

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

THINGS YOUR INDUCTION FURNACE SUPPLIER WANTS YOU TO KNOW

CHOOSING THE RIGHT HEAT TREATER

PROGRAMMABLE SEPARATION OF RUNOUT FROM PROFILE & LEAD INSPECTION DATA

1998 HEAT TREAT PROVIDERS BUYERS GUIDE

PLUS • Guideless CNC Helical Gear Shapers • Asa Jackson's Perpetual Motion Machine



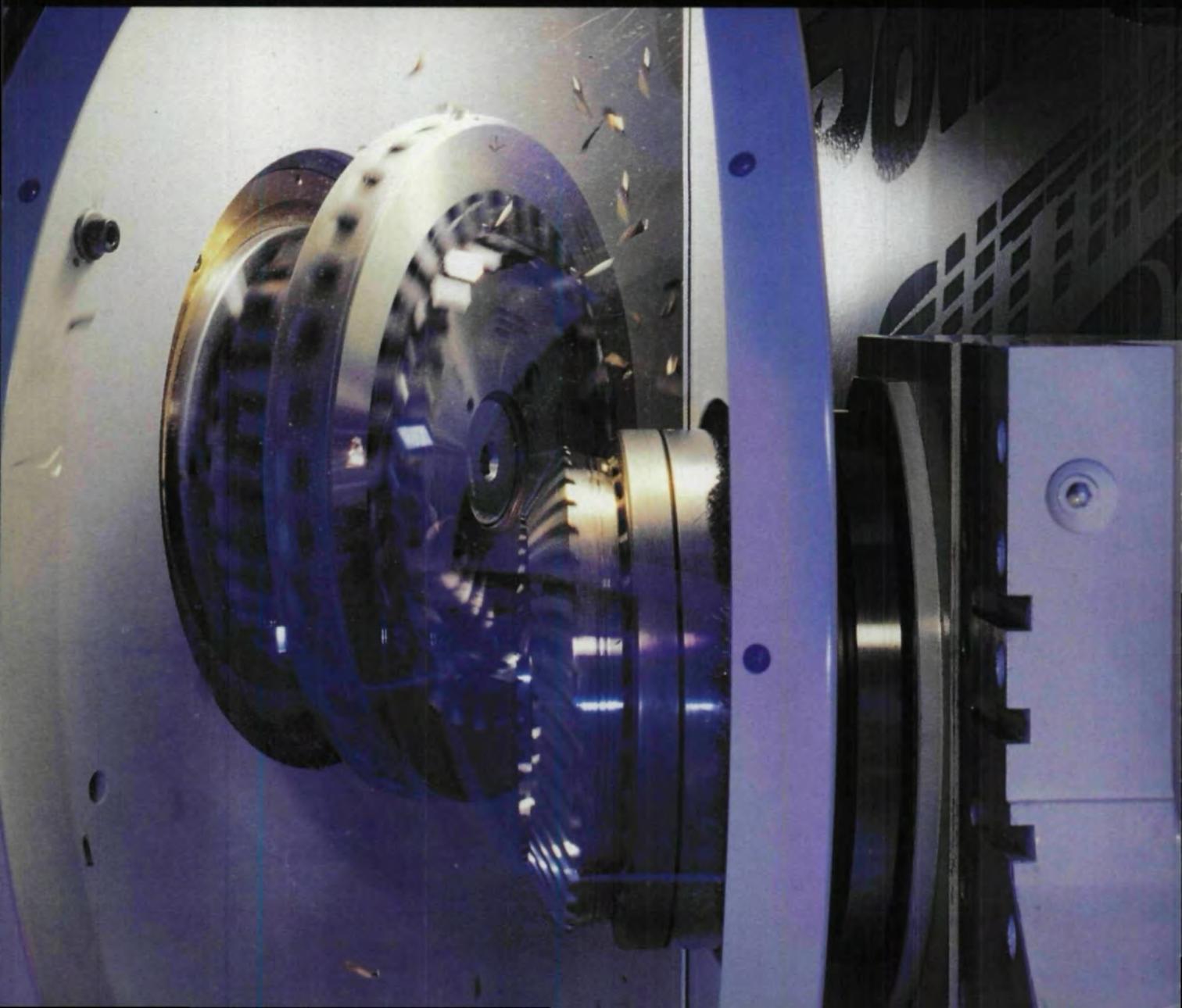
HEAT TREATING

March/April 1998

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MARCH/APRIL 1998

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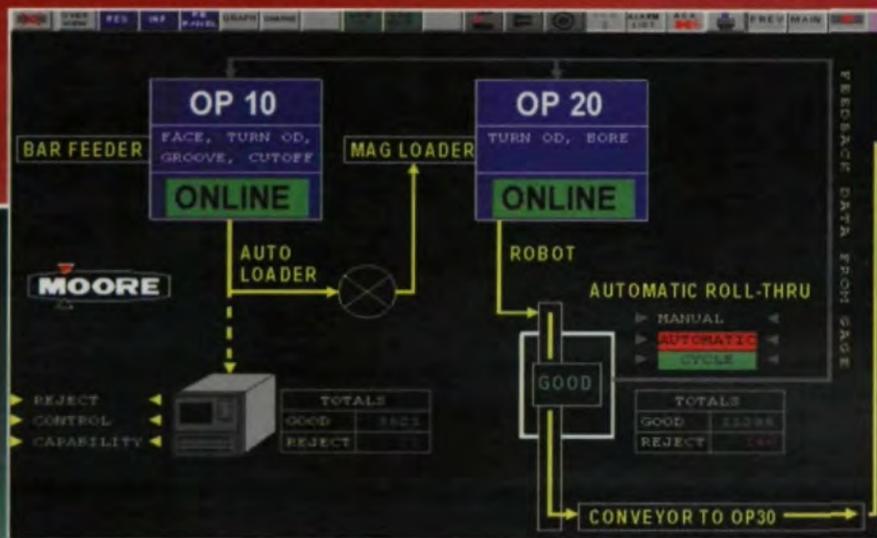
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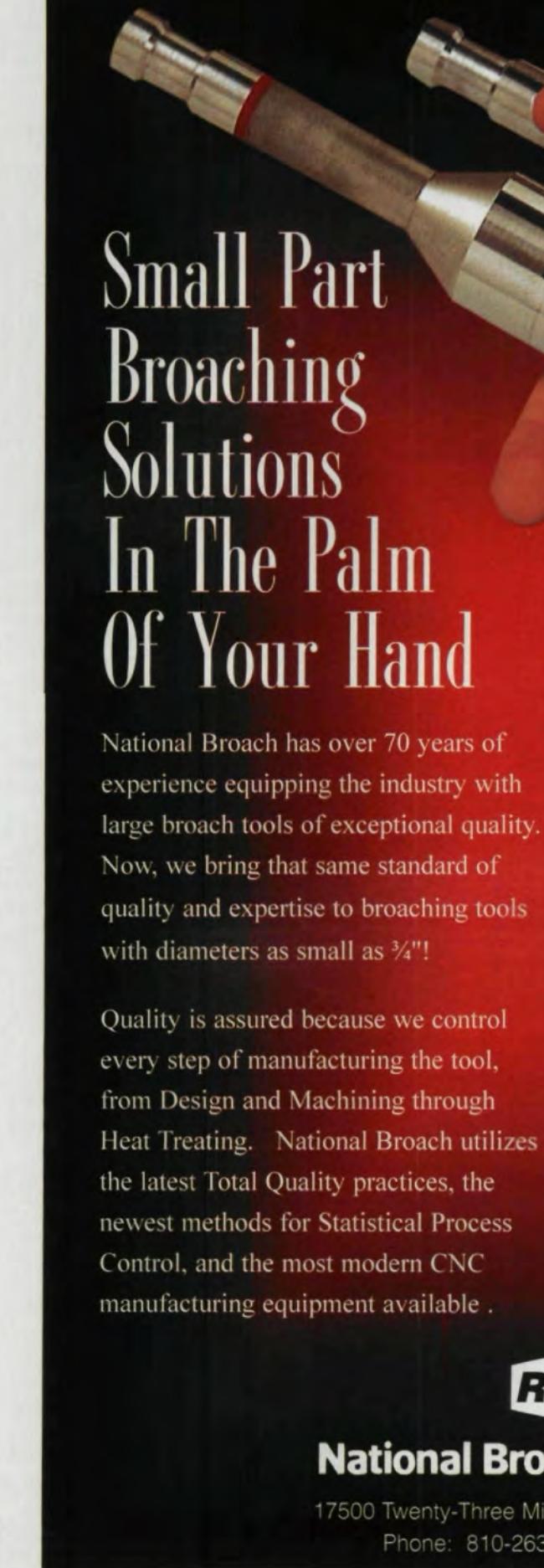
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RIDING OUT

The Good Times

Happy days are here again, says the old song, and given the current economic numbers, one can scarcely argue. Productivity is up; unemployment is down; inflation is practically nonexistent; the budget deficit is shrinking fast.

So we can all kick back, put our feet up and let the good times roll, right? Well, not exactly.

Good times have their own complications. First, there's the nagging question of just how long they're going to last. We're seven years into a recovery, and common sense says that it can't go on forever. Should we prepare for more boom or for a big bust? Then there's the matter of our neighbors in Europe and Asia. Recently both of them, especially Asia, have stumbled badly. In this global economy, one trading partner's misfortune can turn into bad times for everyone with alarming speed. Stagnation in Europe and the free fall of markets in Asia are bound to affect our numbers here. The only questions are how and when?

There is no lack of answers out there. Anybody with access to a microphone, printing press or Web site is willing to tell us what's going to happen next. Unfortunately, the old wag about laying all the economists in the world end to end and still not coming to a conclusion still holds. Pare away the rhetoric, and the answers seem to boil down to, "It all depends."

One thing we can be reasonably certain of is that competition, often ruthless and cut-throat, is going to be part of the picture for some time to come, and no matter what the economic numbers, we are going to be under great pressure to be more efficient and to keep our costs down in order to keep our profits up.

Our customers in Asia and Europe, under the pressure of troubled economic times, can't buy as many of our products as we'd like to sell them, and they can't afford to pay high prices for what they do buy. The only way to keep these markets open is to keep prices—and, therefore, costs—down.

At the same time, these economies are under pressure to unload their goods here because we have become the customer of last resort. We have the money to buy the goods. And because overseas companies need cash now, they will have little option but to cut prices. They're going to be wheeling and dealing with a vengeance because they have to.

Monetary policy factors also play a part here. With our competitors' currencies devalued, their goods are cheaper than ours here, and ours are more expensive there. The result is the same: pressure on us to keep our prices low, our costs down and our productivity up.

Even if you only do business in the U.S., you can't really avoid the problem. Your customers may be trading overseas or competing against imported products, and they're going to have to pressure you to keep your part of their costs down. Whether your markets are here or overseas, these pressures mean you have to wring every dime of efficiency out of your operations.

The buzz word then for us should be modernize, modernize, modernize. If you're still debating about the wisdom of taking the next step, stop. The answer is clear. Do it now.

I've been repeating this mantra for years, but every day that goes

by confirms its importance. Our operations here (and, I would guess, most of yours) are already on the third, fourth or fifth generation of hardware and software. Every time we install an upgrade, once the initial break-in period is over, our productivity and efficiency—the keys to competitive success in this economy—go up. The same thing will continue to happen. The only difference now is that pressures to keep up are growing, and the time lag between important technological improvements is shrinking.

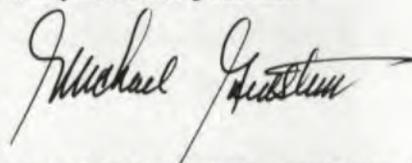
So the drill remains the same. If you already have CNC machinery, now is the time to look at the latest improvements. This is also true if mechanical machines still make sense in your operation. You should be looking at getting the latest models you can afford. Any piece of equipment that will increase your production and keep your costs down is worth the investment today.

Production machinery is not the only place to look for more efficiency. Examine your entire operation—all your processes and practices. Can they be streamlined? Made more cost-effective? Do your computers and software need upgrading? Your testing, sharpening, inspection or quality systems? What about your customer service operation? Your shipping? The pennies shaved from the cost of every operation performed and every part produced can add up to real savings.

And don't forget your people. Investment in training for efficiency and productivity is worth every nickel spent on it. Nor should you overlook that simple, low-cost, low-tech approach to shop floor productivity gains: Ask the people doing the work how to do it better and more efficiently. They usually know better than anyone else and will be glad to tell you without charging the five figures that are the going rate for some out-of-town consultants.

Sure this kind of thing can be expensive in the short term, and deciding on just the right investment moves for your company is a complicated issue. But boom times can't last forever, and if you can't afford improvements now, when will you be able to?

Keeping your footing in this complicated global economy is tricky. It will require a lot of hard work, close analysis and careful investment in the right equipment and people. You may find yourself working harder during these good times than you ever have before. On the other hand, it beats working just as hard or harder just to stay afloat during bad ones.



Michael Goldstein, Publisher and Editor-in-Chief



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Choosing the Right Heat Treater

Getting the right provider for your job.

Kurt Hawker

Heat treating is a critical operation in gear manufacturing. It can make or break the quality of your final product. Yet it is one that frequently gear manufacturers outsource to someone else. Then the crucial question becomes, how do you know you're getting the right heat treater? How can you guarantee your end product when you have turned over this important process to someone else?

The answer is a straightforward one, but one which in my experience is overlooked far too frequently. The secret to buying good heat treating service is to do your homework. Ask lots of questions and demand clear and *documented* answers.

This documentation is crucial. In the present competitive environment, when more and more of your customers are seeking some kind of quality system registration, like ISO 9000, QS-9000 or NADCAP (National Aerospace Defense Contractors Accreditation Program), and demanding the same of you, a heat treater who is also registered or who can provide detailed documentation of his or her processes is becoming almost a necessity.

Even if you or your customers don't absolutely require such documentation, its existence will certainly help you to sleep at night.

But documentation alone is not enough. You need answers to over a dozen important questions before deciding on the right heat treater. The easiest way to get them is to ask your heat treater (or potential heat treater) to fill out a supplier survey (see sidebar on page 00), which should contain the answers to most of them. If a heat treater can't or won't take the time to do that, maybe you should be taking your business elsewhere.

Here are some of the questions that might be included in your survey.

1. *Are the company's operations certified for quality?* If so, by whom? When was it last audited? The last is the most important. Programs like ISO 9000 and QS-9000 require regular audits, and your potential supplier should be current. At the same time, beware of the buzz words in company literature to the effect that "... we have processed work for Ford" or "GM processing capabilities." Maybe the heat treater did one job for Ford or GM 15 years ago. Find out



Good heat treaters have good, documentable quality control systems.

specifically what this phrase means to the company.

2. *What kind of quality system is in place?* How closely is it followed? There should be four parts to this system: A quality control manual explaining the entire system; clearly outlined procedures that are followed consistently; job instruction sheets for each job and controls on portions of the job that involve outside suppliers.

Kurt Hawker

is the director of sales and marketing for Progressive Steel Treating, a commercial heat treater in Loves Park, IL. He has over 15 years' experience in heat treating and quality control.

SAMPLE QUESTIONS FOR A HEAT TREAT SUPPLIER SURVEY

I. GENERAL

- | | | |
|--|-----|----|
| 1. Do you have a written quality policy? | Yes | No |
| 2. Who is responsible for quality assurance and planning _____? | | |
| 3. Is management committed to quality and the use of statistical methods to control quality? | Yes | No |
| 4. Is there a management statement in the manual? | Yes | No |
| 5. Is the quality policy reviewed at least annually, and are actions taken to assure compliance with the policy? | | |
| 6. May we see your quality manual? | Yes | No |

II. ORGANIZATION—ADMINISTRATIVE

- | | | |
|---|-----|----|
| 1. Does a current formal organizational chart exist that defines responsibility and authority? | Yes | No |
| 2. Do departments other than quality participate in the quality planning? | Yes | No |
| 3. Are statistical/analytical or other new techniques used in the planning process to improve process capability? | Yes | No |

III. TRAINING

- | | | |
|---|-----|----|
| 1. Is there a documented quality training program for management, quality and production personnel? | Yes | No |
| 2. Are written test and inspection instructions readily accessible to operators and inspection personnel? | Yes | No |
| 3. Are these updated and reviewed? | Yes | No |

IV. LOT CONTROL

- | | | |
|---|-----|----|
| 1. Are lot control procedures documented? | Yes | No |
| 2. Is product identification maintained throughout the process? | Yes | No |
| 3. Is traceability maintained throughout the operation? | Yes | No |

V. INCOMING PRODUCT/MATERIAL, PROCESS CONTROLS

- | | | |
|---|-----|----|
| 1. Are adequate incoming/receiving inspection procedures and/or instructions available? | Yes | No |
| 2. Is incoming material approved and properly identified prior to release to production operations? | Yes | No |
| 3. Is nonconforming material properly identified prior to release to production operations? | Yes | No |
| 4. Are materials awaiting inspection properly identified and segregated from previously inspected materials? | Yes | No |
| 5. Are in-process routing sheets, process sheets or routing cards used to control material throughout the manufacturing process? | Yes | No |
| 6. Are written operator and inspection instructions that include frequencies and sample sizes available at control points or the proper area? | Yes | No |
| 7. Is statistical process control used for significant product characteristics and process parameters? | Yes | No |

VI. PRODUCT VERIFICATION

- | | | |
|---|-----|----|
| 1. Do all finished materials receive a final audit/inspection? | Yes | No |
| 2. Is there a written procedure outlining final inspection including sample size? | Yes | No |
| 3. Is the final audit performed by the quality department? | Yes | No |
| 4. Is supplier willing to certify conformance to requirements? | Yes | No |

VII. HOUSEKEEPING

- | | | |
|---|-----|----|
| 1. Is there a system to assure plant cleanliness and to assign responsibility for housekeeping? | Yes | No |
| 2. Are the company's facilities clean, well-lighted and properly marked? | Yes | No |
| 3. Do plant, offices and personnel reflect a positive image? | Yes | No |

This form should also contain information about the total number of employees, number of shifts worked, number of q.a. personnel, building size and contact names.

3. *What are the company's capabilities? Can this heat treater do your job? Are his or her furnaces big enough? What about ancillary equipment? For example, if you have very large gears to be worked on, does he have sufficient equipment and facilities to handle your parts without damaging them? Does she have enough personnel to do your job in the time frame you require?*

4. *Can you get a statement of liability? This comes down to the question of whether this heat treater will stand behind his work. If something goes wrong, if there is a catastrophic failure of one of your gears that can be traced to the heat treating process, does this supplier have an umbrella insurance policy to cover losses and damages? In what amount? What happens if your job is damaged or lost in the heat treater's plant? Are you going to be left holding the bag?*

5. *Is there a metallurgist on staff? The answer to this question will tell you a lot about how seriously this heat treater takes quality control. Heat treating is a metal structural transformation process, and someone on staff who is well-versed in the science of metals can solve a lot of small problems before they become big ones and can avoid a great many of them altogether. A metallurgist also can be critical to assessing liability. Supposing a batch of gears fails because of defects in the metal. A heat treater may compensate you for the damages, but with a trained metallurgist on staff, you might discover that the material house was really responsible for the failure.*

MANAGEMENT MATTERS

The compensation should have come from them. Furthermore, this leads to a question you might otherwise not have asked—do I need a different *material supplier*?

6. *Will this company provide you with an organizational chart, and does it show how many departments are really involved in quality control? Who is responsible for quality at this company? What other responsibilities does this person have? Is he or she a full-time quality person, or does he also double as the receptionist and the delivery driver? Does more than one person have input into quality issues? What kind of reporting system exists? What kind of communication takes place between departments? Are there quality checks in every department as a matter of routine?*

7. *How well-trained are the people at this company? How long have they been employed? What kind of ongoing training does the company provide? How do you know the company doesn't routinely call up the local day labor provider and ask for "five loaders and five furnace operators today"?*

8. *What kind of process and lot control goes on here? Are instructions conveyed by word-of-mouth or are computer-generated job instruction sheets assigned to each job that follow it through its time at the facility? A modern plant will have a system of identification and control that tracks a job from the moment it enters the plant until it leaves again. Job instructions may be locked into a computer, with changes to procedures, except by supervisors, prevented. Does*

this company have any way to track its rate of repeatability? How consistent is its work? Can anyone from the company document the answer?

9. *How thorough are the company's inspection procedures? How many samples from each job are checked? Is this number adequate to the size of your job? If the company checks two pieces per load, and your job consists of 10,000 pieces, is that a sufficient sample? Will it meet the documentation requirements of your customer? How often does this heat treater check and calibrate his instruments and furnaces? How new are they?*

10. *How far back are records kept? My company keeps records for seven years or for the life of a program. Do you need that level of documentation? Can this heat treater provide the level you need?*

11. *What about the company's housekeeping practices? This involves more than just keeping a clean and tidy shop, although that is important. How safe is this plant? Is it well-lit? Well-ventilated? Well-organized? Is it in danger of being shut down by OSHA?*

12. *Does this company have a locked and bonded holding area? Short of that, does it have some verifiable method of preventing bad gears from slipping back into the system? Companies that produce aerospace parts will often have a gated area where rejects are kept under lock and key until the customer can be notified of inconsistencies.*

13. *Does this plant do inspections of incoming product? If there is a prob-*



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lem with your gears upon delivery to the heat treater, will you be notified, or will this supplier just go ahead and heat treat them anyway?

14. *Will this heat treater let you come to the plant to see product samples run? Will they allow an on-site inspection?*

After The Vendor Survey

An on-site inspection is really the next step in the procedure. Getting a vendor survey is only the beginning of choosing a good heat treater. You should visit the plant. I'm always surprised at how many manufacturers want to seal the heat treating deal over the phone without ever seeing where their product is going to be sent or how it's going to be handled once it gets there.

You should pay a visit, and your potential heat treat supplier should welcome it. Bring along the important people who will be involved with the production of your gears. These should include your quality control manager, the purchasing manager, the production manager, the expediter and anyone else who's going to be interfacing with the heat treater. They should be able to see a sample of your product run

through the heat treater's system, see how the product's handled and then evaluate what they've seen.

