GEAR TECHNOLOGY

THE JOURNAL OF GEAR MANUFACTURING

JANUARY/FEBRUARY 1991

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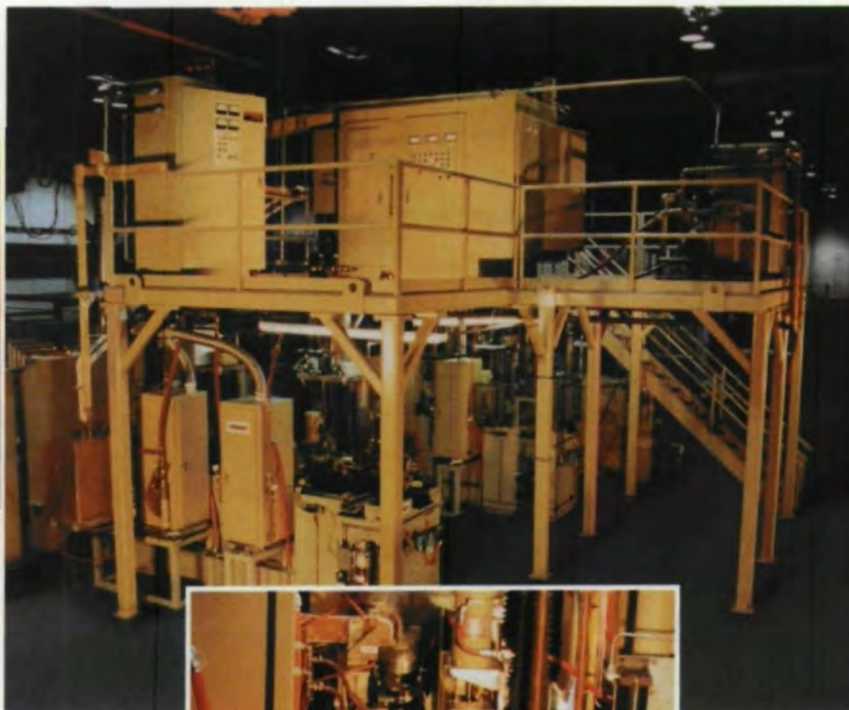

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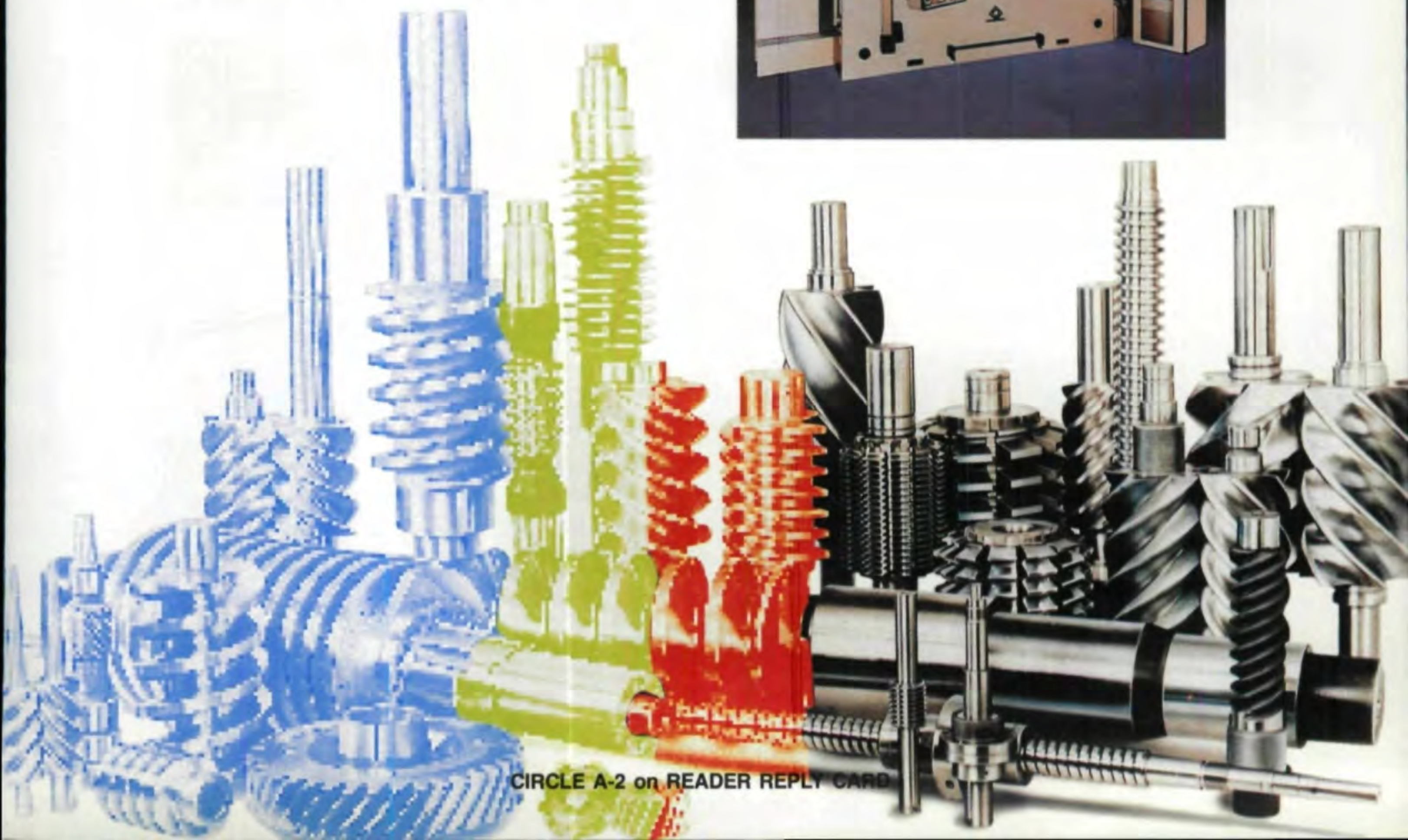

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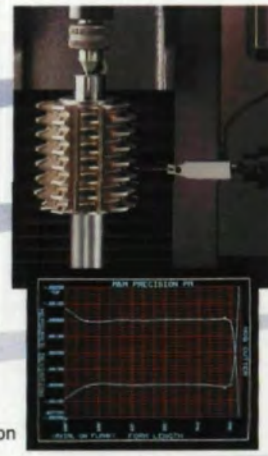
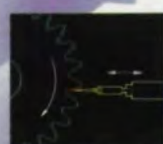


Hob Inspection

Gear Testing using Generative Metrology techniques is enhanced by computerized automation and analysis. True index, lead, and involute testing are performed as the test part and probe are engaged in inter-related continuous movement. Rotary and linear axis are synchronized as required by the test.



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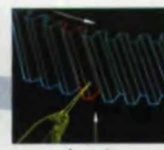

Lead

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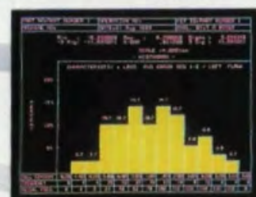

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The Winds of Change

"I have seen the future and it works."
Lincoln Steffens

Nashville – One of the highlights of this year's SME Advanced Gear Processing and Manufacturing Clinic was a tour of the new GM Saturn automobile manufacturing plant outside the city. There in the Tennessee hills is a hopeful vision of the future of the American automobile industry. It may well be the future of American large-scale manufacturing in general.

Lately in this country, a lot of predictions about the future involve gloomy visions of societal malaise, economic decline, and general American second-rate-ism. Places like the Saturn plant suggest that these prophets of gloom could be very wrong.

The Saturn plant is a different kind of manufacturing facility – different in design, layout, and attitude. My first impression of the Saturn plant compares favorably with that of other automotive plants I've seen. The Saturn plant is clean and efficient. The aisles are wide. The shop floor is immaculate. No loose tools, materials, or miscellany are stacked around to impede progress or endanger staff. The general impression is similar to entering an electronic clean room or a medical products manufacturing line.

The second thing that struck me was the amount of automation in place at the Saturn plant. Machinery does most of the work. Furthermore, this machinery is far more flexible than that found at other automobile factories. Every change in part design does not require a change in machinery.

The huge staffs on other automotive plant lines are also a thing of the past at Saturn. Work flows automatically along the production line, monitored by half-a-dozen people, as opposed to the 30, 40, or more on an old-style line. Inventory is not allowed to pile up, but is moved quickly to the next step in the manufacturing process by machine.

While the Saturn plant uses far fewer people than the old-style system, the people who are used are used much more effectively – and this usage shows in their attitude and morale. The people we met were enthusiastic about their jobs. They seemed committed to quality products and excellent performance and determined to do the job right. Most important, I got the distinct impression that this attitude was genuine, not just something put on to impress visitors.

PUBLISHER'S PAGE

I suspect that a good deal of this attitudinal difference has to do with the different managerial techniques that the Saturn plant has implemented. Instead of a hierarchical system with many layers of management, the team concept is used. Everyone involved in the production of a component – designers, processing and manufacturing engineers, shop floor workers, quality control and marketing staffs – all are part of the *team* and part of the decision-making process. Individual workers are given much more control over their areas of responsibility. In short, the line workers are treated as important members of the manufacturing team, not just cogs in the system. This process makes for workers who feel as though they are important team members, involved in the *total* process and committed to its success.

Admittedly, it's still early days at the Saturn plant. The factory is designed to manufacture 1000 cars a day, and, at the time of our tour, was in its shake-down phase, with output of only about 100. No one knows for sure how well this system will work under the pressures of full production. Furthermore, efficient manufacture of a product is only the beginning of making Saturn a success. The complex problem of selling the cars in a crowded market remains. However, at this juncture, everyone involved with Saturn is very enthusiastic and optimistic about the probable results. I think that after the shake-down, the system will work every bit as well as it does now. The people will make it work.

And how does the Saturn experiment relate to American manufacturing as a whole and to gear manufacturers in particular? A number of points are already obvious. First, the future of American manufacturing is moving in the direction of more and more automation, fewer employees, less inventory build-up. Companies that wish to remain competitive need to be looking in that direction when making capital improvements. Secondly, one of the most important new manufacturing tools in the Saturn plant is communication. The most progressive and exciting work in the coming years will be done by companies using some variation of the Saturn team approach.

PUBLISHER'S PAGE

Riding out the winds of change is the manufacturing challenge of the 1990s.

Dismissing the whole Saturn concept is easy. Any of us could build a state-of-the-art manufacturing plant if we had the resources of a General Motors. Those of us in businesses where capital improvement must be done slowly and carefully in small increments may find a Saturn-like manufacturing facility only within the realm of science fiction. At the same time, the Saturn plant is the direction in which we should be looking when we do our capital investing. We can't tear down our factories and start over, but every change we make should be integrating the newest manufacturing processes into our systems.

The other half of the Saturn approach – the management team concept – doesn't take a big capital outlay to implement. What it does take may be something even harder to come by – a change in attitude. We have to look honestly at our own plants and organizational charts and ask ourselves whether or not there may be better ways to do our jobs, even when the present way is comfortable and easy out of long habit. As managers, we will have to shed some long-cherished assumptions about power and how to use it and about our employees and who they are and how they work.

Team concept manufacturing, such as is practiced at the Saturn plant, is not some mysterious Oriental philosophy that can be learned only at the hands of a guru imported at extraordinary expense, nor is it some alien system that runs against the American cultural and emotional grain. The idea came originally from an American industrial designer, W. Edwards Deming. It is simply a way of looking at getting the job done that admits that just because we're managers, we may not know everything; that the people on our shop floors or in other departments may have some valuable insights into the way our products are manufactured; that our employees are people too, and if we treat them like intelligent, responsible associates with a vested interest in getting the job done the best possible way, they might just respond accordingly.

All this is not easy, but it's also not impossible. It does require an attitudinal change, a change in perspective. It's something that doesn't require a capital investment, and it doesn't have to be expensive to implement – at least not as expensive as refusing to change and letting your competitors in this country and elsewhere take away your business and your jobs.

The winds of change are blowing harder and harder through the American economy. Riding them is THE manufacturing challenge of the 1990s. In spite of all the doom and gloom in the forecasts, and in spite of all the legitimate causes for concern about our economic future, the game is far from lost. There are steps we can take and things we can do to keep our footing, both as individual businesses and as a country. The Saturn plant is a shining example of creative innovation. Careful study of it would be a worthwhile exercise for anyone interested in the future of American manufacturing.

Michael Goldstein

Michael Goldstein,
Publisher/Editor-In-Chief

AGMA Responds to Gear Standards Article

VIEWPOINT

The authors of last issue's article comparing AGMA, ISO, and BS methods for Pitting Resistance Ratings are commended. Trying to compare various methods of rating gears is like hitting a moving target in a thick forest. The use of different symbols, presentations, terminology, and definitions in these standards makes it very difficult. But the greatest problem lies with the authors' use of older versions of these documents. ISO drafts and AGMA standards have evolved at the same time their work was accomplished and edited.

This overview is written to convey the current status of these standards. I will clarify where AGMA standards and ISO drafts differ from what was presented in the article by Dr. Walton and his colleagues.

In November, 1988, *Gear Technology* allowed AGMA to review the authors' draft of this article. I thank the publishers for that opportunity and the authors for incorporating a few of my suggestions. However, ensuing events have changed the complexion of ISO drafts.

Two parts of the ISO draft for spur and helical rating (ISO/DIS 6336, developed in the 1970s) were balloted in the early 1980s and *disapproved* – not "approved" as stated. Before 1985 the drafts were reworked into five parts for re-balloting. These drafts were apparently used by the authors. To resolve conflicts, the ISO working group responsible for the standards development made a number of changes to ISO/DIS 6336, most significantly in September, 1989, when:

- The application of the standard was limited in helix angle, pressure angle, and addendum modification (a/k/a profile shift or rack shift) range. This was because calculated ratings were inconsistent with experience at some values.
- The life factor curves were modified because some materials do not have known endurance limits.

Due to lack of consensus, the scuffing proposal (ISO/DIS 6336-4) was changed from a standard in October, 1990, to be rewritten as a Draft Technical Report (DTR). The current status of each of the parts of ISO/DIS 6336 is:

Part 1 (common factors, load distribution, dynamic load, etc.) will be balloted this spring (1991).

Part 2 (pitting) was balloted at the end of 1989.

Part 3 (bending) is being balloted as of this writing, Nov. 1990.

Part 4 (scuffing) has been made a DTR.

Part 5 (allowable material stresses) was balloted in the summer of 1990.

The four sets of ballot comments will be formally resolved by ISO's consensus process in June or September of 1991. After ballot resolution, the DIS could become an international standard in 1992 if there are no appeals.

In the meantime, ANSI/AGMA 2001-B88 (1988) was approved to replace AGMA 218.01 (1982). ANSI (American National Standards Institute) and AGMA documents must be revised or reaffirmed every five years. New versions of ANSI/AGMA standards tend to be implemented fairly rapidly in the USA, primarily because they are widely circulated during the consensus approval process. ANSI/AGMA 2001-B88 is significantly different in the application of measurable material quality to allowable stress levels; the introduction of a rim thickness factor; and a clear difference between "application factor" and the old "service factor." The next revision, AGMA 2001-CXX, is being reworked in committee to incorporate the

Letters for this *column should be addressed to Letters to the Editor, GEAR TECHNOLOGY, P.O. Box 1426, Elk Grove Village, IL 60009. Names will be withheld upon request, however, no anonymous letters will be published.*

latest thinking and experience.

In addition to the differences mentioned above, there are some specific items in the Walton article which should be mentioned:

• The various ISO methods for determining "influence factors" are not "depending on the application and accuracy required." Very little guidance on which method to apply is given. It's simply left to choice. Uninformed users are not made aware of how much accuracy is required. There is little correlation between the complexity of each calculation method and accuracy produced. Experience is lacking to be sure the more complex mathematical methods are capable of predicting gear failures more consistently than the

VIEWPOINT

older, more empirical, methods.

• The word "similar" implies similar calculation results between BS 436 and ISO/DIS 6336. But in some cases only the presentation of symbols is "similar," while calculated results can be quite different. The values for Z_N are a good example.

• The authors' statement that "Like the other standards, the new British standard uses modified Lewis and Hertz equations..." glosses over significant differences. Both the ISO Draft International Standard (DIS) and BS 436 (1986) use a 30° inscribed triangle and tooth tip loading to determine the applied point and maximum amount of bending stress. This approach is very different from Lewis' inscribed parabola, particularly for gears with large addendum modification. In the Hertz equations, the methods for spur gears are identical, except for the inclusion of an extraneous factor in the ISO, DIS, and BS 436. This factor increases the calculated capacity of spur gears by Z_{ϵ^2}, or about 25%, compared to ANSI/AGMA ratings.

• To calcuate the ANSI/AGMA geometry factors, one must know the generating tool configuration. The authors do not express this.

- The statement "...although AGMA and ISO both introduce a service factor..." is incorrect. AGMA 218 and ISO have both introduced an "application factor," which is different in concept from the old AGMA "service factor." The service factor included service life requirements, which the application factor excludes.
- AGMA does not have "...the definition of endurance limits." That concept, as implied by ISO, was deleted with the introduction of the life factor curves in AGMA 218. AGMA standards do not recognize an endurance limit for gears.
- Not only BS, *but also* ANSI/ AGMA standards "allow(s) for the higher permissable stresses to be obtained from using higher quality materials." This was expressed in Sec. 2.5.3 of AGMA 218, and ANSI/ AGMA 2001-B88 gives specific quality requirements for each allowable material stress.
- Standards developers should know the distribution of test or experience points used to develop life factor curves. This distribution, statistically analyzed, is used to determine the life curve and reliability (chance of failure) of a given design. This is a concept which neither BS nor ISO seem to express. ANSI/AGMA life factors are based on a 99% rate of reliability.

The authors have made a significant contribution to the general understanding of different gear rating practices, which are constantly being updated with new developments and experience.

If one wishes to stay up-to-date, involvement in national standard committees is necessary. Participation as a member of a national technical advisory group for ISO is the way to keep up with international standards. If you wish to participate in any way, please contact me at AGMA headquarters.

