# GEAR TECHNOLOGY

The Journal of Gear Manufacturing

## HEAT TREATING TODAY—
### THE PRODUCTS & PROCESSES

March/April 1995

HEAT TREATING & GEAR MANUFACTURING — BEYOND BLACK MAGIC
HOW TO CARBURIZE A FINISHED GEAR
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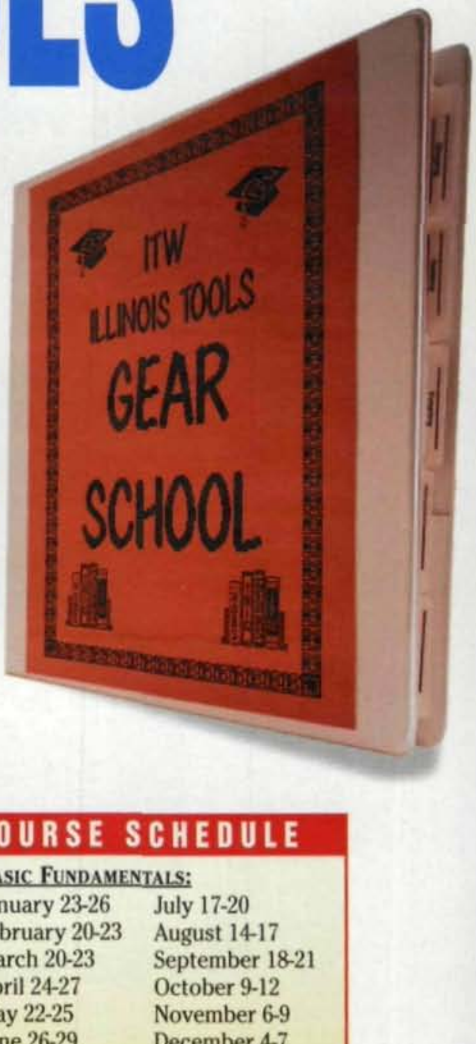


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MARCH/APRIL 1995
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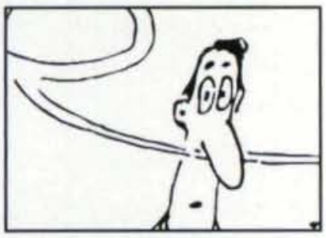

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# FINDING TOMORROW'S LEADERS TODAY

The passage last year of both NAFTA and GATT has gone a long way toward leveling the playing field for American manufacturers and others hoping to compete in the global economy. Add to this news the fact that the domestic economy keeps growing, and it seems as though good times are ahead for the gear industry.

Which is not to say our industry still does not have to face some difficult issues. Recently, the president of one of our leading gear machine manufacturing companies put his finger on one of them: Where is the next generation of managerial leadership to come from in our industry?

The executive we spoke with reminisced about the days twenty-five to thirty years ago when he and his counterparts in other gear companies came to work as newly minted engineers, learning the rudiments of the gear business and setting their sights on the managerial track. Now he looks behind him to see who's going to fill his shoes and sees. . . no one.

This should not be read as arrogance on his part. The fact is that our industry has not done a very good job of recruiting bright young engineers. The ones we have are good, but there simply aren't enough of them. Furthermore, our engineering schools (with a few notable exceptions) haven't done a very good job of training people in gear design and manufacturing. This specialized field gets short shrift in their curricula.

There are a number of reasons for this. Other fields, notably environmental science and computer hardware and software design, appear to be much more exciting, glamorous and potentially lucrative to technically gifted Generation X-ers, and little effort has gone into correcting this mistaken impression. Gearing is also a small piece of the much larger manufacturing industry pie and tends to get overlooked. Cost pressures have forced a number of companies running first-rate, in-house gear training programs to close them down. The decade-long litany that manufacturing as a whole is doomed in the U.S. hasn't helped draw young people to the field either.

But the issue of the scarcity of good people in the leadership pipeline is not one we can overlook.

The gear industry has attempted to address the problem on the shop floor level in a number of ways. Working with local schools (See page 14 of our May/June 1994 issue) is a step in the right direction, but such efforts are few, and much needs to be done to expand these joint ventures.

Engineering the problem out of existence is another approach. One of the forces driving CNC software development is the need to make machines that require fewer and fewer skills on the part of the operators. This solution is all right as far as it goes, but all it does is push the problem up the line. Somebody who understands gear design, development and manufacturing has to program the machines to make the decisions the operators are no longer trained to make. And we're not doing a very good job of training people to do that either.

In the meantime, our overseas competitors continue to have the advantage of a pool of highly trained people to fill their managerial slots. In both Europe and Asia, there are a number of excellent doctoral programs in gearing and, perhaps more important, the undergraduate programs to support them.

As with most complex problems, the solutions are not always simple or even immediately obvious, but we have to begin somewhere. A greater interest in and support for the schools and organizations that are training our next generation of leaders is a start. So are conversations with these institutions wherein we make clear what kind of training we need and explore ways to help provide that training. More aggressive selling of the opportunities at our companies at university job fairs and employment bureaus by both individual companies and industry organizations couldn't hurt either. Neither would the careful nurturing of people we already have on staff (perhaps even through funding some or all of their advanced training).

The fact is, having leveled the playing field in terms of trade barriers, we still have to play catch-up ball in other areas. And as the coach of any successful team will tell you, if you plan to win games two, three or five seasons down the road, you have to look to what's going on with recruiting and training today.

Michael Goldstein, Publisher/Editor-in-Chief

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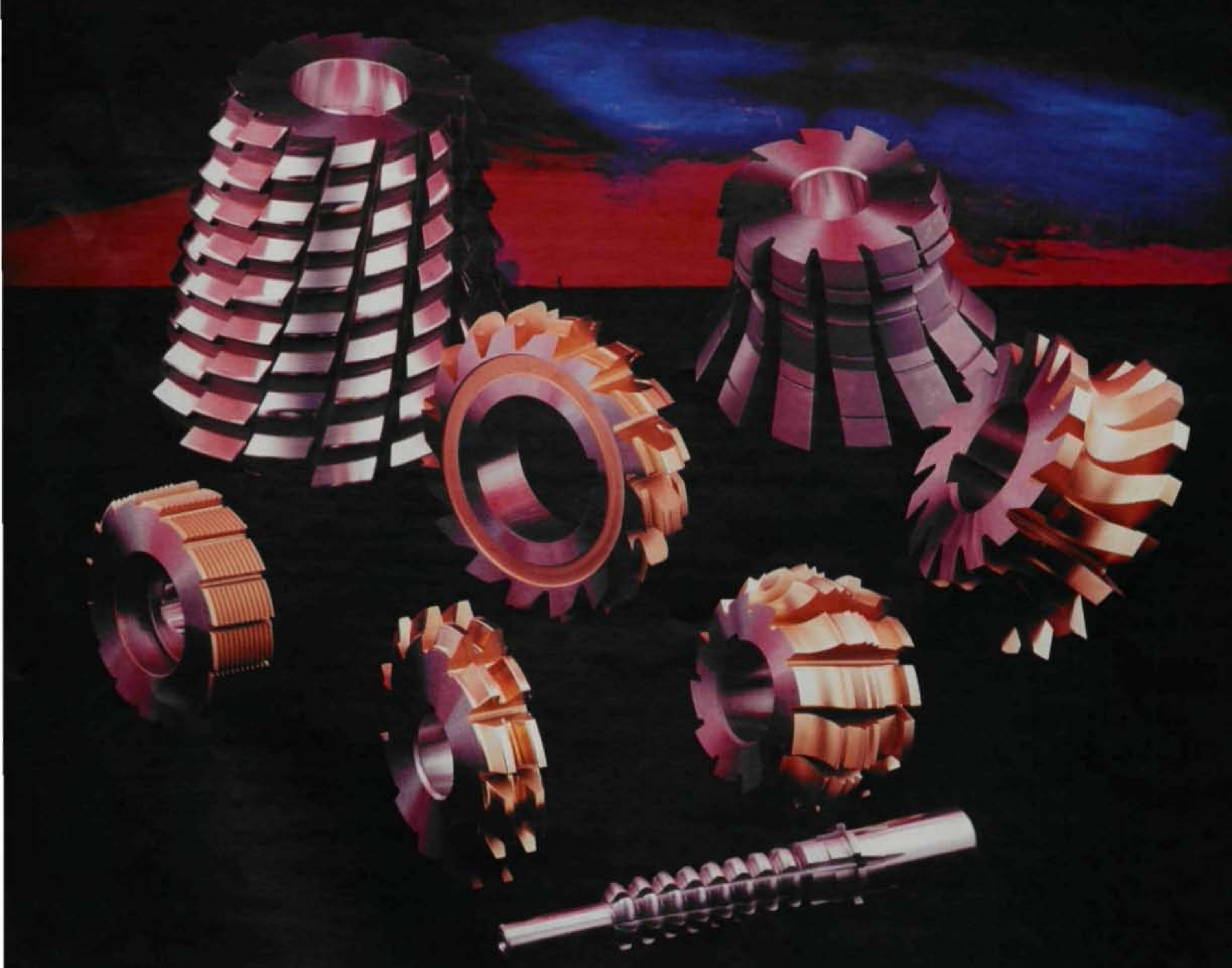

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# FYI...New Books for Gear Engineers

***Encyclopedic Dictionary of Gears and Gearing*** by David W. South & Richard H. Ewert. McGraw-Hill, 1995. In the front of this book is a Chinese proverb, "The beginning of wisdom is to call things by their right name." If that's the case, then this book is the beginning of gear wisdom. It contains some 400 pages of gear terminology from "$A_{cm}$," the temperature of phase changes at equilibrium, to "zone of action," plus separate appendices of nomenclature for grinding, gaging, hobs, shaving cutters and milling cutters. The explanations are clear and concise, the charts useful and the diagrams revealing. Whether you speak fluent "gearing" or are a novice in the field, this is a useful reference book.

***Gear Geometry and Applied Theory*** by Faydor L. Litvin, Prentice-Hall, 1994. Dr. Litvin is one of the important gear geometricians working in the United States today, and this book is a compilation of his years of experience in the field. It gives the mathematics for computer calculation of all the types of gears used in industry, including some of the most complex worms, hypoids and helicoids. The book also includes chapters on overwire measurements, generation of surfaces with CNC machines and coordinate measurements. An expansion on and complement to his earlier NASA publication, *The Theory of Gearing*, (1989), this is an important book for all gear designers. In his foreword to the book, Darle Dudley calls it "indespensible."

***The Handbook of Practical Gear Design*** by Darle W. Dudley, Technomic Publishing Co., 1994. This is not a new book, but it belongs on every gear designer's shelf. If you've never seen this book or if your own copy has begun to disintegrate with use or has migrated to an unknown bookshelf, help is on the way. Technomic Publishing Co., Inc., of Lancaster, PA, has acquired the copyright and is now the exclusive distributor of this classic, which covers all you need to know about designing gears, from preliminary considerations to the kinds and causes of gear failures and special design problems.

***Heat Treating: Equipment and Processes***, ASM International, 1994. This book contains the proceedings of the 1994 International Heat Treating Conference. Eighty papers, covering every aspect of heat treating from furnaces and power sources to environmental considerations, are reproduced. If you need to keep track of where research and development in heat treating are heading, this is a good place to start.

***Heat Treatment in Fluidized Bed Furnaces*** by R. W. Reynoldson, ASM International, 1994. Fluidized bed heat treating is becoming more and more popular today. This book combines theory with practical solutions to questions arising from this process. It is a good introduction to this heat treating technique. (Note: See p. 30 for an excerpt from this book.) ○

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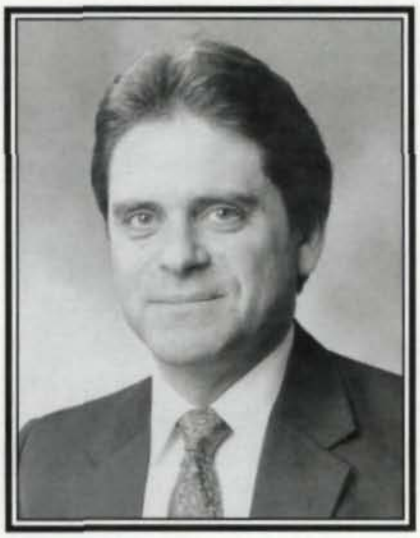
# *Dennis Gimpert of* Koepfer America

*This is the second in our series of interviews with the leaders in the gear industry. This interview is with Dennis Gimpert, president of Koepfer America, South Elgin, IL.*

**GT: What do you see as the state of the American gear industry now?**

**DG:** First of all, we need to define what the gear industry is. There are at least five areas. The first and largest is the automotive, truck and off-highway, which consumes two-thirds of all gears produced. It is the largest and most important segment of the industry. The second area is large gearing; industrial, marine, cement plants, things of that nature. The third area is job shops, which support the entire industry. Fourth, hand tools and fractional horsepower drives; and fifth, instruments and aerospace.

The automotive area is the strongest it has been in decades. This market is extremely "hot," not only in the United States, but also in the emerging markets of Asia, China and South America. This segment will probably represent the biggest competitive challenge in the future for U.S. manufacturers. In the large gear shop segment, my impression is that they still have over-capacity from the defense buildup, which is now flat or in depression. Job shops that support the industry are busy and challenged to meet their customers' needs. The fourth segment, hand tools, fractional drives, etc., is also busy. The fifth area, instruments and aerospace, is flat, which goes along with defense.



*Dennis Gimpert*

**GT: Where do you see the gear industry going into the year 2000 ?**

**DG:** For the automotive industry, with its captive gear manufacturing and companies that support that industry, the biggest challenge will be the emerging international markets, in particular China, Asia and South America. How they respond to those markets will determine if they gain that business throughout the world. In addition to the Asian and South American markets, we shouldn't forget the Eastern Bloc of Europe that is struggling through its emergence into a capitalistic system. They are in a position to consume many products. These markets are going to present a challenge to U.S. industry because those areas are so different from North American markets. The culture, the economy and the pay structures of these markets differ, not the quality and not the technology.

**GT: Speaking of trade status, what are your thoughts on GATT?**

**DG:** I think it really refers to government's influence on manufacturing. Clearly one of the areas of trade that has been restricted to us has been parts of Asia. One of the purposes of GATT is to knock down some of those trade barriers. Whether it will accomplish that and at what cost, I am not sure. An equally important area we've lost sight of has been government cooperation and support of manufacturing. The reestablishment of an investment tax credit and accelerated depreciation would be welcome measures to increase the productivity of our country.

**GT: You characterized the aerospace industry as flat. Do you see down the road an evolution or change in the aerospace industry?**

**DG:** Aerospace is primarily related to commercial and defense aviation. Certainly the commercial aviation industry in the United States, Boeing, McDonnell Douglas, is being challenged by the European consortium and potentially by the Asian consortia. The defense industry, which has been totally captive, is now open to an international market, and our defense systems include a lot of offshore components. This new world market will require increased efficiencies to remain competitive.

**GT: What about strengths and weaknesses of the American gear industry?**

**DG:** I think you can look at what changes have occurred in the gear industry, and the largest single change that I've seen is in quality improvement in the gear elements themselves. I think everyone has always said he or she made a quality component, but I think that today they are actually doing it and being more truthful with themselves. Today it's both essential and practical to use some analytical gear inspection equipment, and if you look at the major suppliers like M&M, Zeiss-Höfler and Klingelnberg, they provide accurate, flexible, efficient machines that inspect gears quickly and without an operator's influence or interpretation. The cost of these systems has gone down in relation to the cost of other capital equipment. So when I look at our customers and others in the industry, I think that they are truly making a higher quality component today.

**GT: We read more and more about on-machine inspection as opposed to separate machines for inspection. How prevalent is on-machine inspection? How fast is it coming?**

**DG:** One of the problems that I see with on-machine inspection is that the hobbing, shaping and other processes used to produce gears are chip-making processes. This creates an environment that is not friendly for inspection. To overcome that environment will require systems that are overly expensive and complicated to integrate with the machine. There are systems certainly that can do it, but they are slow, costly and not yet practical.

