GEAR TECHNOLOGY

The Journal of Gear Manufacturing

HEAT TREATING—

March/April 1996

HEAT TREAT SERVICE PROVIDERS DIRECTORY
MINIMIZING GEAR DISTORTION
WEAR PROTECTION FOR GEARS
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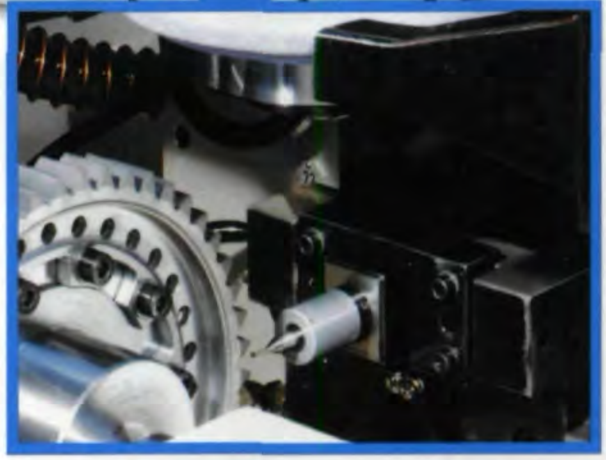

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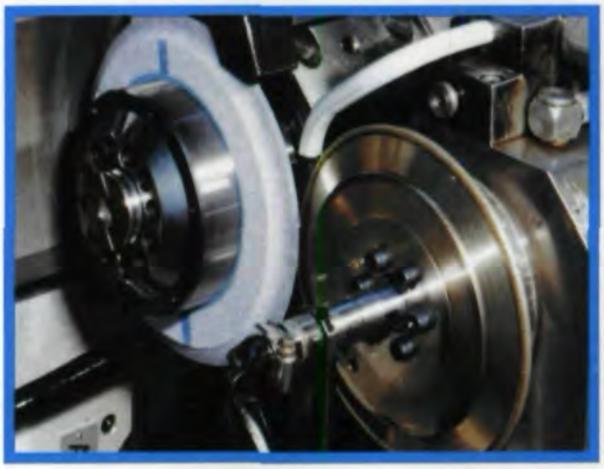

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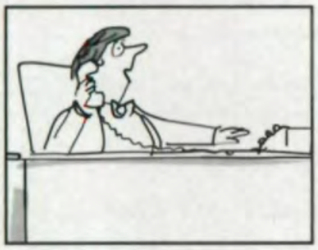

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PULSE BEAT

Every now and then a magazine has to take its own pulse or lose sight of its key mission—providing its readers with information they want. We did it this last year through surveys, interviews with subscribers and focus groups. Our basic question was, how are we doing?

The answers were encouraging (and in some cases flattering) for us, although the people we asked were more than willing to share their ideas for how we could improve. We'd like to share some of their observations with all of you and give you a chance to put in your two cents worth as well.

While most of the people we asked liked the "new" *Gear Technology* and its wider variety of article subjects and types, almost everyone encouraged us to remember our "core competency"; that is, providing technical articles about the design and manufacture of gears and geared products. That's still the thing you seem to want most. A close second was material that is timely. Information about new research, products and processes is very important to you. As we plan our upcoming issues, we'll be keeping these facts in mind.

The readers we spoke with reminded us again of the fact that many of you keep past issues of the magazine and use them for reference. They also expressed concern about the difficulty of finding particular articles from past issues. We've taken the hint, and as the year goes on, we'll be updating our indexes and developing ways to deliver back-issue information to you efficiently.

Some of the most helpful information, from our point of view, was the discussion of reading habits and the ways you do (or don't) respond to the magazine. For years one of our biggest challenges has been getting you to contact our advertisers and us through our reader response cards. We keep asking ourselves, is there a better way to do this? According to the subscribers we spoke with, several factors come into play. The need for rapid response is a key one. As the pace of business has picked up, the need for information NOW as opposed to weeks or months from now has increased. Also affecting the way you use the response cards is the fact that because the gear industry is so small and collegial, it's just easier to call a friend at the company whose product you're interested in and get the information directly.

The traditional reader response system apparently just isn't fast enough. With that in mind, we're working on developing ways to help you get the product information you need more quickly and directly.

We're still encouraging you to contact us through reader service cards or by fax, phone or mail. Your input is absolutely vital to us and our advertisers; but we understand that business realities today require us to make that process easier and faster for you. Therefore, we're also working on ways to widen our lines of communication and make them more user-friendly.

Pulse-taking is always a salutary exercise. Thanks to all of you who have taken time in the past year to let us know what you think about how we're doing. We appreciate the input. Keep your eyes out in the coming months to see the use we make of the information you've given us. And keep those comments coming. They're absolutely key to making *Gear Technology* the best and most useful magazine you receive.

Michael Goldstein
Publisher and Editor-in-Chief

Heat Treating Challenges for the Future

Where the industry should go from here.

Dr. A. H. Soni

The heat treating of gears presents a difficult challenge to both the heat treater and the gear manufacturer. The number and variety of variables involved in the manufacturing process itself and the subsequent heat treating cycle create a complex matrix of factors which need to be controlled in order to produce a quality product. A heat treater specializing in gears or a gear manufacturer doing his own heat treating must have a clear understanding of these issues in order to deliver a quality product and make a profit at the same time. The situation also presents a number of areas that could benefit greatly from continued research and development.

Critical Issues in Gear Heat Treating

Materials and Fabrication Methods. Materials, their chemical compositions and variations from one supplier to another present many challenges to the heat treater of gears. Complicating the issue is the specific gear geometry that must be retained after the heat treating process. The gear geometry parameters, such as number of teeth, involute profile, pressure angle and pitch diameter, are of critical importance, as are geometric alterations to them caused by heat treating.

Gears are fabricated a number of different ways, including hobbing, casting, forging, and powder forming. Heat treating process specifications must also consider the influence of these fabrication processes.

These heat treating issues may be resolved at the gear fabrication stage by cooperation between the gear designer and the heat treater in developing an SPC strategy. Using available predictive models, gear geometry may be purposely altered to account for part distortion after quenching. A controlled quenching process will compensate for such a predetermined alteration in the gear geometry, and the gears will then need few geometrical corrections. Processes such as die quenching should be avoided, for they set up unwarranted residual stresses. Again, a suitable application of control technology to rapid cooling may help obtain the desired result.

Hardening Methods. The heat treater must also address the question of whether the gears are to be surface- or bulk-hardened. Either induction or flame hardening can be used, although induction hardening is the preferred method for gears.

Another surface hardening method is the surface carbon-diffusion carburizing process. Gas carburizing of gear tooth surfaces to achieve the desired carbon content and the corresponding surface hardness is a more commonly accepted process for low-carbon or alloy steels.

Alternatives to surface carburizing are carbonitriding and nitriding. Since nitriding is done at a lower temperature than carburizing, gear distortion is not as severe.

Furnace Atmospheres. Controlling the furnace atmosphere for surface carburizing or nitriding is a critical issue in achieving the desired carbon or nitrogen surface penetration depth. For carburizing, the carbon depth is significant. In nitriding, the surface depth is only skin deep to achieve the desired wear properties. Both of these processes are associated with dimensional changes.

Furnace behavior and atmospheres in the furnaces may be controlled using expert systems, neural nets

This is the first of a series of articles on the future of various technologies that will influence gear design and manufacturing practice in the coming years. We will be bringing you the opinions of industry leaders, scholars and experts in these disciplines.

Dr. A. H. Soni
is director of the Center for Industrial Heat Treating Processes at the University of Cincinnati, Cincinnati, OH. He is also an Ohio Eminent Scholar and has over 25 years of experience in heat treating.

and fuzzy logic integrated controllers. These tools address both the universal and local variables that dictate the quality of heat treated gears. The fuzzy logic controller is able to control the case depth very precisely, while maintaining a controlled furnace atmosphere. Also, since the fuzzy logic controller is able to track the energy input to the furnace, it can deliver carburized gears with optimum energy and cost savings.

These advances in computers and computer-integrated controls make it feasible for heat treaters to adopt such advanced technology. However, the U.S. heat treating industry is lagging behind in its application, which is much more common in Germany and Japan.

Quenching. Gear tooth hardness is achieved through a controlled cooling process called quenching. Quenching involves heating a gear to a desired temperature and cooling it at a rapid rate to achieve desired hardness. While the principles of the quenching process may be known with some degree of reliability, the actual practice in a heat treating shop is a closely guarded mystery.

The rate of cooling is dependent upon the type of quenchant, number of stages involved, agitation rate of the quenchant, gear location and orientation in the quench tank and quench contamination and degradation. The process has too many variables to control and produce uniformly consistent quality results for gear heat treating.

Unfortunately, heat treaters have learned to live with part distortion. Instead of developing a process control strategy, they have spent their resources, expensive equipment and technical talents straightening distorted parts. According to some estimates, the U.S. auto industry spends millions of dollars a year solving problems created during quenching.

Stress Relieving. Stress relieving quenched gears is normal practice in the industry. Controlling the stress pattern within the gear tooth and understanding the microstructures and grain size during heat treating is another matter. The role of the microstructures, grain size and residual stress distribution within heat treated gears

THE U.S. HEAT TREATING INDUSTRY IS LAGGING BEHIND IN THE APPLICATION OF ADVANCED TECHNOLOGY TO ITS PROCESSES.

is generally well understood by heat treaters; however, not much importance is given to these variables in practice. User-friendly technology to analyze the influence of these variables is much needed.

Equipment. Heat treating equipment plays a significant role in developing heat treat processes and heat treat specifications for gears. Since the processes are dependent on the equipment, the technology is vendor-driven. Most commercial heat treat shops

are limited in their resources; hence, they are unable to keep up with the capital investment required for implementation of new processes.

U.S. heat treaters eventually will have to face this fact and develop their own technology instead of depending upon the vendors, but this creates an additional burden on them. A reasonable solution is to develop a joint collaborative effort among the material suppliers, equipment vendors, process controllers and heat treaters to serve their clients. Professional groups such as the ASM Heat Treating Society are in an ideal position to serve this purpose.

Standards. Many heat treatment standards are available today, but with ever-increasing international competition, pressure is on heat treaters to learn to comply with ISO standards and practices. Accepting the ISO as a universal standard is a way to establish common ground for heat treaters to understand their client needs. The existing heat treatment standards will become the backbone of the ISO standards. Such integration of standards will create a win/win situation. Not only will everyone be speaking the same language, but when disputes about processing and legal liability arise, a heat treater would have the commonly accepted ISO standard to back him up.

In the meantime, the University of Cincinnati Center for Industrial Heat Treating Processes has a database-integrated expert system for PCs that permits a user to search for suitable heat treatment standards for a wide variety of materials. These standards (all in English) are from the U.S., Japan, France, Italy, Germany and other countries. Given a material designation or composition, one may search these standards and compare the differences in the various specifications.

Present environmental standards for the industry are another cause for concern. They are very restrictive. In some cases, meeting these standards can put a heat treater out of business. Some kind of common ground will have to be developed to allow heat treaters a reasonable profit margin while still protecting the environment.

Training. Training of personnel to keep up with technical advances is a critical issue for the captive and commercial heat treaters. Most educational organizations do not offer a practice-oriented education training program on heat treating. The practice in industry is labor-intensive and still relies very heavily on local experience. This is another area in which much work needs to be done.

Advances in Heat Treating Science, Technology and Its Practice

We have briefly discussed the issues which influence the way heat treating is done today. How the industry addresses these issues will determine what the industry will look like in the future.

New technology and approaches are now available for the heat treating industry if it will only take advantage of them. They include:

- Process development and its control,
- Networking to share common resources and problems,
- Material handling to bring automation to the captive heat treating auto industry,
- Development of production schedules to reduce cycle times,
- Implementation of real-time process control,
- Training of personnel to learn and implement new heat treating technology.

Because of a large number of variables that affect the outcome of heat treated gears, heat treaters should develop their own process control strategies to deliver quality in their work. While the typical methodologies remain the same in developing such process control strategies, the approach has to be individualized by each heat treating enterprise. The Taguchi method to identify the significantly contributing parameters, statistical process control, quality control, PID control and fuzzy-logic-based control are some of the technologies that one may apply, depending upon the process and the required degree of control.

Networking of heat treaters, equipment vendors and material suppliers is an alternate approach to gaining the knowledge needed to develop a process control. The ASM Heat Treating Society, Ohio's Heat Treat Network, the Metal Treating Institute and the University of Cincinnati's Heat Treating Research Center, among others, provide avenues for heat treaters and the users of their services to link up.

Material handling is a key to automation and is very much needed in the heat treating industry. Because of smaller batch sizes and part and material variation, heat treaters should look into developing flexible heat treating work cells. Adaptation of such new technology will significantly improve serviceability, productivity and profit.

With a suitable development of flexible heat treating work cells, a heat treater is in an ideal position to develop a production schedule and optimize his resources to give the best turnaround.

Real time process control is needed in gas carburizing, nitriding and quenching. However, much work remains

MEETING PRESENT RESTRICTIVE ENVIRONMENTAL STANDARDS CAN PUT A HEAT TREATER OUT OF BUSINESS. SOME COMMON GROUND WILL HAVE TO BE ESTABLISHED TO ALLOW HEAT TREATERS A REASONABLE PROFIT WHILE STILL PROTECTING THE ENVIRONMENT.

to be done in this area beyond integrating the sensors in the furnaces to control the furnace atmosphere.

Training of the personnel is a key to developing a quality heat treating process. However, because of the limited number of resources available to the heat treaters and to the educational institutions, this issue has not been addressed at a satisfactory level. Plenty of room for progress remains.

New Materials and Processes

New materials that will provide some challenges to gear heat treating industries are the composite materials. Metal matrix composites in particular are expected to change the way we will fabricate gears with a desired degree of hardness and other mechanical properties.

The nitriding process has gained significant acceptance in the heat treating industry. With some modification, it may replace the popular gas carburizing process, which is very time-consuming, costly and creates severe metallurgical problems. The induction hardening process may get replaced by a patented gas heat treating process under development that is as fast as induction heating. Since the heating cost is considerably less in this process, the fast heating gas furnaces show promise for the industry. Much development is needed, however, before this fast-heating gas fired furnace's integrated process is commercialized.

Cutting Edge in Heat Treating Research

Some of the important issues that need to be addressed now include:

- An affordable, user-friendly computer simulation model for predicting gear distortion as a result.
- An affordable, user-friendly computer simulation model for predicting residual stresses in heat treated gears.
- An affordable, user-friendly computer model for the quenching process to achieve the desired hardness and microstructures.
- Real-time process control methodology for heat treaters.
- Design and implementation of flexible gear heat treating systems.

Using the finite element technique, The Center for Industrial Heat Treating Processes has developed models for predicting part distortion and residual stresses in gears that are made from plain carbon and alloy steels. The Marathon Monitor has developed a model for the gas carburizing process. The National Center for Manufacturing Science (NCMS) through its CRADA agreement with the national government laboratories is developing a quenching model for heat treating processes.

While a significant amount of new technology is being developed and may be available to the user, the industry is still pursuing a pragmatic, best-compromise approach to delivering the quality heat treating service. The ideal of a 100% guaranteed, completely controllable and predictable process that is affordable for the customer and profitable for the provider is still a long way away. ○

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Minimizing Gear Distortion During Heat Treating

Marcel Suliteanu

Graded hardening technology has proven over the years to yield very good results when used in the heat treating of carburized gears. It is especially advantageous for smaller companies, subject to higher competitive pressures. Unfortunately, despite the fact that graded hardening is a very well-known method, its use has been limited. We strongly recommend this technology to all of those who need to produce gears with high metallurgical quality.

A Few Well-Known Facts

The distortion of the gears made out of case-hardening steel is one of the biggest flaws in the carburizing-hardening process. This distortion causes great difficulties in the manufacturing process, complicates machine tool technology, calls for costly readjustment and straightening operations, prolongs the manufacturing cycle and drives up the costs.

When gear tooth distortions are so great that grinding cannot correct them, a reduction in the case quality follows. Among the results are

- the exaggerated grinding of the carburized layer,
- the removal of carbides out of the carburized layer,
- the decrease in the hardness of the carburized tooth surface,
- anomalies caused by rough grinding of the carburized layer.

In the broader sense of the word, distortion includes both the notion of "variations of dimensions" as well as the notion of "curving." The variation of dimensions caused by structural tensions is unavoidable, while curving is an avoidable distortion of the gear caused by inaccurate heat treatment, such as faulty heating and cooling, inappropriate placement of the gears, uneven carburization, single-side carburization, structural defects, etc.

The variation of dimensions is determined by several elements. One of the most important determining factors is the connection between the depth of the case and the thickness of the gear tooth. The case is dominant in gears with a layer of carburization that is more than half the thickness of the gear itself. Such gears will shrink in the largest dimension.

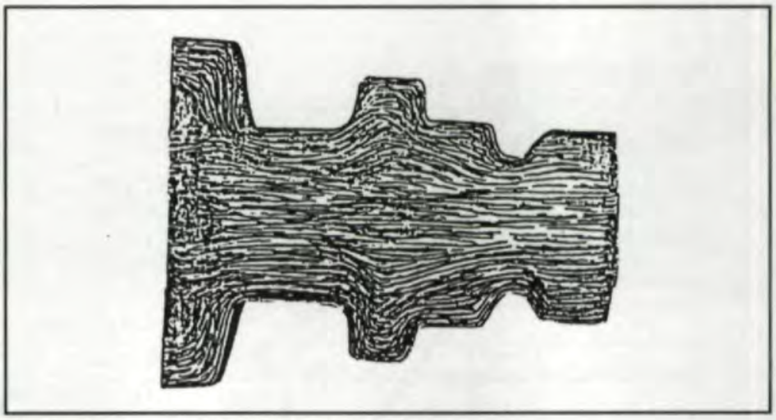

Fig. 1 — The correct distribution of fibers in a gear.

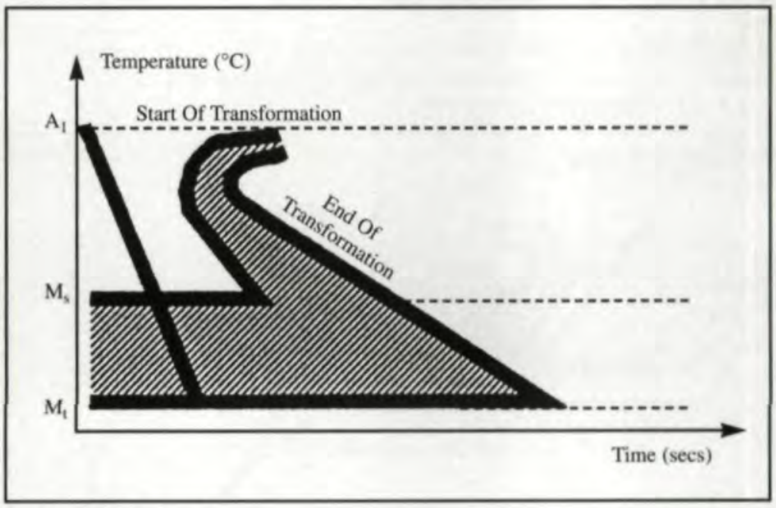

Fig. 2 — Cooling curve.