William A. Bradley,
Manager, Technical Division
AGMA

The Marketing Menagerie: What's Right For You?

Phil Callighan

MANAGEMENT MATTERS

You get calls and letters every day from people wanting you to use their ad agency, their direct mail program, their p.r. or marketing firm to promote your business. It seems everyone wants you to spend your money to communicate to your prospects and customers. But what's the best method for you?

How do you sort through the clutter, the hype, and the "better get on the bandwagon" pitches to reap some real business?

Or maybe you've tried "marketing" before with only limited success. Maybe an agency, a magazine, a printer, or someone else promised big results, but didn't deliver. On the other hand, maybe your experience has been like Fred Young's, president of Forest City Gear. Forest City Gear has a reputation for aggressive marketing, and Young credits it with "filling in the gaps" his sales force can't cover, and "keeping Forest City's name in front of customers and prospects."

Everyone talks about marketing, advertising, and public relations, but few fully understand the choices, the variables, and the possibilities involved, or what makes the difference between a successful plan and a real dud.

Here, then, is a brief overview of the scope of marketing and some of the strategies, creative techniques, media, and timing concerns every business person should consider in order to launch a successful marketing campaign.

The first step in any successful marketing program is planning. Like any other part of your business plan, marketing needs time and effort devoted to it. Marketing, as traditionally defined, oversees and directs pricing, distribution channels, new market research, and product characteristics, as well as communications to the marketplace. Yet, "marketing" is rarely given more than a couple of pages in an ordinary business plan. When marketing is discussed, the focus is generally limited to the communications aspect or confined to research. Marketing personnel in your company (or an outside agency) may be told they are to penetrate a new market, increase sales, or launch a new product; yet, they are often denied the ability to influence the factors that will let them present a powerful communication. Careful planning is what builds a solid foundation for the marketing program.

The scope of marketing is the first item you must address in your marketing plan. Ask yourself these questions:

1) Do you force customers to buy what you have to sell? Or do you allow marketing the chance to tell you what customers *want* to buy?

2) Do you focus your sales efforts on a specialized industry or do you accept nearly any job?

3) Do you mirror the advertising and marketing approach of your number-one competitor, or do you explore new media and new sales approaches?

Your answer to Question One indicates whether marketing can be a driving force in your organization, or if it is a servant to your production limitations.

With the second question, you come to grips with your future. What if the auto-

Managing a business in today's volatile economic environment is tough. Let our new column, "Management Matters," lend a hand. From its pages learn about subjects like marketing, overseas trade, labor relations, economic trends, environmental issues, and product liability. Tell us what management matters interest you. Write to Gear Technology at P.O. Box 1426, Elk Grove Village, IL, 60009, or call our staff at (708) 437-6604.

PHIL CALLIGHAN
is President of the Center for Communications, a division of AdPro, a full-service advertising, promotional, and public relations firm with offices in Sycamore and Batavia, IL. If you have questions for Mr. Callighan, please circle Reader Service No. 46.

motive industry nosedives? What if your market niche becomes crowded? While you may accept nearly any job, each customer must feel that you specialize in his field. How you accomplish that is a major challenge. If you have

Don't be ashamed to mirror the sales approach of your best competitor. If that company has the greatest market share, they must be doing something right.

narrowed your target industries, the challenge is to keep up with those industries' perceptions of their needs.

And Question Three?

Don't feel ashamed if you said "yes" to mirroring the advertising and sales approach of your number-one competitor. If the competitor has the greatest market share, he or she must be doing something right. As long as your message is different, you may not be faulted for copying the media, the frequency, or the promotional ideas of your competitor.

The challenge may be to out-maneuver the budget of the competitor. Big budgets are no match for results. The right message delivered at the right time can yield much more than an oft-repeated mediocre message.

The second marketing item you must address is strategy. The crucial matter is to discover what about your product or service is different from any other. What is your Unique Selling Proposition (USP)? Forest City Gear, for example, boasts it has "the newest gear-cutting equipment of any manufacturer in the world."

Once you know your USP, you will know how to position your product/service in the marketplace. Caution: Define your buyers carefully and know their level of understanding. Don't talk down to them, but don't make the opposite fatal error of assuming they know more than they do.

The next question to ask is what persuasive techniques to use? Everyone may be shouting better price or better quality. How do you prove that's what you actually offer?

Here is a sampling of some ways to communicate your strategy:

1) Customer testimonials.

2) A case history story explaining your problem solving capabilities.

3) An educational article explaining your innovative manufacturing procedures.

4) An announcment of something NEW (for example, business expansion, more efficient manufacturing procedure, etc.).

5) Questions and answers that will explain your product or service.

6) Before and After photographs to demonstrate your work.

7) Startling facts or analogies to set you apart from your competitors.

Too often, companies prepare sales messages and materials based on what they think the market needs. A wiser approach may be to survey your reps or distributor selling channels.

Reps or distributors may be the key to customers for your company. They may have a better understanding of what the end user needs. They know what they can sell. Perhaps a well-planned and well-executed distributor promotion could deliver better results than ideas aimed at end users.

In any case, your buyers must also be able to understand how your product is different and how those differences can benefit them.

This brings us to the third marketing item you must address: your creative presentation. How will you communicate your strategy?

It's crucial to discover your Unique Selling Proposition. How is your product or service different from everyone elses?

For example, if you believe a graph or photo is the best way to prove your product/service benefits, you must ask how dramatic the photo needs to look. Should your visuals emphasize depth and dimension? Do you need to show or explain a size relationship? Is it more important for the customer to see differences in terms of a long-term application rather than short-term results? Should your prospect be able to request an engineering study substantiating your claims?

How can benefits be dramatized? Words are as important as pictures here. "Virtually no deterioration after running 5,000 hours" is much stronger than saying "Dependable."

Is your message distinctive and memorable, or does it fade fast because it looks like everyone else's in the market? Should you use the colors and typefaces everyone else uses?

The fourth item to consider is which media to use. What is your objective for the media? Will you use media to enhance and build upon your other communication channels, or do you need media to multiply your sales efforts rapidly? Will you put all your marketing eggs in one media basket, or use multiple media to complement your efforts and deliver greater overall results?

Consider the following advantages and disadvantages of each medium (listed in no particular sequence).

DIRECT MAIL. *Advantages:* You can target a message precisely to the person or the characteristics of the person to whom you wish to speak. You can select your audience by title, SIC code, gross sales of business, number of employees, geographic area or purchasing characteristics. Asking for some response makes this a highly measurable device. *Disadvantages:* Clutter of mail, chance of being thrown away by protective secretaries. If the list you're using is not current or accurate, you may be wasting time, effort, and money.

PUBLICATION ADVERTISING. *Advantages:* You can reach a wide audience in a specific market. For example, if you want to sell your lubrication products to engineers of all kinds, you might choose a horizontal magazine, such as *American Machinist,* which reaches individuals in all types of industrial businesses. However, not all its readers may be buyers of lubrication products. On the other hand, if you wanted to reach *only buyers* of lubricants, you might choose a more verticle publication like *Lubrication Engineering,* which reaches individuals whose sole interest is the lubrication business. Bingo cards or other calls to action in your ad may generate measurable results. *Disadvantages:* Wasted circulation to readers who lack influence or buying authority. Inability to control when the message may be seen/read. Poor position in a magazine could mean your message is "buried."

TRADE SPEAKING ENGAGEMENTS. *Advantages:* Positions you as an expert in your field. Delivers a captive audience for a specified amount of time. Permits a dialogue with your audience to answer their questions, probe their thinking, and support your message. *Disadvantages:* Requires presentation skills. May invite hostile questions. May reveal proprietary information. (Interestingly, Fred Young believes the proprietary issue often prevents companies from capitalizing on innovations which could arouse customer interest and enhance company image.)

TRADE EXHIBITS. *Advantages:* Permits demonstration to a wide audience. Usually permits a dialogue with your audience. Group excitement and the "keep up with the Joneses" pressure often encourages sales. Encourages quick comparisons with competitors. *Disadvantages:* Pressures you to respond when competitors may offer discount show prices. Cannot hide malfunctions or equipment failures. Attendance often subject to weather and location attractions.

BROCHURES. *Advantages:* Ability to furnish comprehensive data about your product and service. *Disadvantages:* Inexperienced buyers may be dazzled by an exciting presentation, rather than thoroughness. Generally little interaction with customer. Inability to customize message.

VIDEOTAPE. *Advantages:* Tells your story the way you want it told every time. Demonstrates what is difficult to transport or see. A dramatic, portable selling tool that may be viewed out of the office in a relaxed, uninterrupted setting. *Disadvantages:* Often limited to one-on-one or small group presentation. Requires VCR equipment. Can lead to one-way communication.

Of course, in all cases, your product or service may be diminished if the level of sophistication of your audience is not reached. In other words, a brochure that looks cheap may communicate that your product is "cheap" as well. On the other hand, an exotic, splashy brochure design may undercut a plan to promote old world craftsmanship instead of new technology. If your sales force can't explain why your communication materials look the way they do, your customer may also be puzzled about what you stand for and how you work.

The fifth marketing item to consider is timing. When should your message be received? How often? Will your customers be ready to act once they receive your message?

For example, a rule of thumb for ads placed in trade magazines is a minimum three-time consecutive "buy" to measure results. But which three times? Will an advertisement running October, November, and December reach readers while they are planning budgets for the following year? Is this better than January, February, and March, when budgets may already be approved? Or would it be better to feature ads in July, August, and September to support appearances at trade shows, a distributor promotion, or a direct mail campaign? These questions don't have "right" answers; they only have answers that are right for your particular circumstances.

A well-planned and executed distributor promotion may deliver better results than ideas aimed at end users.

Despite all the research, all the gut feelings and all the rationales, some efforts deliver significant bottom results and others seem to fizzle. Why?

When an advertisement, direct mail letter, videotape, or other communication tool doesn't deliver the expected results, people are quick to condemn the media and the effort in total, when really a different creative approach or better timing could deliver better results. In the case of direct mail, the validity and accuracy of the list must be scrutinized. Testing all the elements of your communications should be an ongoing program.

Just as a good business needs a good business plan, good marketing requires a comprehensive communications plan. With such a plan, you are less apt to go in various directions with no consistency or measurability. A plan can make you an active, not a reactive marketer.

A plan is especially helpful when the printers, advertising agencies, magazines, and others call you. Your budget, your media, and your frequency of communication will already be decided. You will have defined your target market and decided how best to explain your benefits. Then, you'll be ready to respond intelligently to that multitude of phone calls about your marketing. ■

Influence of CBN Grinding on Quality and Endurance of Drive Train Components

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Abstract:

The merits of CBN physical characteristics over conventional aluminum oxide abrasives in grinding performance are reviewed. Improved surface integrity and consistency in drive train products can be achieved by the high removal rate of the CBN grinding process. The influence of CBN wheel surface conditioning procedure on grinding performance is also discussed.

Introduction

There is a growing demand in the automotive industry to produce passenger cars and trucks with pleasing noise quality and increased load carrying capacity. Consequently, the focus of manufacturing today is on the manufacture of consistently high-quality drive train products at low cost. This, in turn, has encouraged engineers to re-evaluate the current design and production methods in relation to new process concepts, new machine tools, and cutting tool materials.

The present method of gear manufacturing typically consists of the following steps:

Soft cutting/Rough forging
↓
Finish cutting/Shaving/Rolling
↓
Heat Treatment
↓
Honing/Lapping
↓
Shot Peening (optional)

In the above method, since lapping or honing is not significantly corrective in nature, tooth distortion from heat treatment manifests itself in large runout and transmission errors. Also, the cutter marks in the tooth face and fillet regions, which act as stress raisers and reduce the surface fatigue and bending fatigue strength in the gear, are left behind.

The new approach consists of:

Rough cutting/Near Net Forging
↓
Heat Treatment
↓
CBN Finish Grinding
↓
Lapping/Honing

The final goal of this new approach, however, is to eliminate lapping and make it a three-step process. The finish grinding operation following heat treatment ensures correct tooth geometry and minimizes the tooth-to-tooth pitch variation and runout errors. A short cycle time lapping process is sometimes necessary to improve the noise quality of the gear set.

Based on the above approach, several types of CBN hard gear finishing machines have been introduced for spur, helical, and spiral bevel gear products. Several articles[1-6] have been published describing the CBN gear grinding technology and its advantages. In this article, the merits of CBN grinding are reviewed with some examples. The influence of wheel specification and wheel

Table I
SELECTED PHYSICAL PROPERTIES OF CBN AND ALUMINA ABRASIVES

Property/Units	BORAZON® CBN	Aluminum Oxide	Ratio
Formula	BN	Al_2O_3	
Knoop Hardness, (kg/mm.^{2})	4500	2100	2:1
Density, (gm/cm^3)	3.45	3.97	1:1
Thermal Cond. @ (298°K),(W/m°K)	1300	35	37:1
Specific Heat @ (298°K),/Jkg°K)	506.2	774.9	2.3
Therm. Diff. @ (298°K),(m^2/5) × 10^5	74.4	1.14	65:1

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surface conditioning procedures on part profile and geometry are also presented.

Background on CBN

CBN is a manufactured abrasive surpassed in hardness only by diamond. As an abrasive, it is extremely wear resistant and able to retain its sharpness for a long time. The physical properties of the tool are among the several factors that have a strong influence on increasing the material removal rate, tool life, and surface integrity of the work material. Table I gives selected physical properties of CBN and aluminum oxide (Alox) abrasives. The thermal diffusivity of CBN is almost two orders of magnitude greater than that of Alox. Thermal diffusivity is the ratio of heat conducted versus the heat absorbed in a body. A high value means that much heat is transmitted through the abrasive relative to the heating of the abrasive itself.

The thermal stability and chemical properties of CBN also influence the abrasive performance. CBN reacts with air or oxygen to form boron oxide according to:

$$2BN + 3/2O_2 = B_2O_3 + N_2$$

The boron oxide forms a solid protective layer around the CBN crystal, preventing further oxidation at < 1300°C. CBN also reacts with water and water soluble oils according to:

$$BN + 3H_2O = 2H_3BO_3 + NH_3$$

The boric acid readily dissolves in water, which promotes further degradation of CBN. Straight oil coolant is therefore recommended to get the best performance with CBN.

Johnson[7] illustrated the importance of CBN thermodynamic properties by use of a simple finite element analysis. In a typical grinding process, any single abrasive grain is in contact with the work for only 80 microseconds. The analysis examines the temperature distribution in both an abrasive grain and steel workpiece, 80 microseconds after a grain

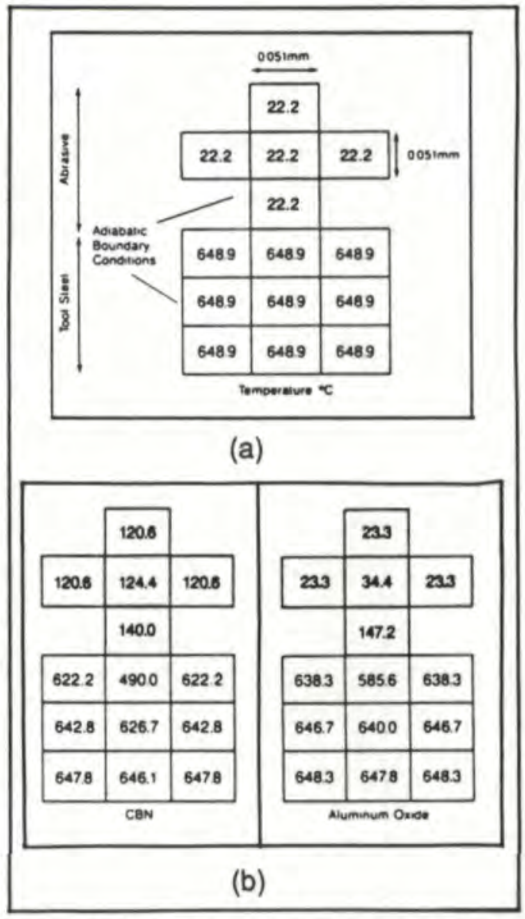

Fig. 1 – Finite element model of temperature distribution in workpiece and abrasive. a) Initial condition at time t= 0 sec. b) Comparison of temperature distribution after 80 microseconds of contact with CBN and aluminum oxide.[7]

at room temperature is placed in contact with a steel workpiece at 648°C. Fig. 1a shows the initial conditions, and Fig. 1b shows the temperature distribution after 80 microseconds. The analysis shows that workpiece surface temperatures would be higher when ground with Alox than with CBN.

Ramanath and Shaw[8] have determined the fraction of grinding energy (R) going into the workpiece to be

$$R = \frac{1}{1 + \left[\frac{k\varrho C_{abr.}}{k\varrho C_{work}}\right]^{0.5}}$$

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Where k is thermal conductivity, ϱ is density and c is specific heat. For aluminum oxide, the calculation shows $R = 0.76$, and for CBN $R = 0.37$. This analysis also suggests that the CBN grinding process will have minimal thermal disturbance and more mechanical action in chip formation. A more rigorous analysis on the thermal aspects of CBN grinding can be found in the work done by Lavine, Malkin, and Jen.[9]

CBN Wheel Specification

CBN can be classified into monocrystalline and microcrystalline types of abrasive. The microcrystalline type is tougher and less friable than the monocrystalline and requires a larger force to fracture the crystal. Monocrystalline CBN has good fracture characteristics for free cutting action in the wheel and is mainly used in gear grinding.

CBN wheels are made either by electroplating or in an impregnated bond system. The electroplated wheels are produced by attaching a single layer of abrasive particles to the steel core of the tool by electrodeposition of nickel. As the nickel is deposited onto the core, it entraps the abrasive particles in a strong mechanical grip. Impregnated bond systems are those where the abrasive particles are molded in a matrix of either phenolic resin or metal powder or glass frits.

