GEAR TECHNOLOGY

THE JOURNAL OF GEAR MANUFACTURING

SEPTEMBER/OCTOBER 1993

SHOW ISSUE

MAXIMUM LIFE SPIRAL BEVEL GEAR REDUCTION DESIGN

LUBRICATION OF PLASTIC GEARS

HOBBING BASICS – PART I

EXPORTING – OVERSEAS ETIQUETTE

SPECIAL GEAR EXPO '93 COVERAGE

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It's Still the Economy, Stupid!

PUBLISHER'S PAGE

Two items of interest have crossed my desk in the last couple of weeks. One of them is a copy of a speech by Harry E. Figge, Jr., Chairman and CEO of Figge, International Inc., and the other is an article by Peter Brimelow in the July 19, 1993, issue of *Forbes*. The two items are directly related to one another, the Brimelow article being a response to the points raised in Figge's speech and in much greater detail in his book, *Bankruptcy 1995: The Coming Collapse of America and How to Stop It.* Both the speech and the response are well worth our attention.

Figge's point is a simple, if terrifying one: If we continue our current economic policies, by 1995 the national debt will be so great that interest payments and expenses will consume most all of the government's income, and the economy will collapse, creating one of two nightmare scenarios — crippling depression or even more crippling hyperinflation. (Figge picks hyperinflation as the more likely of the two.)

Brimelow's article is an analysis of Figge's thesis. He points out some flaws in Figge's economic logic and offers the apparently comforting view that his numbers and timing are off. Economic Armageddon will not arrive in 1995.

That's the good news. The bad news is that, according to Brimelow, while Figge's specifics may be in error, his basic premise is not wrong. Our growing national debt is our Number One problem and, unless we can get a handle on it, our future is threatened.

This, of course, is no longer hot news. Politicians of every stripe have been giving lip-service to the notion for months now. Unfortunately, that's about all they've been doing. Now that the elections are over and the Beltway jobs are safe for another 18 months or longer, the brave new leadership that was promised before last November is melting like ice at a summer picnic.

Washington seems to be back to business as usual. The cut-everybody's-projects-but-mine and the old paper-over-the- problems-with-money approaches to government remain the solutions of choice. And the don't-vote-for-wise-policy-but-for-what-makes-the-other-party-look-bad school of leadership is alive and well on both sides of the aisle. Meanwhile, the deficit continues to grow.

No wonder people like Mr. Figge are beginning to sound a little shrill. How long will it take our leadership to stop re-arranging the deck chairs on the Titanic and really address the tough choices that have to be made? How loud do we as voters have to scream before they get the point?

Very loudly and for a long time, I fear. Each of us who is concerned about this issue will have to continue a steady stream of communication to our Congressional representatives, reminding them that The Issue is, indeed, the economy, stupid. We have to threaten to throw out every rascal who refuses to address the deficit aggressively, and then do so at the first opportunity.

And we have to realign our own thinking. We have to unlearn the pretty myth we bought into in the 1960s when Lyndon Johnson promised us both guns and butter and the equally pretty Reagan fairy tale of prosperity via cutting taxes and increasing spending. We have to relearn a word that for nearly 50 years has been almost un-American — austerity.

We all know from our personal and business finances that one cannot spend

(Continued on p. 61.)

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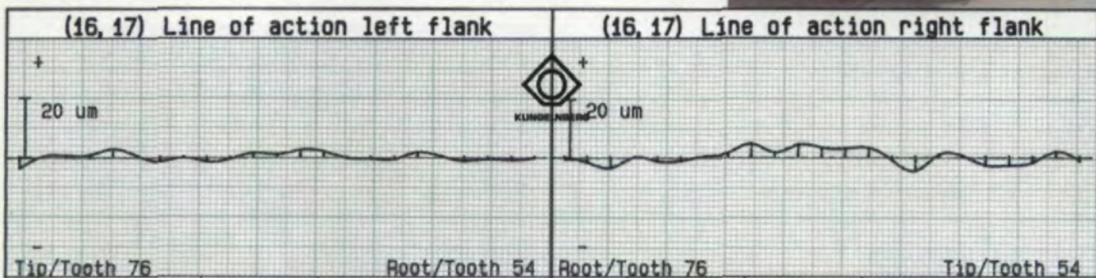

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ADVERTORIAL

GEARING UP FOR HIGHER QUALITY

If you're involved in gear metrology, you're probably already familiar with M&M Precision Systems Corporation.