Each of them should be evaluating the heat treater's system from his or her point of view. Is the quality control manager satisfied with the inspection process and equipment? What about the level of documentation? Does your production manager feel good about the way the product is handled on the shop floor? Is your expediter comfortable with what he's seen in the warehouse in terms of both incoming and outgoing product and storage and handling in between?

This is the time to watch for discrepancies. If a heat treater has said he can handle your 40" gears, but all you see on his floor are small furnaces, this should raise questions. Is he sending your product out to be done by someone else? This sometimes happens, but it's not an acceptable practice without your prior approval. If another supplier is involved, who is it? What kind of quality and documentation can you count on from him? What kind of security can you be assured of? Is your product going to end up running right next to



When evaluating a heat treater, ask how recently his inspection machinery was calibrated.

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CIRCLE 157

MANAGEMENT MATTERS

that of your competitors? What other parts of the process are being outsourced? To whom?

This is also the time to be getting answers to other important questions. When a heat treater says he offers 48-hour turnaround, what does that mean? Does it mean in Friday and back Monday, or in Friday and back Wednesday because the heat treater doesn't work weekends? Does this heat treater offer 24/7/365 service, or does he close on weekends and holidays? That's something you'll want to know if you don't want to find your product accidentally held hostage because the heat treater has closed for the two weeks over Christmas or for a summer vacation.

If you've had a problem with getting product back consistently in a timely manner, the reasons may lie here. If the product is being outsourced, the delay may be with the other vendor or with the fact that your heat treater has built-in delays in her schedule you didn't know about.

**Is All This Effort
Worth It?**

This may seem like a lot of hassle, especially if you're not making aerospace quality gears. If your customers don't demand this level of documentation and quality, why should you care?

Because in this era of increasing global competition and more and more demanding customers, you can't afford not to. Remember that in the end, with your customer, it's *your* reputation that's on the line. He or she is going to buy the excuse that the problem lies

with your heat treat supplier only once—if that.

In the long run, it always pays to get the best heat treater you can afford—one who, ideally, exceeds your expectations. You can get away with heat treating on the cheap for some time, but in the end, the practice will catch up with you. It takes the loss of only one big, expensive job to bad heat treating to cost far more than you would have paid to go with a quality product to begin with.

You can benefit from dealing with an aerospace-quality heat treater for your AGMA 8 or 10 gears in another way. You get his expertise and quality practices without have to pay the aerospace tariff. His or her practices will be the same on your gears as on aerospace gears because the quality is built into the plant systems, and the prices will be competitive because your gears don't require the liability coverage that aerospace gears do. Finally, there's the intangible of having the security of dealing with a company that has a proven quality track record. What is that worth to you and your customers?

The In-House Question

Many gear manufacturers today are addressing the question of getting documented quality heat treating on time and within budget by exploring the option of bringing the whole operation in-house. They think, and not without reason, that there is no better way to ensure the job is done the way they want it done.

But making the decision to bring heat treating in-house is a big one. The ultimate

equation is a simple one—are the costs involved going to be more or less than what you spend on outside heat treating now?—but the variables complicate the issue.

Much more is involved than choosing a furnace. First, generally speaking, you need to be doing a significant amount of heat treating to make bringing the process in-house worthwhile. Also remember that the cost of the furnace is only the beginning. What's a turn-key operation is going to cost; i.e., what is the price of the furnace, the installation, the plumbing, the extra materials like appropriate gases, and the backup equipment to keep it running?

Then there's the question of the skilled labor necessary to do heat treating and to keep the equipment running. Do you have this kind of personnel available? Can you get it? Can you afford the kind of trained personnel it requires to run the machines and manage the department? And there's the issue of what to do if your one furnace breaks down or needs extended maintenance. If you have only one furnace, and it goes off-line for some reason, all of a sudden your entire delivery schedule for this job is in jeopardy. At that point, you have to go to an outside source for one or two jobs, and you'll go to the end of the line after all his or her regular customers have been serviced.

If you can answer all these questions in a way that makes sense to you economically, then maybe bringing heat treating in-house is the answer. But that may not be as likely as you think.

One way that some very large customers address the control problem is to negotiate with a heat treater for a dedicated furnace at the heat treater's site. This can be a mutually beneficial arrangement for both parties, but again, it requires someone with a lot of product to be heat treated to be worthwhile.

In the end, buying quality heat treating is just like buying any other goods or services. It's a matter of doing your homework, taking the time to get the answers to all your pertinent questions and making certain cost/value decisions. As with most other transactions, you get what you pay for.

Good quality gears are the end result of a lot of hard and expensive work. After you've gone to all the trouble and expense of designing and cutting the best gears you can, do you want to jeopardize the whole operation with sloppy heat treating? Scrap is expensive, not only in terms of lost revenue, but also in terms of increased frustration, lost time, missed deadlines and damaged customer relations.

When heat treating is such an important component of building a quality gear, can you afford to settle for anything less than the very best you can afford? ⚙

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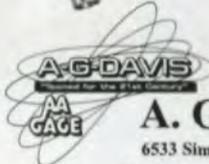


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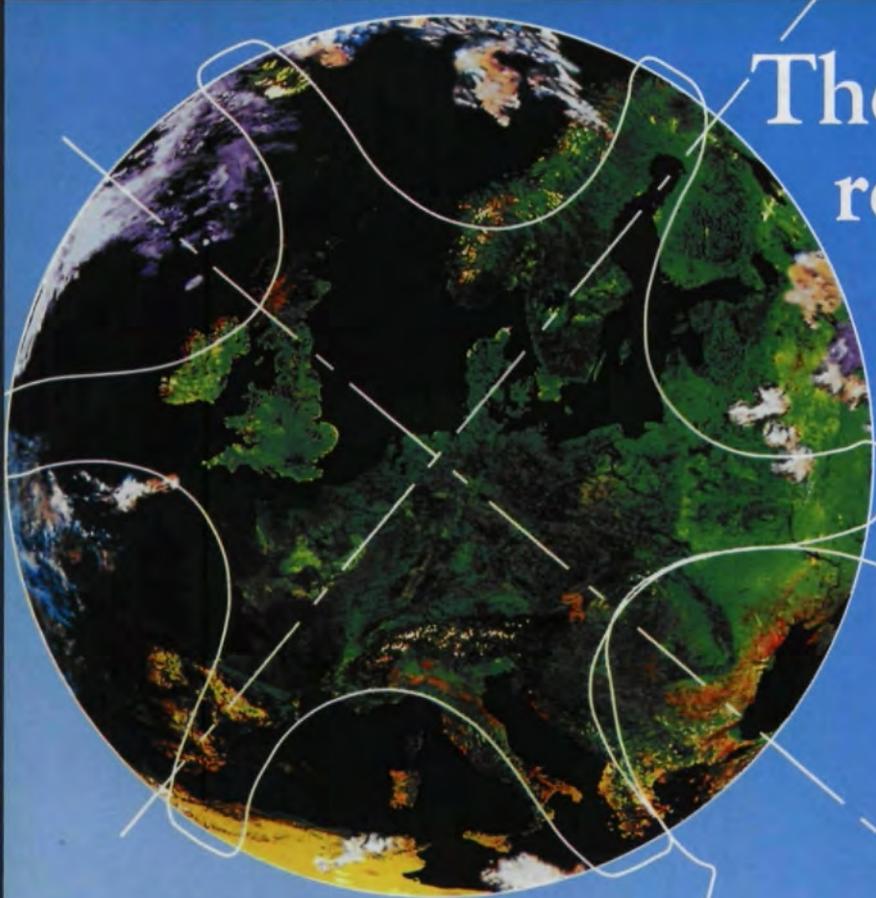
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New Guideless CNC Shaper for Helical Gears

Kenji Ueno

Product announcements so often trumpet minor, incremental advances with words like "revolutionary" and "unique" that even the best thesaurus can fail to offer a fresh alternative to alert the reader when something really innovative and important is introduced. In the case of Mitsubishi's new CNC gear shaper, the ST25CNC, both terms apply.

The ST25CNC (Fig. 1) eliminates the need for expensive helical guides that cost several thousand dollars for each gear size and lead change. Changeover on this machine requires only reprogramming the CNC to cut each new configuration, unlike older machines that require several hours to set up a new guide set. Windows®-based, user-friendly CNC controls with a touch screen feature make custom programming easier and eliminate lengthy programming time. This combination of lower cost, simplified changeover and streamlined programming means that gear designers can now experiment with new refinements in order to provide the most efficient power transfer components.

Engineers at MHI Machine Tool U.S.A., Inc., Itasca, IL—a subsidiary of Mitsubishi Heavy Industries America, Inc.—believe that this new flexibility will be the reason the innovative ST25CNC shaper will be adopted by initial users. S. Amano, President of MHI Machine Tool, reports that a major automotive company in Japan has already placed an order for the new shaper.

The Impetus for Innovation

One strong impetus behind Mitsubishi's investment in the ST25CNC has been vehicle downsizing, which has created the need for smaller transmission gears. Smaller gears have less contact area, which translates directly into lower strengths. To increase contact area and strength at a given gear diameter, designers have increased the helical angle. The 25° angle that was once common has given way to helical angles that are now often more than 35°.

When an internal gear is manufactured, gear shapers are generally used. As shown in Fig. 2, in this machining method, the cutter and workpiece are turned synchronously and the cutter reciprocates axially. In the case of helical gears, because helical motion is matched to the cutter lead, a helical guide is used. When the cutter lead is different, the helical guide must be changed.

The NC Guide Drive Principle

In helical gear machining using a gear shaper, the relationship between workpiece helical angle β and cutter lead H is given by the formula below.

$$H = \frac{\pi dc}{\tan \beta}$$

where β is the workpiece helical angle, H is the cutter lead length and dc is the cutter pitch circle diameter.

In Fig. 3, the design of a conventional shaper (a) is contrasted to that of the new ST25CNC (b). In the latter, the male and female helical guides are absent. In the Mitsubishi design, reciprocating and



Fig. 1 — Mitsubishi Flexible Gear Shaper ST25CNC

**THE ST25CNC'S
CONTROLLER
OPERATES
AT MUCH
HIGHER SPEEDS
THAN THOSE
ON CONVENTIONAL
MODELS.**

Dr. Eng. Kenji Ueno

is Vice President, Gear Machines and Grinders, at Mitsubishi Machine Tool U.S.A., Inc., of Itasca, IL.

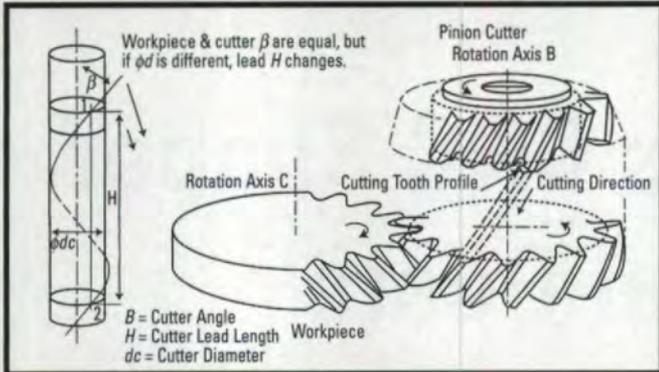


Fig. 2 — Outline of machining method.

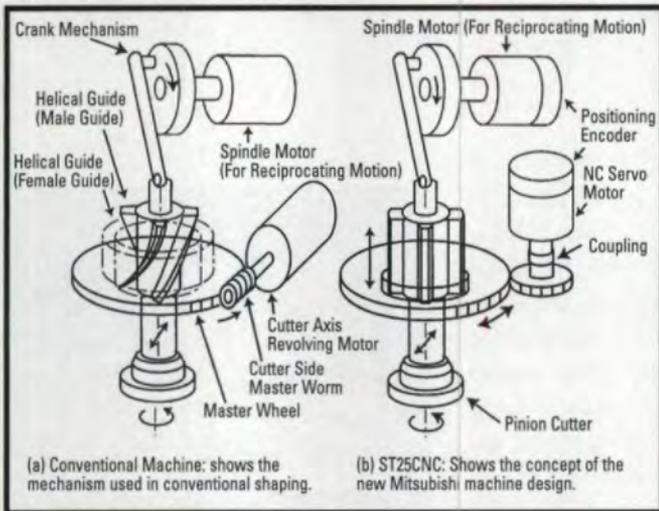


Fig. 3 — Guide mechanism.

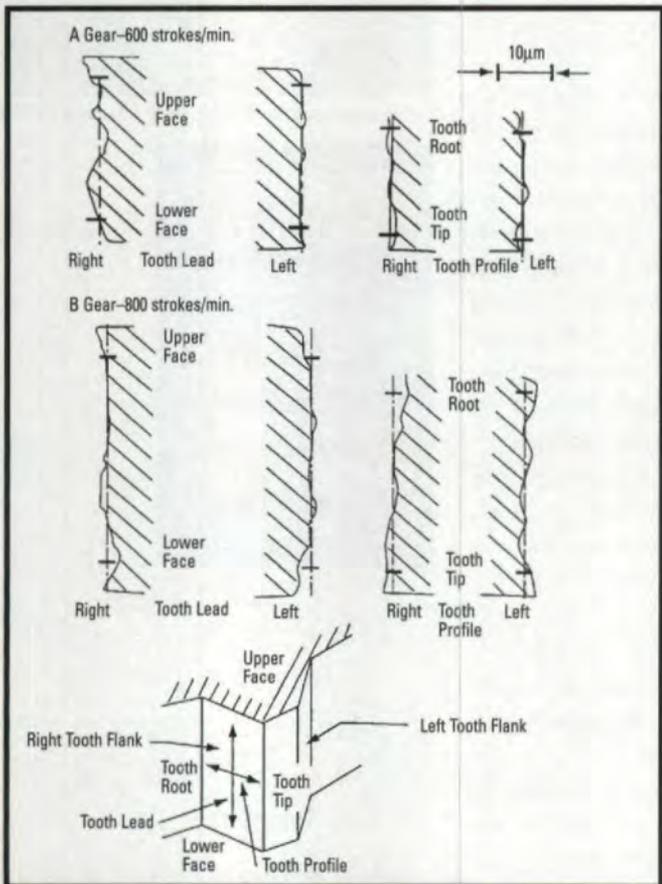


Fig. 4 — Accuracy achieved: AGMA 10 data points obtained from measuring gears cut on ST25CNC according to cutting conditions shown in Table 2.

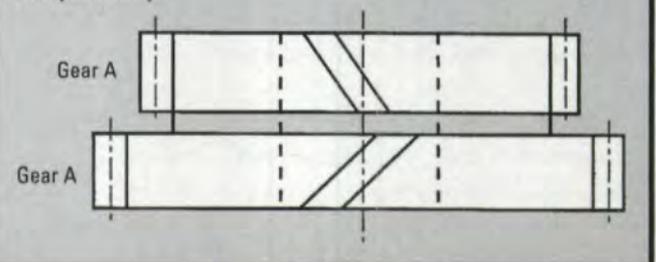
TABLE 1 — MAJOR SPECIFICATIONS

Maximum Helical Angle	±36°
Workpiece Maximum Diameter:	
External Gear	250 mm
Internal Gear	120 mm + cutter diameter
Maximum Module	6
Maximum Machining Face Width	50 mm
Number of Spindle Strokes	200–1000 strokes/mm
Circumferential Feed Rate	5000 mm/min
Radial Cutting Feed	1000 mm/min
Radial Rapid Traverse Rate	10000 mm/min
Radial Travel	300 mm
Number of Passes	1–4 times
Cutter Spindle Diameter	100 mm
Table Diameter	330 mm
Main Motor Output	10 kW AC servo
Machine Weight	6500 kg
Floor Space	2325 x 2775 mm
Machine Total Electric Power	35 kVA

TABLE 2 — GEAR SPECIFICATIONS AND CUTTING CONDITIONS

Item	Dimension	Gear A	Gear B
Workpiece Dimensions	Module	1.75	2.25
	Helical Angle (°)	30	25
	Helical Direction	LH	RH
	Number of Teeth	23	23
	Face Width (mm)	10	15
Cutter Dimensions	Outer Diameter (mm)	44.471	61.6
	Number of Teeth	115	150.7
Machining Conditions	Number of Strokes (strokes/mm)	600/600	800/800
	Circumferential Feed (strokes/mm)	1.5/1.5	1.58/1.58
	Radial Feed (mm/stroke)	0.01/0.006	0.01/0.006
	Cycle Time(s)	57	55

Workpiece Shape



oscillating motion are synchronously controlled by the CNC.

A Faster, Smarter CNC

To synchronously control three axes and produce gears with accuracies of higher than AGMA 10, for example, it was necessary for the CNC to operate at much higher speeds on the ST25CNC gear shaper than on its conventional predecessor, the SD25CNC. Simulation studies revealed that data transmission speeds on the order of under 1 ms would be required, in contrast to the 8 ms speed that was typical of the conventional system.

The ST25CNC's high-speed feed control focuses on extreme accuracy. Using a modified, inverse-transfer function data processing method, with virtually zero servo error, the system reads the NC data in advance of the servo amplifier to compensate for under- or over-torque at the

same point in the next stroke. Again, enhanced accuracy is the result.

In Tables 1 and 2, major machine specifications and representative gear specifications and cutting conditions are given. In the example shown in Table 2, a two-stepped cutter with different helix angles was used to machine the workpiece in one chucking. Fig. 4 demonstrates the machining accuracy realized at 600 strokes/min for Gear A and 800

strokes/min for Gear B. This setup could not be done on a conventional machine. It is now possible to cut Gears A and B in setup times of less than 5 minutes. ☉

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Pfauter-Maag Cutting Tools offers two gear courses, Basic Fundamentals and Advanced Gear Process Dynamics, at its facility in Loves Park, IL, several times throughout the year. Basic Course: March 16-19, April 20-23, May 18-21, June 15-18. Advanced Course: April 28-30. For more information, contact Laurie Harshbarger at 815-282-3000, x313, fax 815-282-3075 or e-mail sales@pfauter.com.

March 12-14. AGMA Annual Meeting. Rio Mar Beach Resort, Rio Grande, Puerto Rico. Business meetings, seminars, recreation. For more information contact AGMA Headquarters. Ph: 708-684-0211; Fax: 703-684-0242; E-mail: webmaster@agma.org; Web: www.agma.org.

March 16-19, 1998. National Manufacturing Week. McCormick Place, Chicago, IL. This week-long exhibition and conference will feature over a half-million sq. ft. of exhibit space for some 65,000 visitors. For more information, contact Reed Exhibition Companies at 203-840-5878, fax 203-840-9879, e-mail nmw@reedexpo.com or log on to <http://nmw.reedexpo.com>.

March 25-26. Seminar, "Innovations Concerning the Bevel Wheel." Aachen Demonstration Laboratory for Integrated Production Engineering (ADITEC), Aachen, Germany. Reports on technology, current issues and trends in bevel gears. Application-oriented reports with focus on the layout, manufacturing, testing and operating performance of bevel gears. For more information call +49-242-836-91 or fax +49-241-837-69

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April 21-22. Gear Manufacturing Through Powder Metallurgy. Arlington Heights Hilton, Arlington Heights, (Chicago) IL. Sponsored by the Metal Powder Industries Federation. Covers fundamentals of gear design and other aspects of manufacturing gears using powder metals. Contact Benny Sun at MPIF. Ph: 609-452-7700, fax 609-987-8523, e-mail info@mpif.org or log on to www.mpif.org.

April 22-27, 1998. Seoul International Machine Tool Show 98. Seoul Yoido Exhibition Center and Yoido Tongil

Exhibition Center. Organized by the Korea Machine Tool Manufacturers' Association and sponsored by the Korean Ministry of Trade, Industry & Energy, this show is designed to promote trade through the international exchange of information and technology. Both domestic and foreign machine tools and related items will be featured. For more information about exhibiting or attending, contact Korea Machine Tool Manufacturers' Association by phone at 82-2-565-2721 or fax 82-2-564-5639.

April 26-May 1. Plastics Gearing Technology. The Product Design & Development Division of the Society of Plastics Engineers and the Plastics Steering Committee of the Emerging Technologies of AGMA is planning sessions on Plastic Gearing Technology to be held at ANTEC '98 in Atlanta, GA. For more information, contact Andrea Knapp at SPE Headquarters, 203-740-5458 or fax 203-775-8490.

May 18-20. Fundamentals of Parallel Axis Gear Manufacturing. Pheasant Run Resort, St. Charles, IL. Sponsored by Koepfer America, this seminar is designed for entry level gear manufacturing personnel. It will be of interest to manufacturing management, industrial engineers, supervisors, set-up personnel, operators and quality control personnel. To register, phone or fax Koepfer America. Phone: 847-931-4121; Fax 847-931-4192.

May 19. INFAC Industry Briefing. INFAC (The Instrumented Factory for Gears) will present its spring industry briefing at the Sheraton Washington in Washington, D.C. This briefing will update attendees on the status of on-going INFAC research projects and preview new developments. For more information, contact Terry Phillippi at 312-567-4264 or fax 312-567-4329.

May 28-30. Ultra-Hard Materials Conference. Sponsored by the Industrial Diamond Association in conjunction with the University of Windsor and the University of Toledo. Windsor Hilton Hotel, Windsor, Ontario, Canada. This conference will offer attendees exposure to the latest developments in diamond and cubic boron nitride technology. It will focus on the types of diamond and cubic boron nitride materials available and their applications. For more information phone 704-684-1986, fax 704-684-7372 or e-mail gray3@juno.com.

May 31-June 4. PM²TEC'98, The International Conference on Powder Metallurgy & Particulate Materials. Las Vegas, NV. Sponsored by the Metal Powder Industries Federation and APMI International. Technical sessions and poster presentations will report on new innovations in metal powders and advanced particulate materials, compaction technologies and processes, rapid prototyping, sintering, powder injection molding and more. For information, call MPIF at 609-452-7700, fax 609-987-8523 or log on to www.mpiif.org.