If, on the contrary, the case is small compared to the tooth section, the variation of dimensions is determined by the way the case responds to the transformation that produces a larger or smaller growth of the largest dimension, according to the type of gear and the quality of the steel. For example, we have noticed an increase in the spindle

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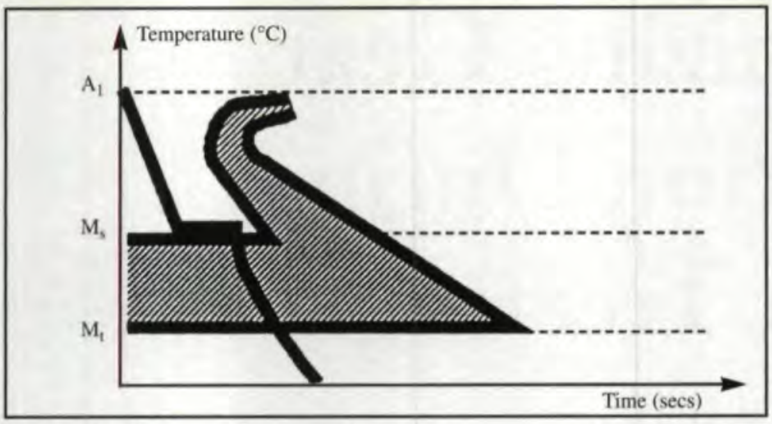

Fig. 3 — Cooling curve using graded hardening.

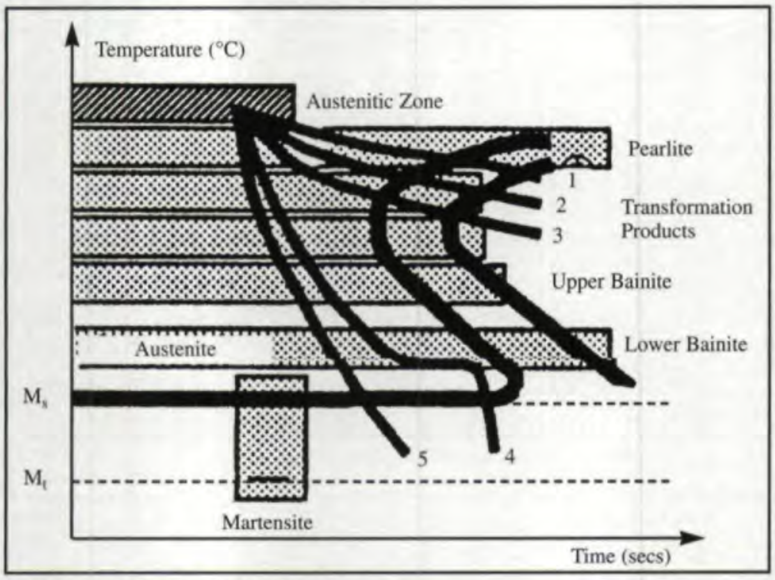

Fig. 4 — Lengthening the holding time.

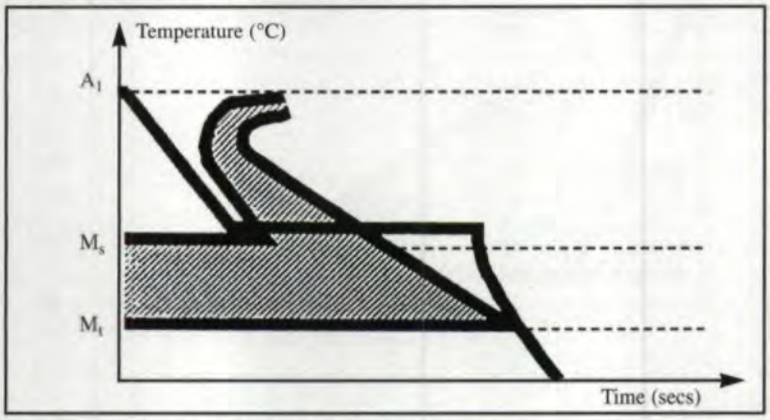

Fig. 5 — Lengthening the holding time even further.

dimension for spindles and shafts, but an increase in the radial dimension of gears, dials and flanges. The higher the hardenability of the steel, the larger the increase in spindle or radial dimensions.

In addition, the gear fibers impact the variation of dimension, which is known to be larger in the direction of the fibers. Fig. 1 shows the correct distribution of the fibers of a gear.

Most gear manufacturers receive relatively small orders, in the range of one to 300 gears. They manufacture the gears by cutting them out of rolled bars and send them to the heat treatment shop for preliminary hardening and tempering. Unfortunately, this type of heat treatment cannot guarantee the desired results. Instead, only isothermal annealing can yield results such as

- a pearlitic ferrite suitable for machining and finishing,
- a structural homogeneity in both the thick and thin areas of the gear, which also helps the dimensional stability after machining at cold temperatures),
- smaller distortions in later heat treatments as shown in Fig. 1 (Refs. 2–3).

It is true that to implement the isothermal annealing technology, one needs to invest in an appropriate furnace, and that such equipment is expensive for the small heat treating shop. However, the gains in quality often more than offset the expenditures.

The Technology

Most gear manufacturers use up-to-date machine tools and quality control technologies, but the high precision employed in machining the gears is often destroyed by the distortions occurring during heat treatment. Some of these distortions can be eliminated through grinding, but it often causes defects in the metallurgical quality of the rectified surfaces.

Fig. 2 shows the well-known cooling curve. This transformation curve is not a particularly useful reference for cooling gears in a quenching medium such as oil because of both the gear thickness and the sectional variations (the thicker the gear, the slower the cooling of its core). Cooling along such a curve yields a high residual stress. This is caused by the difference between the austenite transformations in the material's core and in its outer layers. Another reason is the volume contractions that take place at the edges of the gear while the core is still hot and dilated.

The accumulated residual stresses lead, in turn, to plastic distortions. When the value of these distortions exceeds the yield point and the rate of breaking resistance, cracks occur. We can successfully avoid such mishaps with gears made out of carburized steel by employing a graded hardening method. This works because the cooling of the gear now takes place above the martensite superior point M_s, thus maintaining this temperature for as long as it is necessary to establish an even temperature within the entire mass of the gear (see Fig. 3).

This holding time is calculated so that the conversion of the austenite does not begin in the carburized layer. After the prescribed holding time, the cooling continues in open air, and the austenite begins its conversion to martensite.

If the holding time is lengthened so that the cooling curve intersects the TTT curve (curve 4 in Fig. 4), the result is a heterogeneous structure made out of several structural constituents.

If the holding time is lengthened enough so the cooling curve goes beyond the TTT curve for the end of transformation (as shown in Fig. 5), the result is an isothermal-bainitic hardening, not a martensitic one.

Note in Fig. 5 that the curve first stops at about point M_S; it is maintained at that level without *touching the TTT curve for the beginning* of transformation and then finally continues with the open air cooling. When the part is taken out of the salt bath where the first phase cooling takes place, the martensitic transformation of the carburized layer hasn't yet begun. This explains why the part is still somewhat plastic. The martensitic transformation takes place only during the later cooling in ambient air.

This kind of heat treatment yields a martensitic structure. This is the same as in the standard hardening in oil, except that the crossing of the martensitic interval from a temperature corresponding to the M_S point down to the ambient temperature is done steadily and evenly for all sections on the hardened part. It is very important to know with some precision the point of martensitic transformation M_S, that is, the temperature at which the steel acquires a martensitic structure. It is at this point where the steel acquires the hardness produced by the treatment. This temperature is important because it determines the ideal conditions in which to do the martensitic hardening.

Application to Gear Manufacturing

Graded and isothermal hardening is commonly applied to structural steel. However, its application to carburized steel in the manufacturing of gears seems to be largely unknown and is perceived as difficult.

A gear or any carburized part is made out of several layers, with a decreased ratio towards the core. To simplify the discussion, we shall disregard the variations of the M_S point due to varying percentages of carbon. We shall consider only two temperatures corresponding to the M_S point: one for the core and the other for the case.

The core of the gear will have a martensitic point M_S higher than the corresponding M_S point for the case. This fact leads to the core undergoing the phase transformation inside the cooling bath first, followed by structural transformation of the case outside the cooling bath that is in the ambient air. The structural transformation of the core, involving a corresponding increase in volume, takes place before the case has undergone the phase transformation. Thus it remains in a plastic state.

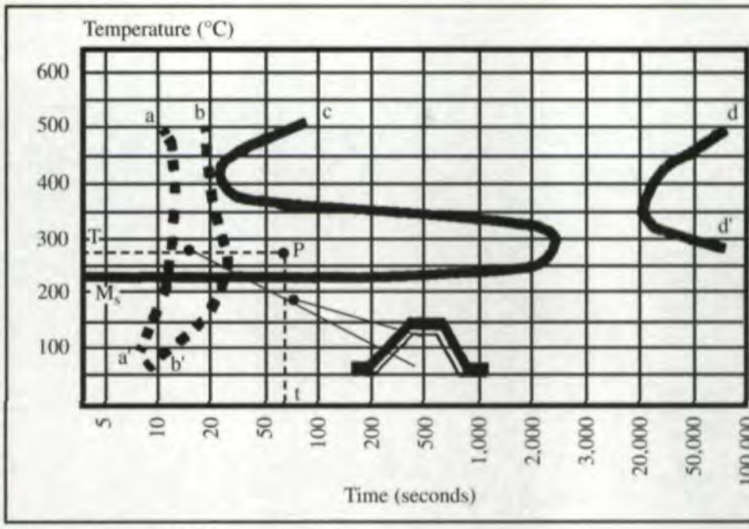

Fig. 6 — Example for a sample steel.

As an example, we shall use a steel containing nickel and chrome that has been carburized. We will use this steel to analyze these two thermic phenomena, that make up the graded hardening of the case-hardened steels.

Fig. 6 shows in semilogarithmic coordinates the beginning (a–a') and ending (b–b') curves of the isothermal transformations of the core (C = .18%) in dotted lines. The same figure shows with a continuous line the beginning (c–c') and ending (d–d') curves of the isothermal transformation of the case (C = 1.00%).

To compute the M_S point for a specific stock of steel, we employ the following formula (Ref. 3):

$$M_S = 539 - 423C - 30.4Mn - 17.7Ni - 12.1Cr - 7.5Mo$$

Thus, for the steel used in our example, after performing the operation of austenitization at approximately 850°C (1,560°F), followed by cooling in a salt bath, we notice that

- the non-carburized core of the gear is transformed into lower bainite, because the curve of transformation of the uncarburized layer is on the left side of the transformation curve for the case,
- the case remains austenitic.

The temperature T (See Fig. 6) must be higher than the martensitic temperature so that the martensitic transformation is avoided during the cooling of the gears in the salt bath.

Note in Fig. 6 that the core is liable to undergo an isothermal transformation—the area between the b–b' and the c–c' curves. Here we obtained a greater cohesiveness and toughness in the core of the gear. Although the bainite is less hard than the martensite by a few Rockwell units, this does not affect the bending resistance of the gear tooth. Often, the appearance of bainite needles is also joined by a martensitic structure.

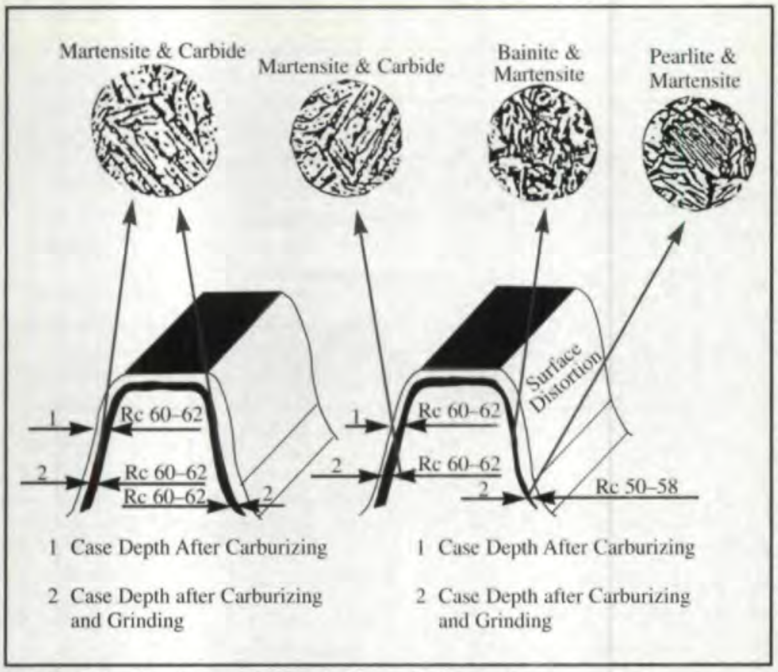

Fig. 7 — Results after graded hardening and oil quenching.

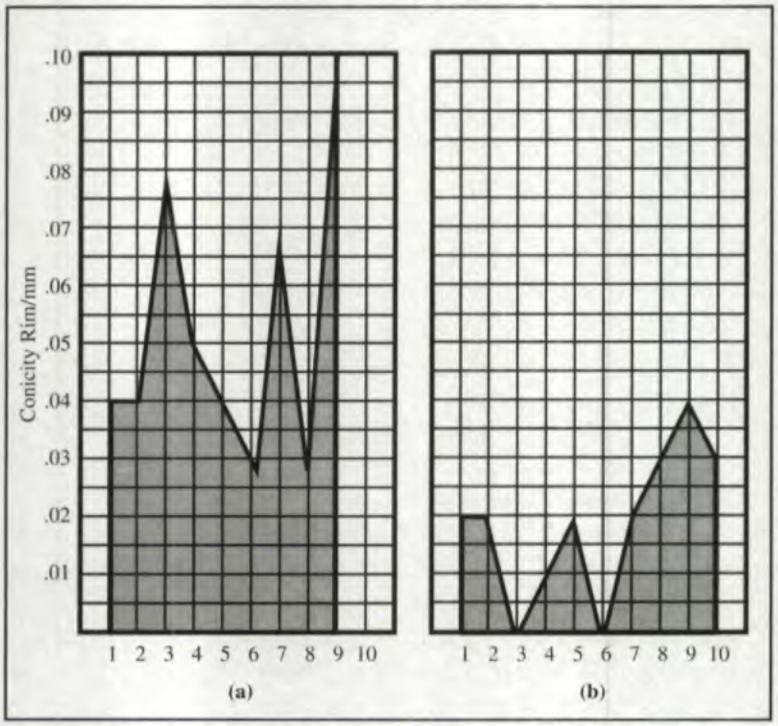

Fig. 8 — Conicity distortion in (a) hardening in oil vs. (b) graded hardening.

The transformation of the core of the carburized gear into a bainitic-martensitic structure is made without important contractions. During this time, the case remains unchanged austenitically.

The martensitic transformation of the case takes place during the cooling in ambient air.

The martensite structure of the case leads to an increase in the specific volume. This in turn leads to compression stress, and therefore the resulting distortions will be very small and within allowed tolerances. This compression stress in the case brings about a higher resistance to fatigue, making the case less sensitive to external potential stretching strains.

To determine the holding time T (see Fig. 6) one must take into account the geometrical shape and weight of the part. The determination is done through a series of tests.

Analysis

The advantage of using graded hardening technology comes from the fact that the martensitic transformation in the case occurs after the transformations have taken place in the core of the gear. While holding the gear in the salt bath, the temperatures in different sections of the gear become even, leading to simultaneous transformations during the subsequent cooling in ambient air. This avoids the distortions and cracks often resulting from the hardening operation.

The TTT curves used in carrying out these heat treatments provide only general hints as to what the transformation temperature may be. They do not help in determining the duration of the transformations because the gear weight sometimes requires modifications of the holding time. In actual practice, the gear weight does sometimes require adjustments of the temperature of the salt bath as well.

Thus one must use the austenite isothermal distortion curve very carefully. For example, a different rate for one of the alloy elements yields a change of the temperature of the M_s point.

Different hardness results may also be obtained for different holding times in the salt bath and different temperatures.

This dependence is useful in the hardening of gears with thick walls, where the danger of reduced hardness is higher. Thus, a lower bainitic structure may yield a hardness of $R_c = 57$, while a superior bainitic structure may yield a hardness of $R_c = 43$ (Ref. 6).

This advantage of being able to get a lower hardness in the gear core is successfully used for gears that must undergo large bending efforts. Examples include the gears used in tank gearboxes, gears for heavy vans, gears used in machine tools, etc. It is worth mentioning that bainite offers a very good quality to the finishing surface, both for low and high machinability speeds.

The holding time in the graded hardening bath is relatively short—approximately five times the duration of the standard hardening in oil. This holding time varies with the gear size.

The salt baths used to cool the gear are somewhat different than ordinary baths: They must guarantee an even temperature during the entire holding time (See Fig. 7).

This technology yields case hardness around $R_c = 58–64$. The hardness in the gear core can be determined from the gear shape.

Conclusions

The advantages introduced by the graded hardening of gears made out of case-hardening steels compared to the standard technology of hardening in oil come from the chronological inversion of the cooling transformations in the case vs. the core. A second basis for these advantages is the fact that the temperature across the part's section is kept even throughout the isothermal holding time.

The graded hardening approach yields reductions in the gear distortions of over 55%, when compared to the distortions measured on gears hardened using the standard method of quenching in oil (Refs. 4–5).

Fig. 8 shows the difference in conicity distortions for the standard hardening in oil (a) vs. the graded hardening technique (b).

Fig. 9. illustrates the ovalness distortions for the same two technologies. The two curves show the values for numbers of gears between 1 and 10 (See Figs. 10–11).

