GEAR TECHNOLOGY

The Journal of Gear Manufacturing

GEAR LUBRICATION

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May/June 1995

GEAR LUBRICATION MYTHS
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LUBE ADDITIVES & SURFACE FATIGUE
PLUS • Near-Net-Shape Gears • Brad Lawton of Star Cutter • Business Ethics • CNC Software Selection • Addendum

THE GEAR INDUSTRY'S INFORMATION SOURCE

GEAR TECHNOLOGY

MAY/JUNE 1995

The Journal of Gear Manufacturing

FOCUS ON LUBRICATION

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SPECIAL FEATURES

15

DEPARTMENTS

48

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BUSINESS ETHICS
Touchstone or Oxymoron?

"*Values*" is one of the buzzwords we hear everywhere today. Family values. Traditional values. Alternative values. Along with a balanced budget, less government and more fiber in our diets, "values"—and their practical counterparts, "ethics"—are being promoted as one of the simple, obvious solutions to what ails us as a country and as individuals.

But critical readers and listeners will note that much of what is being said sheds more light on the 1996 elections than on questions of ethics and values—which does not mean that such questions aren't worthy of discussion. They are.

And perhaps the discussion takes on importance nowhere more than in the arena of business. When it comes to ethical questions, those of us in business find ourselves on the firing line every day.

Some would say that the very term business ethics is an oxymoron and that the discussion is pointless. They suggest that there is only one value in business, the bottom line, and one ethical criterion: What you do to get good numbers is good; what nets bad numbers is bad. Any other discussion is blowing smoke. And even if one is inclined to suggest otherwise, the brutal competition of today's business environment won't allow it. Nice guys finish last.

Others of us, including me, would like to argue that it is indeed possible, even necessary, to do well and do good at the same time. In the long run, the company whose products do what they promise, whose employees' words can be trusted, whose business dealings are above board and that treats both customers and employees fairly and with respect, will be the company that prospers.

Which side of the question do you come down on?

In 1994 the Ethics Resource Center, a non-profit educational organization in Washington, D. C., conducted a survey of some 4,000 individuals from a wide variety of businesses about their attitudes toward and knowledge of ethics and ethics programs at their companies.

The results of this survey are disturbing. In summary, those surveyed showed a good deal of uncertainty about their companies' attitudes toward ethics. In many cases, the perception was that when the choice was between doing what was right and making a profit, making a profit won out every time. Even more disturbing was the fact that this choice was more common in the manufacturing sector than in any of the others surveyed, and that the people who most keenly felt the tension were front-line supervisors, technical and engineering staffs and quality control personnel. At the same time, many of the top management in these same companies perceived their companies as doing an excellent job of implementing good business ethics. (See our story on page 15).

We were so intrigued by this survey that we are taking a much smaller, non-scientific poll of a randomly selected group of our readers to see if we can determine whether what was true of manufacturing in general is also true of the gear business in particular. We will publish the results of our survey in the next issue.

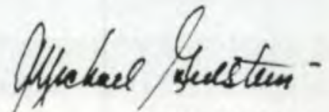
But who cares?

We all should, because ethics are fundamental to doing business. There is no such thing as a value- or ethics-free workplace and, like it or not, almost every business decision has an ethical dimension. Saying that ethics has no place in your business in itself declares an ethical position.

One of the apparent results of the massive political change sweeping Washington is the beginning of a welcome reduction in the amount of government regulation of our businesses. If our leadership delivers as promised, then there will be fewer laws holding us to certain standards in our treatment of our workers, customers, stockholders, competitors and the world around us. We'll have to set our own, and what our ethics and values are will determine what those standards will be.

That raises some knotty issues. Is profit the ultimate good? Should businesses be held to a different standard than everyone else in the name of profit? Can we relegate "ethics" to a quality we want sports heroes, artists, welfare recipients and families to have, while we remain exempt in pursuit of the bottom line? Can we have a moral society driven by an amoral (or immoral) business engine? Is it even possible to have one set of values and ethics for our business lives and another for our private lives?

I think not, but that glib answer belies the difficulty of arriving at the conclusion. These are tough questions with no easy answers. They are, however, questions we have to start thinking about. We owe it to ourselves, our businesses and our communities.



Michael Goldstein
Publisher & Editor-in-Chief

WHO? WHAT? WHERE?

12,000 of your potential **customers want to know,** and you can tell them **ABSOLUTELY FREE.**

In September of this year, in plenty of time for the Gear Expo, *Gear Technology* will publish its **new, expanded and completely revised Buyers Guide.** This guide is designed to be the definitive directory of products and services for the gear industry. It will be mailed out to our entire worldwide subscriber list along with our high-profile September/October Pre-Show Issue.

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- ❑ Chamfering Machines
- ❑ Deburring Machines
- ❑ EDM Machines
- ❑ Generating Machines
- ❑ Grinding Machines
- ❑ Heat Treating Equipment
- ❑ Hobbing Machines
- ❑ Honing Machines
- ❑ Inspection Machines
- ❑ Keyseating Machines
- ❑ Lapping Machines
- ❑ Measuring Machines
- ❑ Shaping Machines
- ❑ Shaving Machine
- ❑ Spline Rolling Machines
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- ❑ Turning Machines
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- ❑ Other______________________

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- ❑ We provide a gear school.
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- ❑ We are a trade association.

❑ DISTRIBUTOR FOR:

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- ❑ Hobs
- ❑ Keyseat Cutters
- ❑ Lapping Compounds
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- ❑ Hypoid
- ❑ Master Gears
- ❑ Non-circular
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- ❑ Powdered Metal
- ❑ Rack & Pinion
- ❑ Spiral Bevel
- ❑ Splines
- ❑ Spur
- ❑ Straight Bevel
- ❑ Worm
- ❑ Other______________________

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- ❑ Gear Design
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- ❑ Shot Peening
- ❑ Tool Coating
- ❑ Other______________________

FIXTURING & WORKHOLDING YOU SELL:

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- ❑ Modular Fixtures
- ❑ Toolholders
- ❑ Other______________________

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Bradley Lawton of Star Cutter

Continuing our series of interviews with industry leaders, Gear Technology *spoke recently with Bradley Lawton, executive vice president of Star Cutter Co., about the role and direction of cutting tools in the gear industry today.*

GT: Star Cutter Company has been in the cutting tool business since 1927 and the machine tool business since 1958. What kind of changes have you seen in these industries?

BL: With regard to cutting tools, it's been a very competitive market. In the last 15 to 20 years, it probably has been impacted the most by the development of tool coatings. As that occurred, there was increased emphasis on materials, design of product, and without question, the use of these technologies to improve the overall performance of the tool. Going back 20 years and before, I don't think that the tool performance was as important as it seems to be in today's marketplace. And it all relates to the advancing technologies that I've mentioned.

The biggest single change in cutting tools is how fast technology moves today as compared to 20 years ago. And the same can be said for the machine tool industry, with the advancements of CNC to get the performance out of the mechanical functions of the machine. And of course, all of this is linked together by quality. Any company today has to have a concerted effort for quality and a continuous improvement aspect in its corporate philosophy.

GT: What do you see as the next improvement in cutting tool technology?

BL: I think it's a continuation of what's been done in the past—sometimes termed "peeling the onion." We're taking one small step at a time with that effort, looking at our customers' needs for increased production, longer tool life and lower cost per piece. We see such things as new materials, new coatings or combinations of both that can be applied to each application to come up with an improved performance.

Bradley Lawton

GT: If you could make one giant step in cutting tool technology, if you had the ability to make this change overnight, what would you do?

BL: I have to look back in history and say, "What were some of those big steps?" Big steps would have been, for example, from high speed steel to carbide, or high speed steel uncoated to high speed steel coated. I certainly don't have a crystal ball to say that none of those opportunities are in the future, but I'll go out on a limb and say that we won't see the dramatic increases in tool performance that we once saw. There will be combinations of coatings, new and interesting coatings, but they will be much more niche-oriented.

GT: Is there anything along those lines that you see being especially good for the gear industry and for gear cutting?

BL: For gear cutting, I see progress with coatings, and I see materials with increased toughness versus hardness. That combination will provide gear cutting tools with improved performance. Again, that performance improvement will not be as dramatic as we have seen at other times, but every little bit helps, and I think that's part of our responsibility, to present that to the marketplace.

GT: Star Cutter was founded as a cutting tool manufacturer. Now your operations have branched into coatings and the manufacture of machine tools. How did that come about?

BL: We first started out supplying remanufactured sharpening machines to our gear hob customers. We've expanded upon that by formalizing a separate machine tool division with a separate facility and a full engineering staff. Today, we manufacture a line of CNC tool grinding equipment that can be used for manufacturing cutting tools or for sharpening or resharpening cutting tools. It's a quite diversified line of equipment, and it can be used for end mills, special drills, special reamers, step tools and broaches as well as gear hobs.

GT: In one division you're trying to sell cutting tools, and in another you're trying to sell the machines that are capable of manufacturing the cutting tools. Are your divisions competing against one another?

BL: We could certainly stand back and say, "Why should we manufacture machines that other people can use to manufacture tools that might in fact compete with us?" I think the truth is that any modern day manufacturer has to look at a product line from the standpoint of saying he may have conflicts of interest within his own group. Those conflicts of interest, if properly administered, can be a benefit to the company rather than a negative. We saw from our customer base a definite need for utilizing advancing technologies, and we are able to come to the customer with a machine and a cutting tool that are more friendly to his needs.

GT: It's been suggested that today's machine tools are having a hard time keeping up with the technology of the cutting tools. Do you agree?

BL: No, I don't. I'm not saying that there are not certain applications where that may be the fact, but I think that in an overall broad sense, cutting tools and machine tools are advancing at a very rapid pace. They're both in the race together. I don't see very many machine tools without a cutting tool, and vice versa. So, it's a much more even situation than what it has been in the past.

GT: What about machine speeds? We've heard that today's cutting tools are capable of higher spindle speeds than the machines they are being used on. Do you agree with that statement?

BL: Again, I think I'd refer to the application. If we're talking about cutting a gear that could be cut with a high performance hob, and the machine was limited in its spindle speeds or table speeds, then I would certainly agree with that statement. But in some cases, the machines have been more advanced. Correspondingly, we've had to work on those applications to press ourselves and our tools to meet the demands of the machine and the potential of production of the customer. It's a hand-in-hand situation.

GT: What is your take on the "disposable" cutting tools on the market?

BL: Well, the disposable tool by Star Cutter Company's definition is a high performance hob. A high performance hob becomes disposable after one application or one use when the customer has increased his return on his investment beyond the point of requiring resharpening. And it's certainly totally at the discretion of the customer. We do not manufacture by design a tool that is not resharpenable. But it is certainly disposable, if that is the wish of the customer, and he's received the return on his investment. We prefer to approach the marketplace with the concept of a high performance hob. The decision whether it's disposable or whether it's resharpenable is really the decision of the customer. We manufacture our product to be resharpened.

GT: How are you changing to keep up with the demands of the marketplace?

BL: We're advancing in materials. We have our own carbide facility, which is able to provide us with carbide for our drill and reamer division and also at the same time provide us with current material for our carbide hobs in the gear cutting market. At the same time, we have our coatings division—thin film coatings—and we are advancing through research and development towards new and better coatings for all of our product lines.

GT: What about the overseas markets. What are their demands?

BL: We're working very diligently to increase our global presentation. Far and away, the majority of our business has been domestic, but we look to the global market as being an increasing part of Star Cutter's business. International use of hobs has focused on the inserted blade or built-up hob. In the past few years that has been changing. That technology has been moving more towards a solid hob, the product that has been more generic to the U.S. market.

GT: Do you see the international market progressing toward where the U.S. market is?

BL: No, I think it's a marriage of technologies, that marriage being the recognition of the rigidity of the solid hob and the advancements in the equipment to be used in international markets. Coatings certainly are a major part of that. I think domestically our marketplace utilizes coatings to a greater extent than international markets do. I think the domestic market utilizes recoating of tools, where on an international basis, that has not been a prime consideration to reducing tool costs.

GT: How important is the gear industry to your company?

BL: The gear industry has been a primary part of the growth of Star Cutter Company, because the company was founded on form relief cutters and gear hobs, and we have been a continuous supplier to the industry. I would consider the gear industry the cornerstone of our company, and I see that role continuing. I feel strongly that as long as there is a gear industry, Star Cutter will be involved.

GT: The gear industry is often regarded as a kind of big family where everyone knows everyone. Do you perceive it that way?

BL: Having just come from the AGMA annual meeting, I would certainly share that perception, because I thought it was an excellent meeting and an opportunity for all those people who depend upon the industry to get together and share concepts of growth and progress. I really feel that the gear industry has stepped itself up a number of notches on the ladder of success and said, "Hey, as we look at ourselves and we know we have to restructure, there are a lot of ways to do it." And a lot of those ways were shared at this meeting.

GT: How do you perceive AGMA's role in the gear industry?

BL: I perceive AGMA to be a key to the future success of the domestic gear industry. It provides a forum for the candid sharing of ideas. We can sit in a meeting and share different approaches to employee relations, the importance of quality, the importance of recognizing a global market rather than a domestic market. These are all very, very important concepts for the future success of the American gear industry.

GT: Some say there is a belief that the gear industry has been slow to accept new technologies, especially when compared to other machining industries. Do you agree?

BL: No. If Star Cutter's participation in the application of coatings is an example, the gear industry has been advanced compared to drills, end mills and reamers. When titanium nitride coatings first came on the market, their first applications were for gear cutting tools because of the high cost of those tools versus the cost of standard high speed steel end mills or reamers. The gear industry experienced tremendous cost improvements because of the extended tool life and production performance of a coated tool compared to an uncoated tool.

GT: What advice would you give to young people interested in pursuing a career in your industry?

BL: I would say to any youngster considering going into the cutting tool industry or the gear cutting industry, go into it with an enthusiasm that is there for the long term. Don't go for the short term. What is the difference between success and failure? Dedication, simply dedication and a willingness to push oneself beyond the current understandings.

GT: Would you say that this is an exciting time to be involved in the gear industry?

BL: Personally, I think it's very exciting. I happen to enjoy the technology that I've been involved in for 30 years and to be able to see the growth in the industry, to see the change in the industry and to see the enthusiasm that we currently have. It wasn't too many years ago that we were labeled as a dying group, and maybe we are, but I don't think so. I believe the involvement of everybody at the recent AGMA meeting demonstrated otherwise.

GT: Can you point to anything that caused these changes in attitudes?

BL: I think it's a basic recognition that if we expect to survive in this technology race, we cannot look at ourselves as being good enough. We have to look at ourselves from the viewpoint of how good we can be. That certainly was clearly voiced at the AGMA meeting. As evidenced by the excellent turnout, everybody felt strongly that they knew they were going to change and they wanted to get across as many ideas as possible as to how to do it and how to be successful in it. ○

For more information about Star Cutter Co., circle Reader Service Number A-50.

Tell Us What You Think... If you found this article of interest and/or useful, please circle Reader Service **Number A-127.**

Hot Dates...

MAY 7–9
AGMA Gear Manufacturing Symposium. Westin Hotel, Cincinnati, OH. Papers and discussions on gear manufacturing issues. Contact AGMA at 703-684-0211 or fax 703-684-0242.

MAY 9
SME Seminar. Heat Treating of Gears. Penn State University, State College, PA. Call Susan Mihalik at SME headquarters, 313-271-1500, x384 or fax 313-240-8254.

MAY 10–11
MIT Conference, "Creating & Managing Corporate Technology Supply Chains." MIT Campus, Cambridge, MA. Led by senior MIT experts and other industry professionals, the conference will focus on how new technology supply chains are changing the rules for planning market strategies, controlling proprietary data, managing customer and supplier relations and reaching make vs. buy decisions. For more information, contact Ms. Diane Kendall, program registrar, at 617-239-1111.

MAY 15–17
Gear Research Institute Conference, Induction Hardened Gears & Critical Components. University Place Conference Center, Indianapolis, IN. For managers, designers, engineers and other professionals interested in the cost-effective use of induction hardening. For more information, contact GRI, 708-491-5900, or fax 708-491-5986.

MAY 22–24
AGMA Technical Seminars. Gear Failure Analysis and Geometry of Spur and Helical Gears. Radisson Suite Hotel, Rosemont (Chicago), IL. **May 22–23**, Robert Errichello will conduct a workshop on failure analysis, including overload, bending and Hertzian fatigue, wear, cracking and gear failure photography. **May 24** John Colbourne will lead a gear geometry seminar covering the geometry of both involute and non-involute spur and helical gears, generating gear cutting, introduction to vector algebra and more. Enroll-ment is limited to 30 per seminar, so enroll early. Contact AGMA at 703-684-0211 or fax 703-684-0242.

JUNE 6–8
University of Wisconsin-Milwaukee Seminar, "Microcomputer Applications in Parallel Axis Gear Design and Analysis." For gear users, designers and beginning to intermediate gear technologists, the course discusses how microcomputers may be used to solve real parallel axis gear design and analysis problems. For more information, contact Richard G. Albers at UWM, 414-227-3125.

JUNE 12–16
AGMA Training School for Gear Manufacturing. Daley College, Chicago, IL. Contact AGMA at 703-684-0211 or fax 703-684-0242 for more information.

JUNE 19–23
ASM International Seminar, "Heat Treatment of Steel." Sponsored by ASM's Materials Engineering Institute. Call 1-800-336-5152 for information on courses and registration.