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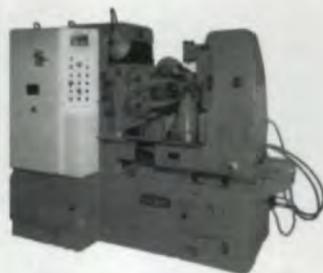
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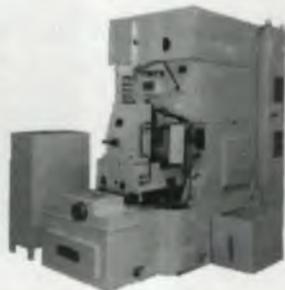
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MULTI-ARC ACQUIRED BY BERNA AG

Multi-Arc, Inc. of Rockaway, NJ, has been acquired by Berna AG, part of the Sauer Group. The acquisition is part of Berna's strategy to expand its thin film coating business. Multi-Arc, with 11 coating centers and four joint ventures in North America, Europe and Asia, as well as an equipment manufacturing facility in St. Paul, MN, will be a part of Berna's newly formed Thin Film Coating Division.

PROMOTIONS, MOVES, NEW HIRES

Carlos Carrasco has been named representative in Mexico of the **Welduction Corporation**, Farmington Hills, MI, a full-service induction heat treating equipment and system manufacturer. . . **Fred R. Specht** has been appointed national sales manager of **Pillar Industries**, Menomonee Falls, WI. Pillar is a worldwide supplier of induction heat treating supplies to the automotive, off-highway, aerospace, appliance and general metal working and forming industries . . . **Larry Habdas** has joined **Kluber Lubrication's** Western Regional Group, which has sales responsibilities in Arizona, Colorado, Nevada, New Mexico and Utah. . . **Don F. Carlson** is the new president of **AMT—The Association for Manufacturing Technology**. He replaces **Albert W. Moore**, who is retiring. Carlson is past president/CEO of **Acme Manufacturing Co.**, Madison Heights, MI . . . AMT has also elected officers and directors for 1997-98. The new chairman is **John Fedor**, president and CEO of **Masco Machine, Inc.** He replaces **James S. Gleason** of the **Gleason Corporation**, who will now serve as an ex-officio member of the board of directors . . . **Thomas E. Gross** has been named Vice President - Rochester Operations for **The Gleason Works**. His responsibilities will include managing manufacturing and engineering-related activities at the Rochester facility . . . **Mahr Corporation** has announced a restructuring of its management team. **Edgar Hochwart** is the new Executive Vice President and General Manager. **Paul Bruemmer** is the new CFO. **Donald Parker** is Sales & Product Manager, Hand Tools Division. **Douglas Brank**, **Danny Moss**, **Todd Golem** and **Bruce Cowley** are the new Product Managers for Form Metrology, Surface Metrology, Gage Calibration Metrology and Gear Metrology & PRIMAR, respectively. **David Rice** is now the Manager, Technical Service. ⚙

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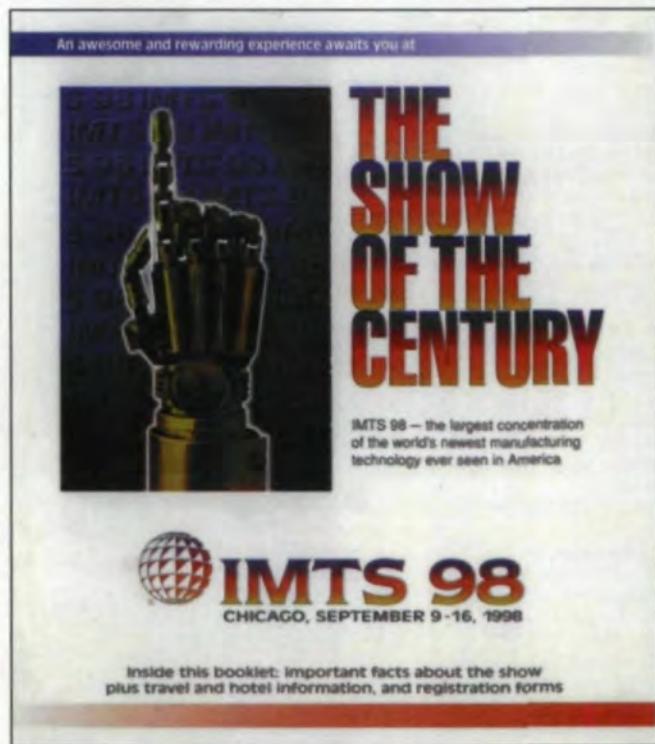
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Welcome to the Company Index of the 1998 *Gear Technology* Directory of Heat Treating Services. Use this list to locate the complete contact information for each company listed in the Services Index. *Gear Technology* advertisers are shown in boldface type. To find the pages on which their ads appear, see the Advertisers Index on page 48.

While we have made every effort to ensure that company names and addresses are correct, we cannot be held responsible for errors of fact or omission. If your company was not listed in this directory, and you would like to be included in 1999, please call 847-437-6604.

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Web: <http://dns.ncentral.com-abbott>

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562-928-1868
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Accurate Steel Treating
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562-927-6528
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Fax: 734-243-4066
Web: www.ahtweb.com

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Fax: 317-789-6839

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130 Verdi St.

Farmingdale, NY 11735
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Fax: 516-249-7889

Alliance Metal Treating
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Rochester, NY 14692
716-461-8051
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Wyoming, MI 49548
616-243-0111
Fax: 616-243-4080

H

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Cuyahoga Falls, OH 44221
800-304-2636
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Fax: 818-609-9372

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513-772-1461
Fax: 513-772-0149

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Eastlake, OH 44095
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Fax: 440-946-2283

Hudapack Metal Treating-Addison
824 South Kay Avenue
Addison, IL 60101-4976
630-543-6033
Fax: 630-543-8686

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Fax: 414-723-3752

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Fax: 216-881-6811

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Detroit, MI 48227
313-838-2800
Fax: 313-838-2802

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

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Danville, IL 61834-1466
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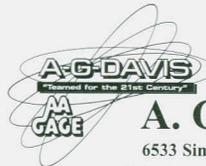


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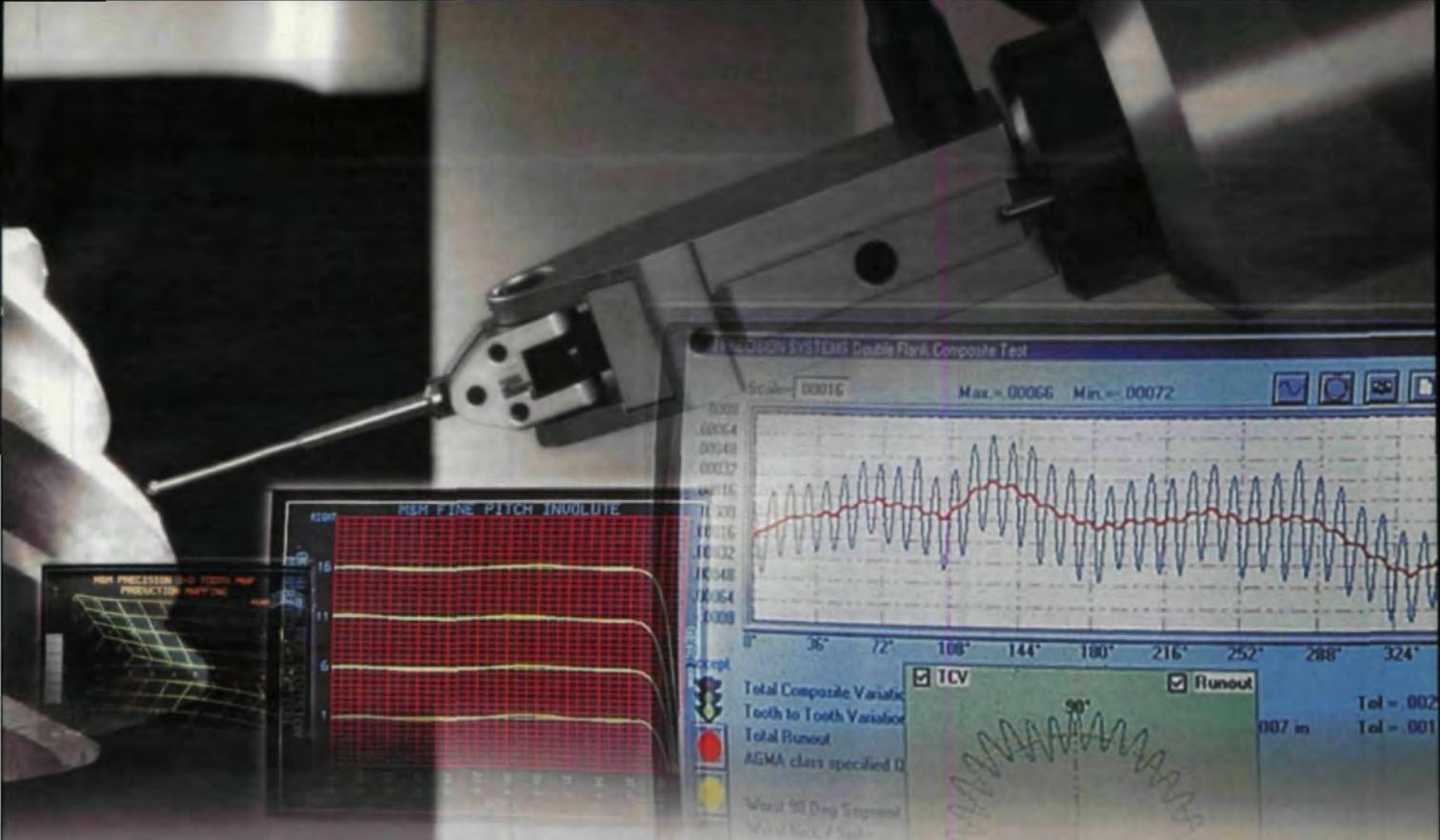
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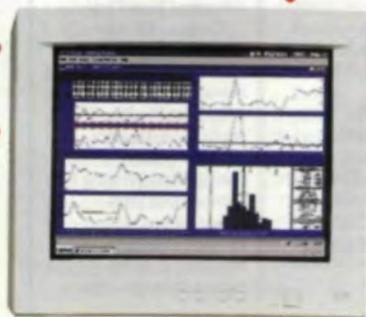
GRS-2 Double-Flank Gear Roller System combines proven performance with easy-to-use PC compatible software to make inspection accurate and simple. Total composite, tooth-to-tooth and runout tests determine if parts conform to specification. Computer analysis lets users specify AGMA or DIN standards, then determine the class of gear achieved.

Dimensions Over Pins Gage measures actual tooth thickness at the pitch diameter. A unique constant-pressure gaging head assures repeatability and accuracy over the full range of the gaging system—while greater throughput allows you to inspect more parts and reduce production costs.

Other M&M Precision Systems inspection products:

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Advertisers Index on page 48.

While we have made every effort to ensure that company names and addresses are correct, we cannot be held responsible for errors of fact or omission. If your company was not listed in this directory, and you would like to be included in 1999, please call 847-437-6604.

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Alpha Heat Treating
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Beehive Heat Treating Benedict-Miller
Certified Metal Craft Cincinnati Steel Treating
Coleman Commercial Heat Treating
Delphi Engineering
Detroit Steel Treating Co.
Dixie Heat Treating
Drever Heat Treating
East-Lind Heat Treat
Edwards Heat Treating
Elmira Heat Treating
Flame Metals Processing
General Heat Treating
Gibson Heat Treat
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Hinderliter — Anaheim
Hitech Metallurgical Co.
Hi-Tech Steel Treating
HTG HiTech Aero
Hudapack — Elkhorn
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Industrial Steel Treating Inc.
Irwin Automation Inc.
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Lindberg Heat Treating Co. — Houston
Lindberg Heat Treating Co. — Rochester
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Metal-Tec Heat Treating
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Paulo Products Co. — Nashville
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Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Richter Precision Inc.
Rotation Products Corp.
Solar Atmospheres Inc.
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Superior Metal Treating
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Coleman Commercial Heat Treating
Delphi Engineering
Dixie Heat Treating
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
East-Lind Heat Treat
Edwards Heat Treating
Elmira Heat Treating
Flame Metals Processing
General Heat Treating
Gibson Heat Treat
Hauni Richmond Inc.
Hitech Metallurgical
Hi-Tech Steel Treating
Horizon Steel Treating
Hy-Vac Technologies
Industrial Metal Treating
Lindberg Heat Treating Co. — Racine
Metal Treating & Research
Metal Treating Inc.
Metlab Co.
Modern Metal Processing
Oakland Metal Treating
Paulo Products Co. — St. Louis
Pennsylvania Metallurgical
Pitt-Tex Inc.
Rotation Products Corp.
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Delphi Engineering
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—Houston
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—Melrose Park
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Washington Metallurgical
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Murfreesboro
Paulo Products Co.—
Nashville
Paulo Products Co.—
St. Louis
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating
Rotation Products Corp.
Shore Metal Technology
Sonec Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating
Inc.—Athens
Specialty Heat Treating
Inc.—Elkhart
Specialty Heat Treating
Inc.—Grand Rapids
Specialty Heat Treating
Inc.—Holland
Specialty Steel Treating—
Farmington Hills
Specialty Steel Treating—
Fraser
State Heat Treat Inc.
Steel Treating Inc.
Steel Treating
Suncoast Heat Treating—
Orlando
Suncoast Heat Treating—
Pompano Beach
Suncoast Heat Treating—
Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Metal Treating Inc.
Thermal Treatment Center
Thermo Electron Metal
Treating Div.
Thermo Treaters Ltd.
TracTech
Treat All Metals Inc.
Trutec Industries
Universal Heat Treating
Washington Metallurgical
Services
Weiss Industries Inc.
Westside Flame Hardening

CRYOGENICS

ABS Metallurgical
Processors Inc.
Accurate Steel Treating
Advanced Thermal
Technologies Inc.
Alco Heat Treating Corp.
Alliance Metal Treating
Alpha Heat Treating
American Brazing
American Heat Treating
Am. Met. Treating Inc.
Applied Cryogenics Inc.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating &
Brazing Co.
Bodycote/Hinderliter
Braddock Metallurgical
Braddock Metallurgical
Alabama
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat
Treating
Century Sun Metal Treating

Certified Heat Treating Inc.
Certified Metal Craft
Cincinnati Flame
Hardening Co.
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Delavan Steel Treating
Detroit Flame Hardening
Detroit Steel Treating Co.
Dixie Heat Treating
Drever Heat Treating
East Carolina Metal
Treating Inc.
East-Lind Heat Treat
Edwards Heat Treating
Elmira Heat Treating
Engineered Heat Treat Inc.
Eric Steel Treating Inc.
Fenton Heat Treating
Flame Metals Processing
Fox Steel Treating Co.
FPM Heat Treating—
Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
General Heat Treating Corp.
**General Metal Heat
Treating Inc.**
Geo. H. Porter Steel
Treating Co.
Gibson Heat Treat Inc.
Hanson-Balk Steel Treating
Haumi Richmond Inc.
Heat-Treating Inc.
Heat Treat Corp. of
America
Hi TecMetal Group—
Cleveland
Hinderliter Heat Treating
Inc.—Anaheim
Hinderliter Heat Treating
Inc.—Dallas
Hinderliter Heat Treating
Inc.—Tazana
Hinderliter Heat Treating
Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Horsburgh & Scott
HTG-HiTech Aero
Hudapack — Elkhorn
Hydro-Vac
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Impact Strategies Inc.
Induction Metal Treating
Industrial Metal Treating
Industrial Steel Treating Inc.
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lexington Heat Treat Inc.
Lindberg Heat Treating Co.
—Berlin
Lindberg Heat Treating Co.
—Houston
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Racine
Magnum Metal Treating
Master Heat Treating Inc.
Metal Improvement Co.—
Columbus
Metal Improvement Co.—
McLean/Wichita
Metal Treating Inc.
Metal Treating Inc.
Metallurgical Inc.
Metals Engineering Inc.
Metals Technology
Metro Steel Treating
Met-Tek Inc.—Clackamas
Midland Metal Treating Inc.
Modern Industries Inc.
Mountain Metallurgical
National Metal Processing

Nitro-Vac Heat Treating
Ohio Metallurgical Service
Paulo Products Co.—
Bessemer
Paulo Products Co.—
Kansas City
Paulo Products Co.—
Memphis
Paulo Products Co.—
Murfreesboro
Paulo Products Co.—
Nashville
Paulo Products Co.—
St. Louis
Penna Flame Industries Inc.
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Shore Metal Technology
Solar Atmospheres Inc.
Sonec Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating Inc.
—Athens
Specialty Heat Treating Inc.
—Elkhart
Specialty Heat Treating Inc.
—Grand Rapids
Specialty Heat Treating Inc.
—Holland
Specialty Steel Treating—
Fraser
Steel Treating
Steel Treating
Sun Steel Treating
Suncoast Heat Treating—
Orlando
Suncoast Heat Treating—
Pompano Beach
Suncoast Heat Treating—
Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Braze Inc.
Thermal Treatment Center
Thermo Electron Metal
Treating Div.
TracTech
Treat All Metals Inc.
Trutec Industries
Universal Heat Treating
Walker Heat Treating
Washington Metallurgical
Services
Westside Flame Hardening

DIE QUENCHING

American Brazing
Beehive Heat Treating
Benedict-Miller Inc.
Bennett Heat Treating &
Brazing Co.
Burbank Steel Treating Inc.
Caterpillar Industrial
Products Inc.
Certified Metal Craft
Cincinnati Gear Co.
Cincinnati Steel Treating
Detroit Steel Treating Co.
Engineered Heat Treat Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Fenton Heat Treating
Fox Steel Treating Co.
Franklin Steel Treating Co.
**General Metal Heat
Treating Inc.**
Gibson Heat Treating
The Gleason Works
Grand Rapids Heat

Treating Co.
Heat Treat Corp. of
America
Hy-Vac Technologies Inc.
Illiana Heat Treating Inc.
Impact Strategies Inc.
Industrial Steel Treating Inc.
Ironbound Heat Treating
Jasco Heat Treating Inc.
John V. Potero Co.
Kowalski Heat Treating Co.
Lindberg Heat Treating
Co.—Racine
Metallurgical Inc.
Metals Technology
Ohio Metallurgical Service
Paulo Products Co.—
Bessemer
Paulo Products Co.—
Kansas City
Paulo Products Co.—
Memphis
Paulo Products Co.—
Nashville
Paulo Products Co.—
St. Louis
Penna Flame Industries Inc.
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Shore Metal Technology
Solar Atmospheres Inc.
Sonec Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating Inc.
—Athens
Specialty Heat Treating Inc.
—Elkhart
Specialty Heat Treating Inc.
—Grand Rapids
Specialty Heat Treating Inc.
—Holland
Specialty Steel Treating—
Fraser
Sun Steel Treating
Therm Tech of Waukesha
Thermal Metal Treating Inc.
Treat All Metals Inc.

FLAME HARDENING

Alco Heat Treating Corp.
American Heat Treating
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating &
Brazing Co.
Bodycote/Hinderliter
The Bowdill Co.
Bucyrus International Inc.
California Surface
Hardening Inc.
Calumet Surface Hardening
Certified Heat Treating Inc.
Chicago Flame Hardening
Chicago Induction
Cincinnati Flame
Hardening Co.
Cincinnati Gear Co.
Cincinnati Steel Treating
Cleveland Flame
Hardening Co.
Coleman Commercial Heat
Treating
Detroit Steel Treating Co.
Detroit Flame Hardening
Drever Heat Treating
East-Lind Heat Treat
Edwards Heat Treating
Eric Steel Treating Inc.
Flame Hardening Co. of
California
Fox Steel Treating Co.
Franklin Steel Treating Co.
Gibson Heat Treat Inc.
Good Earth Tools
Hansen-Balk Steel Treating
Haumi Richmond Inc.
Heat-Treating Inc.
Hinderliter Heat Treating
Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
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Illiana Heat Treating Inc.
Induction Metal Treating Co.
John V. Potero Co.

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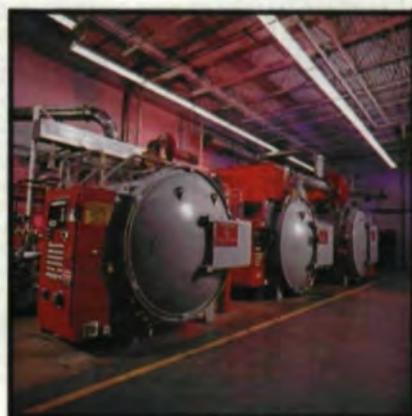
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Metal Improvement Co.—McLean/Wichita
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Metallurgical Inc.
Met-Tek Inc.—Racine
Michigan Flame Hardening
Mid-West Flame Hardening
Midwestern Machinery Co.
National Induction Heating
Ohio Metallurgical Service
Penna Flame Industries Inc.
Pennsylvania Metallurgical
Revas Engineering Co.
Specialty Heat Treating Inc.—Athens
Steel Treaters, Inc.
Suncoast Heat Treating—Orlando
Suncoast Heat Treating—Pompano Beach
Suncoast Heat Treating—Tampa
Superior Metal Treating
Syracuse Heat Treating
Therm Tech of Waukesha
Thermo Electron Metal Treating Div.
Thermo Treaters Ltd.
Washington Metallurgical Services
Westside Flame Hardening
Wohlert Corp.

FREE QUENCHING

ABS Metallurgical Processors Inc.
Advanced Thermal Technologies Inc.
Alliance Metal Treating
AP Westshore
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote/Hinderliter
Braddock Metallurgical
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Certified Heat Treating Inc.
Certified Metal Craft
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Commercial Induction
Commercial Steel Treating
Detroit Steel Treating Co.
Diamond Heat Treating Co.
East Carolina Metal Treating Inc.
Elmira Heat Treating
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Fenton Heat Treating
FPM Heat Treating—Elk Grove
FPM Milwaukee
Franklin Steel Treating Co.
General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
Hanson-Balk Steel Treating
Heat Treat Corp. of America
Heat-Treating Inc.
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating

Inc.—Tarzana
Horizon Steel Treating Inc.
Illiana Heat Treating Inc.
Induction Metal Treating Co.
Industrial Metal Treating
Industrial Steel Treating Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries Inc.
Lindberg Heat Treating Co.—Berlin
Lindberg Heat Treating Co.—Houston
Lindberg Heat Treating Co.—Melrose Park
Lindberg Heat Treating Co.—Racine
Metal Improvement Co.—Lafayette
Metal Improvement Co.—McLean/Wichita
Metal Treating Inc.
Metallurgical Inc.
Metals Technology
Metlab Co.
Met-Tek Inc.—Racine
Midland Metal Treating Inc.
Mid-West Flame Hardening
National Broach
National Induction Heating
Nettleson Steel Treating
Ohio Metallurgical Service
P & L Heat Treating & Grinding
Pfauter-Maag Cutting Tools
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Racine Heat Treating Co.
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Sonee Heat Treating Corp.
Specialty Steel Treating—Farmington Hills
Specialty Steel Treating—Fraser
State Heat Treat Inc.
Sun Steel Treating
Suncoast Heat Treating—Orlando
Suncoast Heat Treating—Pompano Beach
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Thermal Treatment Center
Thermo Electron Metal Treating Div.
Treat All Metals Inc.
Walker Heat Treating
Washington Metallurgical Services
Westside Flame Hardening
Wohlert Corp.