Taking into account the uncertainty and practical difficulties we face when employing the standard hardening in oil, we strongly recommend the graded hardening technology in all cases when small distortions in the heat treated gears are desired. ○

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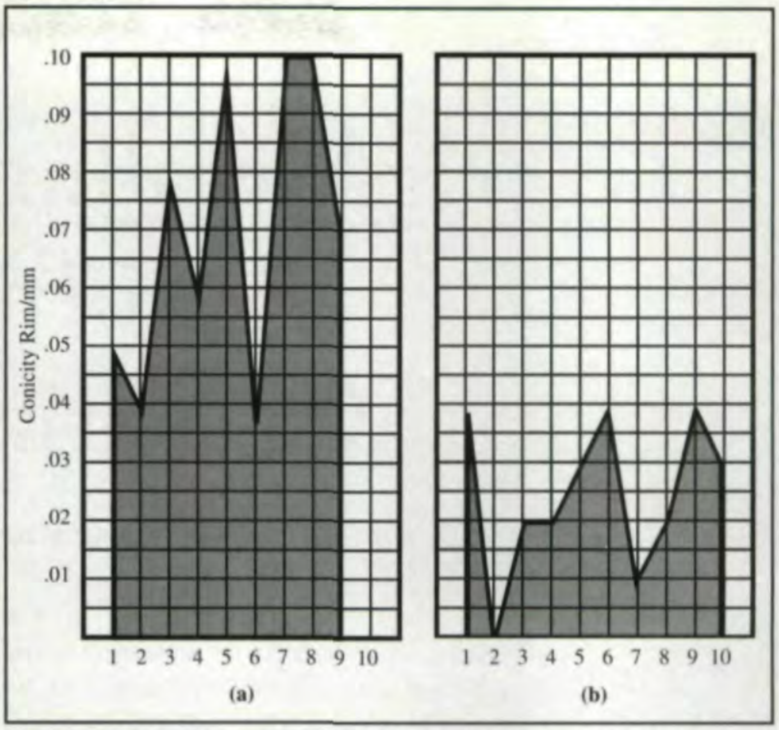

Fig. 9 — Ovalness distortion in (a) hardening in oil vs. (b) graded hardening.

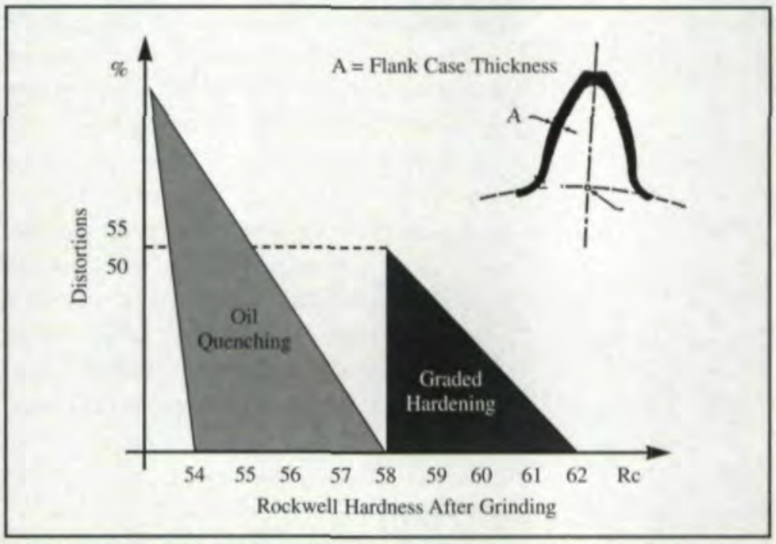

Fig. 10 — Comparison of graded hardening and oil quenching distortions.

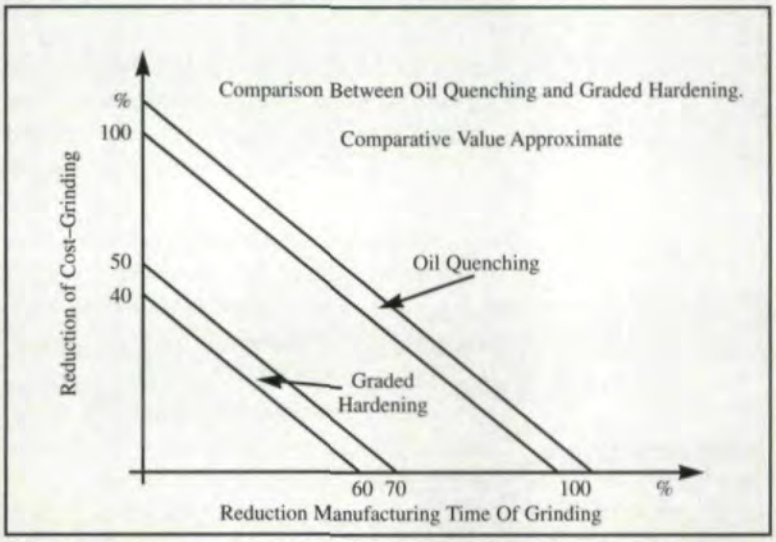

Fig. 11 — Comparison of costs and manufacturing times of graded hardening and oil quenching.

The Effect of Metallurgy on the Performance of Carburized Gears

Dr. Maurice Howes

Introduction

Gears are designed to be manufactured, processed and used without failure throughout the design life of the gear. One of INFAC's objectives (*see p.24) is to help manufacturers improve the manufacture of gears to optimize performance and life. One way to achieve this is to identify failure mechanisms and then devise strategies to overcome them by modifying the manufacturing parameters.

Over 20 modes of gear tooth failure have been identified by AGMA (Ref. 1), and they are often divided into the four broad headings of wear, pitting fatigue, plastic flow and tooth breakage. Nevertheless, Ku (Ref. 2) believed it was more logical to classify the gear-tooth failure modes under the two basic categories of strength-related modes and lubrication-related modes. However, this separation is not entirely possible and in practice many strength related failures are directly or indirectly influenced by lubrication.

From the INFAC perspective, it is assumed that the basic gear characteristics, including the lubrication, the loading and other running conditions, are decided by the gear designer. This article examines manufacturing parameters to determine how metallurgical and processing variables affect gear performance and to what extent gear life can be affected, even if only qualitatively. Most of the variables affecting performance are strength-related, although factors such as surface finish have an impact on lubricant film thickness and ultimately on the gear life.

The Need for Gear Life Performance Prediction

If gear life could be predicted, it would assist gear designers and manufacturers because:

1. Performance testing of gears is expensive and time-consuming.

2. A performance model would enable the interacting variables to be optimized.

3. An understanding of gear life factors would assist the gear designer in optimizing maufacturing cost and gear performance.

Processing with batch-type equipment always causes variation in metallurgical results from part to part. These manufacturing inconsistencies can directly impact performance. It is not sufficient to recognize the effects of processing on gear performance. The processing itself must be applied as consistently as possible to all parts if the gears are to perform in a similar manner.

Metallurgical Characteristics and Gear Performance

The metallurgical characteristics have a profound effect on performance, and the processing parameters must be carefully controlled. Even so, the ideal carburized case has possibly never been produced, but if it could be, it would probably be defined as one with a graduated carbon profile from the surface in towards the core without any surface effects such as decarburization, intergranular oxidation or carbides. The amount of retained austenite that would be tolerated would depend on the product and its use. The hardness at the surface would exceed HRC 60, and the residual stress levels would show a maximum compressive value very near the surface. However, these conditions are difficult to meet, and compromises are necessary to accommodate processing limitations. The following table summarizes metallurgical characteristics that must be considered that affect performance for three grades of gears, grade 3 being the highest, probably equivalent to a high grade aerospace gear. The three grades are intended to be comparable to those used in ANSI/AGMA 2001 and to have similar properties.

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Effect of Metallurgical Characteristics on Gear Performance

Metallurgical Characteristic	Grade 1 Gear (least critical)	Grade 2 Gear	Grade 3 Gear (Highest)
Hardenability	Verification not required because the specified properties are easily attainable.	Verification required to ensure hardenability is sufficient to produce the structures specified in later items. Alloy segregation is a non-homogeneous condition in the base material composition that is observed metallographically in the hardened microstructure when it is severe enough to affect hardenability and produce trace amounts of bainite. This condition is generally not cause for rejection by itself, but it can interact with other variables to produce an unacceptable metallurgical condition.	
Nonmetallic Inclusions	Not specified because the required properties are easily attainable.	It is necessary to control steel cleanliness and prevent inclusions causing unexpected failures in highly stressed areas. Consistent material with controlled levels of defects is essential to prevent unexpected life termination. A study of ISO standards and general European practice shows that even for the highest quality materials, such as VIM-VAR, occasional defects, which can initiate premature cracking, can be expected. *If these defects do not break the surface, then they cannot be detected by* magnetic particle testing. The recommended way to measure these defects is by ultrasonic inspection on the turned blank. The chances of such defects being present and being in a critical area are low, but when it does happen, a catastophic failure can be initiated.	
Material Reduction Ratio	Not specified.	Mechanical working is necessary to refine the structure and make it more homogeneous. Again we see the need for uniform structures and compositions.	
Tempering After Surface Hardening	Recommended.	Required for improved fracture toughness and stability. Also, if the part is not tempered above the working temperature, structural changes caused by heating in service will occur.	
Surface Hardness on Tooth	55–64 HRC.	58–64 HRC. Generally, resistance to pitting fatigue increases with surface hardness.	
Effective Case Depth	Not specified.	Minimum and maximum effective case depth depends on the rating standard (ANSI/AGMA 2004–B89). Optimum performance lies within this range.	
Core Hardness	Not specified for pitting resistance. But 21 HRC minimum for bending fatigue.	21 HRC min. for pitting. 25 HRC min. for bending.	21 HRC min. for pitting. 30 HRC min. for bending.
Surface Carbon	Fatigue strength and hardness increase with carbon content. The surface carbon content of a carburized gear will affect many of the metallurgical and fatigue characteristics that determine gear quality. The surface carbon has to be considered with alloy composition, quench characteristics, tempering conditions and numerous other heat treat cycle parameters used to produce a hardened gear. The process variables need to be controlled independently to make an acceptable part, but the alloy composition of the base material will dictate the surface carbon content range. The following summarizes the surface carbon range as a function of alloy content for Grade 2 and Grade 3 gearing: Broad band carbon range: 0.70% – 1.00. **Alloy Composition Range** — **Recommended Carbon Range** Up to 2.5% total alloy content — 0.80% – 1.00% 2.5% to 3.5% total alloy content — 0.75% – 0.95% Over 3.5% total alloy content — 0.70% – 0.90% These figures are for guidance only! Tighter tolerances are necessary for high quality parts.		
Intergranular Oxidation	This is detrimental to performance when complete networks are formed. Intergranular oxidation (IGO) is intrinsic in atmosphere carburizing furnaces. While the furnace atmosphere is controlled to protect the iron from oxidation, the water vapor and carbon dioxide components in endothermic atmospheres are still oxidizing to most of the alloying elements in the steel. The oxygen from these components is adsorbed at the surface and diffuses along the grain boundaries. As the oxygen diffuses along the grain boundary, it pulls alloying elements from the austenite grains and locally reduces the hardenability, which can have a detrimental effect on microstructure, mechanical properties and fatigue. It is this effect on microstructure that contributes to transformation products being present with IGO. The depth of the intergranular oxidation is generally dependent on case depth, which is a function of the time at carburizing temperature; therefore, deeper case depths will have deeper intergranular oxidation depths. Vacuum carburizing treatments may reduce IGO.		

Continued on page 22.

<table>
<tr><th colspan="4">Effect of Metallurgical Characteristics on Gear Performance (Continued)</th></tr>
<tr><th>Metallurgical Characteristic</th><th>Grade 1 Gear (least critical)</th><th>Grade 2 Gear</th><th>Grade 3 Gear (Highest)</th></tr>
<tr><td>Intergranular Oxidation (cont'd)</td><td colspan="3">For gearing applications intergranular oxidation is allowable to the following maximum limits:
<table>
<tr><th>Diametral Pitch</th><th>Grade 1</th><th>Grade 2</th><th>Grade 3</th></tr>
<tr><td>Fine to 6 DP</td><td>Not Specified</td><td>0.0007"</td><td>0.0005"</td></tr>
<tr><td>6 DP to 3 DP</td><td>Not Specified</td><td>0.0010"</td><td>0.0005"</td></tr>
<tr><td>3 DP to 2 DP</td><td>Not Specified</td><td>0.0015"</td><td>0.0008"</td></tr>
<tr><td>2 DP and larger</td><td>Not Specified</td><td>0.0020"</td><td>0.0010"</td></tr>
</table></td></tr>
<tr><td>Non-Martensitic Transformation Products</td><td>Not specified.</td><td colspan="2">Should be avoided.
Detrimental to performance.</td></tr>
<tr><td rowspan="2">Decarburization</td><td colspan="3">Detrimental to performance. Decarburization is the depletion of carbon on the surface. In carburized parts this usually occurs during reheating or during furnace temperature when the atmosphere carbon concentration is also changing, and the non-equilibrium condition at the part surface causes carbon to be depleted. The surface microstructure of a decarburized part may have a shallow depth of ferrite and/or bainite. The surface hardness may be reduced, depending on the severity of the decarburization condition.
Decarburization on the gear tooth surface will affect bending fatigue and pitting fatigue. The carbon composition change will modify the martensite reaction at the surface and tend to produce a more tensile residual stress at the surface, which will be detrimental to bending fatigue. The softer microstructure on the part surface will also affect the contact pitting fatigue. However, if the surface decarburization is not severe, the metal flow characteristics and the work hardening of the surface under load can combine to improve the load sharing and enhance the contact load carrying capability of the gear.</td></tr>
<tr><td>Does not have a decarburization specification, but the surface must meet the indention hardness specification.</td><td>Decarburization is not acceptable. Partial decarburization that is apparent at 500X is not acceptable, and the gear tooth surface must be Rockwell C58 and file hard.</td><td>Decarburization is not acceptable. Partial decarburization that is apparent at 500X is not acceptable, and the gear tooth surface must be Rockwell C60 and file hard.</td></tr>
<tr><td rowspan="3">Carbide Precipitation</td><td>Continuous networks are not permitted.</td><td>Discontinuous carbides are acceptable.</td><td>Dispersed carbides are acceptable.</td></tr>
<tr><td colspan="3">Carbide structures in the surface microstructure of case-hardened gearing are generally considered undesirable, and care in the heat treatment process must be taken to avoid carbide formation. The chemical composition of the base material will affect the tendency to form carbides. Chromium is the most common carbide forming alloying element used in steelmaking. Carbides are classified into three types: globular or massive carbides, network carbides and surface-film or flake carbides. Each type forms under different heat treatment conditions.
Globular or massive carbides form at the surface of a carburized part when the carbon concentration at the surface exceeds the equilibrium solubility limit. Controlling the atmosphere carbon concentration below the base material's solubility limit at carburizing temperatures will prevent the formation of massive carbides.
Massive carbides can also form during the initial heating process, when nascent carbon from the furnace atmosphere is more readily accepted and diffused into the austenite phase than the carbon from the existing carbide phase which developed during pretreatments. If an equilibrium condition is reached between the austenite and the carbide phases, the carbides will remain in the microstructure. Globular carbides can improve wear, abrasion and scuffing resistance; but they are detrimental to pitting resistance during gear mesh sliding.
Network carbides form during carburizing when the austenite phase is saturated with carbon above the eutectoid composition, and the excess carbon precipitates as carbides in the austenite grain boundaries. This can occur during the diffusion process and during quenching if the cooling rate is not sufficient to retain all of the carbon in the martensite-austenite structure. Network carbides are classified metallographically as continuous network, semi-continuous and discontinuous. The classification reflects the volume of grain boundary carbide present in the case microstructure. Surface-film or flake carbide is a continuous or discontinuous layer or film of carbide on the surface of the carburized case with little or no penetration below the surface. Generally this condition forms when the atmosphere carbon concentration is too high during cooling from carburizing temperature to quench temperature or during furnace cooling under protective atmosphere. This condition will give a high tensile surface stress condition. Under contact load the film will delaminate and give a crazed surface different from pitting. How this condition will affect contact fatigue is a function of the film thickness and the microstructure below the film.</td></tr>
<tr><td>Semi-continuous network carbides are permitted. Small, finely dispersed globular carbides are permitted in the case microstructure.</td><td>Discontinuous network carbides are permissible. Small, finely dispersed globular carbides are permissible on the surface to a depth of 0.003".</td><td>Only a light discontinuous network carbide with small, finely dispersed spheroidal carbides (that often precipitate during reheating) is permissible on the surface to a depth of 0.003".</td></tr>
</table>

Metallurgical Characteristic	Grade 1 Gear (least critical)	Grade 2 Gear	Grade 3 Gear (Highest)
Retained Austenite	Performance increases with retained austenite until hardness starts to significantly decrease. The practical maximum is about 25%. Aerospace gears are generally subzero treated to transform austenite. This treatment has been reported by many references to cause microcracking and thus lower properties and result in a lower life. The INFAC cryogenic tests will be extended to look for the microcracking effect and assess the conditions under which it occurs. Retained austenite is present in most carburized gear case microstructures. Theoretically in carburized case conditions in excess of eutectoid carbon concentration, the martensite transformation reaction can never be complete, and some amount of austenite will remain at room temperature. Retained austenite is relatively soft, even though it is saturated with carbon. Retained austenite in a hard martensite microstructure will reduce the overall hardness of the structure. However, under load the retained austenite can transform to martensite, and it will strengthen the surface of the gear and improve its fatigue characteristics. Excessive amounts of retained austenite or light load conditions will not have this strengthening effect, and some control of the retained austenite content is required. Retained austenite concentration is difficult to measure metallographically; X-ray methods are recommended. The fatigue characteristics of the gear tooth surfaces are dependent on the material strength (hardness) and not usually correlated to the percent of retained austenite. Therefore, it is convenient to control/measure the retained austenite effects as they relate to hardness.		
	Retained austenite is acceptable, provided the gear tooth surface hardness is at least Rockwell C58. At this stress level there is no requirement for retained austenite concentration in the case microstructure.	Retained austenite is acceptable, provided the gear tooth surface hardness is at least Rockwell C58. At this stress level the retained austenite in the case microstructure should not exceed 30% measured metallographically.	Retained austenite is acceptable, provided the gear tooth surface hardness is at least Rockwell C60 (Rockwell 15N 90) and the microhardness at .005" depth is at least Rockwell C59 equivalent. The retained austenite in the case microstructure should not exceed 30% measured metallographically or 40% using X-ray diffraction techniques.
Microstructure of Core	Not specified.	A tempered martensite structure is preferred for maximim resistance to fatigue.	
Microcracks in Case	Microcracks are small cracks that may develop across or alongside high carbon martensite plates. The cracks are believed to be formed when the tip of a growing martensite plate impinges on another plate, cracking the impinged plate and/or the growing plate. There is little information on the influence of microcracks on material properties. However, it is reasonable to conclude that any cracking should be detrimental to material properties. Some controversy exists over the role of sample preparation in the incidence of microcracking. Certain researchers have shown that abusive sample preparation can precipitate microcracking. Also there is some speculation that the etchant may cause stress corrosion cracking of the martensite plates. Therefore, it is recommended that any specimen exhibiting microcracks should be repolished, lightly etched and observed immediately to confirm the existence of microcracks. A specimen shall be considered rejectable for microcracks under either of the following conditions: 1. Seven or more microcracks are visible in any field at 500X, 2. The longest microcrack in any field at 500X is 4 microns or longer.		
Bainite	Detrimental to performance, only trace amounts should be permitted. Bainite as a steel microstructure component is classified either as upper bainite, which is formed just below the pearlite reaction temperature, or lower bainite, which is formed closer to the martensite start temperature. Bainite, which is not a microstructural phase, but rather a mixture of ferrite and carbide, will etch dark in the microstructure. The microstructure appearance of upper bainite will be feathery, and lower bainite will be platelike (acicular) similar to martensite. It is normally assumed that: 1) Most bainite observed in carburized gear microstructures that propagates from the core into the case region is lower bainite formed during the quenching of the carburized gear, and 2) The bainite observed on the surface as a transformation product is upper bainite. Bainite formation from austenite is not athermal, but rather requires time for composition changes and diffusion of carbon. Increasing the rate of heat extraction from the gear tooth and/or increasing the material hardenability will retard the formation of bainite. In general the bainite reaction is not fully understood: however, bainite is not a desirable constituent in carburized gear microstructures. It does not have the high strength properties of martensite and can act as a nucleation site for pitting fatigue, very similar to inclusions in steel. Lower bainite that extends from the case to the gear tooth contact surface is not acceptable.		
	Trace amounts of bainite are acceptable, provided the bainite does not extendup to the surface of the gear tooth.	Gearing applications, trace amounts of bainite that are observable at 500X are acceptable in the gear root fillet area, provided it does not extend into the case region past the minimum effective case depth in the tooth contact area.	Lower bainite that is observable at 500X is not acceptable in the case microstructure in the contact area. In the root area, lower bainite is not acceptable in the first 20% of the case microstructure. Heavy pitch gearing may have special customer provisions.