JUNE 26–28
University of Cincinnati Center for Industrial Heat Treating Processes Workshop. Harley Hotel, Cincinnati, OH. Covers induction hardening, gas carburizing, quenching, part distortion and residual stress analysis of parts. Heavy emphasis on carbon and alloy steels and on industry application needs. For more information, call Dr. A. H. Soni, 513-556-2709/2710 or fax 513-556-3390.

JUNE 26–30
American Society for Nondestructive Testing, "Advanced School on Sensors for Process Monitoring & Quality Control." Banff Centre for Conferences, Banff, Alberta, Canada. Intensive 5-day training session on the basic principles of sensors relating to process monitoring and quality control. Twenty-three presentations by experts in the field. For more information contact ASNT at 1-800-222-ASNT or fax 614-274-6899.

To announce an important technical meeting, exposition or seminar, please send notification to Gear Technology Tech Calendar, P. O. Box 1426, Elk Grove Village, Illinois 60009. Notices should arrive in our offices six weeks prior to the date of the issue in which you wish it to appear. Items are used on a space-available basis.

SEPTEMBER 12–14
Ohio State University, "Gear Noise Seminar." Covers measurement, sources, transmission error, rattle, reduction techniques and more. Contact Susie Young, 614-292-5860.

OCTOBER 16–18
AGMA Fall Technical Meeting. Charleston, SC. Presentations on gear manufacturing and research subjects. For more information, contact AGMA at 703-684-0211 or fax 703-684-0242.

NOVEMBER 12–15
AGMA Gear Expo '95. Indiana Convention Center, Indianapolis, IN. The one trade show devoted exclusively to the gear and gear-related products and services industry. For more information, contact AGMA at 703-684-0211 or fax 703-684-0242.

Motherhood, Apple Pie and the Bottom Line

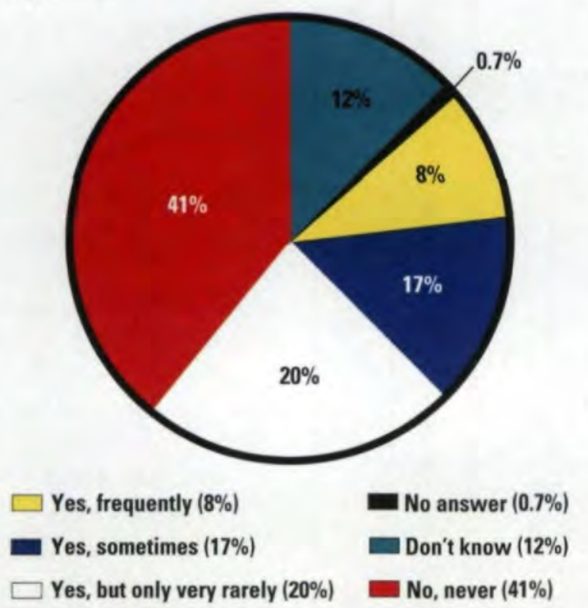
New survey shows that doing well by doing good is not nearly as easy as it sounds.

Nancy Bartels

Business ethics are like apple pie and motherhood. Few people are willing to come out agin'em. But in reality, apple pie is full of fat and refined sugar, motherhood is not what it was when June Cleaver ran the kitchen, and business ethics? Well, it's always been easier to talk about them than to actually practice them, and things certainly haven't improved in the last few years.

Statistical evidence to back up this assessment is found in "Ethics in American Business: Policies, Programs and Perceptions," an 88-page report by the Ethics Resource Center in Washington, D.C. The survey, conducted last year, covered some 4,500 people working in eight major industry groups, from manufacturing to finance and general services, and in seven job categories from accounting to quality control. The results indicate that, while most American businesses are not run by the slimy, greed-driven, amoral robber barons their severest critics like to portray, they're not exactly Sunday School meetings either. The survey also shows a deep perceptual gulf about business ethics between upper management and employees further down in the ranks, and nowhere is that gulf deeper than in the manufacturing sector.

Do you believe that your company "looks the other way" and ignores unethical conduct by employees to meet business objectives?



Ambivalence Abounds

Good intentions are everywhere, but they suffer in the harsh light of the perceived reality of business practice. An overwhelming 97% of the people surveyed agreed with the statement "good ethics make good business sense"; 87% strongly agreed; 56% said they thought their companies were more ethical than most. On the other hand, two-thirds of the respondents also agreed with the statement "ethical conduct is not rewarded in business today." More than 80% agreed that American managers would choose bigger profits over doing the right thing, a response that cut across age, occupation, management level and industry.

The Executive Summary of the survey underlines this basic tension. It points out that "corporate ethics programs are increasing in number and scope at a time when

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Nancy Bartels
is Gear Technology*'s Senior Editor.*

employees are doubtful about whether or not ethics is rewarded in the marketplace and also skeptical about the ethical commitment and behavior of their fellow employees. . . . Nearly one-third of employees reported that they sometimes felt pressured to engage in misconduct to meet business objectives. Also, almost one-third of employees observed misconduct at work last year, but fewer than half reported it to their companies. The majority of those who did report misconduct were not satisfied with their companies' response."

These numbers put a finger on the fundamental dilemma of conducting ethical business. It's easy to talk a good game, but much harder to play it when real numbers and real profits are involved.

But many companies try. Sixty percent of those responding reported that their companies had a code of conduct; 33% reported that their companies had training on business ethics; and 33% reported that their companies had an ethics office or a corporate ethics ombudsman.

And the programs are seen in a positive light. Well over half of respondents said they relied on the codes for guidance, and a similar proportion said that the training was useful. But, like ethics themselves, the results are often ambiguous: While nearly half claimed that their business ethics had improved during the course of their careers, nearly one in ten admitted that they had done things at work in the last year about which they would be ashamed or embarrassed to tell their children.

Deep Fault Lines

Some of the most significant revelations in the study are those reflecting the divergence between what people say are their personal ethics and how they perceive the ethics of their fellow workers and of their companies. More than half of the respondents regarded their own business ethics as higher than those of their peers and their direct subordinates. At the same time, one in four respondents believed their companies at least occasionally ignored ethical standards to meet business objectives, and one in six suggested that their companies actually encouraged ignoring ethical standards to meet specific goals.

Furthermore, 29% of the respondents said they were pressured at least sometimes to violate their companies' standard of business conduct in order to meet business objectives. The top sources of these pressures were meeting schedules, meeting overly aggressive financial or business objectives or helping the company to survive.

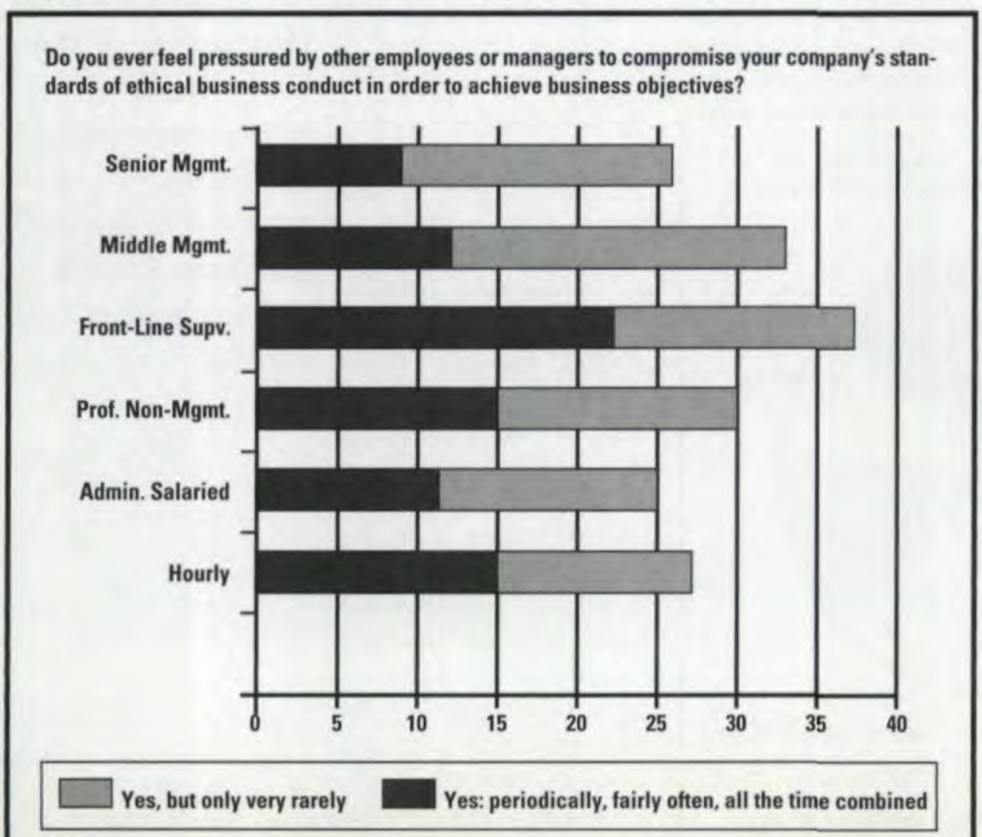
A gap also exists between the perceptions of senior management and other levels of workers. Seventy-four percent of senior management surveyed said that their companies were "more ethical than most," but only 45% of their hourly employees agreed.

The perception of pressure to perform misconduct also goes up as the level of management goes down. Senior management was most likely to believe that their companies fulfill their ethical obligations "exceptionally" well, while front-line managers were most likely to believe that the company would encourage ethical misconduct to achieve business objectives. Twenty-four percent of front-line managers also believe that unethical conduct at their companies had increased in the last five years.

There may be a number of causes for this difference in perception. Senior management encounters less pressure to bend the rules (only 9% report such pressure), and so assumes that ethical standards are higher. Senior management may simply be unaware of the amount of pressure mid-level managers feel to violate rules in order to meet specific corporate goals. Top level employees also may be engaged in a "don't ask, don't tell" style of ethical management. They either deliberately choose not to know, or their subordinates are reluctant to tell them about ethical violations. Fully one-quarter of the survey respondents felt that their companies "look the other way" or "ignore" unethical conduct to meet business objectives.

The View From The Shop Floor

Workers with manufacturing job functions had the darkest view of ethics, followed by



people in customer service and quality control (although the survey authors point out that their quality control sample is too small to be entirely trustworthy). They are closely followed by those in R&D and other technical engineering jobs.

NEARLY 10% DID THINGS AT WORK IN THE LAST YEAR ABOUT WHICH THEY WOULD BE ASHAMED TO TELL THEIR CHILDREN.

When asked whether they agreed with the statement, "When choosing between doing what's right and earning bigger profits, American business managers generally choose bigger profits," 83% of those in manufacturing jobs agreed. Eighty-one percent of those in technical jobs agreed, as did 85% in quality control and 87% in customer service.

When asked whether their personal ethics were higher than their business ethics, 33% of those in manufacturing and quality control jobs agreed, as did 32% of those in customer service. R&D and technical engineers agreed over 20% of the time. Close to 33% of those in manufacturing, quality control and customer service also believed that their companies "looked the other way" when it came to ethical violations, even of their own stated ethical policies.

People working in quality control report the highest percentage (over 25%) of those feeling pressure, at least "fairly often", to compromise company standards to meet business objectives. They are closely followed by those in customer service (20%) and manufacturing and R&D and technical engineering (approximately 18%).

The Bottom Line

Some conclusions from this study seem inescapable. Good intentions on the part of upper management are not enough. Pious statements or even elaborate educational programs will not ensure ethical behavior. What really goes on out on the shop floor and how employees feel about it may be vastly different from the perceptions in the executive wing. Many middle level employees—customer service, quality control and front-line manufacturing supervisors—truly do feel caught in the middle, torn between the desire to do the right thing on a day-to-day basis and pressure to cut corners to improve the bottom line. Furthermore, they are not optimistic about getting support for choosing ethics over profit.

No one ever said doing well by doing good was easy. More than anything else what the ERC report suggests is that talking the talk "good ethics make good business sense" is easy; walking the walk is a far more difficult proposition. ○

The complete report, "Ethics in American Business: Policies, Programs and Perceptions," can be purchased from the Ethics Resource Center, Inc., 1120 G Street, NW, Suite 200, Washington, D.C. 20005.

For more information about the Ethics Resource Center, please circle Reader Service Number A-53.

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Ten Myths About Gear Lubrication

"Home truths" that can wreck your gears and your wallet.

Robert Errichello
Jane Muller

Myth No. 1: Oil Is Oil. Using the wrong oil is a common cause of gear failure. Gears require lubricants blended specifically for the application. For example, slow-speed spur gears, high-speed helical gears, hypoid gears and worm gears all require different lubricants. Application parameters, such as operating speeds, transmitted loads, temperature extremes and contamination risks, must be considered when choosing an oil. Using the right oil can improve efficiency and extend gear life.

Myth No. 2: Oil Never Wears Out. Oxidation limits the life of lubricants. At some point a lubricant will degrade, form acids, lose lubrication abilities and deposit sludge and varnish. At temperatures above 65°C, oils begin to oxidize. Each increase of 10°C cuts the oxidation life in half.

Antiwear, antiscuff, antifoam and anticorrosion additives can be depleted if the gears are repeatedly subjected to conditions requiring reaction of the additives.

Monitoring lubricant properties by laboratory analysis of oil samples helps to determine oil change intervals. Monitor viscosity and acid number. Changes in these properties indicate oxidation. Spectrographic and infrared analyses detect changes in additives.

In many cases contamination requires an oil change long before the oil oxidizes. Unless there is a filter, oil should be changed frequently to remove contamination.

Myth No. 3: Gears Do Not Require Fine Filtration. It is well known that rolling-element and hydrodynamic bearings require clean oil. Less well known is that gear teeth also require clean oil. The oil film separating gear teeth is often only a few microns thick. Solid contaminants indent and abrade gear teeth and significantly shorten gear life. Filters should be as fine as 3 μm to help prevent abrasion, polishing, micropitting and macropitting. We often hear the complaint: "A filter that fine will clog in no time." Our response is: "Good. That means the filter is necessary and doing its job."

Modern filters provide fine filtration without being too large or creating large pressure drops. By starting with a coarse filter, say 100 μm, and changing to progressively finer filters, a lubrication system can be cleaned in a relatively short time. Once clean, it should stay clean if seals, breathers and maintenance are adequate.

Myth No. 4: Snake Oil Additives Improve Lubrication. Major oil companies have some of the best research facilities, employing knowledgeable chemical engineers, material scientists and tribologists. It is unlikely that any of the many independent additive companies could develop beneficial additives that the oil companies have not discovered.

Oil companies have developed additive packages designed to meet gear requirements. Tampering with the balance of oil additives invites gear failure. Before purchasing additional additives, check to see if they are endorsed by any major gear manufacturer or oil company. We doubt it.

Myth No. 5: Oils Are Interchangeable. Additive packages vary from oil company to oil company. A gear oil from one company may have the same viscosity and basic properties as an oil from another company, but their additives may be very different. For example, one company may use borate as an antiscuff additive, and another may use sulfur-phosphorous. Sulfur-phosphorous is much more aggressive than borate and may be totally inappropriate for a particular application.

Oils should never be mixed or interchanged without careful investigation. Synthetic oils such as certain esters, ethers and halogenated hydrocarbons are incompatible with mineral oils and some elastomers. Problems may arise if these synthetics are used in systems that previously held mineral oils.

Myth No. 1:
Oil Is Oil.

Myth No. 2:
Oil Never Wears Out.

Myth No. 3:
Gears Do Not Require Fine Filtration.

Myth No. 4:
Snake Oil Additives Improve Lubrication.

Myth No. 5:
Oils Are Interchangeable.

Myth No. 6: Oil Selection is the Gear Supplier's or User's Responsibility. Many gear failures can be traced to confusion over responsibility for lubricant selection. To get the right oil, the gear supplier and the gear user must cooperate in selecting one that meets application and gear requirements. Gear suppliers should know as much as possible about the application, and gear users should understand what it takes to adequately lubricate gears.

Many times lubrication mistakes are made because the application is misunderstood. There is a long list of application parameters that must be considered. For example, what is the ambient temperature immediately surrounding the gearbox? Is there adequate air flow over the gearbox? Is contamination or corrosion an issue? What maintenance is planned?

There is a trend among system designers to consolidate lubricants and require low-viscosity lubricants, such as automatic transmission fluid (ATF), in slow-speed, heavy-duty gears. These practices will increase gear failures.

Gear suppliers and gear users should ensure that the lubricant complies with the requirements of ANSI/AGMA 9005-D94, "Industrial Gear Lubrication." If it does not, find out why and make changes.

Myth No. 7: Laboratory Tests Are Accurate. This may not be true. Lab tests may accurately measure a particular property, but the property may not be the one you are concerned with. For example, you may wish to know if unusual wear is occurring in a gearbox and send a sample of used oil to a laboratory. Unless you instruct otherwise, the lab will probably run a spectrographic analysis to measure metals. If the laboratory reports relatively low levels of metals, you would probably conclude that the gearbox is healthy. Unfortunately, the usual spectrographic analysis detects only particles less than 10 μm. Gears could be failing and generating only large wear particles that are missed by spectrographic analysis. Therefore, you need to understand the limitations of laboratory analysis to get meaningful data.

It is equally important to get oil samples that represent the true condition of the lubrication. Be sure you are familiar with the requirements for proper sampling.

It is best to visit the laboratory and witness its procedures before signing a contract. Ask the lab staff to demonstrate each of their tests. Watch their housekeeping carefully; the laboratory should be clean and uncluttered. Especially important is handling samples to avoid contamination or mislabeling. Talk to technicians and ask about their qualifications. Many tests require skill to perform them properly and interpret results correctly.