HOT OIL QUENCHING

Abbott Furnace
ABS Metallurgical Processors Inc.
Advanced Metallurgical
Alco Heat Treating Corp.
Alpha Heat Treaters
American Heat Treating
Am. Met. Treating Inc.
Atmosphere Annealing Inc.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote/Hinderliter
Bomak Corp.
Burbank Steel Treating Inc.
Carolina Commercial Heat Treating
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft

Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Cleveland Flame Hardening Co.
Commercial Steel Treating
Custom Heat Treating Co.
Detroit Steel Treating Co.
Disston Precision Inc.
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
East Carolina Metal Treating Inc.
Eckel Heat Treat
Elmira Heat Treating
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Feinblanking Ltd.
Fenton Heat Treating
Fox Steel Treating Co.
FPM Heat Treating—Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating Co.
General Heat Treating
General Metal Heat Treating Inc.
Gibson Heat Treat Inc.
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
HI TecMetal Group—Cleveland
Hinderliter Heat Treating Inc.—Tulsa
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
Horsburgh & Scott
Huron Metallurgical Inc.
Illiana Heat Treating Inc.
Induction Metal Treating Co.
Industrial Metal Treating
Industrial Steel Treating Co.
Irwin Automation Inc.
Jasco Heat Treating Inc.
John V. Potero Co.
Kowalski Heat Treating Co.
Lexington Heat Treat Inc.
Lindberg Heat Treating Co.—New Berlin
Lindberg Heat Treating Co.—Racine
M & M Heat Treat
Magnum Metal Treating
Merit Gear Corp.
Metal Treating & Research
Metal Improvement Co.—Columbus
Metal Improvement Co.—McLean/Wichita
Metal Treaters Inc.
Metallurgical Inc.
Metallurgical Processing
Metals Engineering Inc.
Metals Technology
Metlab Co.
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Mid-West Flame Hardening
Midwestern Machinery Co.
Modern Industries Inc.
Ohio Metallurgical Service
Paulo Products Co.—Bessemer
Paulo Products Co.—Nashville
Paulo Products Co.—St. Louis
Pennsylvania Metallurgical
Pitt-Tex Inc.

Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Specialty Steel Treating—Farmington Hills
Specialty Steel Treating—Fraser
Sun Steel Treating
Suncoast Heat Treating—Orlando
Suncoast Heat Treating—Pompano Beach
Superior Metal Treating
Syracuse Heat Treating
Therm Tech of Waukesha
Thermal Treatment Center
Thermo Treaters Ltd.
Treat All Metals Inc.
Weiss Industries, Inc.
Washington Metallurgical Services
Westside Flame Hardening

INDUCTION HARDENING

Advanced Heat Treat Corp.—Monroe
Advanced Heat Treat Corp.—Waterloo
Advanced Heat Treating
Ajax Magnethermic Corp.
Alco Heat Treating Corp.
Alpha Heat Treaters
Amer. Met. Treating Co.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating & Brazing Co.
Bodycote/Hinderliter
Braddock Metallurgical
Bucyrus International Inc.
Carolina Commercial Heat Treating
Caterpillar Industrial Products Inc.
Century Sun Metal Treating
Certified Heat Treating Inc.
Chicago Induction
Cincinnati Gear Co.
Cincinnati Steel Treating
Coleman Commercial Heat Treating
Commercial Induction
Contour Hardening Inc.
Delavan Steel Treating
Dixie Machine & Heat Treating Inc.
Drever Heat Treating
East Carolina Metal Treating Inc.
Edwards Heat Treating
Elmira Heat Treating
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Flame Metals Processing
Fluxtrol Manufacturing Inc.
Franklin Steel Treating Co.
Gear Company of America
General Heat Treating
Gibson Heat Treat Inc.
Good Earth Tools, Inc.
Hauni Richmond Inc.
Heat Treat Corp. of America
Heat-Treating Inc.
Hi-Tech Steel Treating Inc.
HI TecMetal Group—Cleveland
Hinderliter Heat Treating Inc.—Anaheim
Hinderliter Heat Treating Inc.—Tulsa
Horizon Steel Treating Inc.
Hudapack — Elkhorn
Illiana Heat Treating Inc.

Impact Strategies Inc.
 Induction Services Inc.
 Induction Metal Treating Co.
 Induction Heat Treating
 Inductoheat Inc.
 Industrial Metal Treating
 Industrial Steel Treating Co.
 International Induction Inc.
 Ironbound Heat Treating
 Jasco Heat Treating Inc.
 John V. Potero Co.
 Lawrence Industries Inc.
 Lexington Heat Treat Inc.
 Lindberg Heat Treating Co.
 —Houston
 Lindberg Heat Treating Co.
 —Melrose Park
 Lindberg Heat Treating Co.
 —Racine
 Lindberg Heat Treating Co.
 —St. Louis
 Mannings U.S.A.
 Master Heat Treating Inc.
 Merit Gear Corp.
 Metal Treating & Research
 Metal Improvement Co.—
 Columbus
 Metal Improvement Co.—
 McLean/Wichita
 Metal Processing Co.
 Metal Treating Inc.
 Metal Treating & Research
 Metal Treating Inc.
 Metallurgical Inc.
 Metals Engineering Inc.
 Met-Tek Inc.—Clackamas
 Met-Tek Inc.—Racine
 Michigan Induction Inc.
 Midland Metal Treating Inc.
 Modern Industries Inc.
 Molon Gear & Shaft
 National Induction Heating
 National Metal Processing
 O & W Heat Treat Inc.
 Ohio Metallurgical Service
 Paulo Products Co.
 —Kansas City
 Paulo Products Co.
 —Memphis
 Paulo Products Co.
 —Nashville
 Paulo Products Co.
 —St. Louis
 Pennsylvania Metallurgical
 Pitt-Tex Inc.
 Precision Heat Treating
 Racine Heat Treating Co.
 Revas Engineering Co.
 Roboduction Thermal
 Processing
 S.K.S. Heat Treating Inc.
 Southeastern Heat Treating
 Specialty Heat Treating Inc.
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 Specialty Heat Treating Inc.
 —Grand Rapids
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 —Holland
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 Steel Treating
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 Suncoast Heat Treating—
 Tampa
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 Syracuse Heat Treating
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 Thermal Treatment Center
 Thermet Inc.
 Thermo Electron Metal
 Treating Div.
 Tocco, Inc.
 Treat All Metals Inc.
 Washington Metallurgical
 Westside Flame Hardening
 Wohler Corp.
 Zion Industries

ION NITRIDING

Accurate Ion Technologies
 Advanced Heat Treat Corp.
 —Monroe
 Advanced Heat Treat Corp.
 —Waterloo
 Advanced Metallurgical
 AMT Monroe Inc.
 Century Sun Metal Treating
 Cincinnati Gear Co.
 Fox Steel Treating Co.
 FPM Heat Treating—
 Elk Grove
 FPM Ipsen Heat Treating
 Hansen-Balk Steel Treating
 Hauni Richmond Inc.
 HI TecMetal Group—
 Cleveland
 Magnum Metal Treating
 MPT America
 Progressive Engineering Co.
 Solar Atmospheres Inc.
 Sonee Heat Treating Corp.
 Sun Steel Treating
 Thermal Treatment Center

LASER HARDENING

Cincinnati Gear Co.
 National Metal Processing
 Weiss Industries Inc.

METALLURGICAL TESTING

Accurate Ion Technologies
 Advanced Heat Treat
 Corp. — Monroe
 Advanced Heat Treat
 Corp. — Waterloo
 Advanced Heat Treating
 Advanced Metallurgical
 Alliance Metal Treating
 Alpha Heat Treating
 Benedict-Miller
 Bodycote-Hinderliter
 Burbank Steel Treating
 Century Sun Metal Treating
 Certified Metal Craft
 Cincinnati Steel Treating
 Delevan Steel Treating
 Detroit Steel Treating Co.
 Dixie Heat Treating
 Dynamic Metal Treating
 East-Lind Heat Treat
 Elmira Heat Treating
Engineered Heat Treat, Inc.
 Erie Steel Treating Inc.
 Euclid Heat Treating
 Flame Metals Processing
 General Heat Treating
 Hauni Richmond Inc.
 Hitech Metallurgical Co.
 Hi-Tech Steel Treating
Hudapack — Elkhorn
 Impact Strategies Inc.
 Industrial Steel Treating Co.
 Industrial Steel Treating Inc.
 Ironbound Heat Treating
 Irwin Automation Inc.
 Kowalski Heat Treating
 Lindberg Heat Treating
 Co. — Houston
 Lindberg Heat Treating
 Co. — Rochester
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 Metal Improvement Co.
 — Columbus
 Metal Treating Inc.
 Metallurgical Inc.
 Michigan Induction Inc.
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 Pennsylvania Metallurgical
 Phoenix Heat Treating
 Pitt-Tex Inc.
 Progressive Steel Treating
 Racine Heat Treating Co.
 Richter Presiaion Inc.
 Rotation Products Corp.
 Sonee Heat Treating Corp.

Specialty Heat Treating
 — Grand Rapids
 Superior Metal Treating
 Syracuse Heat Treating
 Thermet Inc.
 TracTech
 Universal Heat Treating
 Weiss Industries Inc.

NITRIDING

Abbott Furnace
 Accurate Steel Treating
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 Albany Metal Treating
 Alco Heat Treating Corp.
 Am. Met. Treating Inc.
 Benedict-Miller Inc.
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 Brazing Co.
 Bodycote/Hinderliter
 Braddock Metallurgical
 Burbank Steel Treating Inc.
 Cal-Doran Division
 Caterpillar Industrial
 Products Inc.
 Cincinnati Gear Co.
 Cincinnati Steel Treating
 City Steel Treating Inc.
 Commercial Steel Treating
 Custom Heat Treating Co.
 Drever Heat Treating
 Dynamic Metal Treating
 East Carolina Metal
 Treating Inc.
 Elmira Heat Treating
Engineered Heat Treat Inc.
 Erie Steel Treating Inc.
 Euclid Heat Treating Co.
Fairfield Mfg. Co.
 Fenton Heat Treating
 Fox Steel Treating Co.
 FPM Heat Treating—
 Elk Grove
 FPM Ipsen Heat Treating
 FPM Milwaukee
**General Metal Heat
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 Treating Co.
 H & M Metal Processing
 Hansen-Balk Steel Treating
 HI TecMetal Group—
 Cleveland
 Hinderliter Heat Treating
 Inc.—Anaheim
 Hinderliter Heat Treating
 Inc.—Dallas
 Hinderliter Heat Treating
 Inc.—Tazana
 Hinderliter Heat Treating
 Inc.—Tulsa
 Horizon Steel Treating Inc.
 Hydro-Vac
 Illiana Heat Treating Inc.
 Impact Strategies Inc.
 Induction Metal Treating Co.
 Industrial Metal Treating
 Industrial Steel Treating Inc.
 Ironbound Heat Treating
 Jasco Heat Treating Inc.
 Lake County Steel Treating
 Lindberg Heat Treating Co.
 —Houston
 Lindberg Heat Treating Co.
 —Melrose Park
 Lindberg Heat Treating Co.
 —Racine
 Lindberg Heat Treating Co.
 —St. Louis
 Merit Gear Corp.
 Metal Improvement Co.
 Metallurgical Inc.
 Metal-Tec Heat Treating Inc.
 Metals Technology
 Metlab Co.
 Metro Steel Treating
 Met-Tek Inc.—Clackamas
 Modern Industries Inc.

Modern Steel Treating
**Nitrex Metal Tech—
 Burlington**
**Nitrex Metal Tech—
 Mason**
**Nitrex Metal Tech—
 St. Laurent**
 Nitron Inc.
 Nitro-Vac Heat Treating
 O & W Heat Treat Inc.
 P & L Heat Treating &
 Grinding
 Peters Heat Treating Inc.
 Phoenix Heat Treating Inc.
 Precision Heat Treating
 Progressive Engineering
 Rochester Steel Treating
 Rotation Products Corp.
 Scot Forge
 Shore Metal Technology Inc.
 Specialty Heat Treating Inc.
 —Elkhart
 Specialty Heat Treating Inc.
 —Grand Rapids
 Specialty Heat Treating Inc.
 —Holland
 Specialty Steel Treating—
 Farmington Hills
 Specialty Steel Treating—
 Fraser
 Steel Treating, Inc.
 Sun Steel Treating
 Suncoast Heat Treating—
 Orlando
 Suncoast Heat Treating—
 Pompano Beach
 Suncoast Heat Treating—
 Tampa
 Syracuse Heat Treating
 T. N. Woodworth Inc.
 Therm Tech of Waukesha
 Thermal Treatment Center
 Treat All Metals Inc.
 Trutec Industries
 Universal Heat Treating
 Walker Heat Treating

NITROCARBURIZING

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 Alliance Metal Treating
 Alco Heat Treating Corp.
 Am. Met. Treating Inc.
 Benedict-Miller Inc.
 Bennett Heat Treating &
 Brazing Co.
 Bodycote/Hinderliter
 Carolina Commercial Heat
 Treating
 Cincinnati Gear Co.
 Cincinnati Steel Treating
 City Steel Treating Inc.
 Coleman Commercial Heat
 Treating
 Commercial Steel Treating
 Dixie Heat Treating
 Dynamic Metal Treating
 Erie Steel Treating Inc.
 Euclid Heat Treating Co.
Fairfield Mfg. Co.
 Flame Metals Processing
 Fox Steel Treating Co.
 FPM Heat Treating—
 Elk Grove
 FPM Ipsen Heat Treating
 FPM Milwaukee
 Gear Company of America
 Hauni Richmond Inc.
 Hinderliter Heat Treating
 Inc.—Anaheim
 Hinderliter Heat Treating
 Inc.—Tazana
 Hinderliter Heat Treating
 Inc.—Tulsa
Hudapack — Elkhorn
 Illiana Heat Treating Inc.
 Impact Strategies Inc.
 Induction Metal Treating
 Industrial Metal Treating
 Industrial Steel Treating
 Ironbound Heat Treating
 Jasco Heat Treating Co.
 FPM Heat Treating—
 Elk Grove
 FPM Ipsen Heat Treating
 FPM Milwaukee
 Gear Company of America
 Hauni Richmond Inc.
 Hinderliter Heat Treating
 Inc.—Anaheim
 Hinderliter Heat Treating
 Inc.—Tazana
 Hinderliter Heat Treating
 Inc.—Tulsa
Hudapack — Elkhorn
 Illiana Heat Treating Inc.
 Impact Strategies Inc.
 Induction Metal Treating Co.
 Industrial Metal Treating

Industrial Steel Treating
 Ironbound Heat Treating
 Jasco Heat Treating Inc.
 Lindberg Heat Treating Co.
 —Houston
 Lindberg Heat Treating Co.
 —Melrose Park
 Lindberg Heat Treating Co.
 —New Berlin
 Lindberg Heat Treating Co.
 —Racine
 Lindberg Heat Treating Co.
 —Rochester
 Lindberg Heat Treating Co.
 —St. Louis
 Merit Gear Corp.
 Metallurgical Inc.
 Metals Technology
 Metal-Tec Heat Treating
 Metlab Co.
 Metro Steel Treating
 Met-Tek Inc.—Clackamas
 Modern Industries Inc.
**Nitrex Metal Tech.
 —Burlington**
**Nitrex Metal Tech.
 —Mason**
**Nitrex Metal Tech.
 —St. Laurent**
 Paulo Products Co.—
 Bessemer
 Paulo Products Co.—
 Kansas City
 Paulo Products Co.—
 Memphis
 Paulo Products Co.—
 Murfreesboro
 Paulo Products Co.—
 Nashville
 Paulo Products Co.—
 St. Louis
 Peters Heat Treating Inc.
 Phoenix Heat Treating Inc.
 Rochester Steel Treating
 Rotation Products Corp.
 Shore Metal Technology
 Specialty Heat Treating Inc.
 —Athens
 Specialty Heat Treating Inc.
 —Elkhart
 Specialty Heat Treating Inc.
 —Grand Rapids
 Specialty Heat Treating Inc.
 —Holland
 Suncoast Heat Treating—
 Pompano Beach
 Syracuse Heat Treating
 Therm Tech of Waukesha
 Thermal Treatment Center
 Trutec Industries

NORMALIZING

Abbott Furnace
 ABS Metallurgical
 Processors Inc.
 Accurate Steel Treating
 Advanced Heat Treating Inc.
 Advanced Metallurgical
 Technology
 Advanced Thermal
 Technologies
 Albany Metal Treating
 Alco Heat Treating Corp.
 Alliance Metal Treating
 Alpha Heat Treating
 American Brazing
 American Heat Treating
 Am. Met. Treating Inc.
 Atmosphere Annealing Inc.
 Beehive Heat Treating Inc.
 Benedict-Miller Inc.
 Bennett Heat Treating &
 Brazing Co.
 Bodycote/Hinderliter
 Bomak Corp.
 The Bowdell Co.
 Braddock Metallurgical
 Braddock Metallurgical

Alabama
 Brazing & Metal Treating
 —Cleveland
 Brazing & Metal Treating
 of KY
 Brazing & Metal Treating
 of MN
 Brite Brazing
 Burbank Steel Treating Inc.
 Cal-Doran Division
 Carolina Commercial Heat
 Treating
 Caterpillar Industrial
 Products
 Century Sun Metal Treating
 Certified Metal Craft Inc.
 Certified Heat Treating Inc.
 Cincinnati Flame
 Hardening
 Cincinnati Gear Co.
 Cincinnati Steel Treating
 City Steel Treating Inc.
 Coleman Commercial Heat
 Treating
 Commercial Induction
 Commercial Steel Treating
 Custom Heat Treating Co.
 Delavan Steel Treating
 Delphi Engineering
 Detroit Steel Treating Co.
 Diamond Heat Treating Co.
 Disston Precision Inc.
 Dixie Heat Treating Co.
 Dixie Machine & Heat
 Treating Inc.
 Drever Heat Treating
 East Carolina Metal
 Treating Inc.
 East-Lind Heat Treat
 Eckel Heat Treat
 Edwards Heat Treating
 Elmira Heat Treating
Engineered Heat Treat Inc.
 Erie Steel Treating Inc.
 Euclid Heat Treating Co.
Fairfield Mfg. Co.
 Feinblanking Ltd.
 Fenton Heat Treating
 Flame Metals Processing
 Fox Steel Treating Co.
 FPM Heat Treating—
 Elk Grove
 FPM Ipsen Heat Treating
 FPM Milwaukee
 Franklin Steel Treating Co.
 Gear Company of America
 General Heat Treating Corp.
**General Metal Heat
 Treating Inc.**
 Geo. H. Porter Steel
 Treating Co.
 Gibson Heat Treat Inc.
 Grand Rapids Heat
 Treating Co.
 Hansen-Balk Steel Treating
 Hauni Richmond Inc.
 Heat Treat Corp. of
 America
 Heat Treating Services
 Heat-Treating Inc.
 HI TecMetal Group—
 Cleveland
 Hinderliter Heat Treating
 Inc.—Anaheim
 Hinderliter Heat Treating
 Inc.—Dallas
 Hinderliter Heat Treating
 Inc.—Tazana
 Hinderliter Heat Treating
 Inc.—Tulsa
 Hi-Tech Steel Treating Inc.
 Horizon Steel Treating Inc.
 Horschburg & Scott Co.
 HTG-HiTech Aero
Hudapack — Elkhorn
 Huron Metallurgical
 Hydro-Vac
 Hy-Vac Technologies Inc.

**NORMALIZING
(Cont.)**

Iliana Heat Treating Inc.
Impact Strategies Inc.
Induction Metal Treating Co.
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
John V. Potero Co.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries Inc.
Lexington Heat Treat Inc.
Lindberg Heat Treating Co.
—Berlin
Lindberg Heat Treating Co.
—Houston
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Racine
Lindberg Heat Treating Co.
—St. Louis
M & M Heat Treat
Magnum Metal Treating
Master Heat Treating Inc.
Merit Gear Corp.
Metal Improvement Co.
—Columbus
Metal Improvement Co.
—Lafayette
Metal Improvement Co.—
McLean/Wichita
Metal Methods
Metal Treating & Research
Metal Treating Inc.
Metallurgical Inc.
Metallurgical Processing Inc.
Metals Engineering Inc.
Metals Technology
Metlab Co.
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Midland Metal Treating Inc.
Modern Industries Inc.
Modern Metal Processing
Mountain Metallurgical
National Broach
National Metal Processing
Nettleson Steel Treating
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Oakland Metal Treating Co.
Ohio Metallurgical Service
P & L Heat Treating &
Grinding
Partek Laboratories Inc.
Paulo Products Co.—
Bessemer
Paulo Products Co.—
Kansas City
Paulo Products Co.—
Memphis
Paulo Products Co.—
Nashville
Paulo Products Co.—
St. Louis
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating Inc.
—Athens

Specialty Heat Treating Inc.
—Elkhart
Specialty Heat Treating Inc.
—Grand Rapids
Specialty Heat Treating Inc.
—Holland
Specialty Heat Treating Inc.
—Farmington Hills
Specialty Steel Treating—
Fraser
State Heat Treat Inc.
Steel Treating, Inc.
Sun Steel Treating
Suncoast Heat Treating—
Orlando
Suncoast Heat Treating—
Pompano Beach
Suncoast Heat Treating—
Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Metal Treating
Thermal Treatment Center
Thermo Electron Metal
Treating Div.
Thermo Treating Ltd.
TracTech
Treat All Metals Inc.
Trojan Heat Treat Inc.
Universal Heat Treating
Vacu Brazze
Walker Heat Treating
Wall Colmonoy Corp.
Washington Metallurgical
Services
Weiss Industries Inc.
Wohlert Corp.