Continued on page 24.

Effect of Metallurgical Characteristics on Gear Performance (Continued)			
Metallurgical Characteristic	**Grade 1 Gear (least critical)**	**Grade 2 Gear**	**Grade 3 Gear (Highest)**
Other Mixed Transformation Products	There are other microstructure considerations that can affect the carburizing heat treatment. These items are generally not permissible in Grade 3 gearing applications and should be reviewed for Grade 2 gearing applications. Transformation Products: These microstructure constituents are generally recognized as detrimental to the function of the gear. The transformation products, which occur along with intergranular oxidation, alloy inversion and decarburization, are usually associated with a localized loss in material hardenability. Generally bainite, ferrite and pearlite are present in the transformation microstructure. Generally trace amounts of transformation product observable at 500X on the tooth contact surface are acceptable in Grade 3 gearing applications. For Grade 2 gearing applications, some transformation product is permissible (5% at 500X) to a depth limit of half of the IGO depth specification. Grade 1 gearing generally will not have a specified requirement.		
Core Structure	Not specified.	Best performance obtained with tempered martensite. A trace of acicular ferrite and bainite is permitted, but blockly ferrite is not.	
Surface Cracks	Not permissible in functional areas.		
Surface Tempering or Burning	Not specified.	Burning or tempering is detrimental to performance and is not permissable, particularly in Grade 3 gear.	
Shot Peening	Not specified.	Enhances fatigue strength due to formation of residual stresses.	
Case Grain Size	A fine grain size is known to improve fatigue strength.		
Residual Stress Profile	Shot peening enhances fatigue resistance, but if not done by an automated method, it produces variable results.		
Case Carbon Profile	The case carbon profile may be changed by altering the parameters of a boost-diffuse cycle. It is believed that a flatter curve near the surface enhances fatigue resistance.		

Summary

Many of the characteristics in this table are connected, and gear performance can be maximized by controlling a few key factors listed below.

Material. The steel has to be uniform in composition, be without surface defects, and have adequate hardenability to produce martensitic structures in the size of gear being manufactured.

Carburizing. The treatment needs to be controlled to produce a uniform profile case, preferably in an atmosphere that excludes oxygen. Surface effects during carburizing must be minimized.

Hardening. The hardening process should not decarburize the steel, and the quench should be uniform, across the batch. A subzero treatment can be used, if necessary, to control austenite.

Grinding. The grinding process needs careful control to prevent surface overheating (burning) or tempering during aggressive metal removal. ○

References:

1. "Nomenclature of Gear Tooth Wear and Failure," AGMA Standard 110.03, 1962.
2. Ku, P. M. "Gear Failure Modes—Importance of Lubrication and Mechanics." ASLE Preprint No. 75AM-SA-1.

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Wear Protection for Gears

Frederick J. Teeter & Manfred Berger

Several trends in mechanical engineering are leading to greater surface stress on components and thus to unacceptable wear. These trends include greater stresses due to increased power densities; the need to maintain high precision of components throughout their service life; and the environmental imperative to reduce use of lubricants and additives.

In gearing, the trend is characterized by a rise in power density. In other words, high torques are being transmitted through small systems. In addition, gears often have to run with poor lubrication. Gear wheels may therefore suffer various kinds of damage, depending on load and peripheral speed (see Fig. 1).

As peripheral speed increases, the viscosity and thickness of the lubricant film decrease as a result of the higher temperature. If the lubricant film ruptures, seizure occurs on the tooth flanks. At low peripheral speeds, no continuous lubricant film forms between the tooth flanks. The surfaces come into direct contact (mixed friction) and abrasion occurs. In the pitting region (where tiny pits are formed on the tooth flank), a load-bearing lubricant film is present; the load capacity is governed by the compressive strength of the gear surface. Prolonged rolling contact produces fine cracks, which start at roughness valleys or inclusions and lead to the detachment of particles from the surface. Small pits (Fig. 2) are created on the tooth flanks.

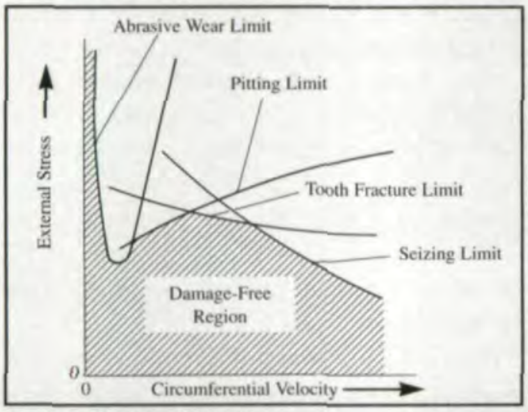

Fig. 1 — Working limits of gears.

Fig. 2 — Pitting on the flanks of gear teeth.

To cope with these varying stresses and meet the need for economical mechanical parts, gears have been made of plastic, medium, low-carbon steels (such as 1020 and 1030), heat-treated steel, induction-hardened steel, nitrided steel and case-hardened steel. The load-carrying capacity increases in this order, but so does the cost of the gears. In particular, the regrinding of hardened gears is expensive.

Factors governing gear life and reliability include not only the material and the stress level, but also the design and the lubrication. There are limits on these factors because of typical service conditions (e.g., slow running) and design constraints such as small volume and target weight.

Protective coating that can be precisely deposited would be desirable as a way of meeting the more and more stringent requirements on heavily loaded gears. Even for high stresses and poor lubrication environments, such coating can provide long-term surface protection in service.

Conventional coatings, such as electrolytic hard chrome and dry lubricant films based on MoS_2, often are not adequate to satisfy these requirements. A new coating made of amorphous carbon with tungsten carbide inclusions (referred to as a WC/C coating) has proved its worth in situations where all other surface coating systems fail.

WC/C Coating

This WC/C coating (BALINIT C) is applied by a PVD (Physical Vapor Deposition) process—more precisely, by reactive sputtering. In this process, the coating material is expelled from targets (WC plates) in a high vacuum by ion bombardment and deposited on the parts being coated.

This high-vacuum technology makes it possible to obtain coating properties that cannot be

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imparted under an atmosphere (thermal spraying) or with gases or baths (nitriding, galvanizing). These properties include:

• Controlled material composition. Amorphous carbon films have the lowest friction of all hard surfaces.

• Extreme precision. PVD coatings are only a few µm thick. They replicate workpiece surfaces exactly, thereby eliminating the need for subsequent machining.

• Maximal load-carrying. High-vacuum deposition avoids contamination of all kinds. As a consequence, there is a metallurgical bond to the substrate, leading to high coating adhesion and load-carrying capability (PVD coatings such as TiN are traditionally employed on severely stressed tools).

Technical data of the WC/C (BALINIT C) coating are as follows:

• Hardness	1000 Hv 0.05
• Coefficient of friction	0.1–0.2 (vs. 0.6–0.7 for steel)
• Coating thicknesses	1–4 µm
• Coating temperature	Max. 250°C (480°F)
• Oxidation resistance	300°C (572°F)
• Color	Black/gray

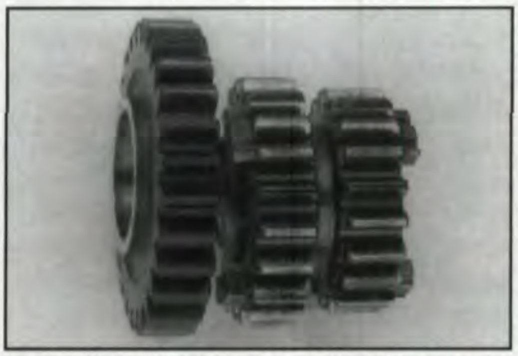

Fig. 4 — Wear of motorcycle gear after oil leakage during a race. Right: uncoated. Left: WC/C-coated.

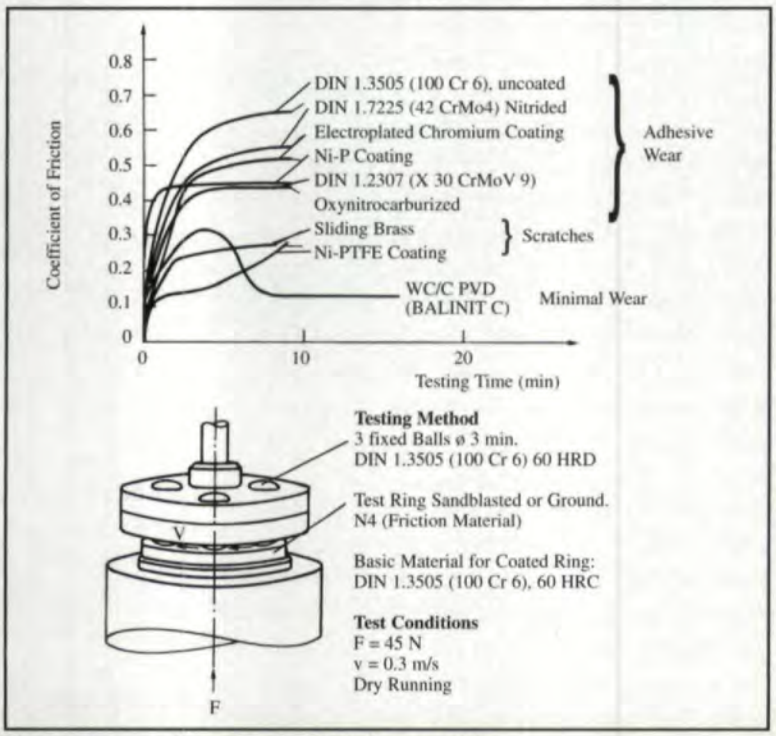

Fig. 3 — Dry running properties of friction materials.

As far as optimal wear protection is concerned, the key combination of properties offered by the WC/C coating is low friction with high hardness.

The sliding properties of the WC/C coating are not attained by conventional surface treatments, such as nitriding, nitrocarburizing or chemical nickel-plating, or by bronzes. This point is seen particularly in the dry friction behavior of these surfaces. Fig. 3 shows the results from a model dry friction test. In this test, hardened steel pins slide on disks of various materials or on various surfaces. While the bronze disk does exhibit low friction, it experiences severe wear in the form of scoring; the hard materials or surfaces, on the other hand, develop high coefficients of friction or display seizure (cold welding) after a short time in the test.

None of these surfaces yield both low friction and wear resistance. Only the WC/C coating exhibits low friction with virtually no wear. This good frictional behavior in the model test also leads to outstanding results in practical gear applications.

Gear Coating in Practice

Motorcycle Gears. Gears for motorcycle transmissions experience high stresses due to high speeds and limited volumes; they are fabricated from case-hardened steels. Application of the WC/C coating to these gears results in enhanced reliability and emergency running reserves. Fig. 4 compares uncoated and coated gears from a motorcycle after a race in which an oil leak developed. Normally, seizure occurs very quickly in such cases. Because the most severely stressed gears had the WC/C coating, the machine was able to finish the race. The coated gear, shown on the left in Fig. 4, has almost no wear in contrast to the uncoated ones.

Concrete Mixer Gears. The case-hardened sun wheel of a concrete mixer gear, which runs slowly under load, was in danger of seizure, since no adequate lubricant film was formed. The WC/C coating prevented premature seizure and enabled the transmission to perform in this special mode. A slow-running model test provided clear confirmation of this capability. The wear rate on the coated gear pair stabilizes at a very low value (Fig. 5).

Motor Control Actuator. Actuating mechanisms for throttle valve controls in car and truck engines cannot be lubricated because electronic components are located nearby. A dry lubricant film of MoS_2 does not provide sufficient wear protection. Hard, low-friction WC/C coating gives long-term protection for this unlubricated actuator.

Bevel Gear Actuator. A bevel gear actuator for aircraft landing flaps is subject to severe tribological stress because of the high forces and low sliding speeds. Even with nitriding, inspection and maintenance intervals were too short. The WC/C coating, which has a much lower coefficient of friction than nitrided surfaces, made it possible to institute acceptable inspection intervals.

Highly Stressed, Fast-Running Gears. If a continuous lubricant film is formed, the service life is limited by the pitting load capacity. With the WC/C coating, load capacity gains of 10–15% for case-hardened gears (Fig. 6) and as much as 30–40% for heat treated gears are seen. As a result, gear loads can be increased or smaller gears can be used for given loads. Coating makes it possible to use a less costly class of materials in a given application where ground and case-hardened gears otherwise would have to be employed. The cause of the increased load capacity in coated gears is that the coating becomes smoother when the gears run together and thus reduce local surface pressure.

Worm Gear Drives. Wear problems are especially severe in worm gear drives because of the kinematic situation (high proportion of sliding contact, low speed). In most cases, bronze worm wheels have to be used to prevent seizing. But these gears are soft, so that abrasion in service makes it necessary to replace them relatively often. Worms made of medium, low-carbon steel also wear easily. The use of case-hardened and ground worms is a costly alternative. The WC/C coating leads to solutions in two directions:

- Precision Drives. Precise positioning (for example, fixture positioning in machine tools) cannot be attained on a long-term basis with rapidly wearing bronzes. Case-hardened worms and worm gears do not have low enough friction, so they seize prematurely. Application of the WC/C coating to worms and worm wheels made of steel protects against both seizure and abrasion.
- Substitution of Case-Hardened Worms. If a conventional pair of a low-carbon steel worm and bronze wheel does not offer adequate wear resistance (Fig. 7), a worm of case-hardened steel is used. This makes the drive appreciably more costly. In many cases (such as a vertical-lift table, for example), a low-cost worm of heat-treated or low-carbon steel can be coated with WC/C. In this way, the friction behavior is improved and gearing costs are drastically cut.

The WC/C coating is an ideal treatment for gear materials. Not only does it offer a solution for extreme load situations, but it also can be used to boost performance or reduce weight, or it can provide an alternative to expensive materials. ❍

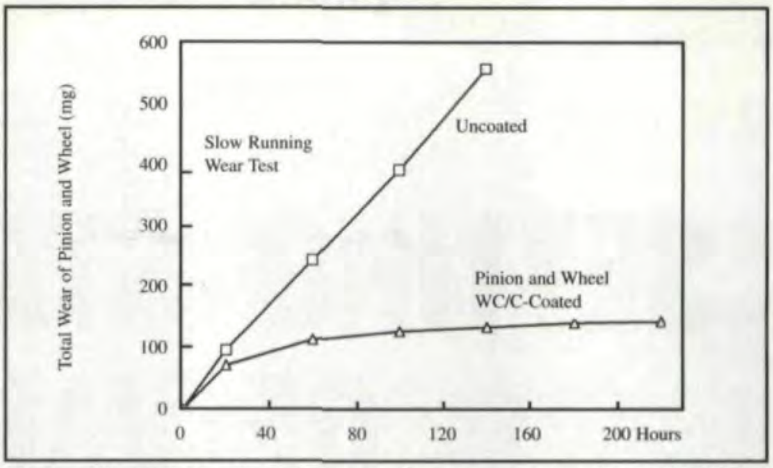

Fig. 5 — Wear test for a slow running gear for a concrete mixer. Stress: 2180 MPa. Sliding velocity: 0.04 m/s.

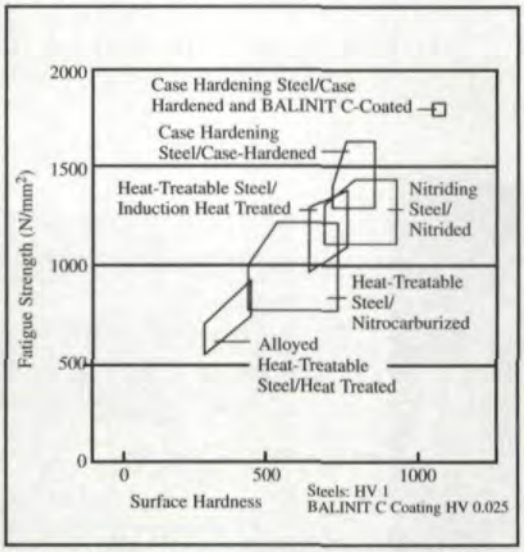

Fig. 6 — Surface fatigue strength of materials for gears.

Worm Material	Cost of worm, related to the cost of low-carbon steel worm
low-carbon steel	1
case hardened steel, ground	6
low-carbon steel, WC/C-coated	1.5
heat treated steel, WC/C-coated	4

Fig. 7 — Wear of conventional worm gears and cost of alternative materials.

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For more information about the product described in this article, please circle **207.**

HEAT TREAT SERVICE DIRECTORY

Welcome to the 1996 *Gear Technology* Heat Treating Services Directory. All of the companies listed below are experienced in heat treating gears. Use this listing to locate a nearby provider with the specialty you require.

The companies are listed alphabetically by region. The chart below shows codes representing various heat treating services and processes. To find a company that performs a certain process or uses a certain type of equipment, look for the appropriate codes in italic type at the end of the listing.