**GT: What about Koepfer? Where is your company going in terms of products, markets and philosophy in the next six to eight years.**

**DG:** Over the last 20 years, there have been repeated changes in technology and products. First a machine tool improvement, followed by a cutting tool improvement, followed by another machine tool improvement and so on. It appears today that cutting tools are emerging once more as the leader over the machine tools. In particular with carbide and cermet tools, the machines are now limiting the correct application of these cutters. It is apparent that it is practical to use much higher surface speeds with these tools than machines are capable of today. One of the major problems we all face is the commercially available servo systems used. Standard commercial spindle drives have a practical limit today of 5,000 rpm, and that is too slow for the next generation of machines. If we look at where we have to go, it has to be to use the cutting tools that are available but not being pushed to the limit.

**GT: Are the servodrive manufacturers addressing that problem?**

**DG:** I think it is similar to the development of CNC hobbing and CNC shaping machines. Initially the equipment manufacturers developed black boxes to solve the problem of the kinematic link between the tool and the work. There was not a commercial unit available to solve this problem. The first electronic hobbing machines were introduced in the 70s with these black boxes, and it really wasn't until a decade later that standard CNC hardware was used. So I think it will be a supply and demand issue.

> *Quality has both objective and subjective components, and they don't always match up. On an objective basis, a gear may be performing completely up to standards, but it may have a perceived quality problem.*
>
> *—Dennis Gimpert*

**GT: What about Koepfer's philosophy and market direction?**

**DG:** We are an international company and we've done business throughout the world for over 100 years. Our markets include Europe, North America, Asia—the entire world. We have been doing business with China for many years. Historically China has always been politically volatile, and as such, we have conducted our business with them cautiously, but we remain optimistic about the largest population group in the world.

One unique feature of our company has been our emphasis on the niche markets. We grew up from the instrument and clock industry and have become larger both as a company and as an equipment manufacturer. Today we emphasize not the largest area of the market, which is automotive, but perhaps the next largest areas—job shops, hand tools, instruments and aerospace. This has allowed us to personalize our technical support to the customer, which gives us an advantage. Manufacturers have been forced to become more agile in their manufacturing philosophy. We respond to this niche market and the agile manufacturing required.

**GT: Where do you see that taking you in terms of new products or new designs?**

**DG:** Today I think the concept is beyond JIT as it applies to the total manufacturing environment, including lean management, direct interface to the shop floor, fewer levels of management and cellular concepts of manufacturing. All of this reduces the work process and increases the annual turns with smaller lot sizes. As the lot sizes have decreased, a need for quicker changeover and setup of equipment has emerged. We emphasize quick setup and extreme flexibility in the machines we produce.

The markets we are in have a requirement for a compact machine. And yet the machines being built today are the largest and heaviest ever built. This is a requirement of the emerging cutting tool technologies.

Although the physical size and weight of the machines have increased, the size of the gears that can be produced are similar.

**GT: What do you see as the role for AGMA in the gear industry for the next 10 years?**

**DG:** I think that AGMA is an essential element in our industry. I would like to take that a step further and say that the new leaders and personnel in AGMA have made changes that are very positive. These changes include the hands-on gear school, a closer link to the international standards groups working throughout the world, the AGMA Gear Expo, etc. My largest disappointment, and it's not necessarily directed to AGMA, is the difficulty of reaching the many gear companies in the United States and OEMs that produce gears. Most people who are in gear shops and who produce gears as a captive market are not members of AGMA. Yet that gear may be an important part of their product. As I see it, two of the biggest challenges for AGMA are, first, to continue to guide the standards towards an international standard so that our products can be accepted worldwide; and second, to gain acceptance by a broader group of members and incorporate those people into the association.

**GT: What are your feelings about ISO 9000 as a quality standard?**

**DG:** I see ISO 9000 as a method of manufacturing a product to its design criteria. I do not see it as a method of producing a "quality" product or a competitive product or a product that is "marketable." It is a philosophy of manufacturing a product to a standard; therefore, it can be potentially a method to produce junk very consistently. I think AGMA and the ISO standards are effective when used with correct statistical process control and inspection techniques. They can provide quality components to the industry.

**GT: How do you define quality?**

**DG:** Quality has both objective and subjective components, and they don't always match up. On an objective basis, a gear may be performing completely up to standards, but it may have a perceived quality problem. One of our customers, a major producer of hand tools, utilizes a simple inspection at the end of the assembly line. The hand tool is plugged in and someone listens to it. That tool may be rejected or accepted based upon the perceived quality of it, which is determined by a personal evaluation of whether the tool is "too noisy." Although that hand tool may have performed for years at the same noise level, the company would no longer ship it. This "perceived quality" originally created a tremendous problem for them. Since then, we have identified the problem and worked *with them to improve the actual quality* of the components. The tool runs more quietly now, and the perceived quality is no longer a problem.

**GT: Where do you see CNC going, and where do you think it should go?**

**DG:** The PC system can be an effective interface tool for the operator, the manufacturing engineers and the gear manufacturing machine. As an interface tool, the PC could perform off-*line programming, obtain statistical* data and control auxiliary functions. I don't think that the existing PC system will be effective as a machine tool control directly. It is a serial data device. It crunches one piece of data at a time, although faster and faster as the chips get better. Most gear manufacturing machines require parallel processing of data to perform multiple functions simultaneously. CNC machine tools need special computer systems. The operational speeds of those systems will rise as the use of carbide and cermet tools increases.

**GT: Do you see more control of the machine from a remote as opposed to on-site, hands-on operation?**

**DG:** It's a mixed bag. In our particular market, we see that the number of required programs is limited. They can be easily stored in the CNC control systems and recalled with tool offsets performed for size changes as required. DNC for our type of equipment is really not necessary. Programming will remain at the machine because of its simplicity.

**GT: Any other topics you would like to address?**

**DG:** One area has been an improved understanding of the gear and the quality being produced in the industry as a whole. The technical knowledge of the manufacturing personnel is better today than it has ever been. People understand that the blank, the fixture, the cutting tool, the machine and the entire system influence the final quality of the gear.

An area of continued interest is hard finishing of components. Heat treatment of gears is still required for life and durability. Although improved, heat treatment is still a problem because of the distortions produced. Who would have dreamed that there would be ground gears in automotive and motorcycle transmissions? Today these products have ground gears in them at an extreme cost. If we look at the niche market that Koepfer is involved in, there is a strong interest in hard finishing techniques that are economical and productive. The area of hard finishing for improved subjective as well as objective quality will continue to be important. ○

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# GEAR HEAT TREATING IN THE 90s: BEYOND BLACK MAGIC

## INCREMENTAL IMPROVEMENTS MOVE HEAT TREATING FROM ALCHEMY TO PREDICTABLE PROCESS.

**HEAT TREATING**—The evil twin of the gear processing family. Heat treating and post-heat treating corrective processes can run up to 50% or more of the total gear manufacturing cost, so it's easy to see why, in these days when "lean and mean" production is the rage, and every part of the manufacturing process is under intense scrutiny, some of the harshest light falls on heat treating.

If heat treating is still not as predictable, consistent and manageable as everyone would like, it's certainly not from lack of trying on the part of the equipment manufacturers.

Some major equipment manufacturers are pushing the envelope on induction hardening and other selective hardening techniques. If there is a single, identifiable trend in techniques, it's the move toward induction hardening. George Welch, Product Manager, Heat Treat Products at Ajax Magnethermic, Warren, OH, says, "Our goal is to replace carburizing in many applications."

Dr. Maurice Howes, Director of the IIT Research Institute's Heat Treatment Center in Melrose Park, IL, concurs. "The future probably lies with selective hardening," he says.

Induction hardening has many virtues. It causes little distortion, and what distortion there is, is predictable. It's an in-line process, seemingly tailor-made for companies moving toward cell manufacturing. Materials can go right from the cutter to heat treatment in the production line.

According to Byron Taylor, President of Inductoheat of Madison Heights, MI, "In the same fashion that various tooling machines have become machining centers, various induction heating applications are now done on one machine."

Furthermore, induction hardening solves many environmental problems. Says Mike Chaplin, Vice President of Engineering at Contour Hardening, Indianapolis, IN, "Induction hardening uses no gases, no copper plating and no chemicals to cause disposal problems."

But induction hardening equipment is expensive, and it's best used in high-volume applications.

*Most gears are still heat treated using carburizing*, and manufacturers of carburizing equipment are not resting on their laurels either. Like their counterparts in induction hardening, they are working toward lowering costs, raising speed and repeatability and addressing environmental concerns.

Says David Hughes, Marketing Director for Surface Combustion in Maumee, OH, "In the future, customers can expect furnace equipment that is more user-friendly, networkable, with lots of good help screens. They can also expect different filtering and processing systems to limit emissions."

But for all the advances companies have made in recent years, it would be a mistake to assume that heat treating nirvana is just around the corner. Much mystery remains and not all of it will be revealed through incremental improvements in current technologies.

The basic metallurgical transformations that define the heat treating process and how they relate to gear design require further study. George Pfaffman, Vice President, Technology & Service Operations for Tocco® of Madison Heights, MI, lists seven issues where further research is needed.

1. Reduction of variation in dimensional change,
2. Prediction and modeling these changes,
3. Control of the carburizing operation,
4. Improvement of process control as an integrated part of the manufacturing operation,
5. Understanding of material behavior,
6. Environmental impact of the process,
7. Evaluation of process cost components.

Research in a number of these areas is an on-going process. John Walenta of Caterpillar's Technical Center in Peoria, IL, says, "Heat treatment simulation is an area of major effort. Caterpillar has had a research program in place for at least three years. The National

Center for Manufacturing Sciences is also working on a program to predict distortion and mechanical properties, as are the Japanese."

**The View From the Shop Floor**

Equipment manufacturers and researchers may be promising breakthroughs and advances that will make heat treating as trouble-free and predictable as heating coffee in your microwave, but the folks out there actually processing parts see it somewhat differently.

Bill Davis, president of American Metal Treating, Cleveland, OH, believes the technology of heat treating itself will remain relatively stable over the coming years. "Technological advances on the job shop level are more along the lines of installing advanced computer equipment, solid-state power supplies and other auxiliary equipment," Davis says. "The actual heat treating process isn't changing much and isn't likely to change significantly in the near future."

But even with limited advances in heat treating processes and equipment, improved technology has had an across-the-board influence on the ability of heat treaters to produce quality products in at least one area: Controls.

"Most of our furnaces are 20 years old," says Gerald J. Wolf, president of Cincinnati Steel Treating, Cincinnati, OH, "but the technology keeps improving from the standpoint of controls." Many of the furnaces at Cincinnati Steel Treating have brand new controls, and most of those will probably have to be replaced within five years, Wolf says.

Improved controls mean more consistent results. For example, with carburizing, the better you can control the level of carbon in the furnace, the better you can control the metallurgical characteristics of a finished gear and the better you can predict how a gear will distort the next time.

So which type of heat treating is best for you? Unfortunately, there is no easy answer.

Says Bill Davis, "If you sat 50 metallurgists in a room and asked them to decide which was best—carburizing or induction hardening—they'd argue about it for two weeks and then split right down the middle."

Contour Hardening produces a multi-phase induction hardening system that can heat treat a whole gear in less than a second. Many in the industry consider this to be the state of the art. Meanwhile, vacuum technology and nitriding also promise to provide less distortion from the heat treating process. "The biggest bugaboo that heat treaters face is how to heat treat parts without too much distortion," Cincinnati Steel's Wolf says.

Another technology that may be on the rise is the use of fluidized bed furnaces, says Eric Pearson, Marketing and Sales Manager for Dynamic Metal Treating, Canton Twp., MI, a heat treating company with its own patented ferritic carbonitriding process using a fluidized bed furnace. One of the main attractions of this process is also that it doesn't distort the parts, Pearson says.

One thing is clear: Equipment alone won't solve the problem. "Every gear manufacturer is convinced that **you've** caused the distortion in his gears," Wolf says, but with the sophistication of heat treating controls steadily increasing, heat treaters are more and more able to produce consistent results.

Often, he adds, unusual distortions can result from inconsistency in the gear manufacturer's choice of material. "Over the years, I've seen parts grow more than we thought they would, and I've even seen parts shrink. There just is very little information regarding how the processing of the part **before heat treating** affects the way it is distorted. However, they've proven that if you buy consistent material, you get consistent results."

Empirical evidence may suggest that, as George Pfaffman puts it, "Gears are cut in heaven, but the devil does the heat treating," but the fact is that in today's competitive environment, you can't count on black—or white—magic to solve your heat treating problems. We haven't reached heat treating heaven yet, but for gear manufacturers willing to spend the time and effort to sort out the available alternatives, heat treating can be converted from a kind of alchemy to a cost-effective, predictable process that improves your product and contributes to, rather than eats away at, your bottom line. ○

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**While no one process is best, there may be a best type of heat treating for a given situation, depending on the type of gear you have, the volume of production and the cost per part you're willing to spend or able to justify.**

**NANCY BARTELS**
**WILLIAM R. STOTT**

# Mechanical Behavior and Microstructure of Ausrolled Surfaces in Gear Steels

**Richard A. Queeney**
**Pennsylvania State University**
**State College, PA**

Ausforming, the plastic deformation of heat-treatable steels in their metastable, austenitic condition, was shown several decades ago to lead to quenched and tempered steels that were harder, tougher and more durable under fatigue-type loading than conventionally heat-treated steels. To circumvent the large forces required to ausform entire components such as gears, cams and bearings, the ausforming process imparts added mechanical strength and durability only to those contact surfaces that are critically loaded. The ausrolling process, as utilized for finishing the loaded surfaces of machine elements, imparts high quality surface texture and geometry control. The near-net-shape geometry and surface topography of the machine elements must be controlled to be compatible with the network dimensional finish and the rolling die design requirements (Ref. 1).

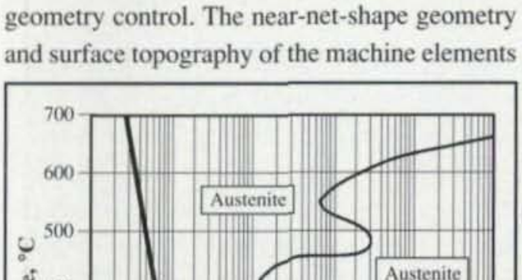


**Fig. 1 — Thermomechanical history for ausrolling AISI 9310 steel with 1.0% carbon.**

The proof testing of ausrolled gears poses unique challenges in assessing the changes wrought in gears by ausroll surface finishing. While hardness profiles within the gear teeth and the physical metallurgical features of the gears themselves can be readily ascertained, rolling contact fatigue, one of the most frequently noted reasons for gear failure, is most conveniently studied using standard rolling contact fatigue (RCF) specimens in a test of that genre (Ref. 2).

Outlined below are some of the recent results of studies at the National Center for Advanced Gear Manufacturing Technologies characterizing the microstructure and response of ausrolled gears and related model specimens. The gears examined are fabricated of AISI alloys 4023 and 9310, both case-carburized to 1.0% carbon (nominal). The former is a typical automotive transmission gear alloy; the latter is utilized in high performance aerospace transmissions.

### Gear Processing

Ausroll processing can be visualized from the thermomechanical history shown in Fig. 1 (Ref. 3). The processing path indicated, with the time allotted to ausrolling at 232°C, would be equivalent to conventional marquenching if that part of the history were devoted to thermal equilibrating. Instead, the ausrolling imposed on the gear teeth imparts a shear strain of several hundred percent at the surface. After ausrolling, the gears are quenched into room temperature oil and tempered in the conventional manner.