PLASMA CARBURIZING

Cincinnati Gear Co.
HI TecMetal Group—
Cleveland

PRESS QUENCHING

Benedict-Miller Inc.
Bennett Heat Treating &
Brazing Co.
Caterpillar Industrial
Products Inc.
Cincinnati Gear Co.
Cincinnati Steel Treating
Engineered Heat Treat Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Franklin Steel Treating Co.
Gibson Heat Treat Inc.
The Gleason Works
Heat Treat Corp. of
America
Impact Strategies Inc.
Industrial Steel Treating Inc.
Jasco Heat Treating Inc.
Kowalski Heat Treating Co.
Lindberg Heat Treating Co.
—Racine
Lindberg Heat Treating Co.
—St. Louis
Metallurgical Inc.
Metals Technology
Metlab Co.
Mountain Metallurgical
Ohio Metallurgical Service
Phoenix Heat Treating Inc.
Roboduction Thermal
Processing
Specialty Steel Treating—
Farmington Hills
Specialty Steel Treating—
Fraser
Treat All Metals Inc.
Washington Metallurgical
Services

SALT BATH NITRIDING

Abbott Furnace
Bomak Corp.

Cal-Doran Division
Cincinnati Gear Co.
Commercial Steel Treating
East-Lind Heat Treat
Engineered Heat Treat Inc.
Flame Metals Processing
Fox Steel Treating Co.
H & M Metal Processing
HI TecMetal Group—
Cleveland
Iliana Heat Treating Inc.
Induction Metal Treating Co.
Jasco Heat Treating Inc.
Lake County Steel Treating
Lexington Heat Treat Inc.
Lindberg Heat Treating Co.
—New Berlin
Lindberg Heat Treating Co.
—Racine
Metal Treating Inc.
Metals Technology
National Broach
Nitro-Vac Heat Treating
O & W Heat Treat Inc.
Superior Metal Treating
Trutec Industries
Walker Heat Treating
Wear-Ever Surface Treating
Weiss Industries Inc.

SHOT PEENING

Metal Improvement Co.
Paulo Products Co.—
Memphis

SINTERING

Abbott Furnace
Allread Products
American Brazing
Bennett Heat Treating &
Brazing Co.
Certified Metal Craft
Cincinnati Gear Co.
Fluxtrol Manufacturing Inc.
Hinderliter Heat Treating
Inc.—Tazana
Hitech Metallurgical Co.
HTG Aerobrazze
HTG-HiTech Aero
Hydro-Vac
Hy-Vac Technologies Inc.
Iliana Heat Treating Inc.
Induction Metal Treating Co.
Metal Improvement Co.—
McLean/Wichita
Metals Technology
Modern Metal Processing
Pennsylvania Metallurgical
Progressive Steel Treating
Solar Atmospheres Inc.
Specialty Heat Treating Inc.
—Athens
Specialty Heat Treating Inc.
—Elkhart
Specialty Heat Treating Inc.
—Grand Rapids
Specialty Heat Treating Inc.
—Holland
Suncoast Heat Treating—
Orlando
Suncoast Heat Treating—
Pompano Beach
Syracuse Heat Treating
Walker Heat Treating

STEAM TREATING

Abbott Furnace
Advanced Heat Treating
Allread Products
Hi-Tech Steel Treating
Industrial Metal Treating
Solar Atmospheres Inc.
Sun Steel Treating
Syracuse Heat Treating

STRAIGHTENING

Century Sun Metal Treating
Cincinnati Steel Treating

Engineered Heat Treat
Midwest Flame Hardening
Treat All Metals
Westside Flame Hardening

STRESS RELIEVING

Abbott Furnace
ABS Metallurgical
Processors Inc.
Accurate Steel Treating
Advanced Heat Treat Corp.
—Monroe
Advanced Heat Treat Corp.
—Waterloo
Advanced Metallurgical
Advanced Thermal
Technologies, Inc.
Albany Metal Treating
Alco Heat Treating Corp.
Alliance Metal Treating
Alpha Heat Treating
American Heat Treating
Am. Met. Treating Inc.
AMT Monroe Inc.
Atmosphere Annealing Inc.
Beehive Heat Treating Inc.
Benedict-Miller Inc.
Bennett Heat Treating &
Brazing Co.
Bodycote/Hinderliter
Bomak Corp.
Bonal Technologies Inc.
The Bowditch Co.
Braddock Metallurgical
Braddock Metallurgical
Alabama
Brazing & Metal
Treating—Cleveland
Brazing & Metal Treating
of KY
Brazing & Metal Treating
of MN
Brite Brazing
Brite Metal Treating Inc.
Bucyrus International Inc.
Burbank Steel Treating Inc.
Cal-Doran Division
Carolina Commercial Heat
Treating
Century Sun Metal Treating
Certified Heat Treating Inc.
Certified Metal Craft
Chicago Flame Hardening
Cincinnati Flame
Hardening Co.
Cincinnati Gear Co.
Cincinnati Steel Treating
City Steel Treating Inc.
Cleveland Flame
Hardening Co.
Coleman Commercial Heat
Treating
Commercial Induction
Commercial Steel Treating
Cooperheat Inc.
Custom Heat Treating Co.
Delavan Steel Treating
Delphi Engineering
Detroit Flame Hardening
Detroit Steel Treating Co.
Diamond Heat Treating Co.
Disston Precision Inc.
Dixie Heat Treating Co., Inc.
Dixie Machine & Heat
Treating Inc.
Drever Heat Treating
East Carolina Metal
Treating Inc.
East-Lind Heat Treat
Eckel Heat Treat
Edwards Heat Treating
Elmira Heat Treating
Engineered Heat Treat Inc.
Erie Steel Treating Inc.
Euclid Heat Treating Co.
Fairfield Mfg. Co.
Feinblanking Ltd.
Fenton Heat Treating

Flame Metals Processing
Fluxtrol Manufacturing Inc.
Fox Steel Treating Co.
FPM Heat Treating—
Elk Grove
FPM Ipsen Heat Treating
FPM Milwaukee
Franklin Steel Treating Co.
General Heat Treating Corp.
**General Metal Heat
Treating Inc.**
Geo. H. Porter Steel
Treating Co.
Gibson Heat Treat Inc.
Global Heat Inc.
Grand Rapids Heat
Treating Co.
H & M Metal Processing
Hansen-Balk Steel Treating
Hauni Richmond Inc.
Heat Treat Corp. of
America
Heat-Treating Inc.
Heat Treating Services
HI TecMetal Group—
Cleveland
Hinderliter Heat Treating
Inc.—Anaheim
Hinderliter Heat Treating
Inc.—Dallas
Hinderliter Heat Treating
Inc.—Tazana
Hinderliter Heat Treating
Inc.—Tulsa
Hitech Metallurgical Co.
Hi-Tech Steel Treating Inc.
Horizon Steel Treating Inc.
Horsburgh & Scott Co.
Houston Flame Hardening
HTG Aerobrazze
HTG-HiTech Aero
Hudapack — Elkhorn
Huron Metallurgical Inc.
Hydro-Vac
Hy-Vac Technologies Inc.
Iliana Heat Treating Inc.
Induction Metal Treating Co.
Induction Services Inc.
Inductoheat Inc.
Industrial Metal Treating
Industrial Steel Treating Co.
Industrial Steel Treating Inc.
Ironbound Heat Treating
Irwin Automation Inc.
Jasco Heat Treating Inc.
JCS Engineering &
Development
John V. Potero Co.
Kowalski Heat Treating Co.
Lake County Steel Treating
Lawrence Industries Inc.
Lexington Heat Treat Inc.
Lindberg Heat Treating Co.
—Berlin
Lindberg Heat Treating Co.
—Houston
Lindberg Heat Treating Co.
—Melrose Park
Lindberg Heat Treating Co.
—Racine
Lindberg Heat Treating Co.
—Rochester
Lindberg Heat Treating Co.
—St. Louis
M & M Heat Treat
Magnum Metal Treating Inc.
Mannings U.S.A.
Master Heat Treating Inc.
Merit Gear Corp.
Metal Improvement Co.—
Columbus
Metal Improvement Co.—
Lafayette
Metal Improvement Co.—
McLean/Wichita
Metal Methods
Metal Treating & Research
Metallurgical Inc.

Metallurgical Processing Inc.
Metals Engineering Inc.
Metals Technology
Metlab Co.
Metro Steel Treating
Met-Tek Inc.—Clackamas
Met-Tek Inc.—Racine
Michigan Flame Hardening
Michigan Induction Inc.
Midland Metal Treating
Midwest Flame Hardening
Midwestern Machinery Co.
Modern Industries Inc.
Modern Metal Processing
Mountain Metallurgical
National Broach
National Induction Heating
National Metal Processing
Nettleson Steel Treating
Nitro-Vac Heat Treating
Oakland Metal Treating Co.
Ohio Metallurgical Service
Partek Laboratories Inc.
Paulo Products Co.—
Bessemer
Paulo Products Co.—
Kansas City
Paulo Products Co.—
Memphis
Paulo Products Co.—
Nashville
Paulo Products Co.—
St. Louis
Penna Flame Industries
Pennsylvania Metallurgical
Peters Heat Treating Inc.
Plauter-Maag Cutting Tools
Phoenix Heat Treating Inc.
Pitt-Tex Inc.
Precision Heat Treating
Progressive Steel Treating
Racine Heat Treating Co.
Roboduction Thermal
Processing
Rochester Steel Treating
Rotation Products Corp.
S.K.S. Heat Treating Inc.
Scot Forge
Shanafelt Mfg. Co.
Shore Metal Technology
Solar Atmospheres Inc.
Sonee Heat Treating Corp.
Southeastern Heat Treating
Specialty Heat Treating
Inc.—Athens
Specialty Heat Treating
Inc.—Elkhart
Specialty Heat Treating
Inc.—Grand Rapids
Specialty Heat Treating Inc.
—Holland
Specialty Steel Treating—
Farmington Hills
Specialty Steel Treating—
Fraser
State Heat Treat Inc.
Steel Treating, Inc.
Steel Treating
Sun Steel Treating
Suncoast Heat Treating—
Orlando
Suncoast Heat Treating—
Pompano Beach
Suncoast Heat Treating—
Tampa
Superior Metal Treating
Syracuse Heat Treating
T. N. Woodworth Inc.
Therm Tech of Waukesha
Thermal Treatment Center
Thermet Inc.
Thermo Electron Metal
Treating Div.
Thermo Treating Ltd.
Tocco, Inc.
TracTech
Treat All Metals Inc.
Trojan Heat Treat Inc.

Trutec Industries
 Universal Heat Treating
 Vacu Braze
 Walker Heat Treating
 Wall Colmonoy Corp.
 Washington Metallurgical
 Services
 Weiss Industries Inc.
 Western Stress Inc.
 Westside Flame Hardening

TEMPERING

Abbott Furnace
 ABS Metallurgical
 Processors Inc.
 Accurate Steel Treating
 Advanced Heat Treat Corp.
 —Monroe
 Advanced Heat Treat Corp.
 —Waterloo
 Advanced Heat Treating
 Advanced Metallurgical
 Advanced Thermal
 Technologies Inc.
 Albany Metal Treating
 Alco Heat Treating Corp.
 Alliance Metal Treating
 Allread Products
 Alpha Heat Treaters
 American Brazing
 American Heat Treating
 American Metal Processing
 Am. Met. Treating Inc.
 AP Westshore
 Atmosphere Annealing Inc.
 Beehive Heat Treating Inc.
 Benedict-Miller Inc.
 Bennett Heat Treating &
 Brazing Co.
 Bodycote/Hinderliter
 Bomak Corp.
 The Bowdil Co.
 Braddock Metallurgical
 Braddock Metallurgical
 Alabama
 Brazing & Metal
 Treating—Cleveland
 Brite Brazing
 Brite Metal Treating Inc.
 Burbank Steel Treating Inc.
 Cal-Doran Division
 Calumet Surface Hardening
 Carolina Commercial Heat
 Treating
 Caterpillar Industrial
 Products Inc.
 Century Sun Metal Treating
 Certified Heat Treating Inc.
 Certified Metal Craft
 Chicago Flame Hardening
 Chicago Induction
 Cincinnati Flame
 Hardening
 Cincinnati Gear
 Cincinnati Steel Treating
 City Steel Treating Inc.
 Cleveland Flame
 Hardening Co.
 Coleman Commercial Heat
 Treating
 Commercial Induction
 Commercial Steel Treating
 Custom Heat Treating Co.
 Delavan Steel Treating
 Delphi Engineering
 Detroit Flame Hardening
 Detroit Steel Treating Co.
 Diamond Heat Treating Co.
 Disston Precision Inc.
 Dixie Heat Treating Co. Inc.
 Dixie Machine & Heat
 Treating Inc.
 Drever Heat Treating
 East-Lind Heat Treat
 East Carolina Metal
 Treating Inc.
 Eckel Heat Treat
 Edwards Heat Treating

Elmira Heat Treating
Engineered Heat Treat Inc.
 Erie Steel Treating Inc.
 Euclid Heat Treating Co.
Fairfield Mfg. Co.
 Feinblanking Ltd.
 Fenton Heat Treating
 Flame Metals Processing
 Fluxtrol Manufacturing Inc.
 Fox Steel Treating Co.
 FPM Heat Treating—
 Elk Grove
 FPM Milwaukee
 Franklin Steel Treating Co.
 Gear Company of America
 General Heat Treating
 General Metal Heat
 Treating Inc.
 Geo. H. Porter Steel
 Treating Co.
 Gibson Heat Treat Inc.
 Grand Rapids Heat
 Treating Co.
 H & M Metal Processing
 Hansen-Balk Steel Treating
 Hauni Richmond Inc.
 Heat Treat Corp. of
 America
 Heat-Treating Inc.
 Heat Treating Services
 HI TecMetal Group—
 Cleveland
 Hinderliter Heat Treating
 Inc.—Anaheim
 Hinderliter Heat Treating
 Inc.—Dallas
 Hinderliter Heat Treating
 Inc.—Tazana
 Hinderliter Heat Treating
 Inc.—Tulsa
 Hitech Metallurgical Co.
 Hi-Tech Steel Treating Inc.
 Horizon Steel Treating Inc.
 Horsburgh & Scott Co.
 Houston Flame Hardening
 HTG Aerobraz
 HTG-HiTech Aero
Hudapack — Elkhorn
 Huron Metallurgical Inc.
 Hydro-Vac
 Hy-Vac Technologies Inc.
 Iliana Heat Treating Inc.
 Impact Strategies Inc.
 Induction Metal Treating
 Induction Services Inc.
 Inductoheat Inc.
 Industrial Metal Treating
 Industrial Steel Treating Co.
 Industrial Steel Treating Inc.
 International Induction Inc.
 Ironbond Heat Treating
 Irwin Automation Inc.
 Jasco Heat Treating Inc.
 JCS Engineering &
 Development
 John V. Potero Co.
 Kowalski Heat Treating Co.
 Lake County Steel Treating
 Lawrence Industries Inc.
 Lexington Heat Treat Inc.
 Lindberg Heat Treating Co.
 —Berlin
 Lindberg Heat Treating Co.
 —Houston
 Lindberg Heat Treating Co.
 —Melrose Park
 Lindberg Heat Treating Co.
 —Racine
 Lindberg Heat Treating Co.
 —Rochester
 Lindberg Heat Treating Co.
 —St. Louis
 M & M Heat Treat
 Magnum Metal Treating
 Master Heat Treating Inc.
 Merit Gear Corp.
 Metal Improvement Co.—
 Columbus

Metal Improvement Co.—
 Lafayette
 Metal Improvement Co.—
 McLean/Wichita
 Metal Methods
 Metal Treating Inc.
 Metal Treating & Research
 Metallurgical Inc.
 Metallurgical Processing Inc.
 Metals Engineering Inc.
 Metals Technology
 Metlab Co.
 Metro Steel Treating
 Met-Tek Inc.—Clackamas
 Met-Tek Inc.—Racine
 Michigan Flame Hardening
 Michigan Induction Inc.
 Midland Metal Treating
 Midwest Flame Hardening
 Midwestern Machinery Co.
 Modern Industries Inc.
 Modern Metal Processing
 Molon Gear & Shaft
 Mountain Metallurgical
National Broach
 National Induction Heating
 National Metal Processing
 Nettleson Steel Treating
 Nitro-Vac Heat Treating
 O & W Heat Treat Inc.
 Oakland Metal Treating Co.
 Ohio Metallurgical Service
 P & L Heat Treating &
 Grinding
 Partek Laboratories Inc.
 Paulo Products Co.—
 Bessemer
 Paulo Products Co.—
 Kansas City
 Paulo Products Co.—
 Memphis
 Paulo Products Co.—
 Murfreesboro
 Paulo Products Co.—
 Nashville
 Paulo Products Co.—
 St. Louis
 Penna Flame Industries
 Pennsylvania Metallurgical
 Peters Heat Treating Inc.
Pflafer-Maag Cutting Tools
 Phoenix Heat Treating Inc.
 Pitt-Tex Inc.
 Precision Heat Treating
 Progressive Steel Treating
 Racine Heat Treating Co.
 Richter Precision Inc.
 Roboduction Thermal
 Processing
 Rochester Steel Treating
 Rotation Products Corp.
 S.K.S. Heat Treating Inc.
 Scot Forge
 Shore Metal Technology
 Solar Atmospheres Inc.
 Sonee Heat Treating Corp.
 Southeastern Heat Treating
 Specialty Heat Treating
 Inc.—Athens
 Specialty Heat Treating
 Inc.—Elkhart
 Specialty Heat Treating
 Inc.—Grand Rapids
 Specialty Heat Treating
 Inc.—Holland
 Specialty Steel Treating—
 Farmington Hills
 Specialty Steel Treating—
 Fraser
 State Heat Treat Inc.
 Steel Treating, Inc.
 Steel Treating
 Sun Steel Treating
 Suncoast Heat Treating—
 Orlando
 Suncoast Heat Treating—
 Pompano Beach
 Suncoast Heat Treating—

Tampa
 Superior Metal Treating
 Syracuse Heat Treating
 T. N. Woodworth Inc.
 Therm Tech of Waukesha
 Thermal Metal Treating
 Thermal Treatment Center
 Thermo Inc.
 Thermo Electron Metal
 Treating Div.
 Thermo Treating Ltd.
 Tocco, Inc.
 TracTech
 Treat All Metals Inc.
 Trutec Industries
 Universal Heat Treating
 Vacu Braze
 Walker Heat Treating
 Washington Metallurgical
 Services
 Weiss Industries Inc.
 Westside Flame Hardening
 Wohler Corp.

VACUUM TREATING

Accurate Steel Treating
 Advanced Metallurgical
 Alliance Metal Treating
 Allread Products
 American Heat Treating
 Am. Met. Treating Inc.
 Beehive Heat Treating
 Benedict-Miller
 Bodycote-Hinderliter
 Braddock Metallurgical
 Alabama
 Burbank Steel Treating
 Century Sun Metal Treating
 Certified Metal Craft
 Certified Heat Treating
 Delavan Steel Treating
 Drever Heat Treating
 Dynamic Metal Treating
 East-Lind Heat Treat
 Elmira Heat Treating
Engineered Heat Treat, Inc.
 Erie Steel Treating Inc.
 Euclid Heat Treating
 Fenton Heat Treating
 Flame Metals Processing
 General Heat Treating
 Hanson-Balk Steel
 Treating
 Hauni Richmond Inc.
 Hinderliter — Dallas
 Hitech Metallurgical Co.
 Hi-Tech Steel Treating
 Horizon Steel Treating
 HTG-HiTech Aero
Hudapack — Elkhorn
 Industrial Metal Treating
 Industrial Steel Treating Inc.
 Ironbond Heat Treating
 Irwin Automation Inc.
 Jasco Heat Treating
 Kowalski Heat Treating
 Metal Treating Inc.
 Metal Treating & Research
 Metallurgical Inc.
 Metals Technology Corp.
 Modern Metal Processing
 National Metal Processing
 Nitro-Vac Heat Treating
 O & W Heat Treat Inc.
 Paulo Products Co. —
 Bessemer
 Paulo Products Co. —
 Kansas City
 Paulo Products Co. —
 Memphis
 Paulo Products Co. —
 Nashville
 Phoenix Heat Treating
 Precision Heat Treating
 Progressive Steel Treating
 Racine Heat Treating Co.
 Richter Precision Inc.
 Solar Atmospheres Inc.

Speciality Heat Treating
 —Grand Rapids
 Specialty Steel Treating
 — Farmington Hills
 Therm Tech of Waukesha
 Superior Metal Treating
 Syracuse Heat Treating
 Thermal Braze Inc.
 Universal Heat Treating

OTHER

Beehive Heat Treating —
 Neutral Salt Hardening
 Benedict-Miller —
 Nitemper
 Cincinnati Gear Co. —
 Electron Beam Hardening
 Cincinnati Steel Treating
 — Sub-Zero
 Contour Hardening —
 Metallurgical Services
 Delphi Engineering —
 Portable h.t. on site
 East-Lind Heat Treat —
 Air, Oil, Water Hardening
Engineered Heat Treat —
Neutral Salt Hardening
 Erie Steel Treating Inc. —
 Plug Quenching
 Flame Hardening of
 California — On-Site
 Work
 Fox Steel Treating —
 Select Hole Quenching
 Heat Treating Network —
 Heat Treating Training
 Hinderliter-Anaheim —
 Kool Kase "FNC"
 Hitech Metallurgical Co.
 — Welding
 IHS — Induction Heating
 Impact Strategies Inc. —
 Consulting & Lab Work
 Induction Services —
 Bonding Heat
 Inductoheat Inc. —
 Induction Heating
 Equipment
 Industrial Steel Treating
 Inc. — Magnetic Particle
 Inspection; Tensile
 Testing
 Ironbound Heat Treating
 — Lab Work

Irwin Automation Inc. —
 Salt Quenching
 Kowalski Heat Treating
 — High Pressure
 Vacuum, 20 Bar
 Metals Technology Corp.
 — Hyperannealing,
 Bright Hardening
 Michigan Induction Inc.
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Programmable Separation of Runout From Profile and Lead Inspection Data for Gear Teeth With Arbitrary Modifications

Xiaogen Su & Donald R. Houser

Abstract

A programmable algorithm is developed to separate out the effect of eccentricity (radial runout) from elemental gear inspection data, namely, profile and lead data. This algorithm can be coded in gear inspection software to detect the existence, the magnitude and the orientation of the eccentricity without making a separate runout check. A real example shows this algorithm produces good results.