While *Gear Technology* has 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 would like to be included in 1997 call 847-437-6604 or fax 847-437-6618, and we will add you to our mailing list.

Annealing	AN	Induction Hardening	IH
Ausforming	AU	Ion Implantation	II
Austempering	AT	Ion Nitriding	IN
Batch Furnace	BTF	Laser Hardening	LH
Box Furnace	BF	Nitriding	NI
Brazing	BZ	Nitrocarburizing	NCR
Carbonitriding	CNI	Normalizing	NO
Carburizing	CR	Pit Furnace	PF
Continuous Belt Furnace	CF	Plasma Carburizing	PC
Cryogenics	CY	Press Quenching	PQ
Die Quenching	DQ	Quenching	QU
Electron Beam Hardening	EBH	Salt Bath Nitriding	SBN
Flame Hardening	FH	Sintering	SI
Fluid Bed Furnace	FBF	Stress Relieving	SR
Free Quenching	FQ	Tempering	TE
Hot Oil Quenching	HOQ	Vacuum Furnace	VF

NEW ENGLAND

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22 S. Main St.
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Fax: 860-589-3566
AN, SI

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

Beehive Heat Treating Inc.
132 Water St.
S. Norwalk CT 06854
Ph: 203-866-1635
Fax: 203-855-9327
AN, BF, CNI, CR, CY, FH, HOQ, IH, NO, PF, SBN, SR, TE, VF

Bomak Corp.
6 Jefferson Ave.
Woburn MA 01801
Ph: 617-935-4100
Fax: 617-932-0542
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Lindberg Heat Treating
675 Christian Lane
Berlin CT 06037
Ph: 860-225-7691
Fax: 860-229-3891
AN, BF, CNI, FQ, NO, PF, SR, TE, VF

Nitron Inc.
26 Wellman St.
Lowell MA 01851-5110
Ph: 508-458-3030
Fax: 508-458-3131
e-mail:
nitron@world.std.com
IN, VF

O & W Heat Treat Inc.
1 Bidwell Rd.
South Windsor CT 06074
Ph: 860-528-9239
Fax: 860-291-9939
AN, BF, FQ, IH, NO, PF, SR, TE, VF

MID-ATLANTIC

Advanced Heat Treating
Trout Run Rd.
St. Marys PA 15857
Ph: 814-781-3744
Fax: 814-781-3230
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Alco Heat Treating Corp.
130 Verdi St.
Farmingdale NY 11735
Ph: 516-249-1660
Fax: 516-249-7889
AN, BF, CNI, CR, CY, DQ, FBF, FH, FQ, HOQ, IH, NCR, NO, PF, PQ, SR, TE

Alpha Heat Treaters
Emig Road
P.O. Box 23
Emigsville PA 17318
Ph: 717-767-6757
Fax: 717-764-0129
AN, BF, CNI, CR, CY, IH, NO, PF, SR, TE

Benedict-Miller Inc.
Marin Ave. &
Orient Way
Lyndhurst NJ 07071
Ph: 201-438-3000
Fax: 201-438-3137
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Bennett Heat Treating &
Brazing Co.
690 Ferry St.
Newark NJ 07105
Ph: 201-589-0590
Fax: 201-589-6518
AN, BF, CNI, CR, CY, DQ, FH, FQ, HOQ, IH, NCR, NI, NO, PF, PQ, SI, SR, TE, VF

Delphi Engineering &
Contracting
131 Blackwood
Barnsboro Rd.
Sewell NJ 08080-4201
Ph: 609-468-4839
Fax: 609-228-9354
AN, BF, FQ, NO, SR, TE

Disston Precision Inc.
6795 State Rd.
Philadelphia PA 19135
Ph: 215-338-1200
Fax: 215-338-7060
BF, HOQ, NO, SR, TE

Fenton Heat Treating
3605 Homestead
Duquesne
West Mifflin PA 15122
Ph: 412-466-3960
Fax: 412-466-7931
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General Heat Treating
6770 Benedict Rd.
E. Syracuse NY 13057
Ph: 315-437-1117
Fax: 315-433-1194
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The Gleason Works
1000 University Ave.
Rochester NY 14692
Ph: 716-461-8051
Fax: 716-461-1492
CR, DQ, PF, PQ
See ad on back cover.

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

Irwin Automation Inc.
715 Cleveland St.
Greensburg PA 15601
Ph: 412-834-7160
Fax: 412-834-4670
AN, CR, CY, FQ, HOQ, NO, PF, SR, TE, VF

Jasco Heat Treating Inc.
P.O. Box 236
Fairport NY 14450
Ph: 716-388-1040
Fax: 716-377-7226
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John V. Potero Co. Inc.
4225-35 Adams Ave.
Philadelphia PA 19124
Ph: 215-533-8988
Fax: 215-533-9210
AN, BF, DQ, FH, HOQ, IH, NO, PF, SR, TE

Lindberg Heat Treating
620 Buffalo Rd.
Rochester NY 14611
Ph: 716-436-7876
Fax: 716-436-5276
CNI, CR, IH, NCR, SR, TE

Mannings U.S.A.
53 Abbett Ave.
Morristown NJ 07960
Ph: 800-447-4473
Fax: 201-984-5833
e-mail:
ManningsUS@aol.com
BF, IH, PF, SBN, SR, TE

Master Heat Treating
51 Brown Ave.
Springfield NJ 07081
Ph: 201-379-7320
Fax: 201-379-3214
AN, BF, CR, CY, DQ, FH, HOQ, IH, NO, PF, SR, TE

Metlab Co.
1000 E. Mermaid Lane
Wyndmoor PA 19038
Ph: 215-233-2600
Fax: 215-233-5653
AN, BF, CNI, CR, NCR, NI, NO, PF, QU, SR, TE

Penna Flame Industries
RR#3 Box 14B
Rte. 588 West
Zelienople PA 16063
Ph: 412-452-8750
Fax: 412-452-0484
CY, FH

Pennsylvania
Metallurgical Inc.
315 Columbia St.
Bethlehem PA 18017
Ph: 800-332-9880
Fax: 610-691-2662
AN, BF, CNI, CR, CY, DQ, FH, FQ, IH, NO, PF, SI, SR, TE
See ad page 33.

Peters' Heat Treating Inc.
215 Race St.
P.O. Box 624
Meadville PA 16335
Ph: 814-333-1782
Fax: 814-333-2533
AN, BF, CNI, CR, CY, FBF, NCR, NI, NO, PF, SR, TE, VF

Pitt-Tex Inc.
P.O. Box 109
Rte 981 & Container Way
Latrobe PA 15650
Ph: 412-537-2009
Fax: 412-537-2140
AN, BF, CR, CY, IH, NO, PF, QU, SR, TE

Richter Precision Inc.
1021 Commercial Ave.
E. Petersburg PA 17520
Ph: 717-560-9990
Fax: 717-560-8741
AN, TE, VF

Rochester Steel
Treating Works
962 East Main St.
Rochester NY 14605
Ph: 716-546-3348
Fax: 716-546-1684
AN, BF, CNI, CR, CY, FBF, HOQ, NCR, NI, NO, SR, TE, VF

Solar Atmospheres Inc.
1969 Clearview Rd.
Souderton PA 18964
Ph: 800-347-3236
Fax: 215-723-6460
AN, CY, II, IN, SI, SR, TE, VF

Steel Treaters, Inc.
100 Furnace St.
Oriskany NY 13424
Ph: 315-736-3081
Fax: 315-736-8849
AN, CNI, CR, CY, FBF, FH, IH, NI, NO, QU, SBN, SR, TE, VF

Syracuse Heat Treating
7055 Interstate Island Rd.
Syracuse NY 13209
Ph: 315-451-0000
Fax: 315-451-3895
AN, BF, BTF, BZ, CF, CNI, CR, CY, FBF, FH, FQ, IH, NCR, NI, NO, PF, SI, SR, VF

Vacu-Braze
115 Lower Morrisville
Fallsington PA 19054
Ph: 215-736-9262
Fax: 215-736-9343
AN, NO, SR, TE, VF

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Advanced Heat Treat
1625 Rose St.
Monroe MI 48162
Ph: 313-243-0063
Fax: 313-243-4066
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Advanced Thermal
Technologies
U.S. Highway 6 West
P.O. Box 875
Kendallville IN 46755
Ph: 219-347-1203
Fax: 219-347-3568
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Ajax Magnethermic
1745 Overland Ave.
Warren OH 44483
Ph: 216-372-8511
Fax: 216-372-8608
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Albany Metal Treating
400 S. Dowden Ave.
Albany IN 47320
Ph: 317-789-6470
Fax: 317-789-6839
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Alfe Heat Treating Inc.
10630 W. Perimeter
Road Suite 100
Fort Wayne, IN 46809
Ph: 219-747-9422
Fax: 219-747-9618
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Alliance Metal Treating
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Aurora IL 60505
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Fax: 708-851-0733
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American Brazing
Division of Paulo
Products Co.
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Willoughby OH 44094
Ph: 216-946-5900
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22720 Nagel
Warren MI 48089
Ph: 810-757-7337
Fax: 810-757-8232
e-mail: AMProcess@aol.com
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Fax: 216-431-1508
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Monroe MI 48162
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Fax: 313-242-0993
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AP Westshore
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Fax: 414-235-2701
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Livonia MI 48150-1046
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Fax: 313-464-6314
email: ADIRON@aol.com
BTF, CF, CNI, CR, FQ, SR, TE

Atmosphere Annealing
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P.O. Box 220
North Vernon IN 47265
Ph: 812-346-1275
Fax: 812-346-4534
AN, CF, HOQ, NO, SR, TE

Bonal Technologies Inc.
21178 Bridge St.
Southfield MI 48034
Ph: 810-353-2041
Fax: 810-353-2028
e-mail: Bonalth@aol.com
SR

The Bowdil Co.
2030 Industrial Place S.E.
Canton OH 44707
Ph: 216-456-7176
Fax: 216-456-4625
AN, BF, CR, FH, NO, PF, QU, SR, TE, VF

Brazing & Metal Treating
1101 E. 55th St.
Cleveland OH 44103
Ph: 216-881-8100
Fax: 216-881-6811
AN, NO, SR, TE

Brite Brazing
5476 Lake Ct.
Cleveland OH 44114
Ph: 216-881-8100
Fax: 216-881-6811
AN, NO, SR, TE

Brite Metal Treating
8640 Bessemer Ave.
Cleveland OH 44127
Ph: 216-341-2266
Fax: 216-341-4273
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Bucyrus-Erie Co.
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S. Milwaukee WI 53172
Ph: 414-768-4092
Fax: 414-768-5221
FH, IH, SR

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

Caterpillar Industrial Products
100 N.E. Adams St.
Peoria IL 61629-4400
Ph: 309-675-5451
Fax: 309-675-6457
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2411 W. Aero Park Ct.
Traverse City MI 49686
Ph: 616-941-7800
Fax: 616-941-2346
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Certified Heat Treating
1200 E. First St.
Dayton OH 45403
Ph: 513-461-2844
Fax: 513-461-4519
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Chicago Flame Hardening Co.
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East Chicago IN 46312
Ph: 219-397-6475
Fax: 219-397-4029
AN, FH, SR, TE

Chicago Induction
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Chicago IL 60624
Ph: 312-826-1213
Fax: 312-826-1178
AN, FH, IH, TE

Cincinnati Flame Hardening Co.
375 Security Dr.
Fairfield OH 45014
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Cincinnati Gear Co.
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Cincinnati OH 45227
Ph: 513-271-7700
Fax: 513-271-0049
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Cincinnati Steel Treating
5701 Mariemont Ave.
Cincinnati OH 45227
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Fax: 513-271-3510
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Cleveland Flame Hardening Co.
935 West St.
Cleveland OH 44113
Ph: 216-241-1333
Fax: 216-241-3946
FH, HOQ, SR, TE

Commercial Induction
11116 Avon Ave.
Cleveland OH 44105
Ph: 216-881-8100
Fax: 216-881-6811
AN, FQ, IH, NO, SR, TE

Commercial Steel Treating Corp.
31440 Stephenson Hwy.
Madison Hts. MI 48071
Ph: 810-588-3300
Fax: 810-588-3300
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Contour Hardening Inc.
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Indianapolis IN 46268
Ph: 317-876-1530
Fax: 317-879-2484
IH, SR, TE

Detroit Steel Treating Co.
1631 Highwood East
Pontiac MI 48340
Ph: 810-334-7436
Fax: 810-334-7891
AN, BF, CNI, CR, CY, FH, FQ, HOQ, NO, PF, SBN, SR, TE

Diamond Heat Treating
5660 W. Jefferson
Detroit MI 48209
Ph: 313-843-6570
Fax: 313-842-0280
AN, BTF, CNI, CR, FQ, NO, SR, TE

Dynamic Metal Treating
7784 Ronda Dr.
Canton Twp. MI 48187
Ph: 313-459-8022
Fax: 313-459-7863
DQ, FBF, NCR, NI, SR, TE

East-Lind Heat Treat
32045 Dequindre
Madison Hts MI 48071
Ph: 810-585-1415
Fax: 810-585-3045
AN, BF, CNI, CR, CY, FBF, FH, NO, PF, QU, SBN, SR, TE, VF

Engineered Heat Treat
31271 Stephenson Hwy.
Madison Hts. MI 48071
Ph: 810-588-5141
Fax: 810-588-6533
AN, BF, CNI, CR, CY, DQ, FQ, HOQ, NI, NO, PF, PQ, QU, SBN, SR, TE, VF

Erie Steel Treating Inc.
5540 Jackman Rd.
Toledo OH 43613
Ph: 419-478-3743
Fax: 419-478-0109
e-mail: eriesteel@toledolink.com
AN, BF, CNI, CR, FH, FQ, HOQ, NCR, NI, NO, PF, SR, TE, VF

Euclid Heat Treating
1408 E. 222nd St.
Cleveland OH 44117
Ph: 800-962-2909
Fax: 216-481-3473
AN, BF, CNI, CR, DQ, FQ, HOQ, IH, NCR, NI, NO, PF, PQ, SBN, SR, TE, VF

Fairfield Manufacturing
U.S. 52 Bypass South
Lafayette IN 47903
Ph: 317-474-3128
Fax: 317-477-7342
AN, BF, CNI, CR, DQ, FQ, HOQ, IH, NI, NO, PF, PQ, SR

Feinblanking Ltd.
9461 LeSaint Dr.
Fairfield OH 45014
Ph: 513-860-2100
Fax: 513-870-5146
AN, BF, CNI, CR, HOQ, NO, SR, TE

Fox Steel Treating Co.
2220 Gratiot Ave.—260 Walker St.
Detroit MI 48207
Ph: 313-568-1640
Fax: 313-568-0148
AN, BF, CNI, CR, FBF, FH, HOQ, NCR, NI, NO, PF, SBN, SR, TE

FPM Heat Treating
1501 S. Lively Blvd.
Elk Grove IL 60007
Ph: 847-228-2525
Fax: 847-228-5912
AN, BF, CNI, CR, CY, FQ, HOQ, II, NCR, NI, NO, PF, SR, TE, VF

FPM Ipsen Heat Treating
666 Route 20
Cherry Valley IL 61016
Ph: 815-332-4961
Fax: 815-332-3022
AN, BF, CNI, CR, CY, FQ, HOQ, IH, NCR, NI, NO, PF, SR, TE, VF

FPM Milwaukee
8201 W. Calumet Rd.
Milwaukee WI 53223
Ph: 414-355-7900
Fax: 414-355-4719
AN, BF, CNI, CR, CY, FQ, HOQ, NCR, NI, NO, PF, SR, TE, VF

Franklin Steel Treating
1070 Ridge St.
Columbus OH 43215
Ph: 614-488-2556
Fax: 614-486-9489
AN, BF, CNI, CR, DQ, FH, FQ, HOQ, IH, NO, PF, PQ, SBN, SR, TE

Gear Company of America
14300 Lorain Ave.
Cleveland OH 44111
Ph: 216-671-5400
Fax: 216-671-5825
AN, BF, CNI, CR, HOQ, IH, NO, PQ, SR, TE

General Metal Heat Treating Inc.
941 Addison Rd.
Cleveland OH 44103
Ph: 216-391-0886
Fax: 216-391-0890
AN, BF, CNI, CR, CY, DQ, FQ, HOQ, NI, NO, PF, PQ, SBN, SR, TE, VF

Geo. H. Porter Steel Treating Co.
1273 E. 55th St.
Cleveland OH 44103
Ph: 216-431-6601
Fax: 216-431-0009
e-mail:
treating@aol.com
AN, BF, CR, CY, NO, PF, QU, SR, TE

Grand Rapids Commercial Heat Treating Co.
3832 Buchanan S.W.
Wyoming MI 49548
Ph: 616-243-0111
Fax: 616-243-4080
AN, BF, CNI, CR, DQ, NI, NO, PF, SR, TE

H & M Metal Processing
1850 Front St.
Cuyahoga Falls OH 44221
Ph: 800-304-2636
Fax: 216-928-5472
AN, NI, PF, SBN, SR, TE

Hansen-Balk Steel Treating Co.
1230 Monroe N.W.
Grand Rapids MI 49505
Ph: 616-458-1414
Fax: 616-458-6868
AN, BF, CNI, FH, HOQ, II, NI, NCR, NO, SR, TE, VF

Heat Treat Corp. of America
1120 W. 119th St.
Chicago IL 60643
Ph: 312-264-1234
Fax: 312-264-4321
AN, BF, CNI, CR, CY, DQ, FQ, HOQ, IH, NO, PQ, SR, TE

Heat Treating Services Corporation of America
P.O. Box 430269
Pontiac MI 48343-0269
Ph: 810-858-2230
Fax: 810-858-2242
AN, CNI, CR, HOQ, NO, SR, TE

Heat-Treating Inc.
1807 W. Pleasant St.
Springfield OH 45506
Ph: 513-325-3121
Fax: 513-325-3117
AN, BF, CNI, CR, CY, FH, FQ, HOQ, IH, NO, PF, SR, TE, VF

HI TecMetal Group
1101 E. 55th St.
Cleveland OH 44103
Ph: 216-881-8100
Fax: 216-881-6811
AN, BF, CNI, CR, CY, FQ, HOQ, IH, NCR, NI, NO, PF, SBN, SI, SR, TE, VF

Hi-Tech Steel Treating
2720 Roberts St.
Saginaw MI 48601
Ph: 800-835-8294
Fax: 517-753-2368
AN, BF, CNI, CR, DQ, FH, FQ, HOQ, IH, NO, PQ, SR, TE, VF

HiTech Aero
34800 Lakeland Blvd.
Eastlake OH 44095
Ph: 216-881-8100
Fax: 216-881-6811
AN, CY, SI, SR, TE, VF

Horizon Steel Treating
231 Jandus Rd.
Cary IL 60013
Ph: 847-639-4030
Fax: 847-639-1981
AN, BF, CNI, CR, CY, FH, FQ, HOQ, IH, NI, NO, PF, SR, TE, VF

Horsburgh & Scott
5114 Hamilton Ave.
Cleveland OH 44114
Ph: 216-431-3900
Fax: 216-432-5861
AN, BF, CR, CY, FH, HOQ, IN, NI, NO, PF, SR, TE

HTG Aerobraze
940 Redna Terrace
Woodlawn OH 45215
Ph: 513-772-1461
Fax: 513-772-0149
AN, SI, SR, TE, VF

Huron Metallurgical
12611 Haggerty Rd.
Belleville MI 48111
Ph: 313-699-6861
Fax: 313-699-6971
AN, CNI, CR, HOQ, NO, SR, TE

Hy-Vac Technologies
15701 Glendale Ave.
Detroit MI 48227
Ph: 313-838-2800
Fax: 313-838-2802
AN, BF, CY, DQ, NO, PF, SI, SR, TE, VF

Hydro-Vac
1177 Marquette St.
Cleveland OH 44114
Ph: 216-881-8100
Fax: 216-881-6811
AN, CY, NI, NO, SI, SR, TE, VF

Illiana Heat Treating Inc.
P.O. Box 1466
Danville IL 61832
Ph: 217-443-5418
Fax: 217-443-5419
AN, BF, CNI, CR, CY, FH, HOQ, IH, NCR, NI, NO, PF, SBN, SR, TE

Induction Heat Treating
775 Tek Drive
Crystal Lake IL 60014
Ph: 815-477-7788
Fax: 815-477-7784
AN, IH, SR, TE

Induction Services Inc.
24800 Mound Rd.
Warren MI 48091
Ph: 810-754-1640
Fax: 810-754-5402
AN, IH

Inductoheat Inc.
32251 N. Avis Dr.
Madison Hts. MI 48071
Ph: 810-585-9393
Fax: 810-585-0429
AN, IH, QU, SI, SR, TE
See ad page 8.