## Case Study No. 1
## AISI 4023 Transmission Gear

The gear in question was a helical automotive transmission gear: it had a diametral pitch of 13.0, a helical angle of 27° and 59 teeth. The gear surface had been carburized to 1.0% carbon to an effective case depth of 0.027 inches, wherein the "effective case depth" is defined as the distance from the surface where the as-marquenched Rockwell hardness falls off to RCH = 50. AISI 4023 has an $M_s$ temperature of 163°C, well below the processing environment of 232°C. Three types of processing were studied for this gear: 1) a conventionally processed gear (CP), wholly austenitized, quenched, tempered and surface ground; 2) a reaustenitized unground (hereafter denoted AUS) replica, induction heated to 925°C, quenched to 232°C, ausrolled, quenched to room temperature and tempered; 3) a reaustenitized unground replica (hereafter denoted MAR), induction heated to 925°C, marquenched to 232°C, maintained isothermally for a time increment equivalent to the ausroll process (20 s), quenched to room temperature and tempered. Fig. 2 compares the hardness profiles obtained by indenting along the tooth pitch line in the center of a sectioned tooth. Note that both reprocessed gears exhibit higher hardnesses in the near-surface regions, which must bear the maximum Hertzian contact stresses; the marquenched sample's increase over the conventionally processed gear may be because of the unground state of its tooth surface. The ausroll finished gear can be seen to have gained a full VHN 100, a notable 12% increase, and a possible strength increase of the order of 50 ksi at those hardness levels.

The residual stresses present in heat-treated gear teeth are capable of markedly affecting the service durability of the gear. Heat treating residual stresses are typically compressive, thereby offsetting by their magnitude the tensile bending stresses present at the tooth root. In addition, they algebraically reduce the subsurface shear stress or distortion energy states caused by Hertzian contact stresses; these components lead to gear failure by tooth pitting and spalling. Surface residual stresses in the plane of the tooth surface at the pitch contact line were examined for the three types of processing—CP, MAR and AUS. Stresses were measured parallel to the involute profile (tip to root sense) and parallel to the lead profile (across the tooth thickness sense): Fig. 3 shows the results of the X-ray diffraction stress analysis. All three types of processing produce roughly the same residual stresses across the gear tooth, although ausroll finishing does show evidence of stresses that are 20% improved over the ground, conventionally processed gear. The other component, that which would most affect root bending stresses, is nearly 100% better; in addition, the two components of stress are more nearly the same magnitude after ausrolling, reducing the shear magnitude.

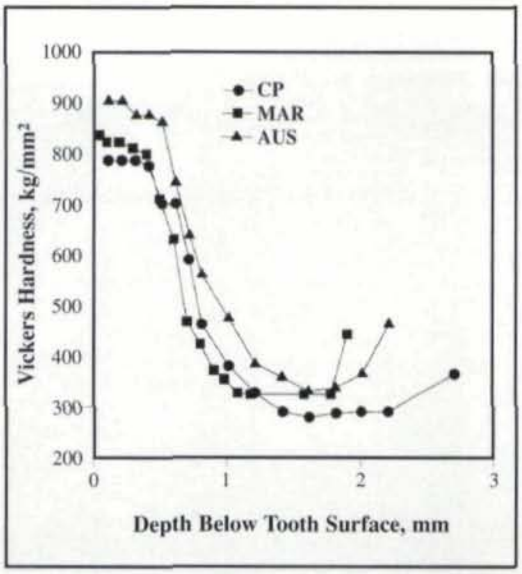


**Fig. 2 — Surface hardness profiles in gear teeth as they depend on processing.**

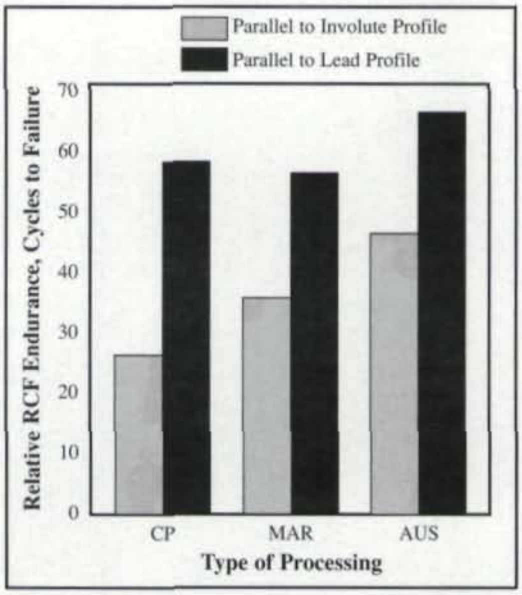


**Fig. 3 — Surface residual stresses and processing in AISI 4023 helical gear teeth.**


**Richard A. Queeney, PhD.,**

*is a Professor of Engineering Science and Mechanics in the College of Engineering at Penn State and a senior research associate of the National Center for Advanced Gear Manufacturing Technologies.*

Fig. 4a — Ausrolled microtwins.

Fig. 4b — Ausrolled dislocations inherited by martensite.

Ausforming of any type induces signature microstructures (Ref. 4) that are not obtainable by any other thermomechanical processing; these, in turn, are responsible for the improved durability of the finished product. The ausrolled gear teeth were examined for the relevant microstructures, whose submicron nature can only be viewed using electron optical methods. Foils were electrolytically milled for near-surface regions of the teeth, and extraction replicas were taken of the tooth surfaces; both were examined by transmission electron microscopy. Fig. 4 is the result of the examination. 4a, 4b, and 4c show the observed microtwinning, inherited dislocation arrays and microcarbides (here, $Mo_2C$), respectively, that should be found in an ausrolled structural element.

### Case Study No. 2
### AISI 9310 Steel Endurance

The fundamentals of pitting and spalling failure as a result of rolling contact fatigue are most systematically studied with easily analyzed specimen geometries and standardized testers. AISI 9310 steel, with a carburized case of 1.0%C, was the gear material of interest. An alloy of this type can tolerate bending stresses of 700 MPa and Hertzian contact stresses of 2800 MPa in high efficiency aerospace transmission gearing. The specimens used in rolling contact fatigue (RCF) endurance testing were cylindrical in cross section, with a one-inch nominal diameter. They were either conventionally marquenched (MAR) or surface ausrolled in one of two modes. If ausrolled with a straight cylindrical die, which was forced into the specimen radially as they counterrotated, they were considered to be deformed in *line contact* (LC). If the die had a crown radius as well and was fed not only radially into the specimen, but along it axially, the deformation mode was idealized as *point contact* (PC). The main significance of the difference in rolling mode is that PC rolling induces a greater extent of plastic deformation than LC forming because the smaller contact area of the former carries the same rolling contact force as the latter (Ref. 5).

Fig. 5 demonstrates the extent of the case hardness profile formed by PC ausrolling and compares it to the profile obtained through conventional marquench processing. Both conditions were tempered at 150°C for two hours. Ausroll processing improves the surface hardness by 25%; moreover, the high hardness persists into the surface far beyond the expected states of maximum Hertzian contact stress. Fig. 6, which shows the relative rolling contact fatigue endurance of all processing states, reflects the enhanced hardness achieved through ausroll finishing, with the especially deep hardness zone of the PC ausrolling leading to an order of magnitude increase in RCF endurance.

### Conclusions

Ausroll finishing of gears has been recognized as a highly cost-competitive operation for fabricating premier quality gearing normally ground to achieve requisite levels of finish and geometry control. Recent studies completed at the NCAGMT have clearly demonstrated that gear ausrolling imparts to the finished gear surfaces all of the property enhancements normally associated with ausforming technology in general. In particular, the tooth surfaces and subsurface regions exhibit greater hardness parameters that extend deeper beneath the surface than in identical cases conventionally marquenched. In addition to a stronger tooth surface, the beneficial residual stresses induced at the tooth surface are also larger than those found in conventional processing; in addition, they are not partially erased by finish grinding operations. Improved material response parameters and residual stress retention have, furthermore, been demonstrated to lead to better than an order of magnitude improvement in rolling contact fatigue endurance. Finally, microscopic examination of actual ausrolled gear teeth has established that the noted improvements in gear performance are indeed the result of the plastic deformation of metastable austenite, as the gear teeth contain the sense microtwins, inherited dislocation substructures and ultrafine precipitated carbides known to be responsible for ausform toughening. ○

**Acknowledgement:** The author is grateful for support from the National Center for Advanced Gear Manufacturing Technologies (NCAGMT) of the Applied Research Laboratory at The Pennsylvania State University. The Center is a nonprofit organization sponsored by the U.S. Navy Manufacturing Science & Technology (MANTECH) program under contract number N00030-02-C-0100.

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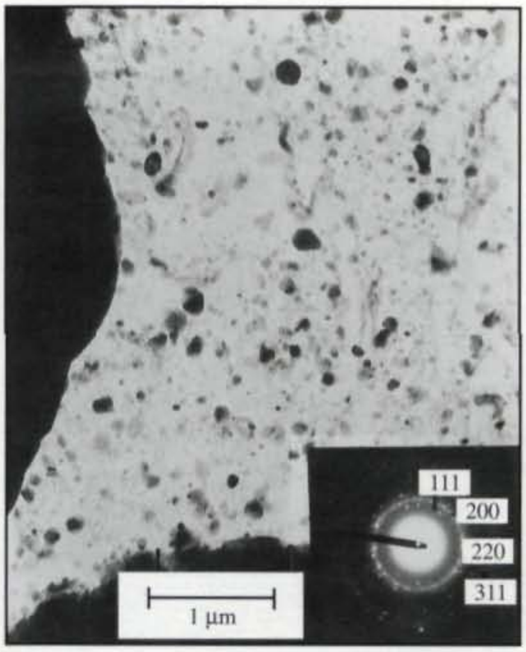


**Fig. 4c — Microcarbides ($Mo_2C$) precipitated by ausrolling.**

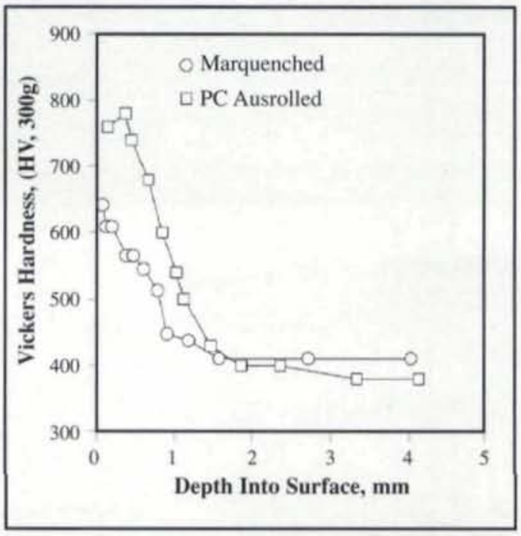


**Fig. 5 — Subsurface hardness profile and processing in AISI steel with 1.0% carbon.**

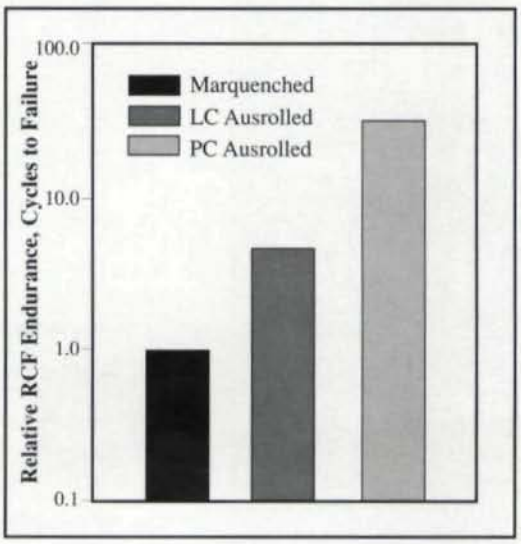


**Fig. 6 — Relative rolling fatigue endurance and processing.**

INDUSTRY NEWS

# Flash! Flash! Flash!

### Acquisitions

**Pfauter-Maag Cutting Tools, L.P.,** has announced the asset purchase of the cutting tool products of **Illinois Tools Unit**, an **Illinois Tool Works Company.** This purchase includes all assets related to the design and manufacture of their hob, shaper cutter and milling cutter product lines. Both companies will operate at the Pfauter-Maag Loves Park (Rockford), IL facility. It has also acquired **Mecup s.r.l.,** a leading Italian manufacturer of gearmaking cutting tools.

**American Pfauter, L.P.,** has become the North American representative for **Höfler-Zeiss** measuring and inspection equipment.

### Contracts

**Giddings & Lewis-Sheffield Measurement** will share in an $8.5 million contract funded in part by the National Institute of Standards and Technology's Advanced Technology Program. It will be part of a consortium of 15 U.S. companies, universities and government research centers whose purpose is to increase American manufacturing competitiveness through high levels of measurement speed, efficiency and accuracy. It will join a four-year program called Rapid Agile Metrology for Manufacturing (RAMM) to develop scanning technology yielding a hundredfold improvement in metrology productivity.

**Procedyne Corp.** has been awarded a contract from the U.S. Army ARDEC, Picatinny Arsenal, NJ, to provide engineering and technical services in support of the design, processing, evaluation and testing of fluidized bed heat treatments for metals and associate armaments components. The objective of the contract is to establish fluidized bed heat treating as an environmentally benign process to be utilized by DOD agencies in the manufacturing and rework of metal components.

### ISO 9000 Certification

**Rank Taylor Hobson**'s operations have been awarded ISO 9001 certification at the company's Leicester, U.K., facility. This site is where the company's metrology equipment and cinematic lens are manufactured.

**Diamond Black Technologies, Inc.**, Conover, NC, has become America's first ISO 9002-registered manufacturer of abrasion-resistant coatings. ○

# How to Carburize a Finished Gear

**Carl Kakes**
**Jason Wilde**
**Merit Gear Heat Treat**
**Antigo, WI**

Precise heat treatment plays an essential role in the production of quality carburized gears. Seemingly minor changes in the heat treating process can have significant effects on the quality, expense and production time of a gear, as we will demonstrate using a case study from one of our customer's gears.

The gear we looked at was a 20-inch, 98-tooth spur gear with a 1/2-inch web used in a construction drill head. The gears were made from normalized 8620 steel with minimum hardenability of HRC 28 at J6 quench rate. The customer called for carburizing with an effective case of .030–.040" to HRC 50, minimum surface hardness of HRC 58 and minimum non-carburized web hardness of HRC 28. A 3/4-inch coupon of the same alloy was heat treated and quenched in the same load to verify both effective case depth and microstructure.

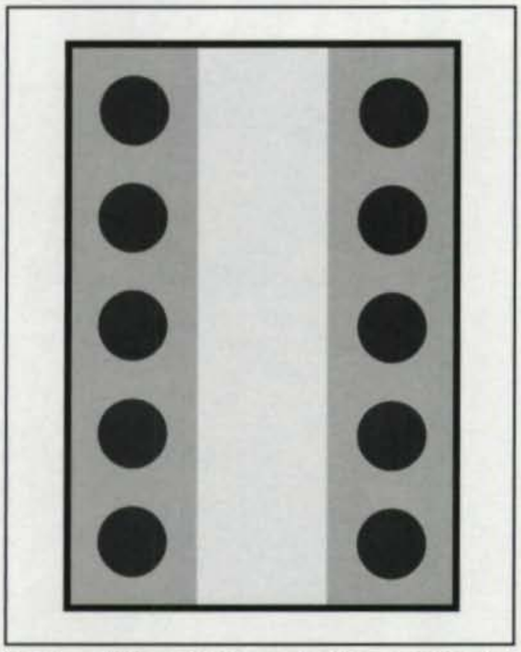

**Fig. 1 — Typical arrangement of burner tubes in a carburizing furnace.**

Initial test and production run results showed nicks on the teeth, an egg-type shape and an unacceptable lead, profile and composite roll check, according to our gear specialists. Using standard carburizing procedures, the gears came out of the furnace with a quality of AGMA Q6 or Q7. Because the gear print called for an AGMA Q8 gear, the parts required additional gear tooth grinding after being heat treated to compensate for distortion. To reduce the cost of the part to our customer, we examined ways of increasing the quality level to AGMA Q8 and eliminating the need for post-heat treatment gear tooth grinding.

To produce a higher quality gear, it is important to follow some important guidelines during the heat treating process. To begin, the gear should be routinely washed, rinsed and dried prior to heat treatment. This is done to ensure that contaminants are neither allowed on the heat treated surface of the gear nor introduced into the furnace during loading. Any contaminant, including dirt and oil, may adversely affect the desired heat treatment result.