Electroplated wheels are predominantly used in gear grinding applications as they can hold the profile geometry in extended use and are easy to fabricate. Electroplated wheels are normally specified by CBN type and the mesh size. However, to achieve the required profile accuracy and surface finish, the particles have to be screened for a narrow size range and shape.[10]

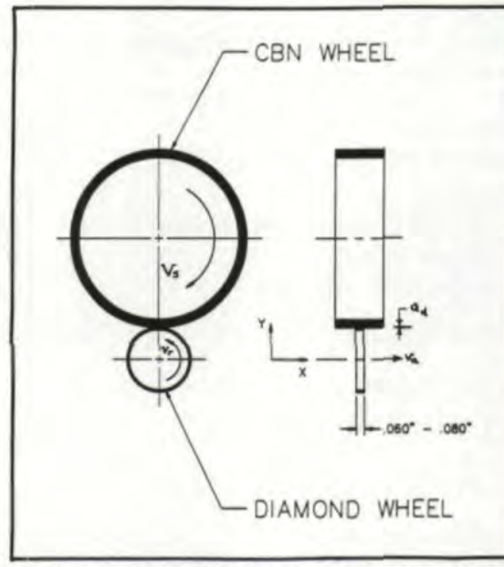

Fig. 2 – Schematic of truing by the generation method. The various truing parameters are 1) Direction of rotation; 2) Speed ratio, $q = v_r/V_s$ fpm/fpm; 3) Depth of cut, a_d inch; 4) Lead, v_a inch/revolution of CBN wheel; 5) Overlap factor, u_d = actual roller width/lead; 6) Diamond wheel specification.

Vitrified bonded (glass frit) CBN wheels can also be used, as they are easy to shape using a CNC truing device and can hold the profile geometry in grinding. These wheels are specified by the CBN type, mesh size, concentration of CBN, volume porosity, and bond hardness. Vitrified CBN wheels have been qualified for use in form gear grinding of spur and helical gears.[11] However, it is still in the development stage of Reishauer type wheels and Gleason type cup shaped wheels.

TABLE II – Summary of Test Conditions

A. Grinding Condition	
Work Material	AISI 52100, R_c 57-60
Grind Mode	Plunge Cylindrical Grind, Up Cut
Wheel Speed, V_s	12000 fpm
Work Speed, V_w	150 fpm
Specific removal rate, Z'	0.4 in^3/in-min.
Radial stock, d	0.05 in.
Dwell time, t_d	2 revs. of work
Volume ground, v'_w	15 in^3/in.
Coolant	Cimperial HD90, 5% Water Soluble
Wheel Specification	CBN-I, 170/200, 200 Conc., R, Vit. Bond
B. Wheel Conditioning	
Diamond Wheel	MBS-750, 40/50, 50 Conc. Metal Bond
Truing Mode	Rotary Cup Wheel, Unidirection
Diamond Wheel Speed V_r	200 fpm
Speed ratio, q	0.2, 0.6, 1.0
Radial Infeed/pass, a_d	0.0001 in.
Lead, v_a	0.006 in/rev.
Overlap Factor, u_d	10

Conditioning a CBN Wheel

Conditioning is the process of preparing a CBN wheel mounted on the spindle to the desired concentricity, profile geometry, and cutting characteristics. Typically, this entails a truing and dressing operation. Truing provides the shape and minimizes the out-of-roundness in the wheel, while dressing relieves the bond around the abrasive for a free cutting action. In resin and metal bonded wheels, truing and dressing are done as two separate operations. In the case of vitrified bonded wheels with volume porosity over 20%, conditioning is a one-step process similar to that for conventional Alox wheels.

In production grinding, the vitrified CBN wheel is conditioned by a powered rotary diamond wheel, either by plunge form truing or profile generation process. The latter method is widely used as the truing forces are low and good profile accuracy is obtained. Fig. 2 is a schematic of the various parameters involved in truing by the generation method. To illustrate the importance of these parameters, plunge cylindrical grinding tests were done on a heat treated AISI 52100 bearing steel. Table II gives the grinding conditions and conditioning parameters. The truing is usually conducted in the unidirection mode, as the radial forces are dominant to fracture the CBN crystals and obtain sharp cutting edges. Fig. 3a, 3b, and 3c show the grinding power, wheel wear, and surface finish versus volume ground. The speed ratio of 0.6 yields the best overall result in terms of power, wear, and finish. A speed ratio of 1.0 is not desirable, as the radial truing forces are at a maximum and result in a reduced diamond truing wheel life. At low speed ratio of 0.2, the normal truing force is so small that the CBN cutting edge remains dull, and there is not sufficient bond relief around the crystal. Consequently, at start of the grind, the power is high enough to cause thermal damage in the workpiece and limits the material removal rate. As a result, the wheel is used gently at the start, until it is free cutting for higher removal rates. When the speed ratio is increased to 0.6 and above, the radial truing forces are adquate to fracture or impart cracks at the working tip of the CBN and relieve the bond around it. This results in grinding without burn from the start at the desired material removal rate. The surface finish and wheel life also tend to be the best at this condition.

The influence of metal bonded diamond truing wheel specification and lead conditions on grinding power and surface finish are illustrated in Figs. 4a and 4b. The grinding power increases with smaller diamond size and higher concentration, while the surface finish is improved. The lead conditions can be varied to change the transient shape of the grinding power and surface finish at the start of grind. An optimum truing condition can be found where the grinding power and surface finish have less transient effects and are relatively stable from the start.

Electroplated CBN wheels are sometimes conditioned to get an acceptable surface finish and profile geometry. However, in doing this the wheel life is compromised by the extent of conditioning done. For electroplated wheels, conditioning is done either with a diamond wheel or a silicon carbide abrasive wheel. The direction of rotation of the diamond wheel is counter direction (upcut) to the CBN wheel, and a low speed ratio of 0.2-0.4 is used. The overlap

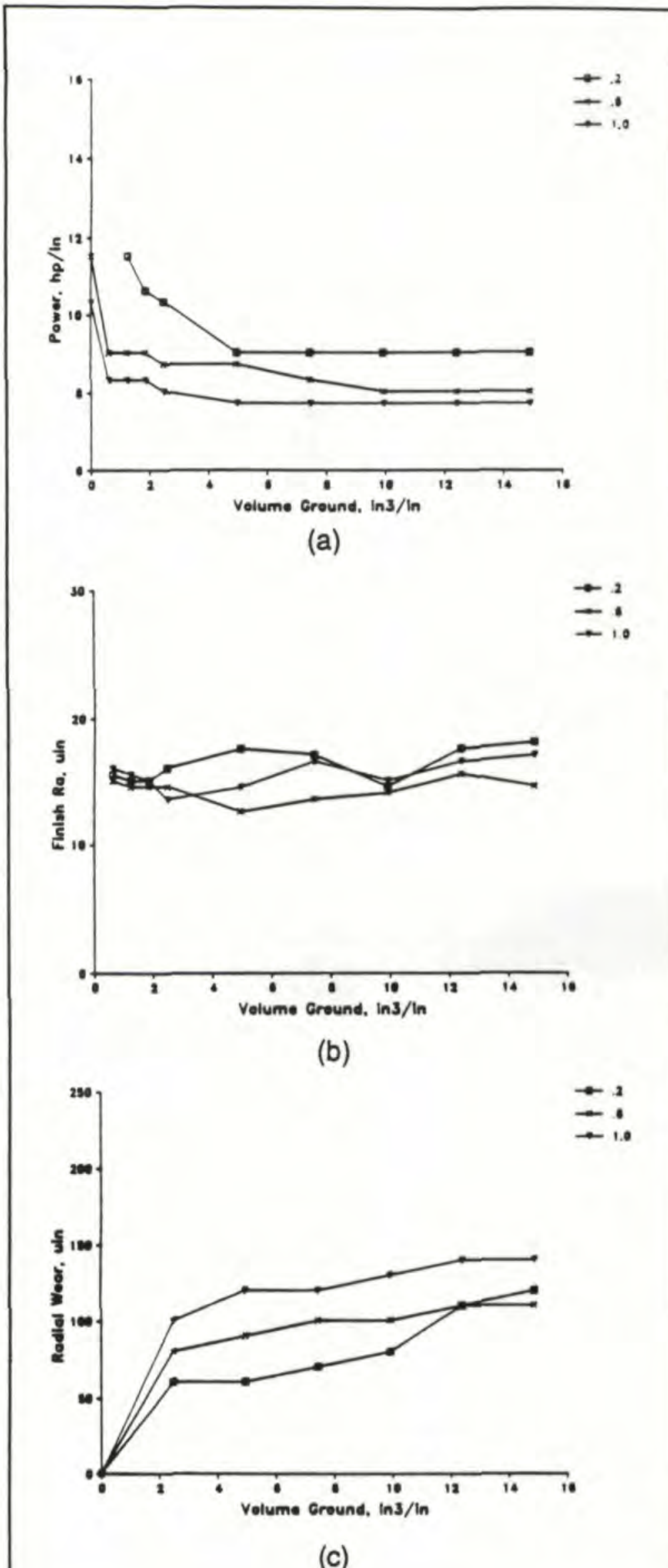

Fig. 3a, b, c—Variation of grinding power, surface finish, and radial wear versus volume ground for CBN wheel conditioned at different speed ratio. See Table II for test conditions.

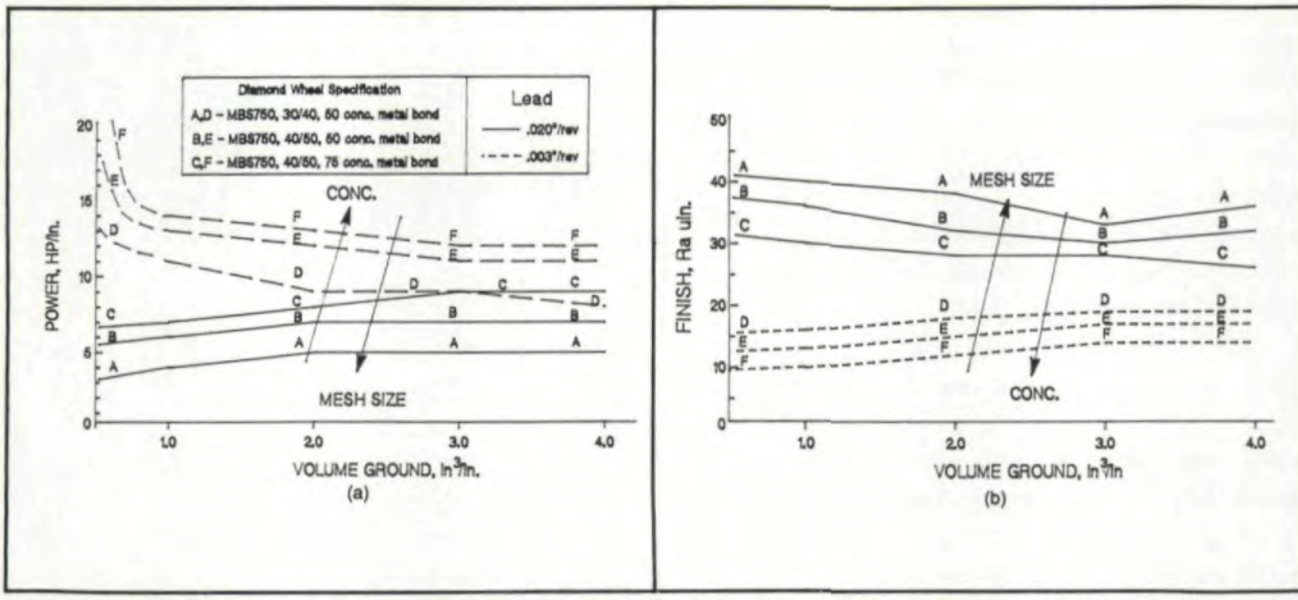

Fig. 4 — Influence of diamond wheel specification and truing lead on the variation of (a) grinding power, (b) surface finish versus volume ground. Test conditions: CBN-I, 120/140 mesh size, 175 conc. vit. bond, work: D2 steel - R_c60, $Z' = .16\ in^3/in\text{-}min.$, $V_s = 12800$ fpm, truing q = 0.15 unidirection, coolant - 3% Adcool #3.

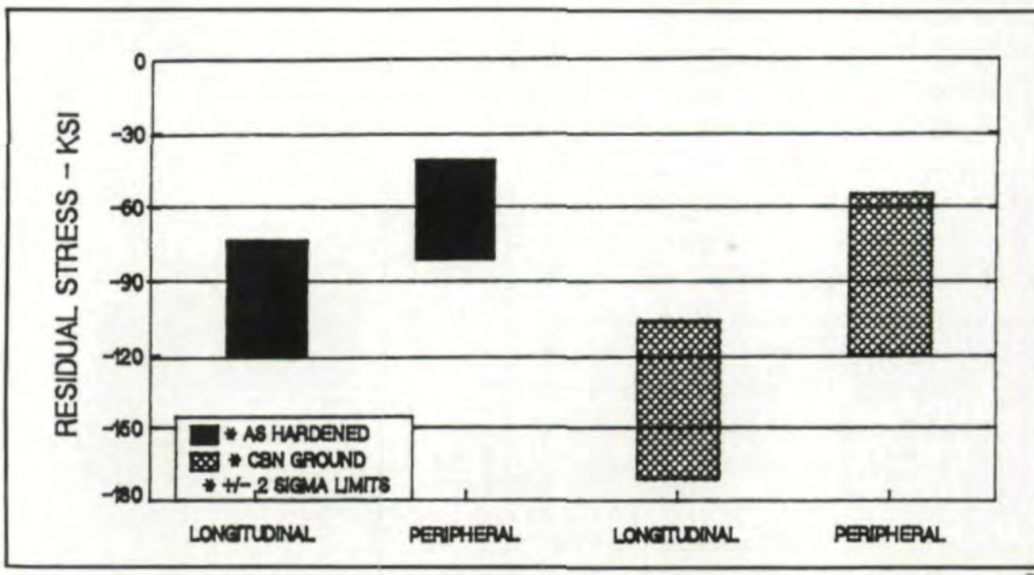

Fig. 5 — Residual stress in SAE 4620 steel before and after grinding with a resin bonded CBN wheel (51 samples).[7]

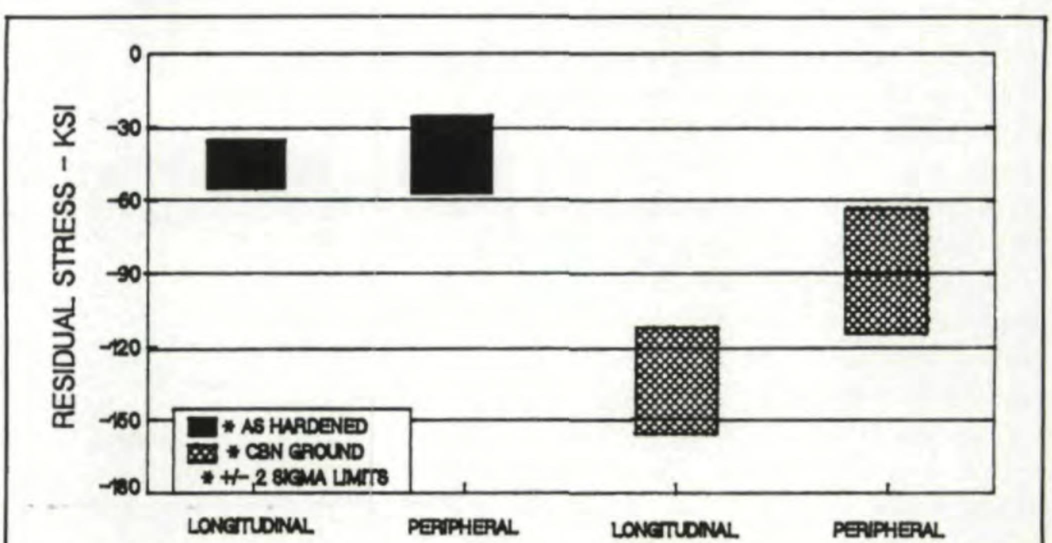

Fig. 6 — Residual stress in SAE 8620 steel before and after grinding with a resin bonded CBN wheel (40 samples).[7]

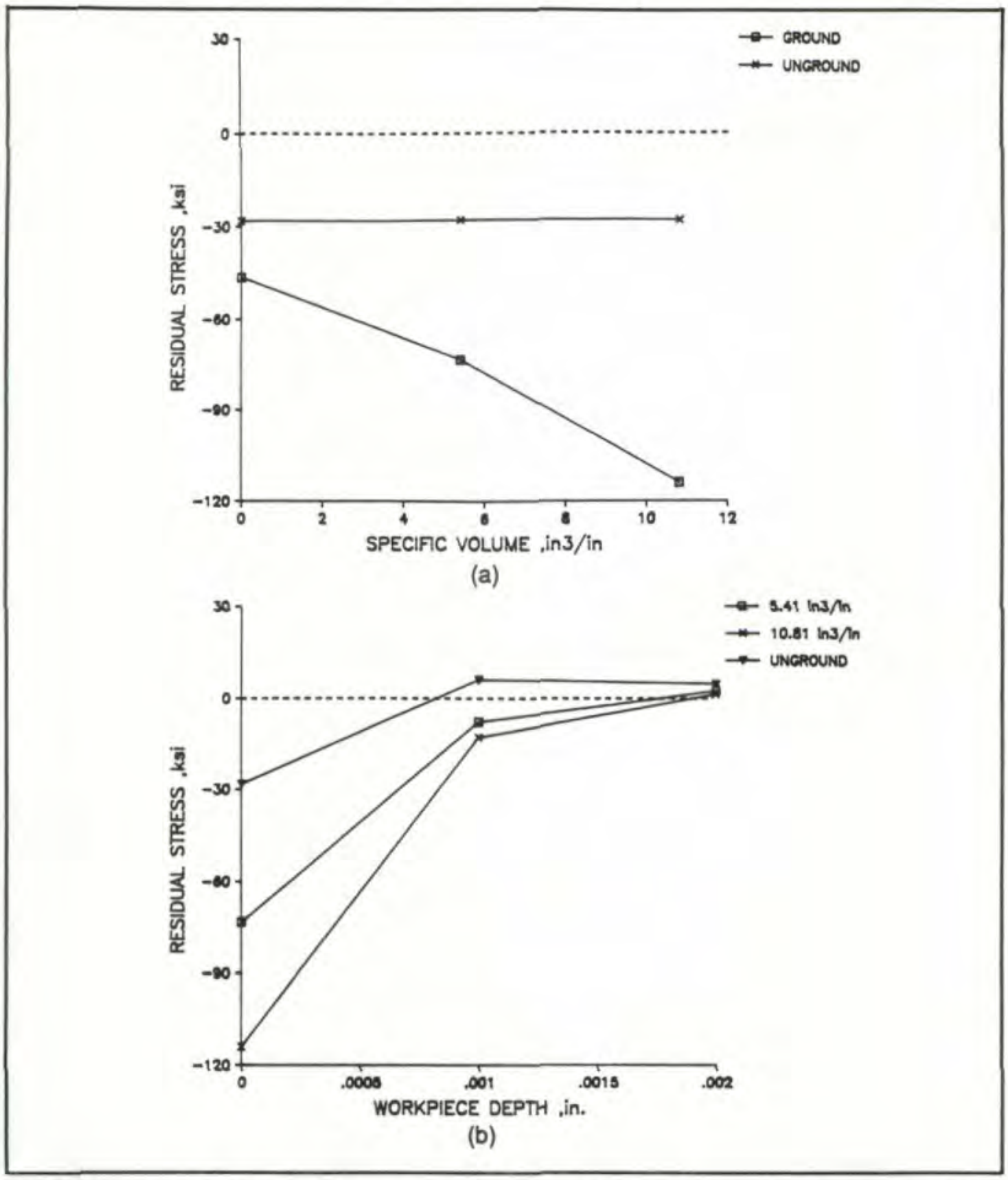

Fig. 7 — a) Variation of surface residual stress versus volume ground. b) Variation in residual stress versus workpiece depth. Test condition: CBN-I, 80/100 mesh size, 200 conc., L, vit. bond, work: 8620 steel, R_c60. V_s = 6000 fpm Z' = 0.45 in^3/in-min., coolant - 5% HD90 Cimperial.

factor is kept high (50-60) to achieve a good surface finish.

