fracture, metallurgical samples were obtained from the origin region and subjected to detailed analysis. Based on this evaluation, the specific mechanism of crack initiation became quite clear.

Once polished and etched, these sections revealed the presence of large concentrations of inclusions, as Figure 16 shows. These inclusions were widely distributed in the region where the cracks originated. Such inclusions are, of course, impurities in the basic steel forging. The effect of inclusions on the capacity of the gear depends very much on their location.

Inclusions act as stress concentration factors which effectively increase the nominal, load induced stress level. Depending on their location on the tooth and the stress field which exists at that point, such inclusions may prove harmless or they may cause substantial localized stress concentrations, which can result in crack initiation. The length of time required for crack initiation and progression depends on many factors including the magnitude of the basic applied stresses. If the basic applied stresses are very high and concentrated in a single region, such as tooth root bending stresses, the crack may initiate and propagate quickly. Conversely, if the basic applied stresses are more diffuse, such as they are in the contact region, cracks may not initiate for a very long time and, once initiated, may also have long propagation times. The latter appears to be the case here.

Inclusions were found throughout the origin region, but the ones which most directly influenced this failure are those which were found close to the surface of the tooth. If the inclusions are well below the tooth surface and widely dispersed, their effect may be small. When close to the surface or in the tooth fillet region, however, they can be quite significant. Concentrations of inclusions can also pose a very great problem for carburized pinions when they are heat treated. This pinion was through hardened, thus this aspect was not observed.

Of even greater significance is the situation which occurs when inclusions occur in clusters, as Figure 17 shows. These clustered inclusions form a very large stress concentration and can adversely affect both the surface load capacity and bending fatigue strength of the teeth. When clustered, the negative effect of an inclusion is magnified many times over.

It was a group of inclusions, such as the ones shown in Figure 17, which caused the failure of this pinion. Specifically, the clustered inclusions were located below the surface but within the high stress region. As Figure 18 shows, the fracture passed through the pitted region. The pitted region itself, however, did not propagate in any significant manner as is also obvious from Figure 18. Early in the life of the part, inclusions contributed to the occurrence of the odd pitting pattern, which was originally ascribed solely to over crowning. It is likely that over crowning may also have played a role by further concentrating the stresses in this weakened area; however, it is not possible to determine with certainty what the proportional effects were. It is likely, however, that the inclusions were the major factor.

In Figure 18, note that the tooth before and the tooth after the pitted tooth in the center of the photograph are both essentially free of pitting. Since crowning (normal or excessive) would be essentially uniform on all teeth but the distribution of material defects such as inclusions is always nonuniform, the lack of distress on some teeth indicates that the inclusions are, in fact, the driving factor.

This pitting, combined with the presence of other inclusions, in the presence of the applied, repetitive surface stresses caused cracks to initiate below the tooth surface. This same loading pattern caused the cracks to progress, very slowly at first (this early manifestation was the pitting pattern observed early in the life of the gear). As the crack length grew, the critical stress threshold also dropped, thus the cracks began, eventually, to propagate more rapidly. Eventually, they propagated through the shaft section, resulting in the catastrophic failure observed.

Failure Scenario

Regarding this pinion's specific failure scenario, it is clear that the cracks which propagated through the shaft originated in the teeth just below the surface due to inclusions, which acted as nucleation points due to their stress concentration effects. The inclusions are an indication that the steel used in these pinions was not of adequate cleanliness for this application. In addition, as described above, because of the appearance of pitting, which is similar to that observed on the failed pinion, the pinions currently installed in the mills are also of some concern in that the same conditions which produced the failure of the first pinion may possibly also exist in these pinions as well.

Ultrasonic Inspection

The presence of inclusions in this pinion also indicates that the raw material (forging) used was either not ultrasonic inspected (UT) or that the inspection was not properly evaluated. Such inclusions can be successfully detected by a properly conducted UT inspection. For example, Figure 19 shows the result of a UT inspection of another forging which did exhibit a subsurface indication. It is important to note that this figure is provided for demonstration purposes only as this forging was not evaluated metallurgically to define the cause of the indication. UT inspections should always be required for all critical pinion and gear blanks.

Fig. 18—Crack passed through pitted region. Note that the teeth before and after the pitted tooth are both free from pitting.

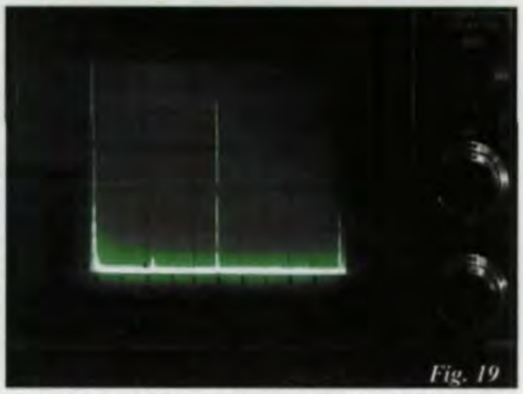

Fig. 19

Fig. 19—Ultrasonic indication of subsurface defect in a gear forging.

Conclusion

Material defects can have a very significant detrimental effect on the long term viability of critical gears. These detrimental effects may occur in a relatively short period if the applied stress levels are high but in the presence of more moderate stresses, failures may occur after a very long period of very successful operation.

Recommendation

All critical forgings should be ultrasonically inspected to detect subsurface material defects before detail machining is started. In addition, material specifications for such gears should include cleanliness requirements and a definition of testing which will confirm the cleanliness rating. The use of vacuum degassed materials will also help to minimize the chance of a subsurface defect adversely affecting the load capacity or life of the finished gear. ○

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Ferritic Nitrocarburizing Gears to Increase Wear Resistance and Reduce Distortion

Loren J. Epler

Quality gear manufacturing depends on controlled tolerances and geometry. As a result, ferritic nitrocarburizing has become the heat treat process of choice for many gear manufacturers. The primary reasons for this are:

1. The process is performed at low temperatures, i.e. less than critical.
2. The quench methods increase fatigue strength by up to 125% without distorting. Ferritic nitrocarburizing is used in place of carburizing and hardening, carbonitriding, nitriding or in conjunction with conventional and induction hardening.
3. It establishes gradient base hardnesses, i.e. eliminates eggshell effect on TiN, TiAlN, CrC, etc.

In addition, the process can also be applied to hobs, broaches, drills and other cutting tools.

History. Ferritic nitrocarburizing was first established in 1947 in a cyanide, salt-based batch process. It was later refined as a *gaseous ferritic nitrocarburizing process* and patented by Lucas Industries in 1961. Lucas demonstrated that they could produce surface layers identical to those produced in salt bath processes using an endothermic, ammonia-based atmosphere.

Fig. 1—.0008" Compound of White Layer on an SAE 1035 Gear, Rockwell C Hardness 75+.

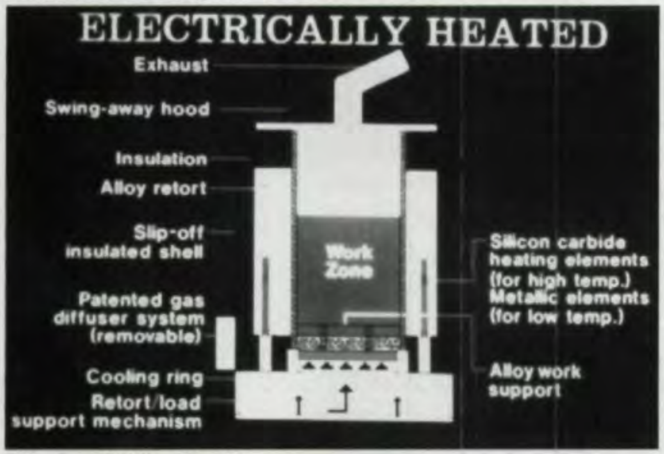

Fig. 2—Fluidized bed furnace.

The process was classified as a *"thermochemical surface treatment"* that involved the diffusion of both nitrogen and carbon into the surface of a metal at a temperature below the austenite transformation temperature. The process would yield a single phase epsilon layer with an atomic weight of Fe_2O_3. The single phase layer makes the product much more wear resistant than gas or ion nitriding, according to Dawes and Trantner (1).

In 1982, Ironbound Heat Treat developed Nitrowear® using similar atmospheres in a fluidized bed medium. Subsequently, Jack Ross, owner and founder of Ironbound, patented and licensed the process to Dynamic Metal Treating. The fluidized bed proved to be up to six times faster than the conventional atmosphere furnaces with less temperature variation, typically ±2° F from the process setpoint. Ferritic nitrocarburizing and its corrosion resistance process, Nitrowear, are similar to ion and gas nitriding but produce less brittleness and greater wear resistance.

Since taking on the license, Dynamic Metal Treating has developed and refined the process and has many of its own patents. Dynamic currently has over 25 derivatives of the process, engineered to meet the product's application and environmental requirements. The process is applied to AISI/SAE 4140, 4150, 5160, 52100, 8620, 12L14, 1144, D-2, H-13, M2, M4, M42 and T-15, just to name a few.

The Ferritic Nitrocarburizing Process

The process temperatures for ferritic nitrocarburizing are anywhere from 700°–1,200°F, depending upon the base material and the desired metallurgical properties. Since the temperature is less than the base material's critical temperature, typically 1340°F for structural and alloy steels, the parts do not experience any distortion when quenched.

During processing, nitrogen, anhydrous ammonia and a carbon producing atmosphere are introduced to the material. Based upon time, temperature and the ratio of these gases, two metallurgical characteristics are diffused (become part of the base metal) into the metal. They are referred to as:

1. Compound layer (also known as white layer or iron epsilon layer), and
2. Diffusion zone (also known as carbon and nitrogen enriched zone or total case).

The white layer has a Rockwell C hardness of 75 and greater, and the diffusion zone can be anywhere from HRC 21 to 70, depending upon the base metal. As a result, the product has:

- High wear characteristics and lower coefficient of friction values,
- Corrosion resistance greater than or equal to stainless steels,
- Low distortion, i.e. no lead, involute, tooth spacing or pitch diameter runout changes and .0002" per side linear growth on measurements over balls.
- Anti-spalling and galling properties.

These characteristics also make this a viable process for cutting tools such as hobs, broaches, etc. and an alternative to titanium nitride or other comparable coatings at one-quarter the cost. Ferritic nitrocarburizing can be applied to all ferrous metals and 400 series stainless steels. When used with precipitation hardening, special surface activation is required.

Fluidization. Fluidization is the technique where aluminum oxide (sand) behaves like a liquid while in a heat treat furnace. This is achieved by introducing gases at a given flow rate and pressure through a diffusion plate and into the sand. The diffusion plate is primarily a distribution plate that causes the pressurized sand and gases to react and become microscopically separated, thus causing the medium to move freely throughout the furnace shell. The furnace is heated electrically with silicon carbide heating elements, which are located outside the heat treat vessel's shell. The heat is rapidly distributed throughout the work zone, thereby attaining excellent furnace temperature uniformity and rapid heat transfer into the workpiece being processed. The temperature is being controlled to within ±2–5°F while conventional pit nitriding experiences ±10–25°F. On pre-heat treated materials, the ferritic nitrocarburizing cycle temperatures can mirror conventional tempering values.

The surface of the part being treated is constantly scrubbed with fresh, reactive gases. The fluidized bed methods are not inhibited by part geometry or blind holes, thus ensuring uniform metallurgical properties regardless of the part's configuration. The aluminum oxide sand particles are nonabrasive and often enhance microfinishes (see Table 1).

Before Ferritic Nitrocarburizing Ra	After Ferritic Nitrocarburizing Ra
< 4 Ra	4–8 Ra
> 4 Ra but < 16 Ra	4–12 Ra
> 16 Ra but < 32 Ra	14–28 Ra
> 32 Ra but < 125 Ra	30–125 Ra

Table 1—Changes in microfinish with the ferritic nitrocarburizing process.

Gear Type	Application
Helical, ductile iron balance gear	Balance gear, 4-cylinder engine
Splined, 8620 gear	Transfer case, 4-wheel drive
4140 and 8620 spur gears	Rear wheel drive applications
H-13 drive gears	Steel mill cranes
1035 gear	Clutch hub, transmission

Table 2—Gear types and applications that could benefit from the ferritic nitrocarburizing process.

Fig. 3—Gears and other components treated with ferritic nitrocarburizing.

The fluidized bed furnace can also perform many other heat treat processes such as nitriding, hardening (up to 1,950°F), steam bluing, annealing, stress relieving, carburizing and carbonitriding.

Gear Applications. The useful life and warranty period for many gears can be extended with ferritic nitrocarburizing. Some of the gear types and applications are listed in Table 2.

Additional benefits for gears include temper resistance (resistance to softening from heat generated in service), increased lubricity at cold start and increases in the tensile, yield and fatigue strength of the base metal as well as high compressive stresses (229,000 KSI). The process can also increase throughput and eliminate problems such as bell-mouthed I.D.s, quench cracking, retained austenite and bainite, and decarburization.

Steel Selection. Gear steels that have been successfully processed using ferritic nitrocarburizing are: 1008-1020, 12L14, 1215, 1141, 1144, 8620, 4140, 4150, 4340, ductile iron and pearlitic-malleable. The low carbon and leaded steels are selected when the application is under low, applied torsional and axial loading needing primarily wear resistance. The 11XX series is used for its increased machinability while maintaining some core hardness properties. Higher torsional and axial loading or where backlash occurs may require higher alloyed materials so that the core properties can be maintained during ferritic nitrocarburizing.

Case Depth/Quality Requirements. Quality assurance of ferritic nitrocarburizing is typically very simple. Parts are checked for file hardness per SAE J864, while white layer and diffusion zones are verified through metallography.

File hardness values for low carbon steels are typically reflected as 58 minimum with the value increasing according to the base material. White layer depths at 1000 X are anywhere from .000050–.0022" (.00127–.056 mm) and diffusion zones from .0013" to > .032" (.033–.81 mm). ○

Loren J. Epler *is president of Dynamic Metal Treating, Inc., of Canton Township, MI. This article is based on the presentation he gave at the SME Heat Treating and Hardening of Gears Clinic that was held on October 25, 1999 in Nashville, TN.*

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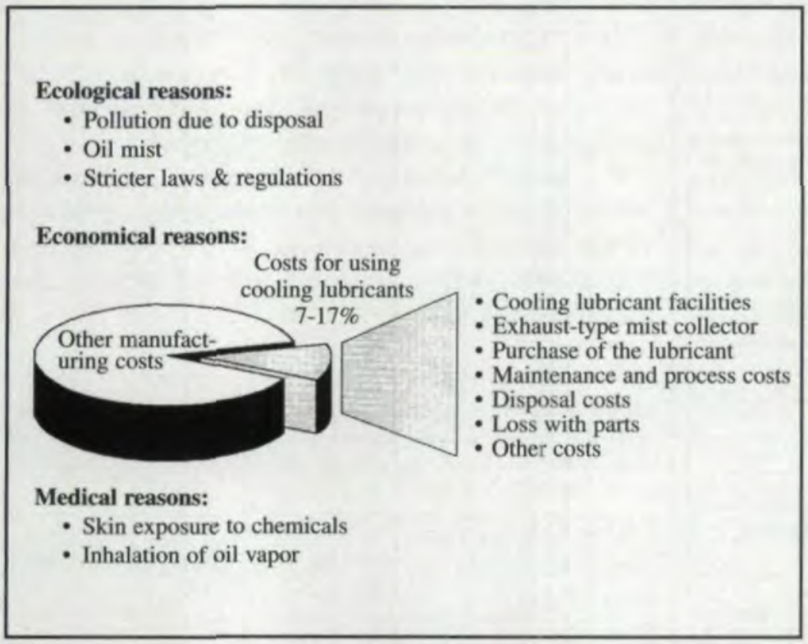
Reducing Production Costs in Cylindrical Gear Hobbing and Shaping

Prof. Dr.-Ing. Fritz Klocke and Dipl.-Ing. Claus Kobialka

Introduction

Increased productivity in roughing operations for gear cutting depends mainly on lower production costs in the hobbing process. In addition, certain gears can be manufactured by shaping, which also needs to be taken into account in the search for a more cost-effective form of production.

One way of increasing the productivity of the hobbing process is to raise cutting speed. Another potential strategy for reducing costs and thus increasing productivity is to eliminate the use of cooling lubricants. High-speed hobbing is now understood almost exclusively as dry machining with carbide tools at cutting speeds in excess of 300 m/min (Ref. 2). Together with the introduction of such new technology, productivity can also be enhanced through the use of innovative high speed steel cutting tools.



Ecological reasons:
- Pollution due to disposal
- Oil mist
- Stricter laws & regulations

Economical reasons:

- Cooling lubricant facilities
- Exhaust-type mist collector
- Purchase of the lubricant
- Maintenance and process costs
- Disposal costs
- Loss with parts
- Other costs

Medical reasons:
- Skin exposure to chemicals
- Inhalation of oil vapor

Fig. 1—Reasons for eliminating cooling lubricants (Ref. 7).

The potential of each of these rationalization measures (use of HSS and carbide tools) is discussed below for the case of hobbing. This information is supplemented by an indication of the technological limits and process reliability of specific applications. Finally, because certain gear cutting applications require the use of shaping, a lubricant-free option for manufacturing internal gears is indicated.

In order to make a comprehensive and reliable assessment of the required productivity, the report first analyzes wear-relevant mechanisms in hobbing and shaping operations. Various tool materials and coatings are investigated at differing cutting parameters in relation to the special stresses encountered in machining at high specific removal rates and differing machining conditions. The objective is to demonstrate both the performance potential and the current limits for existing tool systems. Finally, the tool lives determined in the tests are assessed.

State of the Art

Economic and technological significance of cooling lubricants. Modern cooling lubricant systems make a decisive contribution to the high level of performance of numerous production processes by performing their main tasks of cooling and lubricating the contact point and by transporting chips away from it. Despite their great technological importance, they have been the target of increasing criticism in recent years, stimulated by rising operational and disposal costs due to stricter environmental regulations.

Consideration of these problems has made many users aware of the costs involved in the use of cooling lubricants. A recognition that part-related costs for the cooling lubricant system may be several times higher than tool costs has led to a reevaluation of cooling lubricant use in many companies. The logical consequence is a demand for solutions which reduce or eliminate the use of cooling lubricants and hence the associated costs (Fig. 1, Ref. 1).

Especially in terms of economic criteria, purchase costs for the cooling lubricant must be seen in association with investment costs for a cooling lubricant unit. Cooling lubricants also need maintenance and disposal (Refs. 2-6). Losses on parts and chips, vaporization and evaporation likewise contribute to lubricant consumption. Overall, costs to the company associated with the use of cooling lubricants represent an increasing economic burden and amount to some 7% to 17% of proportional part costs in the automotive industry. Calculations for gear making indicated that between 16% and 30% of hobbing costs result from the use of cooling lubricants. In view of restrictive environmental legislation reshaping regulations for the disposal and reutilization of special wastes, it may be anticipated that lubricant-related costs will rise even further.

Potential of new or optimized gear cutting tools. Together with cost reductions through the elimination of cooling lubricants, it is possible to increase productivity by using higher cutting parameters. Apart from innovative tool materials, tool coating with hard, thin films should not be neglected in this respect.

PVD coating technology in particular opens the way to improved cutting parameters as compared to the use of uncoated tools in machining technology. Coating technology has consequently undergone rapid development in recent years. The results of this development include new hard, thin-film systems that can be deposited with consistent results on tools of any degree of complexity. The effect has been to make the use of fully coated complex tools, especially hobs, state-of-the-art technology (Ref. 8).

Current commercial systems include TiN, Ti(C,N), (Ti,Al)N and other hard, thin films based on the elements titanium and aluminum, which can be deposited either on high-speed steel or on carbide. Because of their wide availability and differentiated mechanical properties, TiN and (Ti,Al)N coating systems will be considered in greater detail below.

Machining Tests

Tool wear behavior and tool lives for hobbing operations with HSS tools using cooling lubricants. All tests were carried out with a maximum crest chip thickness according to Hoffmeister (Ref. 9) of $h_{cu\ max} = 0.18$ mm. Cutting speed was increased in 30 m/min stages from $v_c = 90$ m/min to $v_c = 180$ m/min. The width of wear land versus tool life for cutting speeds from $v_c = 90$ m/min and $v_c = 180$ m/min shown in Figure 2 are representative for all analyzed cutting parameters.

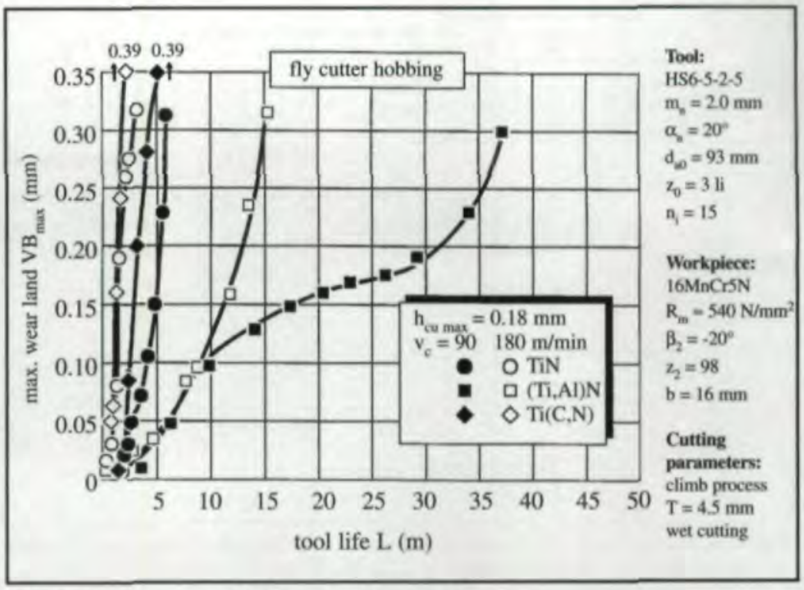


Fig. 2—Wear curve at different cutting speeds.

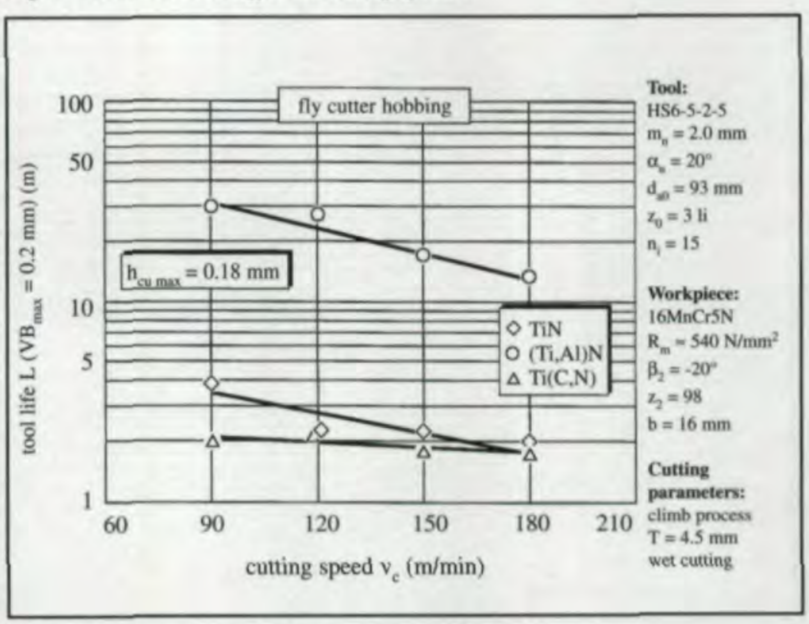


Fig. 3—Comparative tool life as a function of cutting speed.

Initially, the tool life criterion aimed at was a maximum face wear of $VB_{max} = 0.3$ mm. The measured wear curves indicate, however, that a tool life criterion of $VB_{max} = 0.2$ mm is more effective in reducing progressive wear (Fig. 2). The tool life comparison is therefore presented for a tool life criterion of $VB_{max} = 0.2$ mm (Fig. 3).

Shorter tool life was realized as cutting speed was increased from $v_c = 90$ to $v_c = 180$ m/min, irrespective of the coating system. The reason for this is the increased thermal stress on the tool caused by the high relative velocities of the tribological partners and the corresponding

Prof. Dr.-Ing. Fritz Klocke

is Director of the Chair of Manufacturing Technology at the Institute for Machine Tools and Production Engineering (WZL) of the Aachen University of Technology (RWTH Aachen) and Director of the Fraunhofer-Institute of Production Technology (FhG-IPT), Aachen.

Dipl.-Ing. Claus Kobialka

is a research engineer working in the field of gear manufacturing at the Chair of Manufacturing Technology at WZL-RWTH Aachen.

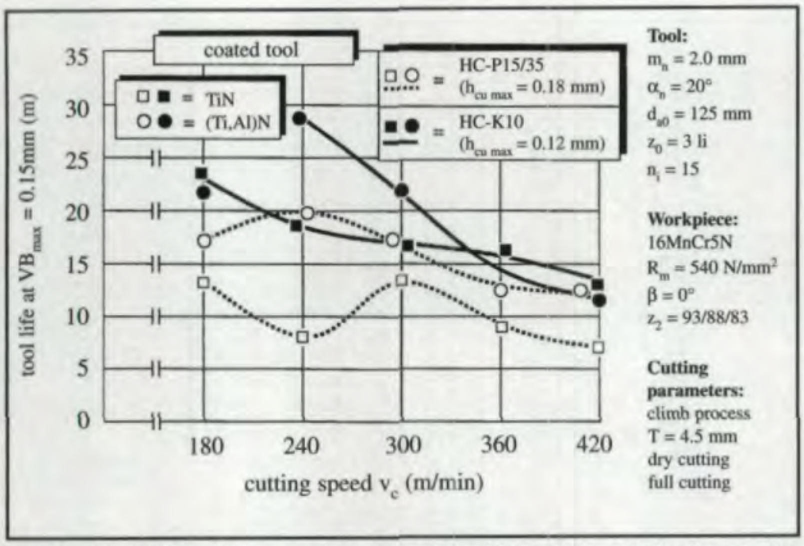


Fig. 4—Tool life for fully coated carbide tools with tool-life-optimized crest chip thicknesses and a maximum width of wear land VB_{max} = 0.15 mm.