Following the cleaning process, any excess oil should be "burned off" the surface of the gear by heating it and holding the temperature of the gear at an appropriate level for a short period of time. This is common procedure if carbon-resistant paint (for example, Condursal Stop-off) is to be used. The paint is most often applied in select areas, normally on or around the inner diameter, to provide a softer post-heat treatment material for further machining. Once the gear is cleaned and carbon-resistant paint has been applied and allowed to dry, the gear load is ready to be arranged on trays, baskets or other fixtures for carburizing.

Load arrangement has a significant effect on the outcome of direct quenched gears. Small, light weight, more intricate gears should be loosely hung on carburizing rods, mounted on special carburizing fixtures or laid flat on their faces. Larger and heavier gears should either rest vertically on their teeth with overhead wiring for added stability or lie flat on their faces.

During our first efforts with the 20" spur gear, we rested the parts in a basket on their outside diameters. However, because the high temperature in the furnace caused the parts to rattle, the gears came out with nicked teeth. The nicks could be ground out in finishing operations, but since we were trying to reduce post-heat treatment finishing, we sought another option. Instead of resting the gears on the flat surface of the basket, we introduced a curved stainless steel pad that conformed to the shape of the outside diameter of the gear. The steel pads eliminated the problem with nicked gear teeth, yet they still allowed for the free flow of oil necessary during the quench.

Another factor to consider when arranging a load for heat treatment is the distortion caused by the burner tubes in the furnace (Fig. 1). Regardless of the way your heat treater presently arranges a gear load, it may be necessary to experiment in order to find the method best suited to the gear in question.

At first, we arranged the gears as shown in Fig. 2. However, we found that the webs of gears numbered 1 through 5 and 14 warped excessively, while those numbered 6 through 13 did not. After removing those gears in the arrangement that were severely warped, we were able to better control the quality and consistency of the load. Although this increased the amount of time it took to process an entire order of gears, we considered it worthwhile because of the gain in quality.

Another important aspect of gear heat treatment is preheating the gear before carburizing. It is usually advisable to preheat the gear prior to loading into a furnace. This is generally done in a draw furnace. A temperature of between 600 and 800 degrees is common, depending on the material being used. Pre-heat treatment is a

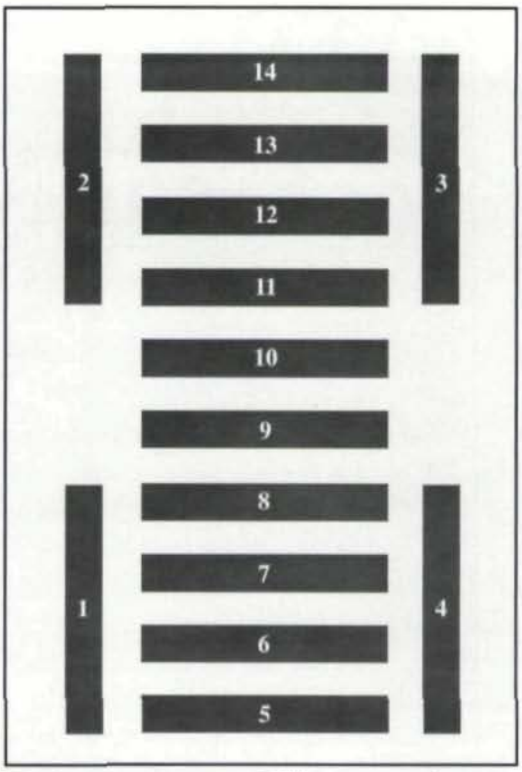


**Fig. 2 — Arrangement of 20" spur gears in carburizing furnace.**

common technique used to help control the distortion that results from introducing the gear from room temperature directly to a furnace temperature exceeding 1400 degrees. Pre-heat treatment also reduces the time required to reach the desired furnace temperature and thus saves on furnace costs.

After making these adjustments and following the guidelines mentioned in this article, the gear we were able to produce came out of the furnaces at a quality level of AGMA Q8B. The only post-heat treatment operation was superficial turning of the non-carburized area of the face and minimal boring.

This example demonstrates some of the ways in which gear heat treatment professionals can affect the quality of your gears. In addition, significant cost savings can result from eliminating post-heat treatment operations such as finish grinding of the gear teeth. For a gear such as the one we examined here, the savings can be as much as $100 per part in gear grinding alone. While this is only a small example of the success attainable through proper heat treatment, it should give gear engineers some understanding of the ways the process can be modified to help them produce a better product. ○

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**Carl Kakes**
*is Quality Manager for Merit Gear Corp.*

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*is a Heat Treatment Lead Person for Merit Gear Heat Treat.*

# ADI — A Designer Gear Material

**John R. Keough, P.E.**
**Applied Process Inc.**
**Livonia, MI**

If someone were to tell you that he had a gear material that was stronger per pound than aluminum, as wear-resistant as steel, easier to machine than free-machining steel and capable of producing gears domestically for 20% less than those now cut from foreign made forgings, would you consider that material to be "high tech"? Probably. Well, throw out all the pre-conceived notions that you may have had about "high tech" materials. The high-performance material they didn't teach you about in school is austempered ductile iron (ADI).

Cast irons and "high tech" scarcely have been uttered in the same breath. . . until now. The common perception of cast iron is based on gray or flake graphite iron. With a maximum tensile strength of 50 ksi and virtually no ductility, it is perceived to be a low-strength material suitable only for low-performance applications. However, ductile irons (or spheroidal graphite irons), with strengths up to 100 ksi and reasonable ductility, have been commercially available for many years. Yet even ductile irons cannot be used in most gear applications. Today, a new member of the cast iron family is available to design engineers even for high-performance applications. That material, ADI, is a specially heat treated iron that offers the gear designer manufacturing flexibility, low weight, excellent fatigue strength and wear resistance, all at a significantly lower price.

| Grade Number | Tensile* Strength | Yield* Strength | Elongation* | Impact Energy** | Typical Hardness |
|---|---|---|---|---|---|
| ASTM 897-90 (English Units) | | | | | |
| | (ksi) | (ksi) | (%) | (ft-lbs.) | (BHN) |
| 1 | 125 | 80 | 10 | 75 | 269-321 |
| 2 | 150 | 100 | 7 | 60 | 302-363 |
| 3 | 175 | 125 | 4 | 45 | 341-444 |
| 4 | 200 | 155 | 1 | 25 | 388-477 |
| 5 | 230 | 185 | n/a | n/a | 444-555 |
| ASTM 897M-90 (Metric Units) | | | | | |
| | (MPa) | (MPa) | (%) | (Joules) | (BHN) |
| 1 | 850 | 550 | 10 | 100 | 269-321 |
| 2 | 1050 | 700 | 7 | 80 | 302-363 |
| 3 | 1200 | 850 | 4 | 60 | 341-444 |
| 4 | 1400 | 1100 | 1 | 35 | 388-477 |
| 5 | 1600 | 1300 | n/a | n/a | 444-555 |

* Minimum value ** Un-notched Charpy @ room temp.

**Fig. 1 — Available grades of ADI and their minimum properties.**

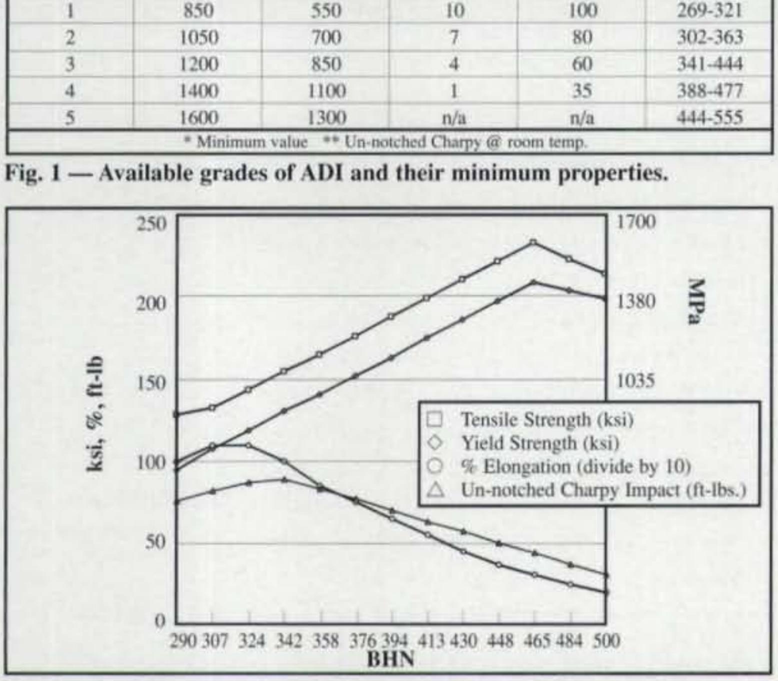


**Fig. 2 — Typical properties of ADI as a function of Brinell hardness.**

Ductile iron is 10% lighter than steel. It is easily cast into complex shapes. When subjected to a specially designed austemper heat treatment, it can exhibit remarkable properties. The available grades of ADI and their minimum properties are outlined in ASTM 897-90 and 897M-90 (Fig. 1). Fig. 2 shows the *typical* properties obtained in commercial ADI.

Because the heat treatment is isothermal in nature, the growth during the process is very predictable and repeatable. In fact, most parts can be finish-machined before austempering (accounting for volumetric growth), and they will grow predictably to specifications. This allows the manufacturer to use a very machinable grade of ductile iron for the casting, thus reducing machining costs even when compared to free-machining and leaded steels. (Ductile iron also produces a discontinuous chip during machining for easy chip handling.)

The fatigue properties of ADI are comparable with those of various heat treated steels. Single tooth bending fatigue data for grades 150-100-07 (Grade 2) and 230-185-00 (Grade 5) are shown in Fig. 3. Additionally, all grades of ADI *exceed* the notched-impact-resistance and low-temperature properties of carburized and hardened 8620 steel.

Because the "ausferrite" matrix in ADI goes through a "strain transformation" under high normal stresses, the contact fatigue resistance also is excellent. It can be greatly improved by rolling, grinding and shot peening. Contact fatigue data for grades 150-100-07 (Grade 2) and 230-185-00 (Grade 5) are shown in Fig. 4. The data clearly shows that Grade 5 ADI can replace carburized and hardened steel in gear applications with contact stresses up to and in some cases exceeding 250 ksi.

ADI can be produced with hardnesses ranging from approximately 30–50 Rc. As can be seen from Fig. 5, however, the wear resistance of ADI for a given hardness level is superior to that of many conventional materials. In fact, in many applications ADI with 42–46 Rc has replaced 60-Rc carburized and hardened 8620 with equal or better performance.

In addition to the aforementioned properties, ADI has superior damping to steel. This is related to the presence of graphite nodules in the matrix. These graphite nodules also improve the lubricity of the material. In some cases this has resulted in measured reductions in frictional losses.

Although ADI costs less per pound than most steel gear materials, the true manufacturing cost savings are more subtle. ADI is 10% less dense than steel; therefore, if you replace a steel gear with an ADI gear of the same configuration, it will weigh 10% less. (Oddly enough, ADI is starting to replace aluminum for weight savings in many applications because of its high strength-per-pound characteristics). Furthermore, modern casting techniques allow us to produce gears and gear blanks that are much nearer net shape, greatly reducing the amount of metal removal required.

ADI is a commercially available alternative to steel for gear applications. It has the strength, wear resistance and manufacturing flexibility desired by gear designers. It can be produced domestically at 15 to 50% less than materials produced by conventional means. The use of ADI in gear applications is certain to rise as engineers become more familiar with its advantages. ○

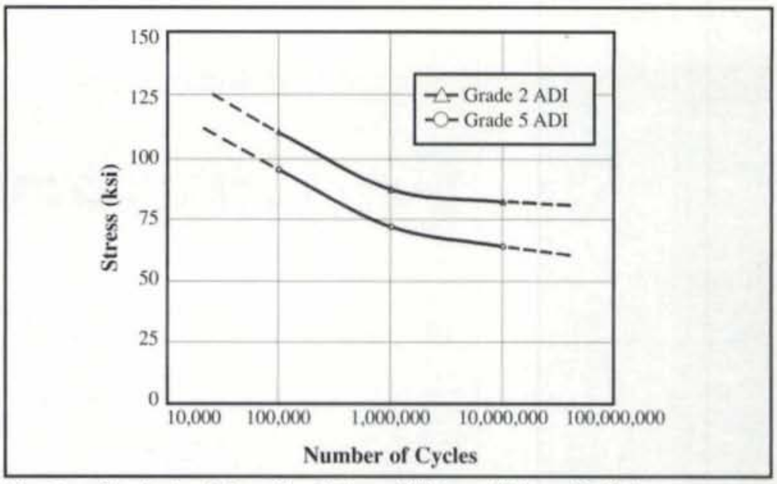


**Fig. 3 — Single tooth bending fatigue (90% confidence limits). From ASME Gear Research Institute[1].**

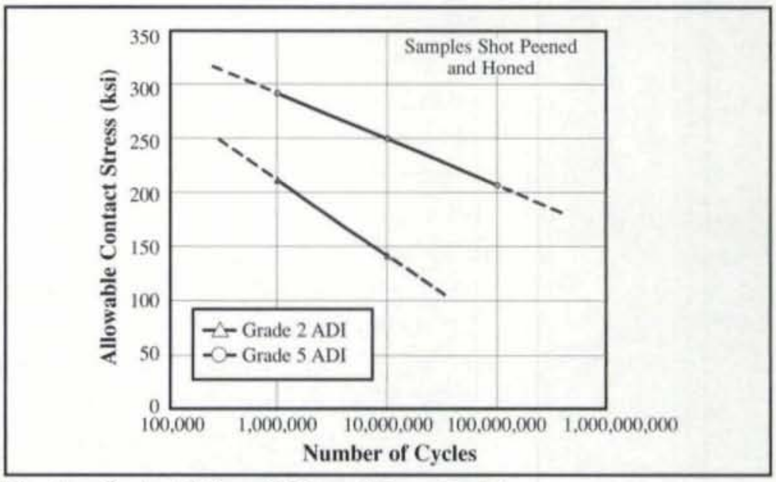


**Fig. 4 — Contact fatigue (90% confidence limits). From ASME Gear Research Institute[1].**

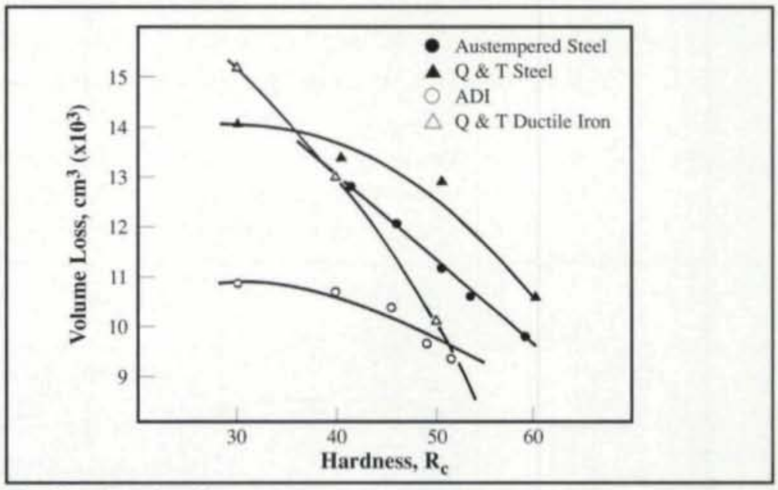


**Fig. 5 — Pin abrasion test.**

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# Heat Treating Equipment Selection

**Ray W. Reynoldson**
**Quality Heat Treatment Pty. Ltd.**
**Melbourne, Australia**

For heat treatment of tool and alloy steels, the end-user has a wide range of basic types of heat treating equipment to choose from. This article reviews them and details the criteria that must be considered in selecting equipment for a specific application. In making this choice, the most important criterion must be the quality of the tool or part after processing.

### Optimum Performance

Part or tool performance is related to the overall microstructure of the piece and is normally measured in terms of hardness, toughness (Izod, Charpy, etc.) and fatigue performance. Other secondary properties, such as wear resistance and resistance to thermal checking, are also important, and all of these criteria can be related to the microstructure of the treated piece.