Surface Integrity

Surface integrity of the workpiece generally refers to surface roughness, the state of stress, hardness variation, and the metallurgical state following a grinding or machining operation. In grinding the gear components after heat treatment, it is essential to preserve the surface integrity of the gear at high material removal rates over the life of the wheel. Reference 12 summarizes the results of several CBN grinding studies conducted on residual stress. The important observations are reviewed here.

Figs. 5 and 6 show the residual stress in SAE 4620 and 8620 steels before and after plunge cylindrical grinding with a resin bonded CBN wheel. The compressive stress in the ground part is greater than in the heat treated condition. Also, the magnitude in the direction perpendicular to grind is greater than along the direction of chip removal because higher temperatures are developed in the chip forming direction relative to the lateral direction, and the resulting thermal stresses tend to decrease the stress developed by mechanical deformation. In the lateral direction, there is no chip removal, but there is considerable mechanical working of the plowed material on the workpiece.

Plunge cylindrical grinding tests were also done with a vitrified bonded CBN wheel on 8620 case-hardened steel. Fig. 7a is a plot of surface residual stress versus volume ground, and Fig. 7b is a plot of

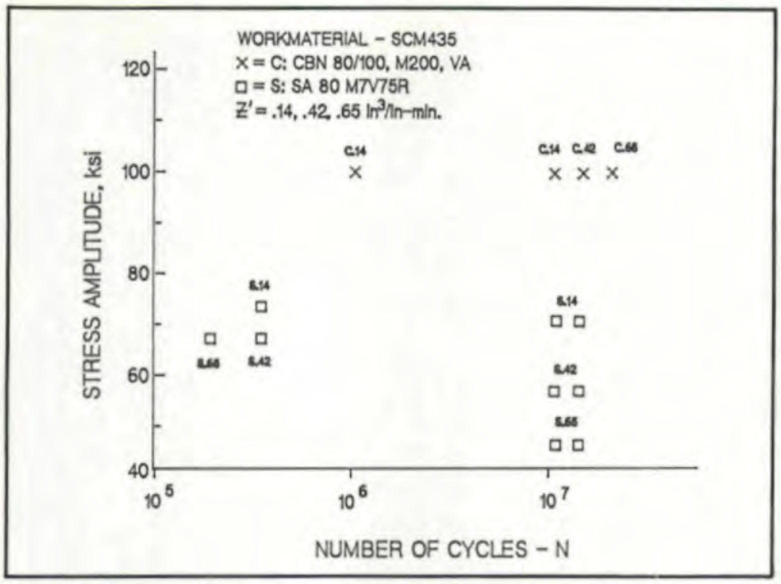

Fig. 8 – Comparison of fatigue strength of aluminum oxide and CBN ground samples at different material removal rates, from Yokogawa.[13]

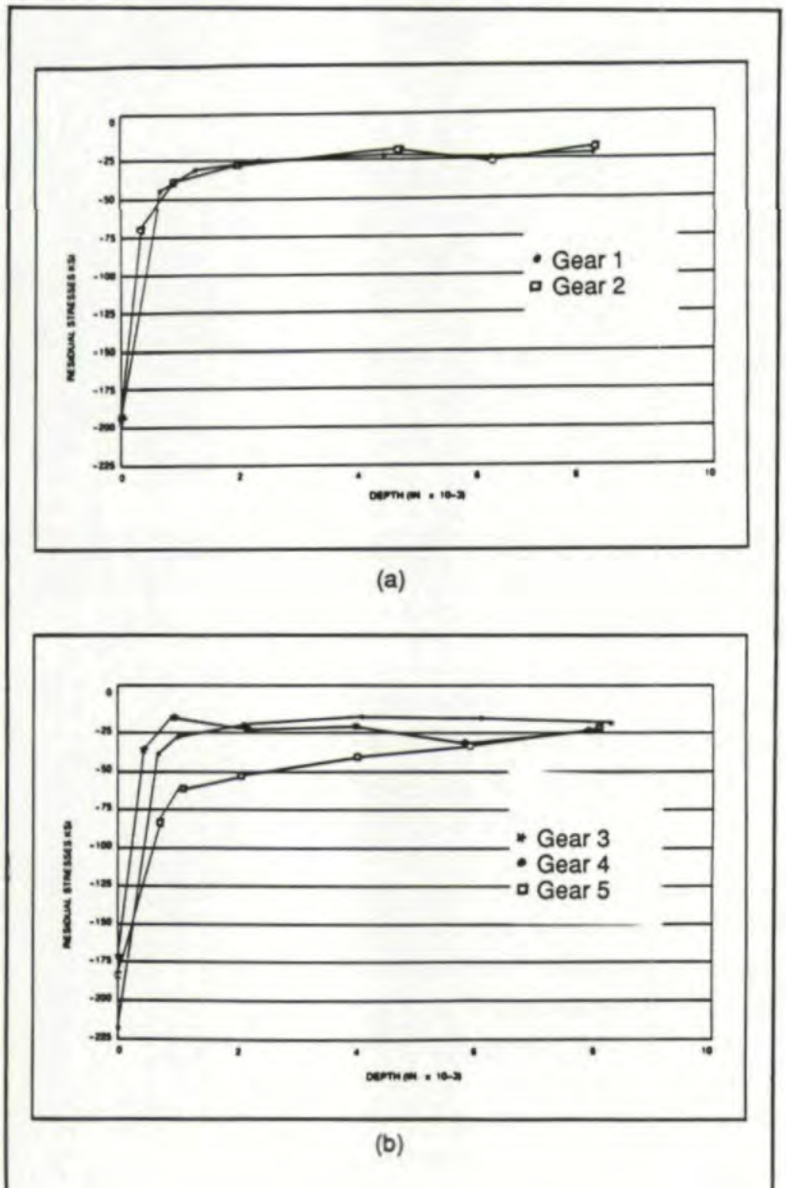

Fig. 9a, b. – Variation of residual stress measured at midflank in the profile direction versus depth, for helical gears ground with a plated CBN wheel.[7]

variation in residual stress with workpiece depth. The magnitude of compressive stress is greater than the heat treated condition and increases with the volume ground. Microhardness measurements across the cross section showed no reduction in hardness. The above results demonstrate that, regardless of the bond system used, residual compressive stress can be generated under proper grinding conditions. These results also correlate well with the physical properties of CBN abrasive described earlier.

Recently Yokogowa[13] compared the fatigue strength (rotary bending test) of Alox and CBN ground samples at different material removal rates. This is illustrated in Fig. 8. The S-N Chart shows that parts ground with the CBN wheel have a stress amplitude of 100 ksi for failure at all removal rates. By contrast, the parts ground with the Alox wheel have a lower stress amplitude for failure at all removal rates. This result clearly demonstrates that with CBN grinding, higher load carrying capacity can be achieved at shorter cycle times relative to Alox abrasives.

Although the kinematics of gear grinding are more complex than O.D. and surface grinding methods, a similar trend in the improvement of results can be observed when grinding with CBN abrasives. Residual stress measurements were made on automotive transmission gears ground with an electroplated CBN wheel in the Kashifuji gear grinding machine. Five gears were selected at random during a trial production run. The midflank residual stress along the profile direction was analyzed, and the results are shown in Figs. 9a and 9b. The residual stress distribution is developed to a depth of .008" below the flank surface. The results also show a remarkable consistency in the compressive stress level at the tooth flank surface. The subsurface profile variations in the stress is probably due to variations in the heat treated profiles and the stock removed.

All of these findings tend to support the results of four-square fatigue testing of CBN ground gears reported by Kimmet and Dodd.[2] Fig. 10 shows the fatigue life comparison of a CBN ground spiral bevel gear over a conventionally hardened and lapped gear set. The bending fatigue strength is at a maximum when the flanks and the fillets are ground. This improvement can be attributed to compressive stress as well as to other factors, such as:

a) Improved blend and shape of the fillet region, which reduce any stress risers that might occur;

b) Improved accuracy of gear tooth geometry, which reduces the dynamic loading on gear teeth;

c) Removal of impurities present from heat treatment, such as a decarburized layer and other undesirable carbide networks.

It can be deduced that the increase in strength may allow for higher load rating of a gear set or downsizing to attain the same rating.

Concluding Remarks

The merits of CBN physical properties and influence of wheel conditioning procedures on grinding performance have been reviewed. It is shown that improved surface integrity and consistency in drive train products can be achieved by the high removal rate CBN grinding process.

However, much more work needs to be done in several areas to further enhance the use of CBN in gear grinding. The various areas are

1) Consistent manufacture of electroplated wheels having acceptable accuracy, surface finish, and wheel life without conditioning the wheel;
2) Development of vitrified bonded CBN wheels and conditioning devices in the machine that can produce the desired cutting characteristics and profile accuracy;
3) Implementation of advanced coolant application methods to avoid thermal damage in the workpiece and increase the wheel life;
4) Development of machine tool and grinding process technology to overcome gear noise and in turn eliminate the lapping and honing process.

CBN grinding has the potential of revolutionizing gear production methods in an economical way, while resulting in improved quality and consistent product performance.

Acknowledgements: *This article was presented at the SME Gear Clinic in Detroit, MI, Oct. 3-5, 1989, and at the AGMA 18th Annual Gear Manufacturing Symposium, Columbus, OH, April 1-3, 1990. Reprinted with permission.*

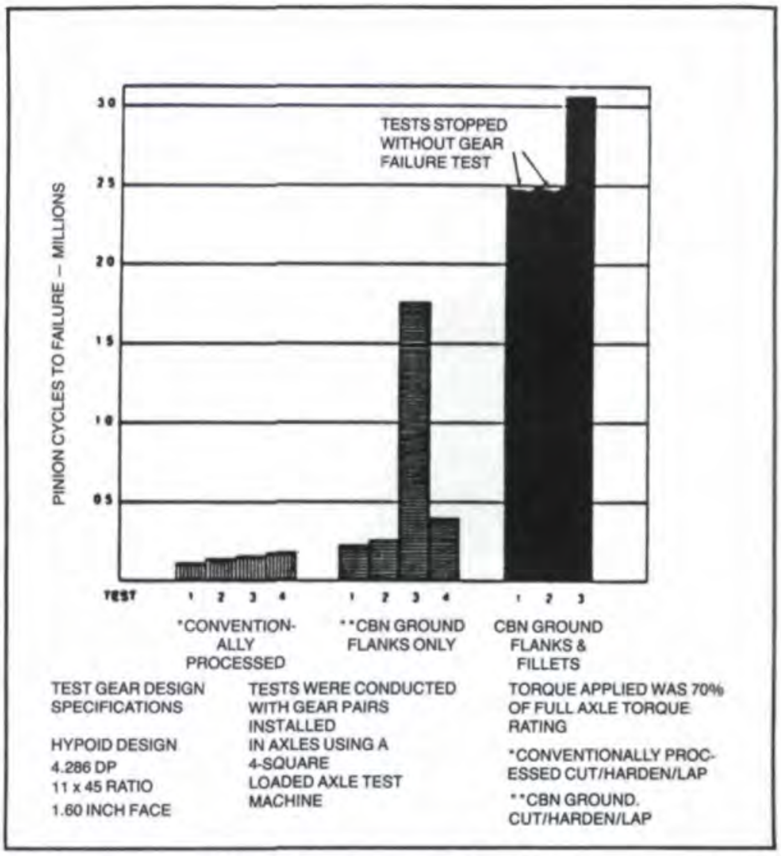

Fig. 10—Comparison of bending fatigue strength of spiral bevel gears conventionally processed versus CBN ground.[2]

References:

1. TSUKAMOTO, R. "Outline of Machining Technology for Transmission Gears in F.F. Cars," *SAE Review*, July, 1984.
2. KIMMET, G.J., DODD, H.D. "CBN Finish Grinding of Hardened Spiral Bevel and Hypoid Gears," AGMA Fall Technical Meeting, October, 1984.
3. DODD, H.D., KUMAR, K.V. "Technological Fundamentals of CBN Bevel Gear Finish Grinding," *Superabrasives '85*, SME Paper MR85-273, April, 1985.
4. DRAGO, R.J. "Comparative Load Capacity Evaluation of CBN Finished Gears." AGMA Technical Paper, 88 FTM 8, October, 1988.
5. TOWNSEND, D.P., PATEL P.R. "Surface Fatigue Life of CBN and Vitreous Ground Carburized and Hardened AISI 9310 Spur Gears," SAE Paper 88 1292, International Off Highway and Powerplant Congress, September, 1988.
6. MONCRIEF, D.A., GRUTZA, Z. "Hard Gear Finishing," *Gear Technology*, March/April, 1988.
7. JOHNSON, G.A., RATTERMAN, E., "Enhanced Product Performance Through CBN Grinding," *Gear Technology*, Sept./Oct., 1988.
8. RAMANATH, S., SHAW, M.C. "Role of Abrasive and Workpiece Properties Relative to Surface Temperature and Residual Stress", *14 NAMRC Proceedings*, May, 1986.
9. LAVINE, A.S., MALKIN, S., JEN, T.C. "Thermal Aspects of Grinding with CBN Wheels," *Annals of CIRP*, Vol. 38/1/1989.
10. CARIUS, A.C., CONNORS, E.J. "The Influence of Size Control on Superabrasive Grinding Products," Third International Grinding Conference, October, 1988.
11. DUPIUS, M.C. "Progress in Automative, Aeorspace and Rotary Tool Production Grinding Conference," MR-88-608, October, 1988.
12. KUMAR, K.V., MATARRESS, R.R., RATTERMAN, E. "Control of Residual Stress in Production Grinding with CBN," SAE Paper 890979, 40th Annual Earthmoving Industry Conference, April, 1989.
13. YOKOGAWA, K. "CBN Wheel Providing Remarkable Improvement in Grinding Process," *Japan Business and Technology*, June, 1989.

Review of Gear Standards – Part II

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Summary:

In Part I differences in pitting ratings betwen AGMA 218, the draft ISO standard 6336, and BS 436:1986 were examined. In this part bending strength ratings are compared. All the standards base the bending strength on the Lewis equation; the ratings differ in the use and number of modification factors. A comprehensive design survey is carried out to examine practical differences between the rating methods presented in the standards, and the results are shown in graphical form.

Comparison of Bending Strength Ratings

Power ratings for bending strength are given by:

$$\frac{X_b S_b Y F N T}{126\,000 P_2} = \frac{F n d}{126\,000 P_n} \frac{Y}{\cos(\beta)} X_b S_b \text{ for BS 436:1940} \quad (1)$$

$$\frac{F n d}{126\,000 P_n} \frac{J}{\cos(\beta)} \frac{K_v}{K_a K_m} \frac{K_S K_L}{K_R K_T} S_{at} \text{ for AGMA 218.01} \quad (2)$$

$$\frac{b n_1 d_1}{126\,000 P} \frac{1}{Y_F Y_S Y_\beta} \frac{1}{K_A K_V K_{F\alpha} K_{F\beta}} \sigma_{FP} \text{ for BS 436:1986} \quad (3)$$

$$\text{where } \sigma_{FP} = \frac{2\,\sigma_{FO}(\sigma_B - \sigma_R) Y_N Y_R Y_X Y_M Y_\delta}{(\sigma_B + \sigma_{FO} Y_N Y_R Y_X) S_{Fmin}} \quad (4)$$

$$\frac{b n_1 d_1}{126\,000 P} \frac{1}{Y_F Y_S Y_\beta} \frac{1}{K_A K_V K_{F\alpha} K_{F\beta}} \sigma_{FP} \text{ for ISO 6336} \quad (5)$$

$$\text{where } \sigma_{FP} = \frac{\sigma_{Olim} Y_N}{S_{Fmin}} Y_\delta Y_R Y_X. \quad (6)$$

ISO provides three different methods for determining the resistance to tooth breakage, the differences primarily being dependent on the assumed position of the load. Method A determines tooth root stresses on the basis of load sharing. Method B calculates the root stress on the basis of a single force at the outer point of single tooth contact. Method C is an even simpler procedure for gear pairs where the overall contact ratio is less than

Table 1. Comparison of Bending Stress Influence Factors.