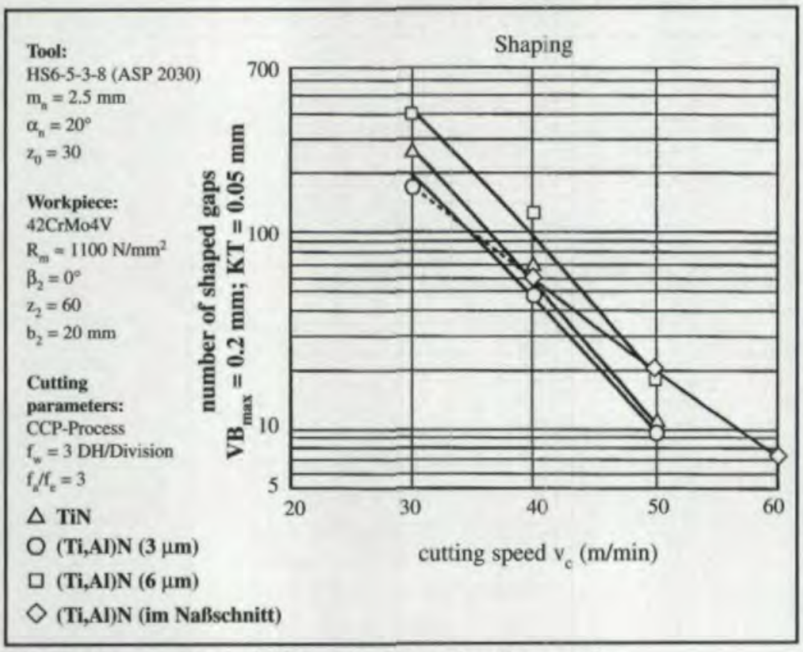


Fig. 5—Comparative tool life as a function of cutting speed.

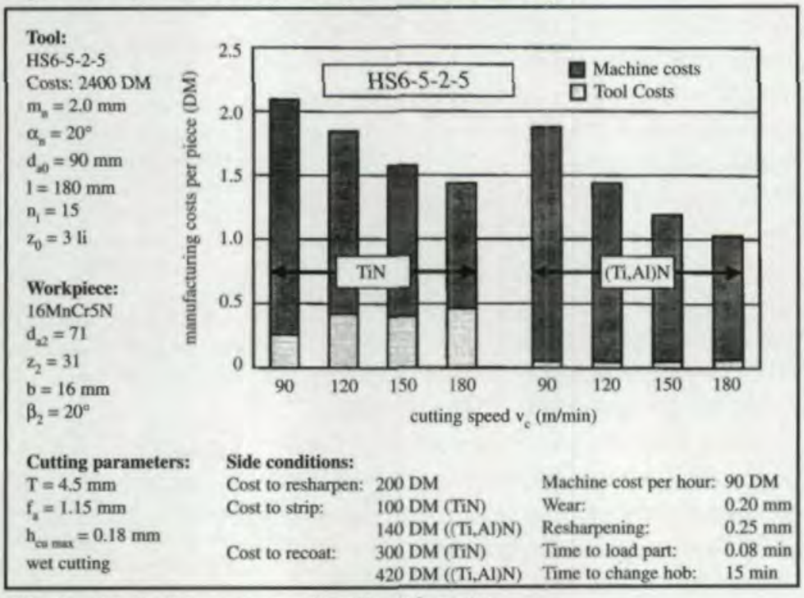


Fig. 6—Production costs as a function of coating.

increase in frictional power. The relatively long tool life seen at a cutting speed of v_c = 180 m/min is nevertheless surprising. The exceptional wear resistance of HSS tools at high cutting speeds may be attributed partly to the insulating effects of the hard, thin film and partly to the shortened chip length in hobbing a workpiece with a width of 16 mm. A calculation of the maximum chip length according to Hoffmeister (Ref. 9) indicates chip lengths of 19.5 to 21.4 mm as a function of the feed rate. This maximum chip length is not reached, due to the workpiece of 16 mm to be machined helically with β = 20°. The thermal stress on the high-speed steel during hobbing of a narrow gear is lower than for solid hobbing of a broader gear.

Whereas tool lives achieved with (Ti,Al)N-coated tools were on average higher than those for TiN-coated tools by a factor of roughly 7, the tool lives of Ti(C,N)-coated tools were even shorter. Almost irrespective of cutting speeds, the maximum attainable tool life for Ti(C,N)-coated tools is approximately 2 m.

Dry hobbing with carbide tools. Carbide hobs have been available on the tool market as an alternative to HSS hobs for a number of years and have been used increasingly in series production since the introduction of hobbing machines designed for dry cutting. Studies of the wear behavior of coated carbide hobs reveal face wear versus tool life trends identical with those already shown for HSS tools in Figure 2.

On the basis of thermal emissions generated by the machining process and proportional to the maximum width of wear land, industry uses carbide tools up to a maximum wear land width of VB_{max} = 0.15 mm. At larger wear land widths, the generated heat may also affect the fixture during a dry cutting operation, leading to fixing problems for new blanks.

Studies on coated carbide tools have shown that maximum tool lives consistent with reliable process behavior are achieved with carbides in applications group P15/35 at a maximum crest chip thickness of $h_{cu\ max}$ = 0.18 mm. Axial feeds in which a maximum crest chip thickness of $h_{cu\ max}$ = 0.12 mm are realized are advantageous in the case of applications group K10 carbides.

Against this background, a comparison of test results for wear land width VB_{max} = 0.15 mm and optimum substrate-dependent crest chip thicknesses with HC-P15/35 and HC-K10 carbides is of interest (Fig. 4).

Longer tool lives are achieved with (Ti,Al)N-coated tools than with TiN-coated tools on identical substrates. In the range of cutting speeds of interest for dry cutting ($v_c \geq 300$ m/min), longer tool lives are achieved with HC-K10 carbide substrates than with HC-P15/35 equivalents. The number of feed markings on a tooth flank must, however, be taken into account separately for each specific application in terms of subsequent production processes for a gear. If, for example, a subsequent shaving process is envisaged in the process chain, values may fall neither above nor below a range of feed markings on the tooth flank, and this fact must be taken into account in selecting the tool substrate or geometry.

Tool lives in shaping. Shaping comes second only to hobbing as a significant production process for the generation of cylindrical parts. Coated HSS tools are mainly used for shaping, because mechanical machine concepts allow high cutting speeds to only a limited extent, and the use of cost-intensive carbide tools for soft cutting does not appear cost-effective. Shaping is used wherever the penetration resulting from the tool and workpiece geometries cannot be generated by a hob. A characteristic example is the generation of internal gear teeth.

Figure 5 summarizes the tool lives that can be achieved with variously coated tools as a function of cutting speed for the case of highly-tempered internal gears. The tool life curves can be approximated very closely by straight lines in the logarithmic presentation.

Tool lives vary inversely with rising cutting speed with all coating systems in the tests. This phenomenon may be attributed to the sharply increasing thermal stress on the tool as the cutting speed rises. Only very slight differences in tool life are observed for all coating systems in the high cutting-speed range. The wear behavior of the tools may be regarded as process-reliable in all the cutting parameter fields shown in the figure.

Of interest is the significant lengthening of tool life when the coating thickness is increased. Doubling the film thickness from 3 µm to 6 µm virtually doubles the number of gaps which can be shaped. Approximately 380 gaps were machined at $v_c = 30$ m/min, corresponding to a tool life length of roughly 7.5 m. In the logarithmic presentation, increasing the coating thickness leads to a parallel shift in the wear curves.

An increase in tool life of some 20 machined gaps per tool tooth as compared to dry cutting methods is achieved by using cooling lubricant. The tool life curve also climbs less steeply when cooling lubricant is used.

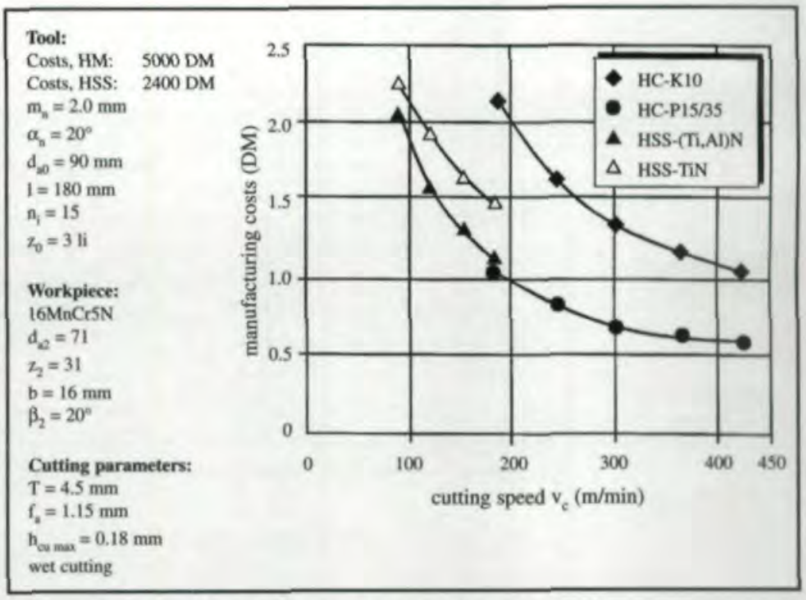


Fig. 7—Part costs in hobbing as a function of cutting speed.

The effects of the selected feed rate on the wear behavior of the tools will not be discussed in greater detail. It may, however, be stated that a reduction in tool life results from an increase in the feed rate, irrespective of the coating. The decrease in tool life is, however, smaller than from an increase in cutting speed. These data have already been described (Ref. 10) for the shaping of 16MnCr5 steel cylindrical gears.

Economic Analysis of Tool Lives

A knowledge of attainable tool life is not in itself sufficient to justify the use of a specific tool system. Of greater interest for the industrial user is a knowledge of part-related production costs. In this section, the technological test results presented above are analyzed for a fictional case to determine the production costs resulting from the tool life.

A machine hourly rate of 90 DM (approximately $60) was assumed for hobbing or shaping operations, rising to 100 DM (approximately $65) per hour if cooling lubricant is used. The tool costs presented in the following figures are based on current cost structures for medium-sized tool batches of roughly 10 to 20 tool inserts per month. (Ti,Al)N coatings are more expensive than TiN coatings, and a cost supplement of 40% was calculated for coating and stripping.

Hobbing. Analysis of the production costs per finished gear using HSS tools indicates lower costs at higher cutting speeds both for TiN- and (Ti,Al)N-coated tools (Fig. 6). The analysis is based on the constraints described in the figure and on the tool lives determined as a function of the coating system and cutting parameters for the case of fly cutter hobbing.

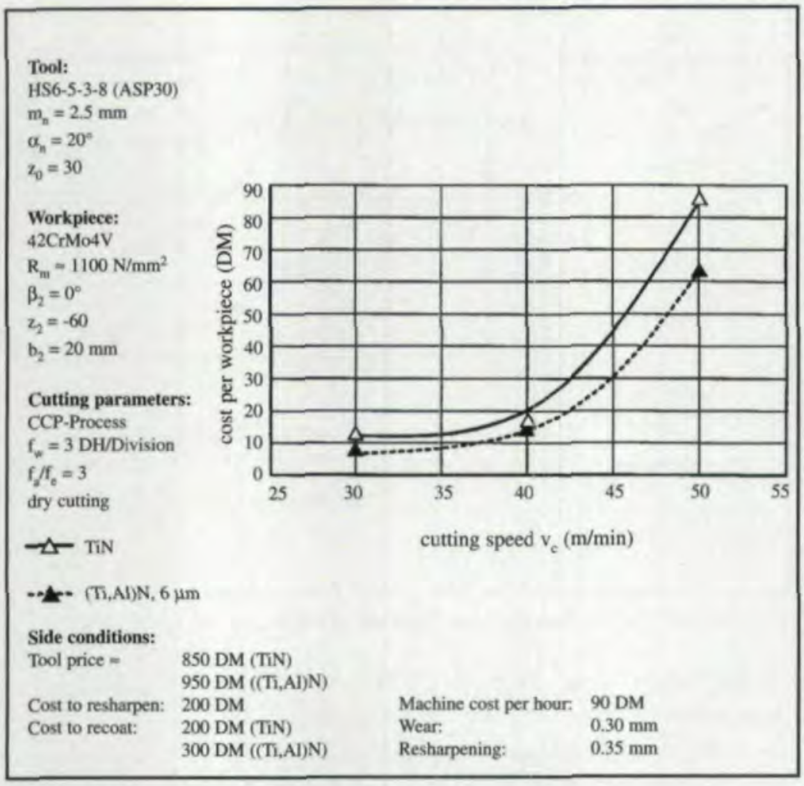


Fig. 8—Part costs for shaping as a function of cutting speed.

The pure production costs take into account the hourly machine rate, the tool purchase costs and the tool conditioning costs (regrinding, stripping and recoating).

Two cost trends emerge with rising cutting speed. On the one hand, the machine costs per part diminish, since more pieces are produced over the same period when the cutting speed is increased. On the other hand, the tool costs per part increase since tool lives shorten as the cutting speed rises, and fewer pieces are produced for each regrinding of the tool. Cumulatively, however, the decrease in machine costs outweighs the increase in tool costs.

Taking hobbing with TiN-coated HSS tools at a cutting speed of $v_c = 90$ m/min as a basis, an increase in cutting speed to 180 m/min results in a cost saving of roughly 15%. This benefit results from the 41% fall in machine costs, although tool costs rise by 100%.

The tool cost component of production costs per part for hobbing with (Ti,Al)N-coated tools at a cutting speed of $v_c = 90$ m/min amounts to no more than 3%; at $v_c = 180$ m/min, the corresponding figure is 11%. This means that potential cost reductions should be sought mainly by shortening machining times and diminishing machine costs, and less by reducing tool costs. If part quality permits an increase in the feed rate from $f_a = 3$ mm to $f_a = 5$ mm, the resulting increase in maximum crest chip thickness $h_{cu\,max}$ from 0.18 mm to 0.24 mm may be used to exploit an additional cost reduction potential through low tool costs and machine costs.

Taking hobbing with TiN-coated tools at a cutting speed of $v_c = 120$ m/min as standard practice in this module range, there is a saving in production costs per part of roughly 47% with (Ti,Al)N-coated HSS hobs and a cutting speed of 180 m/min.

The influence of cutting speed on the production costs determined for HSS tools in the test is also applicable to carbide tools. The basis of calculation is a 10% lower machine hourly rate for dry as opposed to wet cutting. This is due to the elimination of cooling lubricant costs as discussed in Figure 1. Because TiN-coated carbide tools are less expensive than (Ti,Al)N-coated tools, but also attain shorter tool lives, an analysis of the results shown in Figure 4 established no significant difference in production costs between TiN- and (Ti,Al)N-coated tools at the same cutting speed (Fig. 7).

The analysis was based on a 40% higher cost component for coating with (Ti,Al)N as opposed to TiN. In the future, when (Ti,Al)N coatings are in more widespread use, costs are likely to be more favorable.

At the same cutting parameters, a reduction in production costs may be expected simply from the increase in cutting speed (see Fig. 7) because machine costs are such a dominant factor. The increase in tool costs with rising cutting speed is marginal compared with the potential machine cost savings.

The same result is evident if production costs for HSS tools and K10 carbides are compared. Owing to the small chip thicknesses, which can be achieved with HC-K10, a higher gear-cutting rate is possible at a lower feed rate and identical production costs of roughly 1.10 DM per part, because the cutting speed is more than doubled from 180 m/min to 420 m/min. At the same time, a lower feed rate improves part quality due to the lower kinematic roughness.

Shaping. Unlike hobbing, production costs for the shaping of highly-tempered work materials are dominated by disproportionate tool wear and the resulting tool cost component. Coating costs are again assumed to be 40% higher for (Ti,Al)N as opposed to TiN. Because of the technological advantages of a (Ti,Al)N coating, however, a reduction of between 25% and 50% in production costs is feasible. The higher coating costs are outweighed by the longer tool lives (Fig. 8).

Conclusion

It has been shown that improved performance and cost savings of roughly 50% can be achieved with coated HSS tools in a wet cut on conventional hobbing machines if (Ti,Al)N coatings are used and removal rates are adapted accordingly.

The same trends have been demonstrated for the dry cutting of highly-tempered internal gears using a shaping process with HSS tools. Although a higher cutting speed can be obtained with cooling lubricants, the tool life achieved makes dry cutting an ecologically and economically interesting alternative to conventional machining strategies with cooling lubricants. The basic precondition for eliminating cooling lubricants is, however, the use of coated tools.

Cylindrical gear production with carbide tools in a hobbing process reduces production costs simply through shortened machining times, although tool costs are significantly increased. The technological advantage of a (Ti,Al)N hard coating is not mirrored in lower part-related production costs, owing to higher coating costs as compared to the TiN coating. Savings are rather to be found in higher cutting speeds, which can be realized through the hard coating system, allowing reduced machine and production costs.

On both HSS and carbide tools, these cost savings are generated partly by significantly increased tool life, as opposed to conventional TiN coatings, with a corresponding reduction in the tool cost component; and partly through the faster cutting speeds allowed by the lower abrasive wear and greater high-temperature hardness of the coated tools. ○

Acknowledgment

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Microsecond Heat Treatment of Gears

**Dale C. McIntyre, Kerry P. Lamppa, Macie M. Sturm,
Eugene L. Neau, and Regan W. Stinnett**

The performance of metal surfaces can be dramatically enhanced by the thermal process of rapid surface melting and re-solidification (RMRS). When the surface of a metal part (for instance, a gear) is melted and re-solidified in less than one thousandth of a second, the resulting changes in the material can lead to:

- Increased wear and corrosion resistance,
- Improved surface finish and appearance,
- Enhanced surface uniformity and purity, and
- Sealing of surface cracks and pores.

Even though it has long been known that these benefits can be obtained by RMRS, the process has not been used for large-scale commercial applications because of key technological barriers: the inability to produce broad area, efficient and intense energy sources capable of treating large surface areas, and the inability to deliver consistent treatments to complex and non-uniform surfaces.

Recently, these barriers to large scale RMRS have been overcome and the process has been implemented by QM Technologies in Albuquerque, NM, with its commercialization of the Ion Beam Surface Treatment (IBEST^{TM}) process that was developed and patented by Sandia National Laboratories in Albuquerque, NM. This process uses a rapidly pulsed (1–2 Hz), broad area (25–50 square cm) ion beam to melt and re-solidify the top several microns (up to .0005") of the surfaces of most materials. The process causes the surface to be molten for about a microsecond, and the surface cools by rapid thermal diffusion at approximately a billion degrees a second. Because the energy is rapidly injected into only the top few microns of the surface, the average temperature of parts does not typically exceed 100 degrees centigrade. This latter fact allows tight dimensional tolerances (less than a few ten thousandths of an inch) to be maintained.

Examples of the effects of the RMRS process on typical gears and gear materials are presented below.

Creation of a Uniform Microstructure and Removal of Defects Using RMRS

Figure 1 shows the effect of RMRS on the microstructure of a typical carburized, 8000 series gear steel. This figure shows cross sections of the near surface of the steel before and after treatment. The samples were prepared by polishing and etching to reveal the microstructure of the materials.

The treated surface region in the cross section micrograph is essentially featureless. Detailed studies of pulsed ion beam treated steel have shown that the grain size of material in the rapidly re-solidified region is typically less than 100 nm. The process creates a homogeneous, equiaxed grain structure. In addition, melting followed by rapid resolidification results in

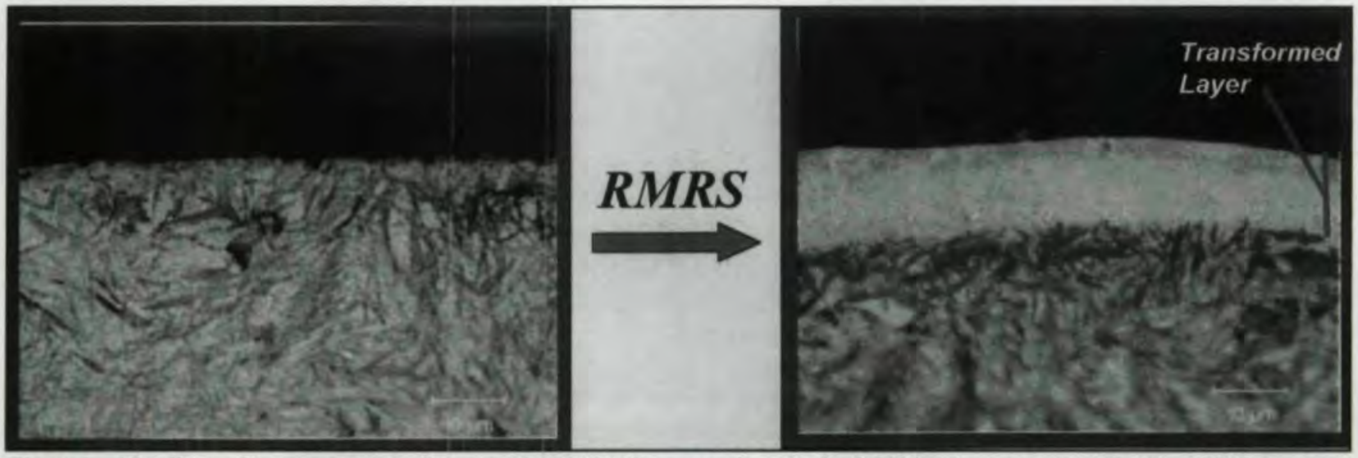


Figure 1—Metallographic cross section of untreated and RMRS processed, carburized, 8000 series gear material. The RMRS processed region is featureless, which is a result of its very small grain size and homogeneous, equiaxed structure.

a uniform redistribution of material in the region and removes localized defects like grain boundary oxidation, grain boundary carbide precipitates, and inclusions.

In carburized steels, rapid melting and re-solidification also creates a near surface region with retained austenite contents in the range of 20% to 30%. It has been reported in the literature that high levels of retained austenite can be beneficial in low cycle fatigue environments in which the enhanced strain at crack tips can cause an austenite to martensite transformation that helps to arrest further crack growth. It has also been reported that retained austenite with very small grain size can enhance high cycle fatigue life. The micrograph in Figure 1 shows that the grain size of the retained austenite in an RMRS transformed layer is very small and unresolvable by standard optical microscopy.

Further modification of the microstructure of the RMRS region has been achieved by subsequent thermal or mechanical processing. Heat treatment, cryogenic treatment, and shot peening have been shown to adjust the level of retained austenite in the transformed region. These post-RMRS processing options allow for customization of the microstructure to fit the requirements of different application environments.

In general, the RMRS process, when applied to metals, will result in the creation of a near surface region with very small, equiaxed grains and a uniform distribution of alloying elements. Defects composed of high vapor pressure constituents (for instance, inclusions) are often removed by the very rapid thermal excursion provided by RMRS.

In addition, features such as cracks and pores may be sealed by the melting process. For example, it has been demonstrated that there is sufficient time during RMRS for molten material to re-flow and fill pores and cracks that are up to several micrometers in size. This capability has facilitated the use of the RMRS process for sealing near surface porosity in metal injection molded parts and higher density (density > 94%) conventional powder metal parts.

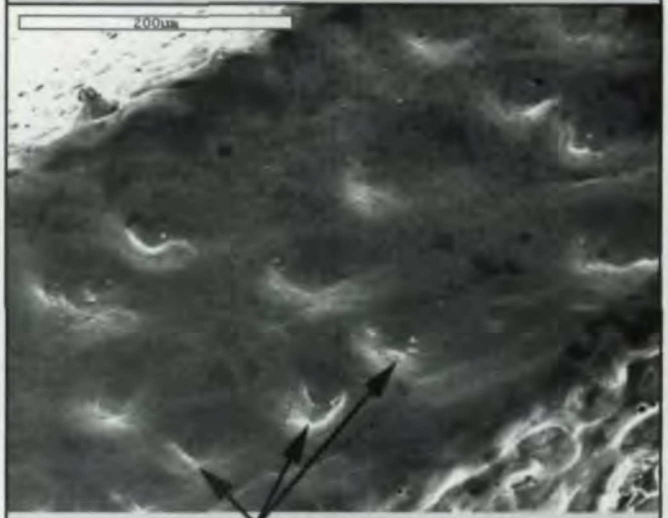
Creation of a Smoother, Isotropic Topography Using RMRS

As mentioned above, rapid melting and re-solidification results in the short range flow of material. As a result, the roughness and topography of a machined surface will be changed by RMRS.

For example, Figure 2 shows scanning electron microscope (SEM) images of the surface of the crown of a carburized steel gear tooth before and after RMRS. The untreated surface exhibits directional machine lines. In contrast, the surface of the treated gear shows that machine lines have been replaced by a longer wavelength, isotropic, shallow dimpled surface.

The treated gear surfaces were characterized using a Wyko NT-2000 optical profilometer. The root mean square roughness (Rq) and skewness (Rsk) of the surface features were measured. The average Rq of this gear was reduced by RMRS from an average of 90 +/- 14 micro-inches to 55 +/- 6 microinches. Other work shows that RMRS can reduce the roughness of metal surfaces by up to a factor of two to three.

Directional Machine Lines on the Gear Crown

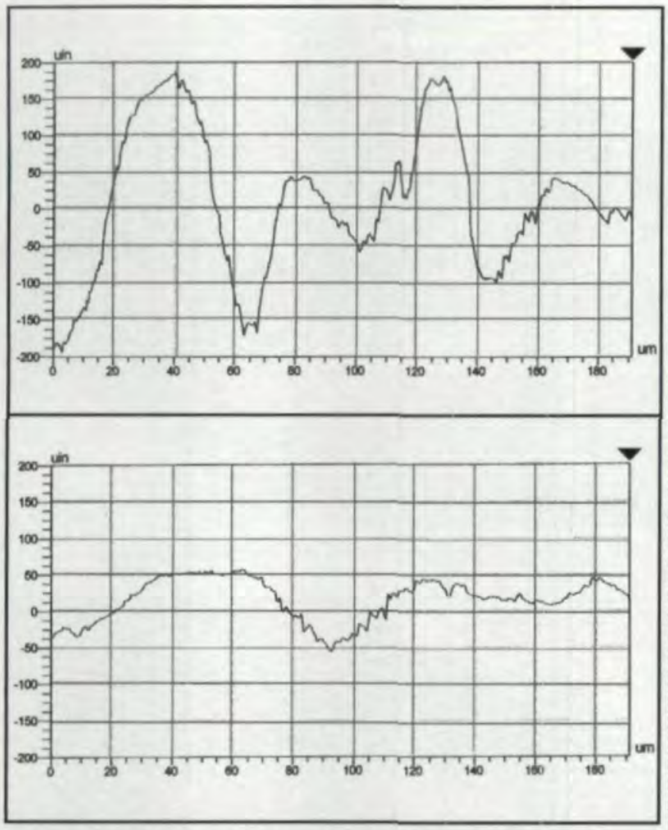


Isotropic Shallow "Valleys" on the Gear Crown

Figures 2a and 2b—Scanning electron microscope images (magnification = 250 X) of untreated and RMRS treated crowns of carburized steel gear teeth. The RMRS process transformed the directional, machined topography of the untreated surface to an isotropic, longer wavelength, and slightly dimpled topography.

A line profile taken from the surface of the untreated and RMRS treated surfaces of a carburized steel gear are shown in Figures 3a and 3b. These plots show that RMRS reduces the amplitude and increases the average wavelength of the surface features.