An Acme-Cleveland company, M&M sells more universal CNC gear inspection systems in the United States than all its competitors combined. Customers say that M&M gear metrology systems help them do more types of inspections, do them more easily and faster. They also say the systems come with more assistance in software and support services than from anyone else.

New developments in the past year have meant expanded inspection capabilities for spiral bevel and hypoid gears, involute scrolls and male-female helical rotor vanes. M&M is fast becoming a recognized leader in these areas, too.

The latest addition to the inspection systems line is the QC 1000, a PC-based system intended for manufacturers and job shops whose needs require basic, economical analytical gear inspection. It offers the same high accuracy as other models but is more compact and comes with a standard, off-the-shelf spur and helical gear inspection software package. **The QC 1000 will be unveiled at Gear Expo '93 in Booth 131.**

M&M introduced the first CNC controlled analytical gear inspection system in 1975. From a few custom-designed machines, the company developed a line of systems within four years, featuring fully automatic test routines and modular inspection/analysis software programs. Today, industry has turned to M&M's analytical gear inspection systems as the accepted standard to fill their needs.

But M&M Precision Systems does more than make gear inspection machines. Founded in 1951 as a die, fixture and gage manufacturer, M&M became a major source for rotary tables and linear positioning slides. That line has expanded in the past 20 years, and the company continues today as a major factor in the motion control business.

M&M's third product line involves master gears and spline gage functional testing products. This line — along with certain gear manufacturing tools — was added in 1984 when M&M acquired Spline Gauges, Ltd. of Birminghan, UK. And a fourth product line — a direct computer control system with inspection software for coordinate measuring machines (CMMs) — is another M&M metrology involvement. These systems are DMIS compatible, PC-based and adaptable to any automatic or joy-stick operated CMM.

Together, M&M offers a variety of high quality metrology and motion products to industries throughout the world, particularly the aerospace, appliances, automotive, machine tools, military and off-highway vehicle markets.

M&M is also active internationally with facilities in England, France and Germany. For further information on the company or its products, use the listing at right:

Model 3012 universal gear inspection system

Wraps come off the QC 1000 at Gear Expo '93

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Explore the World of Gearing from *A* to *Z*

GT advertisers display their wares in Detroit.

Forty of *Gear Technology*'s pre-show and show issue advertisers will be exhibiting a wide range of goods and services at AGMA's Gear Expo '93. The exhibition will be held October 10-13 at Cobo Conference & Exhibition Center in Detroit, MI. Below is an alphabetical listing of these advertisers and a preview of what can be seen at their booths.

Amarillo Gear Co., Booth 437, is a manufacturer of spiral bevel gears and right-angle gear drives. Spiral bevel capacity is from 3 to 100 inches pitch diameter. Applications for drives include vertical pumps, cooling tower fans and frost protection wind machines.

AGMA, Booth 322, is the sponsor of Gear Expo '93. AGMA is the trade association which represents the interests of the American gear industry both here in the U.S. and abroad.

American Metal Treating Co., Booth 621, will be displaying segments of induction-hardened gears featuring single-tooth contour hardening and single-tooth submerged hardening. Stop and discuss the solution to your heat treat and distortion problems with their experts.

American Pfauter Limited Partnership, Booth 601, offers a comprehensive line of gear cutting machines, including gear hobbing, shaping, grinding, inspection and shaving machines. For more details and for assistance with your specific gear manufacturing application, visit the American Pfauter booth.

Ash Gear & Supply Corp., Booth 323, has the largest "in stock" supply of gear cutting tools anywhere — hobs, shapers, single cutters, broaches and more! Sharpening and tool modification service are available in its new shop. The new GCP-1 gear calculation program will be "in action" to solve your gear problems. Bring your part data and watch!

Basic Incorporated Group, Booth 451, is the national distributor for Wolf gear machines. Its product line includes shapers, shavers, hobbers, honers, test equipment and more. Basic also offers service for Wolf gear machines and other makes. Stop by their booth to see a program-controlled hobber, a 20" shaper, a 12" honer and various test equipment.

CIATEQ, A.C., Booth 345, will feature DISENG gear design software, an innovative program created for PCs, which allows the user to design external spur and helical gears dynamically and easily, according to his individual requirements.