The laboratory should adhere to standard ASTM tests if possible. If the laboratory deviates from ASTM procedures, they should explain how the results relate to those obtained with ASTM tests.

Ask how the lab monitors itself. Reputable laboratories have in-house monitoring to continually check results. Many are accredited by independent auditors.

Myth No. 8: If A Little Oil Is Good, A Lot Is Better. Each gearbox has an optimum amount of oil it requires to run cool and efficiently. Too much oil will churn, reduce efficiency and cause the gearbox to run hotter than it should. Excessive oil may cause foaming and leakage. Cost should be considered. Why buy more oil than necessary, especially if there are many gearboxes or if the oil is expensive? There are also environmental concerns; the less oil used, the less used oil discarded.

Myth No. 9: Special Oils Can Repair Gears. Some oil suppliers claim that their products not only reduce wear, but actually repair damaged gear teeth! They may show you before-and-after photographs that look convincing.

The problem is, the only way to repair gear tooth damage is to remove material from surfaces of the gear teeth. An oil may be abrasive and capable of removing steel. Unfortunately, gear teeth wear in a very non-uniform manner, and gear teeth "repaired" by special oils may look better, but their accuracy has undoubtedly decreased.

Myth No. 10: Synthetic Oils Are Superior To Mineral Oils. Synthetic oils have many advantages, including low pour point, high viscosity index and long oxidation life. However, they are costly and may be a waste of money if temperature extremes are not encountered.

Even in high-temperature environments, the long life of synthetic oil may not be realized if the oil must be changed to remove contamination or to replenish additives.

Some synthetic oils improve efficiency. But except for worm gears, the increase in efficiency will probably not be significant.

The optimum lubricant is the product that is least expensive, considering both initial cost and maintenance costs, and meets the requirements of the application. ○

For more information about Geartech, Inc., please circle Reader Service Number A-56.

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Myth No. 6:
Oil Selection is the Gear Supplier's or User's Responsibility.

Myth No. 7:
Laboratory Tests Are Accurate.

Myth No. 8:
If A Little Oil Is Good, A Lot Is Better.

Myth No. 9:
Special Oils Can Repair Gears.

Myth No. 10:
Synthetic Oils Are Superior To Mineral Oils.

Robert Errichello & Jane Muller
are with Geartech, Inc., gear consultants and gear failure analysts in Albany, CA.

Developing a Total Productive Maintenance System

Stopping trouble on the line before it starts is the goal of this gear set maintenance system.

Delos Hudson

There's a reason they call it catastrophic gear failure: For example, if the line goes down at a large aluminum rolling mill because a gear set goes bad, the costs can run up to a whopping $200,000 *a week*. Even in smaller operations, the numbers alone (not to mention all the other problems) can be a plant manager's worst nightmare.

The situation is no different at Haynes International. We manufacture high-performance, nickel-cobalt alloys and fabricate them in plates, sheets, wire, coils and strips. Production is mostly in small lots. Consequently, quality and productivity are critical, particularly as the products are very sensitive to upsets in the manufacturing process.

Gear sets are vital to our operation. Our strategy for keeping them and the rest of our equipment in top shape had always been a preventive maintenance program. But over the years we became dissatisfied with our approach. In spite of our best efforts, one or two pieces of equipment went down every week, a costly situation from both maintenance and production standpoints; production downtime was costing us as much as several thousand dollars an hour, depending on which line or mill was affected. We simply had to do better.

As a solution, we decided to upgrade to a Total Productive Maintenance (TPM) system, one in which both maintenance and production people work together to cut downtime. This system is based on four components:

1. Moving into predictive maintenance through equipment monitoring. This allows us to predict when maintenance will be necessary, as opposed to when it is scheduled.

2. Standardizing if necessary day-to-day maintenance into a computerized maintenance management system.

3. Instituting a Management Planning Group composed of people from both management and the factory floor.

4. Opening a management training center to train maintenance people.

In implementing this system, which is under the direction of maintenance supervisor Larry Peacock, we are using both our own resources and those on the outside. Our principal outside source is our supplier of lubricants for gear systems and other equipment, Mobil Oil Corporation. In addition, the company, like many other lubricant suppliers, provides engineering services that track lubricant and system conditions in our gear reduction sets and in our hydraulic systems. We also use outside infrared thermography and vibration analysis services to give us a better picture of overall machine performance and conditions.

Once a year Mobil engineers sample the gear oils in our 41 gear sets. Samples are sent to the company's customer service laboratory for analysis of viscosity, color, water, sediment, oxidation and the levels of dirt (measured as silicon) and wear metals in the oil. On the basis of these reports, the oil in each system is rated satisfactory or unsatisfactory for further use.

When they sample gear oil, the engineers inspect each gear reduction set, looking for signs of wear, such as pitting, spalling and peening. Using premium heavy-duty industrial gear oils is

Above: High-quality alloy strip is slowly wound onto rolls for shipping. Plastic interleafing protects surface finish.

Right: Delos Hudson, manager of maintenance at Haynes, and Larry Peacock, maintenance supervisor, look over finished coil of alloy ready for shipping.

not enough to prevent all wear. Contamination, misalignment or improper loading could also be culprits, so Mobil provides us with equipment monitoring services, which are key elements in our Total Productive Maintenance system.

This kind of regular inspection provides crucial information that enables us to intelligently plan our maintenance. For example, the latest gear inspection and oil sampling revealed the following:

- On the first gear reduction set on the Schloemann mill, a unit critical to our production, gear wear was totally uneven. Of the two pinion gears mounted on a common shaft, one was taking all the wear. The lubrication engineers suggested adjusting the gear shaft for proper loading. We are working to correct this imbalance.
- The gears in the 10-inch bar still were in poor condition and would need replacement if the mill is to continue in production. However, these are only operated infrequently. So we have decided against replacement right now and are depending on the regular reports to show us they aren't getting worse.
- Gears in the 3-high pinion stand were replaced a year ago because of excessive wear reported in a previous inspection. However, heavy shock loads continue to cause excessive wear. The engineers recommended more frequent observance of the gears to track additional wear and plan replacement.
- The gear oil in the 4-high mill was rated borderline because of oxidation and iron contamination. The lubrication engineers recommended a shorter resampling period to determine when it should be changed.
- Rust was observed on the gear set in the argon-oxygen decarburization vessel. The engineers pointed out that the rust was due to condensation and recommended installing an air breather. Unattended, further rusting could only lead to gear deterioration.

These annual gear inspection reports help us both spot problems requiring immediate attention and track wear from year to year, a great help to our planning. For example, one set of gears has severe wear, but its condition has stabilized, remaining unchanged for the past seven years. So we consider this set of gears satisfactory for continued service as long as there is no further wear. Another set, however, has deteriorated steadily from one year to the next to the point where it needs replacement.

This is how we use the 15-year history of each gear set to forecast major equipment repair and replacement, which is especially important to us on the main mills. The combination of load, speeds, heat and constant operation on some mills, not to mention the ever-present contamination, will cause gears to eventually wear out. We want to maximize production from them and then schedule their replacement when it will hurt us the least. Forecasting on the basis of the annual gear inspection reports allows enough lead time to schedule downtime and order replacement parts. Some of the main gears, for example, have a minimum order lead time of six months for replacement sets, and a replacement set may cost as much as $100,000. However, our main concern is not so much the cost of replacement units, which we can budget for, as the cost of unscheduled downtime, which we can't.

By overhauling our maintenance program, we have greatly reduced unscheduled downtime, with a resulting increase in production and more consistent product quality. Our maintenance costs have likewise dropped. Our Total Productive Maintenance system, including the use of a full range of services from our lubricant supplier, has been a major contributor to this turnaround.

Upper Left: Mobil lubrication engineer Jay Ford performs the yearly gear inspection at Haynes.

Lower Left: Mobil senior lubrication specialist Jay Ford (left) and maintenance manager Delos Hudson go over equipment inspection and lubrication analysis reports.

Below: Max Unger (left) and Larry Peacock of Haynes do a quick check on lubricant inventory.

Delos Hudson

is the manager of maintenance, Haynes International, Inc., Kokomo, IN, a manufacturer of high-performance alloys.

Eco-Friendly Cutting Fluids

Synthetic ester technology eliminates the choice between safe, easy disposal and cutting efficiency. Now you can have both.

John Sliner

Synthetic ester-based cutting fluids have coefficient of friction values under boundary lubrication conditions in the .08–.10 range, four to six points lower than petroleum-based oils. Photo courtesy of The Gleason Works.

The Benefits of Synthetic Ester Additives

- *Low volatility, high flash point, good thermal stability*
- *Resistance to evaporation, burning, sludge and gum forming*
- *Superior heat capacity and thermal conductivity*
- *Good response to other additives*
- *High level of boundary lubrication*
- *Chemically non-reactant to metals*
- *Biodegradable*

Okay, so you want to make some high-quality gears for your customers, and you want to make a profit for your company, but you don't want to make a mess of the environment. What can you do?

The chlorinated and/or sulfurized additives in most lubricants and coolants may help you make gears efficently, but they cause health and safety concerns for your employees; they smell bad, they're messy and expensive to clean up, and their dark color means low visibility. The EPA has now listed certain cholorinated compounds as SARA-reportable substances, making proper disposal very expensive, and failure to so can bring the EPA inspectors to your front door.

But . . . the fact is, until recently lubricants containing those chlorinated and sulfurized additives were the most efficient, cost-effective solution to your cutting problems. They function at elevated temperatures by chemically reacting with metal surfaces to form inorganic films which prevent adhesion between the tool and workpiece, and they work well in the severe conditions and precise requirements of gear cutting operations. The choice has been between cutting tool efficiency and negative side effects.

Not any more. Now it's possible to have environmentally safe *and* efficient cutting fluids at the same time.

A case in point: A major earthmoving equipment manufacturer has solved the problem by switching to cutting fluids with no sulfur or chlorine additives for its gear hobbing operation. The switch has not only solved some environmental and disposal problems, but also improved cutting efficiency.

The company had been cutting forged 18836 steel transmission gears using a heavily sulfochlorinated oil, with all the usual accompanying problems: heavy oil mist, messy clean-up, poor visibility, strong, objectionable odors and expensive disposal of cutting oils.

Since the company switched to Quaker Chemical's NSC series cutting oil, operators have reported less oil misting, a more pleasant odor and improved visibility. Hob life has improved by about 10%, and hob gouging problems have decreased significantly. Cleanup is simpler and easier and disposal problems are minimized since the main lubricant is biodegradable.

What's the secret? Synthetic ester technology.

Synthetic esters are derived from animal and vegetable sources, are biodegradable and they do not chemically react with metal surfaces. They differ significantly from petroleum-derived mineral oils both in their chemical structure and their physical characteristics. Even a highly refined petroleum oil contains hundreds of compounds that together contribute to its characteristics, making it a chemically complex, volatile substance. On the other hand, a synthetic ester is generally more chemically homogeneous, making for improved quality control parameters and more finely tuned performance characteristics.

Esters are formed by a chemical reaction between an alcohol and an organic acid. Through proper selection of these substances by type and purity, fluids are obtained that have low volatility, high flash points and good oxidative and thermal stability. They tend not to evaporate, burn or form gums or sludges as petroleum-based oils do. Esters also have superior heat capacity and thermal conductivity. In addition to their inherently good lubricity, esters have good response to additives to enhance anti-wear, extreme pressure and anti-corrosion properties.

Synthetic esters also offer a high level of boundary lubrication based on their affinity for metal surfaces. When measured on a pendulum-type tester that measures coefficient of friction under boundary lubrication conditions, the values for standard petroleum base oils at room temperature are in the .13–.14 range. The esters tested achieved values in the .08–.10 range. A lower coefficient means less friction and better lubrication.

Quaker Chemical Corporation has applied synthetic ester technology to developing sulfur- and chlorine-free machining and grinding fluids. The company has developed a line of water-soluble and straight oil type products which use a blend of synthetic esters and a non-traditional extreme pressure additive based on inorganic ester chemistry to provide a high degree of film strength and excellent lubrication performance in a wide range of applications.

In machine testing, this Non Sulfur-Chlorine (NSC) technology provides at least equivalent performance to traditional sulfo-chlorinated oils. The heaviest duty versions of both types of products can achieve full load (3,000 lbs without wear or seizure failure) on the Falex pin and vee block test.

Now the choice is no longer between an efficient cutting fluid and a safe, clean shop environment and minimal disposal hassles. Synthetic ester technology has made it possible for gear manufacturers and other users of heavy-duty cutting oils to have both. ○

For more information about Quaker Chemical Corp., circle Reader Service Number A-49.

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Who is SARA and Why Does She Care What You Do with Your Used Cutting Fluid?

SARA is the Superfund Amendments and Reauthorization Act. The Environmental Protection Agency has recently placed a number of chlorinated paraffins, such as those found in certain cutting oils, on the SARA 313 list. This is a list of toxic chemicals subject to reporting under Section 313 of the Emergency Planning and Community Right to Know Act (EPCRA).

Any company that uses 10,000 lbs. or more of a SARA 313-listed material in a calendar year is required to submit a Toxic Chemical Release Inventory Report to the EPA by July 1 of the following year. The first reports on listed chlorinated paraffins will be due July 1, 1996.

This report, called Form R, is about 10 pages long and details all emissions to air, water and land. Filers are also required to report on how the material is waste treated, where it's disposed of and what steps the user is taking toward pollution prevention and waste minimization. Failure to file a Form R and other violations of EPCRA can lead to fines of up to $25,000 per day per violation.

More information about SARA and EPCRA is available from the EPCRA hotline at 1-800-424-9346.

John Sliner *is product manager for machining and grinding fluids at Quaker Chemical Corporation, Conshohocken, PA.*

Who's Who... What's What... Movers... Shakers... Name Changers... and Other Items of Interest

OPENING MOVES . . .


James E. Cronkwright


Richard D. Reenan

Hurth Machine Tool Company of Munich, Germany, announced the establishment of **Hurth America** in West Chicago, IL. This U.S. operation will immediately begin marketing and servicing Hurth gear hobbing, honing and bevel gear cutting machines. **James E. Cronkwright** is the President of **Hurth America** and **Richard D. Reenan** has joined the company as Vice President of Sales & Marketing.

PROMOTIONS . . .


Robert A. Pruden


Russell S. Nagy

Robert A. Pruden has been appointed Vice President and General Manager and **Russell S. Nagy** has been named Manager of Marketing Services for the **Deckel Maho Gildemeister Group. Gene J. VanPatten** has been named National Sales Manager for Rank Taylor Hobson Inc., a leading manufacturer of precision metrology instruments. **Andrea Moll** has been appointed New Product Manager for **Bison Gear** of Downers Grove, IL, a manufacturer of gearmotors, motors and reducers. **Entek Scientific Corp.**, provider of complete software and hardware machine reliability systems, has announced the promotion of **Richard Schiltz** to Vice President of Engineering.

PATENTS . . .

DTM Corporation has been granted a European patent for the technology embodied in the company's Sinterstation® 2000 System for rapid prototyping. The technology is also covered by U.S. patents, and the company has applied for patents in Japan, Korea, Australia and other Pacific Rim and Asian countries. The system uses the SLS® Selective Laser Sintering process, in which specialized powdered materials, such as metal, nylon, polycarbonate and investment casting wax, are transformed into three-dimensional solid objects through the application of a modulated laser beam.

NAME CHANGE . . .

Small Castings, Inc., a manufacturer of precision aluminum and zinc castings has changed its name to **SciCast International, Inc.** The company operates out of a 33,000 sq. ft. facility in Bechtelsville, PA.

NEW HEADQUARTERS . . .

Bison Gear and Engineering has opened a new European headquarters in the Netherlands. The new facility houses the company's European sales office and warehouse, a light assembly operation and full inventory and support services for **Minarik** motor control products, for which Bison serves as European distributor. **Marc Bours** has been named Branch Manager of the new facility.

NEW FACILITIES . . .

Mikron Group has opened a new plant for its Plastics Technology Division in Anderson, SC. The new 50,000 sq. ft. facility will produce precision plastic components and systems. **Falk Corp.** has opened a pit carburizing facility in Milwaukee, WI, for large mill pinions and gears.

NEW SERVICES . . .

Caterpillar has announced its entry into the custom gear manufacturing business. This new service will be available at the company's new Peoria, IL, factory, which also houses a state-of-the-art heat treating facility.

ISO 9000 NEWS . . .

The Gear Works, one of the largest gear manufacturing facilities in the western U.S., has earned ISO 9001 certification. The company's certification is registered by TUV Rheinland of Cologne, Germany. **Master Chemical Corporation** of Perrysburg, OH, has earned ISO 9002 certification for its national headquarters and manufacturing facilities. The certification covers the quality systems used in the manufacture and servicing of the metalworking fluids, recycling and waste minimization equipment produced at its Perrysburg plant. The company is also seeking certification for its facilities in Huntsville, TX and Suffolk, England.

The **Big Three Automakers** have announced the adoption of **QS-9000**, a joint quality management system using the ISO-9000 standard as a building block. Suppliers to the automakers will have to meet and implement all 23 of the standards set in the system model. **General Motors** has already announced that registration to the QS-9000 model will be required by December 31, 1997, and the other automakers are expected to follow suit.

ADVERTISER INDEX

For more information about a product or service advertised in this issue of *Gear Technology*, circle the appropriate number on the Reader Response Card and put the card in the mail.

EHL Film Thickness, Additives and Gear Surface Fatigue

Dennis P. Townsend & John Shimski

Introduction

Aircraft transmissions for helicopters, turboprops and geared turbofan aircraft require high reliability and provide several thousand hours of operation between overhauls. In addition, they should be lightweight and have very high efficiency to minimize operating costs for the aircraft.