Finally, skewness is a measurement of the asymmetry of the surface profile about the mean surface position. A positive skewness indicates that the most distant lying points on a surface profile are proportionately above the mean surface while a negative skewness indicates the most distant lying points are proportionately below the mean surface. The skewness measurements of this gear showed that the average Rsk for the machined surface was approximately 0.0 +/- 0.2 and the average Rsk of a rapidly melted and re-solidified surface was approximately –0.3 +/- 0.2. This change in skewness reflects the creation of shallow "valleys" in the surface that is observed in Figure 2. The slightly negative skewness also suggests that the treated surface has few spikes or bumps that



Figures 3a and 3b—Surface profile scans of untreated and treated crowns of carburized, steel gear teeth taken using an optical profilometer. The RMRS process reduced the root-mean-square roughness from 90 micro-inches to 55 micro-inches and increased the wavelength of the characteristic surface features.

will typically wear away quickly in sliding wear environments. The presence of shallow valleys in the surface can also help with reducing run-in time while increasing lubrication retention in sliding applications. For example, work conducted by QMT on the RMRS processing of steel piston surfaces has shown that this type of surface significantly reduces friction in sliding applications.

The changes in the surface topography caused by RMRS processing have also been shown to significantly improve the adhesion of very hard coatings. In addition to removing contamination from the surface, the RMRS process reduces the population of stress enhancing, de-cohesion points at the hard coating-substrate interface. The increase in surface cleanliness and homogeneity combined with the creation of a smoother, isotropic finish by RMRS creates a better surface for coating.

Conclusions

When applied to gears, the RMRS process has been shown to:

1. Transform the microstructure of the gea material into a very fine grained, equiaxed and homogeneous microstructure with a reduced population of cracks and pores, and
2. Create surfaces that have isotropic, shallow, long wavelength, dimpled features rather than directional machined surface features of shorter characteristic wavelength.

These changes can result in decreased wear rate and increased fatigue life of gear materials. In addition, QMT has shown that the IBEST rapid melting and re-solidification process can be used to significantly enhance the performance of surfaces in many diverse applications. For example, IBEST processing has increased the lubricity and wear resistance of metal injection molded parts, increased the lifetime of steel flexible rotary dies by up to a factor of ten, and extended the lifetime of cemented carbide tools used to machine cast iron by two to three times. ○

Dale C. McIntyre

is the vice president of Applications Development and Marketing at QM Technologies (QMT). He is a co-inventor of IBEST Technology and is a metallurgist with almost 20 years experience in surface modification technologies.

Kerry P. Lamppa

is the manager of the Surface Treatment Center at QMT. He is an electrical engineer on leave from Sandia National Laboratories. Lamppa has 15 years of experience in ion beam source development and ion beam treatment of materials.

Macie M. Sturm

is an electron microscopist and conducts materials characterization at QMT. She has over twenty years of experience in surface analysis, fracture analysis and materials characterization.

Eugene L. Neau

is the executive vice president for Technology and COO at QMT. He is the cofounder of QMT and a co-inventor of IBEST Technology. Neau is internationally recognized as a technical and management leader in the field of repetitive high energy pulsed power.

Regan W. Stinnett

is the president and CEO at QMT. He is the cofounder of QMT and a co-inventor of IBEST Technology. Stinnett is an internationally recognized expert in the area of high power, high energy ion beam source development.

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Beehive Heat Treating
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Burbank Steel Treating
Century Sun Metal Treating
Certified Metal Craft, Inc.
Cincinnati Steel Treating
City Steel Treating
Coleman Commercial Heat Treating
Commercial Induction
Detroit Steel Treating Co.
Dixie Heat Treating
Drever Heat Treating
Dynamic Metal Treating,
East-Lind Heat Treat
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Fenton Heat Treating
Flame Metals Processing
Franklin Steel Treating
General Heat Treating Corp.
General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
H & S Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Hinderliter—Anaheim
Hi-Tech Aero
Hi-Tech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
Horsburgh & Scott Co.
Houston Flame Hardening
HTG Aerobraze
HTG IMT-York
Hudapack Metal Treating —Elkhorn
Hudapack Metal Treating —Glendale Heights
Hydro-Vac
Industrial Metal Treating
Industrial Steel Treating
Ionex, Inc.
Ipsen International Inc. —Atmosphere Products
Irwin Automation Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Wichita
Lindberg Heat Treating Co. —Worcester
M & M Heat Treat
Metal Improvement Co., Inc. —Wichita
Metal Improvement Co., Inc. —Columbus
Metal Improvement Co., Inc. —Emigsville
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metal-Tec Heat Treating
Metlab
Met-Tek Inc.—Clackamas
Midland Metal Treating,
Midwestern Machinery Co.
Modern Metal Processing
Modern Steel Treating
Nettleton Steel Treating
O & W Heat Treat Inc.
Oakland Metal Treating Co.
Oregon Induction Corp.
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Richter Precision Inc.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Steel Treating Inc. —Farmington Hills
Specialty Steel Treating Inc. —Fraser
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Superior Metal Treating
Syracuse Heat Treating
Thermal Braze Inc.
Therm-Tech of Waukesha
Treat All Metals
Walker Heat Treating
Washington Metallurgical Services

ALUMINUM TREATING

A.F.C.-Pifco
Alfe Heat Treating
Alliance Metal Treating
American Heat Treating
American Metal Treating Inc.
Atmosphere Furnace Co.
Beehive Heat Treating
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Certified Metal Craft, Inc.
Cincinnati Steel Treating
Detroit Steel Treating Co.
Dixie Heat Treating
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
East-Lind Heat Treat
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Flame Metals Processing
Franklin Steel Treating
General Heat Treating Corp.
Gibson Heat Treat Inc.
H & S Heat Treating
Hauni Richmond Inc.
Hi-Tech Metallurgical Co.
Horizon Steel Treating, Inc.
Hy-Vac Technologies
Industrial Metal Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Wichita
Lindberg Heat Treating Co. —Worcester
M & M Heat Treat
Metal Improvement Co. Inc. —Wichita
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metlab
Met-Tek Inc.—Clackamas
Midland Metal Treating,
Modern Industries, Inc.
Modern Metal Processing
Modern Steel Treating
O & W Heat Treat Inc.
Oakland Metal Treating Co.
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Rotation Products Corp.
Solar Atmospheres Inc.
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Superior Metal Treating
Syracuse Heat Treating
Therm-Tech of Waukesha
Washington Metallurgical Services
Weiss Industries Inc.

ANNEALING

A.F.C.-Pifco
Abbott Furnace Company
ABS Metallurgical Processors
Accurate Steel Treating
Advanced Heat Treat Corp. —Waterloo/Burton
Advanced Heat Treating
Advanced Metallurgical Technology, Inc.
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
Albany Metal Treating
Alco Heat Treating Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Allread Products
Alpha Heat Treaters
American Brazing
American Heat Treating
American Metal Treating Inc.
Atmosphere Annealing Inc.
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Bomak Corp.
Braddock Metallurgical
Braddock Metallurgical —Alabama
Brazing & Metal Treating —Cleveland
Brazing & Metal Treating —Kentucky
Brazing & Metal Treating —Minnesota
Brite Brazing
Brite Metal Treating Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Chicago Induction Metal Treating Corp.
Cincinnati Gear Co.
Cincinnati Steel Treating Co.
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 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 Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Federal Machine Co.
Feinblanking Ltd.
Fenton Heat Treating
Flame Hardening Co. of California
Flame Metals Processing
Fluxtrol Manufacturing Inc.
Fox Steel Treating Co.
FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating
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., Inc.
H & M Metal Processing
H & S Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat Treating Services
Hinderliter Heat Treating Inc. —Anaheim
Hinderliter Heat Treating Inc. —Dallas
Hinderliter Heat Treating Inc. —Tarzana
Hinderliter Heat Treating Inc. —Tulsa
Hi-Tech Aero
Hi-Tech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
Horsburgh & Scott Co.
HTG Aerobraze
HTG Copper Brazing Industries
HTG IMT-Duncan
HTG IMT-York
HTG Metal Methods
Hudapack Metal Treating —Elkhorn
Hudapack Metal Treating —Glendale Heights

Hydro-Vac
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating
Induction Services Inc.
Inductoheat, Inc.
Industrial Metal Treating
Industrial Steel Treating
Ionex, Inc.
Ipsen International Inc.
—Atmosphere Products
Ipsen International Inc.
—Vacuum Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
John V. Potero Co.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lindberg Heat Treating Co.
—Berlin
Lindberg Heat Treating Co.
—Dallas
Lindberg Heat Treating Co.
—Eden Prairie
Lindberg Heat Treating Co.
—Houston
Lindberg Heat Treating Co.
—Lansing
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Mexico
Lindberg Heat Treating Co.
—Racine
Lindberg Heat Treating Co.
—Rancho Dominguez
Lindberg Heat Treating Co.
—Rosemont
Lindberg Heat Treating Co.
—Solon
Lindberg Heat Treating Co.
—St. Louis
Lindberg Heat Treating Co.
—Sturtevant
Lindberg Heat Treating Co.
—Tulsa
Lindberg Heat Treating Co.
—Worcester
M & M Heat Treat
Magnum Metal Treating Inc.
Master Heat Treating Inc.
Merit Gear Heat Treating
Metal Improvement Co. Inc.
—Wichita
Metal Improvement Co., Inc.
—Columbus
Metal Improvement Co., Inc.
—Emigsville
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Michigan Induction Inc.
Midland Metal Treating, Inc.
Mid-West Flame Hardening
Midwestern Machinery Co.
Modern Industries, Inc.
Modern Metal Processing
Modern Steel Treating
Mountain Metallurgical
National Broach & Machine
National Induction Heating
National Metal Processing.
Nettleton Steel Treating
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Oakland Metal Treating Co.
Ohio Metallurgical Service
Oregon Induction Corp.
P & L Heat Treating & Grinding
Partek Laboratories Inc.
Paulo Products Co.
—Bessemer
Paulo Products Co.
—Kansas City
Paulo Products Co.
—Nashville
Paulo Products Co.
—St. Louis
Pennsylvania Metallurgical
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Richter Precision Inc.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating
—Elkhart
Speciality Heat Treating
—Grand Rapids
Speciality Heat Treating
—Holland
Specialty Heat Treating Inc.
—Athens
Specialty Steel Treating Inc.
—Farmington Hills
Specialty Steel Treating Inc.
—Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc.
—Orlando
Suncoast Heat Treat, Inc.
—Palm Beach Gardens
Suncoast Heat Treating
—Pompano Beach
Suncoast Heat Treating
—Tampa
Superior Metal Treating
Syracuse Heat Treating
The Bowdil Co.
Therm Tech of Waukesha
Thermal Braze Inc.
Thermal Metal Treating Inc.
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Therm-Tech of Waukesha
Tocco, Inc.
Tractech Inc.
Treat All Metals
Trojan Heat Treat Inc.
Universal Heat Treating
Vacu Braze
Walker Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Welduction Corp.
Westside Flame Hardening

AUSFORMING

Cincinnati Gear Co.
Kowalski Heat Treating Co.
Metlab
Suncoast Heat Treat, Inc.
—Palm Beach Gardens

AUSTEMPERING

A.F.C.-Pifco
Abbott Furnace Company
ABS Metallurgical Processors
Accurate Steel Treating
Advanced Heat Treat Corp.
—Waterloo/Burton
Advanced Metallurgical Technology, Inc.
Alco Heat Treating Corp.
Alfred Heller Heat Treating
American Metal Treating Inc.
AP Westshore
Applied Process Inc.
Atmosphere Furnace Co.
Beehive Heat Treating
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Burbank Steel Treating Inc.
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Metal Craft, Inc.
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Flame Metals Processing
Fox Steel Treating Co.
FPM Heat Treating
—Elk Grove
Franklin Steel Treating
General Heat Treating Corp.
General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
HI TecMetal Group
—Cleveland
Horizon Steel Treating, Inc.
Hudapack Metal Treating
—Addison
Hudapack Metal Treating
—Glendale Heights
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Industrial Steel Treating Inc.
Ipsen International Inc.
—Atmosphere Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.
—Eden Prairie
Lindberg Heat Treating Co.
—Lansing
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Rancho Dominguez
Lindberg Heat Treating Co.
—Rosemont
Lindberg Heat Treating Co.
—Tulsa
M & M Heat Treat
Metal Improvement Co. Inc.
—Wichita
Metal Treating Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Midwestern Machinery Co.
National Metal Processing
Paulo Products Co.
—Kansas City
Paulo Products Co.
—Murfreesboro
Paulo Products Co.
—St. Louis
Phoenix Heat Treating Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Steel Treaters, Inc.
Suncoast Heat Treat, Inc.
—Orlando
Suncoast Heat Treat, Inc.
—Palm Beach Gardens
Superior Metal Treating
Therm Tech of Waukesha
Thermo Electron Metal Treating Div.
Westside Flame Hardening

BLACK OXIDING

A.F.C.-Pifco
Abbott Furnace Company
Advanced Heat Treat Corp.
—Monroe
Advanced Heat Treat Corp.
—Waterloo/Burton
Advanced Heat Treat Corp.
—Waterloo/Midport
Advanced Heat Treating Inc.
Alco Heat Treating Corp.
Alpha Heat Treaters
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Central Kentucky Processing, Inc.
Clearing Niagara
Detroit Steel Treating Co.
Gibson Heat Treat Inc.
Hauni Richmond Inc.
Hi-Tech Steel Treating Inc.
Horizon Steel Treating, Inc.
Impact Strategies, Inc.
Ipsen International Inc.
—Atmosphere Products
Ironbound Heat Treating
Jasco Heat Treating Inc.
Metal Improvement Co., Inc.
—Emigsville
Metlab
Midwestern Machinery Co.
Paulo Products Co.
—Kansas City
Paulo Products Co.
—Memphis
Paulo Products Co.
—St. Louis
Peters' Heat Treating Inc.
Rochester Steel Treating Works, Inc.
Speciality Heat Treating
—Elkhart
Speciality Heat Treating
—Grand Rapids
Speciality Heat Treating
—Holland
Superior Metal Treating
Thermal Metal Treating Inc.
Universal Heat Treating
Westside Flame Hardening.

BLAST CLEANING

ABS Metallurgical Processors
Accurate Steel Treating
Advanced Thermal Technologies, Inc.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Heat Treating
American Metal Treating Inc.
Beehive Heat Treating
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Burbank Steel Treating, Inc.
Century Sun Metal Treating
Cincinnati Flame Hardening Co.
Cincinnati Steel Treating Co.
Delphi Engineering
Detroit Steel Treating Co.
Dixie Heat Treating
Drever Heat Treating
East-Lind Heat Treat
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fenton Heat Treating
Flame Metals Processing
FPM Ipsen Heat Treating
General Heat Treating Corp.
General Metal Heat Treating Inc.
Grand Rapids Commercial Heat Treating Co., Inc.
H & S Heat Treating
Hanson-Balk Steel Treating
Hauni Richmond Inc.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG Aerobraze
HTG IMT-York
Hudapack Metal Treating
—Elkhorn
Industrial Metal Treating
Industrial Steel Treating Inc.
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.
—Eden Prairie
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Rancho Dominguez
Lindberg Heat Treating Co.
—Rochester
Lindberg Heat Treating Co.
—Rosemont
Lindberg Heat Treating Co.
—Solon
Lindberg Heat Treating Co.
—Tulsa
M & M Heat Treat
Merit Gear Heat Treating
Metal Improvement Co., Inc.
—Columbus
Metal Improvement Co., Inc.
—Milwaukee
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metlab
Met-Tek Inc.—Clackamas
Midland Metal Treating, Inc.
Midwest Flame Hardening
Midwestern Machinery Co.
Modern Industries, Inc.
Modern Steel Treating
Nettleton Steel Treating
Oakland Metal Treating Co.
Paulo Products Co.
—Nashville
Paulo Products Co.
—St. Louis
Pennsylvania Metallurgical
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Speciality Heat Treating
—Elkhart
Speciality Heat Treating
—Grand Rapids
Speciality Heat Treating
—Holland
Specialty Steel Treating Inc.
—Farmington Hills
Superior Metal Treating
Syracuse Heat Treating
Therm-Tech of Waukesha
Tractech Inc.
Treat All Metals
Universal Heat Treating
Walker Heat Treating
Washington Metallurgical Services
Westside Flame Hardening.

BORONIZING

Bodycote Thermal Processing—Ft. Worth
Lindberg Heat Treating Co.
—Houston
Lindberg Heat Treating Co.
—Lansing
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Rochester
Lindberg Heat Treating Co.
—Rosemont
Metlab

BRAZING

A.F.C.-Pifco
Abbott Furnace Company
Ajax Magnethermic Corp.
Alco Heat Treating Corp.
Alfred Heller Heat Treating
Allread Products
American Brazing
Atmosphere Furnace Co.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Brazing & Metal Treating
—Cleveland
Brazing & Metal Treating
—Kentucky
Brazing & Metal Treating
—Minnesota
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Chicago Induction Metal Treating Corp.
Coleman Commercial Heat Treating
Delavan Steel Treating
Drever Heat Treating
East Carolina Metal Treating Inc.
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Fenton Heat Treating
Flame Metals Processing
Fluxtrol Manufacturing, Inc.
FPM Heat Treating
—Elk Grove
FPM Ipsen Heat Treating
Franklin Steel Treating
General Heat Treating Corp.
Gibson Heat Treat Inc.
Good Earth Tools, Inc.
Hauni Richmond Inc.
Hinderliter Heat Treating Inc.
—Anaheim
Hinderliter Heat Treating Inc.
—Dallas
Hinderliter Heat Treating Inc.
—Tarzana
Hi-Tech Aero
Hi-Tech Metallurgical Co.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG Aerobraze

HTG Copper Brazing Industries
HTG IMT-Duncan
HTG Metal Methods
Hydro-Vac
Hy-Vac Technologies Inc.
IHS—An Inductotherm Industries Co., Inc.
Induction Metal Treating
Inductoheat, Inc.
Industrial Steel Treating
Ipsen International Inc. —Atmosphere Products
Ipsen International Inc. —Vacuum Products
Kowalski Heat Treating Co.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —Sturtevant
Lindberg Heat Treating Co. —Tulsa
Lindberg Heat Treating Co. —Worcester
Magnum Metal Treating
Merit Gear Heat Treating
Metal Improvement Co. Inc. —Wichita
Metal Improvement Co., Inc. —Emigsville
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metlab
Modern Industries, Inc.
Modern Metal Processing
National Induction Heating
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Oregon Induction Corp.
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Heat Treating Inc. —Athens
Specialty Steel Treating Inc. —Farmington Hills
Steel Treating
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Suncoast Heat Treating —Tampa
Superior Metal Treating
Syracuse Heat Treating
Thermal Braze Inc.
Thermo Electron Metal Treating Div.
Wall Colmonoy Corp.
Welduction Corp.

CARBONITRIDING

A.F.C.-Pifco
Abbott Furnace Company
Accurate Steel Treating
Advanced Heat Treat Corp. —Waterloo/Burton
Advanced Heat Treating
Advanced Thermal Technologies, Inc.
Albany Metal Treating
Alco Heat Treating Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Heat Treating
American Metal Processing
American Metal Treating Inc.
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Braddock Metallurgical
Braddock Metallurgical —Alabama
Brite Metal Treating Inc.
Burbank Steel Treating, Inc.
Cal-Doran Division
Carolina Commercial Heat
Caterpillar Industrial Products Inc.
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Coleman Commercial Heat Treating
Commercial Steel Treating
Delavan Steel Treating
Detroit Steel Treating Co.
Diamond Heat Treating Co.
Dixie Heat Treating Co.
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
East Carolina Metal Treating Inc.
East-Lind Heat Treat
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Feinblanking Ltd.
Flame Metals Processing
FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating
General Heat Treating Corp.
General Metal Heat Treating Inc.
Grand Rapids Commercial Heat Treating Co., Inc.
H & S Heat Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
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.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG IMT-York
Hudapack Metal Treating —Elkhorn
Huron
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ipsen International Inc. —Atmosphere Products
Ipsen International Inc. —Vacuum Products
Ironbound Heat Treating
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
Lake County Steel Treating
Lawrence Industries, Inc.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Dallas
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Lansing
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —Solon
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Sturtevant
Lindberg Heat Treating Co. —Tulsa
Lindberg Heat Treating Co. —Waterbury
Lindberg Heat Treating Co. —Worcester
Magnum Metal Treating
Merit Gear Heat Treating
Metal Improvement Co. Inc. —Wichita
Metal Improvement Co., Inc. —Columbus
Metal Improvement Co., Inc. —Emigsville
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Midland Metal Treating, Inc.
Midwestern Machinery Co.
Modern Industries, Inc.
Modern Steel Treating
Mountain Metallurgical
National Broach & Machine
National Metal Processing.
Oakland Metal Treating Co.
Ohio Metallurgical Service
Oregon Induction Corp.
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
Phoenix Heat Treating Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Shore Metal Technology
Southeastern Heat Treating
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Heat Treating Inc. —Athens
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. —Palm Beach Gardens
Suncoast Heat Treating —Pompano Beach
Suncoast Heat Treating —Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Metal Treating
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Tractech Inc.
Treat All Metals
Trutec Industries
Universal Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.

CARBURIZING

A.F.C.-Pifco
Abbott Furnace Company
ABS Metallurgical Processors
Accurate Steel Treating
Advanced Heat Treat Corp. —Waterloo/Burton
Advanced Heat Treating
Advanced Thermal Technologies, Inc.
Albany Metal Treating
Alco Heat Treating Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Heat Treating
American Metal Processing
American Metal Treating Inc.
AP Westshore
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Bomak Corp.
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.
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
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
East Carolina Metal Treating Inc.
East-Lind Heat Treat
Eckel Heat Treat
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
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
Gear Company of America
General Heat Treating Corp.
General Metal Heat Treating Inc.
Geo. H. Porter Steel Treating Co.
Gibson Heat Treat Inc.
Grand Rapids Commercial Heat Treating Co., Inc.
H & S Heat Treating
Hanson-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
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.
Hi-TecMetal Group *Corporate HQ*
Horizon Steel Treating, Inc.
Horsburgh & Scott Co.
HTG IMT-Duncan
HTG IMT-York
Hudapack Metal Treating —Elkhorn
Huron
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ipsen International Inc. —Atmosphere Products
Ipsen International Inc. —Vacuum Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries, Inc.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Dallas
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Lansing
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —Solon
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Sturtevant
Lindberg Heat Treating Co. —Tulsa
Lindberg Heat Treating Co. —Waterbury
Lindberg Heat Treating Co. —Worcester
M & M Heat Treat
Magnum Metal Treating Inc.
Master Heat Treating Inc.
Merit Gear Heat Treating
Metal Improvement Co. Inc. —Wichita
Metal Improvement Co., Inc. —Columbus
Metal Improvement Co., Inc. —Emigsville
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Midland Metal Treating, Inc.
Midwestern Machinery Co.
Modern Industries Inc.
Modern Steel Treating
Mountain Metallurgical
National Broach & Machine
National Metal Processing,
Nettleton Steel Treating
Oakland Metal Treating Co.
Ohio Metallurgical Service
Oregon Induction Corp.
P & L Heat Treating & Grinding
Partek Laboratories Inc.
Paulo Products Co. — Memphis
Paulo Products Co. —Bessemer
Paulo Products Co. —Kansas City
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
Shore Metal Technology
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Heat Treating Inc. —Athens
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. —Palm Beach Gardens
Suncoast Heat Treating —Pompano Beach
Suncoast Heat Treating —Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermal Metal Treating
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Therm-Tech of Waukesha
Tractech Inc.
Treat All Metals
Trutec Industries
Universal Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Westside Flame Hardening

CRYOGENICS

Accurate Steel Treating
Advanced Heat Treat Corp. —Waterloo/Burton
Advanced Thermal Technologies, Inc.
Alco Heat Treating Corp.
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Brazing
American Cryogenics, Inc.
American Heat Treating
American Metal Treating Inc.
Applied Cryogenics Inc.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
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, Inc.
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Cryo-Treatment Specialists, LLC
Delavan Steel Treating
Detroit Flame Hardening
Detroit Steel Treating Co.
Dixie Heat Treating
Drever Heat Treating
East Carolina Metal Treating Inc.
East-Lind Heat Treat
Economy Flame Hardening, Inc.
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fenton Heat Treating
Flame Metals Processing
Fox Steel Treating Co.
FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
General Heat Treating
General Metal Heat Treating Inc.
Geo. H. Porter Steel Treating Co.
Hanson-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
Hinderliter Heat Treating Inc. —Anaheim
Hinderliter Heat Treating Inc. —Dallas
Hinderliter Heat Treating Inc. —Tarzana
Hinderliter Heat Treating Inc. —Tulsa
Hi-Tech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG Aerobraze
Hudapack Metal Treating —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. —Dallas
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. *—Houston*
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —Solon
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Tulsa
Lindberg Heat Treating Co. —Wichita
Lindberg Heat Treating Co. —Worcester
Magnum Metal Treating
Master Heat Treating Inc.
Metal Improvement Co. Inc. —Wichita
Metal Improvement Co., Inc. —Columbus
Metal Improvement Co., Inc. —Emigsville
Metal Treaters Inc.
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Modern Industries, Inc.
Modern Steel Treating
Mountain Metallurgical
Nitrex Metal Technologies —Burlington
Nitrotec Surface *Engineering—Ohio*
Nitro-Vac Heat Treating
Ohio Metallurgical Service
One Cryo Inc.
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
Pennsylvania Metallurgical
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Heat Treating Inc. —Athens
Specialty Steel Treating Inc. —Farmington Hills
Specialty Steel Treating Inc. —Fraser
Steel Treaters, Inc.
Steel Treating
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Suncoast Heat Treating —Pompano Beach
Suncoast Heat Treating —Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermal Braze Inc.
Thermal Metal Treating
Thermet Inc.
Thermo Electron Metal Treating Div.
Therm-Tech of Waukesha
Tractech Inc.
Treat All Metals
Trutec Industries
Universal Heat Treating
Washington Metallurgical Services
Westside Flame Hardening

DIE QUENCHING

A.F.C.-Pifco
Alfred Heller Heat Treating
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Burbank Steel Treating Inc.
Caterpillar Industrial Products Inc.
Century Sun Metal Treating
Cincinnati Gear Co.
Cincinnati Steel Treating
Detroit Steel Treating Co.
Edwards Heat Treating Service
Engineered Heat Treat, Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Fenton Heat Treating
Fox Steel Treating Co.
Franklin Steel Treating
Gibson Heat Treat Inc.
Gleason Works
Grand Rapids Commercial Heat Treating Co., Inc.
Heat Treat Corp. of America
Hi-TecMetal Group Corporate HQ
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Industrial Steel Treating
Ironbound Heat Treating
John V. Potero Co.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rosemont
Metallurgical Inc.
Metlab
Oakland Metal Treating
Ohio Metallurgical Service
Paulo Products Co. —Bessemer
Paulo Products Co. —Kansas City
Paulo Products Co. —Memphis
Paulo Products Co. —Nashville
Phoenix Heat Treating Inc.
Roboduction Thermal Processing
Rotation Products Corp.
Specialty Steel Treating Inc. —Farmington Hills
Specialty Steel Treating Inc. —Fraser
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Therm Tech of Waukesha
Treat All Metals
Walker Heat Treating
Washington Metallurgical Services
Westside Flame Hardening

FLAME HARDENING

Alco Heat Treating Corp.
American Heat Treating
Beehive Heat Treating Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Bowdil Co.
California Surface Hardening, Inc.
Calumet Surface Hardening
Certified Heat Treating Inc.
Chicago Flame Hardening
Chicago Induction Metal Treating Corp.
Cincinnati Flame Hardening Co.
Cincinnati Gear Co.
Cincinnati Steel Treating
Clearing Niagara
Cleveland Flame Hardening

Coleman Commercial Heat Treating
Detroit Flame Hardening
Detroit Steel Treating Co.
Drever Heat Treating
East-Lind Heat Treat
Economy Flame Hardening, Inc.
Edwards Heat Treating Serv.
Erie Steel Treating Inc.
Flame Hardening Co. of California
Fox Steel Treating Co.
Franklin Steel Treating
Gibson Heat Treat Inc.
Good Earth Tools
Grand Rapids Commercial Heat Treating Co., Inc.
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat-Treating Inc.
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Houston Flame Hardening
HTG IMT-York
Illiana Heat Treating Inc.
Induction Metal Treating Co.
Industrial Metal Treating
Jasco Heat Treating Inc.
John V. Potero Co.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.—Dallas
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—St. Louis
M & M Heat Treat
Metal Improvement Co. Inc.—Wichita
Metal Improvement Co., Inc.—Columbus
Metal Treating Inc.
Metallurgical Inc.
Metlab
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Michigan Flame Hardening
Mid-West Flame Hardening
Midwestern Machinery Co.
Modern Industries, Inc.
National Induction Heating
Ohio Metallurgical Service
Oregon Induction Corp.
Penna Flame Industries Inc.
Pennsylvania Metallurgical
Revas Engineering Co.
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Heat Treating Inc.—Athens
Steel Treaters, Inc.
Suncoast Heat Treat, Inc.—Orlando
Suncoast Heat Treat, Inc.—Palm Beach Gardens
Suncoast Heat Treating—Pompano Beach
Suncoast Heat Treating—Tampa
Superior Metal Treating
Syracuse Heat Treating
The Bowdil Co.
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Therm-Tech of Waukesha
Westside Flame Hardening
Wohlert Corp.