Contour Hardening, Inc., Booth 446, will have on display the MICROPULSE® induction system for rapidly hardening gears. MICROPULSE® Type "A" contour hardening differs from other induction. It utilizes large power supplies which permit extremely short heat cycles, minimizing distortion. AGMA 6002-B93 classifies Type "A" contour hardening and carburizing as comparable processes. MICROPULSE® Type "A" significantly exceeded carburized results in standard SAE bending fatigue testing performed by GRI (Project #C-1717).

Diamond Black Technology Inc., Booth 424, manufactures Diamond Black Coating™, a patented low-temperature amorphous process of chemically inert boron carbide applied under 250°F at 2 microns (± 5%). Low coefficient of friction is improved through natural wicking of presented lubricants, and high temperature resistance over 2200°F. Non-transferring submicron wear characteristics virtually eliminate system contamination.

Fellows Corp., Booth 521, offers a full range of CNC Hydrostroke gear shaping machines from 180 mm (7") to 2,500 mm (100"). Also offered are the Fellows/Mikron CNC gear hobbing machines in horizontal sizes 100 mm (4") to 200 mm (8") and vertical sizes 220 mm (8.6") to 550 mm (21.6") along with the Fellows/Mikron CNC gear grinding machine. Stop by the booth for a shaping and hobbing demonstration.

Fette Tools Systems, Inc, Booth 436, is the U.S. subsidiary of a German manufacturer of multi-gash high tech hobs; indexable insert hobs with exchangeable segments for roughing, finishing and skiving; skiving hobs for pre-grind hobbing and hard finishing; specialty hobs and cutters for machining rotors, worm gears, sprockets, belt and chain pulleys; and custom form milling and circular type cutters.

Gear Technology, Booth 518. Meet the editorial and advertising staff of the only English-language magazine devoted exclusively to the subjects of gear research, design, development, engineering and manufacturing. *Let us show you how Gear Technology can be* an important fixture in your gearing "tool box."

The Gleason Works, Booth 533, invites you to its expanding world of parallel axis gear manufacturing products, including the 125GH gear hobber, a revolutionary concept, with a small-footprint design; the TAG 400 grinder, an affordable threaded wheel grinder for high-volume production; the Fassler D-250-C gear honing machine, and the GTR 250VG flexible, compact chamfering and deburring machine.

GMI-Fhusa, Booth 401, is a manufacturer of high-quality, Class "A" and "AA" hobs, which makes solid, shank, worm, inserted blade and hard skiving hobs for all applications. "Line of Action" inspection charts are normal, along with standard charting. They can design and manufacture hobs and cutters for special design applications not suited to standard hob configurations.

GMI-Kanzaki, Booth 401, is a manufacturer of precision machine tools, including hard gear finishing machines, gear shaving machines, horizontal tool changing and multi-spindle drill head machines, gun drilling machines, and transfer-case machining machines. On display will be a new hard gear finisher capable of giving super surface finishes to eliminate noise and make tooth modifications. Full 5-axis, CNC control FANUC/O-MC.

Guehring Automation, Inc., Booth 635, will be exhibiting the new Frenco Universal Rotational Measurement (URM) machine for complete inspection of gear and spline shaft profiles in as little as 8 seconds. Inspections include DOP, runout, roundness, spacing error, lead and taper. Other Frenco products include spline gages and workholding devices. Frenco is also exhibiting HDT hydraulic expansion arbors for gear hobbing, shaving and inspection.

ITW Components & Tools Division, Booth 215, is a manufacturer of precision gear hobs, shaper cutters, master gears, Gerac® dies and Illinite tooling for superior performance.

Explore the World of Gearing from *A* to *Z*

They also make engineered systems utilizing ITW Spiroid® gearing. ITW is serving the industry with their widely recognized gear training program, "The Gear School."

ITW Heartland, Booth 215. For over 70 years, ITW has been a world leader in the design and manufacture of gear inspection systems. They offer innovative high-speed, high-production burnishing machines as a complement to this product line. They will feature the model 2290 Dimension-Over-Pins unit and a sample of computerized analytical gear inspection.

James Engineering, Booth 351, "deburring and chamfering specialists," provides a full line of deburring and chamfering systems for processing parallel axis, bevel, and hypoid gear and cylindrical parts geometries. The feature attraction at their booth will be the Model 962ADS fully automatic system with automatic tool changing and other salient features to assist high-volume gear producers.