	BS 436:1940	AGMA 218.01	BS 436:1986	ISO/DIS6336
Geometry Factors*	$\frac{\cos(\beta)}{Y}$	$\frac{\cos(\beta)}{J}$	$Y_F Y_S Y_\beta$	$Y_F Y_S Y_\beta$
Size Factors*	–	K_S	Z_X	Z_X
Load Distr. Factors†	–	K_m	$\frac{1}{K_{F\alpha} K_{F\beta}}$	$\frac{1}{K_{F\alpha} K_{F\beta}}$
Life Factors†	–	K_H	Y_N	Y_N
Temperature Factor†	–	K_T	–	–
Sensitivity Factors†	–	–	Y_δ	Y_δ
Surface Condition Factors†	–	–	Y_R	Y_R
Residual Stress Factor†	–	–	$\frac{2(\sigma_B - \sigma_R)}{\sigma_B + \sigma_{FO} Y_N Y_R Y_X}$	–

†denotes common and * non-common factors

NOMENCLATURE

BS436:1940

d	Pitch diameters of pinion and wheel
F	Face width
n, N	Pinion and wheel running speed
P	Diametral pitch
P_n	Normal diametral pitch
S_b	Bending stress factor
T	Number of teeth on wheel
X_b	Speed factor for strength
Y	Strength factor
β	Helix angle at pitch cylinder

AGMA 218.01

C_p	Elastic coefficient
d	Operating pitch diameter of pinion
F	Net face width of the narrowest number
J	Geometry factor for bending strength
K_a	Application factor for bending strength
K_L	Life factor for bending strength
K_m	Load distribution factor for bending strength
K_R	Reliability factor for bending strength
K_s	Size factor for bending strength
K_T	Temperature factor for bending strength
K_v	Dynamic factor for bending strength
n_p	Pinion running speed
S_{at}	Allowable bending stress number
β	Helix angle at operating pitch diameter

BS436:1986 and ISO/DIS 6336

b	Face width
d_1	Reference diameter of pinion
K_A	Application factor
$K_{F\alpha}$	Transverse load factor for bending stress
$K_{F\beta}$	Face load factor for bending stress
K_V	Dynamic factor
n_1	Pinion running speed
P	Diametral pitch
S_{Fmin}	Minimum demanded safety factor on tooth root stress
u	Gear ratio
Y_F	Tooth form factor for bending stress
Y_M	(BS only) Material quality factor for bending stress
Y_N	Life factor for bending stress
Y_R	Surface condition factor for bending stress
Y_S	Stress correction factor for bending stress
Y_x	Size factor for bending stress
Y_β	Helix angle factor for bending stress
Y_δ	Sensitivity factor for bending stress
σ_B	(BS only) Ultimate tensile stress.
σ_{FO}	(BS only) Basic endurance limit for bending stress
σ_{FP}	Permissible bending stress
σ_{Olim}	(ISO only) Residual stress
σ_R	(BS only) Residual stress

two. BS uses the same assumption as ISO Method B, where the load is applied at the highest point of single pair tooth contact, while the old BS was based on Lewis's assumption that the critical condition occurred with single tooth contact with the load applied at the tip.

The difference between AGMA 218 and other standards is that AGMA gives allowable errors for load sharing. If the variation in normal base pitch exceeds the allowable error, tip load application is used as the critical position to determine the bending stress.

A comparison between bending stress influence factors is shown in Table 1. These factors can also be divided into common and non-common factors. For simplicity, only those factors which are different from the contact stress comparison are considered.

Load distribution factors. Load factors for bending stresses used in AGMA are the same as those used for contact stresses. ISO and BS set the same values for the transverse load factor, but are different for longitudinal load factors. Longitudinal load factors for bending stresses in these two standards are a function of longitudinal load factors for contact stresses, gear face width, and tooth height.

Life factors. One of the distinguishing differences between life factors for bending and contact stresses are the endurance limits set by ISO and BS. The endurance limit for bending stresses in ISO and BS is $3x10^6$ cycles compared with $2x10^6$, $5x10^7$, and 10^9 (depending on material) for contact stresses.

Size factors. Size factors for bending stresses are included in AGMA, BS, and ISO to take into account possible influences of tooth size on fatigue strength including material quality and its response

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to heat treatment and other manufacturing processes. Values for the factor in BS and ISO range from 0.7 to 1.0 according to tooth size and gear material. These compare with a single size factor value of unity suggested by AGMA, ISO, and BS for determining contact stresses.

Geometry factors. As mentioned above, ISO gives three methods of determining the load locations. Method C adds a contact ratio factor to the geometry factor to approximate the case of outer point single tooth pair contact. Subsequently, the calculation procedures for tooth form factor and stress correction factor are different from those in Method B.

The non-common geometry factor in the BS is similar to ISO Method B, which includes three parts. The first is a tooth form factor, the second is a stress correction factor (used to take into account the effect of the base fillet radius), and the third is a helix angle factor, based on the fact that an inclined line of contact is more favorable than vertical line contact.

The geometry factor defined in AGMA consists of four elements: a tooth form factor which depends on the load position, a stress correction factor, a helical overlap factor, and a load sharing ratio factor.

Temperature factor. Only AGMA takes into account the influence of tooth bulk temperature on the oil film and material properties by using a temperature factor. This factor is usually taken as unity when the temperature of the gear blank is below 120°C.

Sensitivity and surface condition factors. The sensitivity factors used in BS and ISO standards account for the sensitivity of the gear material to the presence of the tooth fillet; i.e., notch sensitivity. In ISO, these two factors may be determined based on a test gear, notched specimen, or an unnotched, polished specimen according to the method selected. BS data is based on unnotched, polished specimens.

Residual stress effects. Residual stresses, which may remain in gears after completion of machining and heat treating, etc., have a marked effect on fatigue properties. Only BS considers residual stress effects, based on the Goodman criteria. The BS also provides procedures to check the permissible stress and power capacity at the tooth core for surface hardened gears.

Design Comparisons

In order to recognize general trends and differences between the standards examined here, sample designs are presented. There are a number of items that could be compared between the standards, such as transmissible powers, torques, basic or total stresses, modification factors, and factors for safety. For a given tooth tangential force, torque is independent of speed, and so in the sample designs, transmissible torque was selected as the objective for comparison. This is examined over a wide range of pinion running speeds. To obtain the large number of results required for comparison, the designs were evaluated by computer, using software previously generated by the authors.[1] These programs enable suitable gear pairs to be designed following the input of a design specification. The programs also ensure that checks on good gear design practice, such as adequate contact ratio and acceptable face width to diameter ratios, are maintained. The design specification shown in Table 2 was used for each standard.

Table 2. Basic Gear Specification for Design Comparisons.

Pinion teeth number	45
Wheel teeth number	120
Diametral pitch	3.175
Gear type	Spur
Profile correction	None
Face width	3 ins
Pinion running speed	20-20,000 rpm
Life	26,000 Hrs

Selecting suitable materials presented a difficulty, as each standard uses different material data for its ratings. In these sample designs AISI 4340 has been used throughout for both pinion and wheel. This is equivalent to En24 under the British material classification system. As no equivalent could be found for the ISO rating, the corresponding material was selected on the basis of the alloying constituents.

To allow comparisons to be made, specific operating conditions, such as quality of drive and gear mounting details, etc., were purposely ignored because these conditions do not appear in all the standards. As shown in Table 3, the operating conditions for the drive and driven gears were assumed to be uniform. Gears were regarded as being of similar quality and were assumed to be perfectly straddle-mounted. Distinct operating conditions are considered in a further comparison aimed at examining their effects on ratings.

The transmissible torque of each gear pair was computed on the basis of strength and wear over the speed range 20 to 20,000 revs/min. More than 200 designs for each standard were analyzed. In order to assist in assimilating the results, the design data has been plotted on single graphs as shown in Figs. 1 and 2. As the ratings alternate between pinion and wheel according to operating conditions and the design specification, Fig. 3 shows the limiting or final design ratings for each standard.

Table 3. Operating Conditions for First Design Comparisons.

AGMA		
Quality number		5
fs* for strength	*Factor of safety	1.00
fs for pitting		1.00
Power source		Uniform
Load on driven machine		Uniform
Gear pair position		Enclosed Gearing
Shaft arrangement		Central
Lead modification		Yes
BS436:1986		
Accuracy grade		5
fs for bending stress		1.40
fs for contact stress		1.00
Viscosity grade		O VG 10
Pinion material quality		A
Wheel material quality		A
Pinion heat treat		Through hardened steel
Wheel heat treat		Through hardened steel
Power source		Uniform
Load on driven machine		Uniform
Lead modification		Yes
Shaft arrangement		Central
Pinion keyed type		Solid or Shrunk on
Assembly adjustment		Yes
ISO		
Accuracy grade		5
fs for bending stress		1.00
fs for contact stress		1.00
Addendum (tool)/Module		1.25
Tip radius/Module		0.25
Viscosity grade		ISO VG 10
Pinion heat treat		Through hardened steel
Wheel heat treat		Through hardened steel
Power source		Uniform
Load on driven machine		Uniform
Lead correction		Yes
Shaft arrangement		Central
Allowing pitting		No
Checking scuffing		No

From these figures the following points can be made:

- Based on bending strength, the ISO and BS ratings are very similar over a wide speed range. The ratings predicted by these standards are very different from those given by AGMA and the old BS. The former predicts much higher transmissible torques over the speed range 20 to just over 2000 revs/min. Above these speeds, the ISO and new and old BS ratings are roughly similar with AGMA ratings, well below the average of the other standards.
- Based on wear (surface durability) all the standards predict widely different ratings over nearly all of the speed range considered. Of particular interest is the wide difference between the ISO and BS ratings. Although the general shapes of the curves

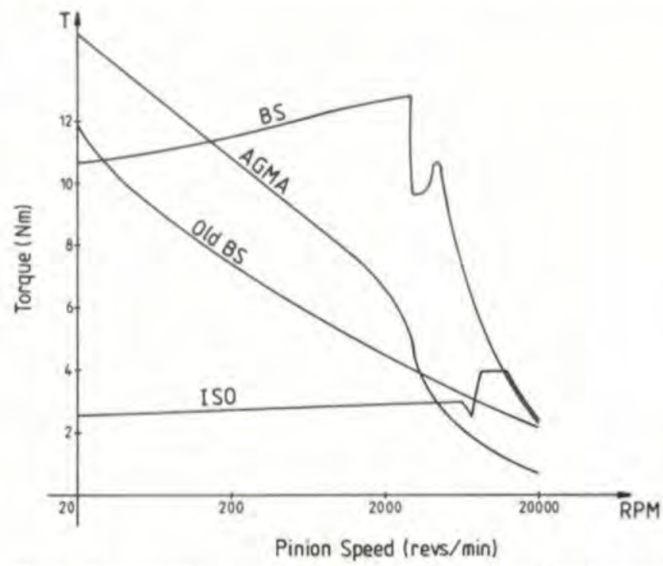

Fig. 1—Transmissible torque ratings against input speed based on surface durability under perfect running conditions.

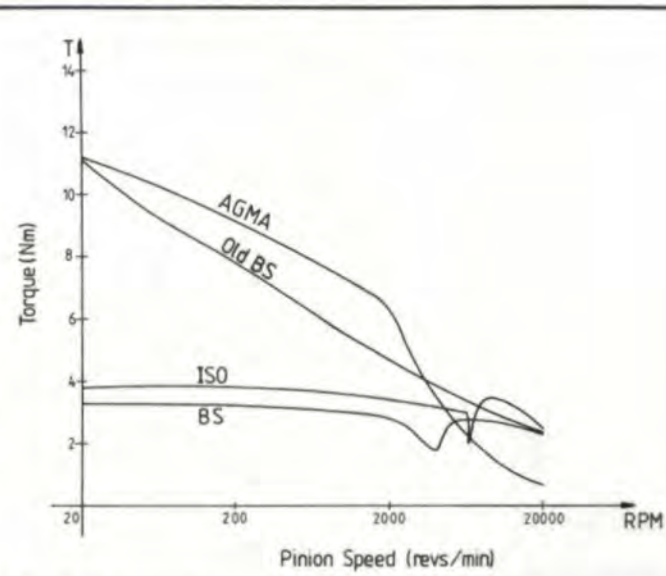

Fig. 2—Transmissible torque ratings against input speed based on bending strength under perfect running conditions.

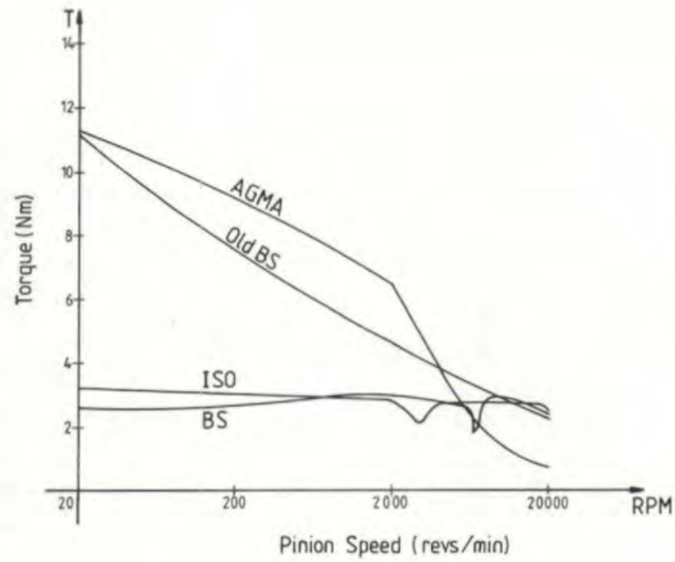

Fig. 3—Limiting ratings under perfect running conditions.

are similar, the magnitude of the BS wear ratings is some four times greater than the ISO values. Up to a speed of 6,000 revs/min, ISO predicts the lowest ratings.

- For the particular design specification, limiting ratings (Fig. 3) are mainly dependent on bending strength. Here ISO and the BS give similar ratings, with AGMA and the old BS generally providing considerably more optimistic figures.
- The sudden dips in the ISO and BS ratings reflect the situations where operating speeds reach the resonance region.

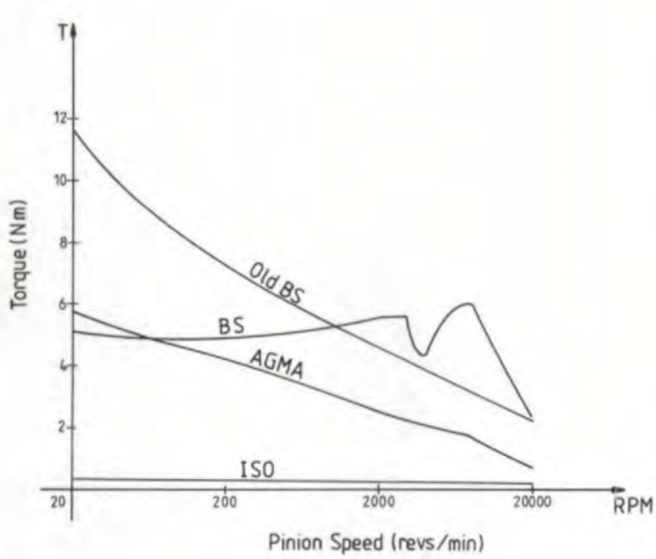

Fig. 4—Transmissible torque ratings against input speed based on surface durability under revised running conditions.

In order to examine the differences which might arise between the standards when specific operating conditions are included in the design specification, such as quality of input and output drives, gear mounting, and lead modification, the design ratings were recalculated to show the changes resulting from the revised specification. The designs were based on the general specification given in Table 2, plus the individual requirement shown according to the standard used, as given in Table 4. Again, each specification is set as close as possible to a common requirement so that the results may be compared directly. Figs. 4-6 show the revised ratings from which the following additional generalizations may be made:

- As expected, although AGMA, BS, and ISO give much lower ratings when specific operating conditions are included in the design specification, the limiting transmissible torque at a particular running speed (Fig. 6) shows similar trends to those under perfect operating conditions. A comparison of Figs. 3 and 6 show that AGMA ratings are significiantly higher than either BS or ISO.
- Gear running conditions have significant effects on gear ratings given by all current standards. The concept of "average ratings" as given in the old BS are seen to be particularly optimistic.

Conclusions

Considering the different backgrounds and the evolution of individual gear standards, ratings obtained between national standards do bear reasonable

Table 4. Revised Operating Conditions Used for Second Design Comparisons.

AGMA	
Quality number	5
fs for strength	1.00
fs for pitting	1.00
Power source	Medium shock
Load on driven machine	Heavy shock
Gear pair position	Open Gearing
Shaft arrangement	Overhung
Lead modification	No
BS436:1986	
Accuracy grade	5
fs for bending stress	1.40
fs for contact stress	1.00
Viscosity grade	ISO VG 10
Pinion material quality	A
Wheel material quality	A
Pinion heat treat	Through hardened steel
Wheel heat treat	Through hardened steel
Power source	Medium shock
Load on driven machine	Heavy shock
Lead modification	No
Shaft arrangement	Overhung
Pinion keyed type	Keyed
Assembly adjustment	No
ISO	
Accuracy grade	5
fs for bending stress	1.00
fs for contact stress	1.00
Addendum (tool)/Module	1.25
Tip radius/Module	0.25
Viscosity grade	ISO VG 10
Pinion heat treat	Through hardened steel
Wheel heat treat	Through hardened steel
Power source	Heavy shock
Load on driven machine	Heavy shock
Lead correction	No
Shaft arrangement	Overhung
Allowing pitting	Yes
Checking scuffing	No

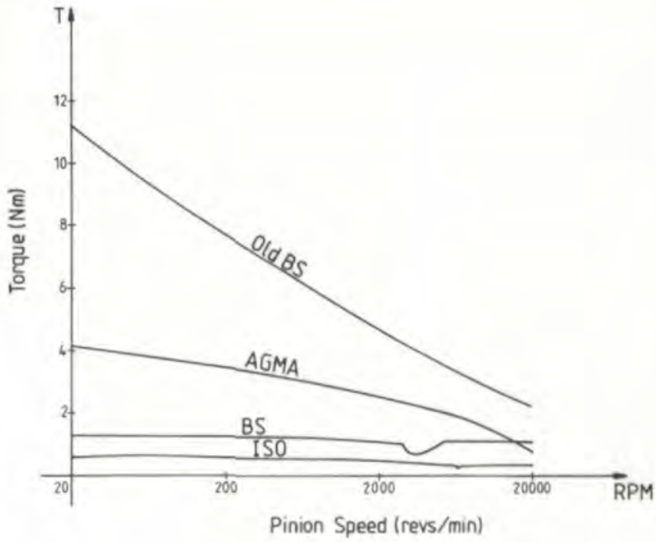

Fig. 5 – Transmissible torque ratings against input speed based on bending strength under revised running conditions.