Industrial Steel Treating
613 Carroll St.
Jackson MI 49202
Ph: 517-787-6312
Fax: 517-787-5441
AN, BF, CNI, CR, CY, HOQ, IH, NO, SR, TE

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

Kowalski Heat Treating
3611 Detroit Ave.
Cleveland OH 44113
Ph: 216-631-4411
Fax: 216-631-8921
e-mail:
KHTHEAT@AOL.COM
AN, AU, BF, CY, DQ, FH, FQ, HOQ, NO, PF, PQ, SBN, SR, TE, VF

Lake County Steel Treating
960 Anita
Antioch IL 60002
Ph: 847-375-8174
Fax: 847-395-7638
AN, CNI, CR, FQ, NI, NO, SBN, SR, TE

Lindberg Heat Treating Harris Metals Division
4210 Douglas Ave.
Racine WI 53402
Ph: 414-681-4280
Fax: 414-639-5719
AU, BF, BTF, CNI, CR, DQ, FQ, HOQ, IH, NI, NCR, NO, PQ, SR, TE
See ad page this page.

Lindberg Heat Treating
16167 W. Rogers Dr.
New Berlin WI 53151
Ph: 414-782-5553
Fax: 414-782-5660
AN, BF, CNI, CR, CY, NI, NCR, NO, PF, SBN, SR, TE, VF

Lindberg Heat Treating
1975 N. Ruby St.
Melrose Park IL 60160
Ph: 708-344-4080
Fax: 708-344-4010
AN, BF, CNI, CR, CY, FQ, NCR, NI, NO, PF, SR, TE, VF

M & M Heat Treat
1309 Main St.
Essexville MI 48732
Ph: 517-893-3677
Fax: 517-893-4423
AN, BF, FH, NO, QU, SR, TE

Merit Gear Corp.
810 Hudson St.
Antigo WI 54409
Ph: 800-756-3748
Fax: 715-623-2290
AN, BF, BTF, CNI, CR, FH, HOQ, IH, NI, NO, PF, SR, TE
See ad page 46.

Met-Tek Inc.
1800 Melvin Ave.
Racine WI 53404
Ph: 414-639-8357
Fax: 414-639-7152
AN, BF, CNI, CR, FH, FQ, HOQ, IH, NO, SR, TE, VF

Metal Improvement Co.
1515 Universal Rd.
Columbus OH 43207
Ph: 614-444-1181
Fax: 614-444-0421
AN, CNI, CR, CY, HOQ, IH, NO, SR, TE

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

Metal Treating
1575 W. Pierce St.
Milwaukee WI 53204
Ph: 414-645-2226
Fax: 414-645-9118
AN, BF, CNI, CR, DQ, IH, NO, SBN, SR, TE, VF

Metallurgical Processes
P.O. Box 10842
Fort Wayne IN 46854
Ph: 219-423-1691
Fax: 219-422-2656
AN, BF, CNI, CR, NO

Metals Engineering Inc.
1800 South Broadway
Green Bay WI 54306
Ph: 414-437-7686
Fax: 414-437-7687
AN, BF, CNI, CR, FQ, HOQ, IH, NO, SBN, SR, TE

Metals Technology
25 Laura Dr.
Addison IL 60101
Ph: 708-543-9513
Fax: 708-543-9523
AN, AT, BF, CNI, CR, FQ, HOQ, NI, NCR, NO, PF, SR, SBN, TE, VF

Metropolitan Steel Treating
9792 Grinnell
Detroit MI 48213
Ph: 313-921-5522
Fax: 313-921-0363
AN, BF, CNI, CR, FBF, FH, HOQ, NCR, NI, NO, PF, SBN, SR, TE

Michigan Flame Hardening Co.
2241 Bellingham
Troy MI 48083-2099
Ph: 810-689-3737
Fax: 810-689-0860
BF, FH, SR, TE

Michigan Induction Inc.
8468 Ronda Dr.
Canton MI 48187
Ph: 313-459-8514
Fax: 313-459-8795
IH

Mid-West Flame Hardening Inc.
500 W. 150th St.
East Chicago IN 46312
Ph: 219-397-8423
Fax: 219-397-8480
FH, TE

Midland Metal Treating
5512 W. Airways Ave.
Franklin WI 53132
Ph: 414-421-5140
Fax: 414-421-2360
e-mail:
midlandmet@aol.com
AN, BF, CNI, CR, CY, FQ, IH, NO, TE

Modern Metal Processing Inc.
3448 Corwin Rd.
Williamston MI 48895
Ph: 517-655-4402
Fax: 517-655-3795
AN, NO, PF, SI, SR, TE, VF

Modern Steel Treating
28910 Lakeland Blvd.
Wickliffe OH 44092
Ph: 216-881-8100
Fax: 216-881-6811
AN, BF, CNI, CR, CY, FQ, HOQ, NO, SR, TE

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

EAST NORTH CENTRAL (cont'd)

National Broach & Machine
17500 23 Mile Rd.
Macomb MI 48044
Ph: 810-263-0100
Fax: 810-263-4571
AN, BF, CNI, CR, FQ, NO, SBN, SR, TE

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

Nettleton Steel Treating
1371 E. 45th St.
Cleveland OH 44103
Ph: 216-881-8100
Fax: 216-881-6811
AN, BF, FQ, NO, PF, SR, TE

Nitrotec Surface Engineering
28910 Lakeland Blvd.
Wickliffe OH 44092
Ph: 216-881-8100
Fax: 216-881-6811
AN, BF, CNI, CR, CY, FQ, HOQ, NCR, NO, SR, TE

Nitro-Vac Heat Treating
23080 Dequindre
Warren MI 48091
Ph: 810-754-4350
Fax: 810-754-5195
AN, BF, CY, NI, PF, SBN, SR, TE, VF

Ohio Metallurgical Service
1033 Clark St.
Elyria OH 44036
Ph: 216-365-4105
Fax: 216-365-9527
AN, CNI, CR, CY, DQ, FH, FQ, HOQ, IH, NO, PQ, SR, TE, VF

P & L Heat Treating & Grinding
313 E. Wood St.
Youngstown OH 44503
Ph: 216-746-1339
Fax: 216-746-7029
AN, BF, CR, FBF, FQ, NI, NO, PF, TE

Pfauter-Maag Cutting Tools
1351 Windsor Rd.
Loves Park IL 61111
Ph: 815-877-8900
Fax: 815-282-0264
AN, FBF, FQ, SR, TE, VF
See ads on pages 1 & 46.

Progressive Steel Treating
922 Lawn Drive
Loves Park IL 61111
Ph: 815-877-2571
Fax: 815-877-7922
AN, BF, CNI, CR, CY, FQ, HOQ, NO, PF, SR, TE, VF
See ads on pages 10 & 33.

Racine Heat Treating Co.
1215 8th St.
Racine WI 53403
Ph: 414-637-9893
Fax: 414-637-9854
AN, BF, CNI, CR, CY, FQ, HOQ, IH, NO, PF, SR, TE, VF

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

Roboduction Thermal Processing Inc.
P.O. Box 5090
Southfield MI 48086
Ph: 810-356-2577
Fax: 810-356-3989
BF, DQ, IH, PQ, SR, TE

Rotation Products Corp.
2849 N. Catherwood Ave.
Indianapolis IN 46219
Ph: 317-542-8563
Fax: 317-542-1171
AN, BF, CNI, CR, CY, FQ, NI, NO, SR, TE

S.K.S. Heat Treating Co.
3286 Industrial Dr.
Saginaw MI 48601
Ph: 517-777-0270
Fax: 517-777-0273
AN, BF, CNI, CY, FQ, HOQ, IH, NO, SR, TE

Scot Forge
8001 Winn Rd. Box 8
Spring Grove IL 60081
Ph: 847-587-1000
Fax: 847-587-2000
AN, BF, FQ, NO, SR, TE

Shanafelt Mfg. Co.
2633 Winfield Way N.E.
Canton OH 44705
Ph: 216-455-0315
Fax: 216-455-4487
SR

Shore Metal Technology
5475 Avion Park Dr.
Cleveland OH 44143
Ph: 216-473-2020
Fax: 216-473-0947
AN, BF, CNI, CR, CY, HOQ, NCR, NI, NO, PF, SR, TE

Specialty Heat Treating
3700 Eastern Ave.
Grand Rapids MI 49508
Ph: 616-245-0465
Fax: 616-245-3060
AN, CNI, CR, CY, HOQ, IH, NCR, NO, SR, TE, VF

Specialty Steel Treating
31610 W. Eight Mile Rd.
Farmington Hills MI 48336
Ph: 810-478-5900
Fax: 810-478-9626
AN, BF, CNI, CR, FQ, HOQ, NO, PQ, SR, TE

Specialty Steel Treating
34501 Commerce Rd.
Fraser MI 48026
Ph: 810-293-5355
Fax: 810-293-5390
AN, BF, CNI, CR, CY, DQ, FQ, HOQ, NI, NO, PF, PQ, SR, TE, VF

State Heat Treat Inc.
520 32nd St. S.E.
Grand Rapids MI 49548
Ph: 616-243-0178
Fax: 616-243-6337
e-mail: bharvey@aol.com
AN, BF, CNI, CR, FQ, IH, NI, NO, PF, SR, TE

Sun Steel Treating
550 Mill St.
South Lyon MI 48178
Ph: 810-471-0844
Fax: 810-437-3140
AN, CY, IN, NI, NO, PF, SR, TE

T. N. Woodworth Inc.
1600 Farrow St.
Ferndale MI 48220
Ph: 810-541-1960
Fax: 810-541-3864
AN, CNI, CR, CY, FQ, NI, NO, PF, SR, TE, VF

Therm-Tech of Waukesha
301 Travis Lane
Waukesha WI 53186
Ph: 414-549-1878
Fax: 414-549-4320
AN, BF, CNI, CR, CY, FH, HOQ, NCR, NI, NO, PF, SBN, SR, TE

Thermet Inc.
203 Travis Lane
Waukesha WI 53186
Ph: 414-544-9800
Fax: 414-544-5959
FH, IH, SR, TE

Thermo Treaters Ltd.
101 McCoy Creek Dr.
Buchanan MI 49107
Ph: 616-695-6700
Fax: 616-695-6737
AN, BF, CNI, CR, CY, FH, FQ, HOQ, NCR, NI, NO, PF, SR, TE

Tocco, Inc.
30100 Stephenson Hwy.
Madison Hts. MI 48071
Ph: 810-399-8601
Fax: 810-399-8603
AN, IH, SR, TE

TracTech
11405 Stephens
Warren MI 48090
Ph: 810-759-3880
Fax: 810-759-1645
AN, BF, CNI, CR, CY, DQ, NO, SR, TE

Treat All Metals Inc.
5140 N. Port Washington Rd.
Milwaukee WI 53207
Ph: 414-962-2500
Fax: 414-962-4702
AN, BTF, CNI, CR, CY, DQ, FQ, HOQ, NCR, NI, NO, PF, PQ, SR, TE

Trojan Heat Treat Inc.
320 East Plain St.
Homer MI 49245
Ph: 517-568-4403
Fax: 517-568-4435
AN, NO, SR

Trutec Industries
4700 Gateway Blvd.
Springfield OH 45502
Ph: 513-323-8833
Fax: 513-323-9192
BF, CNI, CR, CY, FQ, NCR, NI, PF, SBN, TE

Universal Heat Treating
3878 E. 93rd St.
Cleveland OH 44105
Ph: 216-641-2000
Fax: 216-641-6703
CNI, CR, CY, NI, NO, VF

Walker Heat Treating
10601 Briggs Rd.
Cleveland OH 44111
Ph: 216-881-8100
Fax: 216-881-6811
AN, BF, CY, FQ, NI, NO, PF, SBN, SI, SR, TE, VF

Wear-Ever Surface Treating Corp.
23624 Roseberry
Warren MI 48089
Ph: 810-778-2330
Fax: 810-778-2393
BF, NI, SBN

Weiss Industries Inc.
2480 N. Main St.
Mansfield OH 44901
Ph: 419-526-2480
Fax: 419-526-1158
AN, BF, CNI, CR, FQ, HOQ, LH, NO, PF, SR, TE, VF

Westside Flame Hardening Inc.
38200 Executive Dr. N.
Westland MI 48185
Ph: 313-729-1665
Fax: 313-729-3520
CY, DQ, FH, FQ, HOQ, IH, NO, SR, TE

Wohlert Corp.
708 E. Grand River Ave.
Lansing MI 48906
Ph: 517-485-3750
Fax: 517-485-0501
BF, FH, FQ, IH, NO, TE

Zion Industries
6229 Grafton Rd.
Valley City OH 44280
Ph: 216-225-3246
Fax: 216-483-3942
e-mail: KeithStar@aol.com
IH

WEST NORTH CENTRAL

Advanced Heat Treat
2839 Burton Ave.
Waterloo IA 50703
Ph: 319-232-5221
Fax: 319-232-4952
BF, IH, NCR, NI, SR, TE, VF

Brazing & Metal Treating
2501 HiTec Ave.
Albert Lea MN 56007
Ph: 507-373-9630
Fax: 507-373-3771
AN, BZ, NO, SR

Flame Metals Processing Corp.
7317 W. Lake St.
Minneapolis MN 55426
Ph: 612-928-7230
Fax: 612-925-0572
AN, BF, CNI, CR, FQ, HOQ, IH, NCR, NI, NO, SBN, SR, TE, VF

Good Earth Tools
4 Industrial Drive
Crystal City MO 63019
Ph: 314-937-3330
Fax: 314-937-3386
IH

Lawrence Industries Inc.
2720 S. Cornhusker Ave.
Hastings NE 68901
Ph: 402-463-3158
Fax: 402-463-4128
BF, CNI, CR, FQ, IH, NI, NO, SR, TE

Lindberg Heat Treating
650 E. Taylor Ave.
St. Louis MO 63147
Ph: 314-382-6200
Fax: 314-382-3741
AN, BF, CNI, CR, CY, DQ, FQ, HOQ, IH, NCR, NI, NO, PF, PQ, SR, TE, VF

Metal Treaters Inc.
859 N. Prior
St. Paul MN 55104
Ph: 612-646-1316
Fax: 612-646-7705
AN, CNI, CR, CY, HOQ, IH, SBN, SR, TE, VF

Metallurgical Inc.
900 E. Hennepin Ave.
Minneapolis MN 55414
Ph: 612-378-1500
Fax: 612-378-0462
AN, BF, CNI, CR, DQ, FH, FQ, HOQ, IH, NI, NO, PF, PQ, SR, TE, VF

Midwestern Machinery
902 E. 4th St.
Joplin MO 64802-0458
Ph: 417-624-2400
Fax: 417-624-2430
AN, BF, CNI, CR, FH, HOQ, NO, PF, SR, TE

Paulo Products Co.
5711 West Park Ave.
St. Louis MO 63110
Ph: 314-647-7500
Fax: 314-647-7518
AN, CNI, CR, CY, FBF, FH, HOQ, IH, NCR, NI, PQ, SR, TE, VF
See ad page 10.

Paulo Products Co.
4827 Chelsea
Kansas City MO 64130
Ph: 816-861-7500
Fax: 816-924-7300
AN, CNI, CR, CY, HOQ, IH, NCR, NI, NO, SBN, SR, TE, VF
See ad page 10.