FREE QUENCHING

A.F.C.-Pifco
ABS Metallurgical Processors
Accurate Steel Treating
Alfred Heller Heat Treating
Alliance Metal Treating
AP Westshore
Atmosphere Furnace Co.
Benedict-Miller Inc.
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Braddock Metallurgical
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Certified Heat Treating Inc.
Cincinnati Gear Co.
Cincinnati Steel Treating Co.
City Steel Treating Inc.
Commercial Steel Treating
Detroit Steel Treating Co.
Diamond Heat Treating Co.
East Carolina Metal Treating Inc.
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Fenton Heat Treating
FPM Heat Treating—Elk Grove
FPM Milwaukee
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
Hi-Tech Metallurgical Co.—Huron
Illiana Heat Treating Inc.
Induction Metal Treating Co.
Industrial Metal Treating
Industrial Steel Treating Inc.
Ipsen International Inc.—Atmosphere Products
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries, Inc.
Lindberg Heat Treating Co.—Berlin
Lindberg Heat Treating Co.—Dallas
Lindberg Heat Treating Co.—Eden Prairie
Lindberg Heat Treating Co.—Houston
Lindberg Heat Treating Co.—Lansing
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rancho Dominguez
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—Solon
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Tulsa
Lindberg Heat Treating Co.—Worcester
Merit Gear Heat Treating
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metlab
Met-Tek Inc.—Racine
Mid-West Flame Hardening
National Broach & Machine
National Induction Heating
Nettleton Steel Treating
Ohio Metallurgical Service
P & L Heat Treating & Grinding
Paulo Products Co.—St. Louis
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.
Suncoast Heat Treating—Pompano Beach
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermo Electron Metal Treating Div.
Treat All Metals
Wohlert Corp.

HOT OIL QUENCHING

A.F.C.-Pifco
Abbott Furnace Company
ABS Metallurgical Processors
Advanced Heat Treat Corp.—Waterloo/Burton
Advanced Metallurgical Technology, Inc.
Advanced Thermal Technologies, Inc.
Alco Heat Treating Corp.
Alpha Heat Treaters
American Heat Treating
Atmosphere Annealing Inc.
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Bomak Corp.
Burbank Steel Treating Inc.
Carolina Commercial Heat Treating
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Cincinnati Gear Co.
Cincinnati Steel Treating Co.
City Steel Treating Inc.
Clearing Niagara
Cleveland Flame Hardening
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.
Euclid Heat Treating
Fairfield Mfg. Co.
Federal Machine 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
General Heat Treating Corp.
General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horoburgh & Scott
Hudapack Metal Treating—Elkhorn
Huron
Illiana Heat Treating Inc.
Induction Metal Treating Co.
Industrial Metal Treating
Industrial Steel Treating Inc.
Ipsen International Inc.—Atmosphere Products
Ipsen International Inc.—Vacuum Products
Irwin Automation Inc.
Jasco Heat Treating Inc.
John V. Potero Co.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.—Lansing
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Rosemont
Magnum Metal Treating
Merit Gear Heat Treating
Metal Improvement Co., Inc.—Columbus
Metal Treating & Research
Metallurgical Inc.
Metallurgical Processing Inc.
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Mid-West Flame Hardening
Midwestern Machinery Co.
Modern Industries, Inc.
Modern Steel Treating
National Broach & Machine
Oakland Metal Treating Co.
Ohio Metallurgical Service
Oregon Induction Corp.
Paulo Products Co.—Bessemer
Paulo Products Co.—Nashville
Paulo Products Co.—St. Louis
Pennsylvania Metallurgical
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
Suncoast Heat Treat, Inc.—Orlando

Suncoast Heat Treat, Inc.—Palm Beach Gardens
Suncoast Heat Treating—Pompano Beach
Therm Tech of Waukesha
Thermo Treaters Ltd.
Tractech Inc.
Treat All Metals
Washington Metallurgical Services
Weiss Industries, Inc.

INDUCTION HARDENING

Advanced Heat Treat Corp.—Waterloo/Burton
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 & Brazing Co.
Bodycote Induction Processing
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Braddock Metallurgical
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Heat Treating Inc.
Chicago Induction Metal Treating Corp.
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 Service
Elmira Heat Treating, Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Federal Machine Co.
Flame Metals Processing
Fluxtrol Manufacturing Inc.
Franklin Steel Treating
Gear Company of America
General Heat Treating Corp.
Gibson Heat Treat Inc.
Good Earth Tools, Inc.
H & S Heat Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG IMT-York
HTG Metal Methods
Hudapack Metal Treating—Elkhorn
IHS—An Inductotherm Industries Co., Inc.
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Heat Treating
Induction Metal Treating Co.
Induction Services Inc.
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.—Melrose Park
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Tulsa
Mannings U.S.A.
Master Heat Treating Inc.
Merit Gear Heat Treating
Metal Improvement Co., Inc.—Columbus
Metal Improvement Co., Inc.—Emigsville
Metal Processing Co.
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Michigan Induction Inc.
Midland Metal Treating, Inc.
Modern Industries, Inc.
Molon Gear & Shaft
National Induction Heating
National Metal Processing
O & W Heat Treat Inc.
Ohio Metallurgical Service
Oregon Induction Corp.
Paulo Products Co.—Kansas City
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
Rochester Steel Treating Works, Inc.
S.K.S. Heat Treating Inc.
Southeastern Heat Treating
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Suncoast Heat Treat, Inc.—Palm Beach Gardens
Suncoast Heat Treating—Pompano Beach
Suncoast Heat Treating—Tampa
Superior Metal Treating
Syracuse Heat Treating
Thermal Braze Inc.
Thermal Metal Treating
Thermet Inc.
Thermo Electron Metal Treating Div.
Tocco, Inc.
Washington Metallurgical Services
Welduction Corp.
Westside Flame Hardening
Wohlert Corp.
Zion Industries, Inc.

ION IMPLANTATION

Ionex, Inc.

ION NITRIDING

Accurate Ion Technologies
Advanced Heat Treat Corp.—Monroe
Advanced Heat Treat Corp.—Waterloo/Midport
Advanced Metallurgical Technology, Inc.
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 Corporate HQ
Hydro-Vac
Ionex, Inc.
Ipsen International Inc.—Vacuum Products
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—Sturtevant
Magnum Metal Treating
Modern Industries, Inc.
MPT America
National Broach & Machine
Progressive Engineering
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Sun Steel Treating Inc.

LASER HARDENING

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

METALLURGICAL TESTING

Accurate Ion Technologies
Advanced Heat Treat Corp.—Monroe
Advanced Heat Treat Corp.—Waterloo/Burton
Advanced Heat Treat Corp.—Waterloo/Midport
Advanced Heat Treating
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Metal Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Burbank Steel Treating
Century Sun Metal Treating
Certified Metal Craft, Inc.
Cincinnati Steel Treating
Delavan Steel Treating
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
Flame Metals Processing
General Heat Treating
General Metal Heat Treating Inc.
Gleason Pfauter Hurth Cutting Tools
Hauni Richmond Inc.
Hi-Tech Metallurgical Co.
Hi-TecMetal Group Corporate HQ
Horsburgh & Scott Co.
HTG Aerobraze
HTG IMT-York
Hudapack Metal Treating—Elkhorn
Huron
Impact Strategies, Inc.
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ipsen International Inc.—Vacuum Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating
Laser Machining, Inc.
Lindberg Heat Treating Co.—Rochester
Merit Gear Heat Treating
Metal Improvement Co., Inc.—Wichita
Metal Improvement Co., Inc.—Columbus
Metal Improvement Co., Inc.—Emigsville
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metlab
Met-Tek Inc.—Clackamas
Michigan Induction Inc.
Midland Metal Treating
Modern Steel Treating
O & W Heat Treat Inc.
Oregon Induction Corp.
Paulo Products Co.—Nashville
Paulo Products Co.*—St. Louis*
Pennsylvania Metallurgical
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Richter Presiaion Inc.
Rotation Products Corp.
Sonee Heat Treting Corp.
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
Sun Steel Treating Inc.
Syracuse Heat Treating
Thermal Metal Treating Inc.
Thermal Treatment Center
Therm-Tech of Waukesha
Tractech Inc.
Treat All Metals
Universal Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Welduction Corp.
Westside Flame Hardening

NITRIDING

A.F.C.-Pifco
Abbott Furnace Company
Accurate Steel Treating
Albany Metal Treating
Alco Heat Treating Corp.
Alfred Heller Heat Treating
American Metal Treating Inc.
Atmosphere Furnace Co.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Braddock Metallurgical
Burbank Steel Treating Inc.
Cal-Doran Division
Caterpillar Industrial Products Inc.
Century Sun Metal Treating
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Commercial Steel Treating
Custom Heat Treating Co.
Drever Heat Treating
Dynamic Metal Treating
East Carolina Metal Treating Inc.
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Fenton Heat Treating
Fox Steel Treating Co.
FPM Heat Treating—Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
Gleason Pfauter Hurth Cutting Tools
Grand Rapids Commercial Heat Treating Co., Inc.
H & M Metal Processing
Hansen-Balk Steel Treating
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.
Hi-TecMetal Group Corporate HQ
HTG IMT-York
Hudapack Metal Treating—Elkhorn
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating
Ionex, Inc.
Ipsen International Inc.—Atmosphere Products
Ipsen International Inc.—Vacuum Products
Ironbound Heat Treating
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lindberg Heat Treating Co.—Houston
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rancho Dominguez
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—Solon
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Tulsa
Lindberg Heat Treating Co.—Worcester
Merit Gear Heat Treating
Metallurgical Inc.
Metals Technology Corp.
Metal-Tec Heat Treating
Metlab
Metro Steel Treating
Modern Industries, Inc.
Nitrex Metal Technologies—Burlington
Nitrex Metal Technologies—Mason
Nitrex Metal Technologies—St. Laurent
Nitron Inc.
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Oregon Induction Corp.
P & L Heat Treating & Grinding
Paulo Products Co.—St. Louis
Peters' Heat Treating Inc.
Precision Heat Treating
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
Scot Forge
Shore Metal Technology
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
Steel Treaters, Inc.
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc.—Orlando
Suncoast Heat Treat, Inc.—Palm Beach Gardens
Suncoast Heat Treating—Pompano Beach
Suncoast Heat Treating—Tampa
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm-Tech of Waukesha
Treat All Metals
Trutec Industries
Universal Heat Treating
Walker Heat Treating
Wear-Ever Surface Treating Corp.

NITROCARBURIZING

A.F.C.-Pifco
Abbott Furnace Company
Accurate Steel Treating
Advanced Heat Treat Corp.—Waterloo/Burton
Alco Heat Treating Corp.
Alfred Heller Heat Treating
Alliance Metal Treating
American Metal Treating Inc.
Atmosphere Furnace Co.
Benedict-Miller Inc.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Carolina Commercial Heat Treating
Century Sun Metal Treating
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Commercial Steel Treating
Dixie Heat Treating
Dynamic Metal Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Flame Metals Processing
Fox Steel Treating Co.
FPM Heat Treating—Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Gear Company of America
Hauni Richmond Inc.
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Tarzana
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG Copper Brazing Industries
HTG IMT-York
Hudapack Metal Treating—Elkhorn
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating Co.
Industrial Steel Treating
Ipsen International Inc.—Atmosphere Products
Ipsen International Inc.—Vacuum Products
Ironbound Heat Treating
Lindberg Heat Treating Co.—Dallas
Lindberg Heat Treating Co.—Eden Prairie
Lindberg Heat Treating Co.—Houston
Lindberg Heat Treating Co.—Lansing
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rancho Dominguez
Lindberg Heat Treating Co.—Rochester
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—Solon
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Tulsa
Lindberg Heat Treating Co.—Worcester
Metals Technology Corp.
Metal-Tec Heat Treating
Metlab
Metro Steel Treating
Modern Industries, Inc.
Nitrex Metal Technologies—Burlington
Nitrex Metal Technologies I—St. Laurent
Nitrotec Surface Engineering—Michigan
Nitrotec Surface Engineering—Ohio
Paulo Products Co.—Bessemer
Paulo Products Co.—Kansas City
Paulo Products Co.—Memphis
Paulo Products Co.—Nashville
Paulo Products Co.—St. Louis
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
Shore Metal Technology
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Heat Treating Inc.—Athens
Suncoast Heat Treating—Pompano Beach
Syracuse Heat Treating
Therm Tech of Waukesha
Treat All Metals
Trutec Industries

NORMALIZING

A.F.C.-Pifco
Abbott Furnace Company
ABS Metallurgical Processors
Accurate Steel Treating
Advanced Heat Treat Corp.—Waterloo/Burton
Advanced Metallurgical Technology, Inc.
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
Albany Metal Treating
Alco Heat Treating Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Heat Treating
American Metal Treating Inc.
Atmosphere Annealing Inc.
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Bomak Corp.
Braddock Metallurgical
Braddock Metallurgical—Alabama
Brazing & Metal Treating—Cleveland
Brazing & Metal Treating—Kentucky
Brazing & Metal Treating—Minnesota
Brite Brazing
Bowdil Co.
Burbank Steel Treating
Cal-Doran Division
Carolina Commercial Heat Treating
Caterpillar Industrial Products
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Cincinnati Flame Hardening Co.
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
Delphi Engineering
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 Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Federal Machine 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
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., Inc.
H & S Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat Treating Services
Heat-Treating Inc.
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Dallas
Hinderliter Heat Treating Inc.—Tarzana
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Aero
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
Horsburgh & Scott Co.
HTG Aerobraze
HTG IMT-Duncan
HTG IMT-York
HTG Metal Methods
Hudapack Metal Treating—Elkhorn
Hudapack Metal Treating—Glendale Heights
Huron
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating Inc.
Ipsen International Inc.—Atmosphere Products
Ipsen International Inc.—Vacuum Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
John V. Potero Co.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries, Inc.
Lindberg Heat Treating Co.—Berlin
Lindberg Heat Treating Co.—Dallas
Lindberg Heat Treating Co.—Eden Prairie
Lindberg Heat Treating Co.—Houston
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rancho Dominguez
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—Solon
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Tulsa
Lindberg Heat Treating Co.—Worcester
M & M Heat Treat
Magnum Metal Treating
Master Heat Treating Inc.
Merit Gear Heat Treating
Metal Improvement Co., Inc.—Wichita
Metal Improvement Co., Inc.—Columbus
Metal Improvement Co., Inc.—Emigsville
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology Corp.
Metlab
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Midland Metal Treating.
Modern Industries, Inc.
Modern Steel Treating
Mountain Metallurgical
National Broach & Machine
National Metal Processing.
Nettleton Steel Treating
Nitro-Vac Heat Treating
Oakland Metal Treating
Ohio Metallurgical Service
Oregon Induction Corp.
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
Pennsylvania Metallurgical
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating Works, Inc.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shore Metal Technology
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Heat Treating Inc.—Athens
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc.—Orlando
Suncoast Heat Treat, Inc.—Palm Beach Gardens
Suncoast Heat Treating—Pompano Beach
Suncoast Heat Treating—Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermal Metal Treating Inc.
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Therm-Tech of Waukesha
Tractech Inc.
Treat All Metals
Trojan Heat Treat Inc.
Universal Heat Treating
Vacu Braze
Walker Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Westside Flame Hardening
Wohlert Corp.

PLASMA CARBURIZING

Cincinnati Gear Co.
Gleason Pfauter Hurth Cutting Tools
Ionex, Inc.
Ipsen International Inc.—Vacuum Products

PRESS QUENCHING

A.F.C.-Pifco
Alfred Heller Heat Treating
Atmosphere Furnace Co.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Caterpillar Industrial Products Inc.
Cincinnati Gear Co.
Cincinnati Steel Treating
Engineered Heat Treat, Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Franklin Steel Treating
Gibson Heat Treat Inc.
Gleason Works.
Heat Treat Corp. of America
Hi-Tech Metallurgical Co.
Impact Strategies, Inc.
Industrial Steel Treating
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rosemont
Metallurgical Inc.
Metlab
Mountain Metallurgical
Ohio Metallurgical Service
Paulo Products Co.—St. Louis
Phoenix Heat Treating Inc.
Roboduction Thermal Processing
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
Tractech Inc.
Treat All Metals
Washington Metallurgical Services

SALT BATH NITRIDING

Bodycote Thermal Processing—Canton
Bomak Corp.
Cal-Doran Division
Century Sun Metal Treating
Cincinnati Gear Co.
Commercial Steel Treating
East-Lind Heat Treat
Engineered Heat Treat, Inc.
Flame Metals Processing
Fox Steel Treating Co.
Franklin Steel Treating
H & M Metal Processing
HI TecMetal Group—Cleveland
Illiana Heat Treating Inc.
Induction Metal Treating
Lake County Steel Treating
Metal Treaters Inc.
Met-Tek Inc.—Clackamas
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Trutec Industries
Wear-Ever Surface Treating Corp.
Weiss Industries Inc.
Westside Flame Hardening

SHOT PEENING

Alpha Heat Treaters
Bodycote Thermal Processing—Canton
Coleman Commercial Heat Treating
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Flame Metals Processing
Gibson Heat Treat Inc.
Horizon Steel Treating
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.—Melrose Park
Metal Improvement Co., Inc.—Addison
Metal Improvement Co., Inc.—Blue Ash
Metal Improvement Co., Inc.—Brampton
Metal Improvement Co., Inc.—Carlstadt
Metal Improvement Co., Inc.—Charlotte
Metal Improvement Co., Inc.—Columbus
Metal Improvement Co., Inc.—Grand Prairie
Metal Improvement Co., Inc.—Houston

Metal Improvement Co., Inc. —Lynwood
Metal Improvement Co., Inc. —Maple Grove
Metal Improvement Co., Inc. —Miami
Metal Improvement Co., Inc. —Milwaukee
Metal Improvement Co., Inc. —Phoenix
Metal Improvement Co., Inc. —Romulus
Metal Improvement Co., Inc. —Santa Ana
Metal Improvement Co., Inc. —Twinsburg
Metal Improvement Co., Inc. —Vernon
Metal Improvement Co., Inc. —Wakefield
Metal Improvement Co., Inc. —Wellington
Metal Improvement Co., Inc. —West Babylon
Metal Improvement Co., Inc. —Windsor
Paulo Products Co. —Memphis
Superior Metal Treating
Syracuse Heat Treating
Tractech Inc.
Westside Flame Hardening

SINTERING

A.F.C.-Pifco
Abbott Furnace Company
Allread Products
Atmosphere Furnace Co.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Certified Metal Craft, Inc.
Cincinnati Gear Co.
Fluxtrol Manufacturing Inc.
Hinderliter Heat Treating Inc. —Tarzana
Hi-TecMetal Group Corporate HQ
HTG Aerobraze
Hydro-Vac
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Induction Metal Treating
Ionex, Inc.
Ipsen International Inc. —Atmosphere Products
Ipsen International Inc. —Vacuum Products
Metals Technology Corp.
Paulo Products Co. —St. Louis
Pennsylvania Metallurgical
Progressive Steel Treating
Specialty Heat Treating Inc. —Athens
Suncoast Heat Treating —Pompano Beach

STEAM TREATING

A.F.C.-Pifco
Abbott Furnace Company
Accurate Ion Technologies
Advanced Heat Treating
Atmosphere Furnace Co.
Gleason Pfauter Hurth Cutting Tools
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Industrial Metal Treating
Ipsen International Inc. —Atmosphere Products
Modern Industries, Inc.
Nettleton Steel Treating
Solar Atmospheres Inc.
Sun Steel Treating Inc.
Syracuse Heat Treating

STRAIGHTENING

ABS Metallurgical Processors
Accurate Steel Treating
Alfe Heat Treating
Alfred Heller Heat Treating
American Metal Treating Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Calumet Surface Hardening
Century Sun Metal Treating
Certified Metal Craft, Inc.
Chicago Flame Hardening
Cincinnati Flame Hardening Co.
Cincinnati Steel Treating
Clearing Niagara
Commercial Induction
Detroit Flame Hardening
Detroit Steel Treating Co.
Dynamic Metal Treating
Economy Flame Hardening, Inc.
Edwards Heat Treating Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Flame Metals Processing
Franklin Steel Treating
Gibson Heat Treat Inc.
Gleason Pfauter Hurth Cutting Tools
Grand Rapids Commercial Heat Treating Co., Inc.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
Horsburgh & Scott Co.
Houston Flame Hardening
Hudapack Metal Treating —Elkhorn
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co. —Dallas
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —Solon
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Sturtevant
Lindberg Heat Treating Co. —Tulsa
Lindberg Heat Treating Co. —Wichita
Lindberg Heat Treating Co. —Worcester
M & M Heat Treat
Merit Gear Heat Treating
Metal Improvement Co. —Wichita
Metal Improvement Co. —Columbus
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metlab
Met-Tek Inc.—Clackamas
Midwest Flame Hardening
Modern Steel Treating
National Broach & Machine
Oakland Metal Treating Co.
Oregon Induction Corp.
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Phoenix Heat Treating Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Steel Treating Inc. —Farmington Hills
Specialty Steel Treating Inc. —Fraser
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Superior Metal Treating
Syracuse Heat Treating
Thermet Inc.
Therm-Tech of Waukesha
Tractech Inc.
Treat All Metals
Washington Metallurgical Services
Westside Flame Hardening

STRESS RELIEVING

Abbott Furnace Company
ABS Metallurgical Processors
Accurate Steel Treating
Advanced Heat Treat Corp. —Monroe
Advanced Heat Treat Corp. —Waterloo/Burton
Advanced Metallurgical Technology, Inc.
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
Albany Metal Treating
Alco Heat Treating Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
American Brazing
American Heat Treating
American Metal Treating Inc.
AMT—Monroe, Inc.
Atmosphere Annealing Inc.
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Bomak Corp.
Bonal Technologies, Inc.
Bowdil Co.
Braddock Metallurgical
Braddock Metallurgical —Alabama
Brazing & Metal Treating —Cleveland
Brazing & Metal Treating—Kentucky
Brazing & Metal Treating—Minnesota
Brite Brazing
Brite Metal Treating Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Chicago Flame Hardening
Cincinnati Flame Hardening Co.
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Clearing Niagara
Cleveland Flame Hardening
Coleman Commercial Heat Treating
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 Co.
Disston Precision Inc.
Dixie Heat Treating Co., Inc.
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 Service
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fairfield Mfg. Co.
Feinblanking Ltd.
Fenton Heat Treating
Flame Metals Processing
Fluxtrol Manufacturing Inc.
Fox Steel Treating Co.
FPM Heat Treating —Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating
General Heat Treating Corp.
General Metal Heat Treating Inc.
Geo. H. Porter Steel Treating Co.
Gibson Heat Treat Inc.
Gleason Pfauter Hurth Cutting Tools
Global Heat Inc.
Grand Rapids Commercial Heat Treating Co., Inc.
H & M Metal Processing
H & S Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat Treating Services
Heat-Treating Inc.
Hinderliter Heat Treating Inc. —Anaheim
Hinderliter Heat Treating Inc. —Dallas
Hinderliter Heat Treating Inc. —Tarzana
Hinderliter Heat Treating Inc. —Tulsa
Hi-Tech Aero
Hi-Tech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
Horsburgh & Scott Co.
Houston Flame Hardening
HTG Aerobraze
HTG Copper Brazing Industries
HTG IMT-Duncan
HTG IMT-York
HTG Metal Methods
Hudapack Metal Treating —Elkhorn
Hudapack Metal Treating —Glendale Heights
Huron
Hydro-Vac
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating
Induction Services Inc.
Inductoheat, Inc.
Industrial Metal Treating
Industrial Steel Treating Inc.
Ionex, Inc.
Ipsen International Inc. —Atmosphere Products
Ipsen International Inc. —Vacuum Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
John V. Potero Co.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries, Inc.
Lindberg Heat Treating Co. —Berlin
Lindberg Heat Treating Co. —Dallas
Lindberg Heat Treating Co. —Eden Prairie
Lindberg Heat Treating Co. —Houston
Lindberg Heat Treating Co. —Lansing
Lindberg Heat Treating Co. —Melrose Park
Lindberg Heat Treating Co. —Mexico
Lindberg Heat Treating Co. —Racine
Lindberg Heat Treating Co. —Rancho Dominguez
Lindberg Heat Treating Co. —Rochester
Lindberg Heat Treating Co. —Rosemont
Lindberg Heat Treating Co. —Solon
Lindberg Heat Treating Co. —St. Louis
Lindberg Heat Treating Co. —Sturtevant
Lindberg Heat Treating Co. —Tulsa
Lindberg Heat Treating Co. —Worcester
M & M Heat Treat
Magnum Metal Treating
Mannings U.S.A.
Master Heat Treating Inc.
Merit Gear Heat Treating
Metal Improvement Co., Inc. —Wichita
Metal Improvement Co., Inc. —Columbus
Metal Improvement Co., Inc. —Emigsville
Metal Treaters Inc.
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metals Engineering Inc.
Metals Technology Corp.
Metal-Tec Heat Treating Inc.
Metlab
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
Modern Steel Treating
Mountain Metallurgical
National Broach & Machine
National Induction Heating
National Metal Processing.
Nettleton Steel Treating
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
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Ohio Metallurgical Service
Oregon Induction Corp.
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Paulo Products Co. —Kansas City
Paulo Products Co. —Memphis
Paulo Products Co. —Nashville
Paulo Products Co. —St. Louis
Penna Flame Industries
Pennsylvania Metallurgical
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Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
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Rochester Steel Treating Works, Inc.
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S.K.S. Heat Treating Inc.
Scot Forge
Shanafelt Mfg. Co.
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating —Elkhart
Speciality Heat Treating —Grand Rapids
Speciality Heat Treating —Holland
Specialty Steel Treating Inc. —Athens
Specialty Steel Treating Inc. —Farmington Hills
Specialty Steel Treating Inc. —Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc. —Orlando
Suncoast Heat Treat, Inc. —Palm Beach Gardens
Suncoast Heat Treating —Pompano Beach
Suncoast Heat Treating —Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermal Metal Treating
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Therm-Tech of Waukesha
Tocco, Inc.
Tractech Inc.
Treat All Metals
Trojan Heat Treat Inc.
Trutec Industries
Universal Heat Treating
Vacu Braze
Washington Metallurgical