### Surface Finish and Sub-Surface Properties

Where the workpiece will not undergo further machining or polishing of critical working surfaces after heat treatment, e.g., as on certain plastic mold tools, its surface quality is equal in importance with its microstructure. In most other cases, however, surface quality generally ranks second. However, sub-surface effects, such as those caused by electrical discharge machining or by carburization and decarburization, are also important and cannot be ignored.

### Shape and Size Distortion

Distortion is less a problem to the end-user than to the tool or part maker, who must take preventive action to ensure that the final dimensions will be achieved, or alternatively, to provide for sufficient machining allowance after heat treatment so that the required tolerances can be met. As a result, this is an area where conflicts can arise between the toolmaker and the end user, because sometimes each has different criteria (e.g., the former requires minimum distortion, while the latter requires maximum performance).

### Equipment Selection

The metallurgical criteria must be satisfied when considering which technique or equipment is to be used for the heat treatment cycle. In assessing equipment the following factors are generally compared:

- Temperature range and uniformity
- Heating and cooling rate
- Atmosphere integrity

These factors rank highest because they most directly affect the major criteria of quality control and reproducibility. If the equipment meets these requirements, then the other considerations to be weighed are

- Environmental considerations
- Capital and operating costs
- Ease of operation and maintenance.

The basic heat treatment equipment types and techniques from which this selection can be made are reviewed below.

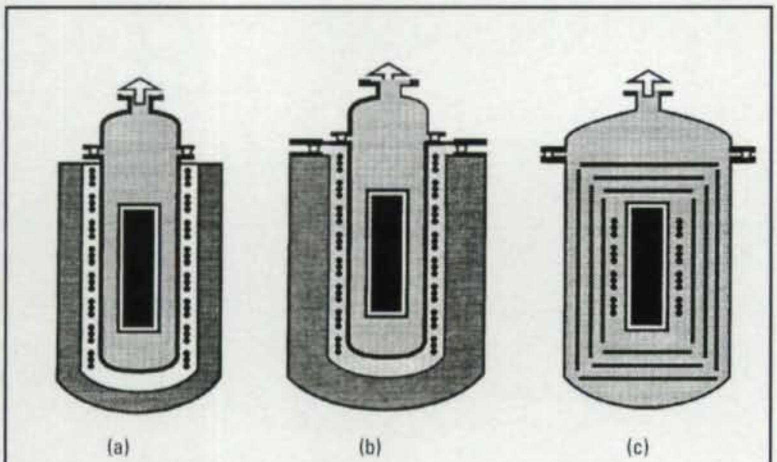


**Fig. 1 — Typical electrical resistance batch-type vacuum furnaces. (a) Hot-wall, externally heated type. (b) Hot-wall, double-chamber, externally heated type. (c) Cold-wall vacuum furnace.**

## Vacuum Furnaces

Vacuum furnaces vary from batch type (Fig. 1) to semi-continuous (Fig. 2). They can be either of cold-wall or hot-wall design.

***Temperature Range and Uniformity***. The temperature range of vacuum furnaces is generally 700–1400°C (1290–2550°F). Below 700°C, convection heating is more effective, and vacuum-purged, hot-wall furnaces are generally preferred for tempering. Temperature uniformity in an empty furnace that has reached equilibrium is typically 5°C (9°F), although this can vary to a much greater degree when loads are in the hot zone, because this almost always means some workpieces are shielded from direct radiation, particularly at low temperatures. This problem has prompted manufacturers of the more recently designed vacuum furnaces to add forced convective heating in nitrogen or another inert atmosphere, up to temperatures of 700°C, before switching to vacuum processing at higher temperatures.

***Heating and Cooling Rate***. Without forced convection, the heating rate of vacuum furnaces at low temperatures is very slow compared with that of other types of furnaces. At higher temperatures it increases because of the radiation effect. Because of shadowing, heating uniformity is only average compared with other furnace types. Vacuum furnace quench cooling methods are numerous, but they can be classified into three main types.

*Sub-Atmosphere Pressure Quenching*. Initially most vacuum furnaces were built with this option, which, after vacuum treating, backfills the heating chamber with an inert gas to slightly below atmospheric pressure. The gas is recirculated at varying flow rates through an internal or external heat exchanger until the charge cools down (Fig. 3).

*Positive Pressure Quenching*. The fast cooling rates required for certain grades of steels led to development of positive pressure quenching for vacuum furnaces. Quenching pressures up to 20 bar (290 psi), but normally 3 to 6 bar (44 to 87 psi) above atmospheric pressure, can yield the cooling rate improvements shown in Fig. 4, over sub-atmospheric cooling. (Atmospheric pressure is 750.1 torr or 1 bar and is acknowledged as absolute atmosphere, so that in practice a vacuum or negative pressure is any pressure below 750.1 torr (1 mm Hg), and any pressure above 1 bar is considered to be a positive pressure. Therefore what is commonly known in the trade as a 2-bar pressure quench furnace has a positive pressure in the chamber of 1 bar, and a 6-bar furnace has a positive pressure of 5 bar. This causes confusion in some literature, and this factor should be taken into consideration whenever conversions for bar to psi are encountered.)

*Liquid Quenching*. Some vacuum furnaces have also been integrated with oil quenching

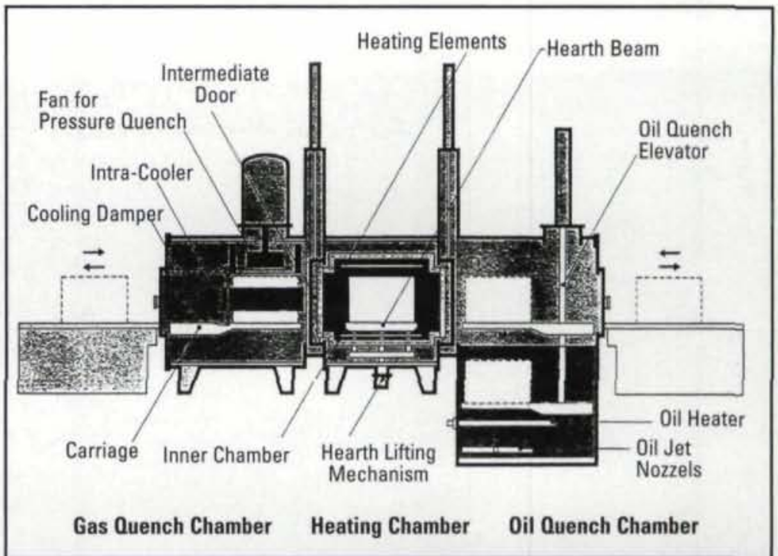


**Fig. 2 — Semi-continuous vacuum furnace.**

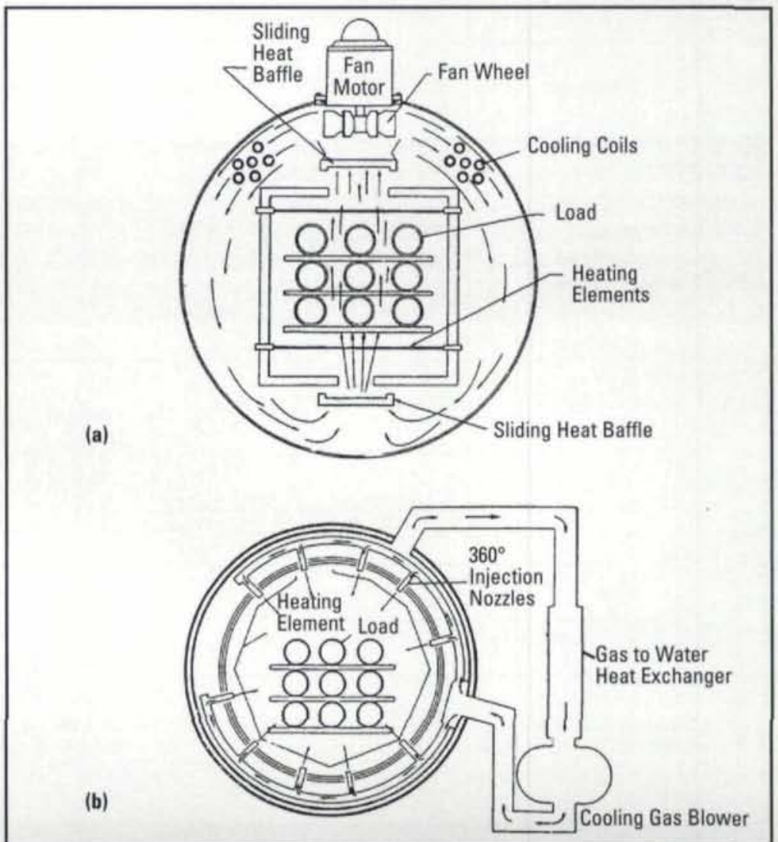


**Fig. 3 — Representative cooling systems in vacuum furnaces. (a) Internal heat exchange and enclosed fan cooling. (b) External cooling.**


**Ray W. Reynoldson**

*is the Managing Director of Quality Heat Treatment Pty. Ltd. of Melbourne, Australia.*

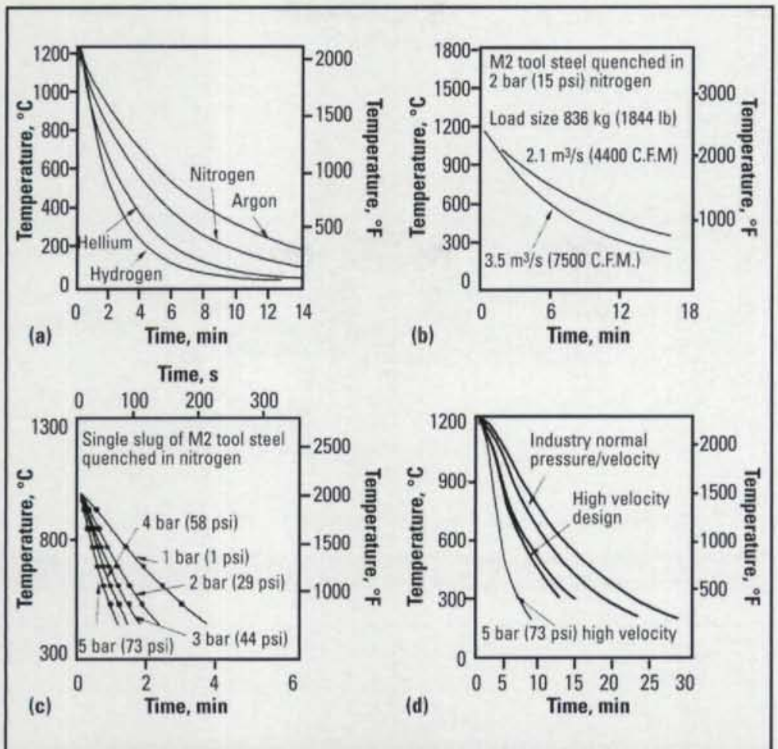


**Fig. 4 — Representative improvements in cooling rates by the use of positive pressure quenching. (a) Effects of gas properties on the cooling of 25 mm (1 in.) diameter steel slugs. (b) Effect of gas velocity on cooling of 25 mm (1 in.) diameter steel slugs. (c) Effects of gas pressure on cooling of 25 mm (1 in.) diameter steel slugs. (d) Range of cooling characteristics in industrial furnaces.**

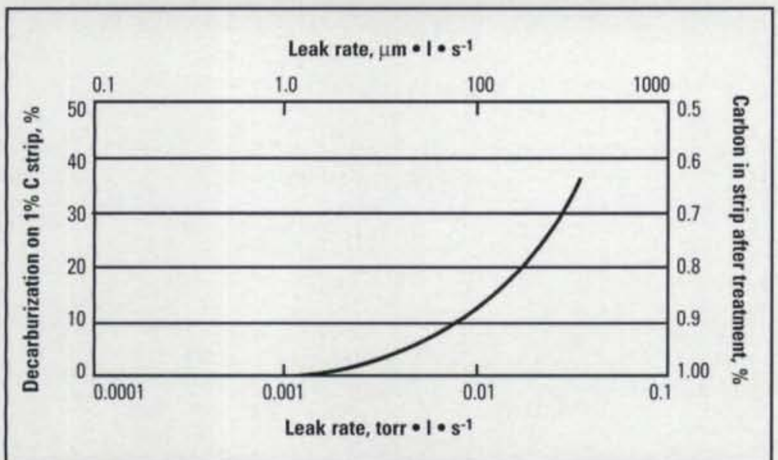


**Fig. 5 — Relationship between leak rate in a vacuum furnace and decarburization of a 1% C steel strip 0.15 mm (0.006 in.) thick. Treatment time: 2: hours at 1050°C (1920°F).**

facilities to permit oil and gas quenching to be performed in the same furnace.

***Atmosphere Integrity***. The "atmosphere" of a vacuum furnace, which guarantees neutrality to the surface of the part, is really a vacuum and as such is subject to leakage. For this type of furnace, the greatest variable in atmosphere integrity is its leak rate, which controls the effectiveness of the vacuum. Fig. 5 shows the effect of leak rate on decarburization of a 1% plain carbon steel. However, it is also important to remember that the vapor pressure of various alloying elements (e.g., manganese and chromium) can affect their behavior in a vacuum. Care must be taken to match the vacuum level used to the alloy steel being heated to avoid alloying element losses. Fig. 6 shows chromium loss related to vacuum level for type D3 steel.

## Salt Baths

A metallurgical salt bath is a container of metal or ceramic filled with molten salts, such as nitrites, nitrates, carbonates, cyanides, chlorides or caustics, in which metal components can be heat treated by heating and cooling them. Salt bath furnaces may be externally heated by gas or oil or by electrical-resistance elements or by passing alternating current through them from immersed electrodes, generating heat resistively within the salt itself. This heat is quickly distributed by a downward stirring action imparted by the electrodes. Molten salt baths heat the workpiece by conduction, quickly and uniformly. When a cold workpiece is plunged into a salt and its temperature approaches that of the bath, a thin insulating film of solid salt forms between the molten bath and the metal. As work is withdrawn from the bath, a thin film of liquid salt protects it from oxidation as it is transferred to the quench.

***Temperature Range and Uniformity***. In general, salt baths have a temperature range from just above solidus up to 1300°C (2370°F). Unfortunately the various salts used for heat treatment have varying operating ranges, and this can cause some problems with drag-over and contamination. In addition, it means that several furnaces are needed to cover the full range of processes. The temperature uniformity of salt baths is better than ±5°C (±9°F), and uniformity of heating, because the salt acts as a liquid, is excellent.

***Heating and Cooling Rate***. The salt bath is one of the fastest methods of heating available, second only to a molten lead bath in terms of general heat treatment, although of course much slower than induction. The cooling rates of various combinations of salts can vary from almost as fast as those of oil to relatively slow, depending on the conditions chosen. Uniformity of heating and cooling are good because of the fluid nature of the bath, and stirring the salt makes for excellent uniformity. In most aspects salt baths are ideal for heat treatment, but the environmental and corrosion problems they give rise to are the reason why they are now being replaced by other types of furnaces.

***Atmosphere Integrity***. In the case of salt baths, it is the salt composition and its equilibrium with the steel being heated that replaces a totally neutral atmosphere. (In practice, provided careful quality control is performed, parts or tools heated in salt experience neutrality on their surfaces although, as detailed later, some surface roughening is observed.) Careful control of the salt composition is crucial to what might be referred to as the "atmosphere integrity" of this type of furnace.

### Fluidized Beds

***Temperature Uniformity and Range***. Because, like the salt bath, the fluidized bed acts as a liquid, temperature uniformity can be typically ±3°C (±5.4°F), and each part is uniformly heated. The range of the fluidized beds is currently up to 1250°C (2282°F), and this can be achieved in one furnace, although two or more units are usually employed.

***Heating and Cooling Rate***. The heating rate of the fluidized bed is slightly slower than those of salt and lead, but faster than those of vacuum, atmosphere and forced convection furnaces. With the use of special gases, cooling rates approaching those of oil quenching can be achieved. Fluidized beds behave in a similar manner to molten salt to all intents and purposes.