Steel Treating
2250 Fuller Rd.
W. Des Moines IA 50265-5529
Ph: 515-225-6565
Fax: 515-226-8772
AN, BF, CNI, CR, CY, FBF, IH, NO, PF, SR, TE, VF

Superior Metal Treating
2540 Indiana Ave.
Kansas City MO 64127
Ph: 816-924-1966
Fax: 816-924-3199
AN, BF, CNI, CR, CY, FBF, FH, FQ, IH, NO, PF, SBN, SR, TE, VF

SOUTH ATLANTIC

American Metal Treating Inc.
500 Manley St.
High Point NC 27260
Ph: 910-889-3277
Fax: 910-889-7950
AN, BF, CNI, CR, CY, FBF, HOQ, IH, NCR, NI, NO, PF, SBN, SR, TE, VF

Braddock Metallurgical
14600 Duval Place West
Jacksonville FL 32218
Ph: 904-741-4777
Fax: 904-741-4813
e-mail: jfrim@aol.com
AN, BF, CNI, CR, CY, FQ, IH, NI, NO, SR, TE, VF

Carolina Commercial Heat Treating
P.O. Drawer 1368
Fountain Inn SC 29644
Ph: 803-862-3516
Fax: 803-862-4466
AN, BF, CNI, CR, CY, FQ, HOQ, IH, NCR, NO, SR, TE, VF

Dixie Machine & Heat Treating Inc.
711 E. Franklin
Gastonia NC 28054
Ph: 704-864-5454
Fax: 704-864-5456
AN, CNI, CR, HOQ, IH, NO, SR, TE

Drever Heat Treating
6201 Robinwood Rd.
Baltimore MD 21225
Ph: 410-789-6160
Fax: 410-789-6659
AN, BF, CNI, CR, CY, FH, FQ, HOQ, IH, NI, NO, PF, SR, TE, VF

East Carolina Metal Treating Inc.
1010 S. Saunders St.
Raleigh NC 27603
Ph: 919-834-2100
Fax: 919-833-1764
e-mail: RockyIII@aol.com
AN, BF, CNI, CR, CY, IH, NI, NO, QU, SR, TE, VF

Hauni Richmond Inc.
2800 Charles City Rd.
Richmond VA 23231
Ph: 804-222-5262
Fax: 804-236-5284
AN, CNI, CR, CY, HOQ, IH, NCR, NI, NO, SR, TE, VF

SOUTH ATLANTIC (cont'd)

Induction Metal Treating Co.
1688 Fairhope Rd.
York SC 29745
Ph: 803-684-2548
Fax: 803-684-9387
AN, BF, CNI, CR, CY, FBF, FH, FQ, HOQ, IH, NCR, NI, NO, PF, SBN, SI, SR, TE, VF

Industrial Metal Treating Corp.
402 E. Front St.
Wilmington DE 19801
Ph: 302-656-1677
Fax: 302-656-4370
AN, BF, CNI, CR, FQ, HOQ, IH, NI, NO, PF, SR, TE, VF

JCS Engineering & Development Corp.
211 W. 22nd St.
Hialeah FL 33010
Ph: 305-888-7911
Fax: 305-888-9913
AN, CR, NO, QU, SBN, SR, TE

Progressive Engineering Co.
2010 E. Main St.
Richmond VA 23223
Ph: 800-868-5457
Fax: 804-780-2230
NI, VF

Southeastern Heat Treating Inc.
10 Old Shoals Rd.
Arden NC 28704
Ph: 704-684-4572
Fax: 704-684-5982
AN, BF, CNI, CR, CY, IH, NO, PF, QU, SR, TE, VF

Suncoast Heat Treating
316 S. Hughey Ave.
Orlando FL 32801
Ph: 407-843-7145
Fax: 407-422-3276
AN, BF, CNI, CR, CY, FH, FQ, HOQ, NI, NO, PF, SI, SR, TE, VF

Suncoast Heat Treating
4704 W. South Ave.
Tampa FL 33614
Ph: 813-870-1510
Fax: 813-871-3792
AN, BF, CNI, CR, CY, FH, FQ, HOQ, NI, NO, PF, SI, SR, TE, VF

Suncoast Heat Treating
3181 SW 15th St.
Pompano Beach FL 33069
Ph: 305-968-6200
Fax: 305-972-0970
AN, BF, CNI, CR, CY, FH, FQ, HOQ, IH, NCR, NI, NO, PF, SI, SR, TE, VF

Thermal Braze Inc.
230 Juno St.
Jupiter FL 33458
Ph: 561-746-6640
Fax: 561-746-7452
AN, BZ, CY, IH, VF

Thermal Metal Treating
314 S. Pine St.
Aberdeen NC 28315
Ph: 910-944-3636
Fax: 910-944-3280
AN, BF, CNI, CR, CY, NO, QU, SR, TE

Western Stress Inc.
7523 Whitepine Rd.
Richmond VA 23237
Ph: 804-271-5447
Fax: 804-271-7692
SR, TE

EAST SOUTH CENTRAL

Braddock Metallurgical
3008 Red Morris Pkwy.
Anniston AL 36207
Ph: 205-831-5199
Fax: 205-831-5680
AN, BF, CNI, CR, CY, HOQ, NO, PF, SI, SR, TE, VF

Brazing & Metal Treating
1379 Jamike Lane
Erlanger KY 41018
Ph: 606-647-1115
Fax: 606-647-1165
AN, NO, SR, TE

Coleman Commercial Heat Treating
2867 Hangar Rd.
Memphis TN 38118
Ph: 901-366-0204
Fax: 901-366-0770
AN, BF, CNI, CR, FH, HOQ, IH, NI, NO, SR, TE

Dixie Heat Treating Co.
Rt. 11 Box 91 Church Rd
Florence AL 35630
Ph: 205-767-1572
Fax: 205-767-1573
AN, BF, CNI, CR, CY, FQ, NCR, NO, PF, SR, TE

Gibson Heat Treat Inc.
2037 Brookside Lane
Kingsport TN 37660
Ph: 423-246-5542
Fax: 423-246-8629
e-mail:
JohnGibsn@aol.com
AN, BF, CR, FH, FQ, HOQ, IH, NO, PF, PQ, SR, TE

Lexington Heat Treat
657 E. 7th St.
Lexington KY 40505
Ph: 606-231-0236
Fax: 606-211-9464
AN, AT, CNI, CR, CY, HOQ, IH, NO, SBN, SR, TE, VF

Metal Methods
260 Chenault Rd.
Frankfort KY 40601
Ph: 502-695-5700
Fax: 502-695-5702
AN, NO, SR, TE

Metal-Tec Heat Treating Inc.
4723 W. Station St.
Eight Mile AL 36663
Ph: 334-456-1133
Fax: 334-456-1134
NCR, NI, PF, SR

Mountain Metallurgical
P.O. Box 460
Elizabethton TN 37644
Ph: 423-543-7212
Fax: 423-542-3519
AN, BF, BTF, CNI, CR, CY, NO, PF, PQ, SR, TE

Paulo Products Co.
1307 Rutledge Ave.
Murfreesboro TN 37129
Ph: 615-896-1385
Fax: 615-895-9613
CNI, CR, HOQ, NI, SR, TE
See ad page 10.

Paulo Products Co.
1540 Channel Ave.
Memphis TN 38113
Ph: 901-948-5523
Fax: 901-948-7501
AN, CNI, CR, CY, HOQ, IH, NCR, NI, NO, SR, TE, VF
See ad page 10.

Paulo Products Co.
705 N. 22nd St.
Bessemer AL 35020
Ph: 205-428-1294
Fax: 205-425-9841
AN, CNI, CR, CY, HOQ, NI, SR, TE, VF
See ad page 10.

Paulo Products Co.
3206 Ambrose
Nashville TN 37207
Ph: 615-228-2526
Fax: 615-228-2734
AN, CNI, CR, CY, FH, HOQ, IH, NI, NO, SR, TE, VF
See ad page 10.

Specialty Heat Treating
105 W. Sanderfer Rd.
Athens AL 35611
Ph: 205-233-1147
Fax: 205-232-5595
AN, BF, CNI, CR, CY, FH, HOQ, NCR, NI, PF, SI, SR, TE, VF

WEST SOUTH CENTRAL

Advanced Met. Tech. Inc.
212 Page Ave.
Fort Worth TX 76110
Ph: 817-921-5700
Fax: 817-921-5372
AN, BF, CNI, CR, FQ, HOQ, II, NCR, NI, NO, PF, SR, TE, VF

Cooperheat Inc.
910 Walcot Rd.
Westlake LA 70669
Ph: 318-882-1800
Fax: 318-882-1821
AN, NO, SR, TE

Custom Heat Treating
4117 Meadow Lane
Bessier City LA 71111
Ph: 318-742-6662
Fax: 318-742-4135
AN, BF, HOQ, NI, NO, PF, SR, TE

Eckel Heat Treat
8035 W. County Rd.
Odessa TX 79764
Ph: 915-362-4336
Fax: 915-362-1827
e-mail:
Heckel@aol.com
AN, BF, CR, HOQ, NO, SR, TE

Hinderliter Heat Treating Inc.
1240 N. Harvard
Tulsa OK 74115
Ph: 918-834-0855
Fax: 918-836-4162
AN, BF, CNI, CR, CY, FH, HOQ, IH, NCR, NI, NO, SR, TE, VF

Hinderliter Heat Treating Inc.
2005 Montgomery St.
Fort Worth TX 76107
Ph: 817-737-6651
Fax: 817-377-9610
AN, BF, CNI, CR, CY, FH, FQ, HOQ, IH, NCR, NO, PF, SR, TE, VF

Hinderliter Heat Treating Inc.
10530 Doric St.
Dallas TX 75220
Ph: 214-357-0394
Fax: 214-357-0195
AN, BF, CNI, CR, CY, FQ, NCR, NI, NO, SR, TE, VF

Houston Flame Hard'ng.
215 N. Jenkins St.
Houston TX 77003
Ph: 713-926-8017
Fax: 713-926-8316
BF, FH, SR, TE

Lindberg Heat Treating
8316 E. Freeway
P.O. Box 24369
Houston TX 77229
Ph: 713-672-6601
Fax: 713-672-5164
AN, BF, CNI, CR, IH, NI, NO, PF, QU, SR, TE

Magnum Met. Treating
4400 N. Frazier St.
Conroe TX 77303
Ph: 409-856-6607
Fax: 409-856-6271
AN, CNI, CR, NI, NO, PF, SR, TE, VF

Partek Laboratories Inc.
225 S. Hollywood Rd.
Houma LA 70360
Ph: 504-851-5310
Fax: 504-851-5312
AN, BF, CR, NO, PF, QU, SR, TE

Wall Colmonoy Corp.
4700 S.E. 59th St.
Oklahoma City OK 73135
Ph: 405-672-1361
Fax: 405-670-3763
AN, NO, PF, SI, SR

MOUNTAIN

ABS Metallurgical Processors Inc.
4313 E. Magnolia St.
Phoenix AZ 85034
Ph: 602-437-3008
Fax: 602-470-0309
AN, AU, BF, CNI, CR, CY, FQ, HOQ, NO, PF, SR, TE

Metal Treating & Research
1680 E. 69th Ave.
Denver CO 80229
Ph: 303-286-9338
Fax: 303-286-9366
AN, BF, CNI, CR, HOQ, NO, PF, SR, TE, VF

Phoenix Heat Treating
2405 W. Mohave
Phoenix AZ 85009
Ph: 602-258-7751
Fax: 602-258-7767
AN, BF, CNI, CR, CY, FQ, HOQ, NCR, NO, PF, SBN, SR, TE, VF

Sonee Heat Treating
3900 N. 31st. Ave.
Phoenix AZ 85017
Ph: 602-277-4757
Fax: 602-230-7811
AN, BF, CR, CY, FBF, FQ, HOQ, NI, NO, PF, SBN, SR, TE, VF

PACIFIC

Accurate Steel Treating
10008 Miller Way
South Gate CA 90280
Ph: 310-927-6528
Fax: 310-927-8591
AN, BF, CNI, CR, CY, FBF, FQ, NCR, NI, NO, PF, SBN, SR, TE, VF

Burbank Steel Treating
415 S. Varney St.
Burbank CA 91502
Ph: 818-842-0975
Fax: 213-849-3739
AN, BF, CNI, CR, DQ, FQ, HOQ, NI, NO, PF, PQ, SBN, SR, TE, VF

Cal-Doran Division
1804 Cleveland Ave.
National City CA 91950
Ph: 619-477-2121
Fax: 619-477-3219
AN, BF, CNI, CR, CY, FQ, NI, NO, SBN, SR, TE

Cal. Surface Hdng.
1315 S. Alameda
Compton CA 90220
Ph: 310-608-5576
Fax: 310-608-2072
FH, SR

Certified Metal Craft
877 Vernon Way
El Cajon CA 92020
Ph: 619-593-3636
Fax: 619-593-3635
AN, BF, BZ, CR, CY, FQ, HOQ, NO, PF, SBN, SI, SR, TE, VF

City Steel Treating Inc.
13007 Los Nietos Rd.
Santa Fe Springs CA 90670
Ph: 310-941-1246
Fax: 310-941-1247
AN, BF, CNI, CR, CY, FQ, HOQ, NCR, NI, NO, SR, TE

Edwards Heat Treating
642 McCormick St.
San Leandro CA 94577
Ph: 510-638-4140
Fax: 510-638-1438
AN, BF, CNI, CR, FH, FQ, IH, NO, PF, SR, TE

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

Hinderliter Heat Treating Inc,
1025 N. Pauline St.
Anaheim CA 92801
Ph: 714-776-8312
Fax: 714-776-8446
AN, BF, BZ, CNI, CR, CY, FBF, FQ, HOQ, NCR, NI, NO, PF, SR, TE, VF

Hinderliter Heat Treating Inc., West
18600 Oxnard St.
Tarzana CA 91356
Ph: 818-344-0216
Fax: 818-609-9372
AN, BF, CNI, CR, CY, FQ, IH, NCR, NI, NO, PF, SI, SR, TE, VF

Hitech Metallurgical
7384 Trade St.
San Diego CA 92121
Ph: 619-586-7272
Fax: 619-586-7598
e-mail:
AAJB84D@PRODI-GY.COM
AN, CY, NO, SI, SR, TE, VF

Industrial Steel Treating
3370 Benedict Way
Huntington Park CA 90255
Ph: 213-583-1231
Fax: 213-589-1255
AN, AU, BF, CNI, CR, CY, DQ, FBF, FQ, HOQ, NCR, NI, NO, PF, PQ, SR, TE, VF

Met-Tek Inc.
15651 S.E. 125th
Clackamas OR 97015
Ph: 503-656-3203
Fax: 503-655-6898
AN, AU, BF, CNI, CY, HOQ, IH, NCR, NI, NO, PF, SR, TE, VF

Oakland Metal Treating
450 Derby Ave.
Oakland CA 94601
Ph: 510-261-9675
Fax: 510-261-5678
AN, BF, CNI, CR, HOQ, NO, PF, SR, TE

Washington Metallurgical Services
2447 6th Ave. South
Seattle WA 98134
Ph: 206-622-8960
Fax: 206-623-5045
AN, BF, CNI, CR, CY, DQ, FH, FQ, HOQ, IH, NO, PQ, SR, TE, VF

TECHNICAL CALENDAR

MARCH 7–9

AGMA's 80th Annual Meeting. Marriott's Harbor Beach Resort, Fort Lauderdale, FL. This year's theme will be "The Pressures of Reality—Manufacturing in a Changing World." Call AGMA Headquarters, 703-684-0211 or fax 703-684-0242 for more information.

MARCH 12

SME course in Fundamentals of Coating for Cutting Tools, Charlotte, NC. Contact Susan Mihalik at SME Headquarters, 313-271-1500 or fax 313-271-2861 for more information.

MARCH 17–18

ASM Heat Treating Courses. Cincinnati Convention Center, Cincinnati, OH: Basics of Induction Heating, Nitriding Processes Technology, FEA in Heat Treat Applications, Laser Transformation Hardening, Practical Guide to Improving Performance of Precision Tooling & Component Wear Parts. Call ASM at 216-338-5151 for more information.

MARCH 19–21

ASM's 16th Heat Treating Society Conference & Exposition, The Cincinnati Convention Center, Cincinnati, OH. For more information, call ASM International at 216-338-5151 or fax 216-338-4634.

MARCH 26–27, APRIL 2–3

SME conference on Implementing the QS 9000 Automotive Standards. Contact Susan Mihalik at SME Headquarters 313-271-1500 or fax 313-271-2861 for more information.

APRIL 22–24

Verein Deutscher Ingenieure (VDI) First International Conference on Gears. Hilton Hotel, Dresden, Germany. Co-sponsored by AGMA and other international gear organizations. For more information, contact the Organizing Secretariate in Düsseldorf by phone at 49-211-6214-501 or by fax at 49-211-6214-575.

APRIL 22–26

ASM Seminar, The Principles of Heat Treating. Materials Park, OH. Week-long conference covering basic heat treating metallurgy. For engineers, technicians and management. Contact ASM at 1-800-336-5152 x300 or fax 216-338-4634.

APRIL 23–24

SME course on Designing and Manufacturing Plastic Gears in Chicago, IL. Contact Susan Mihalik at SME headquarters 313-271-1500 or fax 313-271-2861 for more information.

APRIL 29–MAY 1

University of Wisconsin, Milwaukee Seminar on Plastic Gear Manufacture, Application & Design. University Center for Continuing Education, Milwaukee, WI. Contact Roger Hirons at 414-227-3105 or fax 414-227-3119 for more information.


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Holcroft is a recognized industry leader in the manufacturing, selling, and servicing of high-quality industrial heat treat furnace systems. Numerous worldwide patents attest to our ability to create innovative product designs with customer satisfaction and cost-efficiency in mind.
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A Division of Thermo Process Systems Inc.
See us at the ASM Heat Treat Expo, March 19–21, 1996, Cincinnati, Ohio, Booth #353
CIRCLE 120 on READER SERVICE CARD

PRODUCT NEWS

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. Send your new product releases to: *Gear Technology*, 1401 Lunt Avenue, Elk Grove Village, IL 60007, Fax: 847-437-6618.

Large Diameter Gear Cutter

The Gleason Works has introduced the Phoenix® 1000HC hypoid cutting machine for production of precision bevel and hypoid gears up to 39" (1000 mm) nominal diameter (face milling with 5:1 ratios). The machine also offers flexible, fully automatic setup and operation, CNC control of all 6 axes for part-to-part and job-to-job repeatability, and a cast iron frame and special roller-style linear bearings for maximim stiffness and damping characteristics.

Circle 300

Spline Roller

West Michigan Spline, Inc. has introduced a new line of spline rolling machines. The Models 24, 36 and 48 spline rollers have been redesigned to provide for superior strength and eliminate tie bars. Their one-piece "C" frame welded construction is thermally stress relieved. The machines have externally based coolant tanks, filters and pumps designed with preventive maintenance in mind.

Circle 301

Dual-Head Grinding Machine

Mutschler Technologies introduces the Model GR 202 bench-top, dual-head grinding machine for chamfering and deburring two surfaces simultaneously. The compact machine is well-suited for grinding a variety of gears including helical, spur, angle, pinion and spiral bevel. It features electronic and pneumatic control panels and a programmable counter. Holds parts up to 28" in diameter and 100 lbs. Available with a manual 3-jaw chuck or an optional self-centering air chuck.

Circle 302

500°F Drawer Oven

The #784 is a 5-tier, electrically heated drawer oven from **Grieve**. It can stress relieve parts to a maximum operating temperature of 500°F. It has a 24 kW total power input, installed in Incoloy-sheathed tubular heating elements. Its work space is 50" wide x 26" deep x 38" high overall. Each drawer measures 44" x 10" x 3.5". It also has a digital indicating temperature controller, a manual reset excess temperature control with separate contactors, an SCR power controller and a 700 CFM, 3/4 hp recirculating blower.