Most of the aircraft operating today use turbine engine lubricants to lubricate the transmissions. These provide good lubrication, thermal stability and low operation temperatures for the turbine engines, but they are less than optimum for reliability and long life for transmissions.

Tests with rolling element bearings have shown that bearing life is affected by the lubricant elastohydrodynamic (EHL) film thickness (Refs. 1 and 2). When the EHL film thickness divided by the composite surface roughness h/σ is less than one, the life of rolling element components is considerably reduced.

In gearing the effect of operating with an h/σ of less than one is more pronounced than it is with bearings. The higher sliding conditions encountered with gearing cause increased surface heating and higher friction coefficients, resulting in reduced EHL film thickness and surface fatigue life and increased wear or scoring risk.

Gear tests conducted with several lubricant additives have shown that the gear surface fatigue life can be improved somewhat with the right choice of additives (Refs. 3 and 4). Lubricants with the same viscosity, but with different additives, produced gear surface fatigue lives with a difference of five to one. The above-mentioned tests indicated the necessity of having the proper additive in the lubricant but did not determine what effect different lubricant viscosities of the same base stock would have on gear fatigue life.

The effect of the EHL film thickness on scoring and wear under various slide-to-roll ratios was determined in Reference 5 using rolling sliding cylinders. When the specific film thickness, Λ or h/σ, was less than or equal to 0.3, the rolling sliding cylinders experienced wear and scoring and elevated friction coefficient and temperature. These tests also showed an increase in scoring load capacity with EP additives in the lubricant.

Lubricant suppliers have recognized the need to supply better lubricants for modern gearboxes operating at increased power density (Ref. 6). Tests have shown that lubricants with the proper base stock, viscosity and additives can improve the load capacity and efficiency of transmissions.

The research work reported herein was undertaken to investigate the effects of lubricants with the same base stock, but with different viscosities on the surface fatigue life of AISI 9310 spur gears. The objectives were: (1) to investigate the effect of seven different lubricants on the surface fatigue life of hardened steel spur gears, (2) to compare

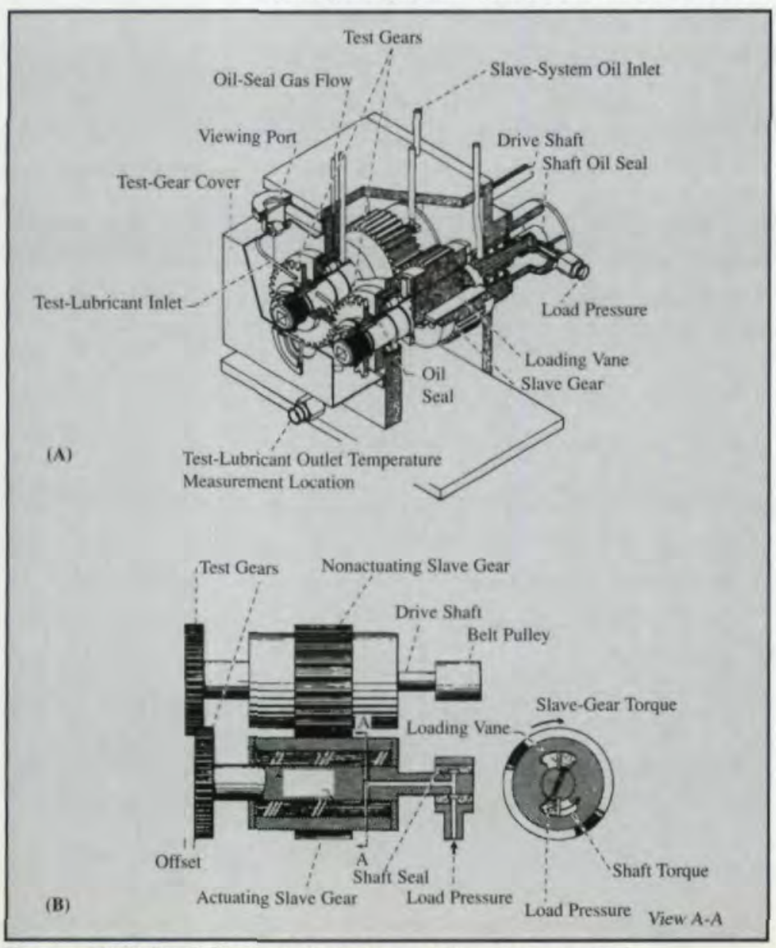

Fig. 1 — NASA Lewis Research Center's gear fatigue test apparatus.

the gear fatigue life with six of the seven lubricants to a reference lubricant and (3) to determine the effects of lubricant viscosity and specific EHL film thickness on the surface fatigue life of carburized and hardened spur gears.

To accomplish these objectives, one lot of spur gears was manufactured from a single heat of consumable-electrode, vacuum-melted (CVM) AISI 9310 material. The gears were case-carburized, hardened and ground to the same specifications. The pitch diameter was 8.89 cm (3.5"). The lot was divided into seven groups, each of which was tested with a different lubricant. All the test lubricants were synthetic polyolester with different viscosity properties and additives. Test conditions included a bulk gear temperature of 350 K (170°F), a pitch line maximum Hertz stress of 1.71 GPa (248 ksi) and a speed of 10,000 rpm.

Apparatus and Procedure

Gear Test Apparatus. The gear surface fatigue tests were performed in the NASA Lewis Research Center's gear test apparatus (Fig. 1A). This test rig uses the four-square principle of applying the test gear load so that the input drive only needs to overcome the frictional losses in the system.

A schematic of the test rig is shown in Fig. 1B. Oil pressure and leakage flow are supplied to the load vanes through a shaft seal. As the oil pressure is increased on the load vanes inside the slave gear, the loop torque is applied. This torque is transmitted through the test gears back to the slave gear, where an equal, but opposite torque is maintained by the oil pressure. This torque on the test gears, which depends on the hydraulic pressure applied to the load vanes, loads the gear teeth to the desired contact or Hertz stress level. The two identical test gears can be started under no load, and the load can be applied gradually without changing the running track on the gear teeth.

Separate lubrication systems are provided for the test gears and the main gearbox. The two lubrication systems are separated at the gearbox shafts by pressurized labyrinth seals. Nitrogen is the seal gas. The test gear lubricant is filtered through a 5-µm-nominal fiberglass filter. The test lubricant can be heated electrically with an immersion heater. The temperature of the heater is controlled to prevent overheating the test lubricant. A water cooler and temperature controller are also provided in the test oil and slave oil system to control the inlet oil temperature.

A vibration transducer mounted on the gearbox is used to automatically shut off the test rig when a gear surface fatigue or tooth fracture occurs. The gearbox is also automatically shut off if there is a loss of oil flow to either the main gearbox or the test gears, if the test gear oil overheats or if there is a loss of seal gas pressurization.

The operating speed for the test was 10,000 rpm. The four test rigs are operated 24 hours a day, seven days a week to provide the large number of test cycles required for surface fatigue testing.

Test Gears. Dimensions for the test gears are given in Table 3. The gear pitch diameter was 8.89 cm (3.5"). All gears have a nominal surface finish on the tooth face of 0.406 µm (16 µin), rms, and a standard 20° involute profile with tip relief. Tip relief was 0.0013 cm (0.0005"), starting at the highest point of single tooth contact.

The test gears were manufactured from (CVM) AISI 9310 steel from the same heat of material. The nominal chemical composition of the material is given in Table 1. All sets of gears were case-carburized and heat treated in accordance with the heat treatment schedule of Table 2. Fig. 2 is a photomicrograph of an etched and polished gear tooth showing the case and core microstructure of the AISI 9310 material. This material has a case hardness of Rockwell C60 and a case depth of 0.97 mm (0.038"). The nominal core hardness was Rockwell C38.

Test Lubricant. Seven lubricants were selected for surface fatigue endurance tests with the CVM AISI 9310 steel gear test specimens. Lubricant A is an unformulated base stock lubricant with no

Table 1 — Nominal Chemical Composition of AISI 9310 Gear Materials

Element	AISI 9310
Carbon	0.1
Nickel	3.22
Chromium	1.21
Molybdenum	0.12
Copper	0.13
Manganese	0.63
Silicon	0.27
Sulfur	0.005
Phosphorous	0.005
Iron	Balance

Table 2 — Heat Treatment for AISI 9310 Gears

		Temperature		
Step	Process	K	°F	Time, hr
1	Preheat in air	–	–	–
2	Carburize	1,172	1,650	8
3	Air cool to room temperature	–	–	–
4	Copper plate all over	–	–	–
5	Reheat	922	1,200	2.5
6	Air cool to room temperature	–	–	–
7	Austenitize	1,117	1,550	2.5
8	Oil quench	–	–	–
9	Subzero cool	180	-120	3.5
10	Double temper	450	350	2 each
11	Finish grind	–	–	–
12	Stress relieve	450	350	2

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additives and a viscosity between the MIL-L-7808J and MIL-L-23699 specifications, but it does not meet either specification. Lubricant A was used as the reference to compare the results with the other lubricants.

Lubricant B is a 5 cSt lubricant meeting the MIL-L-23699 specification. This lubricant had a small amount of a boundary lubrication additive to provide some boundary lubricating film. Lubricant C meets the MIL-L7808J specification and had the lowest viscosity of all the lubricants tested and also had a proprietary additive package. Lubricant D was developed for helicopter gearboxes under the specification DOD-L85734 and was also a 5 cSt lubricant with an anti-wear additive package. Lubricant E was a 7.5 cSt lubricant with an anti-wear additive package meeting a special development specification DERD-2487. Lubricants F and G were 9 cSt ester-based lubricants. Lubricant F was a base stock lubricant without additives, while G was a base stock industrial grade. Six of the seven could be classified as synthetic polyolester base stock lubricants, while E is a polyalkylene-glycol with a small amount of boundary lubrication additive.

The pitch line (EHL) film thickness was calculated by the method of Reference 8. The temperature used in the film thickness calculation was the gear surface temperature at the pitch line, which was assumed to be equal to the oil outlet temperature, even though the temperature of the oil jet lubricating the gear was much lower. Probably the gear surface temperature was higher than the oil outlet temperature based on temperature measurements made in Reference 5.

Table 4 shows the computed EHL film thicknesses and the initial Λ ratios (film thickness divided by composite surface roughness, h/σ) at the 1.71 GSPa (248 ksi) pitch line maximum Hertz stress.

Test Procedure. After the test gears were cleaned to remove the preservative, they were assembled on the test rig. The 0.635-cm (0.25") wide test gears were run in an offset condition with a 0.30-cm (0.12") tooth-surface overlap to give a load surface on the gear face of 0.28 cm (0.11"), thereby allowing for the edge radius of the gear teeth. If both faces of the gears were tested, four fatigue tests could be run for each set of gears. All tests were run in at a pitch-line load of 1225 N/cm (700 lb/in.) for one hour, which gave a maximum Hertz stress of 0.756 GPA (111 ksi). The load was then increased to 5784 N/cm (3305 lb/in.), which gave a pitch-line maximum Hertz stress of 1.71 GPa (248 ksi) if plain bending is assumed. However, because there was an offset load, an additional stress was imposed on the tooth bending stress. Combining the bending and torsional moments gave a maximum stress of 0.26 GPa (37 ksi). This does not include the effects of tip relief, which would also increase the bending stress.

Operating the test gears at 10,000 rpm gave a pitch-line velocity of 46.55 m/s (9163 ft/min). Lubricant was supplied to the inlet mesh at 800 cm^3/min (0.21 gpm) at 321 K (120°F). The tests ran continuously until they were automatically shut down by the vibration detection transducer. The lubricant circulated through a 5 μm fiberglass filter to remove wear particles. After each test the lubricant and the filter element were discarded. Inlet and outlet oil temperatures were continuously recorded on a strip-chart recorder.

The pitch-line EHL film thickness was calculated by the method of Reference 8. It was assumed for this film thickness calculation that the gear temperature at the pitch line was equal to the outlet oil temperature, even though the inlet oil temperature was considerably lower. Possibly the gear surface temperature was even higher than the outlet oil temperature, especially at the end points of sliding contact. The EHL film thickness and the initial ratio of film thickness to composite surface roughness, Λ, was computed at the 1.7 GPa (248 ksi) pitch-line maximum Hertz stress. The values are shown in Table 4.

Table 3 — Spur Gear Data
[Gear tolerance per AGMA class 12]

Number of teeth	28
Diametral pitch	8
Circular pitch, cm (in.)	0.9975 (0.3297)
Whole depth, cm (in.)	0.762 (0.300)
Addendum, cm (in.)	0.318 (0.125)
Chordal tooth thickness (reference), cm (in.)	0.485 (0.191)
Tooth width, cm (in.)	0.635 (0.25)
Pressure angle, deg	20
Pitch diameter, cm (in.)	8.890 (3.500)
Outside diameter, cm (in.)	9.525 (3.750)
Root fillet, cm (in.)	0.102 to 0.152 (0.04 to 0.06)
Measurement over pins, cm (in.)	9.603 to 9.630 (3.7807 to 3.7915)
Pin diameter, cm (in.)	0.549 (0.216)
Backlash reference, cm (in.)	0.0254 (0.010)
Tip relief, cm (in.)	0.001 to 0.0015 (0.0004 to 0.0006)

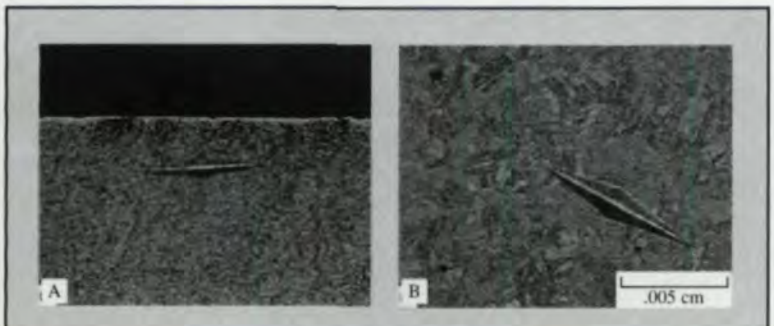

Fig. 2 — Photomicrographs of case and core of CVM AISI 9310 spur gears. (A) Case. (B) Core.

Results and Discussion

Gear Life. The surface pitting fatigue lives of the AISI 9310 gears run with all seven lubricants are shown in Fig. 3 and Table 5. These data are shown on Weibull coordinates and were analyzed by the method of Reference 9. The life shown is the life of gear pairs in millions of stress cycles or millions of revolutions. A failure is defined as one or more spalls covering more than 50% of the width of the Hertzian contact. Typical fatigue spalls for each lubricant are shown in Fig. 4.

Lubricant A (Fig. 3A) is the reference oil for these tests. The 10% and 50% system (two gears) lives (the life at 90% and 50% probability of survival) were 5.1 million and 20.4 million revolutions or stress cycles, respectively. The failure index was 30 out of 30, which is the number of failures out of the number of tests conducted. A typical fatigue spall with Lubricant A is shown in Fig. 4A.

The surface pitting fatigue lives of the AISI 9310 gears run with Lubricant B are shown in Fig. 3A. A typical fatigue spall for B is shown in Fig. 4B. A 5 cSt lubricant, B meets the MIL-L-23699 specification. The 10% and 50% system lives of the gears run with it were 12.1 million and 75 million revolutions or stress cycles, respectively. The failure index was 20 out of 20. These data indicate that the fatigue life of 9310 gears run with B is approximately 2.4 times that for A. The confidence number for the life difference between B and A was 84%, a statistically significant difference. The confidence number indicates the percentage of time the order of the test results will be the same. For a confidence number of 84%, 84 out of 100 times the test is repeated, the gear life with B will be higher than with A. Experience has shown that a confidence number of 80% or greater would indicate a meaningful life difference.

The life difference between A and B of over two to one would not be expected based on the small difference in viscosity and specific film thickness. However, given that A does not have an additive package including an EP additive, the life difference is more in line with expected results based on the test conducted in References 3 and 4.

The surface pitting fatigue lives obtained with Lubricant C are shown in Fig. 3B. A 3 cSt lubricant, C meets the MIL-L-7808J specification. A typical fatigue spall is shown in Fig. 4C. The 10% and 50% system lives of the 9310 gears run with C were 5.67 million and 20.7 million revolutions

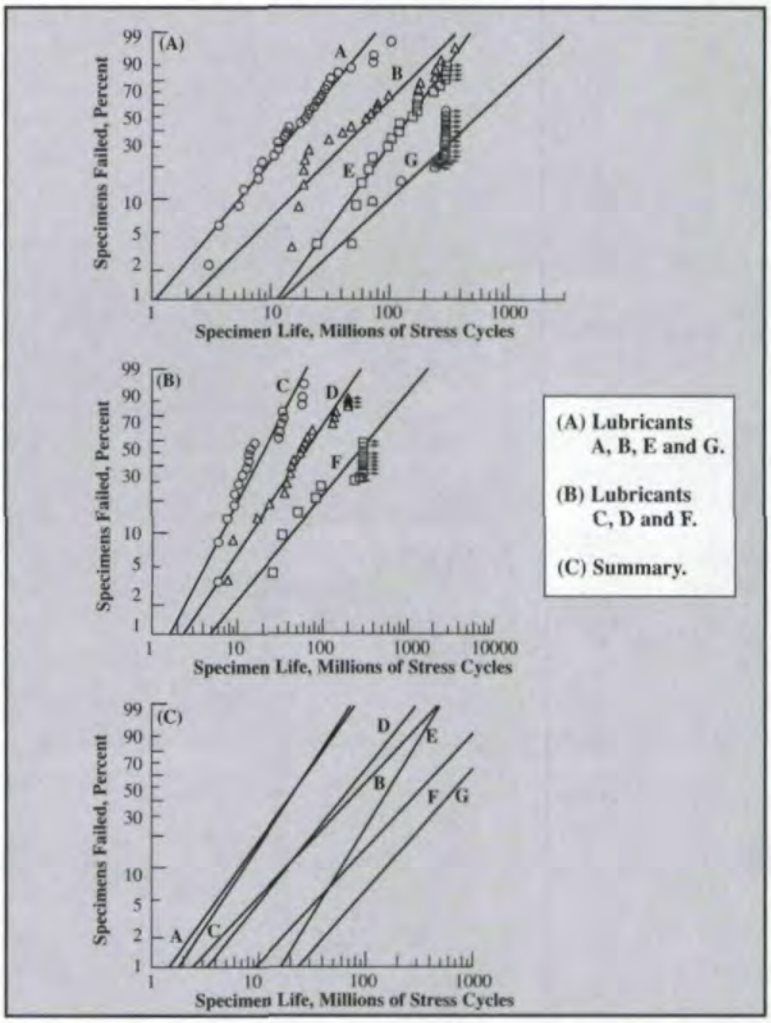

Fig. 3 — Surface pitting fatigue lives of AISI 9310 gears run with seven different lubricants. Pitch diameter 8.39 cm (3.5"); speed 10,000 rpm; maximum Hertz stress 1.71 GPa (248 ksi); gear temperature 350 K (170°F).