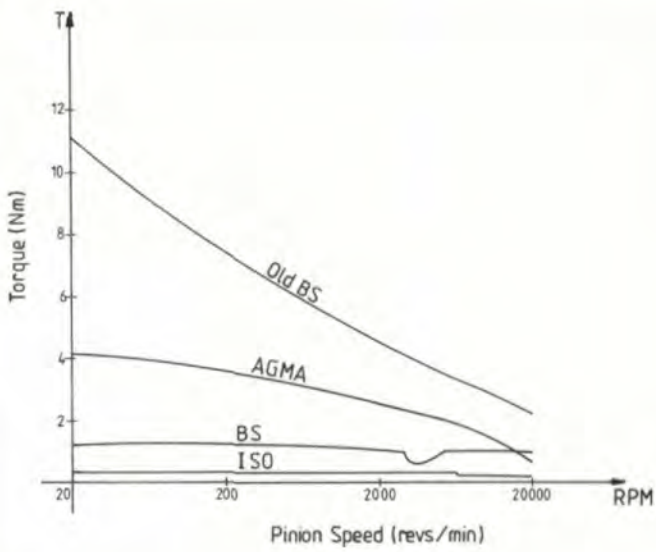

Fig. 6 – Limiting ratings under revised running conditions.

comparison. Even so, the differences between AGMA and European standards (ISO and BS) may give rise for concern. While the ratings may be closer than those shown for many operating conditions, it may equally be argued that the differences could be greater in other cases. However, the complexities of each standard deter all but the hardiest designer from examining the possibilities of experimenting with different design codes. The comparisons indicate the amount of work still needed before a truly international standard can be adopted.

References:

1. WALTON, D. TAYLOR, S. and PRAYOONRAT, S. "Computer Aided Design and Optimization of Geared Transmission Systems." *Proc. 2nd World Congress on Gears*, Vol. 2, pp. 735-742. Paris, March, 1986.

The Effect of Surface Hardening on the Total Gear Manufacturing System

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Abstract:

Carburized and hardened gears have optimum load-carrying capability. There are many alternative ways to produce a hard case on the gear surface. Also, selective direct hardening has some advantages in its ability to be used in the production line, and it is claimed that performance results equivalent to a carburized gear can be obtained. This article examines the alternative ways of carburizing, nitriding, and selective direct hardening, considering equipment, comparative costs, and other factors. The objective must be to obtain the desired quality at the lowest cost.

Introduction

The major heat treatment used for high quality gears is a case hardening process designed to form a hard surface layer on the gear surface. This layer gives the gear a hard, wear-resistant finish, but also causes a compressive stress system to be present at the surface, which helps to resist fatigue failures. The type of fatigue encountered in a gear is usually pitting fatigue present at the tooth contact points.

The most usual process is carburizing, although nitriding is used for parts particularly susceptible to distortion. Carburizing involves the diffusion of carbon from a gas atmosphere while the part is heated to about 1700°F in an atmosphere furnace. After carburizing, the part is quenched, usually in oil, to produce a hard martensitic layer on the surface. The diffusion times used are from 4 to 20 hours, depending on the temperature of treatment and the case depth required. The case depth is related to the pitch of the gear and is increased as the size of the gear is increased to produce the correct residual stress pattern. Nitriding involves the diffusion of nitrogen from a gas atmosphere in a temperature range of 925° to 1050°F. After nitriding, the parts are hard without quenching, and they have some degree of compressive stresses due to compound formation in the surface layers. Nitriding takes anywhere from one day to one week due to the slow diffusion rates.

As an alternative to carburizing and nitriding, a hard case may be produced by selective direct hardening. Instead of increasing the carbon content of the steel surface by diffusing extra carbon into the case, the steel composition is selected that already contains from 0.4% to 0.6% carbon. This steel could then be through hardened and tempered in a furnace, but a hard case and tough core can be produced by selectively heating the specified surface to the depth required, leaving the core in the original hardened and tempered condition. Both methods produce a case: one by controlling the depth of carbon or nitrogen diffusion, and the other by depth of heating.

Carburizing

Ask a gear maker what his biggest production problem is, and he usually says "heat treatment." This may be because heat treatment frequently causes significant scheduling and quality problems. Heat treatment, such as carburizing and hardening, takes parts away from the production flow for long periods, heats them to high temperatures, exposes them to complicated gas atomospheres, and finally quenches them. The risks of things going wrong during this treatment are high. It is worth considering some of the factors that makes this type of processing subject to variability in results.

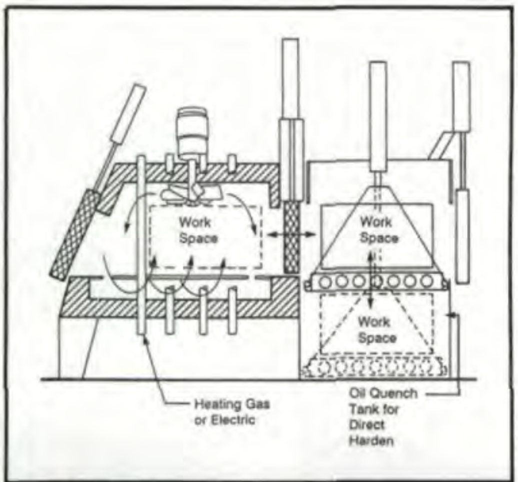

Fig. 1 – Batch-type carburizing furnace.

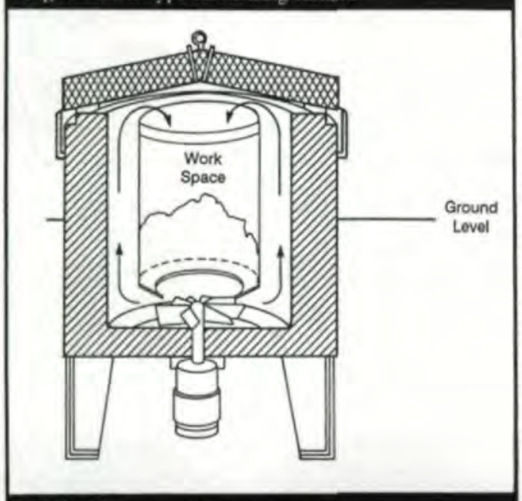

Fig. 2 – Pit-type carburizing furnace.

The furnace itself may be schematically represented by Fig. 1, which shows a typical batch-type furnace supplied with a gas atmosphere from an atmosphere generator. Fig. 2 shows a pit-type furnace which is so called because it is often installed in a pit to make loading the furnace more convenient. The furnace has a circulation system which circulates the atmosphere and helps even out variations in gas composition and in temperature. Government MIL specifications require that furnaces be checked for temperature variation over the load space, but make no requirement for supply of carburizing gas. If areas in the workspace are deficient in temperature or gas circulation, then case carbon and depth of case will suffer.

Carburizing gases are a complex mixture of gasses like N_2, H_2, CO, CO_2, H_2O, CH_4, and O_2, and their carburizing potentials are $(CO)^2/CO_2$ and $CH_4(H_2O)^2$. It is common to measure one component, such as CO_2, CH_4, H_2O, or O_2, and assume that carbon potential is directly related without considering the other component of the ratio, which may be varying due to gas source, air leak, carbon buildup, and other factors. If shim stock is used to assess atmosphere, the measurement gives a good indication of the condition when the shim stock was exposed to the carburizing gas, which may not be the same when the work itself is exposed.

Control of the carbon content is often not very precise,and when consistent results are obtained, it is due to the experience of the heat treatment supervisor rather than scientific control.

The designer's usual choice for treating the highest performance gears is to specify a carburized alloy steel as the material of manufacture. Carburizing diffuses carbon into the steel to a specified depth, the source of the carbon being usually a hydrocarbon-containing atmosphere. After quenching, the higher carbon surface layer hardens, leaving the core at a lower hardness and in a tougher condition. The process should leave the part with high residual compressive stresses in the surface, thus increasing the resistance to fatigue failure. Since the process produces a hard surface layer, it is often referred to as case carburizing.

The source of carbon can be solid, liquid, or gaseous, but for the last 10 years the preferred method has been to carburize in a gaseous atmosphere. This has been because of the lower costs and the possibility of controlling the carburizing conditions. The rate at which carbon is absorbed and diffuses into steel is temperature-dependent: the higher the carburizing temperature, the more quickly a case depth can be attained. The time required to develop case depths of up to 0.100 in. is shown in Fig. 3.

It is possible to reduce carburizing time by increasing carburizing temperature. Fig. 4 shows the

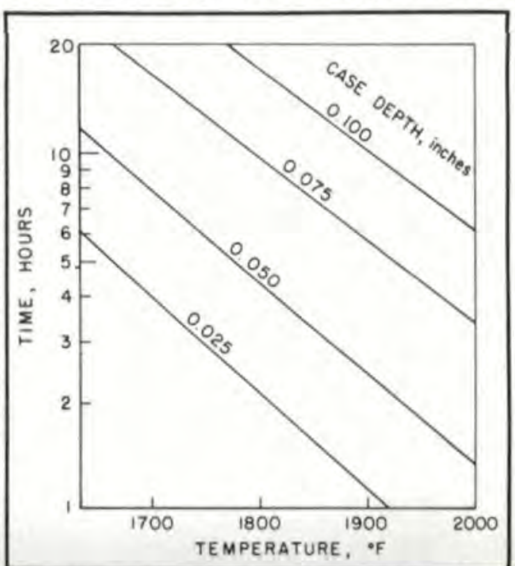

Fig. 3 – Time required to produce a case depth that has a minimum hardness of R_c 55.

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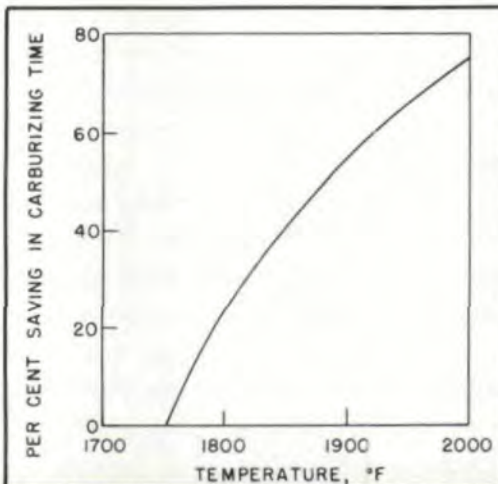


Fig. 4—The effect of processing temperature on carburizing time.

percent savings in carburizing time by increasing the temperature beyond 1750°F.

Control of the Process

Gas carburizing atmospheres can be controlled to be in equilibrium with a wide range of carbon contents. As the surface carbon in a case is gradually increased the hardness of the quenched steel will also rise until it reaches a maximum value. The decrease in hardness from this point is due to retained austenite present in the case. Fig. 5 shows the effect of carburizing a 3310 steel to 0.6% and 1.0% carbon. The carbon increases the hardenability of the steel, but increased carbon depresses the temperatures at which martensite starts to form and at which martensite formation is complete to the 50% and 90% levels. At a case carbon level of 0.6%, martensite formation is complete at above room temperature, but at 1.0% carbon there would be substantial retained austenite, necessitating a subzero treatment to transform it to martensite.

To obtain the desired carbon content in the surface of the case, an atmosphere control system should be installed and well-maintained. Some heat treaters control carbon potential at the desired level through the carburizing cycle; however, others favor a "boost-diffuse" technique, where carbon is introduced to the surface at a much higher level than required in the final case for much of the cycle, and it is reduced to the required level for this last part of the cycle. This is a faster way of introducing the case.

Whichever method is used, atmosphere control is necessary. It is difficult to measure carbon potential directly, but usually some other factor is measurable that is related and can be used for control purposes. The carburizing reactions occurring can be summarized as:

$$2CO \rightleftharpoons C_2 \ ⅓ \ CO$$
(in steel)

$$\text{and } CH_4 \rightleftharpoons C \ ⅓ \ 2H_2$$
(in steel)

$$\therefore \text{ Carburizing potential } \frac{[CO]^2}{CO_2}$$

$$\text{and } \frac{CH_4}{[H_2]^2}$$

For a particular carrier gas, the concentration of carbon monoxide and hydrogen is roughly con-

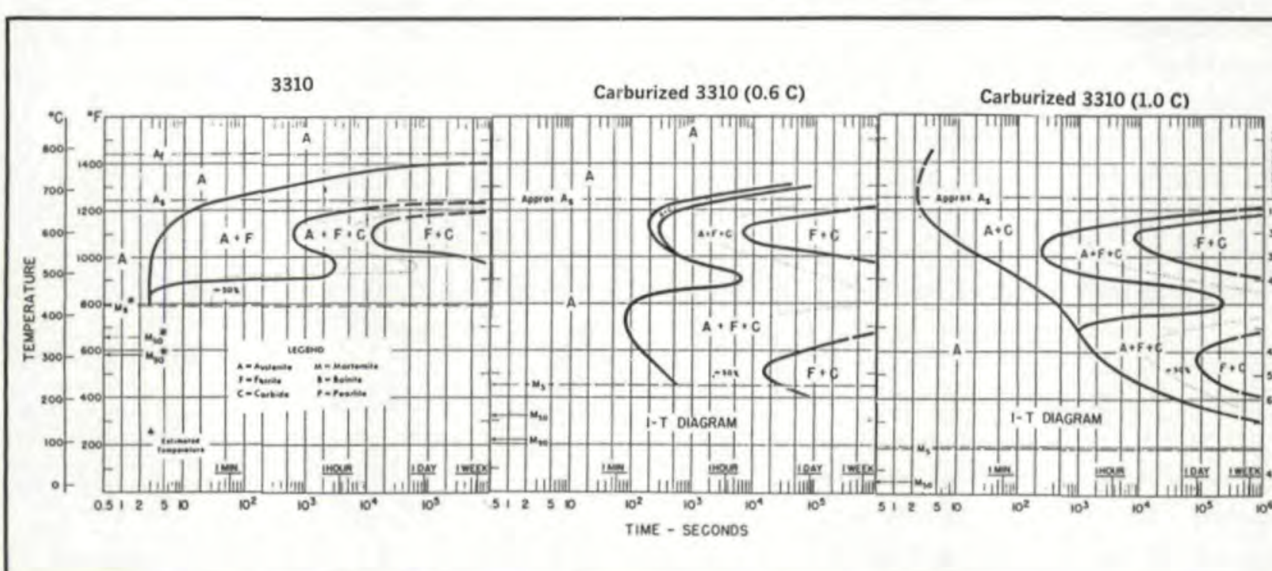


Fig. 5—Effect of case carbon level on isothermal transformation characteristics.

stant for a wide range of carbon potential, therefore increasing the amount of methane or other hydrocarbon. Reducing the carbon dioxide content will increase the carburizing potential. The carbon dioxide will react with hydrogen as follows:

$$CO_2 \tfrac{1}{3} H_2 = CO \tfrac{1}{3} H_2O$$

Thus, the carbon dioxide content and water content or dewpoint are interdependent. A high dewpoint will promote the formation of carbon dioxide and, therefore, reduce the carburizing potential.

Methane and other hydrocarbons will react with water as follows:

$$CH_4 \tfrac{1}{3} H_2O = CO \tfrac{1}{3} 3H_2$$

Therefore, hydrocarbons may be added to reduce the dewpoint and increase the carburizing potential.

Oxygen potential is related to the carbon potential as follows:

$$C \tfrac{1}{3} \tfrac{1}{2} O = CO_2$$

Therefore, carburizing potential

$$\frac{CO}{[O_2]^{1/2}}$$

From this it can be seen that the carburizing potential can be determined by measurement of CO_2, dewpoint, or oxygen level. The relationship between these factors is shown in Fig. 6.

It should be carefully noted, however, that most users of carbon control believe that they are measuring factors relating to carbon potential directly; whereas, actually they are measuring one factor in a ratio and assuming the other factor (usually CO) is constant. If CO, hydrogen, or other components vary, the reactions will shift, making the carbon potential relationship inaccurate. For example, some heat treatment installations generate endothermic gas from natural gas. This is supplied by the local gas company to a calorific value, not to a chemical composition. In time of supply difficulties (mid-winter), the gas company may boost the supply from different fields or even use waste refinery products, causing instability in the gas composition and deviations in case carbon content, even though the control instruments are still showing that everything is under control.

Methods of Carburizing

The majority of gears are carburized in a gas atmosphere usually using natural gas, propane, or nitrogen as the atmosphere source. However, over the last 25 years two other methods have developed, one involving vacuum technology, and the other using plasma.