***Atmosphere Integrity***. In the fluidized bed, the integrity of the atmosphere, like all retort type atmosphere furnaces, is dependent on the purity of the fluidizing gas used. Use of high-purity gases such as nitrogen and argon, combined with the metal retort and the fact that a positive pressure is prevalent in the bed itself, assures integrity equivalent to that of vacuum furnaces and the very best of the atmosphere furnaces. The quality of the gas must be monitored because contaminated gas can lead to surface decarburization.

### Controlled Atmosphere Furnaces

In controlled atmosphere furnaces, there are again many variations, but they can be categorized into ceramic-lined and metal-lined furnaces. Representative types are shown in Figs. 7 and 8.

***Temperature Range and Uniformity***. The temperature uniformity of controlled atmosphere furnaces is similar to that of radiation type

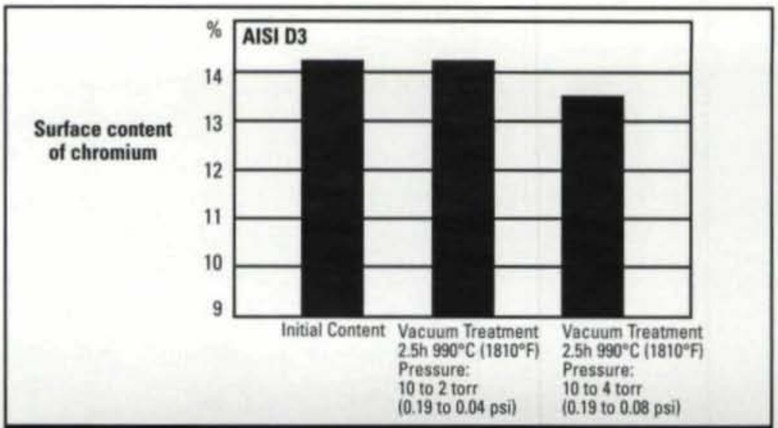


**Fig. 6 — Relationship between loss of chromium from a D3 type tool steel and vacuum level.**

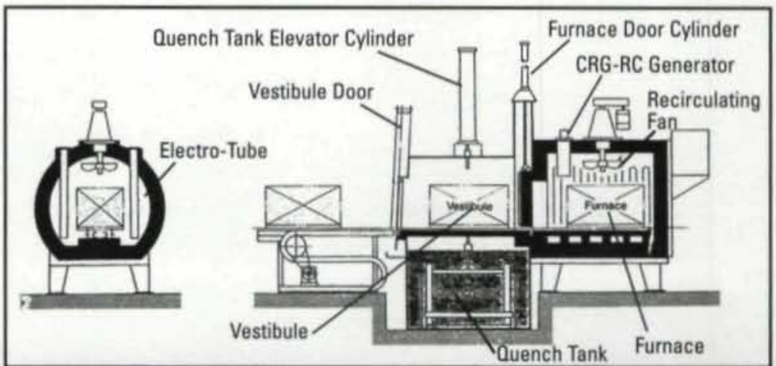


**Fig. 7 — Ceramic-lined batch atmosphere furnace.**

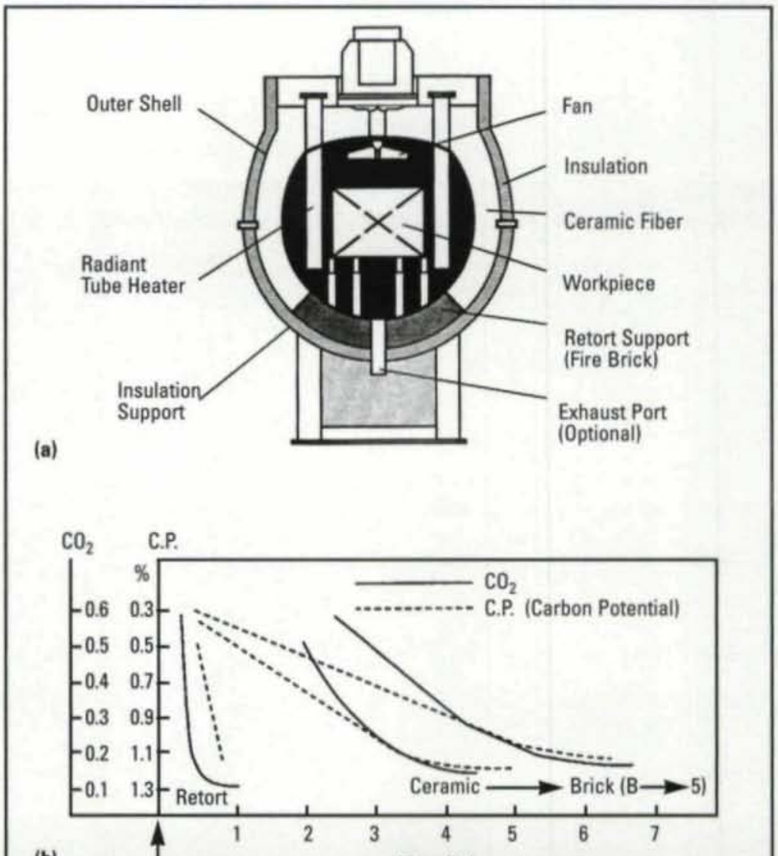


**Fig. 8 — (a) Metal-lined batch atmosphere furnace. (b) Relative rate of conditioning between ceramic-lined and metal-lined batch atmosphere furnaces.**

furnaces, such as vacuum furnaces above and below 700°C (1290°F). As with forced air circulation furnaces, variations do occur across a load. It has been shown that the circulation of the protective gas has little effect on temperature uniformity above 700°C (1290°F) because of the density of the hot gas and relatively low gas velocities. The temperature range can be up to 1250°C (2280°F), depending on the type of furnace, but normally controlled atmosphere furnaces are limited to about 1100°C (2010°F).

***Heating and Cooling Rate***. The cooling rate options are similar to the options discussed for vacuum furnaces.

***Atmosphere Integrity***. The atmosphere integrity depends on the type of furnace lining. While ceramic furnaces can be used after suitable conditioning, the metallic type is preferred. (Fig. 8 shows the relative rate of conditioning between the two types of furnaces.) When the metal retort type is used, high atmosphere integrity can be guaranteed subject to the purity levels of the gases being used. The control of the level of oxygen or mixtures of gas, such as nitrogen/methanol, needs to be monitored by oxygen probes or an equivalent system.

**Pack Hardening**

Pack hardening is very rarely used because of its lack of control and poor efficiency. It is worth noting that in certain circumstances the parts to be treated can be wrapped in stainless steel foil and then pack hardened. This improves the surface of the part being processed, but does not guarantee surface integrity.

**Ranking of Equipment Types**

A rating of each type of equipment discussed is given in Table 1. The basis of the rating system is detailed below.

*Temperature Range and Uniformity*. On the basis that 1200°C (2190°F) is generally the maximum temperature used for heat treatment of most tools and alloy steels, all plants with the exception of the pack process receive the maximum points in this category.

The temperature uniformity within a part and throughout a load are important factors. In general all furnaces subject to suitable equalization of temperature in an empty furnace can exhibit better than ±5°C (±9°F) and in the case of salt baths and fluidized beds, ±3°C (±5.4°F). However, the temperature variation is significant in loaded vacuum and controlled atmosphere furnaces and reflects the problems mentioned in the previous section. Therefore the rating for uniformity of temperature is reduced for these two alternatives.

*Heat Transfer Rate and Uniformity of Heating*. An important aspect of heat treatment is the uniform heating of all parts in a load during a heat treatment cycle. Liquid-like media are far

**Table 1 — Rating of Equipment Based on Quality Factors**

| Factor | Possible Points | Vacuum Furnaces < 1 Bar (14.5 psi) | Vacuum Furnaces +5 Bar (73 psi) | Vacuum Furnaces Option (Multi) | Fluidized Bed | Atmosphere Furnace Ceramic | Atmosphere Furnace Metal | Salt Bath | Pack Hardening |
|---|---|---|---|---|---|---|---|---|---|
| Temperature Uniformity Empty | 10 | 8 | 8 | 8 | 10 | 8 | 8 | 10 | 5 |
| Temperature Uniformity Loaded | 10 | 7 | 7 | 7 | 10 | 8 | 8 | 10 | 5 |
| Heating Rate | 10 | 6 | 6 | 6 | 9 | 8 | 8 | 10 | 5 |
| Uniformity of Heating | 10 | 8 | 8 | 8 | 10 | 9 | 9 | 10 | 6 |
| Surface Finish | 10 | 10 | 10 | 10 | 8 | 8 | 8 | 7 | 5 |
| Surface Structure | 10 | 10 | 10 | 10 | 10 | 8 | 10 | 9 | 7 |
| Temperature Range 1200°C (2190°F) | 10 | 10 | 10 | 10 | 10 | 7 | 10 | 10 | 8 |
| Cooling Structure | 10 | 5 | 8 | 10 | 10 | 8 | 8 | 9 | 5 |
| Cooling Distortion | 10 | 10 | 8 | 10 | 9 | 9 | 9 | 9 | 10 |
| Quality Control of Variables | 10 | 9 | 9 | 10 | 10 | 8 | 9 | 7 | 7 |
| **Rating %** | **100** | **83** | **84** | **89** | **96** | **73** | **83** | **91** | **63** |

more uniform, achieving similar heating performance throughout a load, than those processes relying on radiation and/or convective heating unless, of course, only one part is being treated. Liquid salt baths give excellent results. Correct loading of the parts and correct processing have been shown in a number of papers to produce uniform results.

Similar results can also be shown with fluidized bed furnaces. For uniform quality of heat treatment, all parts should have exactly the same time at holding temperature, but in practice, because of radiation and part shielding in the center of loads, a wide tolerance is placed on the holding time with vacuum furnaces. Alternatively, techniques such as forced convective heating, stepped heating or holding at a lower hardening temperature for a longer time have been adopted to overcome this problem, and, subject to careful control, reported results have been satisfactory. However, these steps introduce a time and economic penalty by comparison with salt and fluidized bed furnaces and therefore are rated lower in Table 1. Atmosphere furnaces have similar problems in practice, although the use of a high-temperature fan circulating the protective gas is an improvement.

*Distortion Control During Heating*. The control of distortion during heating is achieved differently in different processes. In general, to minimize distortion it is important to equalize the temperature throughout the part before it undergoes phase changes. In the case of liquid-like media, step heating at various temperatures is used to equalize the temperature between the center and surface of the part. In radiation furnaces where the temperature difference between the center and surface of the part is less, some preheating steps are still necessary. For example, Fig. 9 shows the differences between the center and surface of sections 25 to 100 mm (1 to 4 in.) diameter, when heated to 1000°C (1830°F) in cast iron chips and a salt bath furnace. If the procedures above are adopted, then experience shows that control of distortion during cooling is more important than during heating.

*Distortion Control During Cooling*. It is in the cooling phase of heat treatment that most shape and size distortion occurs. For example, for optimum structure in H13, M2 and high-speed steels, the fastest cooling rate possible is required to avoid formation of proeutectoid carbides, pearlite and bainite. This causes significant size distortion during quenching, and while tempering reduces it somewhat, for optimum quality this distortion must be accepted by the user. A compromise process called marquenching, which balances good microstructure against low distortion, requires quenching as quickly as possible to just above the martensite start temperature and equalizing the section temperature before further cooling. For this use, salt baths and fluidized beds with fluid-like media prove best.

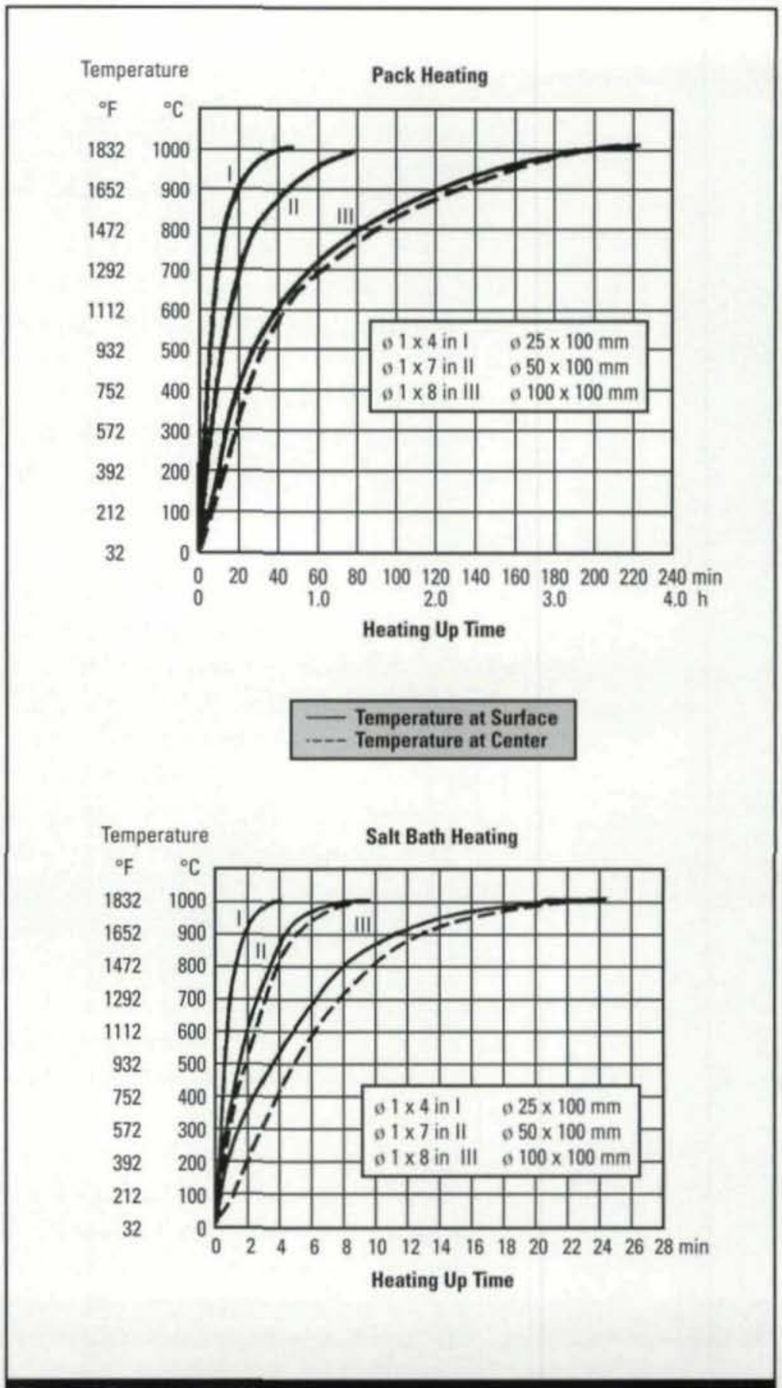


**Fig. 9 — Comparison of heating rates, salt bath heating vs. pack hardening.**

In vacuum furnace pressure quenching, the use of step quenching, as originally proposed by this author in 1972, is theoretically possible and in some cases practiced, but some inherent problems must be overcome. The gas used for the quench is generally at approximately 50–70°C (120–160°F), to achieve maximum cooling rate, and this can cause thin sections of the workpiece to transform to martensite long before the rest of it has reached 500°C (930°F). If an attempt is made to avoid this by decreasing the cooling rate, an unsatisfactory microstructure results.

In addition, many heating and cooling tests confirm that forced convection causes variable cooling rates over the surface of parts being treated, because of a large difference in the relative rate of heat transfer between vertical and horizontal flow, as well as temperature differentials in the gas being circulated. Quenching in salt baths and fluidized bed furnaces is much more satisfactory than in vacuum and controlled-atmosphere furnaces. Another factor to be considered is the relative cost of pressure quenching, which requires 52–75 kW (70–100 hp) fans vs. 1.5 kW (2 hp) for fluidized beds, compared with salt bath or fluidized bed cooling. The use of fluidized beds and salt baths in conjunction with vacuum, i.e., heating in a vacuum and quenching in a fluidized bed, is an obvious way to overcome the problems associated with pressure quenching.