Services
Weiss Industries Inc.
Western Stress Inc.
Westside Flame Hardening

TEMPERING

A.F.C.-Pifco
Abbott Furnace Company
ABS Metallurgical Processors
Accurate Steel Treating
Advanced Heat Treat Corp.—Waterloo/Burton
Advanced Heat Treating
Advanced Metallurgical Technology, Inc.
Advanced Thermal Technologies, Inc.
Ajax Magnethermic Corp.
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Alco Heat Treating Corp.
Alfe Heat Treating
Alfred Heller Heat Treating
Alliance Metal Treating
Alpha Heat Treaters
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American Cryogenics, Inc.
American Heat Treating
American Metal Processing
American Metal Treating Inc.
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Atmosphere Annealing Inc.
Atmosphere Furnace Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
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Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
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Bowdil Co.
Braddock Metallurgical
Braddock Metallurgical—Alabama
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Brite Metal Treating Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft, Inc.
Cincinnati Flame Hardening Co.
Cincinnati Gear
Cincinnati Steel Treating Co.
City Steel Treating Inc.
Clearing Niagara
Cleveland Flame Hardening
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Commercial Induction
Commercial Steel Treating
Custom Heat Treating Co.
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Detroit Flame Hardening
Detroit Steel Treating Co.
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Dixie Heat Treating Co.
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
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East Carolina Metal Treating Inc.
East-Lind Heat Treat
Eckel Heat Treat
Economy Flame Hardening, Inc.
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Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
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Feinblanking Ltd.
Fenton Heat Treating
Flame Metals Processing
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FPM Heat Treating—Elk Grove
FPM Milwaukee
Franklin Steel Treating
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., Inc.
H & M Metal Processing
H & S Heat Treating
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat Treating Services
Heat-Treating Inc.
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Dallas
Hinderliter Heat Treating Inc.—Tarzana
Hinderliter Heat Treating Inc.—Tulsa
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Hi-Tech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horsburgh & Scott Co.
Horizon Steel Treating, Inc.
Houston Flame Hardening
HTG Aerobraze
HTG IMT-Duncan
HTG IMT-York
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Hudapack Metal Treating—Glendale Heights
Huron
Hydro-Vac
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Impact Strategies, Inc.
Induction Metal Treating
Induction Services Inc.
Inductoheat, Inc.
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
International Induction Inc.
Ipsen International Inc.—Atmosphere Products
Ipsen International Inc.—Vacuum Products
Ironbond Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
John V. Potero Co.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries, Inc.
Lindberg Heat Treating Co.—Berlin
Lindberg Heat Treating Co.—Dallas
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Lindberg Heat Treating Co.—Houston
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Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Mexico
Lindberg Heat Treating Co.—Racine
Lindberg Heat Treating Co.—Rancho Dominguez
Lindberg Heat Treating Co.—Rochester
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—Solon
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Sturtevant
Lindberg Heat Treating Co.—Tulsa
Lindberg Heat Treating Co.—Waterbury
Lindberg Heat Treating Co.—Worcester
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Master Heat Treating Inc.
Merit Gear Heat Treating
Metal Improvement Co., Inc.—Wichita
Metal Improvement Co., Inc.—Columbus
Metal Improvement Co., Inc.—Emigsville
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Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology Corp.
Metlab
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 Co.
Modern Industries Inc.
Modern Metal Processing
Modern Steel Treating
Molon Gear & Shaft
Mountain Metallurgical
National Broach & Machine
National Induction Heating
National Metal Processing
Nettleton Steel Treating
Nitrex Metal Technologies—Mason
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Oakland Metal Treating
Ohio Metallurgical Service
Oregon Induction Corp.
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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Pennsylvania Metallurgical
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 Works, Inc.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Heat Treating Inc.—Athens
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
State Heat Treat Inc.
Steel Treaters, Inc.
Steel Treating
Sun Steel Treating Inc.
Suncoast Heat Treat, Inc.—Orlando
Suncoast Heat Treat, Inc.—Palm Beach Gardens
Suncoast Heat Treating—Pompano Beach
Suncoast Heat Treating—Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermal Metal Treating
Thermet Inc.
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Therm-Tech of Waukesha
Tocco, Inc.
Tractech Inc.
Treat All Metals
Trutec Industries
Universal Heat Treating
Vacu Braze
Walker Heat Treating
Washington Metallurgical Services
Weiss Industries Inc.
Welduction Corp.
Westside Flame Hardening
Wohlert Corp.

VACUUM TREATING

A.F.C.-Pifco
Accurate Ion Technologies
Accurate Steel Treating
Advanced Heat Treat Corp.—Waterloo/Burton
Advanced Metallurgical Technology, Inc.
Alliance Metal Treating
American Brazing
American Heat Treating
American Metal Treating Inc.
Atmosphere Furnace Co.
Beehive Heat Treating
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote Thermal Processing—Canton
Bodycote Thermal Processing—Ft. Worth
Bodycote Thermal Processing—Tulsa
Braddock Metallurgical—Alabama
Burbank Steel Treating
Central Kentucky Processing, Inc.
Century Sun Metal Treating
Certified Heat Treating
Certified Metal Craft, Inc.
Delavan Steel Treating
Drever Heat Treating
Dynamic Metal Treating
East-Lind Heat Treat
Elmira Heat Treating, Inc.
Engineered Heat Treat, Inc.
Erie Steel Treating Inc.
Euclid Heat Treating
Fenton Heat Treating
Flame Metals Processing
General Heat Treating
General Metal Heat Treating Inc.
Gleason Pfauter Hurth Cutting Tools
Hanson-Balk Steel Treating
Hauni Richmond Inc.
Hinderliter—Dallas
Hi-Tech Aero
Hi-Tech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Hi-TecMetal Group Corporate HQ
Horizon Steel Treating, Inc.
HTG Aerobraze
HTG Metal Methods
Hudapack Metal Treating—Elkhorn
Hydro-Vac
Impact Strategies, Inc.
Industrial Metal Treating
Industrial Steel Treating Inc.
Ionex, Inc.
Ipsen International Inc.—Vacuum Products
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
JCS Engineering & Development Corp.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.—Berlin
Lindberg Heat Treating Co.—Dallas
Lindberg Heat Treating Co.—Eden Prairie
Lindberg Heat Treating Co.—Houston
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Mexico
Lindberg Heat Treating Co.—Rancho Dominguez
Lindberg Heat Treating Co.—Rosemont
Lindberg Heat Treating Co.—St. Louis
Lindberg Heat Treating Co.—Sturtevant
Lindberg Heat Treating Co.—Tulsa
Lindberg Heat Treating Co.—Worcester
Metal Improvement Co. Inc.—Wichita
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Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metals Technology Corp.
Metlab
Modern Metal Processing
National Metal Processing
Nitrex Metal Technologies—Mason
Nitrotec Surface Engineering—Michigan
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Paolo Products Co.—Kansas City
Paulo Products Co.—Bessemer
Paulo Products Co.—Memphis
Paulo Products Co.—Nashville
Paulo Products Co.—St. Louis
Peters' Heat Treating Inc.
Phoenix Heat Treating Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Richter Precision Inc.
Rochester Steel Treating Works, Inc.
Solar Atmospheres Inc.
Speciality Heat Treating—Elkhart
Speciality Heat Treating—Grand Rapids
Speciality Heat Treating—Holland
Specialty Steel Treating Inc.—Farmington Hills
Specialty Steel Treating Inc.—Fraser
Suncoast Heat Treat, Inc.—Orlando
Suncoast Heat Treat, Inc.—Palm Beach Gardens
Superior Metal Treating
Syracuse Heat Treating
Thermal Braze Inc.
Therm-Tech of Waukesha
Universal Heat Treating
Walker Heat Treating
Wall Colmonoy Corp.
Washington Metallurgical Services
Westside Flame Hardening

OTHER

ABS Metallurgical Processors—*Chemical Processing*
Accurate Steel Treating—*10-Bar Vacuum Processing*
Alfe Heat Treating—*Neutral Salt Hardening, Spheriodized Annealing*
American Metal Treating Inc.—*6-Bar Program Quenching*
Atmosphere Furnace Co.—*Atmosphere Generating Equipment*
Beehive Heat Treating—*Neutral Salt Hardening*
Bodycote Thermal Processing—Ft. Worth—*Titanium Heat Treating*
Bonal Technologies, Inc.—*Vibratory stress relief*
Brazing & Metal Treating—Cleveland—*Cleaning Services*
Central Kentucky Processing, Inc.—*Zinc and Nickel Plating*
Century Sun Metal Treating—*10- and 12-Bar Vacuum Treating*
Cincinnati Gear Co.—*Electron Beam Hardening*
Contour Hardening—*Metallurgical Services*
Delphi Engineering—*Coatings*
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Erie Steel Treating Inc.—*Plug Quenching*
Federal Machine Co.—*Hard Chrome Plating and Grinding*
Flame Hardening of California—*On-Site Work*
Fox Steel Treating—*Select Hole Quenching*
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H & S Heat Treating—*Neutral Hardening*
Heat Treating Network—*Heat Treating Training*
Hinderliter-Anaheim—*Kool Kase*
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Hi-TecMetal Group Corporate HQ—*Nitrotec Melonite*
HTG Copper Brazing Industries—*Nitrotec*
HTG IMT-Duncan—*E-Coating*
HTG IMT-York—*Melonite*
Hudapack Metal Treating—Glendale Heights—*Salt to Salt*
Impact Strategies, Inc.—*Consulting*
Induction Services—*Bonding Heat*
Inductoheat, Inc.—*Power Supplies*
Industrial Steel Treating—*Magnetic Particle Inspection;Tensile Testing*
Ipsen International Inc.—Atmosphere Products—*Parts, Service, Rebuilding, Control Retrofit*
Ipsen International Inc.—Vacuum Products—*Parts, Service, Rebuilding, Control Retrofit*
Ironbound Heat Treating—*Lab Work*
Jasco Heat Treating Inc.—*Large Salt Bath Lines*
Kowalski Heat Treating—*20 Bar Quenching*
Lindberg Heat Treating—Rancho Dominguez—*Super Alloys*
Mannings U.S.A.—*On-Site Services*
Merit Gear Heat Treating—*NATCO Gear Hardening*
Metallurgical Processing—*Clean or Neutral Hardening*
Michigan Induction Inc.—*Consulting on Induction*
National Metal Processing—*Continuous Belt Furnace*
Nettleton Steel Treating—*Atmosphere Heat Treating*
Nitrotec Surface Engineering—Michigan—*Nitrotec*
Paulo Products—Murfreesboro—*Zinc & Phosphate Plating*
Paulo Products—Kansas City—*Inspection*
Phoenix Heat Treating—*Copper Plating*
Progressive Steel Treating—*Grit Blasting*
QM Technologies—*Ion Beam Surface Modification (Hardening)*
Rebco/Rolock/MTech—*Sales and Service*
Speciality Heat Treating—Elkhart—*Gas Nitriding and Salt*

Tempering
Speciality Heat Treating—Grand Rapids—*Gas Nitriding and Salt Tempering*
Speciality Heat Treating—Holland—*Gas Nitriding and Salt Tempering*
Sun Steel Treating Inc.—*Salt Bath Hardening*
Suncoast Heat Treat, Inc.—Orlando—*Malcomizing*
Thermal Braze Inc.—*Induction Brazing*
Thermal Metal Treating Inc.—*Fe-Mn-2 Phosphate Coating*
Therm-Tech of Waukesha—*Marquenching*
Westside Flame Hardening—*Electron Beam Hardening*

HEAT TREAT EQUIPMENT & SUPPLIES

A.F.C.-Pifco—*Batch & Continuous, Fully Automated and Computerized Heat Treat Systems for Steel, Aluminum and Brass Components*
Abbott Furnace Company
Ajax Magnethermic Corp.*—Induction Heat Treating Equipment*
American Cryogenics,—*Cryogenic Processors*
Atmosphere Furnace Co.—*All Types of Fully Automated, Continuous and Batch heat treat systems.*
Can-Eng Furnaces Ltd.—*Ferrous and Nonferrous Equipment including Continuous Mesh Belt and Roller Hearth Equipment*
Cryo-Treatment Specialists—*Computer Controlled Deep Cryogenic Processing Equipment*
Duffy Company—*Condursal Stop-off Paints for Selective Atmosphere Heat Treating*
Grieve Corporation—*Ovens and Furnaces for Aluminum Treating, Brazing, Stress Relieving, Tempering, etc.*
Holcroft*—Heat Treating Equipment and Supplies*
IHS—An Inductotherm Industries Co., Inc.—*Induction Heating Equipment*
Inductoheat, Inc.*—Induction Heat Treating Machines and Power Supplies*
Ionex, Inc.—*Plasma Ion Nitriding & Ion Implantation Systems*
Laser Machining, Inc.—*Laser Heat Treating and Welding Systems*
Macdhui Probe of America—*Carbon Probes*
Mannings U.S.A.—*Portable Heat Treatment Units, Resistance and Induction Insulation, Furnaces and Ovens*
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)*
One Cryo Inc.—*Cryogenic Tempering Equipment*
Pillar Industries—*Brazing and Induction Equipment*
QM Technologies—*Ion Beam Surface Treatment Machines for Surface Modification (Hardening)*
Quality Heat Technologies U.S.A.*—Fluidized bed and Vacuum Equipment, Lab and Quality Control Services*
Radyne Corp.—*Induction Heating Equipment*
Rebco—*Ipsen Furnaces, Rolock Fixtures and Equipment, Midwest Vacuum Pumps*
Surface Combustion, Inc.—*Wide Variety of Batch & Continuous Furnaces for Atmosphere, Vacuum and Non-Atmosphere Heat Treating*
Wall Colmonoy Corp.—*Nicrobraze Brazing Filler Metals and Colmonoy-Nickel-base Alloys for Coatings*
Welduction Corp.—*Induction Hardening Equipment*
Westside Flame Hardening—*Flame Hardening Equipment*
ZYP Coatings, Inc.—*Stop-off Coatings for Carburizing, Nitriding and Other Processes*

SEE PAGE 47 FOR THE COMPLETE COMPANY LISTINGS.

9th International Induction Heating Seminar

The Inductoheat Group is hosting its *9th International Induction Heating Seminar* May 10-12, 2000 at the Hilton Clearwater Beach Resort in Clearwater Beach, Florida.

The world's largest group of experts from North America, Europe, Australia, South America and Asia will present information on NEW processes and developments in induction heating.

• Breakthrough in the induction hardening of crankshafts • Innovations in induction hardening of camshafts, gears & critical components • Obtaining desired metallurgical properties • Cracks, shape & distortion control • Induction tempering & stress relieving • Ferrous & non-ferrous metals • Billet/bar/wire heating • Slab/strip/plate heating • Tube & pipe heating • Cellular manufacturing designs • New coil design technologies • Diagnostics, monitoring & QA • Brazing & soldering technology • Failure analysis • IGBT & MOS FET transistorized power supplies • Load matching • Advanced induction heating techniques • & more

New Solutions to Current Needs

Bring your questions, concerns and induction experiences to world recognized experts and end-users and get the advice and answers you're looking for.

Two-and-a-Half Day Seminar

- Registration/reception Tuesday evening
- Formal presentations Wednesday & Thursday
- Roundtable discussions Friday until noon

It's Not Too Early to Register

Be sure to register via phone, fax, e-mail or our website to guarantee your spot in the seminar. The seminar fee is $195.00 per person until April 10, 2000. Registration after the 10th is $250.00 per person. Please make checks payable to Inductoheat, Inc.

The 8th International Induction Heating Seminar, *held in November, 1998, featured guest speakers and attendees from 19 countries.*

The Inductoheat Group's 9th International Induction Heating Seminar will be held at the Hilton Clearwater Beach Resort in Clearwater, Florida.

Contact:
Laurie Taylor
INDUCTOHEAT, INC.
32251 North Avis Drive
Madison Heights, MI 48071
1-800-624-6297
Tel: 248/585-9393 Fax: 248/585-0429
e-mail: lltaylor@inductoheat.com
www.inductoheat.com

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CIRCLE 161

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COMPANY INDEX

Welcome to the Company Index of the 2000 *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 17.

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: *abbott@penn.com*
Web: *www.penn.com/abbottfurnace*

ABS Metallurgical Processors
4313 E. Magnolia
Phoenix, AZ 85034
602-437-3008
Fax: 602-439-5349

Accurate Ion Technologies, LLC
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: 562-927-8591
E-mail: *astmike@earthlink.net*
Web: *www.heattreaters.com*

Advanced Heat Treat Corp.—Monroe
1625 Rose St.
Monroe, MI 48162
734-243-0063
Fax: 734-243-4066
E-mail: *office@foxberry.net*
Web: *www.ahtweb.com*

Advanced Heat Treat Corp.
—Waterloo/Burton
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 Treat Corp.
—Waterloo/Midport
2825 Midport Blvd.
Waterloo, IA 50703
319-232-5221
Fax: 319-232-4952
E-mail: *mkt@ion-nitriding.com*
Web: *www.ahtweb.com*

Advanced Heat Treating
1057 Trout Run Rd.
St. Marys, PA 15857
814-781-3744
Fax: 814-781-3230

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

Advanced Thermal Technologies, Inc.
P.O. Box 875
3668 U.S. Hwy. 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*
Web: *www.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

Alfe Heat Treating
2349 E. Cardinal Dr.
Columbia City, IN 46725
219-248-2551
Fax: 219-244-4083
Web: *www.al-fe.com*

Alfred Heller Heat Treating Co.
5 Wellington St.
Clifton, NJ 07011
973-772-4200
Fax: 973-772-0433
E-mail: *ahti@bellatlantic.net*

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
Web: *www.allreadproducts.com*

Alpha Heat Treaters
Div. of Metal Improvement Co.
270 Emig Rd.
Emigsville, PA 17318
717-767-6757
Fax: 717-764-0129

American Brazing
Div. of Paulo Products Co.
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 44129
216-431-4492
Fax: 216-431-1508
E-mail:
bruce@americanmetaltreating.com

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
734-242-1733
Fax: 734-242-0993

AP Westshore, Inc.
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
E-mail: *www.nsengine@aol.com*

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

Atmosphere Furnace Company
see A.F.C.-Pifco

B

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

Benedict-Miller Inc.
340 Orient Way
P.O. Box 912
Lyndhurst, NJ 07071-0912
201-438-3000
Fax: 201-438-4962
E-mail: *info@benedict-miller.com*
Web: *www.benedict-miller.com*

Bennett Heat Treating & Brazing Co.
690 Ferry St.
Newark, NJ 07105
800-689-0590
Fax: 973-589-6518
E-mail: *davidquaglia@bennettheat.com*
Web: *www.bennettheat.com*

Bodycote S.W. Inc.
1240 N. Harvard Ave.
Tulsa, OK 74115
918-834-0855
Fax: 918-836-4162
E-mail: *ctygart@bodycote-na.com*
Web: *www.bodycote-na.com*

Bodycote Thermal Processing—Canton
8580 Haggerty Rd.
Canton, MI 48187
734-451-2264
Fax: 734-451-2803
Web: *www.bodycote-na.com*

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

Bodycote Thermal Processing—Tarzana
18600 Oxnard Street
Tarzana, CA 91356
818-344-0216
Fax: 818-609-9372

Bomak Corp.
6 Jefferson Ave.
Woburn, MA 01801
617-935-4100
Fax: 617-932-0542
E-mail: *bomak@industry.net*

Bonal Technologies Inc.
21178 Bridge St.
Southfield, MI 48034
248-353-2041
Fax: 248-353-2028
E-mail: *bonalth@aol.com*
Web: *www.bonal.com*

The Bowdil Co.
2030 Industrial Place S.E.
Canton, OH 44707
216-456-7176
Fax: 216-456-4625

Braddock Metallurgical
14600 Duval Place West
Jacksonville, FL 32218
904-741-4777
Fax: 904-741-4813

Braddock Metallurgical—Alabama
3008 Red Morris Pkwy.
Anniston, AL 36207
205-831-5199
Fax: 205-831-5680

COMPANY INDEX

Brazing & Metal Treating—Cleveland
Div. of HI TecMetal Group
1101 E. 55th St.
Cleveland, OH 44103
216-881-8100
Fax: 216-881-4852
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Brazing & Metal Treating—Kentucky
Div. of HI TecMetal Group
1379 Jamike Avenue
Erlanger, KY 41018
606-647-1115
Fax: 606-647-1165
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Brazing & Metal Treating—Minnesota
2501 HiTec Avenue
Albert Lea, MN 56007
507-373-9630
Fax: 507-373-3771
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Brite Brazing
5476 Lake Ct.
Cleveland, OH 44114
216-881-8100
Fax: 216-881-6811

Brite Metal Treating Inc.
8640 Bessemer Ave.
Cleveland, OH 44127
216-341-2266
Fax: 216-341-4273

Bucyrus International, Inc.
1100 Milwaukee Ave.
S. Milwaukee, WI 53172
414-768-4000
Fax: 414-768-5221

Burbank Steel Treating
415 S. Varney St.
Burbank, CA 91502
213-849-7480 or 818-842-0975
Fax: 213-849-3739

C

Cal-Doran Division
1804 Cleveland Ave.
National City, CA 91950
619-477-2121
Fax: 619-477-3219

California Surface Hardening Inc.
1315 S. Alameda St.
P.O. Box 736
Compton, CA 90223
310-608-5576
Fax: 310-608-2072
E-mail: *calsrf@earthlink.net*

Calumet Surface Hardening
6805 McCook Ave.
Hammond, IN 46323
219-844-5600
Fax: 219-845-1046

Can-Eng Furnaces Ltd.
P.O. Box 235
Niagara Falls, NY 14302-0235
905-356-1327
Fax: 905-356-1817
E-mail: *furnaces@can-eng.com*
Web: *www.can-eng.com*

Carolina Commercial Heat Treating
P.O. Drawer 1368
Fountain Inn, SC 29644
803-862-3516
Fax: 803-862-4466

Caterpillar Industrial Products Inc.
100 N.E. Adams St.
Peoria, IL 61629-4375
309-675-5451
Fax: 309-675-6457
E-mail: *catgears@cat.e-mail.com*

Central Kentucky Processing
657 E. 7th St.
Lexington, KY 40505
606-231-0226
Fax: 606-231-9464
Web: *www.ckpinc.com*

Century Sun Metal Treating
2411 West Aero Park Ct.
Traverse City, MI 49686
616-941-7800
Fax: 616-941-2346

Certified Heat Treating Inc.
1200 E. First St.
Dayton, OH 45403
937-461-2844
Fax: 937-461-4519

Certified Metal Craft Inc.
877 Vernon Way
El Cajon, CA 92020
619-593-3636
Fax: 619-593-3635
E-mail: *cmci@certifiedmetalcraft.com*
Web: *www.certifiedmetalcraft.com*

Chicago Flame Hardening Co.
5200 Railroad Ave.
East Chicago, IN 46312
219-397-6475
Fax: 219-397-4029

Chicago Induction Metal Treating Corp.
3305 W. Harrison St.
Chicago, IL 60624
773-826-1213
Fax: 773-826-1178
E-mail: *info@chicagoinduction.com*
Web: *www.chicagoinduction.com*

Cincinnati Flame Hardening Co.
375 Security Dr.
Fairfield, OH 45014
513-942-1400
Fax: 513-942-1414

Cincinnati Gear Co.
5657 Wooster Pike
Cincinnati, OH 45227
513-271-2700
Fax: 513-271-0049

Cincinnati Steel Treating
5701 Mariemont Ave.
Cincinnati, OH 45227
513-271-3173
Fax: 513-271-3510
E-mail: *cst@steeltreating.com*
Web: *www.steeltreating.com*

City Steel Treating Inc.
13007 Los Nietos Rd.
Santa Fe Springs, CA 90670
562-941-1246
Fax: 562-941-1247

Clearing Niagara
P.O. Box 475
Buffalo, NY 14240
716-893-4070
Fax: 716-893-4084
Web: *www.cnb-intl.com*

Cleveland Flame Hardening Co.
935 West Ave.
Cleveland, OH 44113
216-241-1333
Fax: 216-241-3946

Coleman Commercial Heat Treating
2867 Hangar Rd.
Memphis, TN 38118
901-366-0204
Fax: 901-366-0770

Commercial Induction
Div. of Hi TecMetal Group
4010 E. 116th Street
Cleveland, OH 44105
216-883-4820
Fax: 216-883-4822
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Commercial Steel Treating Corp.
31440 Stephenson Hwy.
Madison Heights, MI 48071
248-588-3300
Fax: 248-588-3300

Contour Hardening Inc.
7898 Zionsville Rd.
Indianapolis, IN 46268
317-876-1530
Fax: 317-879-2484

Cooperheat Inc.
410 Walcot Rd.
Westlake, LA 70669
318-882-1800
Fax: 318-882-1821

Cryo-Treatment Specialists, LLC
900 Briggs Road, Suite 155
Mt. Laurel, NJ 08054
856-787-0004
Fax: 856-787-0006
E-mail: *cryotreat1@aol.com*
Web: *www.cryo-treat.com*

Custom Heat Treating Co.
4117 Meadow Lane
Bessier City, LA 71111
318-742-6662
Fax: 318-742-4135

D

Delavan Steel Treating Operation
2250 Fuller Road
West Des Moines, IA 50265
515-225-6565
Fax: 515-226-8772

Delphi Engineering
131 Blackwood-Barnsboro Rd.
Sewell, NJ 08080
800-220-4101
Fax: 856-228-9354
E-mail: *dec76@aol.com*
Web: *www.delphienginering.com*

Detroit Flame Hardening Co.
17644 Mt. Elliott
Detroit, MI 48212
313-891-2936
Fax: 313-891-3150
E-mail: *dfhinc@earthlink.net*
Web: *www.network1000.com/detflame*