Gas Carburizing. Gas carburizing using atmospheric pressure treatments in gas-fired or electrically heated furnaces is still the most popular method. Furnace equipment varies widely in construction, but essentially is constructed to be gas-tight and provides means for uniform heating and circulation of the gas atmosphere. For the highest

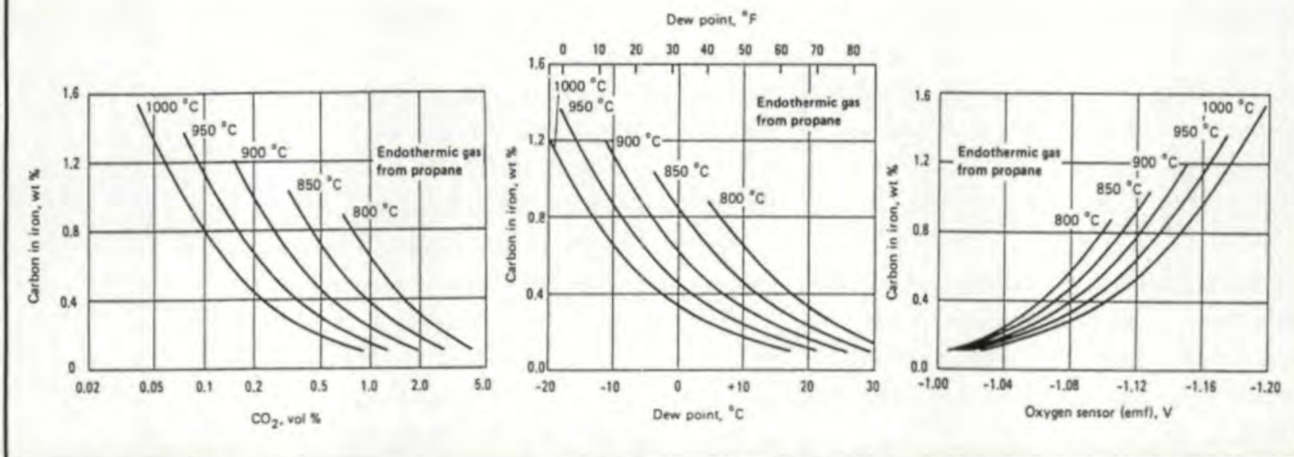


Fig. 6 – Relationship between CO_2, dewpoint and oxygen sensor voltage, and carburizing potential.

quality work, pit furnaces (Fig. 2) are preferred, since temperature uniformity is optimum because of the circular shape, and the fan (generally at the bottom) gives uniform gas and temperature distribution. It is more difficult to automate loading procedure, and direct quenching is not usually possible, since the load is difficult to handle, thus taking a long time to transfer to a quench tank, during which period the parts are not in a protective atmosphere. Many precision gears are treated in pit furnaces, slow-cooled, reheated, and hardened.

Horizontal box furnaces with integral quench (Fig. 1) are used particularly for lower class gears. They are very convenient for load handling, but may suffer from lack of temperature uniformity, particularly near the front loading door. Because of the shape, gas circulation is not uniform, particularly at the extreme corner of the furnace chamber. The circulation system not only supplies the furnace atmosphere, but also is part of the heating system. Deficient circulation leads to lack of atmosphere and lower temperature, both factors adversely affecting case depth.

Continuous furnaces are used for large quantities of gears, often for the automotive industry. Pusher furnaces are developments of the horizontal batch furnaces, and since the parts are moved through different zones during the cycle, more uniform results are possible. Pusher furnaces may be adapted with the last zone at the quench temperature so that gears can be plug- or press-quenched from the furnace.

Vacuum Carburizing. Vacuum carburizing has been used since the early 60s and has developed to a full production process, sometimes with oil quench capabilities. Closed loop carbon control is not currently possible because the gas reactions are out of equilibrium, making it necessary to use a controlled boost-diffuse cycle based on past experience. The furnace is operated under vacuum conditions except under actively carburizing conditions, when a few millimeters pressure of carburizing gas are added, and during the gas cool after carburizing, when the furnace is backfilled with nitrogen. If the furnace is equipped with an oil quench, the load may be reheated under vacuum and quenched without removing it from the furnace.

Vacuum carburizing is often faster because it is carried out at higher temperatures (1800° to 1950°F), rather than the 1700° to 1800°F typically used in gas carburizing. Some gas carburizing furnaces can operate at higher temperatures, and achieve the same carburizing rates as vacuum processing, but a typical gas carburizing furnace takes longer to reach carburizing temperature because of the furnace heat load. Vacuum equipment can be started and shut down in much shorter times than gas carburizers.

The costs of vacuum treating and gas carburizing are likely to be comparable, especially for deeper case depths because of the higher temperature capability. The acquisition costs will also be similar since endothermic generation equipment is not required. Vacuum treatment parts are likely to be cleaner and of more consistent quality.

Plasma Carburizing. This process uses equipment similar to vacuum carburizing, except that the work carrier is electrically insulated from the furnace frame. A DC potential difference is applied across the work, making the work carrier the cathode. A plasma is formed around the work, which is said to enhance the absorption of carbon at the surface of the gear being carburized. Plasma is maintained at a few millimeters of pressure of methane using a DC voltage of 500 to 600 volts. Unlike ion nitriding, additional heating is necessary to achieve carburizing temperatures, and this is accomplished with graphite elements. Carbon level is controlled using a boost-diffuse cycle followed by a controlled cool to about 1550°F, when the parts may be oil quenched.

As with ion nitriding, a high degree of cleanliness is important, and the work carriers must be scrupulously cleaned after use to remove quench oil and other foreign matter. Contamination causes arc-over in the plasma layer, causing the power supply to shut down and restart. Until the parts are clean, a stable plasma will not be established.

The equipment is more costly than a vacuum unit, and the full advantages have yet to be completely documented for gear treatment.

Selective Direct Hardening

Although carburizing is widely used, especially for higher quality gears, it is not a popular process in the manufacturing sequence. Manufacturing engineers do not like it because it is a lengthy batch process done off the main production sequence. Quality engineers dislike it because it is responsible for many quality problems due to variation in case quality and dimensional tolerances. Shop personnel may be disenchanted when their beautifully machined parts are ultimately returned looking burnt, twisted, and unrecognizable.

To overcome some of these disadvantages, selective direct hardening is often applied. In this process the hard case is produced by heating the surface layer only to above the austenitizing temperature and rapidly quenching, leaving the core in the original condition. Carburizing is not necessary because a medium carbon steel is used with the required carbon already in the steel. Since a large proportion of the part remains cool, thus stabilizing the material, distortion is much less than if the entire part were heated. The higher carbon content material compared with a carburized grade may make machining more difficult. Four methods have been used for selective heating for direct hardening of cases. All rely on applying a large amount of energy in a short time.

Flame Hardening. Flame hardening is probably the oldest selective hardening process and, as the name suggests, it employs direct flame contact with the surface being hardened. With coarse pitch gears, individual teeth may be hardened, but with finer pitches, a gear may be spun in a ring of gas burners. Flame hardening, even with oxy-gas fuels, does not provide as rapid an energy transfer as the other methods discussed, and thus has difficulty in producing a hard case of less than about 0.050 to 0.100 in. deep. However, in situations where flame hardening will meet the required specifications and quality levels, it is the lowest cost method. As with induction hardening, self-quenching is usually not possible, and an external quench is necessary.

Induction Hardening. Induction hardening is achieved by using an alternating current in a work coil surrounding the part to be heated. The entire circumference of small gears may be heat treated at the same time, but coils may be designed to treat one tooth at a time if the tooth pitch is such that individual teeth are large. An alternating magnetic field is established that induces a potential in the part, causing a current to flow in the closed circuit. Heating is produced by the resistance to the induced current. The rate of heating depends on the strength of the magnetic field. The depth of the field varies inversely with the frequency of alternation. The higher the frequency, the more shallow the heating effect.

If the circular coil is used to heat a gear, then the tips of the gear are closer or better coupled to the coil, and, thus, they heat more, resulting in a deeper case depth. Techniques are available to reduce this effect, such as pulse or dual frequency hardening.

After the heating is complete, the current is turned off, and the part is quenched by synchronized jets of a quenching fluid, usually water-based.

Laser Heat Treatment. Laser heat treatment is a surface-hardening process in which laser energy is used to heat the surface to above the austenitizing temperature. When the source of energy is removed, the part self-quenches, owing to the diffusion of heat into the mass of the part. This is made possible by the extremely rapid heating rate that the laser can achieve. As the rate of heat input increases, the depth of hardening is reduced, since the temperature gradient becomes

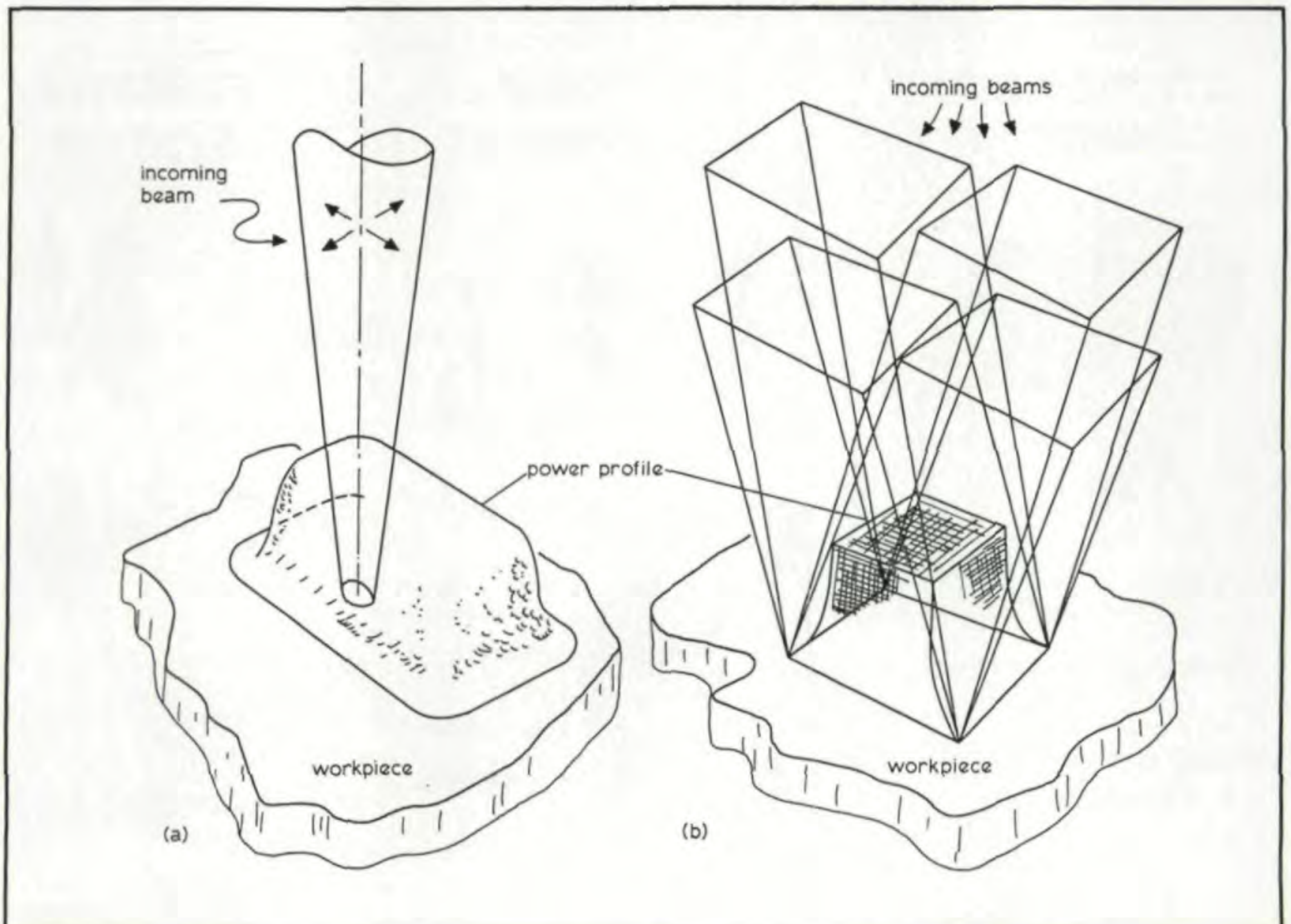
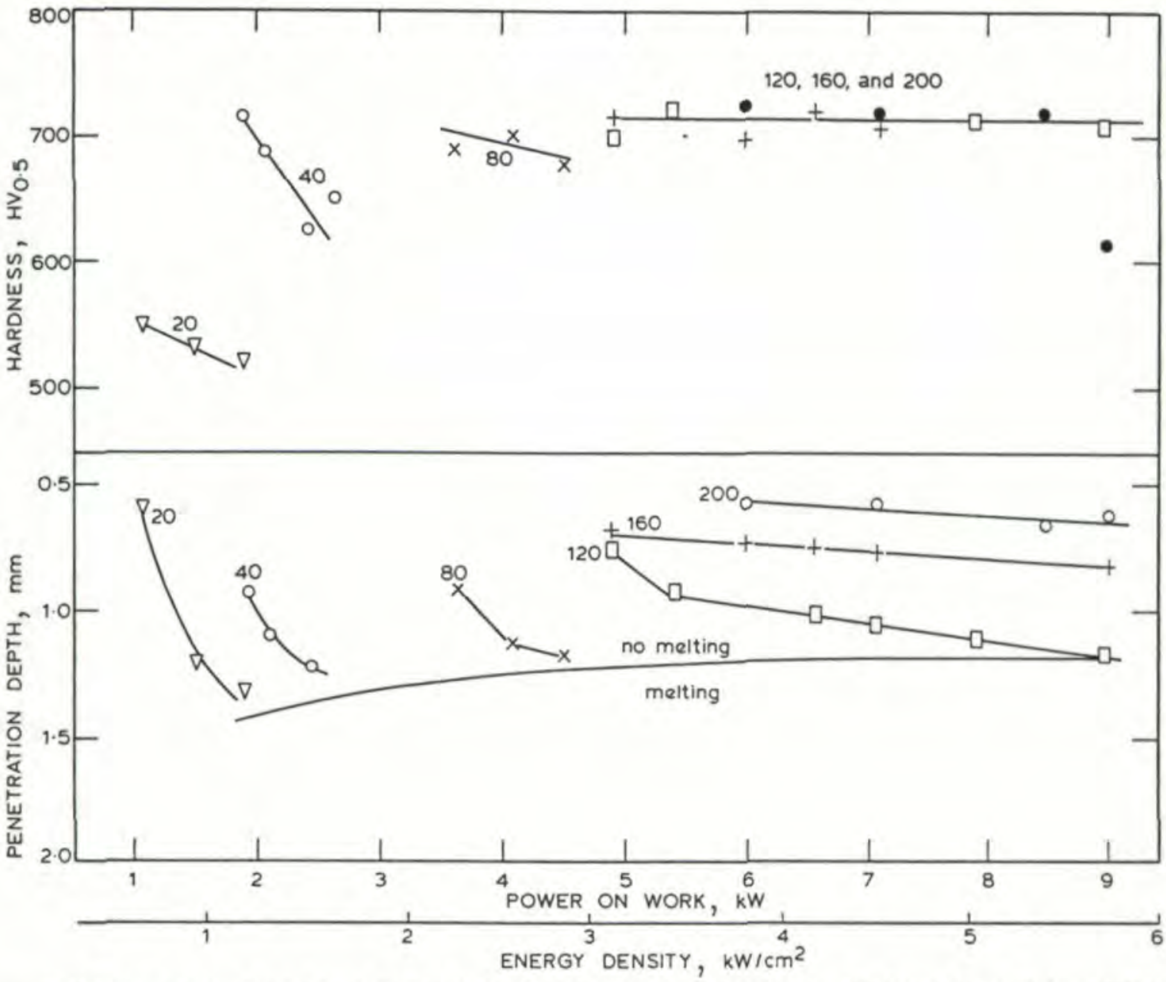


Fig. 7 – Representation of power distribution with (a) oscillator optics and (b) integrator optics.



speed of work travel, cm/min, indicated for each curve; transverse oscillation 450 Hz; axial oscillation 120 Hz; pattern 1·27 × 1·27

Fig. 8 – Hardness and depth of penetration obtained with oscillating optics (F105) on AISI 1045 steel using a manganese phosphate coating.

steeper, and the surface temperature is limited by the need to avoid melting.

The method of applying the energy becomes a critical part of the heat treatment process. If a sharply focused laser beam is used, then the hardened zone becomes quite narrow, although it is more usual to use a defocused beam to increase the area over which the laser energy is spread. This, however, represents the most unsophisticated way of controlling the heat treated area and, in a modern work station, other types of optics would be preferable.

Two of these methods are illustrated in Fig. 7. Fig 7a shows the use of oscillating optics, in which a defocused beam is oscillated in two directions to produce a rectangular patch of energy. Oscillation frequency is typically 100 to 500 Hz in both directions. This method also allows control of the shape of the energy patch. Fig. 7b shows the use of integration optics using a faceted mirror. The beam is broken into segments and recombined with or without magnification at a plane in space that coincides with the location of the work surface. This method is lower in cost than oscillation equipment, but will only produce a fixed shape energy patch.

Laser Power. The influence of power on penetration is direct, but not linear. Useful tradeoffs can be made if low-speed processes can be tolerated. For example, in Fig. 8 power levels as low as 1 kW produced slight hardening with the ½ x ½ mm rectangular spot in these tests. At 2 kW significant surface hardness occurred if the speed was increased from 20 cm/min to 40 cm/min, and a reduction of 0.5 m (30%) could be tolerated in depth of hardening. The suggestion here is that speed or exposure time is a more important process element than power, per se.

In fact, increasing power at a given speed was clearly detrimental to hardening until relatively high speeds were reached in Fig. 8.

The power at which surface melting occurs is directly related to speed in Fig. 8, and the boundary formed by this relationship forms the major process limits.

Speed of beam. It is possible to interchange speed and power to achieve a given depth of hardening for a specific beam impingement area (a ½ x ½ in. rectangle in this case). For example, in Fig. 8, a hardened depth of 1 mm can be obtained at 7 kW, and 160 cm/min or at 2 kW at 40 cm/min. If the lower speed satisfies production requirements, the potential for a reduction in capital expenditures is clear. However, the 40 cm/min process is sensitive to power variations in terms of both penetration and hardness. For example, a 0.4 kW increase in power reduced hardness from 725 HV to 685 HV. At the same time, penetration increases by 0.3 cm. Such sensitivity places a premium on accuracy of beam generation (and delivery). Rejection rates may be increased in the lower speed procedures outlined in Fig. 8.