Table 4 — Lubricant Properties

NASA Identification	Lubricant						
	A	B	C	D	E	F	G
Kinematic Viscosity 331 K (100°F) 372 K (210°F)	21.0 4.31	29.7 5.39	12.2 3.2	27.6 5.18	34.7 7.37	60.54 8.84	52.4 8.98
Flash Point, K (°F) Pour Point, K (°F)	516 (470) 200 (-100)	539 (510) 217 (-70)	489 (420) —	544 (520) 211 (-80)	519 (475) 214 (-75)	519 (475) 228 (-49)	561 (550) 213 (-76)
Specific Gravity at 289 K (60°F)	1.00	1.00	—	0.995	0.947	0.96	0.986
Total Acid Number (tan) Mg Koh/g oil	0.07	0.03	0.15	0.40	0.06	0.00	1.01
EHL Film Thickness h mm (min) Λ ratio (h/σ)	0.43 (17) 0.75	0.52 (20) 0.90	0.34 (13) 0.58	0.50 (20) 0.87	0.66 (26) 1.15	0.76 (30) 1.33	0.76 (30) 1.33
Specification	none b.stock	MIL-L- 23699	MIL-L 7808J	DOD-L- 85734	DERD- 2487	none	none

or stress cycles, respectively. The failure index was 20 out of 20. These data indicate that the fatigue life of 9310 gears run with C was nearly equivalent to that with A. The confidence number for the life difference between C and A was 55%. The gear life with C would not be expected to equal the gear life with A based on the lubricant viscosity alone. However, C is a formulation that contained some EP additives, while A is a base stock lubricant without EP additives. Since the tests with both A and C were run with specific film thickness in the mixed or boundary regime, the EP additives in C would improve the gear life over that for A. This points out the need for EP additives in lubricants used for gears operating with specific film thicknesses less than one, as demonstrated in other tests.

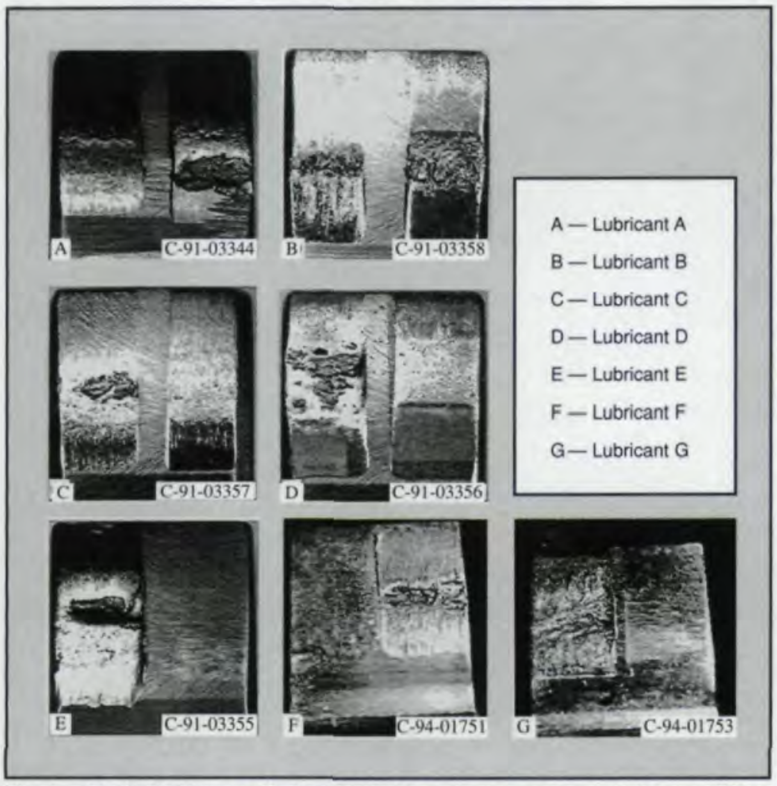

Fig. 4 — Typical fatigue spalls for AISI 9310 steel spur gears run with seven different lubricants. Pitch diameter 8.39 cm (3.5"); speed 10,000 rpm; maximum Hertz stress 1.71 GPa (248 ksi); gear temperature 350 K (170°F).

Table 5 — Surface Pitting Fatigue Lives of AISI 9310 with Different Lubricants

Lubricant Code	Lubricant Basestock	Gear System Life, millions of stress cycles		Weibull Slope	Failure Index[a]	Confidence Index[b] Percent
NASA		10 percent	50 percent			
A	polyolester	5.1	20.4	1.36	30 of 30	—
B	polyolester	12.1	76	1.02	20 of 20	84
C	polyolester	5.7	20.7	1.46	20 of 20	55
D	polyolester	11.8	50.8	1.29	17 of 20	83
E	polyalkylene-glycol	46.5	152	1.59	15 of 19	99
F	polyolester	45.2	276	1.04	7 of 17	99
G	polyolester	103	568	1.1	5 of 18	99

a Number of failures out of number of tests.
b Percent of time that 10% life obtained with each lubricant will have the same relation to the 10% life of Lubricant NASA A.

The gear surface pitting fatigue lives obtained with Lubricant D are shown in Fig 3B. The 10% and 50% system lives of the 9310 gears tests with D were 11.75 million and 50.8 million revolutions or stress cycles, respectively. The failure index was 17 out of 20, and there were three suspended tests that completed 300 million stress cycles without failure. A typical fatigue spall for D is shown in Fig. 4D. The life for D was 2.3 times that for A and was nearly identical to the life for B. Lubricant D has more boundary additive and nearly the same viscosity as B, which could provide better surface fatigue life. However, both B and D had nearly identical fatigue lives. Lubricant A, on the other hand, has only slightly less viscosity than D, but does not have an additive package or EP additive, which is the most probable reason for the shorter life of A. The confidence number for the life difference between D and A was a statistically significant 83%.

The gear surface pitting fatigue lives obtained with Lubricant E are plotted on Weibull coordinates shown in Fig. 3A. A typical fatigue spall for E is shown in Fig. 4E. The 10% and 50% system lives of the 9310 spur gears tested with E were 46.5 million and 152 million stress cycles or revolutions, respectively. The failure index for E was 15 out of 19, with four tests that were suspended after 500 hours or 300 million stress cycles without failure. The confidence number for the life difference between E and A was 99%.

The gear pitting life obtained with Lubricant F is shown in Fig. 3B. The 10% and 50% system lives of the AISI 9310 gears for this lubricant were 45 million and 276 million stress cycles respectively. The failure index was 7 out of 17. Ten tests completed 300 million cycles without failure. A typical fatigue spall for F is shown in Fig. 4F. The 10% surface fatigue life for F was nine times that for A, a 5 cSt lubricant, and about equal to that for E, a 7.5 cSt lubricant. The main reason that F did not produce a better gear surface fatigue life than E appears to be that F is a base stock lubricant without an anti-wear additive package, while E contains a good additive package. The confidence number for F compared to A was 99%. The confidence number for F compared to E was only 50%, which means the lives were approximately equal.

The gear pitting life obtained with Lubricant G is shown in Fig. 3A. The 10% and 50% system lives of the AISI 9310 gears were 103 million and 568 million stress cycles respectively. The failure index was 5 out of 18, which means that there were 13 tests that completed 300 million cycles without failure. A typical fatigue spall for G is shown in Fig. 4G. The 10% surface fatigue life for

G was 20 times that for A, a 5 cSt lubricant, and about 2.3 times that for E, a 7.5 cSt lubricant and F, a 9 cSt lubricant. It appears that the main reason for the life improvement of G over F, which has the same viscosity, is the fact that F has no antiwear additive package, while G has some additive that provided boundary lubrication. The confidence number for G compared to A was 99%, which means that the life difference was statistically significant. The confidence number for G compared to F was 70%, which means the life difference was also statistically significant.

The life results are summarized in Fig. 3C and Table 5. The life of Lubricant G was more than twenty times that for A and more than two times that for E and F. A 9cSt lubricant, G had a calculated specific film thickness Λ of 1.33. It was, therefore, expected that it would produce longer fatigue life than the other, less viscous lubricants. However, it could not be analytically determined just how much improvement in surface fatigue could be obtained with this higher viscosity lubricant. The surface fatigue testing was, therefore, necessary to determine gear life with these lubricants.

Fig. 5 is a plot of specific film thickness ratio Λ versus the relative gear surface fatigue life and shows how the gear life is affected by the specific film thickness ratio. The test results are conclusive in showing that when gears are operated with lubricants that provide specific film thickness around one or greater, the surface fatigue will show large improvements over some of the turbine engine lubricants that provide lower EHL specific film thickness. In addition, as the EHL specific film thickness ratio increases above 1, the surface fatigue is further improved. The above results also point to the need to provide separate lubricants with higher viscosities than the engine lubricants for power transmissions such as turboprop or turbofan reduction gearboxes and helicopter gearboxes to provide increased life and reliability of these systems.

Conclusions

The following results were obtained:

1. Lubricants with a viscosity providing a specific film thickness greater than one and with an additive package produced surface fatigue lives 4 to 8.6 times those of lubricants with a viscosity providing a specific film thickness less than one.

2. As the lubricant viscosity is increased to give EHL specific film thickness ratios Λ well above 1, the gear surface fatigue life is further improved.

3. A low viscosity lubricant with an additive package produced surface fatigue lives equivalent to similar base stock lubricant with 30% high viscosity, but without an additive package.

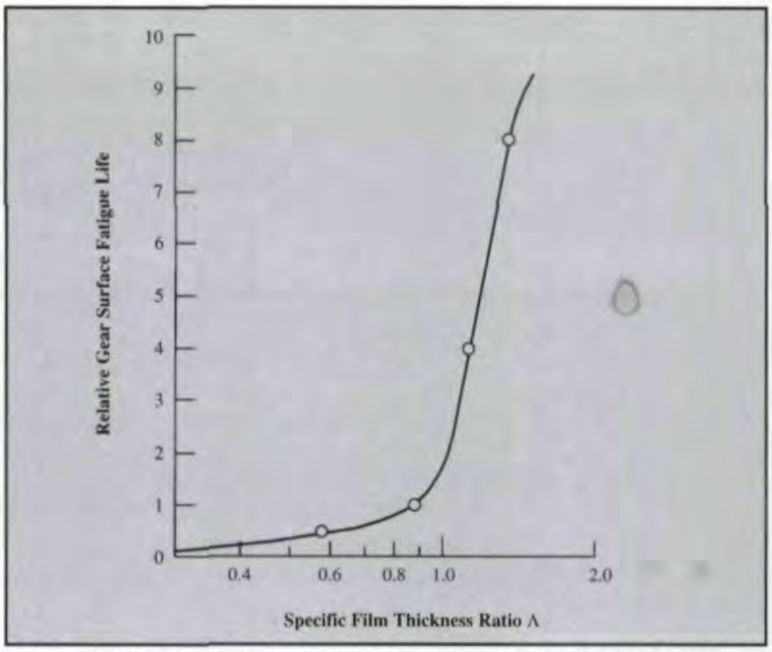

Fig. 5 — Relative gear surface fatigue life versus specific film thickness ratio Λ. Test conditions: 10,000 rpm, maximum Hertz stress 1.71 GPa (248 ksi), and a bulk gear temperature of 350 K (170°F).

4. Lubricants with the same viscosity and similar additive packages gave equivalent gear surface fatigue lives. ○

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Long-Life, Low-Cost, Near-Net-Shape Forged Gears

Years of research pay off for Presrite.

John Mullally

Near-net gear forging today is producing longer life gears at significantly lower costs than traditional manufacturing techniques. Advances in forging equipment, controls and die-making capability have been combined to produce commercially viable near-net-shape gears in diameters up to 17" with minimum stock allowances. These forged gears require only minimal finishing to meet part tolerance specifications.

"It's been a long, technically challenging process," advises Chris E. Carman, Operations Manager, Bessemer Division, Presrite Corporation, Cleveland, OH, but the effort has paid off in the development of a viable, cost-effective production technique for gears.

Carman cautions that near-net forging is not the process of choice for all gears. "Some small, fine-pitched gears aren't suited to this process yet," explains Carman, who has led the precision forging company's near-net gear development effort since 1989. His multi-disciplined engineering and production team worked in conjunction with a major off-highway equipment supplier to overcome the technical problems evident in early near-net gear forging attempts.

What is "Near-Net"?

Near-net forged gears come from the forging press in almost the exact shape of the finished gear. Gear teeth are forged with an envelope of material around the tooth profile, unlike near-net blanks, which are forged cylinders into which the teeth must be cut by hobbing. Near-net gears have teeth forged with a thin envelope of excess steel, which is removed by single-pass grinding, resulting in a finished gear that is more accurately machined than if hobbed and shaved.

Straight bevel, spiral bevel, helical and spur gears have been produced with the new forging process. Maximum diameter for the forged gear is under 20". Most production gears are within a range of 3–17" in diameter, limits determined by current press and processing equipment capacities.

Lower Net Cost Gears

The driving force behind the effort to develop a commercial near-net gear forging process is cost reduction. In theory, the near-net forging process reduces work-in-process and eliminates the need for some specialized, high-cost capital equipment, expensive expendable tooling and high labor rate machining steps.

Because the near-net process produces a gear shape complete with teeth, no rough and finish hobbing is required. Instead, finish hobbing, shaving or grinding can be used. Grinding speeds product flow through the manufacturing process and avoids the cost of specialized shavers and attendant high labor rates. The increase in product throughput reduces the amount of work-in-process and shortens delivery times.

However, putting this theory into practice proved very challenging. Initial attempts in the early 1990s produced excessive scrap, high tooling costs, short tool life, high cycle and poor delivery times.

However, notes Presrite's Carman, the potential benefits of the program could be seen through the challenges as the technical problems with the process became more clearly defined. This definition helped plot the path to correcting the process deficiencies at each step.

Early Benefit

Despite production problems, one benefit of the forging process became quickly apparent—

Fig. 1 — Forging dies are produced in-house from CAD programs on a precision wire EDM machine.

Fig. 2 — Near-net forged gears have an envelope of material around the tooth profile, which is removed by single-pass grinding.

Fig. 1

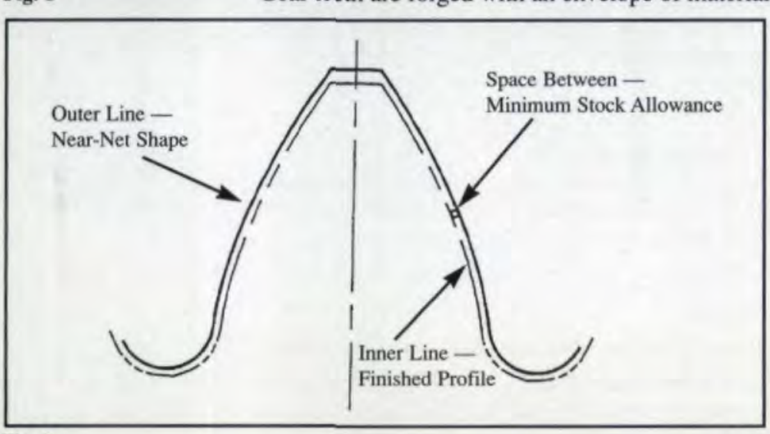

Fig. 2

longer life gears. Customer-run B-10 gear life tests of the forged gears showed them to have almost double the world average field life of a conventionally produced gear.

This long life is attributed to the lack of stress induced into the gear as it is forged. A forged gear has improved mechanical properties because of the consistent, unfractured grain structure of the forged steel. Furthermore, the steel is stable with the workpiece kept under 2200°F, reducing heat distortion. The elimination of traditional gear cutting reduces machine stresses, resulting in a more stable heat-treated product.

Although these finished gears performed exceptionally well, the manufacturing process was having development problems. Early forging scrap rates approached 20%. Forging die life was only 20% of a projected number of parts per forge setup.

"What near-net gear forging forced us to do," explains Carman, "was to tighten our traditional production forging tolerances by 400%. That was a challenge."