Detroit Steel Treating Co.
1631 Highwood East
Pontiac, MI 48340
248-334-7436
Fax: 248-334-7436
E-mail: *detsteeltreating@aol.com*

Diamond Heat Treating Co.
5660 W. Jefferson
Detroit, MI 48209
313-843-6570
Fax: 313-842-0280

Disston Precision Inc.
6795 State Rd.
Philadelphia, PA 19135
215-338-1200
Fax: 215-338-7060

Dixie Heat Treating Co.
425 County Road 30
Florence, AL 35630
205-767-1752
Fax: 205-767-1573

Dixie Machine & Heat Treating Inc.
711 E. Franklin
Gastonia, NC 28054
704-864-5454
Fax: 704-864-5456

Drever Heat Treating
6201 Robinwood Rd.
Baltimore, MD 21225
410-789-6161
Fax: 410-789-6659

The Duffy Company
283 East Hellen Road
Palatine, IL 60067
847-202-0000
Fax: 847-202-0004
E-mail: *duffyco@bigplanet.com*
Web: *www.duffycompany.com*

Dynamic Metal Treating, Inc.
7784 Ronda Dr.
Canton, MI 48187
734-459-8022
Fax: 734-459-7863

E

East Carolina Metal Treating Inc.
1010 S. Saunders St.
Raleigh, NC 27603
919-834-2100
Fax: 919-833-1764
E-mail: *rockyIII@aol.com*

East-Lind Heat Treat
32045 Dequindre
Madison Heights, MI 48071
248-585-1415
Fax: 248-585-3045
E-mail: *eastlind@aol.com*

Eckel Heat Treat
8035 W. County Rd.
Odessa, TX 79764
915-362-4336
Fax: 915-362-1827

Economy Flame Hardening, Inc.
896 East 70th Street
Cleveland, OH 44103
216-432-4410
Fax: 216-432-0515
E-mail: *sassoon@erols.com*
Web: *www.heattreaters.com*

Edwards Heat Treating
642 McCormick St.
San Leandro, CA 94577
510-638-4140
Fax: 510-638-1438
E-mail: *whenlde@aol.com*
Web: *www.edwardsheattreating.com*

Elmira Heat Treating, Inc.
407 S. Kinyon St.
Elmira, NY 14871
607-734-8904
E-mail: *info@elmira-heat-treat.com*
Web: *www.elmira-heat-treat.com*

Engineered Heat Treat Inc.
31271 Stephenson Hwy.
Madison Heights, MI 48071
248-588-5141
Fax: 248-588-6533
E-mail: *sal@enght.com*
Web: *www.ehtinc.com*

Erie Steel Treating Inc.
5540 Jackman Rd.
Toledo, OH 43613
419-478-3743
Fax: 419-478-0109
E-mail: *eriesteel@toledolink.com*
Web: *www.erie.com*

Euclid Heat Treating Co.
1408 E. 222nd St.
Cleveland, OH 44117
800-962-2909
Fax: 216-481-3473

F

Fairfield Mfg. Co.
P.O. Box 7940
Lafayette, IN 47903
765-474-3474
Fax: 317-477-7342

Federal Machine Co.
1007 2nd Ave. West
West Fargo, ND 58103
701-282-8134
Fax: 701-282-8135

Fenton Heat Treating
3605 Homestead Duquesne Rd.
West Mifflin, PA 15122
412-466-3960
Fax: 412-466-7931

Flame Hardening Co. of California
6057 State St.
Huntington Park, CA 90255
213-589-5066
Fax: 213-589-5403

Flame Metals Processing Corp.
7317 W. Lake St.
Minneapolis, MN 55426
612-929-7815
Fax: 612-925-0572
E-mail: *jimc@flamemetals.com*

Fluxtrol Manufacturing Inc.
1388 Atlantic Blvd.
Auburn Hills, MI 48326
810-393-2000
Fax: 810-393-0277

Fox Steel Treating Co.
2220 Gratiot Ave.
Detroit, MI 48207
888-818-0808
Fax: 313-568-0148

FPM Heat Treating
1501 S. Lively Blvd.
Elk Grove, IL 60007
847-228-2525
Fax: 847-228-9887

FPM Ipsen Heat Treating
666 Route 20
Cherry Valley, IL 61016
815-332-4961
Fax: 815-332-3022

FPM Milwaukee
8201 W. Calumet Rd.
Milwaukee, WI 53223
414-355-7900
Fax: 414-355-4719

Franklin Steel Treating Co.
1070 Ridge St.
Columbus, OH 43215-1190
614-488-2556
Fax: 614-486-9489

G

Gear Company of America
14300 Corgin Ave.
Cleveland, OH 44111
216-671-5400
Fax: 216-671-5825

General Heat Treating Corp.
6770 Benedict Rd.
East Syracuse, NY 13057
315-437-1117
Fax: 315-433-1194
E-mail: *tomght@dreamscape.com*
Web: *www.generalheattreating.com*

General Metal Heat Treating Inc.
941 Addison Rd.
Cleveland, OH 44103
216-391-0886
Fax: 216-391-0890

Geo. H. Porter Steel Treating Co.
1273 E. 55th St.
Cleveland, OH 44103
216-431-6601
Fax: 216-431-0009
E-mail: *treating@aol.com*

Gibson Heat Treat Inc.
2037 Brookside Ln.
Kingsport, TN 37660
423-246-5542
Fax: 423-246-8629
E-mail: *HTTreat@aol.com*

Gleason Pfauter Hurth Cutting Tools
1351 Windsor Road
Loves Park, IL 61111
815-877-8900
Fax: 815-877-0624
E-mail: *sales@pmct.com*
Web: *www.pmct.com*

The Gleason Works
1000 University Ave.
Rochester, NY 14692
716-461-8051
Fax: 716-461-1492

Global Heat Treat Inc.
54 Route 130
Yardville, NJ 08620
609-298-1200
Fax: 609-298-7958

Good Earth Tools, Inc.
Four Industrial Drive
Crystal City, MO 63019
314-937-3330
Fax: 314-937-3386
E-mail: *goodearthtools@usa.net*

Grand Rapids Commercial
Heat Treating Co., Inc.
3832 Buchanan Ave. S.W.
Grand Rapids, MI 49548
616-243-0111
Fax: 616-243-4080
E-mail: *florist47florist@netscape.net*

The Grieve Corporation
500 Hart Road
Round Lake, IL 60073
847-546-8225
Fax: 847-546-9210
E-mail: *sales@grievecorp.com*
Web: *www.grievecorp.com*

H

H & M Metal Processing
1850 Front St.
Cuyahoga Falls, OH 44221
800-304-2636
Fax: 216-928-5472

H & S Heat Treating
133 South St. N.
Port Robinson, ON L0S1K0
Canada
905-384-9355
Fax: 905-384-9110
E-mail: *hsheat@vaxxine.com*

Hansen-Balk Steel Treating Co.
1230 Monroe N.W.
Grand Rapids, MI 49505
616-458-1414
Fax: 616-458-6868

Hauni Richmond Inc.
2800 Charles City Rd.
Richmond, VA 23231
804-236-5241
Fax: 804-236-5284
Heat Treat Corp. of America
1120 W. 119th St.
Chicago, IL 60643
773-264-1234
Fax: 773-264-4321

Heat-Treating Inc.
1807 W. Pleasant St.
Springfield, OH 45506
513-325-3121
Fax: 513-325-3117

Heat Treating Network
16600 W. Sprague Road, #275
Cleveland, OH 44130
440-243-8990
Fax: 440-243-8992
E-mail: *hsatnet@aol.com*

Heat Treating Services Corp.
217 Central Ave.
Pontiac, MI 48341
810-858-2230
Fax: 810-858-2242

Hi TecMetal Group Corporate Headquarters
(see also HTG)
1101 E. 55th St.
Cleveland, OH 44103
216-881-8100
Fax: 216-881-6811

Hinderliter Heat Treating Inc.—Anaheim
1025 N. Pauline St.
Anaheim, CA 92801
714-776-8312
Fax: 714-776-8446

Hinderliter Heat Treating Inc.—Dallas
10530 Doric St.
Dallas, TX 75220
214-357-0394
Fax: 214-357-0195

Hinderliter Heat Treating Inc.—Tarzana
18600 Oxnard St.
Tarzana, CA 91356
818-344-0216
Fax: 818-609-9372

Hinderliter Heat Treating Inc.—Talsa
1240 N. Harvard
Tulsa, OK 74115
918-834-0855
Fax: 918-836-4162

HiTech Aero
Div. of Hi TecMetal Group
34800 Lakeland Blvd.
Eastlake, OH 44095
440-946-2280
Fax: 440-946-2283
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Hitech Metallurgical Co.
Div. of Hi TecMetal Group
7384 Trade St.
San Diego, CA 92121
858-586-7272
Fax: 858-586-7598
E-mail: *hitech@hitechmetal.com*
Web: *www.hitechmetal.com*

Hi-Tech Steel Treating Inc.
2720 Roberts St.
Saginaw, MI 48601
800-835-8294 or 517-753-1455
Fax: 517-753-2368
Web: *www.hitechsteel.com*

Holcroft
12068 Market St.
Livonia, MI 48150
734-591-1000
Fax: 734-591-6443
E-mail: *titus@holcroft.com*
Web: *www.holcroft.com*

Horizon Steel Treating Inc.
231 Jandus Rd.
Cary, IL 60013
847-639-4030
Fax: 847-639-1981
E-mail: *harveystout@hotmail.com*

Horsburgh & Scott Co.
5114 Hamilton Ave.
Cleveland, OH 44114
216-432-5804
Fax: 216-432-5861
E-mail: *rpc@horsburgh-scott.com*
Web: *www.horsburgh-scott.com*

Houston Flame Hardening
215 N. Jenkins St.
Houston, TX 77003
713-926-8017
Fax: 713-926-8316
E-mail: *housflame@aol.com*

HTG Aerobraze
Div. of Hi TecMetal Group
940 Redna Terrace
Woodlawn, OH 45215
513-772-1461
Fax: 513-772-0149
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

HTG Copper Brazing Industries
Div. of Hi TecMetal Group
2845 E. Ten Mile Road
Warren, MI 48091
810-756-4900
Fax: 810-756-3463
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

HTG Commercial Induction
Div. of Hi TecMetal Group
4010 East 116th Street
Cleveland, OH 44105
216-881-8100
Fax: 216-883-4822
E-mail: *htgsales@apk.net*

HTG Hitech Aero Division
Div. of Hi TecMetal Group
34800 Lakeland Blvd.
Eastlake, OH 44095
440-946-2280
Fax: 440-946-2283
Web: *www.hitecmetalgroup.com*

HTG IMT-Duncan
Div. of Hi TecMetal Group
235 Commerce Court
Duncan, SC 29334
864-433-8231
Fax: 864-433-8233
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

HTG IMT-York
Div. of Hi TecMetal Group
1688 Fairhope Rd., Box 748
York, SC 29745
803-684-2548
Fax: 803-684-9387
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

HTG Metal Methods
Div. of Hi TecMetal Group
260 Chenault Rd.
Frankfort, KY 40601
502-695-5700
Fax: 502-695-5702
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Hudapack Metal Treating—Elkhorn
979 Koopmen Lane
Elkhorn, WI 53121-2203
414-723-3345
Fax: 414-723-3752
E-mail:
gary@hudapackmetaltreating.com
Web: *www.hudapackmetaltreating.com*

Hudapack Metal Treating—Glendale Hts.
550 Mitchell Road
Glendale Heights, IL 60139-2581
630-858-0505
Fax: 630-858-1313
Web: *www.hudapackmetaltreating.com*

Huron Metallurgical Inc.
12611 Haggerty Rd.
Belleville, MI 48111
248-452-2301
E-mail: *htsq1@aol.com*

Hydro-Vac
Div. of Hi TecMetal Group
1177 Marquette St.
Cleveland, OH 44114
216-881-1656
Fax: 216-881-1358
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Hy-Vac Technologies Inc.
15701 Glendale Ave.
Detroit, MI 48227
313-838-2800
Fax: 313-838-2802

I

IHS, an Inductotherm Co.
5009 Rondo Drive
Ft. Worth, TX 76106
817-625-5577
Fax: 817-625-1872

Illiana Heat Treating Inc.
P.O. Box 1466
Danville, IL 61834-1466
217-443-5418
Fax: 217-443-5419

Impact Strategies Inc.
P.O. Box 5317
Clinton, NJ 08809
908-730-9163
Fax: 908-730-8334

Induction Heat Treating Corp.
775 Tek Drive
Crystal Lake, IL 60014
815-477-7788
Fax: 815-477-7784
E-mail: *ihtcorp@mc.net*
Web: *www.ihtcorp.com*

Induction Metal Treating Co.
P.O. Box 748
York, SC 29745
803-684-2548
Fax: 803-684-9387

Induction Services Inc.
24800 Mound Rd.
Warren, MI 48001
810-754-1640
Fax: 810-754-5402

Inductoheat Inc.
32251 N. Avis Dr.
Madison Heights, MI 48071
248-585-9393
Fax: 248-589-1062
E-mail: *lltaylor@inductoheat.com*
Web: *www.inductoheat.com*

Industrial Metal Treating Corp.
402 E. Front St.
Wilmington, DE 19801
302-656-1677
Fax: 302-656-4370
E-mail: *ribec@voicenet.com*

Industrial Steel Treating Co.
P.O. Box 98
Jackson, MI 49202
517-787-6312
Fax: 517-787-5441
E-mail: *swilcox@indstl.com*
Web: *www.indstl.net*

Industrial Steel Treating Inc.
3370 Benedict Way
Huntington Park, CA 90255
213-583-1231
Fax: 213-589-1255
Web: *www.industry.net/ist*

International Induction Inc.
1504 10th Ave.
Port Huron, MI 48060
810-984-3803
Fax: 810-984-3801

Ionex, Inc.
6633 Bellaire Highway
Bellaire, MI 49615
616-533-6660
Fax: 616-533-6669
E-mail: *ljbarnard@ionex.com*
Web: *www.ionex.com*

Ipsen International—Atmosphere Products
984 Ipsen Road
Cherry Valley, IL 61016
815-332-4941
Fax: 815-332-4995
E-mail: *sales@abaripsen.com*
Web: *www.ipsen-international.com*

Ipsen International—Vacuum Products
984 Ipsen Road
Cherry Valley, IL 61016
815-332-4941
Fax: 815-332-4995
E-mail: *sales@abaripsen.com*
Web: *www.ipsen-international.com*

Ironbound Heat Treating
304 Cox Street
Roselle, NJ 07203
908-245-0717
Fax: 908-245-6255
Web: *www.ibht.com*

Irwin Automation Inc.
715 Cleveland St.
Greensberg, PA 15601
724-834-7160
Fax: 724-834-4670
E-mail: *iai@westol.com*

J

Jasco Heat Treating Inc.
75 Macedon Center Road
Fairport, NY 14450
716-388-1040
Fax: 716-377-7226
E-mail: *jagpitts@aol.com*
Web: *www.memo.com/jasco/*

JCS Engineering & Development
211 W. 22nd St.
Hialeah, FL 33010
305-888-7911
Fax: 305-888-9913
E-mail: *gcoty@ibm.net*

John V. Potero Co.
4225-35 Adams Ave.
Philadelphia, PA 19124
215-533-8988
Fax: 215-533-9210

K

Kowalski Heat Treating Co.
3611 Detroit Ave.
Cleveland, OH 44113
216-631-1144
Fax: 216-631-8921
E-mail: *khtheat@aol.com*

L

LAI East/Laser Applications, Inc.
1110 Business Parkway S.
Westminster, MD 21157
410-857-0770
Fax: 410-857-0774
E-mail: *laser@laico.com*
Web: *www.laico.com*

Lake County Steel Treating
960 Anita
Antioch, IL 60002
847-375-8174
Fax: 847-395-7638

Laser Machining, Inc.
500 Laser Drive
Somerset, WI 54025
715-247-3285
Fax: 715-247-5650
E-mail: *sales@lasermachining.com*
Web: *www.lasermachining.com*

Lawrence Industries Inc.
2720 S. Cornhusker Ave.
Hastings, NE 68901
402-463-3158
Fax: 402-463-4128
E-mail: *hotparts@kdsi.net*

Lindberg Heat Treating—Berlin
675 Christian Lane
Berlin, CT 06037
860-225-7691
Fax: 860-229-3891
Web: *www.lindberght.com*

Lindberg Heat Treating—Dallas
2727 Ruder Street
Dallas, TX 75212
214-638-8718
Fax: 214-634-9304
Web: *www.lindberght.com*

Lindberg Heat Treating—Eden Prairie
10150 Crosstown Circle
Eden Prairie, MN 55344
612-944-5500
Fax: 612-944-8847
Web: *www.lindberght.com*

Lindberg Heat Treating—Houston
4201 Robertson Street
Houston, TX 77009
713-691-4544
Fax: 713-691-1923
Web: *www.lindberght.com*

Lindberg Heat Treating—Lansing
2127 West Willow Street
Lansing, MI 48917
517-487-4989
Fax: 517-487-1628
Web: *www.lindberght.com*

Lindberg Heat Treating—Melrose Park
1975 Ruby St.
Melrose Park, IL 60160
708-344-4080
Fax: 708-344-4010
Web: *www.lindberght.com*

Lindberg Heat Treating—New Berlin
16167 W. Rogers Dr.
New Berlin, WI 53151
262-782-5553
Fax: 262-782-5660
Web: *www.lindberght.com*

Lindberg Heat Treating—Racine
4210 Douglas Ave.
Racine, WI 53402
262-681-4280
Fax: 262-639-5719
Web: *www.lindberght.com*

Lindberg Heat Treating—Rancho Dominguez
515 West Appa Street
Rancho Dominguez, CA 90220
310-604-8000
Fax: 310-604-9545
Web: *www.lindberght.com*

Lindberg Heat Treating—Rochester
620 Buffalo Rd.
Rochester, NY 14611
716-436-7876
Fax: 716-436-5276
E-mail: *troberts@lindberght.com*
Web: *www.lindberght.com*

Lindberg Heat Treating—Rosemont
6133 N. River Road, Suite 700
Rosemont, IL 60018
847-823-2021
Fax: 847-823-0795
Web: *www.lindberght.com*

Lindberg Heat Treating—St. Louis
650 E. Taylor Ave.
St. Louis, MO 63147
314-382-6200
Fax: 314-382-3741
Web: *www.lindberght.com*

Lindberg Heat Treating—Santa Catarina
Blvd. Industriales del Poniente
Km 19, Departamento 100
Santa Catarina, N.L.
Mexico C.P. 66350
(52) 8-388-1798
Fax: (52) 8-390-4296
Web: *www.lindberght.com*

Lindberg Heat Treating—Solon
6111 Cochran Road
Solon, OH 44139
440-248-4000
Fax: 440-248-9515
Web: *www.lindberght.com*

Lindberg Heat Treating—Sturtevant
7316 Durand Avenue
Sturtevant, WI 53177
262-554-8770
Fax: 262-554-9733
Web: *www.lindberght.com*

Lindberg Heat Treating—Tulsa
4208 South 74th East Avenue
Tulsa, OK 74145
918-627-7324
Fax: 918-627-0008
Web: *www.lindberght.com*

Lindberg Heat Treating—Waterbury
130 Huntingdon Avenue
Waterbury, CT 06708
203-755-9119
Fax: 203-577-0521
Web: *www.lindberght.com*

Lindberg Heat Treating—Wichita
1009 South West Street
Wichita, KS 67213
316-943-3288
Fax: 316-943-3025
Web: *www.lindberght.com*

Lindberg Heat Treating—Worcester
284 Grove Street
Worcester, MA 01605
508-754-1724
Fax: 508-791-0816
Web: *www.lindberght.com*

M

M & M Heat Treat
1309 Main St.
Essexville, MI 48732
517-893-3677
Fax: 517-893-4423

Macdhui Probe of America
9300 Pinecone Drive
Mentor, OH 44060
440-350-0400
Fax: 440-350-0047

Magnum Metal Treating
4400 N. Frazier St.
Conroe, TX 77303
713-353-8615
Fax: 409-856-6607

Mannings U.S.A.
200 Richards Ave.
Dover, NJ 07802-0896
800-447-4473
Fax: 973-537-1581
E-mail: *sales@manningsusa.com*
Web: *www.manningsusa.com*

Master Heat Treating Inc.
51 Brown Ave.
Springfield, NJ 07081
201-379-7320
Fax: 201-379-3214

Merit Gear Heat Treat
P.O. Box 486
Antigo, WI 54409-0486
715-623-2307
Fax: 715-627-2032

Metal Improvement Co.—Addison
678 Winthrop Avenue
Addison, IL 60101
630-543-4950
Fax: 630-543-8075
Web: *www.metalimprovement.com*

Metal Improvement Co.—Blue Ash
11131 Luschek Drive
Blue Ash, OH 45241
513-489-6484
Fax: 513-489-6499
Web: *www.metalimprovement.com*

Metal Improvement Co.—Brampton
105 Alfred Kuehne Blvd.
Brampton, Ontario L6T 4K3
Canada
905-791-8002
Fax: 905-791-4490
Web: *www.metalimprovement.com*

Metal Improvement Co.—Carlstadt
472 Barell Avenue
Carlstadt, NJ 07072
201-935-1800
Fax: 201-935-8670
Web: *www.metalimprovement.com*

Metal Improvement Co.—Charlotte
500 Spring Brook Road
Charlotte, NC 28217
704-525-3818
Fax: 704-525-3118
Web: *www.metalimprovement.com*

Metal Improvement Co.—Columbus
1515 Universal Rd.
Columbus, OH 43207
614-444-1181
Fax: 614-444-0421
Web: *www.metalimprovement.com*

Metal Improvement Co.—Emigsville
270 Emig Road
P.O. Box 23
Emigsville, PA 17318
717-767-6757
Fax: 717-764-0129
Web: *www.metalimprovement.com*

Metal Improvement Co.—Grand Prairie
1450 Avenue S
Grand Prairie, TX 75050
972-641-8011
Fax: 972-660-3692
Web: *www.metalimprovement.com*

Metal Improvement Co.—Houston
9410 East Hardy
Houston, TX 77093
713-691-0257
Fax: 713-691-4744
Web: *www.metalimprovement.com*

Metal Improvement Co.
116 Southpark Rd.
Lafayette, LA 70508
318-837-9273
Fax: 318-837-2505
Web: *www.metalimprovement.com*

Metal Improvement Co.—Lynwood
2588-A Industry Way
Lynwood, CA 90262
323-563-1533
Fax: 323-563-2105
Web: *www.metalimprovement.com*

Metal Improvement Co.—Maple Grove
8630-A Monticello Lane
Maple Grove, MN 55369
612-425-2400
Fax: 612-425-4669
Web: *www.metalimprovement.com*

Metal Improvement Co.—Miami
1940 N.W. 70th Avenue
Miami, FL 33126
305-592-5960
Web: *www.metalimprovement.com*

Metal Improvement Co.—Milwaukee
8201 N. 87th St.
Milwaukee, WI 53224
414-355-6119
Fax: 414-355-9114
E-mail: *metalimp@execpc.com*
Web: *www.metalimprovement.com*

Metal Improvement Co.—Phoenix
103 S. 41st Avenue
Phoenix, AZ 85009
602-278-2811
Fax: 602-278-3911
Web: *www.metalimprovement.com*

Metal Improvement Co.—Romulus
30100 Cypress Drive
Romulus, MI 48174
734-728-8600
Fax: 734-729-8605
Web: *www.metalimprovement.com*

Metal Improvement Co.—Santa Ana
2151 South Hathaway
Santa Ana, CA 92705
714-546-4160
Fax: 714-546-8643
Web: *www.metalimprovement.com*
Metal Improvement Co.—Twinsburg
1652 E. Highland Road
Twinsburg, OH 44087
330-425-1490
Fax: 330-425-1494
Web: *www.metalimprovement.com*

Metal Improvement Co.—Vernon
3239 East 46th Street
Vernon, CA 90058
323-585-2168
Fax: 323-585-0157
Web: *www.metalimprovement.com*

Metal Improvement Co.—Wakefield
One Nablus Road
Wakefield, MA 01880
781-246-3848
Fax: 781-246-4521
Web: *www.metalimprovement.com*

Metal Improvement Co.—Wellington
440 North West Road
Wellington, KS 67152
316-326-5509
Fax: 316-326-6043
Web: *www.metalimprovement.com*

Metal Improvement Co.—West Babylon
195 Field Street
West Babylon, NY 11704-1499
516-694-8770
Fax: 516-694-8775
Web: *www.metalimprovement.com*

Metal Improvement Co.—Wichita
1019 S. McLean Blvd.
Wichita, KS 67208
316-267-6264
Fax: 316-267-7904
E-mail: *micw520@worldnet.att.net*
Web: *www.metalimprovement.com*

Metal Improvement Co.—Windsor
145 Addison Road
Windsor, CT 06095
860-688-6201
Fax: 860-285-8809
Web: *www.metalimprovement.com*

Metal Methods
260 Chenault Rd.
Frankfort, KY 40601
502-695-5700
Fax: 502-695-5702

Metal Processing Co.
3257 N. 32nd St.
Milwaukee, WI 53216
414-871-9010
Fax: 414-871-3910

Metal Treaters Inc.
859 N. Prior
St. Paul, MN 55104
651-646-1317
Fax: 651-646-7705

Metal Treating Inc.
1575 W. Pierce St.
Milwaukee, WI 53204
414-645-2226
Fax: 414-645-9118

Metal Treating & Research
1680 E. 69th Ave.
Denver, CO 80229
303-286-9338
Fax: 303-286-9366
E-mail: *annamtr@dimensional.com*

Metallurgical Inc.
900 E. Hennepin Ave.
Minneapolis, MN 55414
612-378-1500
Fax: 612-378-0462
Web: *www.Met-MN.com*

Metallurgical Processing
P.O. Box 10842
Fort Wayne, IN 46854
219-423-1691
Fax: 219-422-2656

Metals Engineering Inc.
1800 South Broadway
Green Bay, WI 54304
414-437-7686
Fax: 414-437-7687

Metals Technology Corp.
120 North Schmale Rd.
Carol Stream, IL 60188
630-221-2500
Fax: 630-221-0120
E-mail:
metalstechnology@mindspring.com
Web: *www.metalstechnology.com*

Metal-Tec Heat Treating Inc.
4723 W. Station St.
Eight Mile, AL 36613
334-456-1133
Fax: 334-456-1134

Metlab Co.
1000 E. Mermaid Ln.
Wyndmoor, PA 19038
215-233-2600
Fax: 215-233-5653
E-mail: *metlab@worldnet.att.net*
Web: *www.thomasregister.com/metlab/*

Metro Steel Treating
9792 Grinnell
Detroit, MI 48213
313-921-5522
Fax: 313-921-0363

Met-Tek Inc.—Clackamas
15651 S.E. 125th Ct.
Clackamas, OR 97015
503-636-3203
Fax: 503-655-6898

Met-Tek Inc.—Racine
1800 Melvin Ave.
Racine, WI 53404
414-639-8357
Fax: 414-639-7152