*Atmosphere Integrity*. The effects of atmosphere integrity are most evident in the surface microstructure and finish of the workpiece. It is important to understand the variables that can affect the surface in any of the above processes. For example, the surface finish after heat treating in a vacuum furnace may be bright, but the surface may have been decarburized, or certain of the alloying elements may have been removed from it. In a vacuum furnace, the absence of an atmosphere is what preserves surface quality. The two critical parameters are the leak rate of the furnace and the vacuum level at which it is operated. It is generally recognized that a well-maintained vacuum furnace has excellent atmosphere integrity. Such furnaces are used for critical applications in the aerospace industry. In using a vacuum furnace, it is important to check its leak rate at regular intervals. In critical work, it should be monitored by means of a residual gas analyzer, because every time a vacuum lock or door opens or closes, the possibility of a leak increases. It should also be understood that most vacuum furnaces have pumps that are sufficiently oversized to maintain a reasonably good vacuum despite the presence of a significant leak. Thus a vacuum gage reading at the proper level does not necessarily mean atmosphere integrity is perfect.

For controlled atmosphere furnaces or fluidized beds, the effect of trace gases on the surface of metals has been thoroughly discussed in the literature and will not be covered in detail. The major gases of concern are oxygen, carbon dioxide, carbon monoxide and water vapor, as well as traces of hydrocarbon gases. Where high-purity gases such as nitrogen or argon are

**Table 2 — Recommended Grit Sizes for Polishing After Heat Treatment**

| | Grit Size | | | | |
|---|---|---|---|---|---|
| **Steel Grade** | **Vacuum** | **Cast Iron Chips** | **Salt Bath** | **Fluidized Bed** | **Protective Gas** |
| O1 | ≤600 | ≥180 | ≥180 | ≤400 | ≥400 |
| P20 | ≤600 | ≥180 | ≥180 | ≤400 | ≥400 |
| H13 | ≤600 | ≥180 | ≥180 | ≤400 | ≥400 |
| D2 | 600 | ≥180 | 60 | 400 | ≥220 |
| M2 | ≤600 | ≥180 | ≥180 | ≤400 | ≥400 |
| Stainless Steel | ≤600 | ≥180 | ≥180 | ≤400 | ≥400 |

used to protect the surface of the part, trace gases can be critical to satisfactory results. For instance, nitrogen must contain less than 10 ppm of oxygen, the same specification required for the nitrogen used for quenching in a vacuum furnace. It is not enough to check the gas as delivered. The gas must also be checked and monitored in the furnace chamber itself, because piping leaks and backward diffusion of unwanted gases into the chamber can contaminate it in use. In some controlled atmosphere or fluidized bed processes, endothermic gas is used as the carrier gas, with additions of hydrocarbon gases to produce the correct carbon potential. Monitoring the ratio of the gases is performed by oxygen probe, carbon dioxide, dew point or a similar system. With proper control of the atmosphere and correct quenching, the surface of the workpieces can be free of decarburization or carburization. As discussed below, the degree of surface roughening caused by heat treating in controlled atmosphere furnaces or fluidized beds is only marginally less than that which occurs in a vacuum. In addition, metallurgical and chemical analysis shows the sub-surface structure to be unaffected when all process variables are correctly controlled.

In a salt bath, atmosphere integrity is a matter of controlling the salt chemistry. In practice, decarburization in barium chloride salts must be monitored closely, e.g., by examination of periodic test coupons of the steel undergoing heat treatment.

Finally, the importance of cleaning the work load before processing is important, because surface contamination can affect critical reactions during processing. In this respect, vacuum cleans the surface more effectively than the other techniques, because it tends to remove any contaminants present during initial pumpdown. In tests performed to establish the relative effects of various atmospheres on surface chemistry and surface finish, samples of typical tool steels were processed for up to 1 hour at hardening temperature, followed by immediate quenching to avoid any possibility of surface contamination. The samples were tested for surface roughness before and after hardening and then chemically analyzed to determine their base carbon level 10µm (394 µin.) below the surface. Fig. 10 shows the results of these tests on a D2 tool steel. The vacuum furnace

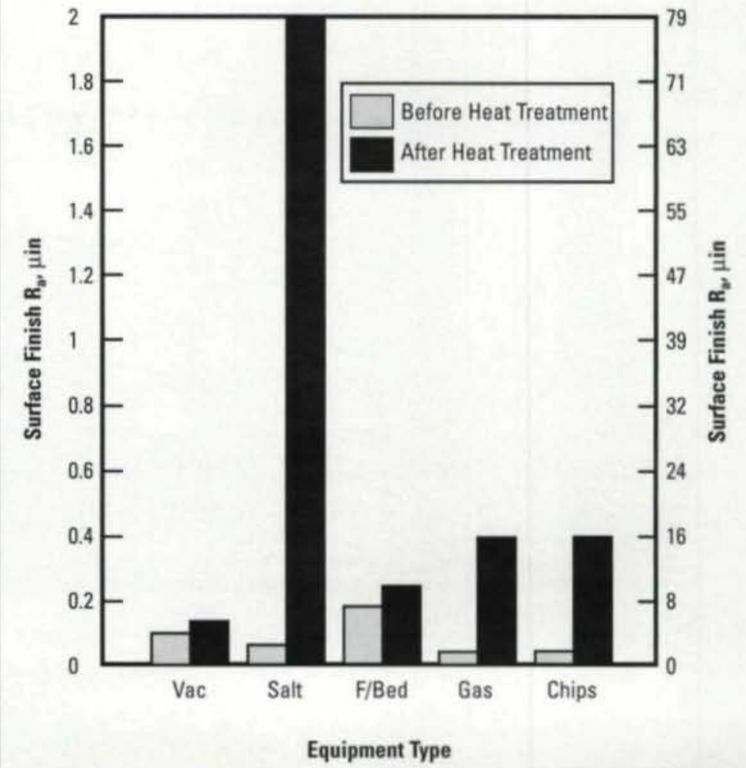


**Fig. 10 — Comparison of surface finish before and after heat treatment.**

produced a bright finish and required a minimum of polishing after heat treatment. However, the controlled atmosphere and fluidized bed furnaces also produced bright finishes with only a slight amount of surface roughness. In this respect, salt bath and pack carburizing yield clearly inferior results. Based on these factors, recommended grit sizes for polishing after heat treatment are given in Table 2. Apart from pack carburizing, all results of chemical analysis were satisfactory, with no carburization or decarburization detected. ○

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# What to Look For Before You Leap

*How to spec the hardware for your new CNC system.*

E. Peter Kovar
U.S. Tech Corporation
Chicago, Illinois

*Question:*

**We are interested in purchasing our first gear hobbing machine. What questions should we ask the manufacturer, and what do we need to know in order to correctly specify the CNC hardware and software system requirements?**

*Answer:*

Buying a gear cutting machine is no small investment. You can't afford to make mistakes, and key to a successful purchase is being clear ahead of time about just what you need. In this issue we will discuss the considerations that go into speccing CNC hardware. Next issue, we'll talk about the software requirements.

It is a good idea to have some basic understanding of the capabilities of modern CNC-equipped machines. Not all machine manufacturers offer identical capabilities, and asking the correct questions will ensure that you are not surprised or disappointed when your new machine arrives at your plant.

New users of CNC gear machinery are especially vulnerable to disappointment. A number of firms who have never produced gears before are considering purchasing their first machine. These typically are shops that have been turning blanks and sending their blanks out for cutting and are now considering buying a machine to do this work in-house. Many shops that already manufacture gears are also unsure of what to specify when it comes to machine controls and electrical systems and leave this important decision up to the vendor. Finally, users who are considering updating their machine control systems should arm themselves with some basic knowledge in order to effectively communicate their needs to the machinery or retrofit provider and to more accurately compare competitive quotations.

Although the following guidelines are specific to gear hobbers, most of the suggestions are also valid if you are specifying a shaping, grinding or other gear finishing machine.

**Which Axes Will Be Controlled by the CNC?**

A "full" CNC machine will *generally* direct all six axes normally found in a gear hobber. (See Fig. 1.) Not all CNCs control all six axes. Make sure you understand which axes are controlled by the CNC and which ones are manual. At a minimum, a CNC machine should control the three most important axes, the axial, radial and tangential slides. Depending on your needs, you can also automate the hob spindle, hobhead swivel and worktable.

In general, the more axes controlled by the CNC, the more expensive the machine. The trade-off of expense vs. changeover time depends on the type of gear products you are generating. The more changeovers you do and the more intricate the parts you manufacture, the more axes

***Gear Technology's* newest column will answer your questions about gear machinery controls and electrical systems. Send your questions about CNC, software and machinery electrical systems to Mission: Controls, P. O. Box 1426, Elk Grove, IL 60009 or fax them to 708-437-6618.**

**Peter Kovar**
*is the Vice President of U.S. Tech Corporation and a recognized authority on CNC applications.*

manufacture, the more axes you will want automated.

You should clearly explain to your vendor what type of parts you are manufacturing so that he can suggest the number of axes to control. For example, if you are using flexible manufacturing or cutting multiple gears on a long shaft, and you are concerned with long setup times, you will require a full six-axis CNC machine. On the other hand, a machine for automotive use may not have the hobhead swivel controlled by the CNC, since it is usually cutting only one part, and the position of the hobhead may not change for years.

Before you decide that a particular axis can remain manual for your application, keep in mind that it is not only the time it takes for an operator to change over the machine that you should consider. A gear engineer will need to specify the machinery settings and calculate the correct input. In a full CNC machine, the control automatically calculates many of the more complicated settings. CNC machines require fewer inputs (making for fewer input errors), since some of the inputs are calculated for you. You will need simpler setup sheets, fewer tools and specialized operator skills and less changeover time.

CNC machines have numerous other automated features. For example, the CNC today can calculate from the menu entry the usable hob length, how many parts can be cut on the loaded hob and automatically reposition the hob to recut a workpiece.

### Digital Versus Analog Drives and Motors

Digital drive and motor systems should be specified whenever possible. The older analog drives require periodic maintenance that far outweighs the higher upfront cost of a digital system.

Analog drives (like analog radio tuners) will over time "drift" out of tune. The

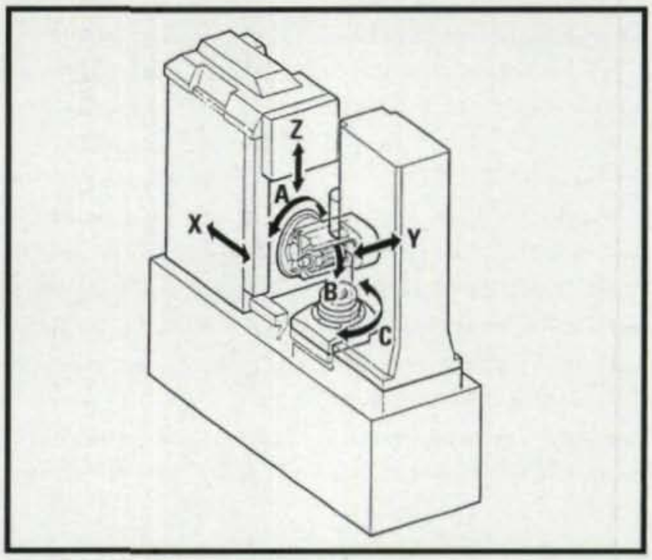


**Fig. 1 — Typical 6-axis machine. X = radial; Y = tangential; Z = axial; A = hobhead swivel; B = hob spindle; C = worktable. (Courtesy of NUM Corporation. Used with permission.)**

result is that the machine may not be able to make quality parts or run at full speed. Retuning the drives requires a skilled technician and is not normally attempted by the maintenance department. Digital drives do not require periodic tuning and run maintenance-free.

### DC or Brushless DC Motors

DC motors run on direct current. They have a "commutator" that changes the direction of electric current in order to make a rotary magnetic field, which in turn moves the motor. The commutator is nothing more than copper contacts with brushes. These brushes will eventually wear out, especially if the motor develops a leak or is not sealed properly.

A brushless DC motor has an electronic commutator that changes the direction of the electric current using transistors (no brush contact). These motors require little or no maintenance. (Some engineers argue that a brushless DC motor is really an AC motor because the transistors emulate the alternating current.)

You should weigh the advantage of a maintenance-free brushless DC motor against the lower cost of a traditional DC motor when specifying your machine tool.

### Drives

If you have a CNC system, you have a drive. It is an intermediary device that helps the CNC system communicate with the electric motors of the machine itself. CNC systems are very low power devices; on the other hand, the electric motors attached to the machines require high voltage, current and frequency. The CNC therefore needs to send the appropriate data to the "drive" hardware to interpret, amplify, filter and "drive" the motor.

### Absolute Scales

Modern CNC machines are equipped with absolute scales (optical, magnetic, etc.), which give the machine a reference point for positioning on the slide. Without these scales, a machine will need to be taught the home position whenever it is turned on. "Homing" is the term for sending the machine slides to a known reference position. Most modern machines are equipped with absolute scales that will remember the exact position of the machine, even if the machine is turned off. In addition to eliminating the need for homing, absolute scales also increase the accuracy of the machine. The cost of absolute scales is negligible, and in general they should be specified whenever possible.

Keep in mind that the leading cause of machine crashes is the incorrect manual homing by the operator. Operators must be trained to manually home a machine correctly if absolute scales are not purchased. Tool or fixture interference can sometimes make this task difficult.

### Rotary Encoders

Many modern machines come with built-in rotary encoders. One difference between scales and rotary encoders is that rotary encoders are more rigid and dependable. Scales still require some maintenance (occasional cleaning), although new technologies are being introduced to make scales as maintenance-free as rotary encoders. An absolute scale will give you more accuracy on the machine because the measurement of the slide is direct. The rotary encoder measures the slide position indirectly as a factor of the turning of the ballscrews. Modern rotary encoders and CNCs can even correct the inherent errors in the ballscrews. During the manufacturing process, the machine tool builder can "teach" the CNC where the errors are in the ballscrew and compensate for these errors. The only problem with this correction is that it is not consistent over the lifetime of the machine. As the ballscrew mounting brackets loosen or the screws get out of position, the machine's error correction will come out of alignment. The error compensation can be corrected in the field, but again, this is out of the area of expertise of most gear shops.

### Screen Type and Size

This is not a minor issue and should be discussed with your supplier. As you might guess, the bigger the better as far as screen size is concerned. Larger screens generally result in reduced eye strain and fewer screens to flip between because more information is displayed per screen. Do not assume that the screen size can be increased later if necessary. If you later decide to increase the screen size, the software may not display properly without a costly rewrite.

Color screens are generally easier to use than monochrome screens. Make sure that the software you purchase uses the color capability wisely. Warnings, data input screens, help screens, etc., should use color intuitively to convey important information and reduce the number of input errors.

All major CNC manufacturers are offering a color matrix flat screen option to the more traditional cathode ray tube. These screens are limited in size for now and are quite expensive. Machine vendors may use this type of screen when they mount screens on machinery with space limitations or in an effort to make the machine more ergonomic.

The mounting of the screen should also be discussed with your vendor. Depending on the type of machine, you may wish to have the screen mounted on the machine or electrical cabinet or on a pendent. You should also consider the possibility of the vendor providing some type of hand wheel device for data input and machine setup. Give some weight to ergonomics when analyzing your total system costs. Ask the vendor for a layout of how the finished product will look.

### Data Input

If you plan to input large amounts of data (say you are a job shop making many parts), you should discuss with your vendor what data input options are available.

Some manufacturers offer a full "QWERTY" keyboard option. These typewriter-style keyboards are much less cryptic and easier to use than the multipurpose keypads that are usually part of a standard CNC. A pointing device or mouse may also be helpful on some systems.

If you are interested in loading part, process and tooling data from a central computer, ask for a quote on a DNC (direct numerical control) option. Additional hardware and software may be required.

You should also ask your vendor how the CNC system is to be backed up. Some vendors use diskettes; others may use PCMCIA cards or back up the systems using the RS232 or DNC port. The media is not really that important, but the method you use to back up the system should be straightforward.