This forging tolerance improvement was required because of the one-step finishing process for gears. The forging process had to meet the minimal allowable stock envelope to match the capabilities of the grinding process, which also posed challenges. An early manufacturing cell producing forging and finish-ground gears generated scrap rates in excess of 25%. Grinding tool life was much less than anticipated, nearly tripling projected grinding costs.

Evolutionary Development

Equipment and tooling development were the initial targets of the Presrite team. The first major step was the shift from forging hammers to forging presses. "Presses make the forging process much more repeatable than hammers," notes Carman.

To take advantage of the repeatability of the newer presses, new controls had to be developed. "These controls had to be developed in-house, because they aren't available from forging press manufacturers," says Carman. "With them we brought the forging process from the 1940s right into the 90s with one step."

The problem of very short forging die life also had to be resolved. The design of this precision tooling was completely revamped with the addition of an in-house die design and manufacturing capability. Presrite introduced CAD and CAM to this function, which reduced design time and provided wide gear design flexibility.

For cost-efficient die manufacturing, the forger installed CNC W/EDM machines to tighten repeatable die tolerances and reduce tooling costs. "You have to have hands-on control of the die making and design to make this precision operation cost-efficient," states the development team leader.

Fig. 3

Fig. 3 — Presrite is able to near-net forge a variety of gear shapes, including straight bevel, spiral bevel, helical and spur gears, in diameters up to 17".

Fig. 4

Fig. 4 — A fully equipped gear lab checks dimensional accuracy of near-net gear forgings using a Zeiss coordinate measurement machine (CMM).

To extend the life of the finished forging dies, Presrite engineers investigated a variety of die materials and coatings, including titanium and carbide, to find the right combination.

Another area that drew engineering attention was billet heating prior to forging. Carman notes that consistent, repeatable billet heating is critical to the process. With new controls and a switch to electric induction heating, billet heating is controlled to +/-25°F just prior to forging.

Attitude Adjustment

"A gear is a lot more than just a forging," admits Carman. In addition to the equipment and process changes to traditional forging operations, new people with new talents and perspectives were required. "You need 'gear people' involved in this forging process if it's going to be successful."

The specialty talents brought into the forging operation include gear designers and specialty gear quality technicians who understand gear technology and can use precision, gear-specific testing and quality control equipment in a dedicated, in-house gear lab.

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is a writer on technical and manufacturing subjects.

Fig. 5 — Precisely sawn and surface-improved billets are induction heated to about 2,100°F in preparation for the forging process.

Fig. 6 — A single stroke of the forging press produces the near-net gear profile with an engineered minimal stock allowance ready for grinding to final profile.

Fig. 6

The Process

Manufacturing begins with steel bar stock, usually turned and polished to improve the surface. Surface-improved billets are cut to exact weight. Because this process utilizes a "closed die," the weight is critical. The amount of steel must completely fill the die to produce the complete gear profile. However, the amount cannot be excessive or severe die damage may result.

The billets are heated in an electric induction furnace, and in a single stroke, standard mechanical forging presses in the 1000T–6000T range form near-net-shape gears with the complete allowable material envelope.

Mechanical presses provide the controllability required for process repeatability. The controls include a force monitoring and control system. With the addition of new controls, PLCs and other monitoring equipment, the process can be consistently repeated with minimal process variance.

Forging dies are designed and manufactured in-house as part of a concurrent, near-net gear design program.

A dedicated, climate-controlled gear lab is also essential to the die design and gear production process. Located within a 200,000 sq. ft. gear forging complex, the lab is responsible for quality audits for both gears and dies.

A Zeiss Model #UMM 550/500/450 coordinate measurement machine (CMM) runs custom programs developed by the customer/partner to provide dimensional analysis of forged dies and gears. Dies are checked before and after press runs and gears are checked during press runs to provide part deviation tracking.

Cost-efficient manufacture of forging dies, maintains Carman, can only be accomplished with in-house CNC machine tools. Having the capability in-house provided both cost and quality controls. He also cites advances in CNC controls for W/EDM machines for making the physical manufacturing of the forging dies both possible and economically reasonable.

Post-Forging Operations

The raw forged gear is hydraulically ejected from the press and allowed to atmospherically cool to ambient temperature.

To assure a complete and consistent allowable material envelope and provide a surface compatible with efficient finish grinding, the forged near-net gear is cold drawn through a finish sizing die. This die is also designed and produced in-house by Presrite.

The forged gears are then finish ground. Efficient precision finish grinding techniques for near-net gears have been developed by grinding wheel manufacturers working with machine tool builders. These grinding techniques make significant contributions to the cost efficiency of near-net-shape forged gears.

Production Reality

It's been a long, complex road at Presrite, but the effort has been worth it. Based on actual gear production, near-net-shaped forgings produce gears of longer service life at a lower cost per gear than traditional cutting techniques. Says Chris Carman, "Near-net-shape gear forging is a production reality and the low-cost production technique for most gear types." ○

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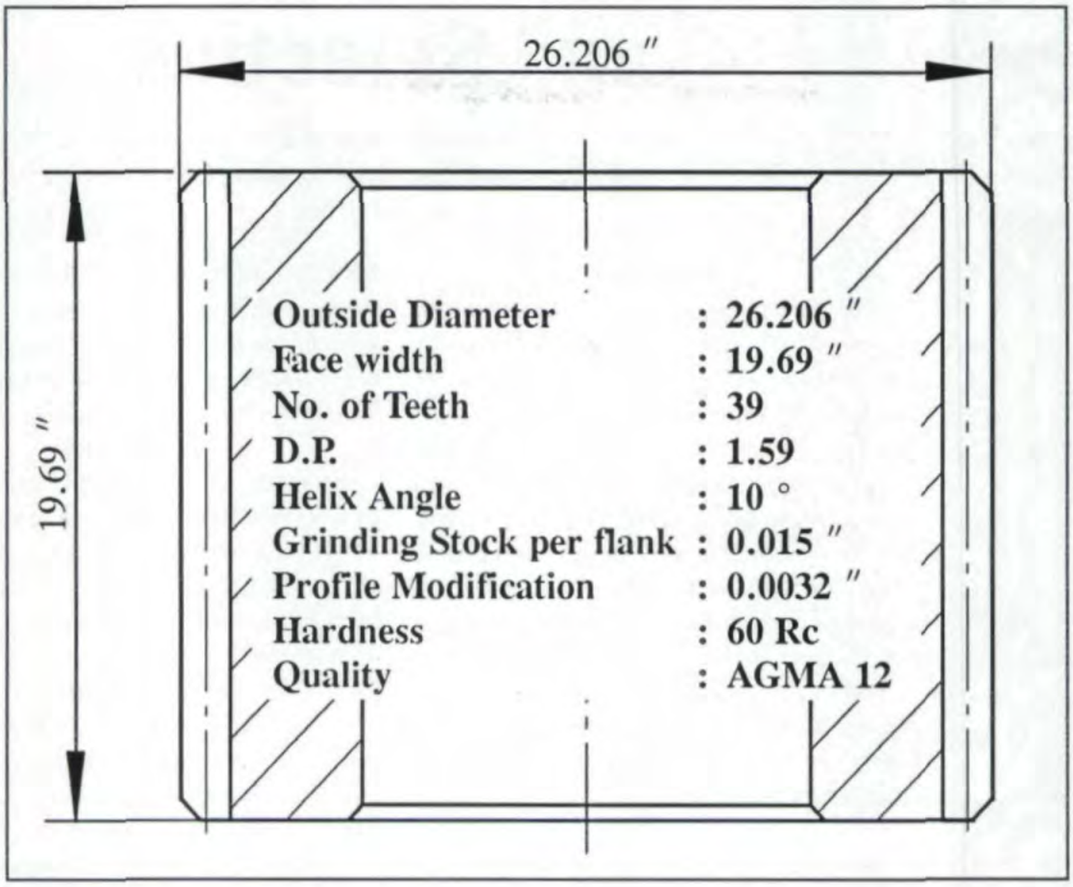
Ground in 210 Minutes



Total Grinding time, including dressing time: 210 min.

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Gear Oil Classification and Selection

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Introduction

Today gear drive operators have several options when selecting the proper lubricant for their gearboxes. As in the past, the primary lubricant used for gearbox lubrication is mineral oil. But with the advances in technology, synthetic hydrocarbons (PAOs) and polyglycols show very specific advantages in certain applications. With gear drives becoming more and more precise, it is now also to the benefit of the gear operator to verify that he or she has the proper additive package and viscosity in the lubricant selected. Fig. 1 shows that a gear oil is a combination of a base oil and specific additives. The base oils can be either mineral oil, a synthetic or even in some cases a combination of the two.

Mineral Oils

Mineral oils are a mixture of hydrocarbons and typically divide into

- Paraffinic oils having a paraffin base of more than 75%,
- Naphthenic oils having naphthene base of more than 75%,
- Aromatic oils having an aromatic base of more than 50%.

Sometimes the oil combination does not fit one of these classifications and is then termed a "mixed base mineral oil." Gear oils are made almost exclusively from paraffinic oils. Apart from the chemical characteristics, the physical values, such as density, viscosity, flow behavior, temperature dependency and other properties, are important. Mineral oils account for approximately 90% of the demand for lubricating oils.

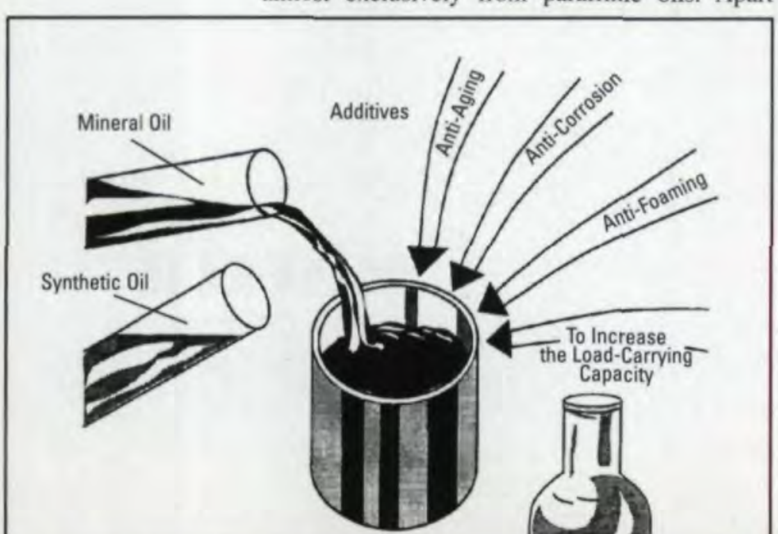


Fig. 1 — Lubricating oils.

Synthetic Oils

Synthetic oils are artificial fluids that can be used for lubricating purposes. These synthetic liquids have some characteristics that are superior to those of mineral oil lubricants, at least for certain types of applications. In general, the advantages of synthetic oils with respect to lubrication are their thermal and oxidation stability, their favorable viscosity-temperature behavior, high flash point and good low temperature behavior. For gear oils, polyalphaolefins (PAOs) and polyglycols also provide lower frictional losses in the gear train. Fig. 2 shows the average values of the most important properties of mineral oil compared to polyglycols and PAOs.

Additives

The second component of a lubricating gear oil is its additive package. Additives are put into lubricating oils to enhance some of the natural properties of the lubricating oil or to provide properties that are not present in the base oil. Fig. 3 shows a list of possible additives. Not all of these additives would be used in a single formulation, but all could be used in various different products, depending on the primary use of the oil.

One of the primary additives put in gear oils is an extreme pressure (EP) additive. This additive is needed to prevent microscopic welding between metal surfaces under high pressure or temperature, thereby protecting the gear tooth surface from scoring and premature fatigue failure. Various dynamic test machines can measure extreme pressure performance of a lubricating oil. Fig. 4 shows five of the common tests. Of these tests, the FZG procedure most resembles the actual loading conditions experienced by a gear system. If the lubricant can pass the twelfth load step without exceeding the specified wear rate or maximum weight loss, it is considered an extreme pressure oil. Such an oil will meet the needs of almost all gearing systems, provided that it meets the other parameters of the application, such as required viscosity, thermal resistance and oxidation stability.

Viscosity

Viscosity is the most important property of a lubrication oil. It is a measure of internal friction, describing the resistance to relative motion between the molecules under sheer stress. Viscosity depends on pressure and temperature. Since viscosity is dependent on temperature, it is typically measured at 40°C and 100°C. Fig. 5 shows the ISO viscosity grades for lubrication oils, the equivalent AGMA viscosity grades, approximate viscosity values at various temperatures and the equivalent SAE viscosity grades.

Since the lubricating oil's viscosity changes with temperature, the rate of change is an important property identified by the viscosity index (VI). Most mineral oil gear oils will have a viscosity index of 95. A lower viscosity index indicates that the oil changes viscosity faster with temperature change than the specified mineral oil at 95 VI. Conversely, a higher viscosity index indicates a much slower rate of change in viscosity as temperature changes. An oil with a high viscosity index will tend not to thicken as much at lower temperatures as a lower viscosity index product. At higher temperatures, the oil will tend not to thin as much. The ability of the oil to maintain a small viscosity differential over the operating range of the gearbox provides a more consistent lubricating film to the gears and more predictable wear performance. Fig. 6 shows the viscosity temperature curves for a mineral oil, a PAO and a polyglycol. Each of these products has an ISO viscosity grade of 460, or AGMA viscosity number of 7.

Mineral Oil Vs. Synthetic Oil

Synthetic oils have specific advantages in certain applications. Because of high oxidation resistance, synthetic oils can provide a much longer lubricant life in a gearbox. This will lengthen relubrication intervals and reduce overall oil consumption, as well as waste disposal.

Specific research has determined whether synthetic lubricants will provide less lost energy than

Lubricating Oils Properties	Mineral Oils	PAOs	Polyglycol Oils
Density (g/ml) at 20°C	0.9	0.85	0.9...1.1
Viscosity Index (VI)	80...100	130...160	150...270
Pour Point (°C)	-40...-10	-50...-30	-56...-23
Flash Point (°C)	< 250	>200	150...300
Oxidation Resistance	Moderate	Good	Good
Thermal Stability	Moderate	Good	Good
Lubricity	Good	Good	Very Good
Compatibility with Elastomers, Coatings, etc.	Good	Good	Insufficient to Good
Price Relation	1	5-10	6-10

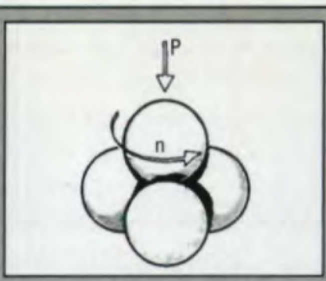
Fig. 2 — Properties of some lubricating oils (average values).

Type of Agent	Chemical Compound	Purpose	Mechanisms of Action
Oxidation Inhibitors	Hindered phenols, amines, organic sulphides, zinc phosphorodithloates	Minimize polymerization to form resin, varnish, sludge, acids or polymerizates.	Stop the chain reaction of oxidation by reducing organic peroxides. Decrease acid formation by reduced oxygen absorption of the oil. Inhibit catalytic reactions.
Corrosion Inhibitors	Zinc phosphorodithloates, sulphurized terpenes, phosphosulphurized terpenes, sulphurized olefines	Protect bearing and other metal surfaces against rust.	Have the effect of anti-catalysts, film formation on metal surfaces to protect them against the attack of acids and peroxides.
Rust Inhibitors	Aminophosphates, sodium, calcium & magnesium sulphonates, alkyl succinic acids, fatty acids	Protect ferrous metal surfaces against rust.	Polar molecules are primarily adsorbed on metal surfaces and serve as a barrier against water. Neutralize acids.
Metal Deactivators	Triarylphosphites, sulphur combinations, diamines, dimerkaptane thiadiazole derivates	Eliminate catalytic influences on oxidation and corrosion.	Adsorption of a protective film on metal surfaces, which prevents the contact between the base metal and the corrosive substances.
Anti-Wear Additives	Zinc phosphoro-dialkyl-dithioates, tricresylic phosphates	Reduce excessive wear between metal surfaces.	The reaction with metal surfaces leads to the formation of layers which undergo a plastic deformation and improve the contact pattern.
Extreme Pressure Additives	Sulphurized greases and olefines, chlorinated hydrocarbons, lead salts of organic acids, aminophosphates	Prevent microscopic welding between metal surfaces under high pressure or temperature.	The reaction with metal surfaces leads to new compounds with a lower shear stability than the base metal. A continuous process of shearing-off and rebuilding.
Friction Modifiers	Fatty acids, fatty amines, solid lubricants	Reduce friction between metal surfaces.	Molecules with a high polarity are adsorbed on metal surfaces and separate the surfaces. Solid lubricants form a friction-reducing film on the surface.
Pour Point Depressants	Paraffin alkylation of naphthalenes and phenoles, polymethacrylates	Lower the pour point of the oil.	Prevent the agglomeration of paraffin crystals by covering them.
Viscosity Index Improvers	Polyisobutylenes, polymethacrylates, polyacrylates, polyethylene-propylene, stryrene maleic acid ester copolymers, hydrogenated butadiene-styrene copolymers	Reduce the dependency of viscosity on temperature.	Polymer molecules have a high tendency to coiling in unsuitable solvents (cold oil), whereas they uncoil in suitable solvents (warm oil) and, consequently, become larger in volume. This leads to a relative thickening of the oil.
Anti-Foam Agents	Silicone polymers, tributylphosphate	Prevent a stable foam formation.	Attack the oil film surrounding each air bubble, thus reducing interfacial tension. This leads to the agglomeration of small bubbles into larger bubbles which then rise to the surface.
Tackifiers	Soaps, polyisobutylenes and polyacrylate polymerizates	Improve the oil's adhesiveness.	Increase of viscosity. Agents are thick and sticky.