Michigan Flame Hardening Co.
2241 Bellingham
Troy, MI 48083
810-689-3737
Fax: 810-689-0680

Michigan Induction Inc.
8468 Ronda Dr.
Canton, MI 48187
313-459-8514
Fax: 313-459-8795
E-mail: *mimaster@oeonline.com*
Web: *www.michigan-induction.com*

Midland Metal Treating Inc.
5512 W. Airways Ave.
Franklin, WI 53132
414-421-5140
Fax: 414-421-2360
E-mail: *midmetal@miliserv.net*

COMPANY INDEX

Midwest Flame Hardening Inc.
500 W. 150th St.
East Chicago, IN 46312
219-397-8423
Fax: 219-397-8480

Midwestern Machinery Co.
902 E. 4th Street
Joplin, MO 64802-2214
417-624-2400
Fax: 417-624-2430
Web: *www.mwdrill.com*

Modern Industries Inc.
613 West 11th St.
Erie, PA 16512
814-455-8061
Fax: 814-454-3090
E-mail:denniss@mi-erie.com
Web: www.mi-erie.com

Modern Metal Processing Inc.
3448 Corwin Rd.
P.O. Box 22
Williamston, MI 48895
517-655-4402
Fax: 517-655-3795
E-mail: *mmp@acd.net*

Modern Steel Treating
Div. of Hi TecMetal Group
28910 Lakeland Blvd.
Wickliffe, OH 44092
440-943-4555
Fax: 440-943-4730
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Molon Gear & Shaft
335 E. Illinois St.
Palatine, IL 60067
847-259-3750
Fax: 847-705-8349

Mountain Metallurgical Corp.
P.O. Box 460
Elizabethton, TN 37644
423-543-7212
Fax: 423-542-3519

MPT America
27525 Newhall Ranch Rd. Unit 4
Valencia, CA 91355
805-257-1933
Fax: 805-257-1936
E-mail: *mpt-jeg@plasma-nitride.com*
Web: *www.plasma-nitride.com*

N

National Broach & Machine Co.
17500 Twenty-Three Mile Rd.
Macomb, MI 48044-1103
810-263-0100
Fax: 810-263-4571
E-mail: *tomalisd@redringproducts.com*
Web: *www.redringproducts.com*

National Induction Heating
630 E. Ten Mile Rd.
Hazel Park, MI 48030
810-547-5700
Fax: 810-547-5702

National Metal Processing Inc.
450 N. Estill Ave.
P.O. Box 280
Richmond, KY 40476-0280
606-623-9291
Fax: 606-623-9291
E-mail: *NSGraves@aol.com*
Web: *www.nmpheattreat.com*

Nettleton Steel Treating
Div. of Hi TecMetal Group
1371 E. 45th St.
Cleveland, OH 44103
216-431-9590
Fax: 216-431-9591
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Nitrex Metal Technologies Inc.
—Burlington
4211 Mainway Drive
Burlington, Ontario L7L 5N9
Canada
905-319-9258
Fax: 905-319-9260
E-mail: *nmtburl@worldchat.com*
Web: *www.nitrex.com*

Nitrex Metal Technologies Inc.
—Mason
822 Kim Drive
P.O. Box 155
Mason, MI 48854
517-676-6370
Fax: 517-676-6427
E-mail: *nitrex@voyager.net*
Web: *www.nitrex.com*

Nitrex Metal Technologies Inc.
—St. Louis
3474 Poirier Blvd.
St. Laurent, Quebec H4R 2J5
Canada
514-335-7191
E-mail: *nitrex@nitrex.com*
Web: *www.nitrex.com*

Nitrotec Surface Engineering—Warren
Div. of Hi TecMetal Group
2845 Ten Mile Road
Warren, MI 48091
810-756-4900
Fax: 810-756-3463
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Nitrotec Surface Engineering—Wickliffe
Div. of Hi TecMetal Group
28910 Lakeland Blvd.
Wickliffe, OH 44092
440-943-4555
Fax: 440-943-4730
E-mail: *htginfo@apk.net*
Web: *www.hitecmetalgroup.com*

Nitro-Vac Heat Treating Inc.
23080 Dequindre
Warren, MI 48091
810-754-4350
Fax: 810-754-5195

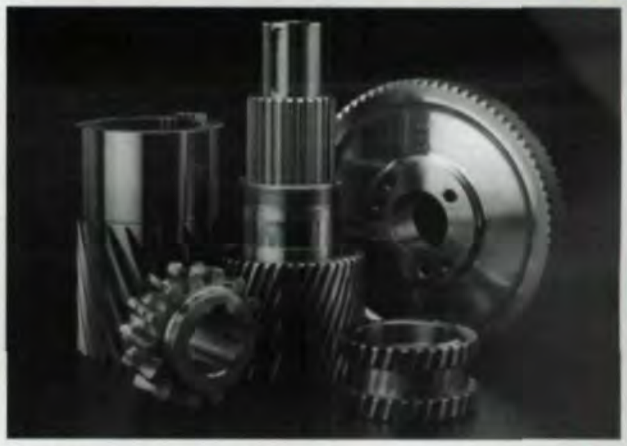
Nitron Inc.
26 Wellman St.
Lowell, MA 01851
508-458-3030
Fax: 508-458-3131

O

O & W Heat Treat Inc.
One Bidwell Rd.
South Windsor, CT 06074
860-528-9239
Fax: 860-291-9939

Oakland Metal Treating Co.
450 Derby Ave.
Oakland, CA 94601
510-261-9675
Fax: 510-261-5678

Ohio Metallurgical Service
1033 Clark St.
Elyria, OH 44036
216-365-4105
Fax: 216-365-9527



One Cryo Inc.
8549 Parkline Blvd, Suite C
Orlando, FL 32809
407-856-1455
Fax: 407-856-0244
E-mail: *sales@onecryo.com*
Web: *www.onecryo.com*

Oregon Induction Corp.
911 N.W. East Wind Dr.
Troutdale, OR 97060
503-661-1123
Fax: 503-661-7333

P

P & L Heat Treating & Grinding
313 E. Wood St.
Youngstown, OH 44503
216-746-1339
Fax: 216-746-7029

Partek Laboratories Inc.
225 S. Hollywood Rd.
Houma, LA 70360
504-851-5310
Fax: 504-851-5312

Paulo Products Co.—Bessemer
705 N. 22nd St.
Bessemer, AL 35020
205-428-1294
Fax: 205-425-9841
E-mail: *GMassey@paulo-us.com*
Web: *www.paulo.com*

Paulo Products Co.—Kansas City
4827 Chelsea
Kansas City, MO 64130
816-861-7500
Fax: 816-924-7300
E-mail: *DCoulis@paulo-us.com*
Web: *www.paulo.com*

Paulo Products Co.—Memphis
1540 Channel Ave.
Memphis, TN 38113
901-948-5523
Fax: 901-948-7501
E-mail: *DKermick@paulo-us.com*
Web: *www.paulo.com*

Paulo Products Co.—Murfreesboro
1307 Rutledge Ave.
Murfreesboro, TN 37129
615-896-1385
Fax: 615-895-9613
E-mail: *JJenkins@paulo-us.com*
Web: *www.paulo.com*

Paulo Products Co.—Nashville
3206 Ambrose
Nashville, TN 37207-3206
615-228-2526
Fax: 615-228-2734
E-mail: *EPfrommer@paulo.com*
Web: *www.paulo.com*

Paulo Products Co.—St. Louis
5711 West Park Ave.
St. Louis, MO 63110
314-647-7534
Fax: 314-647-7518
E-mail: *sales@paulo.com*
Web: *www.paulo.com*

Penna Flame Industries Inc.
RR#3 Box 14B
Zelienople, PA 16063
412-452-8750
Fax: 412-452-0484
E-mail: *jorr@pennaflame.com*
Web: *www.pennaflame.com*

Pennsylvania Metallurgical Inc.
315 Columbia St.
Bethlehem, PA 18017
610-691-1313
Fax: 610-691-2662

Peters Heat Treating Inc.
215 Race St.
P.O. Box 624
Meadville, PA 16335
814-333-1782
Fax: 814-333-2533

Phoenix Heat Treating Inc.
2405 W. Mohave
Phoenix, AZ 85009
602-258-7751
Fax: 602-258-7767
E-mail: *info@phxheatreat.com*
Web: *www.phxheatreat.com*

Pillar Industries
21905 Gateway Road
Brookfield, WI 53045
262-317-5300
Fax: 262-317-5353
E-mail: *sales@pillar.com*
Web: *www.pillar.com*

Pitt-Tex Inc.
P.O. Box 109
Latrobe, PA 15650
412-537-2009
Fax: 412-537-2140
E-mail: *Pitt-Tex@prodigy.net*

Precision Heat Treating Corp.
2711 Adams Center Rd.
Fort Wayne, IN 46803
219-749-5125
Fax: 219-749-0108

Progressive Engineering Co.
2010 E. Main St.
Richmond, VA 23223
804-648-7221
Fax: 804-780-2230
E-mail: *sales@pecgears.com*
Web: *www.pecgears.com*

Progressive Steel Treating Inc.
922 Lawn Drive
Loves Park, IL 61111
815-877-2571
Fax: 815-877-7922
E-mail: *prosteel_1@aol.com*

Q

QM Technologies
3701 Hawkins St. NE
Albuquerque, NM 87109
505-342-2851
Fax: 505-342-2852
E-mail: *dalem@qminc.com*
Web: *www.qminc.com*

Quality Heat Technologies USA
920 E. State Parkway
Schaumburg, IL 60173
847-490-1082
Fax: 847-490-1228
E-mail: *jpowalisz@qualityheatusa.com*
Web: *www.qualityheatusa.com*

R

Racine Heat Treating Co.
1215 8th St.
Racine, WI 53403
414-637-9893
Fax: 414-637-9854

Radyne Corporation
211 W. Boden St.
Milwaukee, WI 53207
414-481-8360
Fax: 414-481-8303
E-mail: *sales@radyne.com*
Web: *www.radyne.com*

Rebco
2769 Sandra Lane
P.O. Box 375
Jefferson, OH 44047
440-275-3075
Fax: 440-275-3075
E-mail: *rebnet@compuserve.com*

Revas Engineering Co.
555 W. 16th St.
Indianapolis, IN 46202
317-635-6311

Richter Precision Inc.
1021 Commercial Ave.
East Petersburg, PA 17520
717-560-9990
Fax: 717-560-8741

Roboduction Thermal Processing
P.O. Box 5090
Southfield, MI 48086
810-356-2577
Fax: 810-356-3989

Rochester Steel Treating Works
962 East Main St.
Rochester, NY 14605
716-546-3348
Fax: 716-546-1684

Rotation Products Corp.
2849 N. Catherwood Ave.
Indianapolis, IN 46219
317-542-8563
Fax: 317-542-1171

S

Scot Forge
8001 Winn Rd. Box 8
Spring Grove, IL 60081
847-587-1000
Fax: 847-587-2000
E-mail: *sales@scotforge.com*
Web: *scotforge.com*

Shanafelt Manufacturing. Co.
2633 Winfield Way N.E.
Canton, OH 44705
216-455-0315
Fax: 216-455-4487

Shore Metal Treating Technology Inc.
5475 Avion Park Dr.
Cleveland, OH 44143
216-473-2020
Fax: 216-473-0947

S.K.S. Heat Treating Inc.
3286 Industrial Dr.
Saginaw, MI 48601
517-777-0270
Fax: 517-777-0273

Solar Atmospheres Inc.
1969 Clearview Dr.
Souderton, PA 18964
800-347-3236
Fax: 215-723-6460
E-mail: *info@solaratm.com*
Web: *www.solaratm.com*

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Mansfield, OH 44901
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Fax: 248-735-2821
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Fax: 330-483-3942
E-mail: *sfaucher@zscan.com*
Web: *www.zscan.com*

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Oak Ridge, TN 37830
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March 29–31. Plastic Gears—Design and Manufacturing. University of Wisconsin, Milwaukee, WI. Offered through the Center for Continuing Engineering Education. Advances in materials and molding technology have provided opportunities for plastic gears to play a larger role in power transmission in many product development activities. This seminar will merge information from their plastics part design and gear technology curriculum. The objective is for participants to understand the complexity of plastic gear development, design and production. For more information contact the registration office at (414) 227-3139 or visit their website at *www.uwm.edu/dept/ccee.*

April 5–7. Fundamentals of Gear Design—Part 2 of 2. University of Wisconsin, Milwaukee, WI. Offered through the Center for Continuing Engineering Education, this is the second part of a 2-part course (Part 1 was held in December) and features Ray Drago as instructor. Topics include: manufacturing methods and considerations, inspection and quality control, materials and heat treatment, drawing data requirements and specifications, basics of load capacity rating and lubrication types and methods. For more information contact the registration office at (414) 227-3139 or log onto *www.uwm.edu/dept/ccee.*

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Gear Heat Treating by Induction

Dr. Valery Rudnev, Don Loveless, Brian Marshall,
Dr. Konstantin Shepeljakovskii, Norm Dyer and Micah Black

The induction hardening and tempering of gears and critical components is traditionally a hot subject in heat treating. In recent years, gear manufacturers have increased their knowledge in this technology for quality gears.

In contrast to carburizing and nitriding, induction hardening does not require you to heat a whole gear. With induction, the heating is localized to those areas where metallurgical changes are desired. The induction hardening process is a combination of electromagnetic, heat transfer and metallurgical phenomena that occurs when a workpiece (i.e. gear) is heated rapidly to a temperature above that which is required for a phase transformation to austenite and then rapidly quenched. One of the goals of induction hardening is to provide a fine grain martensitic layer on specific areas of the gear to increase hardness and wear resistance while allowing the remainder of the part to be unaffected by the process. Another goal deals with an ability to provide significant compressive stresses at the workpiece surface. This is a crucial feature, since it reduces crack propagation.

Induction heat treating is typically accomplished in a relatively short time and with high efficiency because energy is applied to the part only where it is needed. Induction equipment can be easily automated and incorporated into a work cell. The ability to heat treat in-line, as opposed to batch processing, provides high productivity and controllability and takes less shop floor space.

Fig. 1—Sample induction hardened gears.

The kind of steel or iron used and its prior microstructure and gear performance characteristics dictate the required hardness profile, gear strength and residual stress distribution. Minimum gear shape distortion and pattern repeatability are among the most critical parameters that should be satisfied when heat treating gears.

Not all workpieces are well suited for induction heating. The best candidates are parts that have a classical geometry, including bushings, bars, pins, rings, plates, shafts, etc. External spur and helical gears, bevel and worm gears, internal gears, racks and sprockets are also among the parts that often undergo heat treating by induction (Fig. 1).

Hardening Patterns

The first step in designing an induction gear heat treatment machine is specifying the required hardness profile. There is a common misconception that a uniform contour profile is always the best pattern for gear hardening applications. It is not. In many cases, a certain hardness gradient profile can provide a gear with better performance. Let's briefly evaluate a variety of hardening patterns (Fig. 2) and their effect on a gear's load carrying capacity and life.

Pattern A is a flank hardening pattern that has been used since the late 1940s for hardening large gears (outside diameter greater than 300 mm with tooth modules of 10–12 and larger). This pattern provides the required wear resistance, but the typical failure mode of gears with this type of pattern is a fatigue crack initiating at the tooth root area. It is typically strongly recommended that one use a pattern that hardens the root area as well, such as that pictured in pattern I.

Pattern B is a flank and tooth hardening pattern. This pattern has a similar shortcoming to the previous one, featuring poor load carrying capacity. It can be used in cases where wear resistance is of prime concern. However, patterns E, F and G provide better results

Dr. Valery Rudnev
is group director, science & technology, for Inductoheat, Inc. He has an M.S. in electrical engineering and a Ph.D. in induction heating. From 1993 to 1999, he worked as chief scientist for Inductoheat. He has 24 years of experience in induction heating. His credits include 14 patents and 92 scientific and engineering publications.

Don Loveless
is group vice president, research & development, for Inductoheat, Inc. He has 28 years of experience in induction heating. He concentrates on the research and development of high-/medium-frequency thyristorized and transistorized power supplies. Among his credits are 4 patents and 18 research/engineering publications devoted to different aspects of induction heating.

Brian Marshall,
applications engineer, joined Inductoheat, Inc. in 1979. He has been involved in the design and development of machines and processes for a variety of induction heat treating applications, including heat treatment of gears.

Dr. Konstantin Shepeljakovskii,
retired, has a Ph.D. in material science. Among his credits are more than 60 patents. He works as a consultant for Inductoheat, Inc. and NPO TechMash (Russia).

Norm Dyer,
international sales manager, joined Inductoheat, Inc. in 1989. He holds a B.Sc. degree from Wayne State University. Mr. Dyer has been involved in the improvement of a variety of induction metal heat treating processes.

Micah Black,
induction coil design supervisor, joined Inductoheat, Inc. in 1981. He has been involved in the development of a number of advanced induction processes and coil designs. Among his credits are 6 engineering/research publications.

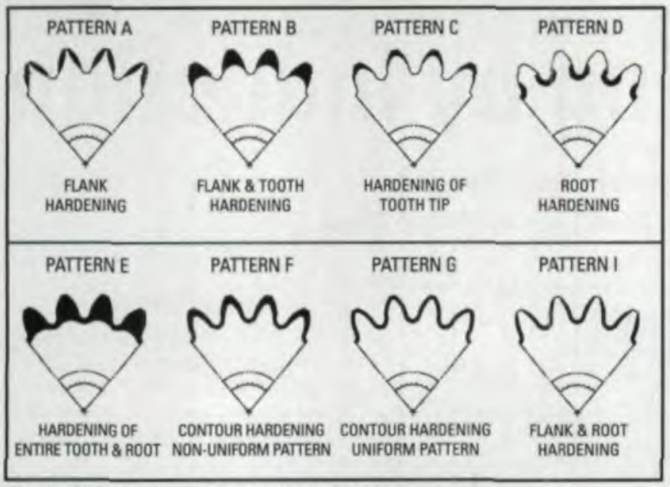

Fig. 2—Induction hardening patterns for gears.

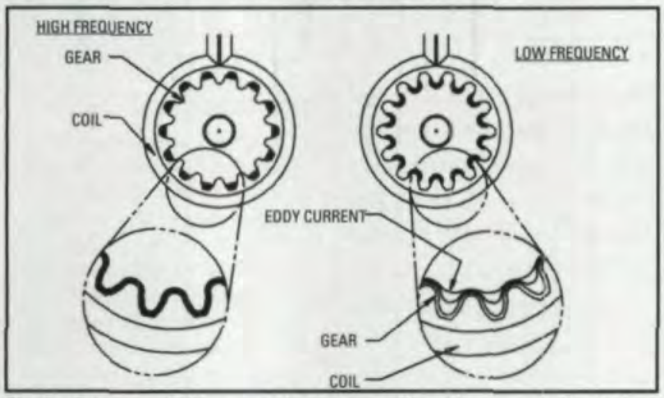

Fig. 3—Frequency influence on hardness profile with an encircling induction coil.

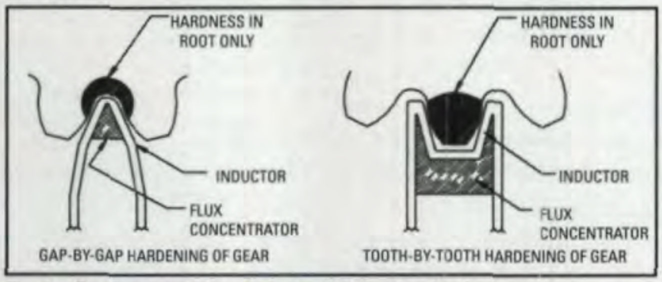

Fig. 4—Gap-by-gap and tooth-by-tooth induction hardening.

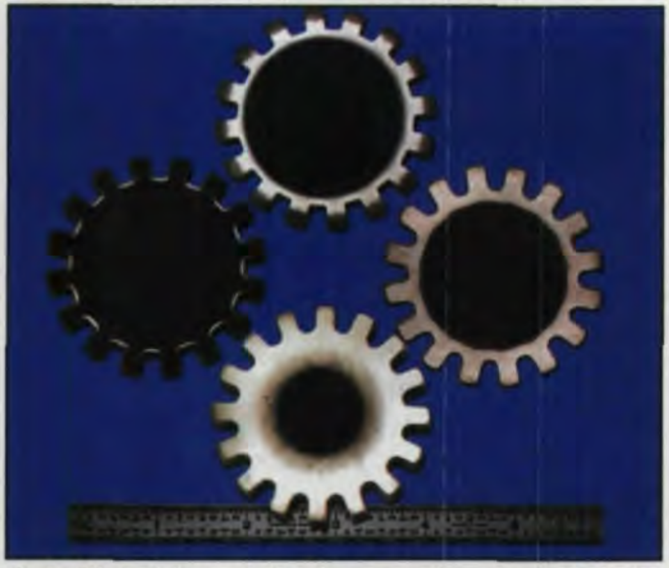

Fig. 5—Effects of changes in time, frequency and power on the hardening patterns in a steel shaft.

when wear, tear and fatigue resistance are required.

Pattern C is a tooth tip hardening pattern. In this case, the gear has minimum shape distortion. The application of gears with this pattern is extremely limited because the two most important gear areas (flank and root) are not hardened. In most cases, patterns F and G would be better choices.

Pattern D is a root hardening pattern. Application of this pattern is very limited as well, since it has poor wear resistance. Theoretically, it is possible to imagine the necessity of using this pattern as well as the previous one; however, practically, it is better to use another pattern, such as pattern I.

Pattern E is one of the most popular induction hardening patterns, particularly for small gears and sprockets. Since the body of the tooth is through hardened, there is a danger of brittle fracture in gears subjected to shock loads. Therefore, one typically applies a low-temperature tempering that lowers the final hardness down to 52–58 HRC. This pattern offers good resistance to wear and pitting.

Patterns F & G are popular patterns for medium size gears in many applications. Case depth at the root area is typically 30–40% of the depth in the tooth tip. It is very important to harden an entire gear perimeter, including flank and root area. A relatively ductile tooth core (28–44 HRC) and a hard surface (56–62 HRC) provide a good combination of such important gear properties as wear strength, toughness and bending fatigue.

Pattern I is one of the most popular choices for induction hardening large gears and pinions (300 mm or more in outside diameter) with coarse teeth (modules greater than 10–12). This pattern provides an exceptional combination of fatigue and tear strength and shock resistance, which is very important for heavily loaded gears and pinions experiencing severe shock loads.

Coil Geometry and Heat Mode

The variety of required hardness profiles calls for different coil designs and heat modes. Development, including coil design, is largely based on induction principles, the results of mathematical evaluation and experience with previous jobs. The development establishes not only process parameters, including cycle times and power levels, but also coil geometry.

Tooth-by-tooth and gap-by-gap inductors. Generally speaking, gears are induction heat treated by either encircling the part with a coil (Fig. 3) or, in larger gears and pinions, heating them tooth-by-tooth or gap-by-gap (Fig. 4). Both tooth-by-tooth and gap-by-gap techniques can be realized by applying a single-shot or scanning mode. A gap-by-gap inductor can be designed to heat only the root and/or flank of the tooth, leaving the tip and the core soft and ductile. There are many variations of coil designs applying these principles. Probably one of the most popular is a "zigzag" shaped inductor.

Generally speaking, power requirements of both tooth-by-tooth or gap-by-gap hardening are relatively low, and applied frequencies are usually in the range of 1-10 kHz. At the same time, this is a time-consuming process with a low production rate. Pattern uniformity is very sensitive to coil positioning. In addition, there is typically an appreciable shape or size distortion. Shape distortion is particularly noticeable in the last heating position. The last tooth can be pushed out by 0.1-0.3 mm. Therefore, final grinding is often required. Distortion can be minimized by hardening every 2nd tooth or tooth gap, (but this requires 2 revolutions to harden the entire gear). It is necessary to mention here that due to small coil-workpiece air gaps (0.5-1.5 mm) and harsh working conditions, the induction coils often require intensive maintenance and have relatively short lives compared with inductors that encircle the gear. When designing this type of inductor, particular attention should be paid to electromagnetic end/edge effects and the ability to provide the required pattern in the gear face areas.

Encircle inductors. When applying encircle coils, there are five parameters that play a dominant role in obtaining the required hardening pattern: frequency, power, cycle time, coil geometry and quenching conditions. Proper control of these parameters can result in totally different hardened profiles. Figure 5 illustrates a diversity of induction hardening patterns that were obtained on the same carbon steel shaft thanks to variations in time, frequency and power. As a basic rule, when it is necessary to harden the tooth tips only, a higher frequency and high power density should be applied (Fig. 3, left picture). When hardening the tooth root, a lower frequency and lower power density should be used (Fig. 3, right picture). A high power density generally gives a shallow pattern; conversely, a low power density will produce a deep pattern.

Figure 6 shows three of the most popular design concepts of the induction gear heat treating processes that employ encircle-type coils: conventional single frequency concept (CSFC), pulsing single frequency concept (PSFC) and pulsing dual frequency concept (PDFC). All three concepts can be used in either a single-shot or scanning mode.

The conventional single frequency concept is typically used for hardening gears with small teeth. As one can see in Figure 2 (patterns B & E), the teeth are usually through hardened. Quite often, CSFC can also be successfully used for medium size gears. As an example, Figure 7 shows the induction gear hardening machine that applies this concept. The part being heat treated in this application is an automotive transmission component with helical teeth on the inside diameter and large teeth on the outside diameter. Both the inside diameter and the outside diameter require hardening (Fig. 8). The hardening of the inside diameter gear teeth requires a higher frequency than the outside diameter. Therefore, a frequency of 10 kHz was chosen for O.D. hardening, and a 200 kHz frequency was chosen for I.D. heating. Precise control of the hardening operations and a sophisticated design concept minimize part distortion and provide desirable residual stresses in the finished gear.

Gears are conveyed to the machine, where they are transferred by a cam-operated robot to the spindle of a heat treating

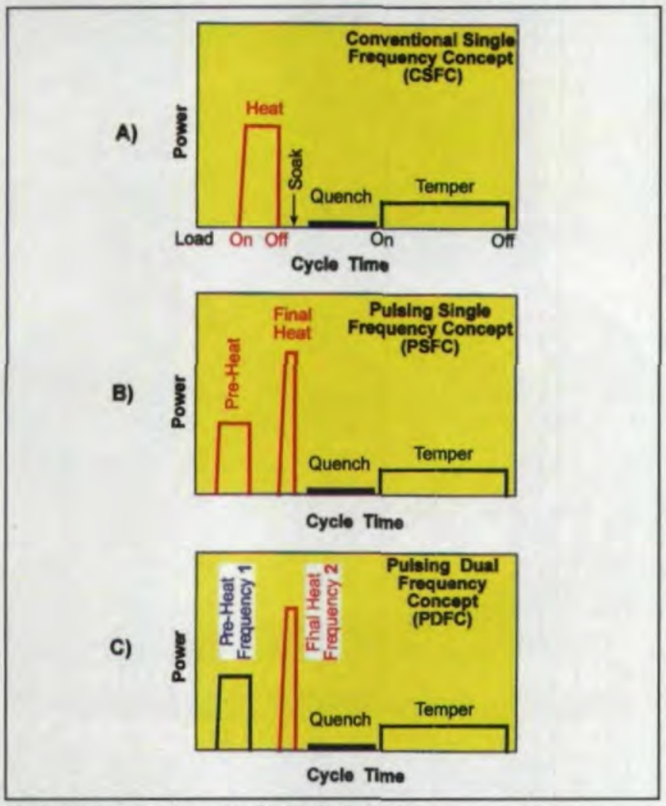

Fig. 6—Concepts of gear hardening by induction.