Introduction

The effect of radial runout (or eccentricity) on the profile and lead deviations has been noticed for a long time. Gear engineers know that radial runout changes the slopes of the traces of profiles and leads. A normal gear inspection usually measures profiles and leads from three or more teeth, and the average is often taken to compensate for this effect. In 1993, Laskin *et al.* (Ref. 1) found the analytical equations which describe the interaction between these element measurements and the radial runout. The equations show the profile and lead traces of all teeth are segments of a sine curve if no profile and lead modifications are introduced. More recently, Laskin and Lawson (Ref. 2) developed the method to separate out the effect of runout from these elemental inspection data. They used linear or cubic fitting to get the slope of every elemental inspection curve. From the information given by the slopes, a sine curve is fit, and the effect of the runout represented by the sine curve is removed. The method does not apply to the case where arbitrary modifications exist, either on the profile or on the lead. However, the method works for partly modified profiles and leads, but the validity of the results is compromised because the fitting processes use only that portion of the profile (or the lead) that is free of modifications. If considerable roughness exists on the tooth surfaces, the curve fitting of these short trace segments is not very reliable.

This article presents a method that applies to any kind of modification of either profiles or leads. More importantly, only one fitting process that takes into consideration all the inspection data is used. The process is non-iterative, and a good result can be expected. This method only applies to gears with eccentricity (radial runout). It does not apply to egg-shaped gears or gears with considerable wobble (axial runout).

Extraction of Profile Modification from the Inspection Data

We start our discussion with profile inspection data. The same procedure applies to the lead inspection data. Referring to Fig. 1, the teeth and the base circles are plotted. Eq. 1 in Laskin *et al.* is cited here, and their symbols are used as well. The equation says:

$$M_{\phi_i} = M_i M = e \sin(\angle EO_m N) = e \sin[(\theta_{e1M} - \alpha_{pB_i}) + (k-1)\tau + \epsilon_M] \quad (1)$$

where $\theta_{e1M}(\angle EO_m H)$ is the angle from the eccentricity direction to the center of Tooth 1. $\alpha_{pB_i}(\angle B_o O_m H)$ is the angle extended by the half base tooth thickness. $\tau(2\pi/\text{teeth number})$ is the tooth pitch angle. $\epsilon_M(\angle BO_m N)$ is the roll angle at the measurement point. e is the eccentricity.

If no profile modification exists, using Eq. 1 and Fig. 2, the profile trace f_p on each tooth is a segment of a sine curve having amplitude e . If an arbitrary profile modification $m_p(\epsilon_M)$ is applied, the measured profile trace ($f_p + m_p$) is the sinusoidal segment superimposed by the profile modification.

In real measurements, the inspection data may be presented separately or may be overlaid together and supplemented with a K chart. The final inspection data v_{pi} is ($f_p + m_p$) shifted by D (referring to Fig. 2b, c).

$$v_{pi} = f_{pi} + m_p(\epsilon_M) - D_i \quad i = 1, 2, \dots, n. \quad (2)$$

n is the total number of measured teeth. $D_i(1, 2, \dots, n)$ are constants representing the shifts of profile traces, and they are unknown. Usually, three or four teeth are inspected, and n is either 3 or 4. From Eq. 1, the sinusoidal segment for the i^{th} measured profile trace is:

$$f_{pi} = e \sin[(\theta_{e1M} - \alpha_{pB_i}) + (k_i - 1)\tau + \epsilon_M] \quad i = 1, 2, \dots, n. \quad (3)$$

$k_i(i = 1, 2, \dots, n)$ are the tooth numbers. If we set:

$$\phi_i = (k_i - 1)\tau \quad i = 1, 2, \dots, n. \quad (4)$$

$$\epsilon = (\theta_{e1M} - \alpha_{pB_i}) + \epsilon_M \quad (5)$$

These substitutions simplify Eq. 3 to:

$$f_{pi} = e \sin(\varepsilon + \phi_i) \quad i = 1, 2, \dots, n. \quad (6)$$

Substituting Eq. 6 into Eq. 2 gives a new equation for the shifted profile traces.

$$v_{pi} = e \sin(\varepsilon + \phi_i) + m_p(\varepsilon_M) - D_i \quad i = 1, 2, \dots, n. \quad (7)$$

Expanding and rewriting Eq. 7, we get:

$$e \sin(\varepsilon) \cos(\phi_i) + e \cos(\varepsilon) \sin(\phi_i) + m_p(\varepsilon_M) = v_{pi} + D_i \quad i = 1, 2, \dots, n. \quad (8)$$

The profile modification m_p can be solved through any combination of three out of these n equations. If i_1^{th} , i_2^{th} , i_3^{th} equations are used, we have:

$$\left. \begin{aligned} e \sin(\varepsilon) \cos(\phi_{i_1}) + e \cos(\varepsilon) \sin(\phi_{i_1}) + m_p(\varepsilon_M) &= v_{pi_1} + D_{i_1} \\ e \sin(\varepsilon) \cos(\phi_{i_2}) + e \cos(\varepsilon) \sin(\phi_{i_2}) + m_p(\varepsilon_M) &= v_{pi_2} + D_{i_2} \\ e \sin(\varepsilon) \cos(\phi_{i_3}) + e \cos(\varepsilon) \sin(\phi_{i_3}) + m_p(\varepsilon_M) &= v_{pi_3} + D_{i_3} \end{aligned} \right\} \quad (9)$$

Taking $e \sin(\varepsilon)$, $e \cos(\varepsilon)$ and $m_p(\varepsilon_M)$ as three unknowns, the mean profile modification, $m_p(\varepsilon_M)$, can be solved.

$$m_p = \frac{\begin{vmatrix} \cos(\phi_{i_1}) & \sin(\phi_{i_1}) & v_{pi_1} \\ \cos(\phi_{i_2}) & \sin(\phi_{i_2}) & v_{pi_2} \\ \cos(\phi_{i_3}) & \sin(\phi_{i_3}) & v_{pi_3} \end{vmatrix} + \begin{vmatrix} \cos(\phi_{i_1}) & \sin(\phi_{i_1}) & D_{i_1} \\ \cos(\phi_{i_2}) & \sin(\phi_{i_2}) & D_{i_2} \\ \cos(\phi_{i_3}) & \sin(\phi_{i_3}) & D_{i_3} \end{vmatrix}}{\begin{vmatrix} \cos(\phi_{i_1}) & \sin(\phi_{i_1}) & 1 \\ \cos(\phi_{i_2}) & \sin(\phi_{i_2}) & 1 \\ \cos(\phi_{i_3}) & \sin(\phi_{i_3}) & 1 \end{vmatrix}} \quad (10)$$

This solution depends on the reference of each profile which dictates the applied shifts, D_i ($i = 1, 2, \dots, n$). These shifts are unknown at this stage. But Eq. 10 reveals that the D_i s only shift m_p upwards or downwards and do not change m_p 's shape. Setting D_i to zero gives rise to:

$$m_p = \frac{\begin{vmatrix} \cos(\phi_{i_1}) & \sin(\phi_{i_1}) & v_{pi_1} \\ \cos(\phi_{i_2}) & \sin(\phi_{i_2}) & v_{pi_2} \\ \cos(\phi_{i_3}) & \sin(\phi_{i_3}) & v_{pi_3} \end{vmatrix}}{\begin{vmatrix} \cos(\phi_{i_1}) & \sin(\phi_{i_1}) & 1 \\ \cos(\phi_{i_2}) & \sin(\phi_{i_2}) & 1 \\ \cos(\phi_{i_3}) & \sin(\phi_{i_3}) & 1 \end{vmatrix}} \quad (11)$$

Normalize m_p by making its maximum zero if necessary:

$$m_p - \max(m_p) \Rightarrow m_p$$

If we want to make use of all of the inspection data to get a better result, all different combinations (i_1, i_2, i_3) out of (i_1, i_2, \dots, i_n) can be used separately and the m_p s found can be averaged. In other words, if four profile traces are available, there are four combinations of these traces that could be used to get four mean profile traces that can be further averaged to give a global average.

The extracted profile modification m_p not only includes intended profile modifications, such as tip and root relief, but also includes some systematic profile error which shows the same tendency on each gear tooth. An example of a systematic profile error could be a pressure angle error (Ref. 4).

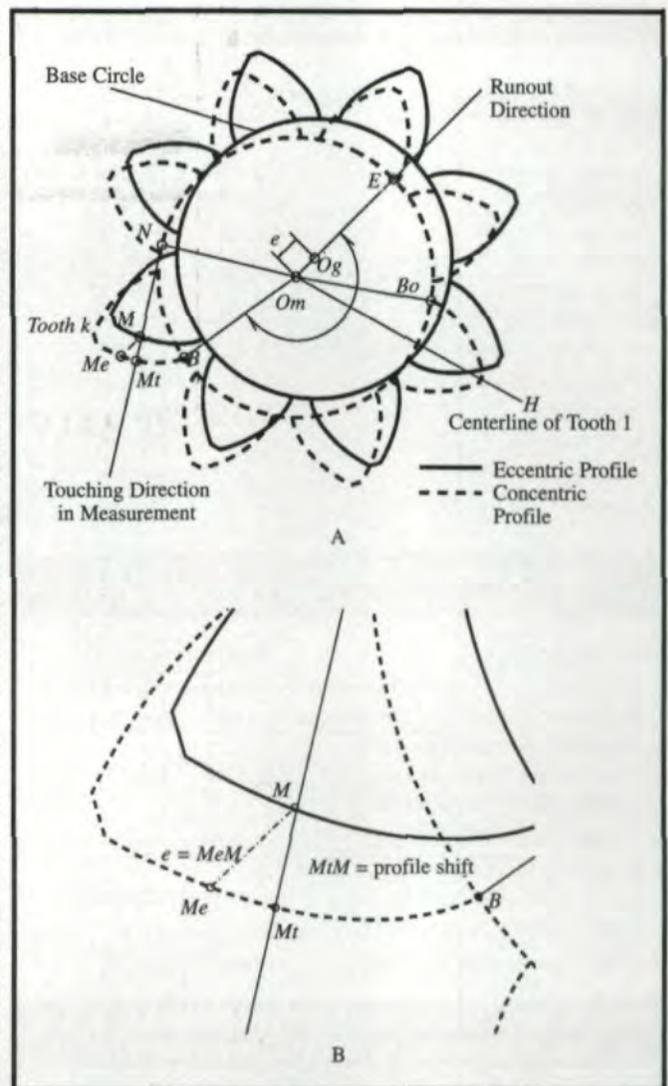


Fig. 1 - Profile Measurement on Eccentric Gear (left flank).

If the inspected teeth are exactly (in most cases, approximately) evenly spaced around the gear, the profile modification can be calculated simply by averaging the profile deviations measured on all inspected teeth. This practice is well known, and the proof is given here. Summarize Eq. 7 over $i = 1, 2, \dots, n$.

$$\sum_{i=1}^n v_{pi} = e \sum_{i=1}^n \sin(\varepsilon + \phi_i) + n m_p(\varepsilon_M) - \sum_{i=1}^n D_i$$

When the measured teeth are evenly distributed, $\sum_{i=1}^n \sin(\varepsilon + \phi_i)$ tends to disappear. Setting D_i to be zero shows that the average profile trace $m_p(\varepsilon_M)$ is a simple average of the individual profile traces.

$$m_p(\varepsilon_M) = \frac{\sum_{i=1}^n v_{pi}}{n} \quad (12)$$

Separation of Runout from Profile Inspection Data

After the modification is found, it can be removed from the individual profile traces, v_{pi} ($i = 1, 2, \dots, n$). The residuals, $v_{pi} - m_p(\varepsilon_M)$ ($i = 1, 2, \dots, n$), caused by a pure eccentricity are the segments of a sine curve. A best fit is made to find the sine curve (both amplitude and phase) as shown in Eqs. 13-24.

Introducing new variable ε_1 :

$$\varepsilon_1 = (\theta_{e1M} - \alpha_{pBt}) \quad (13)$$

TABLE 1 — GEAR GEOMETRY

Parameter	Value	Unit
No. of Teeth	25	
Face Width	31.75	mm
Normal Pressure Angle	23.4541	degree
Helix Angle	21.5	degree
Normal Module	2.9541	mm
Normal Tooth Thickness	4.53	mm
Pitch Diameter	79.37	mm
Base Diameter	71.94	mm
Transverse Pressure Angle ϕ_{Mt}	25	degree
Transverse Tooth Thickness	4.87	mm
Helix Lead	633.05	mm
Helix Angle at Base Dia.	19.65	degree
Angle α_{pBt} in Eq. 1	5.23	degree
Angle α_{pMt} in Eq. 27	3.52	degree

TABLE 2 — BEST FIT RESULTS FROM PROFILE TRACES WITH ARTIFICIAL ECCENTRICITY

Parameter	Value	Unit
Introduced Eccentricity Magnitude	0.0718	mm
Introduced Eccentricity Orientation	-118.77	degree
Magnitude e Found Out From Traces of Left Flanks	0.0693	mm
Orientation θ_{e1M} Found Out From Traces of Left Flanks	-120.31	degree
Magnitude e Found Out From Traces of Right Flanks	0.0746	mm
Orientation θ_{e1M} Found Out From Traces of Right Flanks	-122.48	degree

TABLE 3 — BEST FIT RESULTS FROM LEAD TRACES WITH ARTIFICIAL ECCENTRICITY

Parameter	Value	Unit
Introduced Eccentricity Magnitude	0.0718	mm
Introduced Eccentricity Orientation	-127.8	degree
Magnitude e Found Out From Traces of Left Flanks	0.0588	mm
Orientation θ_{e1} Found Out From Traces of Left Flanks	128.66	degree
Magnitude e Found Out From Traces of Right Flanks	0.0462	mm
Orientation θ_{e1} Found Out From Traces of Right Flanks	128.24	degree

TABLE 4 — BEST FIT RESULTS FROM PROFILE TRACES WITHOUT ARTIFICIAL ECCENTRICITY

Parameter	Value	Unit
Eccentricity Magnitude Detected by Runout Check	0.0105	mm
Eccentricity Orientation Detected by Runout Check	-164.2	degree
Magnitude e Found Out From Traces of Left Flanks	0.0101	mm
Orientation θ_{e1M} Found Out From Traces of Left Flanks	-174.34	degree
Magnitude e Found Out From Traces of Right Flanks	0.01014	mm
Orientation θ_{e1M} Found Out From Traces of Right Flanks	-146.5	degree

$$\epsilon = \epsilon_1 + \epsilon_M \quad (14)$$

Eq. 7 becomes:

$$v_{pi} = e \sin(\epsilon_1 + \epsilon_M + \phi_i) + m_p(\epsilon_M) - D_i \quad i = 1, 2, \dots, n. \quad (15)$$

We have $(n + 2)$ unknowns, $D_i (i = 1, 2, \dots, n)$, e and ϵ_1 . Eqs. 15 are linearized by introducing:

$$D_{n+1} = e \sin(\epsilon_1) \quad (16)$$

$$D_{n+2} = e \cos(\epsilon_1) \quad (17)$$

Then,

$$f_i(\epsilon_M) = -D_i + D_{n+1} \cos(\epsilon_M + \phi_i) + D_{n+2} \sin(\epsilon_M + \phi_i) + m_p(\epsilon_M) - v_{pi} = 0 \quad i = 1, 2, \dots, n. \quad (18)$$

If p points are measured on each flank, then totally $p \times n$ equations exist. We will solve all $p \times n$ equations by minimizing F , where

$$F = \sum_{j=1}^p \left(\sum_{i=1}^n f_i^2(\epsilon_{Mj}) \right) \quad (19)$$

$\epsilon_{Mj} (j = 1, 2, \dots, p)$ are the roll angles corresponding to the measured points. Setting $\partial F / \partial D_k (k = 1, \dots, n + 2)$ to zero gives $(n + 2)$

$$\partial D_k$$

linear equations:

$$[A]_{(n+2) \times (n+2)} [D]_{(n+2) \times 1} = [B]_{(n+2) \times 1} \quad (20)$$

where,

$$a_{ij} = \begin{cases} p & i = j \\ 0 & i \neq j \end{cases} \quad i, j = 1, 2, \dots, n.$$

$$a_{n+1,j} = a_{i,n+1} = -\sum_{j=1}^p \cos(\epsilon_{Mj} + \phi_i) \quad i = 1, 2, \dots, n$$

$$a_{n+2,j} = a_{i,n+2} = -\sum_{j=1}^p \sin(\epsilon_{Mj} + \phi_i) \quad i = 1, 2, \dots, n$$

$$a_{n+1,n+1} = \sum_{j=1}^p \sum_{i=1}^n \cos^2(\epsilon_{Mj} + \phi_i)$$

$$a_{n+1,n+2} = a_{n+2,n+1} = \sum_{j=1}^p \sum_{i=1}^n \sin(\epsilon_{Mj} + \phi_i) \cos(\epsilon_{Mj} + \phi_i)$$

$$a_{n+2,n+2} = \sum_{j=1}^p \sum_{i=1}^n \sin^2(\epsilon_{Mj} + \phi_i)$$

$$b_i = -\sum_{j=1}^p [v_{pj}(j) - m(\epsilon_{Mj})] \quad i = 1, 2, \dots, n$$

$$b_{n+1} = \sum_{j=1}^p \sum_{i=1}^n [v_{pj}(j) - m(\epsilon_{Mj})] \cos(\epsilon_{Mj} + \phi_i)$$

$$b_{n+2} = \sum_{j=1}^p \sum_{i=1}^n [v_{pj}(j) - m(\epsilon_{Mj})] \sin(\epsilon_{Mj} + \phi_i)$$

The solution is:

$$[D] = [A]^{-1} [B] \quad (21)$$

$$\text{eccentricity magnitude } e = \sqrt{D_{n+1}^2 + D_{n+2}^2} \quad (22)$$

$$\epsilon_1 = \arctan \left(\frac{D_{n+1}}{D_{n+2}} \right) \quad (23)$$

$$\text{eccentricity location } \theta_{e1M} = \epsilon_1 + \alpha_{pBt} \quad (24)$$

The system of Eq. 20 can be very efficiently solved using the Gaussian Elimination Method (Ref. 3). It is not necessary to invert the coefficient matrix A . The profile deviations after the removal of the effect of runout are:

$$\bar{v}_{pi} = v_{pi} + D_i - e \sin(\varepsilon_i + \varepsilon_M + \phi_i) \quad i = 1, 2, \dots, n. \quad (25)$$

For the right flank, Eq. 4 in Laskin *et al.* (Ref. 1) says:

$$M_{\phi R} = e \sin[-(\theta_{e1M} + \alpha_{pBt}) - (k-1)\tau + \varepsilon_M] \quad (26)$$

Similar steps can be followed to obtain the magnitude and orientation of the eccentricity from the profile traces of the right flanks.

Separation of Runout from Lead Inspection Data

For spur gears, runout does not affect the lead inspection data. The separation is applicable only for helical gears. Referring to Fig. 6 in Laskin *et al.* (Ref. 1), Eq. (13) of the sinusoidal curve of lead traces says:

$$M\psi_L = e \cos(\psi_b) \sin[\theta_{e1} + (\phi_{Mt} - \alpha_{pMt}) + (k-1)\tau + x_M \frac{2\pi}{L}] \quad (27)$$

where ψ_b is the base helix angle. θ_{e1} is the angle from the eccentricity direction to the center of tooth 1 at the top face. ϕ_{Mt} is the transverse pressure angle at the measurement diameter. α_{pMt} is the angle extended by the half tooth thickness at the measurement diameter. L is the helix lead (negative for left handed gears). x_M is the axial distance from the top face to the measurement point.

Eq. 27 has the same format as Eq. 1. We first define:

$$e_i = e \cos(\psi_b) \quad (28)$$

$$\varepsilon_i = \theta_{e1} + (\phi_{Mt} - \alpha_{pMt}) \quad (29)$$

$$\varepsilon_M = x_M \frac{2\pi}{L} \quad (30)$$

$$e = \varepsilon_i + \varepsilon_M \quad (31)$$

From Eqs. 27-31, the lead trace f_i due to the eccentricity can be expressed as:

$$f_{ii} = e_i \sin(\varepsilon + \phi_i) \quad i = 1, 2, \dots, n. \quad (32)$$

If an arbitrary lead modification m_i is applied, the measured lead deviations can be written as:

$$v_{ii} = e_i \sin(\varepsilon + \phi_i) + m_i(\varepsilon_M) - D_i \quad i = 1, 2, \dots, n. \quad (33)$$

The mean lead modification m_i can be expressed by the ratio of two determinants.

$$m_i = - \frac{\begin{vmatrix} \cos(\phi_{i1}) \sin(\phi_{i1}) & v_{ii1} \\ \cos(\phi_{i2}) \sin(\phi_{i2}) & v_{ii2} \\ \cos(\phi_{i3}) \sin(\phi_{i3}) & v_{ii3} \end{vmatrix}}{\begin{vmatrix} \cos(\phi_{i1}) \sin(\phi_{i1}) & 1 \\ \cos(\phi_{i2}) \sin(\phi_{i2}) & 1 \\ \cos(\phi_{i3}) \sin(\phi_{i3}) & 1 \end{vmatrix}} \quad (34)$$

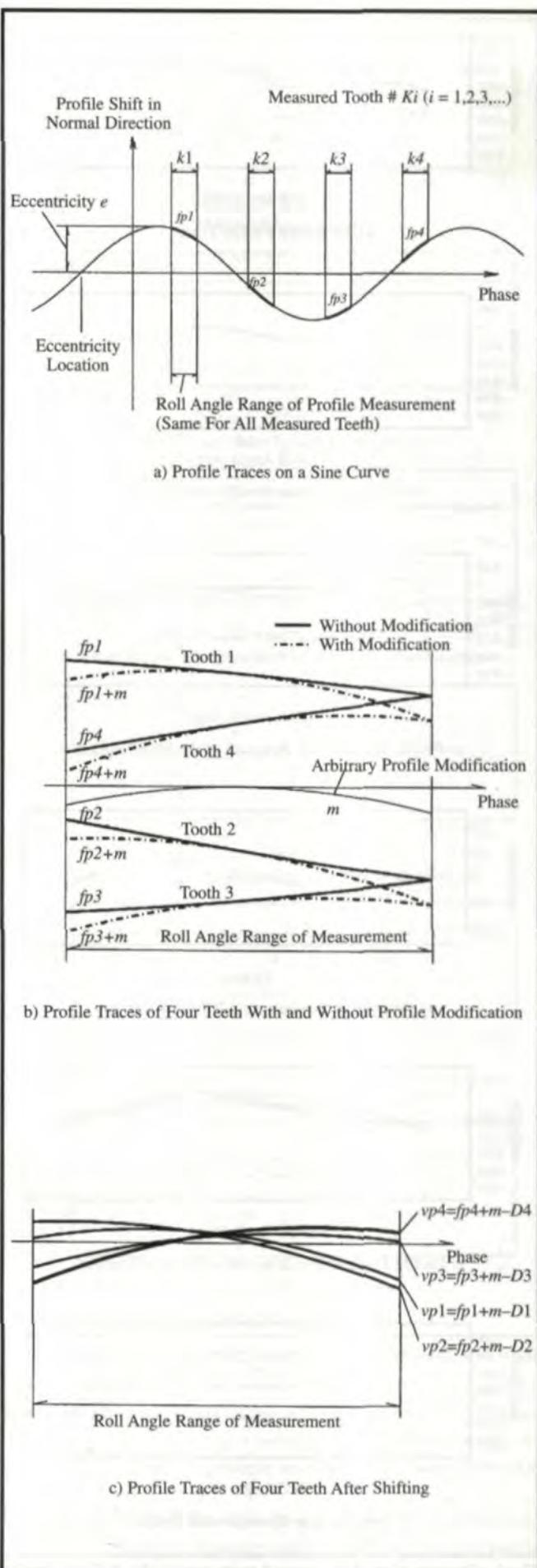


Fig. 2 - Profile Measurements with Arbitrary Modification.