Electron Beam Heat Treating. This method is similar in principle to laser heat treating, except that heating is achieved by an accelerated stream of electrons instead of a light or infrared beam. When the electron beam is turned off, the part self-quenches. Many of the same considerations apply that are true for laser processing, but there are basic differences in the equipment used. The beam and workpiece are manufactured in a vacuum environment, which is not necessary with a laser, and this requirement introduces some complications into the fixturing. Another difference is in beam manipulation, since laser energy may be directed and focused by mirrors, and an electron beam is manipulated by magnetic coils.

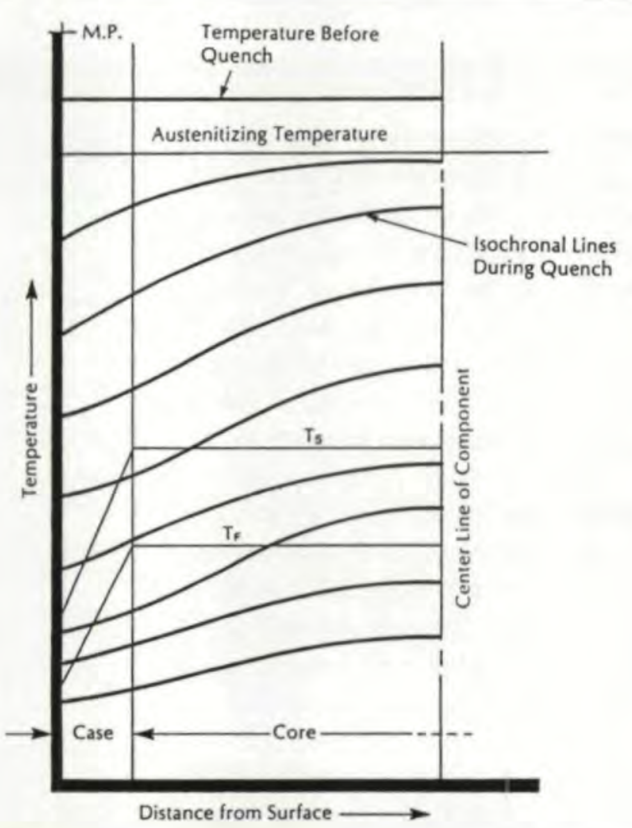


Fig. 9–Temperture distribution in steel parts during quench after carburizing.

However, electron beams have some important advantages. First, the cost of electron beam power is lower than laser energy, since the conversion efficiency is higher. Secondly, higher electron beam power is available, and while a 40 kW electron beam gun is commonplace, a 15-20 kW laser is very large. The third advantage, which is not generally exploited, is the availability of programmable raster patterns. While laser beams may be patterned by oscillating optics and integrator optics, the pattern produced is not capable of the flexibility made possible by scanning an electron beam. This could be of particular importance in hardening complex geometric shapes, such as gear teeth, where different amounts of energy are required on different parts of the surface as the geometry changes. Electron beam equipment may be more compatible with CNC controls, particularly in a flexible manufacturing situation.

Residual Stress Patterns

One advantage of case carburized parts is that when the treatment is properly carried out, it leaves a compressive stress system at the surface. Compressive stresses help counteract tensile stresses produced during bending fatigue and contact fatigue and, thus, increase the expected life. Fig. 9 represents conditions during the quenching of a carburized part. This part has been carburized and heated to a temperature above the austenitizing temperature and then quenched. The isochronal lines show how the surface cools faster than the center of the section because heat is abstracted from the surface by the quenching media. This trend continues right through the quenching process. Fig. 9 also shows lines representing the start of martensitic transformation (T_S) and the finish of transformation (T_F). It will be seen that these temperatures are depressed as the case carbon increases. The net result is that transformation of austenite to martensite starts at the case/core interface with an expansion as martensite is formed. The case is the last material to transform, and the expansion to martensite causes compressive stresses because the core is already transformed and restrains the case.

The situation is different in selective hardening (Fig. 10), but the results are similar. Energy is transmitted quickly into the surface, resulting in a surface layer heated above the austenitizing temperature. This layer will later become the hardened case. When the energy is turned off, rapid cooling progresses, and again the case is the last to transform, and the restraint induces residual compressive stresses as the surface expands during transformation from austenite to martensite.

Nitriding

Nitriding is an alternative case hardening process often specified for gears when distortion would be difficult to control if the gear were case carburized and quenched. In nitriding, nitrogen is introduced into the surface of the steel at relatively low temperature (925° to 1050°F) from a nitrogen-containing atmosphere, such as ammonia. A hard case is produced by the formation of hard compounds in the surface, making quenching unnecessary.

Special steels are needed for nitride containing elements, such as aluminum or chromium, that will form hard nitrides during treatment. The steel is nitrided in the hardened and tempered condition. The process is controlled by adjusting the dissociation of the ammonia. More often the Floe process is used, which is a double stage process analogous to the boost diffuse cycle in carburizing. In the first stage, the dissociation level is controlled at 15 to 30% by using a temperature range of 925° to 975°F, producing a white nitride layer which is diffused in the second stage by increasing the dissociation to 80 to 85%. The high dissociation can be achieved by increasing the temperature range to 1025° to 1050°F and using an external dissociation. Even with the two-stage process, nitriding is slow, taking about a day (24 h) to produce a 0.020 in. case. The process produces very hard cases with minimum distortion. Volume increases during nitriding cause favorable compressive stresses to build up in the case.

Ion Nitriding. Ion nitriding or plasma nitriding is similar to plasma carburizing in that a plasma is formed around the work during treatment. It is claimed that the process gives more reproducible results and a shorter process time.

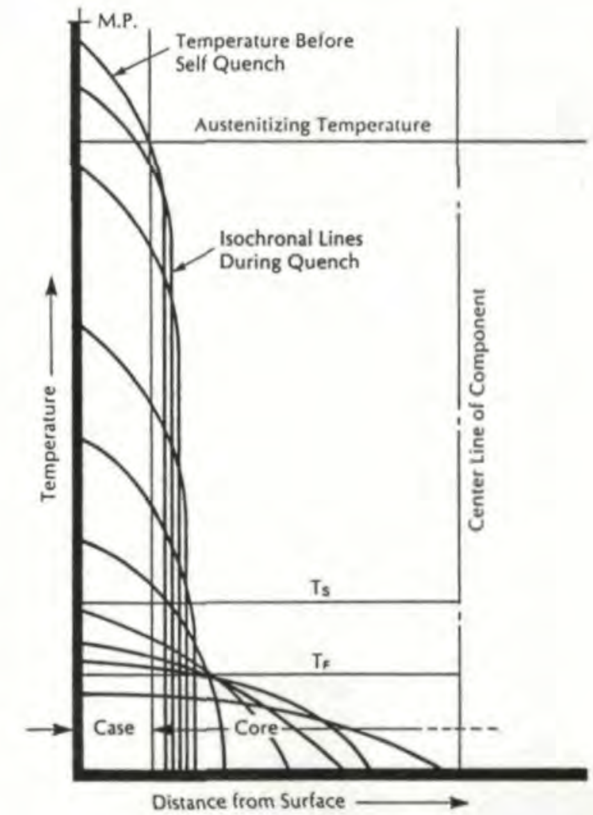


Fig. 10 – Temperature distribution in a steel part after laser heat treatment.

Dimensional Problems Caused by Heat Treatment

It is believed that heat treatment causes more quality problems than any other manufacturing step. This is because heat treatment causes dimensional changes due to volume changes, resulting from phase transformation. Distortion is caused by a combination of geometric factors and stress relief. These two factors acting together often cause unpredictable results. Variables that contribute to the dimensional changes include:

Variations in material composition
Residual stress differences
Size of part (within tolerance range) before heat treatment
Surface condition
Carburizing heating cycle
Carburizing atmosphere control
Depth of case
Quenching parameters
Quenching die dimensions
Post heat treatment.

Gear manufacturers hope to bring the component size under control in the finish grinding or hard turning stage. This leads to a dilemma: if excess material is left on the part prior to heat treatment, there will be enough stock to enable the size to be brought under control: however, if too much is taken off, the most effective parts of the carburizing (or nitrided) case are removed. Fig. 11 shows excessive material being removed from a tooth after heat treatment. In the example shown in Fig. 12, the tooth has distorted to the right, and to correct the profile, excess stock has to be ground from the right side of the tooth. This has several serious consequences.

First, there is lack of uniformity in case depth leading to uneven residual stress distribution. Second and worse is that the gear appears satisfactory in a nondestructive inspection, even though the performance of the gear will be less than optimum. Third, a considerable thickness of material has to be removed during grinding, increasing the probability of grinding burns. There is little doubt that some problems that are blamed on grinding can in reality be traced back to heat treatment. Thus the effects of the heat treatment process have to be considered before and after the process in both the soft machining and hard finishing stages. The attraction of selective direct hardening processes that minimize distortion and can be done on the manufacturing floor, reducing the work in

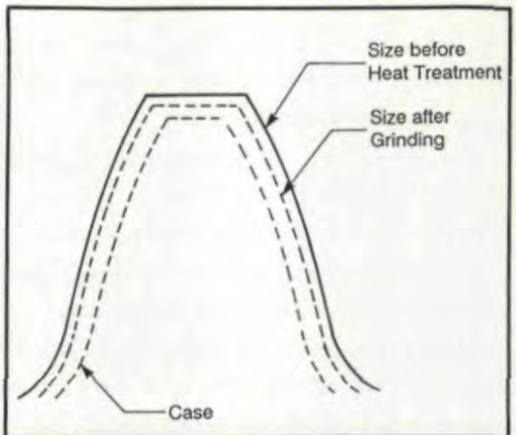


Fig. 11 – Schematic of material ground from gear tooth.

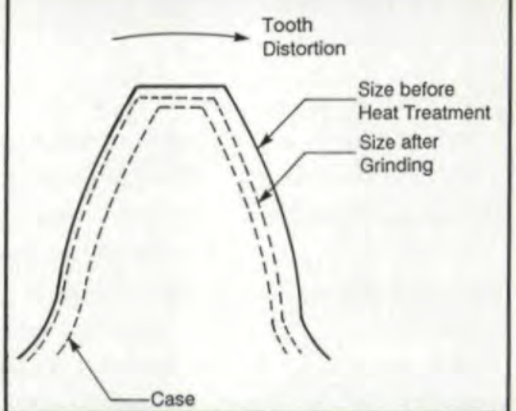


Fig. 12 – Schematic of material ground from a distorted gear tooth.

Table 1. Comparison of Case Hardening Processes

Process	Cost of Equipment	Cost of Operating	Quality of Product	Environmental Effects	Time Taken to Complete Process	On-Line Process
Case Hardening						
Gas carburizing	M	M	M	H	M	N
Vacuum carburizing	M-H	M	M	L	M	N
Plasma carburizing	H	M-H	H	L	M	N
Nitriding	M	H	H	M	H	N
Ion nitriding	H	H	H	L	H	N
Selective Direct Hardening						
Flame hardening	L	L	L-M	M	L	Y
Induction	M	L	M-H*	L	L	Y
Laser	H	L	H*	L	L	Y
Electron beam	H	L	H*	L	L	Y

Legend: H = high; M = medium; L = low; Y = yes; N = no.

*Design engineering may be reluctant to change from carburizing to direct hardening since a material change is necessary, and an extensive acceptance testing program may be required.

Note: Lot size should be considered when selecting a case hardening process, since small lots sizes often mean the use of smaller, less automated equipment. It may be difficult to justify the tooling usually required in a direct hardening process if only a few parts are contemplated.

progress, become apparent, and there will be serious attempts to use these processes wherever possible.

Conclusions

Cost comparisons between plants and companies are difficult to make because of variables, such as energy costs, labor costs, part geometry, lot size, and accounting practice, but Table 1 attempts to compare generally perceived costs together with product quality and the environmental effect of the process.

In diffusion type processes, gas carburizing is the most generally used process using endothermic gas atmospheres. Vacuum and plasma carburizing are slowly being introduced as cleaner, more consistent processes. If distortion is difficult to control, then nitriding or the newer ion nitriding is used. All of the above processes are done in a special heat treatment area off the production area.

The size of batch-type heat treatment equipment is often determined by the lot size and quantity of parts to be treated. Large volume producers may use continuous carburizing furnaces, while small job shops may use much smaller base furnaces. Small work lots may be accumulated to make a full furnace load if the parts are of comparable size and require the same case depth.

Production engineers would like to heat treat gears as part of the manufacturing sequence on machines situated in the production line. This is achievable by selective direct hardening, which can be done by one of several methods in times comparable with the manufacturing process. However, a medium carbon steel has to be used, which can be more difficult to machine and causes designers concern that a direct-hardened gear may not be equivalent to a carburized gear for power transmission purposes. The selection of a direct hardening process and equipment may be influenced by lot size, since it may not be feasible to provide the necessary tooling for treating a few parts.

Process selection is often determined by the available equipment, but it is worth knowing all the options that are available to the gear maker, particularly when difficulties are encountered or new equipment is purchased.

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What Is Runout, And Why Should I Worry About It?

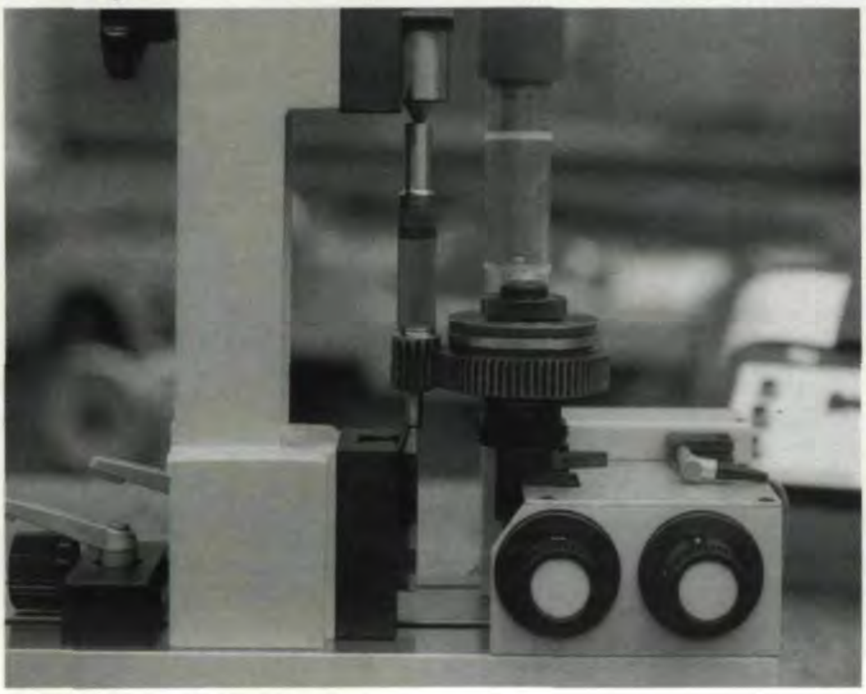
Robert E. Smith

Runout is a troublemaker! Good shop practice for the manufacture or inspection of gears requires the control of runout.

Runout is a characteristic of gear quality that results in an effective center distance variation. As long as the runout doesn't cause loss of backlash, it won't hurt the function of the gear, which is to transmit smooth motion under load from one shaft to another. However, runout does result in accumulated pitch variation, and this causes non-uniform motion, which does affect the function of the gears. Runout is a radial phenomenon, while accumulated pitch variation is a tangential characteristic that causes transmission error. Gears function tangentially. It is also possible to have a gear with accumulated pitch variation, but little or no runout.

In fact, runout affects every other characteristic of gear quality, such as involute or tooth form, index or pitch variation, lead or tooth alignment variation, and noise and vibration. It is quite common for one to have problems trying to meet specifications for index or pitch variation when the cause is actually runout. The various measures of gear quality are not independent parameters. They are all influenced by runout.

Much time can be wasted trying to fix the wrong source of the problem in a machine tool. For example, if a perfect gear were to be produced on a machine, but put into an inspection machine with runout in the arbor or centers, it would have apparent involute and index er-



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SHOP FLOOR

"Shop Floor" is *your* column. When you have questions you can't answer or need information you can't seem to find, let our panel of experts help. Your questions will be directed to gear consultants Robert E. Smith, Bill Janninck, and Don McVittie, who bring to our pages over 120 years of combined experience in gearing. Address your questions to them, care of Shop Floor, *Gear Technology*, P.O. Box 1426, Elk Grove Village, IL 60009, or call our editorial staff at (708) 437-6604.

Robert E. Smith

is the principal in R. E. Smith & Co., Inc., gear consultants. He has over 40 years' experience in the gear industry, working in gear methods, manufacture, and research applications. His specialities include manufacture, metrology, noise control, and transmission error testing. He is presently Chairman of the AGMA Handbook Measuring Methods and Practices Subcommittee and the Calibration Committee. If you have other questions for Mr. Smith, circle Reader Service No. 45.

rors, as well as possible tooth alignment variation.

It is extremely important throughout the manufacturing and measurement process to be careful that the center axis of the pitch cylinder of the teeth is coincident with the center of rotation of the machine or journals. Many inspection machines and some finishing machines use centers for locating the gear. Unfortunately, the gears are never used from centers in the application. They either mount from a bore or from journals and shoulders. Most people believe that because the journals and teeth were finished from centers, that they all run true. "Murphy" says that even though the journals were ground from centers, they will never run true again. Just check them and see!

SHOP FLOOR

Care should be taken with the choice of arbor types used. If a solid, cylindrical arbor goes into a bore, there has to be clearance; therefore, the gear can drop off center, causing runout – maybe only a few ten thousandths of an inch, but this is a lot when trying to meet involute tolerances. If a slow taper arbor is used in a cylindrical bore, the gear will tip, causing wobble and tooth alignment variation. The only way to use these types of arbors with confidence is to use pre-qualified axial and radial proof spots or bands that are true with the actual journals. These can be indicated and trued before finishing or measuring.

Some of the recommended arbor types that will take up the clearance in the bore or journals are hydraulic expanding, expanding collet, precision 3-jaw mandrels, and ball sleeve interference fit.

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