Fig. 7—Induction heat treating an automotive transmission gear with internal and external teeth.

Fig. 8—Cross section of an automotive transmission component after induction hardening.

station. Parts are monitored at each station and accepted or rejected based on all the major factors that affect gear quality. This includes energy input into the part; quench flow rate; temperature and pressure; and heat time. An advanced control/monitoring system verifies all machine settings to provide confidence in the quality of processing for each individual gear.

Quite often, in order to prevent problems such as pitting, spalling, tooth fatigue and endurance, it is necessary to harden a contour of the gear (contour hardening). In some cases, this can be a difficult task due to the difference in current density (heat source) distribution and heat transfer conditions within a gear tooth. Two main factors complicate the task of obtaining a required contour hardness profile.

The first factor is that with encircle-type coils, the root area does not have a good coupling with the inductor compared to the coupling at the gear tip. Therefore, it is more difficult to induce energy in the gear root. Secondly, there is a significant heat sink located under the gear root (below the base circle, Fig. 3). In order to overcome these difficulties and be able to meet customer specifications, the pulsing single frequency concept (PSFC) has been developed (Fig. 6b). In many cases, PSFC allows the user to avoid the shortcomings of CSFC and obtain a contour hardening profile. Pulsing provides desirable heat flow towards the root of the gear tooth without noticeable overheating of the tooth tip.

A typical "dual pulse" contour hardening system, which applies a pulsing single frequency concept, has been discussed in Reference 2. This machine is designed to provide gear contour heat treatment (including pre-heating, final heating, quenching and tempering) with the same coil using one high frequency power supply. Figure 6b illustrates the process cycle with moderate power preheat, soaking stage, short high power final heat and quench followed by low power heat for temper. Preheating ensures a reasonable heated depth at the roots of the gear, enabling the attainment of the desired metallurgical result and decreasing the distortion in some materials. Obviously, preheating reduces the amount of energy required in the final heat.

A third concept—the pulsing dual frequency concept (PDFC)—is not a new one. The idea of using two different frequencies has been around since the late 1950s. This concept was primarily developed to obtain the contour hardening profile of helical and straight spur gears. Since several different companies, including Contour Hardening, Inductoheat and others, have pursued this idea, several different names and abbreviations have been used to describe it. However, regardless of the differences in nomenclature and the slight process variations, the basic idea is the same.

According to PDFC (Fig. 6c), the gear is preheated within an induction coil to a temperature determined by the process features that is usually 50–100°C below the critical temperature A_{c1}. Typically, this is accomplished by using a medium frequency (3–10 kHz).

Depending on the type of gear, its size and material, a high frequency (30–450 kHz) and high power density are applied during the final heat stage. For the final heating stage, the frequency selected allows the current to penetrate only to an exact repeatable depth. Quenching is done to complete hardening and bring the gear to ambient temperature. In some cases, dual frequency machines produce parts with lower distortion and more favorable distribution of residual stresses compared to other techniques.

The main drawback of this process is its complexity and high cost, since it is necessary to have two different power supplies. In some cases, it is possible to use one dual-frequency power supply instead of two single frequency inverters. However, the cost of these variable frequency devices is high, and their reliability is quite low.

Special attention should be paid when designing induction hardening machines for powdered steel gears. These gears are affected to a much larger extent by variations in the material properties of powder metals as compared to gears made by casting or forming. This is because the electrical resistivity, thermal conductivity and magnetic permeability strongly depend on the density of the powder metal.

TSH Technology for Gears

An impressive result can be achieved not only by developing a sophisticated process, but also by using existing processes with a combination of advanced steels. Through and surface hardening technology (TSH) is a synergistic combination of advanced steels and special induction hardening techniques. These steels were invented by Dr. K. Shepeljakovskii (Ref. 6). The new low-alloyed carbon steels are characterized by very little grain growth during heating into the hardening temperature range. They can be substituted for more expensive, standard steels that are typically hardened by conventional induction, carburizing or quenching and tempering.

Main features of TSH technology include:

- TSH steels are relatively inexpensive, incorporating significantly smaller amounts (3–8 times less) of alloying elements such as manganese, molybdenum, chromium and/or nickel.
- Lower induction hardening frequency (1–10 kHz) reduces power supply cost.
- High surface compressive residual stresses (500 Mpa/73 ksi +).
- Hardened depth is primarily controlled by the steel's chemical composition and initial microstructure. This makes the heat treating process repeatable and robust.
- Reduced chance of overheating part edges and sharp corners due to end effect.

Figure 9 shows an induction heat treated gear made from TSH steel. One of the unique features of that gear is that instead of using a two-step approach (first O.D. heat and then I.D. heat, or vice-versa), that gear has been heated and quenched in a single step using only one inductor. O.D. and I.D. teeth have fine grained martensite with a hardness of 62 HRC. The microstructure of the core is a combination of very fine pearlite and bainite having a hardness of 25–40 HRC.

TSH technology parts are stronger and more durable than some made of conventionally heat treated standard steels. Typical applications include gears, bushings, shafts, coil springs and bearings (Ref. 6).

Induction Tempering

The stress relieving/tempering process takes place after the part is hardened. It is a subsequent but no less important step in metal heat treating. The main purpose of tempering is to decrease the gear brittleness without causing too great a decrease in the as-quenched hardness, to relieve internal stresses, and in some cases to improve shape stability (Ref. 5).

A conventional method of tempering induction hardened gears is to heat them in an oven or a gas-fired or infrared furnace, which is typically located in another area of the plant. This has penalties in terms of floor space, labor and time needed to transport parts. In addition, a furnace tempering operation may take two to three hours to complete. Short-time induction tempering was developed to overcome these drawbacks.

Time and temperature are two of the most critical parameters in short-time induction tempering. However, temperatures higher than those used for furnace tempering must be used to provide a similar effect. There are several ways to determine the time-temperature correlation between conventional long-time, lower temperature furnace tempering and short-time, higher temperature induction tempering, including, for example, the Hollomon-Jaffe equation and the Grange-Baughman tempering correlation.

There is a common misconception that tempering removes all internal stresses. Tempering does decrease some stresses. It makes the steel softer and reduces the chance of noticeable distortion and the possibility of cracking. As a matter of fact, it is not really desirable to relieve all stresses. As mentioned above, in most gear heat treating applications, the existence of good compressive residual stresses at the gear surface is useful and very desirable since it reduces the possibility of crack development.

There is a balance of residual stresses in the workpiece. Therefore, if in certain areas of the gear there are compressive residual stresses, then somewhere within the workpiece, there must be tensile stresses. Applied stresses are maximum at the gear surface and then rapidly drop off. Therefore, one of the important "duties" of tempering is not only the reduction of tensile stresses, but also the shifting of the maximum of these stresses toward the core.

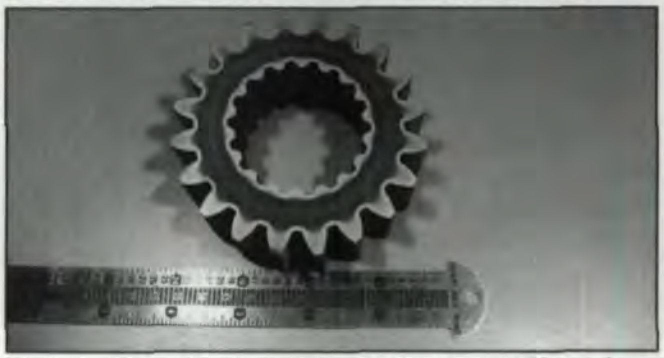

Fig. 9—An induction heat treated gear made from specialty TSH steel.

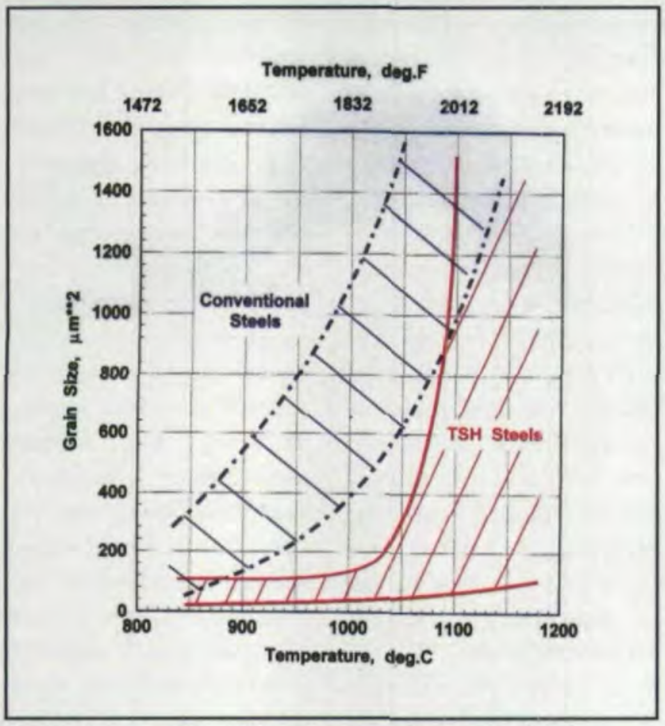

Fig. 10—Grain growth for TSH steels vs. that of conventional grades.

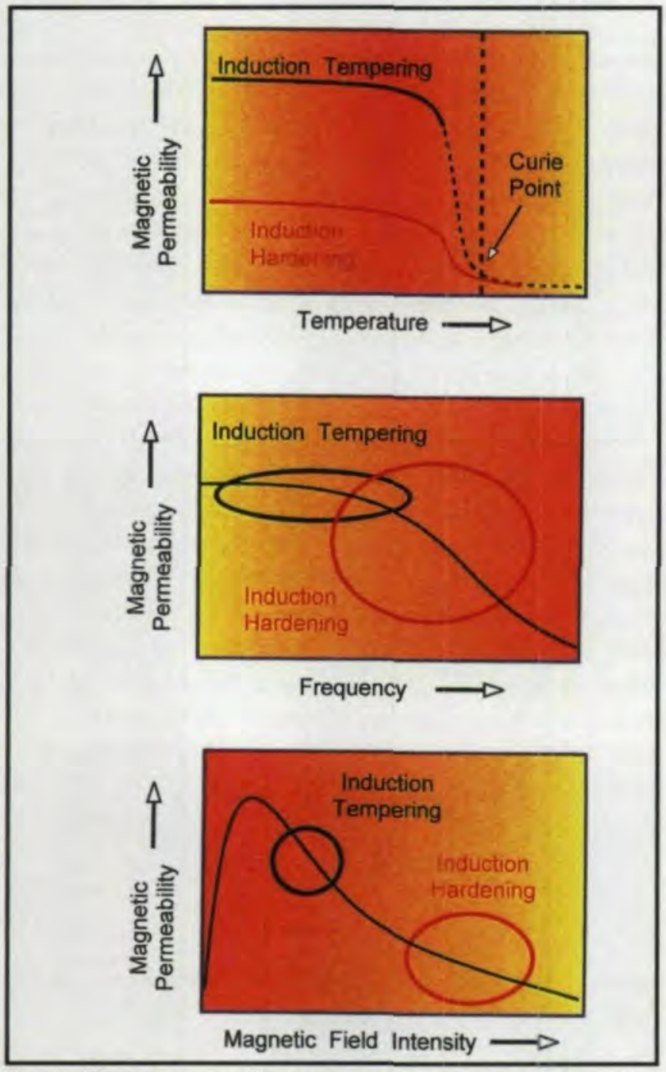

Fig. 11—Magnetic permeability vs. temperature, frequency and magnetic field intensity.

It is important that the time from quench to temper be held to a minimum. If this "transient time" is long enough, the internal stresses may cause a noticeable size and shape distortion, or even cracking. Therefore, a long transient time between quenching and tempering will *decrease or eliminate the tempering benefits.*

In the case of induction tempering any complex parts (including gears), the choice of frequency, power density and coil geometry is dictated by the need to apply enough energy into certain areas of the part. In gear tempering applications, it is necessary to induce enough energy into the root area of the tooth without overheating its tip.

The root of the gear is a critical area because the maximum concentration of stresses is typically located there. As a result, fatigue cracks occur primarily in the root area. Therefore, it is very important for this area to be stress relieved. There are three factors that make this task quite a complicated one. Two factors are similar to hardening and were discussed above. One of them deals with poor electromagnetic coupling between the coil and the tooth root compared with the tooth tip. Another one deals with the existence of a heat sink phenomenon in the root. The third factor derives from the fact that the tempering temperatures are always below the Curie point. Therefore, the gear is magnetic and the skin effect is always pronounced (Fig. 3, left figure). The use of high frequency for induction tempering will result in an essential power surplus in the tip of the tooth compared to its root and will have a tendency to overheat edges and sharp corners. In order to overcome these difficulties, low frequency, loose coil coupling and low power density should be used for tempering.

As discussed above, it is possible to harden and temper gears in the same coil using *the same power supply.* In some cases, it is the best concept and has an obvious low capital cost advantage and less tooling to store. In other cases, it might not best suit customer requirements.

Since the power density required for tempering is quite low, it is necessary to heat a gear at a slow rate to avoid tooth tip overheating. Depending upon the type of power supply, this is not always an easy task from the load matching point of view. In addition, the depth of current penetration in carbon steel at tempering temperatures is very small compared to its value during hardening. This is due to the fact that tempering temperatures are always below the Curie point, and therefore, steels are always in a magnetic state. In addition, the relative magnetic permeability of steel during induction tempering is more than ten times higher compared to the permeability of steel during induction hardening. This is due to the low magnetic field intensities used in induction tempering (Fig. 11).

A substantial increase in magnetic permeability results in a significant decrease in penetration depth of an induced current. Therefore, in order to heat a gear for tempering to the same depth as hardening, it is wise to use a lower frequency.

In addition, time required for induction tempering is typically 2–4 times that of induction hardening. Therefore, when one uses the same coil for hardening and tempering, the production and power supply utilization might suffer.

Heating for tempering with a separate coil and dedicated power supply is a more costly solution from a capital investment point of view, but at the same time, it has several noticeable advantages. The current distribution and power density can be optimized specifically for the tempering operation. A separate, loosely coupled, channel-type, single- or multi-turn coil can be used effectively for this purpose. Equipment will be used very effectively with high production. One hardening machine can operate in conjunction with two or three tempering machines.

The decision to induction temper should be carefully weighed (Ref. 5). Some metallurgists are not comfortable with tempering for a short time and then only in the hardened area. They feel that furnace heating of the entire part and holding it a temperature for hours, vs. seconds or minutes, is more reliable. The key to any gear or critical component production process is how well the finished part performs in service. An induction tempered gear, like any other machine component, should be thoroughly tested and evaluated for reliability. Necessary test data for induction and furnace tempered parts should be compared. It is important to remember that the surface temperature alone is not a valid indication of a proper temper. If tempering has been done correctly, there will be only a slight reduction in hardness, which will be more than offset by the benefits obtained, including internal stress relief, improved ductility or toughness, and shifting of the maximum tensile stress farther away from the applied stress.

The advantages of induction tempering—system compactness, single part processing, energy efficiency, and precise control and monitoring of an individual part—in many cases far outweighs the disadvantages and fear of the untried.

Conclusion

Space limits this discussion to major features of induction gear heat treating. There are many aspects involved in designing and manufacturing contemporary gear hardening and tempering systems. This includes an effect of prior microstructure and grain size on hardening pattern. Others deal with quenching, cracking, shape/size distortion and residual stress distribution. ○

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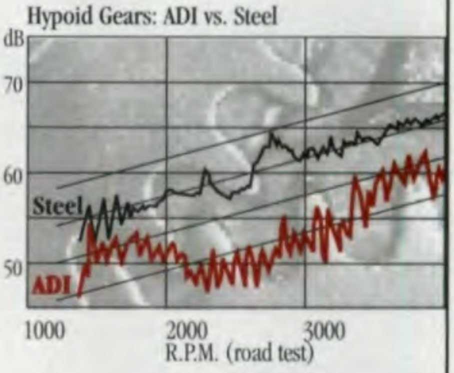

Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.

New 2-Speed Machine Tool Gearbox

"Built-in" RAM-MSD 2-speed gearboxes, available from Andantex USA, Inc., are integrated in-line between the water-cooled motor and the spindle inside of the machine tool's RAM. These units extend the constant power speed range of the motor, providing high output speeds (8,000 rpm) for finishing aluminum and high torque at low speeds for hogging out steel or cast iron. Standard ratios are 1:1, and reductions range from 2.5:1 to 5:1.

Other design features include a round, water-cooled housing, a hollow through bore, low backlash, and compact, high-quality planetary gearing to insure minimum vibration, quiet and cool operation. The integration of the compact, lightweight gearbox into the RAM enables rapid Z-axis acceleration and minimum chip-to-chip tool change times. For more information, contact Andantex at (800) 713-6170 or visit their Web site at *www.andantex.com.*

Circle 300

Two New Items from Ogasawara

The GRT-04 Gear Rolling Tester is designed to measure the composite error of fine pitch gears relative to the function of center distance oscillation during dual flank meshing between the test piece and the master gear. This machine is suitable for either the lab or the shop floor. The unit can also be used to measure other gear products such as plastic gears and motor shaft gears up to a foot in length. Center distance deviations are detected continuously with the GRT-04's small displacement detecting system, which utilizes a differential capacitance device for frequency modulated (FM) signal output. With optional data analyzing software, you can classify your gear products to meet with a specified gear accuracy such as AGMA, ISO or DIN.

The new HBS-1520 Hob Cutter Sharpening Machine is the result of a collaboration between Ogasawara, which designed the machine, and Saikuni, which built it. Using Ogasawara's optimal dressing method, the HBS-1520 can achieve both a mirror finish on the cutting surface and extreme geometrical accuracy. Carbide hobs can be sharpened using a diamond wheel and helical flutes can be ground with the optional spindle head. The machine is easy to set up and operate and it can reduce grinding costs with its automatic grinding procedures.

For more information, contact Ogasawara Precision Hob Lab, Ltd. at +(81) 44-877-3511 or visit their Web site at *www.og-pl.co.jp*. You may also contact their American representatives, Russell, Holbrook and Henderson, Inc., at (201) 670-4220 or visit their Web site at *www.tru-volute.com.*

Circle 301

New RV Gear Reducer from Harmonic Drive

Harmonic Drive Technologies introduces the Rotary Vector (RV)-C hollow shaft gear reducer. The RV-C gear is open through the center, allowing vacuum lines, wiring harnesses, concentric shafting and cooling lines to be run through it. Hole sizes range from 31 mm (1.2") to 138 mm (5.4"). The RV-C also has specially designed, built-in output bearings that support large thrust and overhung loads.

The RV-C is one of three heavy-duty RV power transmission configurations manufactured by Teijin Seiki and supplied by Harmonic Drive Technologies. These are precision drives that offer high-ratio gear reduction in a compact design. RV drives offer very high torsional rigidity and an overload torque capacity of 500% of the unit's rated torque. Total lost motion from all sources including backlash, spring rate and hysteresis, is limited to one arc-minute. For more information call (800) 921-3332 or visit Harmonic Drive Technologies' Web site at *www.harmonic-drive.com.*

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Rotary Diamond Dressing Roll Holds Tip Longer

Norton Company introduces a line of patent-pending precision rotary diamond roll dressers that maintain tip geometry longer, when CNC-profile-dressing intricate forms into conventional and superabrasive wheels.

The new Lap-Free BPR Profile Dressing Rolls are different from conventionally manufactured infiltrated and plated profiling rolls, which often use polycrystalline diamond (PCD) or natural diamond material. They are designed not to require relapping and are available in forms with included angles not previously available for CNC profile dressing.

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Possessing high strength and hardness, along with excellent corrosion resistance, the new precipitation hardening stainless alloy is a candidate material for rod-end bearings, a variety of aircraft structural components and some engine parts. The new alloy may be considered a more machinable version of the standard 15Cr-5Ni stainless, which has been used for industrial applications such as gun barrels, valve parts, fittings and fasteners, shafts, gears and process equipment. For additional information or a technical data sheet, contact Jim Dahl by phone at (610) 208-2235 or by e-mail at *jdahl@cartech.com.*

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

Clocks with wooden gears? In these days of gears made from plastic, steel and exotic materials; it is a little unusual to hear about a practical application for wooden gears. But that is exactly what David Scholl, the owner of Changing Times, a Harlingen, TX, clockmaker, is offering us.

His company specializes in making wooden geared clocks. It is a one-time hobby that Scholl made into a business. "I made my first wooden clock in about 1980," says Scholl. "At the time, I was attending college and working on an Industrial Arts/Business Administration degree. While thumbing through a woodworking magazine, I found an article describing the basic principles involved in clock mechanisms. Eventually, I found the name and address of a company under the direction of R. D. Thomas. Mr. Thomas sold (sells) plans for wooden geared clocks, so I ordered them and got to work." The clocks he makes today are weight driven and can be made to run from 24 hours up to eight days depending on the drive train.

A wooden geared clock. Courtesy of Changing Times.

That drive train is made up of wooden spur gears with involute teeth. These are not little, fine pitched gears, either. "Because wood is less dense than other materials, there is an increased need for structural mass in order to add strength and stability to the gear teeth. Therefore, both for appearance and function, larger DP sizes are used beginning at 10 DP and going up," says Scholl, who adds that the gears are made using modified woodworking equipment. "Table saws have been modified to accept standard milling cutters," he says. "Many jigs and fixtures are needed in order to accommodate the many sizes of gears that we make. The rough cut gears are hand-faced on a wood lathe. Also, larger gears are laminated from up to 18 different pieces of wood and then cut. This is because wooden gears are more susceptible to dimensional changes due to temperature and humidity than are gears made from other materials. This means that warping is a factor to consider. The lamination process minimizes this factor."

The average sized gear has between 30 and 72 teeth. The diameter of a 30-tooth gear with a 7 DP is approximately 4.5 inches. A gear with 72 teeth would have a diameter of 10.5 inches. Pinions start at 8 teeth and are approximately 1.25 inches in diameter. And, according to Scholl, these gears will last. "Because of the low torque and low revolutions-per-minute, these gears should last quite some time." He also adds that no grease or oil is used with the wooden gears. In fact, no lubrication is used on the teeth surfaces at all. "There are ball bearings mounted on the gear arbors in order to reduce start up friction," he says. "This is necessary because, in reality, the clocks stop and restart every second."

Wooden Gears. Courtesy of Changing Times.

Changing Times sells the wooden-geared clocks through local specialty shops, but Scholl plans to open a Web site soon. Until then, if you want more information about Changing Times and its wooden-geared clocks, send e-mail to Scholl at *chngtimes@aol.com.* ○

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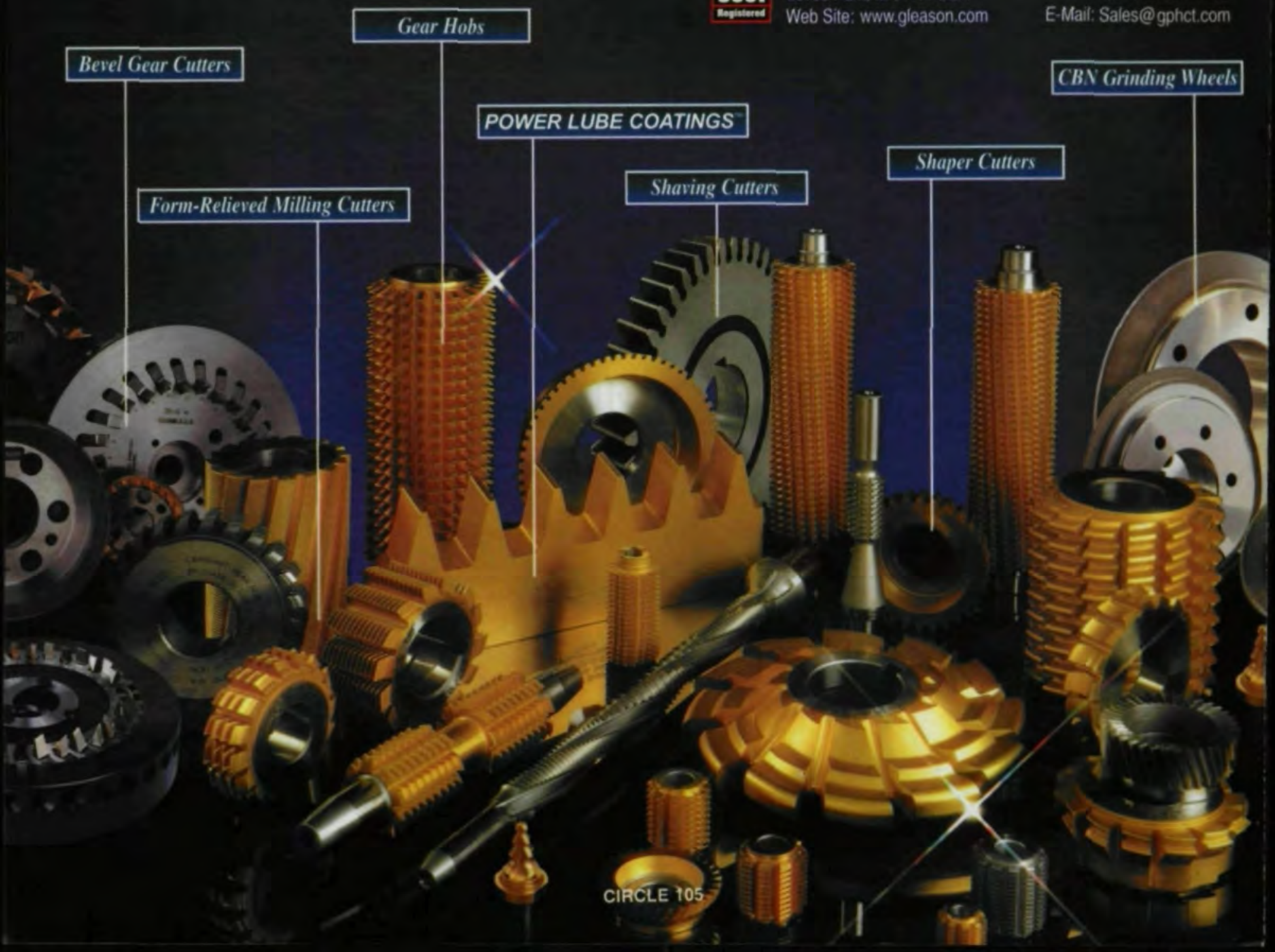
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