Fig. 3 — Important types of additives.

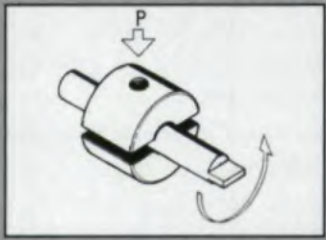
FOUR-BALL EP AND WEAR TESTER (DIN 51 350, ASTM D 2596)

Purpose:	Determine extreme pressure properties of oils, dispersions, greases and pastes
Test Piece	4 balls @ 12.2 mm
Sliding Velocity	0.55 m•s-1
RPM	1420
Load	0.6-12 kN (57 load steps)
Test Period	1 min per load step
Type of Contact	3 stationery balls w/ 4th rotating on top
Type of Friction	Sliding friction
Value Measured	Welding load, O.K.load



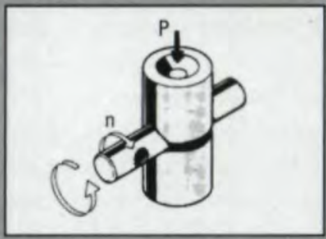
ALMEN-WIELAND EP/WEAR TESTER

Purpose:	Determine extreme pressure and wear properties of oils, dispersions, greases and pastes
Test Piece	1 steel shaft, 2 steel bearing shells
Sliding Velocity	0.066 m•s-1
RPM	200
Load	0-20 kN
Type of Contact	Linear (shaft against bearing shells)
Type of Friction	Sliding friction
Value Measured	Stress load, abrasion, temperature, friction force



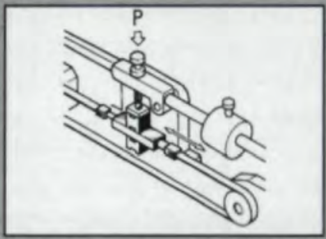
FALEX EP/WEAR TESTER

Purpose:	Determine extreme pressure properties of oils, dispersions, greases, pastes and bonded coatings
Test Piece	1 steel shaft, 2 v-shaped steel blocks
Sliding Velocity	0.055 m•s-1
RPM	290
Load	Up to 20 kN
Type of Contact	Linear
Type of Friction	Sliding friction
Value Measured	O.K. load, wear



TANNERT STICK-SLIP TESTER

Purpose:	Determine sliding properties of lubricants and materials at low speed (e.g. slideway oils, sliding oils, adhesive oils)
Test Piece	2 stationary test blocks, 1 flat sliding member
Sliding Velocity	0-0.243 mm•s-1
Load	Varies from 12.5 to 30 N/cm2
Type of Contact	Surface
Type of Friction	Sliding friciton
Value Measured	Friction number, stick-slip



FOUR-SQUARE GEAR TEST RIG (FZG PROCEDURE) (DIN 51 345)

Purpose:	Determine lubrication properties of gear oils
Test Piece	2 gear wheels
Circumferencial Speed	8.3 m•s-1 ir 16.6 m•s-1
RPM of Pinion	2170 or 4340
Load	12 load steps up to a max. pinion torque of 545 Nm
Test Period	15 min. per load step
Type of Friction	Rolling friction
Type of Motion	Turning wheels
Value Measured	Specific wear in mg/kWh
Fretting Load	Sudden increase in loss of weight (scuffing occurs)

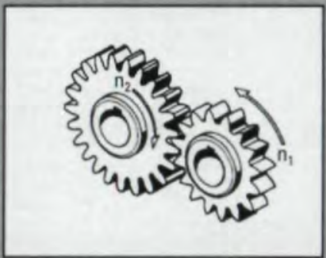


Fig. 4 — The most common testing machines for lubricating oils.

ISO (DIN 51 519)	AGMA Lubricant Viscosity Number	Average Viscosity (40°C) and Approximate Viscosity Values in mm²•s-1 (cSt) at					Approximate classification of	
		20°C A [mm²•s-1]	40°C [mm²•s-1]	50°C B [mm²•s-1]	50°C [Engler]	100°C [mm²•s-1]	motor oils SAE	automotive gear oils SAE
5		8 (1.7E)	4.6	4	1.3	1.5		
7		12 (2E)	6.8	5	1.4	2.0		
10		21 (3E)	10	8	1.7	2.5		
15		34	15	11	1.9	3.5	5W	
22		55	22	15	2.3	4.5	10W	70W 75W
32		88	32	21	3	5.5		
46	1	137	46	30	4	6.5	15W 20W 20	80W
68	2	219	68	43	6	8.5		
100	3	345	100	61	8	11	30	85W
150	4	550	150	90	12	15	40	90
220	5	865	220	125	16	19	50	
320	6	1340	320	180	24	24		140
460	7	2060	460	250	33	30		
680	8	3270	680	360	47	40		
1000	8A	5170	1000	510	67	50		250
1500		8400	1500	740	98	65		

Fig. 5 — ISO viscosity grades, DIN 51 519.

mineral oil lubricants in heavily loaded gearboxes. One study was performed using the FZG gear testing rig to determine the relative friction loss with mineral oil at various viscosities as compared to frictional loss of a PAO and polyglycol. For the same viscosity grade, a PAO and polyglycol gave lower frictional losses than straight mineral oil. With less friction, the synthetics provide less heat, less energy consumption and a higher efficiency rating for the gear drive. Friction modifiers help mineral oils, but at high speeds, synthetic lubricants significantly out-perform the mineral oil lubricants. At the higher speeds, the polyglycol and the PAO have very similar frictional loss.

Not only do gearboxes experience less friction, but documented studies have shown that just switching to a synthetic oil immediately reduced the shock impulse activity in the gearbox as well as the vibration. Fig. 7 shows the results of this study.

In worm gearboxes with high reduction ratios, polyglycol oils provide a significant advantage over mineral oils in the following performance factors:

- Improved energy efficiency
- Reduced maintenance, improved reliability and longer life
- Increased design ratings.

At 60% of rated power, a polyglycol was found to operate approximately 10°C cooler in a worm drive gear than a mineral oil. At 100% rated power, the polyglycol operates at the same temperature as mineral oil operating a 70% rated power. Less heat means less friction, which consumes less energy and produces less wear (Fig. 8).

Viscosity Selection

The correct viscosity is the most important parameter in selecting the proper gear oil. The manufacturer of the gearbox or gear system generally makes a viscosity recommendation, and this recommendation should always be followed. If the OEM of the gear system has not provided these recommendations, and the viscosity has not been calculated based on elastohydrodynamic (EHD) theory, it can be selected in accordance with various worksheets. The differing viscosity-temperature and viscosity-pressure behavior of synthetic oils as compared to mineral oils also must be taken into account.

The correct viscosity must be selected independently of any specific gear stage, realizing that a compromise is required for multi-stage gears. The selection of the correct viscosity in accordance with the worksheet is based on the oil's expected operating temperature; i.e., the sump temperature or the temperature of the injected oil. This temperature is calculated by determining the

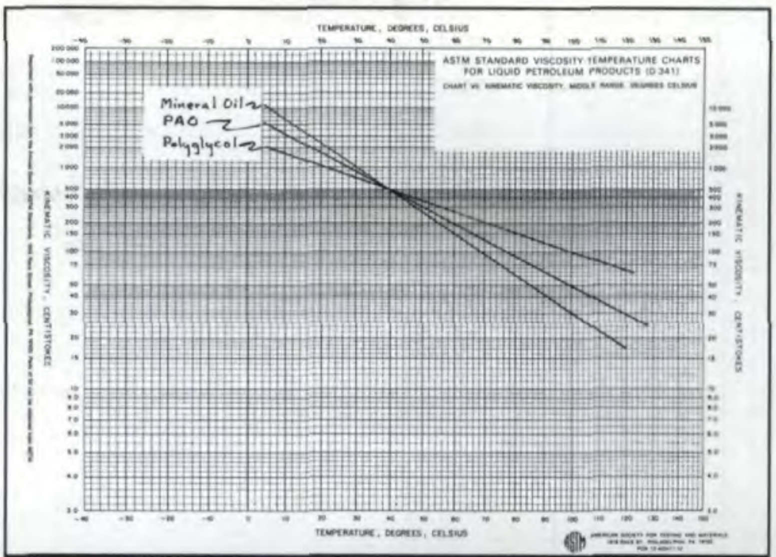


Fig. 6 — ASTM standard viscosity-temperature charts for liquid petroleum products (D 341).

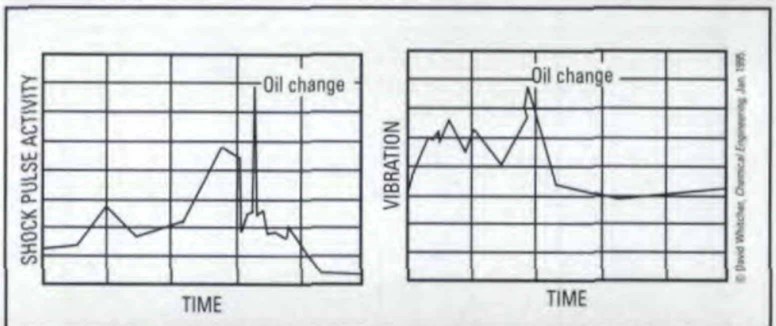


Fig. 7 — Switching to a synthetic oil immediately reduces shock pulse activity and vibration.

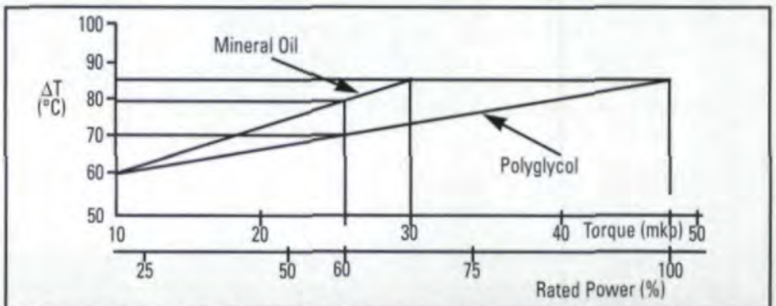


Fig. 8 — Comparison of polyglycol vs. mineral oil in a worm drive gearbox.

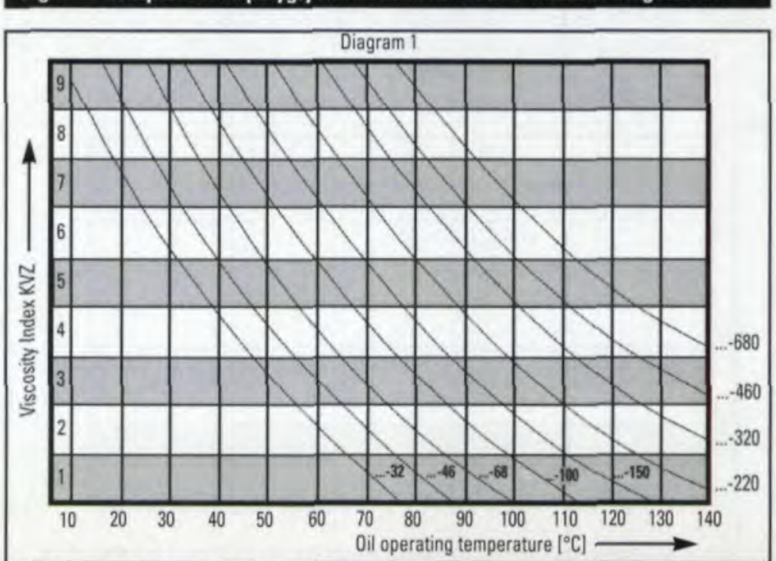


Fig. 9 — PAO viscosity selection chart.

Table I — Determination of the Viscosity Index for a Spur Gear Drive

Force-speed factor $K_s/v \left[\frac{MPa \cdot s}{m}\right]$	Viscosity Index KVZ
≤0.02	1
>0.02 to 0.08	2
>0.08 to 0.3	3
>0.3 to 0.8	4
>0.8 to 1.8	5
>1.8 to 3.5	6
>3.5 to 7.0	7
> 7.0	8

v = Peripheral speed at the reference circle [m/s]

K_s = Rolling pressure acc. to Stribeck [N/mm²]

$$K_s = \frac{F_t}{b \cdot d_1} \cdot \frac{U+1}{U} \cdot Z_H^2 \cdot Z_\varepsilon^2 \cdot K_A \ [N/mm^2 \triangleq MPa]$$

F_t = Nominal peripheral force [N]

b = Tooth width [mm]

d_1 = Diameter of reference circle [mm]

U = Gear ratio Z_2/Z_1

Z_H = Distribution factor *1

Z_ε = Contact ratio *1

K_A = Application factor *2

*1 Note: Determination of Z_H and Z_ε according to DIN 3990 Pt 2. For a rough calculation: $Z_H^2 \cdot Z_\varepsilon^2 \approx 3$.

*2 Note: Determination of K_A according to DIN 3990 Pt. 1. For a rough calculation: $K_A = 1$.

Example 1

Single-stage spur gear driving a fan.

Drive	Electric Motor
Nominal peripheral force	F_t = 3000N
Tooth width	b = 25 mm
Diameter of reference circle	d_1 = 230 mm
Gear ratio	U = 2.5
$Z_H^2 \cdot Z_\varepsilon^2$	≈ 3
K_A	≈ 1
Peripheral speed	4 m/s
Expected oil sump temperature	≈ 90°C
Rolling pressure acc. to Stribeck	K_s = 2.2 MPa
Force-speed factor	$K_s/v = 0.55 \frac{MPa \cdot s}{m}$
Acc. to Table I, viscosity index	KVZ = 4

Table II — Determination of the Viscosity Index for a Worm Gear Drive

Force-speed factor $K_s/v \left[\frac{N \cdot min}{m^2}\right]$	Viscosity Index KVZ
≤ 60	5
>60 to 400	6
>400 to 1800	7
>1800 to 6000	8
> 6000	9

$$\text{Force-speed factor } K_s/v = \frac{T_2}{n_1 \cdot a^3} \cdot f_1 \left[\frac{N \cdot min}{m^2}\right]$$

T_2 = Output moment [Nm} n_1 = Worm speed [min⁻¹]

a = Center distance [m] f_1 = Application factor

Note: The application factor is listed in the manufacturer's instructions. For rough calculation: $f_1 = 1$.

Example 2

Worm gear stage of a gearmotor driving a circular conveyor.

Output moment T_2 = 250 Nm Worm speed n_1 = 350 rpm

Center distance a = 0.063m Application factor f_1 = 1

$K_s/v = 2856.6 \frac{N \cdot min}{m^2}$

Expected oil sump temperature ≈ 85°C

Viscosity index acc. to Table II KVZ = 8

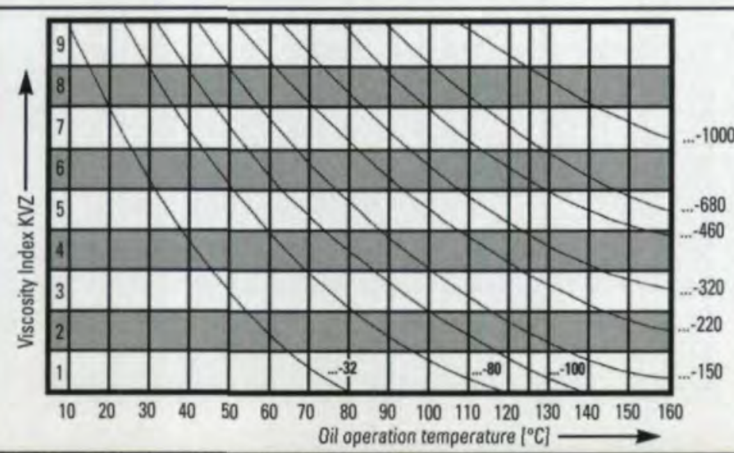


Fig. 10 — Polyglycol viscosity selection chart.

gear's thermal economy, taking into account the frictional losses, or in the case of gears already installed, by measuring the temperature of the sump. A lubricant with a lower viscosity might have to be chosen to assure that oil is supplied during a cold start or at lower ambient temperatures. In every case, it is necessary to check the viscosity at the existing starting temperature, especially in the case of oil circulation systems.

Tables I and II are typical worksheet methods for determining the viscosity for a spur gear drive and a worm gear drive. Table I and Example 1 apply to a typical spur gear drive situation; Table II and Example 2 to a typical worm drive situation. Once the KVZ is determined, Figs. 9 and 10 must be used to determine the correct ISO viscosity grade (VG) depending on the chemistry of the oil. Because of the different viscosity-temperature behavior of different oils, different ISO viscosity grades are selected for the same KVZ. In Example 1, an ISO-VG 220 would be selected for a PAO gear oil, and an ISO-VG 150 would be selected for a polyglycol. Conversely, in Example 2 an ISO-VG 680 PAO would be selected vs. an ISO-VG 460 polyglycol.

This article has only hit upon a few of the highlights about gear oil lubrication. The more informed gear drive operators are, the better decisions they can make concerning lubricant selection. They should locate a knowledgeable and reputable lubricant supplier and use this source for making important decisions that will affect energy consumption, machine life, lubricant consumption and waste oil generation. ○

For information about Kluber Lubrication, circle Reader Service Number A-54.

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CNC Software Savvy

How to get the software you need for the jobs you want to do.

E. Peter Kovar

Question:

When we purchase our first CNC gear hobbing machine, what questions should we ask about the software? What do we need to know to correctly specify the system requirements?