### Limit Switches

Be certain the machine you are buying has emergency stop limit switches. Some manufacturers omit these safety devices in an effort to lower the cost of the machinery. Even machines equipped with absolute encoders can sometimes lose their memory if the backup battery fails. In this case the machine will need to be re-homed. If this is not done properly, you can damage the machine. Limit switches on key slides will save you money. The cost is low, about $100 per axis. Over the life of the machine, these low-cost limit switches will save you money even if you have only one crash. Not specifying limit switches is akin to buying an expensive electrical device and not protecting it with a low-cost fuse.

### Mechanical Variable Speed Drives

If you are purchasing an older machine and retrofitting it with a modern control, one problem you may need to address is whether to have the variable speed drives replaced with a CNC-controlled motor.

A mechanical variable speed drive is generally used to mechanically control the main spindle speed (from pre-CNC days), and in the past was also used for the feed drives. Variable speed drives are high-maintenance items and should be replaced with a direct drive motor whenever possible. Depending on how you size the motor, a retrofitted machine may have reduced cutting torque and horsepower at low speeds compared to a mechanical variable speed drive.

A simple alternative to a variable speed spindle is a lower cost, fixed-speed main spindle. This is an acceptable alternative for some simple applications, but for multiple cutting cycles or complex cutting cycles, you will need to change the spindle speed. ○

**Tell Us What You Think...** If you found this article of interest and/or useful, please circle Reader Service **Number A-134.**

## TECHNICAL CALENDAR

**March 9–11**
AGMA 79th Annual Meeting, Loews Ventana Canyon Resort, Tucson, AZ. This year's theme is "Restructuring for the 21st Century." For more information, call (703) 684-0211 or fax (703) 684-0242.

**April 4–5**
SME Course. Statistical Process Control for Gears. SME Headquarters, Dearborn, MI. Two-day course covers metrology, SPC basics, gear applications, problem solving and more. Case studies included. For more information call Susan Mahilik, (313) 271-1500, x384.

**April 4–6**
American Pfauter/Pfauter-Maag Gear Clinic, Loves Park, IL. A 3-day clinic on modern methods, applications and hardware in spur and helical gear manufacturing and measurement. Contact Connie McIntosh at (815) 282-3000 x336 or by fax at (815) 282-3075.

**April 10–14**
AGMA Training School for Gear Manufacturing, Spring Session. Daley College, Chicago, IL. Basic training for gear manufacturing. Call AGMA at (703) 684-0211 or fax (703) 684-0242.



***Gear Technology*
Employee Executions:**
Yesterday in the parking lot, by falling on her blue pencil, the editor who mis-identified Joe Arvin of Arrow Gear in our last issue. Mr. Arvin is the president of Arrow Gear Company in Downers Grove, IL. We apologize to Mr. Arvin and regret any inconvenience to our readers.

Material Update

ADVERTISING

# Cut your teeth on ADI material...

## and watch your numbers improve... most of all, your profits.


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- Improved impact strength

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Austempering heat treatment generally costs less than typical carburizing and hardening heat treatment and produces a higher degree of uniformity and predictable growth. It's also the key to ductile iron's transformation into a new material.

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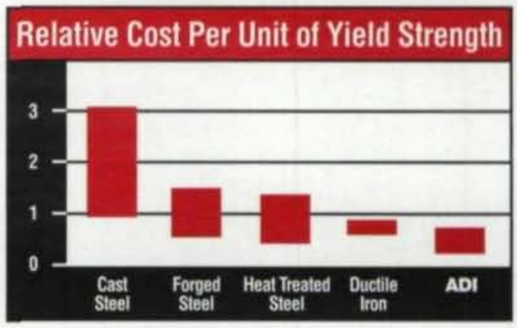
Gears are being produced in ADI material from a few grams to several tons in weight:

- Automotive timing gears, ring and pinion gears and other differential gears
- Industrial face, spur, bevel and bull gears
- Construction equipment gears

ADI is also being applied in gears for agricultural, heavy truck, railroad and maritime equipment.




**Applied Process, Inc.,** based in Livonia, MI, began as the research division of Atmosphere Furnace Company, developers and builders of heat treating equipment. AFC's research into improving heat treating processes centered on the fundamental technology of the austempering process. Applied Process, Inc. was formed from this research to provide contract heat treating services keyed to the austempering of ductile iron. Its team of management and technical professionals will continue to innovate in the metalworking field and has already expanded with a new plant in Wisconsin and a foreign licensee in Australia.

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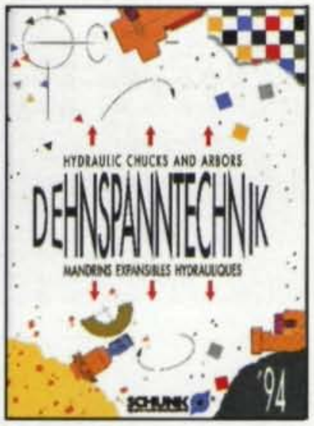
ADVERTISING SECTION

# LITERATURE MART




### ULTRA Precision Tooling

.00012" (3μm) or less is the total indicated runout for the Hydraulic Chucks and Arbors shown in this new Schunk Intec catalog. Schunk arbors are commonly used in gear manufacturing and testing applications, and Schunk chucks are used in a wide array of applications, from boring to milling, where accuracy and tool life must be optimized. For more information or to receive a free catalog, call 1-800-772-4865.

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### Video-Train Heat Treaters

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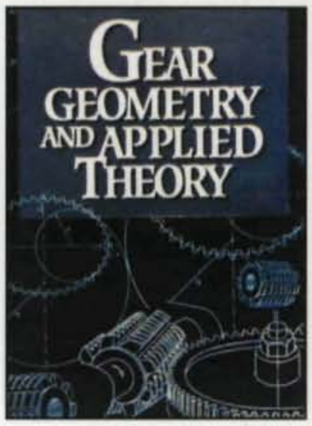



### The Complete Gear Book

*Gear Geometry & Applied Theory*, by Faydor L. Litvin, covers the modern theory of gearing, geometry, design and computerized simulation of meshing and contact for almost all gears; the geometry for face-gear drives, double circular-arc helical gears; CNC applications and new approaches for tool design. **Prentice-Hall**, 1994. $72.00. To order call (800) 947-7700.

# The Second Edition...

*Gear Technology's bimonthly aberration — more gear trivia, humor, weirdness and oddments for the edification and amusement of our readers — and absolutely nothing about O.J. Contributions are welcome.*

### Gearing for Munchkins

Gene Kasten, president of Repair Parts, Inc., of Rockford, IL, is the proud owner of a miniature Barber-Colman hobber, the only one of its kind in the world. The machine, a replica of the old B-C "A" machine, was built between 1933 and 1941 by W. W. Dickover, who devoted 2,640 hours of his spare time to the project.

The machine, made from cast aluminum, stainless steel and bronze, was built to scale from the original drawings of the full-sized machine. Driven by a $^1/_{32}$ hp motor, the miniature "A" weighs 19 lbs. It's $13^1/_2$" long, 6" wide and $11^1/_2$" high. The maximum travel of the hob slide is 2", and the work size is $2^1/_4$" diameter x 2" face x 40 DP or finer. The machine will cut spur and helical gears and spline shafts.

The 8-year project was something of a hobbyist's tour de force. Dickover, a toolmaker and later a salesman for Barber-Colman, reduced the drawings to $^1/_6$th size himself and made every one of the 642 parts, with the exception of the castings and the gears, in his basement workshop. He also made his own cutting tools to produce parts for the machine.

The hobber actually works. Dickover cut a 48-pitch, 48-tooth gear with adjacent tooth spacing that checked to within .0003" and non-adjacent spacing to within .0004".

The machine is on display at Repair Parts, Inc. Call 815-968-4499 for more information.

### Let There Be Lightbulb Jokes

If you thought these were as passé as Madonna, you're wrong. Some of the latest circulating on the Internet, according to *Wired* magazine, the hot chronicler of cybernews, include:

**Q: How many q/c testers does it take to change a lightbulb?**
**A:** *We just noticed the room was dark; we don't actually fix the problem.*

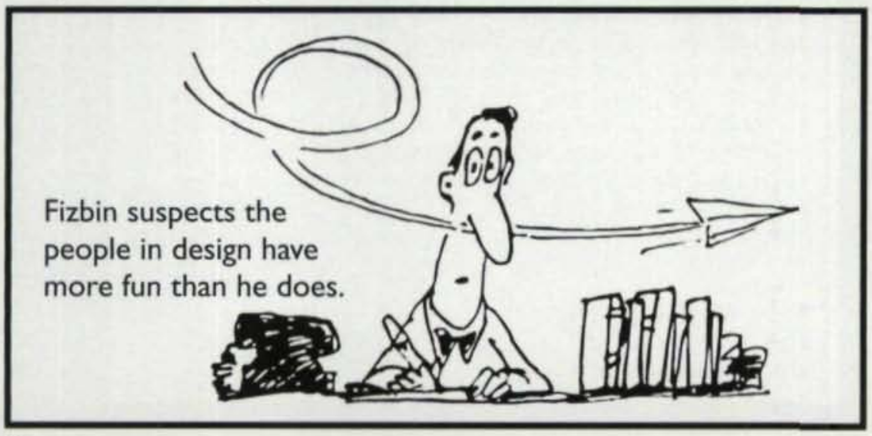
**Q: How many shipping department personnel does it take to change a lightbulb?**
**A:** *We can change the lightbulb in seven to ten working days, but if you call before 2 p.m. and pay an extra $15, we can get the bulb changed overnight.*

### Mark This Place

U.S. Patent No. 5,311,835 was issued to Horace Knowles for his PlaceMark, which the inventor says is state-of-the-art in bookmarks. For those of us who have trouble remembering where we left the book, much less where on the page we stopped reading, the PlaceMark has "Odd" printed on one side and "Even" on the other. The top third of each side is a scale marked "top, $^1/_4$, $^1/_2$, $^3/_4$." The bookmark is inserted so that it indicates to the memory-impaired reader whether to start reading on the odd or even numbered page and how far down the page to begin. Knowles predicts that the PlaceMark, "has the potential of changing forever the way many millions of readers mark their place in a book." Maybe.

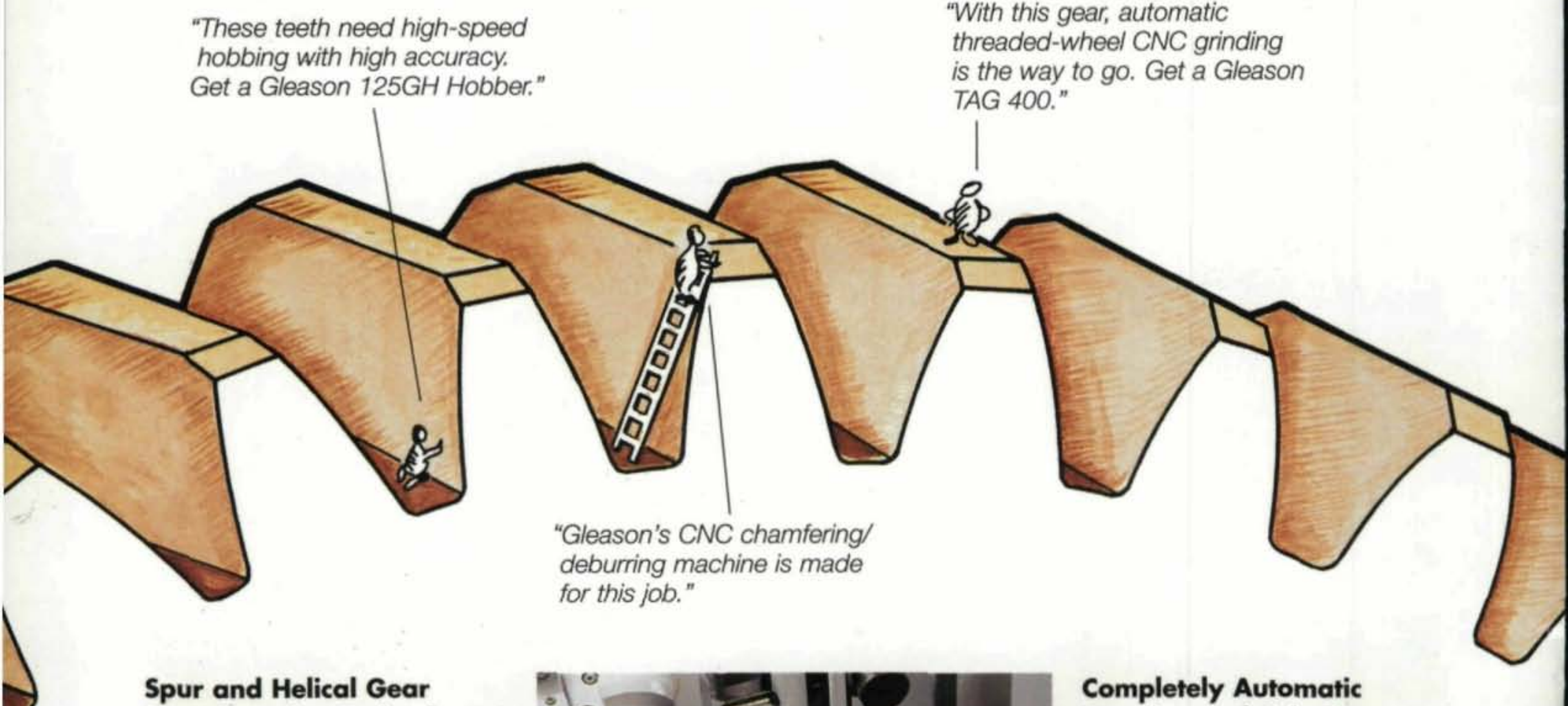
### Solutions

If you're still struggling with the answer to our "Puzzling Scales," relax. Try the following algebraic solution. Let: b=weight of a bottle; g=weight of a glass; p=weight of a pitcher; s=weight of a saucer. Each weight now can be represented by an equation. (1) $b+g=p$; (2) $b=g+s$; (3) $2p=3s$. We want to find $b=?g$. Transform equation (3) to $(2/3)p=s$. Replace $(2/3)p$ for s in equation (2), and we get $b=g+(2/3)p$. Call this equation (4). Simplify this equation and solve for b in terms of g, giving $b=5g$. Therefore, 5 glasses balance 1 bottle.



Fizbin suspects the people in design have more fun than he does.

# THE WHOLE TOOTH... AND NOTHING BUT THE TOOTH.

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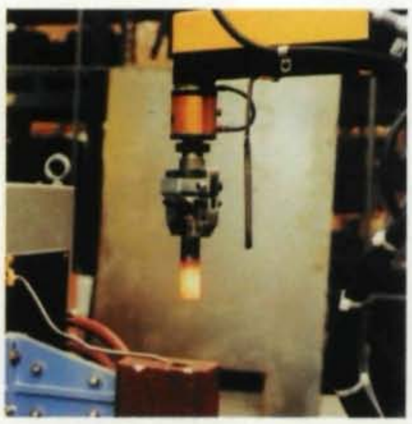

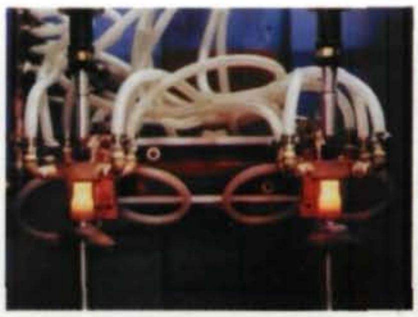

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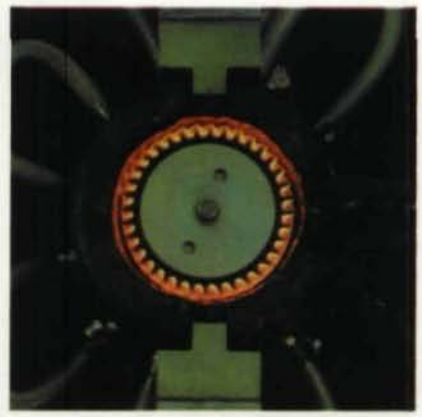

Let Ajax help make your next heat treat project a success. Write to: Ajax Magnethermic Corp., 1745 Overland Avenue, Warren, Ohio 44482. Call toll-free 1-800-547-1527, Fax (216) 372-8644 or in Canada call (905) 683-4980.

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