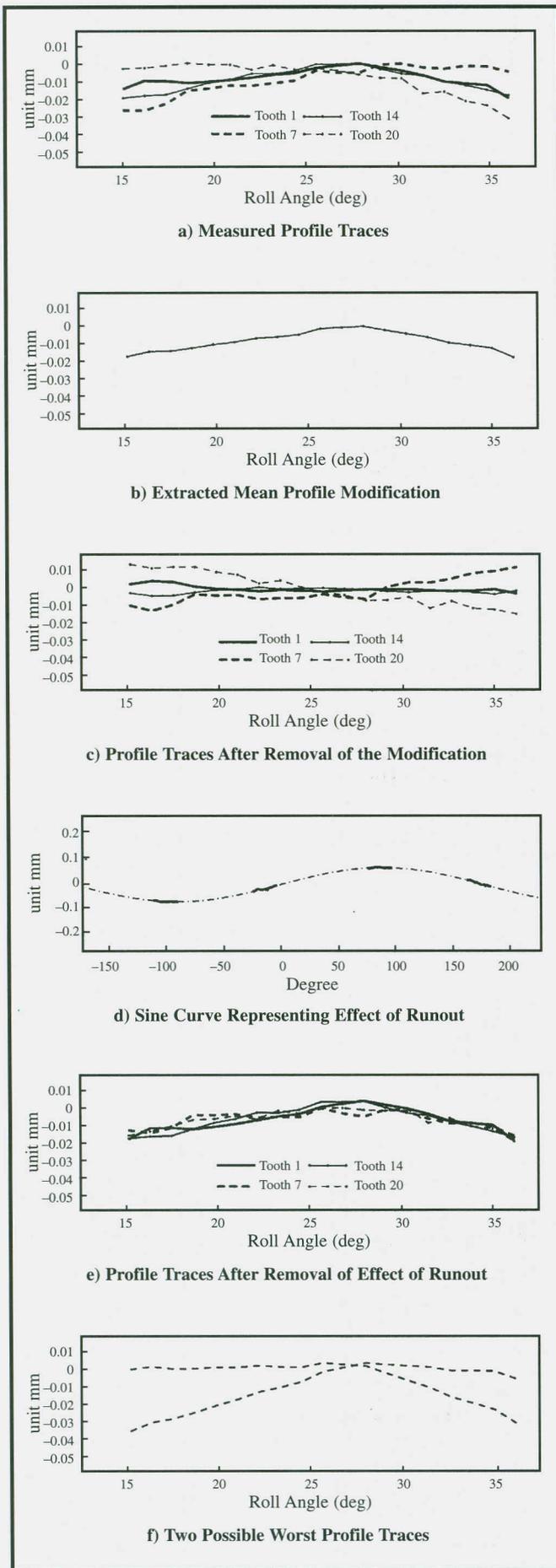


Fig. 3 - Example Gear Inspection: 4 teeth inspected; left flank; profile trace.

where ϕ_i , D_i ($i = 1, 2, \dots, n$) have the same meanings as in Eq. 10.

The extracted mean lead modification, m_p , not only includes the intended lead modification, such as crowning, but also includes the systematic lead error which shows the same tendency on each gear tooth. An example of such a systematic lead error could be the alignment error (Ref. 4).

Similarly, if the inspected teeth are exactly (in most cases, approximately) evenly spaced around the gear, the mean lead modification can be calculated simply by averaging the individual lead traces measured on all inspected teeth.

Using Eqs. 31 and 33:

$$v_{ii} = e_i \sin(\epsilon_i + \epsilon_M + \phi_i) + m_i(\epsilon_M) - D_i \quad i = 1, 2, \dots, n. \quad (35)$$

Eq. 35 has the same format as Eq. 15. Solution of Eqs. 19-21 could be used, but v_{ii} ($i = 1, 2, \dots, n$) should be used instead of v_{pi} ($i = 1, 2, \dots, n$), while b_k ($k = 1, 2, \dots, n + 2$) in Eq. 20 are calculated. e_i and ϵ_i are obtained,

$$e_i = \sqrt{D_{n+1}^2 + D_{n+2}^2} \quad (36)$$

$$\epsilon_i = \arctan\left(\frac{D_{n+1}}{D_{n+2}}\right) \quad (37)$$

The amplitude and the phase of the sine curve from the eccentricity are:

$$\text{eccentricity magnitude} \quad e = e_i / \cos(\psi_b) \quad (38)$$

$$\text{eccentricity location} \quad \theta_{e1} = \epsilon_i - (\phi_{Mi} - \alpha_{pMi}) \quad (39)$$

Example Inspection of A Real Helical Gear

A Boeing NASA helical gear was inspected to verify the developed algorithm. The geometry of the gear is listed in Table 1. Originally the gear had very little eccentricity, so an artificial eccentricity of 0.0718 mm was created on the CMM (Coordinate Measurement Machine). Four teeth were inspected by a universal CMM. The CMM has a resolution of one micron, and an accuracy of about three microns. According to the specification, a circular profile modification was applied from the form diameter to the outside diameter. No lead modification was required. The profile inspection was performed at the middle of the face width, and the lead inspection was performed at the pitch diameter.

Fig. 3 shows the profile inspection data. Only the traces of the left flanks are given here. The original deviation curves are drawn in Fig. 3a. The extracted mean profile modification is presented in Fig. 3b. The profile traces after the removal of the modification are shown in Fig. 3c. The fitted sine curve is shown in Fig. 3d. The profile traces after the removal of the effect of runout are shown in Fig. 3e. The maximum and minimum slopes of the fitted sine curve is its amplitude e and $-e$ respectively. If these slopes are added to the mean profile trace m_p , we can get the two possible worst profile traces that could be obtained in profile inspection. These two possible worst profile traces are shown in Fig. 3f. The results of the best fit are listed in Table 2.

Fig. 4 shows the lead inspection data. No lead modification appears to exist on the gear. The results are presented in Fig. 4a-4f and Table 3 respectively. Note that the orientation angles of the introduced eccentricity are different in Table 2 and Table 3 because the first one is relative to the centerline of Tooth 1 at the middle of the face width where profile measurements were performed, and the second one is relative to the centerline of Tooth 1 at the top face as stated in Eq. 27.

Conclusions and Comments

A new programmable algorithm is developed to separate out the effect of runout from the profile and lead inspection data. The method presented here is more convenient, more reliable and easier to program than that proposed by Laskin and Lawson (Ref. 2). Because the pure radial runout does not contribute to the noise and vibration of transmissions as much as the real profile and lead deviations (Ref. 2), the separation of the effect of runout from profile and lead inspection data is significant.

In the Gear Dynamics and Gear Noise Research Laboratory at The Ohio State University, a CMM is often used to inspect gears. The effect of runout was removed using a two-step inspection, where runout inspection was performed, a new center was determined; profile and lead inspections were performed based on the new center. This approach takes more time. The approach presented in this paper gives us an alternative way to save inspection time.

In our example, the fitting process from the profile inspection data produces a better result than the fitting process from the lead inspection data. It is expected because a regular gear with non-negligible wobble (axial runout) is used instead of a test gear of very good accuracy as in Laskin and Lawson (Ref.2). In most cases, the profile traces are preferred in the separation of the effect of runout, particularly when the face width of a gear is relatively small compared with its helix lead. In this case, the lead traces are tiny segments (Fig. 4d) of the sine curve, and this makes the fitting process less reliable. Compared with Fig. 3d, the profile traces are longer than the lead traces for our test gear (1.5:1). The use of lead inspection data to separate out the effect of runout should be avoided unless the helix angle and/or the face width are really large.

The same gear was inspected once more. This time no artificial eccentricity was introduced. Its actual eccentricity was detected through a separate runout check. The eccentricity was also calculated from the profile traces. The results were listed in Table 4.

The separation of eccentricity based on the profile traces was very successful, but the separation of eccentricity based on the lead traces failed in this case. The reason is the gear has wobble (axial runout) comparable with the eccentricity (radial runout) that violates the wobble-free assumption from which Eq. 27 was derived.

A more ambitious approach would be to use all the inspection data from both flanks to make one sine curve fitting. Take the profile inspection data as example. The sine curves represented by Eq. 26 (for right flank) and Eq. 1 (for left flank) can be viewed as the same sine curve (the phase difference can be calculated). We could then fit the profile traces of both left and right flanks to one single sine curve. This approach has not been tried yet by the authors. 

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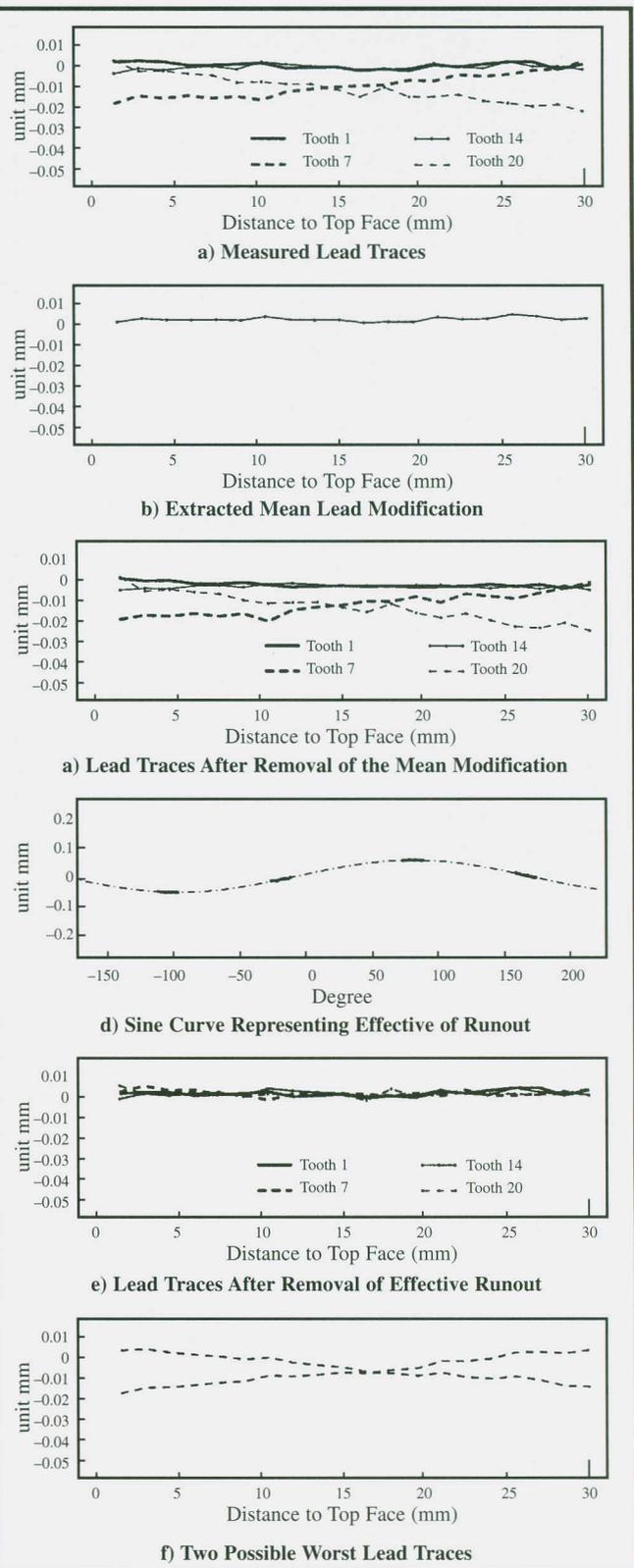


Fig. 4 - Example Gear Inspection: 4 teeth inspected; left flank; lead trace.

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CIRCLE 130

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Fahrenheit 451: Gear Up For Induction Hardening

Daniel J. Williams & Ellen F. Kominars

So, you've been assigned the task to buy an induction heating system for heat treating: It's an intimidating, but by no means impossible, assignment. With the help of the information in this article, you should be able to develop common ground with your supplier and have the tools to work with him or her to get the right machine for your jobs.

Begin your task by asking questions, lots of them. Your induction heating equipment manufacturer possesses a wealth of information and experience that he or she is only too willing to share.

What Is Induction Heating?

Induction is a noncontact electromagnetic process where metal pieces to be heat treated are passed through a magnetic field that emanates about a copper induction coil. The coil is fed current at a specified frequency and power level to cause the heating. Most of the heating is due to currents induced into the part. Some heating is due to hysteresis. The induction method requires no warm-up, is fast, predictable, clean and like resistance heating, is an in-line process, eliminating the need to store inventory between operations. Likewise, the induction method is a noncontact process and can be readily used with atmospheres to eliminate or reduce scale.

When Should a Gear Manufacturer Consider Induction?

Most gears must be heat treated to maximize strength and minimize wear. Inexpensive, medium carbon steels are easily machined and hardened and are compatible with induction heat treat processes.

Warning: all cutting, forming and hobbing should be done prior to induction hardening. Whenever possible, heat treating should be the final step.

The two methods used to heat treat gears are in furnaces or by induction.

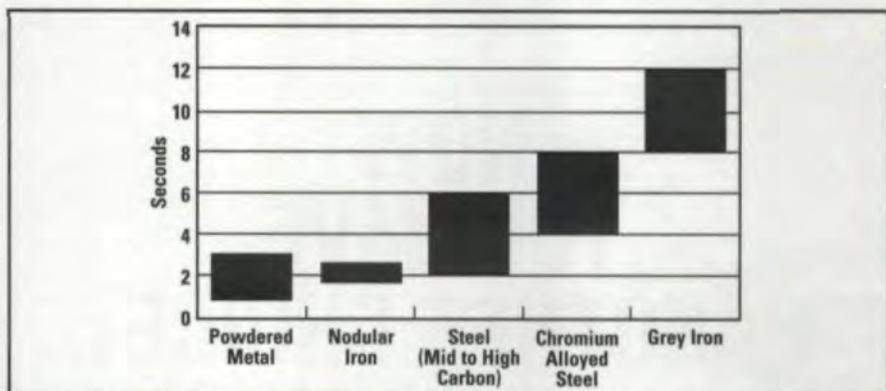


Fig. 1 — Nominal heat times to get carbon into solution for induction hardening at 10 kW/in² nominal power density.

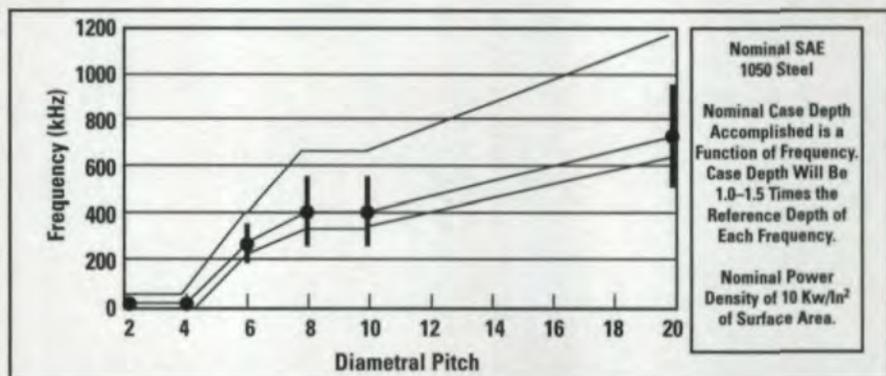


Fig. 2 — Proper frequency selection is needed to accomplish even heating across the tooth face. Selecting a frequency that is too low will only heat the tooth root as a result of field cancellation at the tips. Too high a frequency will overheat the gear tooth tips and not heat into the roots sufficiently.

Table 1 — XYZ Gear Part #945

Variables	Specifications
Part Measurements	4" x 1/2" face width, 6 D.P.
Production Rate	45,000 pieces/mo.
Part Material	SAE-5135
Case Depth	0.15-0.30 mm below root
Hardness Required After Heating	Rc 55 at 1/2 depth

Table 2 — Estimated Cycle Time (in seconds) = 20.0 180 parts/hr.

Unload/Load Machine	7.0
Initiate Cycle	1.0
Towers Raise	2.0
Heat On	3.0
Quench Gear	5.0
Lower Tower	2.0
Total Cycle Time	20.0
Parts Per Hour	180.0

Induction heating is often the method of choice for a number of reasons.

1. Because of their size and heat output, furnaces are often located in remote dedicated areas of the plant away from the production line. Induction lends itself to synchronous, in-line, cell-type manufacturing. The inductor can be mounted on the line, in several places if necessary, for uninterrupted flow.

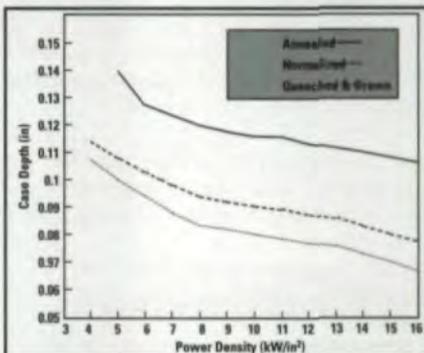


Fig. 3 — Effect of prior microstructure on case depth.

2. Fewer processes are needed with induction. Stop-off paints and copper plating operations are entirely eliminated as selective areas of the gear can be hardened.

3. While furnaces require batches of product to heat, one gear at a time can be processed with induction. Individual parts are accepted or rejected based on the correct process parameters being applied.

4. Induction equipment does not produce emissions.

5. Induction equipment is more efficient than furnaces, as only the area of the part to be hardened is heated (opposed to the entire part). Ambient air is not heated. As the induction unit is idle about 75% of the time, much less energy is consumed.

6. Gas furnaces need to be preheated; induction machinery does not.

7. Induction heating causes minimal distortion of gears.

What Does Your Induction Heating Machinery Supplier Need To Know?

Your potential short-, medium- and long-term applications. Mention all of these to your supplier even if they are not confirmed. Induction equipment can process different types of gears (with retooling); however, the supplier must know your needs beforehand.

Measurements of the gear(s) to be heat treated. Drawings and process sheets are very helpful. Your induction equipment supplier will study your gear prints and use your specifications to determine process parameters for the application.

Production rates. Determine how many parts need to be produced (by day, week or month). Specify the number of shifts the plant runs per day. From this data, your induction heat supplier can determine how many pieces need to be processed per machine cycle and calculate the power supply needed to meet this rate. The best information to have for your supplier is the total gross hourly production rate required of the equipment.

Part material. Carbon content, alloying elements and prior microstructure will affect the amount of power and time required to heat the gear. Gears with lower carbon content (below 0.2%) can undergo carburization prior to induction heating to speed up the heating rate in applications involving hardening.

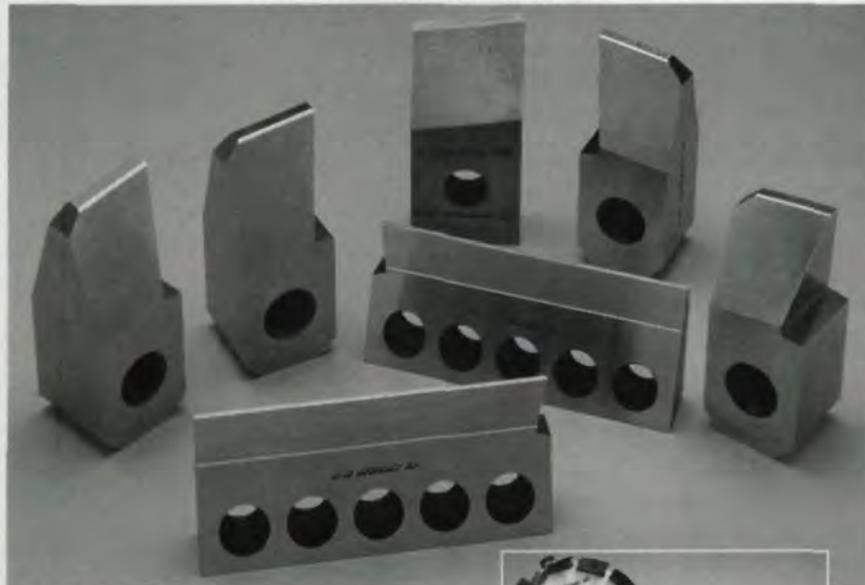
Fig. 1 shows approximate heat times for various types of metals. Of course, actual times will vary based on the diameter, thickness and area of the part to be heated.