Answer:

Software used in gear manufacturing machines such as hobbers, grinders or other gear finishers is quite different from that used on other kinds of machine tools. Shops that do their own gear blank turning and are familiar with programming their machines themselves may find it difficult to make the transition to gear cutting. New users are advised to look for CNC systems that are easy to use and will automatically calculate some of the more complicated gear geometry entries.

Getting What You Need

Make certain that the features you need will be provided. This may seem simple enough, but far too often users discover after the fact that an important feature they thought was standard equipment is an expensive option.

Begin with a list of features you require. When you begin comparing vendors, start a worksheet of the software features each provides. This is important. Never accept obscure descriptions by vendors of the "standard" software they provide. Get a specific listing, or list your needs as part of your purchase order; otherwise you may be asking for trouble. See the sample worksheet on page 42 or make up your own.

What Features Should I Get?

Required features depend on the type of work you will be doing. If you are a job shop with many changeovers, or if your operator personnel are not extremely conversant in gear geometry, you should make sure that the software is easy to use and is able to make some of the more complicated geometry calculations automatically. Some of the considerations to take into account with any CNC software purchase follow.

Operator Interface. This is the software that enables your operators to interact with the machine. Again, the type of interface you should specify will depend on what you expect the machine to do and the skill level of the operators. An interface is extremely user-friendly when it does many of the calculations for the operator, offers "conversational input" or a menu and enables the operator to make choices by simply pushing buttons or clicking on specified places on the screen.

Some shops prefer a more basic input approach and wish to make calculations externally of the control. These users are very familiar with gear manufacturing and typically have an engineer prepare the machinery inputs. This "parametric programming" of the machine is used in low-cost versions of operator interface software.

Some users will wish to limit access to certain data entry screens to qualified personnel. This feature is typical in an automated environment such as in the automotive industry. Access is usually limited by the use of a password or key switch.

All user interface programs should have context-sensitive help screens. It is inefficient for operators to keep referring to hard copy manuals, which are often misplaced or out of date. A well-written operator interface should have a very small operator manual.

Ask the vendors to let you try their software. Is the input simple and easy to use or cumbersome? Are commands simple and intuitive? Is the use of color consistent and helpful? Are you able to load and save often-used setups of parts, tools or processes in the CNC? Also note how fast the screens refresh or the software runs. This is a clue to the efficiency of the software. Ask the vendor if the software has been installed in the field. Talk to other users of the exact version of software you are buying to find out if it is "buggy." Do not be the first user of a new piece of software, or, if you are, request that a software engineer be on site until all features are tested

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

Peter Kovar
is the Vice President of U.S. Tech Corporation, Chicago, IL, providers of high-end services for CNC gear machinery systems.

and accepted. (This can be time-consuming and risky, and may cost you money in downtime and wrecked parts.)

Graphical Interface. Many users find a graphical interface is easier to use for data input. This type of interface allows operators to view the gear or tool as they would normally see a blueprint. This preview will reduce scrap costs. A graphical interface is usually supplemental to some type of menu input. Some manufacturers also offer a *diagnostic* graphical interface, which spotlights certain conditions on screen, typically on a rendering of the machine for easier problem location.

Vendors are offering Microsoft Windows-based front ends on their CNC equipment in order to provide graphical user interfaces (GUIs) on the screens. These Windows- and PC-based front ends add to

Gear Hobbing Software Feature Worksheet

Use this worksheet when comparing the features offered by competing vendors, or make your own. Highlight the critical features for your application.

Software Feature Comparison Worksheet:
Note if Standard (S), optional (O) or not available (NA)

- ❑ Number of axes controlled by the CNC ____
- ❑ Radial hobbing cycle
- ❑ Radial/axial hobbing cycle
- ❑ Radial/axial with crowning (symmetrical/asymmetrical, concave/convex)
- ❑ Diagonal hobbing cycle
- ❑ Equal and alternating hobbing cycles
- ❑ Multiple cutting cycles (note number of cycles ___)
- ❑ Single index hobbing for helical gears
- ❑ Single index hobbing for spur gears
- ❑ Taper root spline cutting cycle
- ❑ Multiple gear, tool and process setups; note number of gear, tool and process setups that can be input on the CRT and executed in a single cycle (___)
- ❑ Automatic hob shifting
- ❑ Programmable lubrication control
- ❑ Power clamping of workpiece (manual machines)
- ❑ Tail center operation (manual machines)
- ❑ Automatic parts loading sequence (automated machines)
- ❑ Minimum programmable increment of ___mm (or inch) linear, _____rotary axis
- ❑ Hour meter and part counter display
- ❑ Graphical spindle load display
- ❑ Graphical axis position following error, speed, current, input/output status display
- ❑ Inch or metric menu input
- ❑ Data conversion utilities
- ❑ Context-sensitive help screens
- ❑ On-machine gear tooth spacing measurement
- ❑ *Automatic tool/workpiece alignment*
- ❑ Graphical user interface screens
- ❑ Diagnostic graphical interface
- ❑ ____________
- ❑ ____________
- ❑ ____________
- ❑ ____________

the price of the package. The cost of the PC is *in addition* to the hardware and software normally needed to control the machine, and industrial-quality PC boards are expensive. Furthermore, as you may already know from your experience with Windows applications on your office or home PC, you are subject to faults and additional general errors. Be careful when buying current Windows front ends. You may be better served by waiting until the bugs are worked out or until the next (presumably more bug-free) version of Windows '95 is released.

Gear Size Compensation. Size compensation is a feature that will adjust the machine settings to reflect changes in the machine or part geometry during the manufacturing process. These changes are usually caused by heat generated during cutting or changes in ambient temperature.

Size compensation can be done passively via the use of temperature measuring devices or size correction estimating algorithms stored in the software, or it can be done actively via a probe measuring the current gear size or operator input.

Other Features

Gear Geometry Measurement. Some CNC systems can be equipped with measurement probes or other devices to provide on-machine measurement. This option is especially useful for applications where a large part needs to be moved to a measurement device (gear checker). The part must be mounted and aligned on the measuring machine in the exact position it held when removed from the hobbing machine. On-machine measurement greatly reduces the down time when manufacturing large, cumbersome gears.

On-machine measurement is usually not done on smaller, more easily handled parts. Since this measurement takes time, you do not want to do it on a gear hobbing machine in a high-production environment.

Modifications. Can the software you buy easily be modified or edited? Can you or someone on your staff do the modifications, or does it require an investment in programming tools or outside software engineers? You should also find out if process programs can easily be edited for custom specific cycles.

Warranty. Ask your vendor how long the control is under warranty by the original manufacturer and how much an extended warranty costs. Typically, the cost is very low because of the high reliability of modern systems.

Conclusion

Purchasing a new machine or retrofitting an older one with modern controls is a large investment for any gear cutting firm. The basic strategy for making such a purchase successfully is the same as for any other large capital investment—do your homework. Ask your vendor detailed and informed questions. Know what your quality and production requirements are and convey them clearly to your vendor. Don't buy more machine than you need, but certainly don't settle for less. And remember that the lowest bottom-line figure now does not necessarily mean the lowest long-term costs later. ☼

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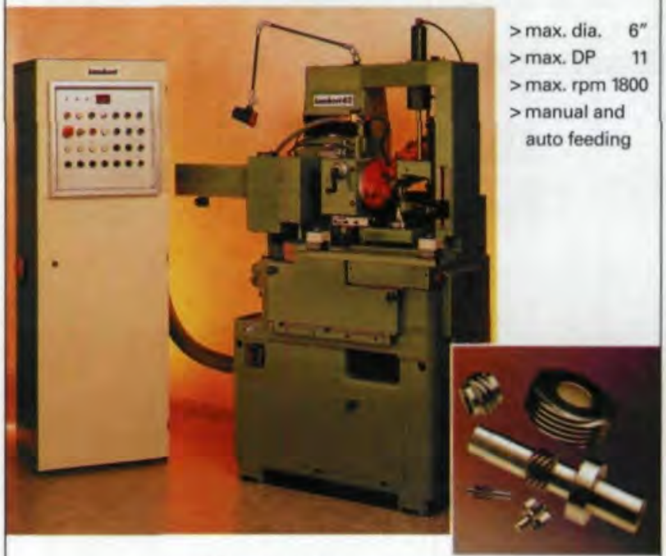


Welcome to our new Product News page. Here we will feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.

New Grease for Severe Duty Applications

Nye Lubricants is offering a new NLGI Grade 1 grease for heavily loaded planetary gears, worm gears and other devices. Nye Rheolube 377AL is a synthetic hydrocarbon-based, soap-gelled grease blended with solid lubricants, special anti-wear additives and oxidation and corrosion inhibitors. It comes in 1-, 7-, 35- and 110-pound containers and is available for immediate delivery.

Circle Reader Service No. A-30

Environmentally Friendly Fluid Storage Option

Master Chemical Corporation now offers customers an environmentally sound storage alternative for the company's line of cutting and grinding fluids that saves space and shipping costs. SpaceKraft is a corrugated bulk container that holds as much as four to six 55-gallon drums and requires 20% less storage space than steel drums. After use, the product can be recycled, biodegraded or incinerated, rather than occupying costly plant storage space. The system includes four components: an outer corrugated sleeve, a film bag, a corrugated cap and a polyethylene shroud.

Circle Reader Service No. A-31

Air-Operated Grease Pump

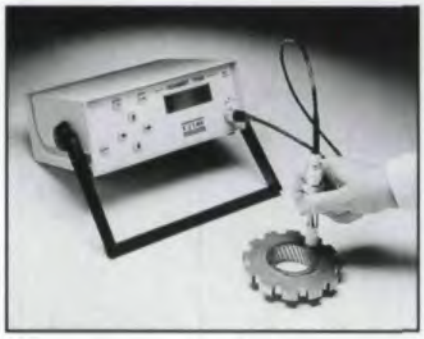
Bijur Lubrication Corporation offers a new centralized lubricator called SureMatic. The unit can deliver pre-selected amounts of grease to satisfy a wide range of lubrication needs for small, medium and large machines. Ruggedly constructed to withstand normal industrial applications as well as demanding environments, the unit is offered in various reservoir configurations, from 2- to 5-liter capacity. It has fixed outputs from 1.0 to 6.0 cm^3 per stroke, a built-in low level switch and a springless weighted grease follower, which permits the use of greases up to and including NLGI No. 2.

Circle Reader Service No. A-32

Gage for Measuring Dimensions & Displacements

Ono Sokki Technology, Inc. introduces the EG-225 digital linear gage, designed to measure dimensions, thickness, curvature, eccentricity, height, depth, flatness, variation, runout, roundness, distortion and deflection. It can also be used for load and pressure inspection. It performs measurement to 0.00005" and allows the user to obtain maximum, minimum and range values simultaneously with one sweep of the part. The EG-225 satisfies AGD Group II specifications, making it directly interchangeable with existing mechanical gages and compatible with virtually every major SPC data acquisition system.

Circle Reader Service No. A-33



Portable Hardness Tester With SPC

K. J. Law Engineers, Inc. offers a new, portable Verimet 7700 eddy current tester for performing on-location inspection of large, bulky or difficult to move parts. It is able to store multiple setups (up to 10) and provide users with basic SPC capability while sorting ferrous parts for proper heat treat, hardness, case depth or material mixes. Operates on either AC power or a single battery charge for up to 8 hours.

Circle Reader Service No. A-34

Advanced Spiral Bevel Gear Inspection System

M & M Precision Systems has introduced Command Link, a communications technology that uses spiral bevel gear inspection data to make corrections at any CNC bevel gear machine automatically. The system lets M & M's QC 3000 Gear Analyzer transmit setting changes to correct for machining errors throughout the gear manufacturing process. The QC 3000 system with spiral bevel gear software can indicate tooth form errors, including toe, heel, length, width and bias for spiral bevel and hypoid gears.

Circle Reader Service No. A-35

Automated Honing Machine

Sunnen Products Company's new automated EC-3500 Power Stroked Honing Machine provides consistent bore size and finish without the labor cost of a dedicated operator. The EC-3500 features a patent-pending, two-stage feed pressure which reduces cycle times. The feed force available on the machine is more than twice that of previous honing machines. The EC-3500 offers adjustable spindle speeds up to 3000 rpm and stroke rates up to 500 spm. It accommodates a wide variety of parts, including odd sizes, unusual shapes and those with keyways and splines.

Circle Reader Service No. A-36

Oerlikon CNC Form Grinders

Liebherr announces the new Opal 500 and 1000 CNC gear grinders from **Oerlikon Gear Technology.** They are designed to help manufacturers of commercial, truck and aircraft gears meet productivity, processing flexibility, quick changeover and cost goals. The machines can utilize conventional vitrified or CBN-plated grinding wheels. They have user-friendly CNCs, automatic stock dividing, high frequency spindles, internal grinding heads, topographical grinding and optional CNC on-machine measurement of profile, lead, pitch and tooth-to-tooth spacing.

Circle Reader Service No. A-37

Hydraulic Clamping Devices

Albert Schrem is offering a new hydraulic locknut that accepts the S.B.S. Balancing System for in-process balancing. The D93-U30 nut fits on Gleason Tag, Reishauer and Okamoto gear grinders. Schrem hydraulic clamping devices are being used to clamp cutters, workpieces, grinding wheels, shaper cutters, shaving cutters and other applications that require high pressure clamping.

Circle Reader Service No. A-38

Talyrond 262 Measuring Machine

Rank Taylor Hobson introduces the Talyrond 262, a 3-axis circular geometry measurement instrument with automatic centering and leveling. The Talyrond 262 will measure roundness, flatness, concentricity, eccentricity, squareness, runout, parallelism, vertical and horizontal straightness, coaxiality, harmonics and slope. It also has facilities for Gaussian and bandpass filtering, interrupted surface measurement, automatic edge detection and asperity removal.

Circle Reader Service No. A-39

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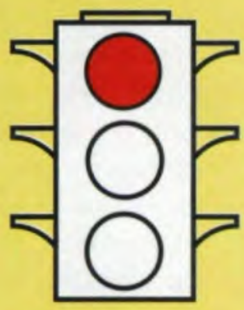

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Addendum III — The Return

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

Gears on Film

It's Friday night at the video store, and as usual, all the new releases are checked out. You can't decide between *Killer Teenage Cheerleaders from Outer Space* and a documentary on the mating rituals of the hippopotamus.

Gear Technology is here to help. The Addendum page is proud to present a list of films for gear lovers. All of these films feature *the industry's own star*, the late **Luella Gear**.

Born in 1900 in New York, Gear made her broadway debut in 1917. Best known for her acid wit, she went on to roles in motion pictures, appearing in *The Perfect Marriage (1946)* with Loretta Young and David Niven; *Jigsaw* (1949), starring Marlene Dietrich, Henry Fonda and Burgess Meredith; and *Phffft! (1954)* with Judy Holliday and Jack Lemmon.

But our favorite Luella Gear movie has to be *Carefree (1938)*, starring Fred Astaire and Ginger Rogers. Gear plays the role of Aunt Cora in this musical comedy about a psychiatrist (Astaire) and his patient (Rogers).

If none of these films is available at your video store, some of them may occasionally be featured on cable TV. But if that doesn't work out, you could always go for the hippo flick.

Hey, I've Been Looking for One of Those

The Missouri State Highway and Transportation Department is trying to give away the Mark Twain Memorial Bridge across the Mississippi River at Hannibal, MO. No, they're not kidding. The cost to repair the bridge, which is listed on the National Register of Historic Places, is greater than the cost to build a new one, so the state must try to find an alternative use for the structure before it can tear it down.

More than 100 proposals were submitted before the March 17 deadline. If any of the proposals is accepted, the state will dismantle the bridge, but the new owner will be responsible for hauling it away and reassembling it.

Look Out, Cooperstown!

Given the current disenchantment with the game, tourists may be looking for someplace to visit besides the Baseball Hall of Fame in Cooperstown, NY. We'd like to recommend the lesser-known, but just as important Machine Tool Hall of Fame at the American Precision Museum in Windsor, VT.

Recently, the Hall elected four new members. George O. Gridley (1869–1956) held more than 60 patents for his early machine tool designs; William L. Bryant (1875–1931) was instrumental in the development of early ginding machines; Francis J. Trecker (1909–1987) oversaw the development of the Milwaukee-Matic, the first true machining center; and John T. Parsons (1913–) was one of the first pioneers of numerically controlled machine tools.

• PUZZLE • PUZZLE • PUZZLE • PUZZLE •

The supply room at Wacky Widgets Gearmotor Company contains two shelves. Shelf A has half spur gears and half helical gears. Shelf B has two-thirds spur gears and one-third helical.

Every gearmotor made by Wacky Widgets turns out slightly different (that's why they're Wacky). Their production method is to blindfold the foreman, spin him around 100 times and send him into the supply room to select the gears for their gearmotor. Whatever he comes out with is combined into a single product.

For the latest Wacky Widgets design, the foreman is allowed to choose only one gear from each shelf. What is the probability that he will emerge from the supply room with one helical and one spur gear? Two spur gears? What is the probability he will throw up before he picks any? Answers next issue.

Munchkins Part II

Last issue we brought you Gearing for Munchkins. This time it's the world's smallest motorized car. Built by the Japanese company Nippondenso, the Micro-Car was displayed at the recent Society of Automotive Engineers convention in Detroit.

The car, certified by the *Guinness Book of World Records* as the world's smallest, is a 1/1000th scale model of the 1936 Toyota Model AA—about the size of a grain of rice. The Micro-Car consists of 24 parts, including wheels, axle, spare tire, headlights and steel bumpers. The car is powered by a magnetic motor that can run at 600 rpm.