Circle 303

CNC Gear Measuring Centers

Klingelnberg introduces its new PNC 33 Gear Measuring Center. The small-footprint, 13" capacity, 4-axis machine accommodates workpieces up to 102". The machine can be used on spur and helical gears, spiral bevel gears, rotors and camshafts and tools including shaper cutters and hobs. It has a multi-axis 3-D tracer head that can measure non-gear components, a 3-D digital probe with high-resolution Heidenhain glass scales and a special collision protection system. Other features include a new machine control, networking possibilities, software diagnostics via modem and optional manual profile and lead checks.

Circle 304

Over Ball/Pin Size Measurement System

Manufactured Gear & Gage introduces the industry's first 1,000-pound capacity over ball/pin size measurement system. The Heavy Duty Gage-O-Matic Model G12-1001 provides quick and easy gear or spline size inspection of heavy parts. The base machine uses a linear scale with digital readout for fast setups and convenient operation. Accuracy is 0.0001" (0.0025 mm) with a resolution of 0.00005" (0.0012 mm) and repeatability of ±0.0001" (0.0025 mm). External capacity is max. 12" O.D.; between centers up to 20" length; face up to 8" wide; 21 D.P. max. at 6" P.D.

Circle 305

Honing Mandrels

Sunnen introduces its new KR series of honing mandrels with retractable stone assemblies for greater efficiency in bore sizing and finishing operations. Easier loading and unloading of parts and fewer marks and scratches. Available on the KR6 through KR20

(Continued, page 42.)

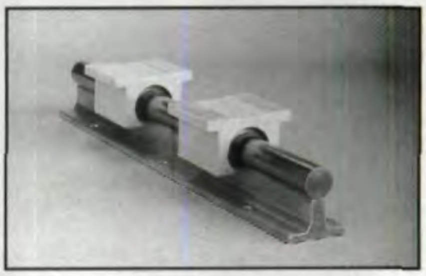
(Continued, from page 40.)
series (.185"–.744" I.D.), the retractable mandrels and stone assemblies also will be offered in longer sizes designated as the *BLR* series.

Circle 306

New TiAIN Coatings

Multi-Arc Inc. announces an improved ION BOND© TiAIN coating for titanium & nickel-based alloys, stainless steel and cast materials. The company says the new coating offers twice the life of its first-generation TiAIN coating. Called ION BOND 17-II, the coating is ideal for high speed machining, dry hobbing and other machining operations where high temperature is generated at the point of cut. It also offers excellent ductility, which makes coated tools less susceptible to chipping when used for interrupted cutting.

Circle 307



Bearing Assembly

Pacific Bearing Company has introduced a new preassembled shaft, rail and bearing assembly that the company says significantly eases installation and reduces downtime. The assembly is made of hardened steel shafting with aluminum support rails. Either two single or one twin open pillow block are available at no extra cost. The assemblies are available in all standard shaft lengths and diameters as well as custom lengths.

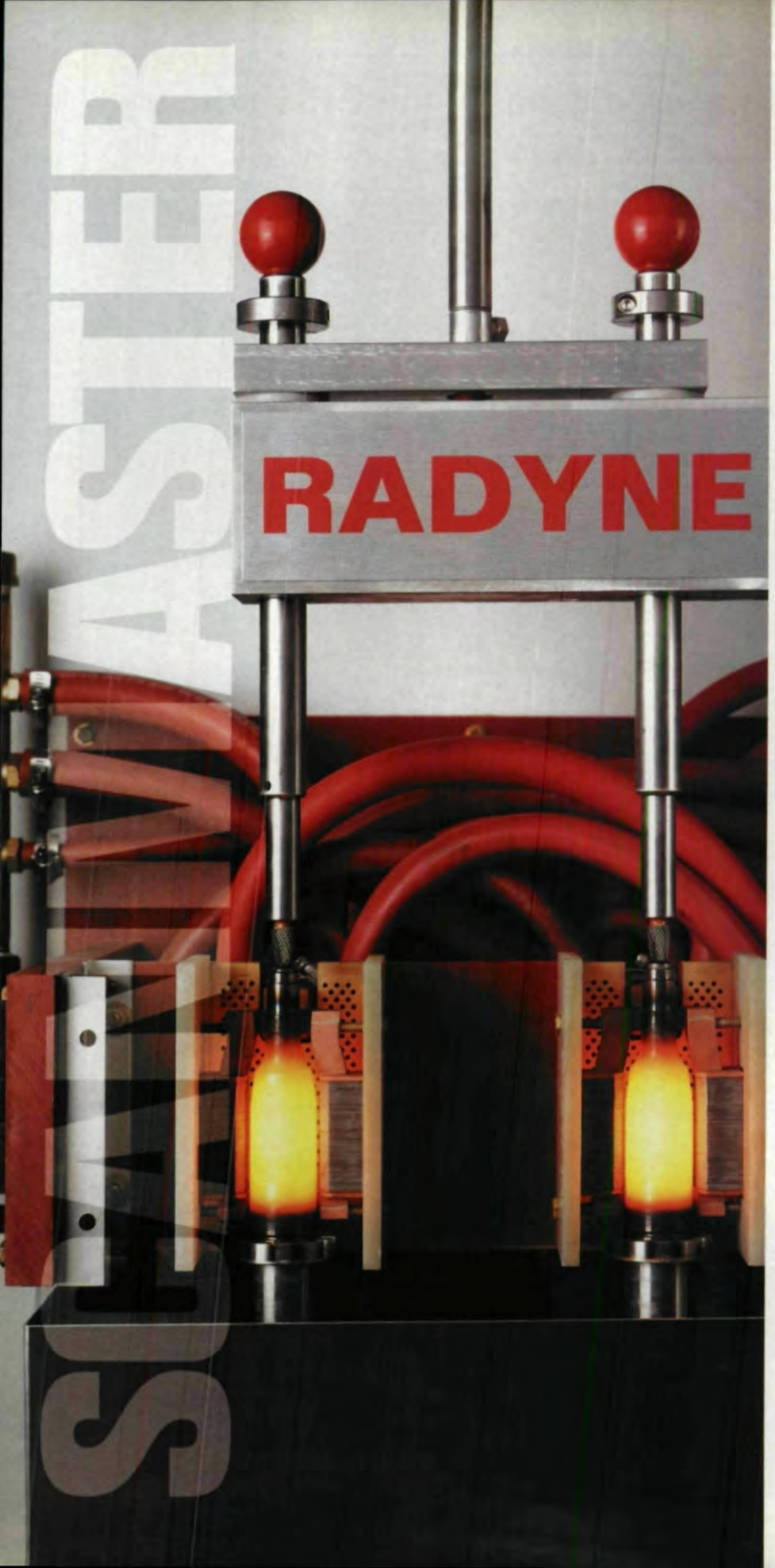
Circle 308

Quick Change Tool System

Madison Cutting Tools introduces the Madison-Hektobore® quick change tooling system. In this system, only the lightweight cutting head portion of the tool needs to be replaced when changing size or operation sequence. Four master bar sizes handle the system's entire cutting range from .985" to 23.625". Thirteen cutting heads and six pairs of cutting slides for a broad range of rough and semi-finished boring operations with a minimum tool inventory. Comes with a precision slide and single-point cartridge fitting on the same head for finish boring.

Circle 309

Tell Us What You Think...
If you found this article of interest and/or useful, please ***circle 208.***



ScanMaster™

Vertical-Scanning Induction Heat-Treating System

Radyne's ScanMaster™ system uses modular components that can be incorporated together or separately to meet the specific needs of the heat treater. User friendly, Microsoft® Windows,™ PC-compatible control of all system variables maintains close tolerance of heat-treated parts, while providing a paperless tracking system. The ScanMaster™ system provides for easy system set-up, production monitoring, on-board fault logging and diagnostics. An optional off-line program editor is also available.

When it comes to quality monitoring, Radyne's PC-compatible APEX QA system is fast becoming the industry standard. This system is capable of continuously tracking, in real time, eight significant process variables which are graphically displayed. Data collection and logging of each process variable is maintained for future SPC analysis.

The Perfect Integration

The combination of Radyne's ScanMaster™ and APEX QA Quality Assurance system, operating in a Microsoft® Windows™ environment, represents the latest in induction heat-treating technology.

See us at the ASM Heat Treat Expo, March 19–21, 1996, Cincinnati, Ohio, Booth #676

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CIRCLE 127 on READER REPLY CARD

People, Places, Etc.

Ronald D. Bullock, owner and president of **Bison Gear & Engineering** and **Bison Electric** in St. Charles, IL, has been named chairman of the National Association of Manufacturer's Small Manufacturers Forum. He will also serve on NAM's Executive Committee and as a member of the Board of Directors . . . **James S. Gleason**, chairman and president of **Gleason Corporation**, Rochester, NY, has been elected first vice chairman of the board of directors of AMT—The Association for Manufacturing Technology . . . **Curtis T. Atkisson, Jr.** has retired as president and Chief Operating Officer of **SPX Corporation,** Muskegon, MI. SPX is a leader in the design, manufacture and marketing of specialty service tools and original equipment components for the motor vehicle industry.

WAY TO GO, GUYS

Don McVittie, president of **Gear Engineers, Inc.**, of Seattle, WA, has received the Meritorious Service Award from the American National Standards Institute (ANSI) for his participation in ANSI and support of U.S. voluntary standards . . . **Gary Martin**, president of **Martin Sprocket and Gear, Inc.**, Arlington, TX, has won the Power Transmission Distributors Association's (PTDA) Warren Pike Award for outstanding long-term contributions to the power transmission/motion control industry and extraordinary service to PTDA . . . **Mike Antosiewicz** of **Falk Corp.**, Milwaukee, WI, and **John Colbourne** of the **University of Alberta** were recipients of the AGMA Technical Division Executive Committee's Award for significant contributions to the continuing development of domestic and international standards. **Dave McCarthy** of the **Dorris Co.** and **Don Root** of **Otis Elevator** received Letters of Merit.

COMPANY NEWS

Delphi Saginaw Steering Systems has opened its new $20.6 million Advanced Systems Center in Saginaw, MI, to develop the steering and driveline systems of the future and the processes to produce them. The Center has already established Delphi's leadership in electro-hydraulic steering. The Center includes an Advance Product Center for the development and testing of concepts and technologies, an Advanced Manufacturing Center to design and build the processes, tooling and controls to produce next-generation systems, an expanded Prototype Center for sample production and an Acoustics and Vibration Center, scheduled to open in mid-1996. The division has been awarded a contract to supply the world's first high-volume, production electrohydraulic steering system . . . **Lovejoy Inc.** has added a second manufacturing plant in Downers Grove, IL for the primary purpose of producing a broad line of mechanical power transmission gear couplings recently acquired from **Sier-Bath**. The new operation adds 20% to Lovejoy's total manufacturing space. Lovejoy purchased the intellectual properties of Sier-Bath gear couplings in 1993 . . . **NILES Machine Tool Company and Fritz Werner Machine Tool Company** of Berlin, Germany, have announced their merger. The new company will be known as **Fritz Werner and NILES Machine Tools Corporation**. The new company will have two product groups, one for gear grinding machines (formerly NILES) and one for machining centers and flexible manufacturing systems (formerly Fritz Werner). Their representative in the U.S. is the **NILES America Division** of **WMW Machinery Company, Inc.**, in West Nyack, NY . . . **Cincinnati Gear Company** has purchased the gearing division of **BHS Sonthofen Works** in Germany. The new European company will be called **GHS-Cincinnati Getriebetechnik GmbH**. It will combine design and manufacture of high powered/high speed gear units for shipbuilding, gas compression, power plants and other machine systems . . . **Computational Systems, Inc. (CSI)**, specialists in predictive maintenance systems and technology, has opened new training centers in Detroit, MI, and San Diego, CA. The company also has training facilities in Knoxville, TN, and Houston, TX. **The Gleason Works,** Rochester, NY, has been chosen to be the primary gear processing equipment supplier for Black & Decker. Divisions to be served by Gleason include plants manufacturing power tools in Easton, MD, Fayetteville, NC, and Singapore. . . **Oxford Instruments Microanalysis Group**, Concord, MA has acquired the **Microspec Corporation** in Fremont, CA, adding the company's WDX-400/600 wavelength dispersive (WDX) spectrometers to its range of Link products and systems . . . **3D Systems Corp.** has opened new offices in Toronto, Canada to provide local sales, service and support to the Canadian market. The company has also broken ground on a 67,000 sq. ft., $4 million manufacturing facility in Grand Junction, CO.

NEW STANDARDS

AGMA has announced the publication of two new rating standards. **ANSI/AGMA 2001-C95** is a revision of the 2001-B88, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth.* It incorporates numerous changes reflecting the latest thinking about helical rating and has been edited to make it more understandable and easier to use. An international metric version of the standards, **ANSI/AGMA 2101-C95** is also available from AGMA.

ISO has just published **ISO 1328-1**: *ISO System of Accuracy—Part 1: Definitions and Allowable Values of Deviations Relevant to Corresponding Flanks of Gear Teeth* and **ISO 10825**: *Gears—Wear and Damage to Teeth—Terminology.*

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The Gears of Avon & Other Tragedies

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

As part of the Addendum Team's never-ending quest to improve the overall cultural tone of the gear industry, we bring you the following: April 23 is the 432nd birthday of William Shakespeare.

No matter how much you remember from those long-ago lit classes, we'll bet you didn't know that in addition to his many other talents, Shakespeare was a gear engineer.

What, you say? You don't remember this from high school English? Well, maybe you just weren't paying attention.

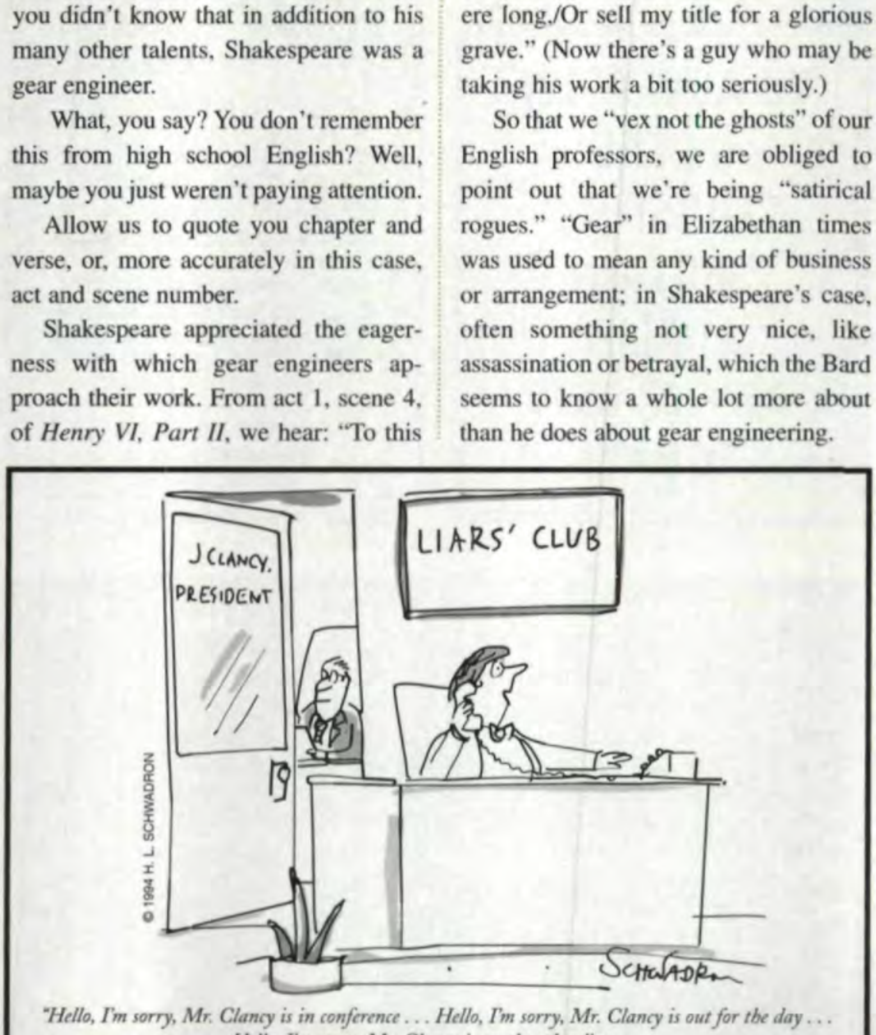
Allow us to quote you chapter and verse, or, more accurately in this case, act and scene number.

Shakespeare appreciated the eagerness with which gear engineers approach their work. From act 1, scene 4, of *Henry VI, Part II*, we hear: "To this gear, the sooner the better." And from *Richard III*, act 1, scene 4, "Come, shall we to this gear?"

He also understood the tragedy of gear failure. In *Troilus & Cressida*, act 1, scene 1, Pandarus laments, "Will this gear ne'er be mended?"

And he knew how committed gear engineers are to their work. In *Henry VI, Part II*, act 3, scene 1, the Duke of York promises: ". . . I will remedy this gear ere long,/Or sell my title for a glorious grave." (Now there's a guy who may be taking his work a bit too seriously.)

So that we "vex not the ghosts" of our English professors, we are obliged to point out that we're being "satirical rogues." "Gear" in Elizabethan times was used to mean any kind of business or arrangement; in Shakespeare's case, often something not very nice, like assassination or betrayal, which the Bard seems to know a whole lot more about than he does about gear engineering.



"Hello, I'm sorry, Mr. Clancy is in conference . . . Hello, I'm sorry, Mr. Clancy is out for the day . . . Hello, I'm sorry, Mr. Clancy is on the other line . . .

And On Other Fronts . . .

While lurking in the library for evidence of Elizabethan gear manufacturing (you didn't think we made this stuff up, did you?), we came across an artifact that pre-dates Shakespeare by a couple of hundred years. The following is from a contract signed in 1344 by an early gear engineer, Walter Lorgoner of Southwark, with the administrators of St. Paul's Cathedral, London:

"The said Walter shall make a dial for the clock of the same church with roofs and all manner of apparatus appertaining to the said dial and for turning the angel in front of the clock so that the said clock may be good and suitable and profitable to show the hours of the day and night. The said clock is to remain without defects, and in case defects shall be found afterwards in the same clock, the said Walter binds himself by this indenture to make the repairs whenever he shall be summoned by the ministers of the Church. And for this work well and duly done and completed, the aforesaid Dean and Chapter shall pay him six pounds sterling—and the said Walter shall find at his own cost the iron, brass, and all manner of other things for carrying out the said work; and shall have for himself the old apparatus which will no longer serve."

No mention of holidays, vacations, coffee breaks or a health care plan. Just thought you'd want to know that before you quit your day job looking for greener pastures or a career in the theater. ○

The Addendometer: If you've read this far on the page and enjoyed it, please circle 214.