Case depth (depth of heating). Frequency selection is very important to obtain specified results. Too low a frequency will leave the tooth tips unheated. On the other hand, heating with too high a frequency will not heat the root area, but it will overheat the tips. There is a direct correlation between diametral pitch and frequency.

Frequency determination starts with carefully evaluating the desired or specified pattern. Take special note of these details: Is through-hardening of the tooth tip desired, or is the pattern profiled along the face of the gear? Is hardness required in the root? If so, to what depth?

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Hardness required after heating. Hardness is dependent on material and is generally specified by the buyer. Carbon content, alloying elements and prior microstructure all affect hardness.

Application needed. A variety of applications can be handled by induction. Your equipment supplier will need to know which ones you will be using. Among those possible with induction heating are

- Surface hardening. Heating the surface of a component above transformation temperature, then rapidly quenching to create a hardened case on the surface.
- Through-hardening. Heating the entire workpiece above transformation temperature, then rapidly quenching to harden the part from surface to core.
- Tempering or stress relieving. Heating to a low temperature (120°–600°C) and allowing the heat to soak into the piece to relieve residual stress and reduce surface hardness to prevent cracking.
- Normalizing. Heating above transformation temperature and allowing piece to air cool.
- Annealing. Heating above transformation temperature and using controlled cooling.

What Will Your Induction Heat Machinery Supplier Determine?

A typical induction heat treat application is governed by the following equipment process parameters: Heat time, power level, power frequency, quench flow part position/rotation, and quench concentration. Your equipment supplier will need the range of these settings used in your applications—specifically:

1. *Cycle Time.* The induction heat treat process comprises the following primary elements:

Load/unload	6–10	seconds
Index in/out of coil	2–4	seconds
Heat	1–10	seconds (material dependent)
Delay to quench	0–2	seconds
Quench	2–10	seconds
TOTAL	11–36	seconds*

*If tempering is needed, add six to eight seconds.

Actual time will be based on production rates, part material, power supply, etc. (See Fig. 2.)

2. *Power level.* Power level is a function of surface area:

$$\text{Surface area} = \pi dh \times 2 \text{ (for gears)}$$

For example, if a gear measures 4" wide by 1/2" high,

$$\begin{aligned} \text{Surface area} &= \\ 3.14 \times 4 \times 1/2 \times 2 &= \\ 12.5" \times 10 &= 125 \text{ kW.} \end{aligned}$$

(The actual formula for determining definitive gear surface is more complex than this, but for the purposes of this arti-

cle, we are using a simplified version.)

In some cases, the specific heat of the material, along with the weight of material to be processed and temperature to be reached, is used to determine the power supply size. (See Fig. 3.)

3. *Power frequency.* Based on case depth, the required level of hardening depth is calculated. Frequency is a function of case depth. The higher the frequency, the shallower the case depth. If



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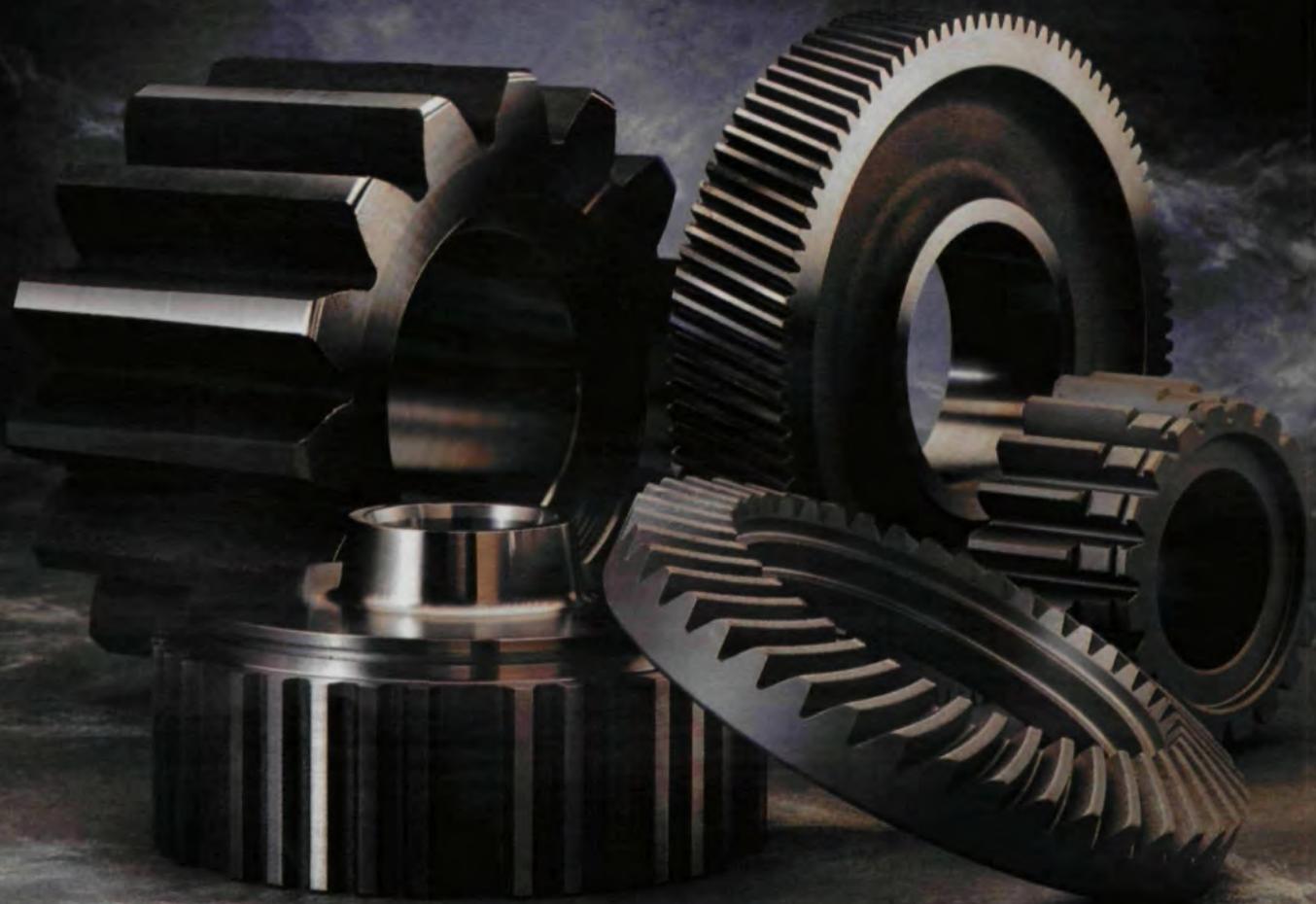
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the frequency is too low, the piece does not get heated properly (Fig. 2).

4. *Part position/rotation.* Based on production volume and mix, budget requirements, plant standards and other information, the supplier will suggest ways to best meet production with manual or automated loading. Among other factors to consider are these: Manual loading is less expensive, but automation is more dependable.

5. *Quench flow.* This is critical only to hardening applications. Heat must be extracted very rapidly and precisely from the steel. The rate of heat extraction is largely a function of quench flow.

6. *Quench concentration and filtration method.* Quenchants are application specific. Water, polymer-water, soluble oil, salt water oil and even lead can be selected as quench alternatives. A few applications, such as low-hardenability materials, are best suited for a straight water quench. Polymer quenchant manufacturers should be consulted for each application to assure compatibility with other fluids that may be introduced.

Filtration of quench is necessary to assure process consistency and extend the useful life of the quenchant. Particles in the quenchant can block the small holes on quench barrel assemblies. Quench hole size is considered with selecting strainers and/or filters on quench water systems. Strainer hole size must be smaller than the quench hole size to prevent blockages.

Other less critical factors to be considered include quench temperature and quench time.

Additional Information

The cost of induction heat treating equipment can vary from \$100,000 to \$500,000, depending on production rate. The average price is \$250,000. If XYZ Gear were to manufacture 200,000 gears a year over five years (or 1,000,000 gears), the cost per gear would be 25 cents.

When purchasing induction heat treating equipment, it is helpful to note additional budget items: Electricity, cooling tower or chiller water, quenchant, disposal of quenchant, inductor coils and part touch tooling, floor space, cost of preventative maintenance, operator/attendant

costs, maintenance and daily destructive evaluation of production samples.

A Case Study

XYZ Gear needs to induction heat treat gear #945, which is 4" wide and 1/2" high (See Table 1).

ABC Induction Supplier determines the needed machine using the following calculations.

1. Power supply. The general rule is 10 to 15 kW per square inch. (Metric

measurements need to be converted into the English system.)

$$4" \times 1/2" \times 3.14 \times 2 = 12.56 \text{ in}^2 \times 10 = 125.60 \text{ kW.}$$

Based on standard tables, a 150kW/30 kHz power supply is selected.

2. Production rate. XYZ Gear operates two 6.5 hour shifts, five days per week and is open 4.3 weeks per month.

$$45,000 \text{ pieces/mo} = 162 \text{ pieces/hr at } 279 \text{ hrs/mo.}$$

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126-185

A piece must be processed every 22.2 seconds.

Given the production rate, the power supply and company experience in this type of job, the applications engineer calculates the cycle time as shown in Table 2.

What Do You Need To Know About Commercial Heat Treaters?

Perhaps your production is low enough to consider outsourcing heat

treating. Commercial heat treaters charge somewhere between 50 cents and \$3.00 per gear. Companies can work out the economic feasibility based on an approximate cost of \$2.50 per gear versus an investment in the capital equipment of \$250,000 (the average price of induction heat treating equipment), plus ancillary costs.

Other factors should be considered

before outsourcing. Are you willing to give up control of this process? Can you trust an outside heat treater to process gears that meet your standards?

A good place to begin is by consulting the directory included in this issue of *Gear Technology* or the *Directory of Commercial Heat Treaters*. Keep the following in mind:

- Make sure your commercial heat-treater has the proper equipment and experience.
- Make sure the skill set and equipment needed reside within the commercial heat treater now. Don't let anyone experiment with your project or use your job as a "learning experience."
- Make sure quality systems are in place. ⚙

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Interview with Deborah A. Erzen, applications engineer, Welduction Corporation, Farmington Hills, MI, September, 1997.

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Williams, Daniel J. and Traverse, Gilbert J. "Fundamentals of Specifying Induction Power Supplies for Wire and Rod Heating," *Wire Journal International*, June 1997, pgs. 92-99.

Daniel J. Williams

is president and CEO of Welduction Corporation, Farmington Hills, MI. He holds a degree in electrical engineering and has done advanced study in metallurgy and thermodynamics. He is the author of numerous articles on induction heating, quenching, process controls and quality systems.

Ellen F. Kominars

is the marketing manager of Welduction. She has an undergraduate degree in economics from the University of Michigan and an MBA from the University of the Americas.

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PRODUCT NEWS

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Meteor Temperature Compensation System

Albion Devices has announced the availability of its Meteor temperature compensation system for column and bench-top gages. The company says that the system can improve shop floor gage performance and dimensional control and reduce cost of scrap, rework and warranty while helping users meet quality control specifications and ANSI and ISO standards. Meteor can correct column and other bench top gages for the effects of temperature automatically and in real time; interfaces electronically with gages via analog or RS232 ports; can display results as if workpiece, master and gage were constantly at the International Reference Temperature; can run via PC or laptop and includes setup software and a complete temperature compensation instruction guide.

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CIRCLE 112

Dimensioning Standards Guide

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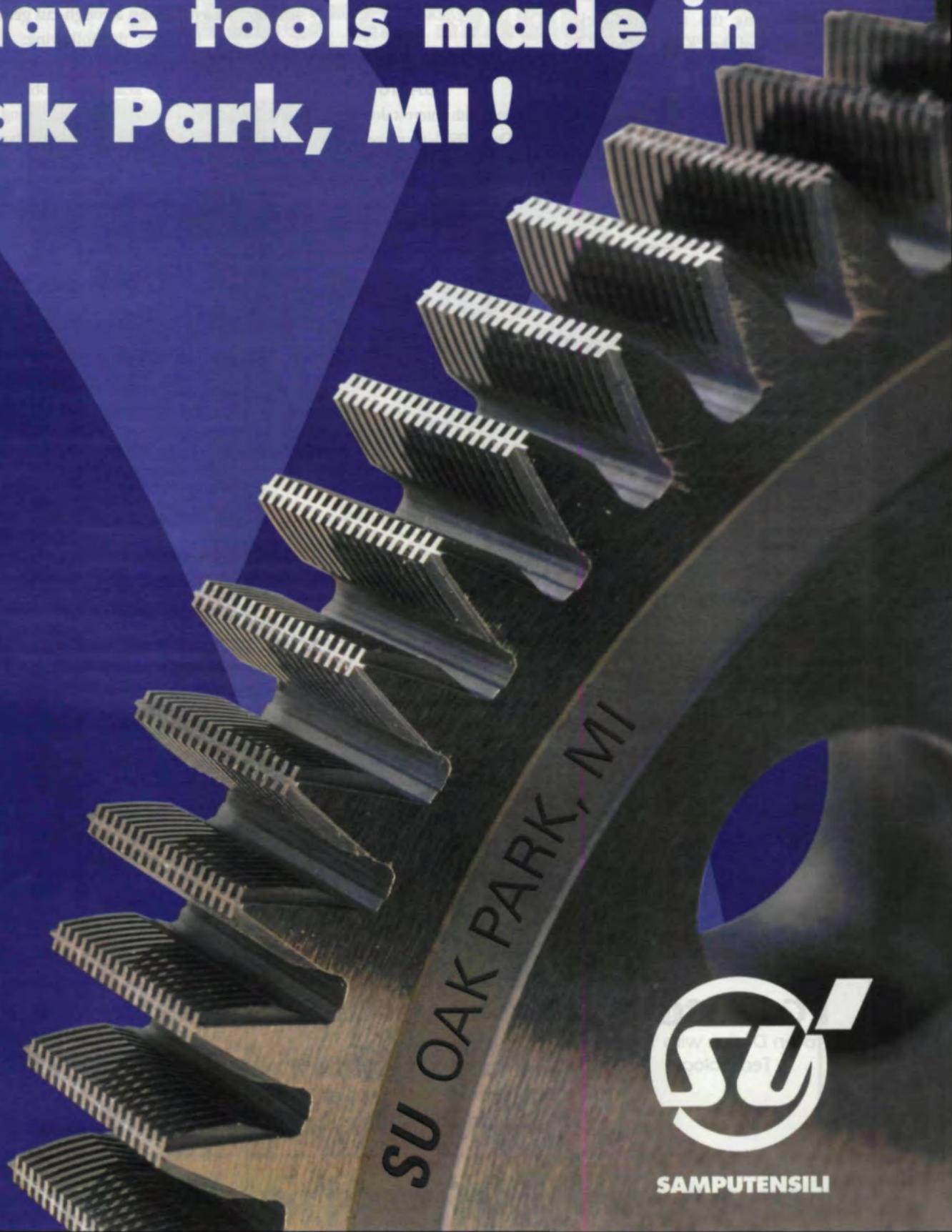


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THE KISH HUNTING METHOD

I read with surprise the letter from Mr. Mosier concerning the ancient Greek Euclidean origin of the "Kish method." I would like to assure your readers that I never met Mr. Euclid. The only thing I know about him is that he had something to do with geometry. The situation sort of reminds me of a patent application I once submitted that was rejected because an identical device was patented for an ele-

vator in 1870. There really is nothing new in the world of gearing, is there?

Jules Kish, Sikorsky Aircraft

MORE ON GEAR SHAVING BASICS

I read with interest John Dugas' article (Nov/Dec, 1997) about gear shaving basics in your last issue. I would have expected a more convincing presentation in favor of the shaving process, even though it has

been in vogue for over 60 years. **Shaving is still the most effective and economical way to finish a rough-cut gear.**

Consider the following: A few years ago, Ford's German operations tried to resolve the gear noise problem with a high tech solution—finish grinding or honing all gears in the manual gear box. It's interesting to note that Ford's newly built Brazilian transmission plant does not use the honing/finish grind operation to the large extent they did in Germany. Perhaps Ford realized that the reduction in gear noise obtained by hard finishing the gears was not significant enough to justify the additional cost incurred by this very expensive operation. (As the Italian proverb has it, the play was not worth the candle.)

Lately, some leading Japanese and German companies, lured by lower production costs, have set up manufacturing facilities in the U.S. Very often gear prints provided by German companies do specify the production gear process. Nevertheless, with the new generation of CNC shaving cutter resharpening machines and CNC shaving machines, the quality of shaved gears has definitely increased one or two class points, enlarging the shaving operation field. Perhaps an adequate hobbing/shaping operation, followed by a good shaving operation with proper workholding fixtures would be enough to produce those gears that, if made in Germany, probably would have been ground.

In the last analysis, the grinding/honing process should not be regarded as a panacea for all gear problems. Correcting heat treat distortions by finish grinding is very costly.

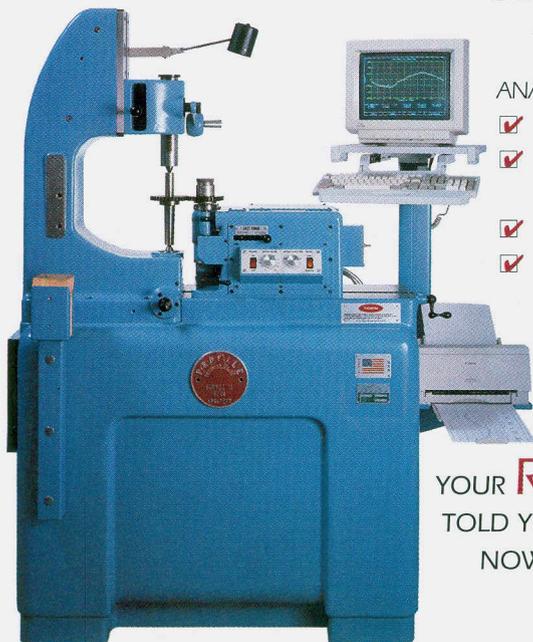
To conclude, I would urge gear manufacturers to fully evaluate the process they will use when producing gears in a global market economy. The bottom line is being able to evaluate the manufacturing cost for the quality required. This is the determining factor in which manufacturer ultimately gets the order.

It will be interesting to see in ten years whether the majority of gears will be finished by shaving or by hard finishing.

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Mr. Jackson's Amazing, Mysterious Machine

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

In our never-ending quest to bring our readers information about the unusual, the unique and—dare we say it?—the bizarre, the Addendum Staff has traveled for this issue to the wilds of Darkest Tennessee and the Museum of Appalachia. This museum of Appalachian folk art, crafts and history is located in Norris, TN, about 16 miles north of Knoxville. Among the 250,000 items collected by the museum's founder, John Rice Irwin, is a "thing," a "contraption," an "*objet trouvé*"; to wit, Asa Jackson's mysterious machine.

Jackson family history and popular folk wisdom in Appalachia say that it's a perpetual motion machine and that it worked at one time, running longer than a month without stop. And perhaps it did. But you couldn't prove it by anyone now alive.

This problem is this: Its builder, Asa Jackson (1792–1870), a local farmer, was a very secretive man. He didn't write down any of his plans or instructions for the assembly of the device. Jackson family members say he hid the machine in a cave outside Murphreesboro during the Civil War to keep it out of the hands of both the Union Army and any poachers who might be casting lustful



Asa Jackson's perpetual motion machine.

eyes on his invention. When no one was in attendance on the machine, he took it apart so no one could figure out how the thing worked. Irwin suggests that he may have even built extra, dummy parts just to confuse the inappropriately curious. When Jackson died, the machine, but none of the instructions or plans for it, passed to his descendants.

And what was Farmer Jackson's motive for building such a machine? Family history suggests that he built it in response to a competition of some sort, perhaps sponsored by the federal government, that offered a million dollars—a powerful incentive even in 1998 dollars—to the person who could design a perpetual motion machine. Whatever the motive, it was enough to make the construction of the machine something of an obsession with Jackson. Apparently he neglected his farm and went into debt to work on it.

Irwin acquired Asa Jackson's machine from his great-great grandsons in 1994 and brought it to the museum. Engineers from up the road at the government Y-12 plant in Oak Ridge have devoted some of their spare time to studying Jackson's machine, videotaping it and its extra parts and experimenting with various ways to put it together. So far, they haven't even agreed on exactly how it's supposed to be assembled. And none of them has displayed the daring of Asa Jackson in suggesting that they've repealed the laws of physics or out-guessed the likes of Galileo and Sir Isaac Newton and found a perpetual motion machine. Still, they'd like to know exactly how it works.

One likely scenario is that weights powered the large wooden wheel (about 5 feet in diameter) much like a clockworks. As the wheel turned, it com-

It went "zip" when it moved,
And "pop" when it stopped,
And "whirrr" when it stood still.
I never knew just what it was,
And I guess I never will.

Tom Paxton, "The Marvelous Toy"
Cherry Lane Music, Inc., ASCAP

pressed springs, which when released, returned the weights to their original position, allowing the cycle to start all over again.

Whatever its original purpose or practicality, Jackson's machine is an amazing piece of construction. It is built entirely of wood, and all the connections and fasteners are also of wood, pegged into place in much the same manner as furniture of the period was made. All the parts, including the large toothed wheel, were hand-carved. Originally, the machine is believed to have hung in a frame some 25 feet square, but the frame has long since disappeared. Now it is on display in the Museum of Appalachia in one possible configuration.

Okay, all you reverse engineering fans, here's your challenge should you choose to accept it: Take the trip to Norris. Study the machine. See if you can figure out how it works. John Rice Irwin, Asa Jackson's family and a lot of curious engineers would be be delighted if you could. ⚙

For more information about The Museum of Appalachia, call 423-494-7680 or 423-494-0514.

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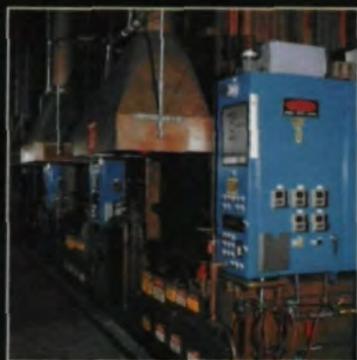
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