Koepfer America Limited Partnership, Booth 551. Since 1867 Koepfer has served fine to medium pitch gear manufacturers throughout the world. Koepfer CNC and mechanical hobbing machines, as well as HSS and carbide cutting tools, are considered the quality standard in many plants. Flexible automation systems provide the highest possible output. Full technical support is provided from Elgin, IL.

Liebherr, Booth 142, is a manufacturer of bevel gear cutting and grinding machines, gear hobbing and gear shaping machines, parallel axis grinding machines, gear measuring centers, hob sharpening machines and gear cutting tools.

M & M Precision Systems Corporation, Booth 131, will introduce the QC 1000 basic gear inspection system, an automatic CNC gear inspection machine offering well-known M & M quality, reliability and support. Also featured will be the QC 3012 and QC 3025 universal gear inspection systems, providing universal gear testing for most cylindrical parts. Double-flank gear rollers, functional spline gages and master gears will also be featured.

Merit Gear, Booth 218, is a full-service gear manufacturer with an internal heat treat department. Company services include prototype, replacement-breakdown and production quantity runs. They are a builder of complete O.E.M. enclosed drives. They grind gears and want to be your "in-house gear department," meeting your power transmission needs.

Mitsubishi Machine Tool USA, Inc., Booth 201, is the only manufacturer to offer a complete line of gear machines up to one meter. This offers the user the convenience of a single controller and common programming for all hobbing, shaping and shaving applications. This commonality will also make maintenance a much easier task.

National Broach & Machine Co., Booth 100, is featuring seven machines this year, offering a full complement of gear roughing and finishing machines. Hob, chamfer and broaching machines will be displayed along with gear grinding, honing, shaving and rack rolling machines. Red Ring's new line of hob and shaper cutter tools will also be on display.

Niagara Gear Corporation, Booth 422, is a contract manufacturer of precision ground spur and helical gears to AGMA Class 15.

Nixon Gear, Inc., Booth 419, a member company of Gear Motions, Inc., houses one of the nation's most modern fleets of Reishauer gear grinders — highlighted by the RZ301S and the RZ300E. Gear Motions combines a diverse group of specialized custom gearing shops into a single organization. Member companies include Nixon Gear, Oliver Gear and Rawling Gear.

Normac, Inc., Booth 231, will be showing a CNC gear grinder for form grinding spur and helical gears and a CNC wheel profiling center.

Pfauter-Maag Cutting Tools Limited Partnership, Booth 601, is a manufacturer of cutting tools, including hobs, shaper cutters and milling cutters. The company also provides coating, sharpening and heat treating services.

Presrite Corporation, Booth 433, offers innovative ways to meet your gear needs with high-quality, closed-die forgings. Capabilities include forged parts up to 300 lbs. and 18 inches in diameter, near-net and net shape capabilities, micro-alloy capabilities, a Total Quality Management System, and a state-of-the-art metallurgical lab.

Profile Engineering, Inc., Booth 637, specializes in Fellows model gear measuring instruments and offers complete rebuilding, design updates, recorder retrofits, field service, mechanical and electrical repairs, parts and special requests, and gear inspection service. They are introducing a computer analyzing system for Fellows gear composite red liners.

Redin Corporation, Booth 338, designed and built the first gear deburring machine in the U.S. in 1950. In 1991 Redin designed and built the first ten-axis, CNC, programmable, automated gear deburring machine. Stop by the booth to discuss Redin's latest designs and future plans.

Reef Gear Manufacturing, Booth 530, is a manufacturer of spur and helical involute gears and splines, with volumes from 50 per day to 3,000 per day. They are Q1 at Ford and certified at G.M., Chrysler, Luk, Lucas, Navistar and Rockwell. The company has 45+ years of gear manufacturing experience.

Reishauer Corp., Booth 645, manufactures precision gear grinders to 880mm capacity, thread grinding machines to 2,000mm length, and tap grinding machines to 25mm diameter. On display at the show will be the company's new gear honing machine with capacity up to 250mm.

Roto-Technology, Inc., Booth 227, will show a RC-400 Roto-Check CNC gear inspection system, which is IBM-compatible and fully automatic. The basic system includes inspection of index, pitch, space variation, lead and involute profile, and it provides a printout. Many options are available — inspection of hobs, cams, crankshafts, etc. Inspection sizes range from tiny gears to large 40" ring gears.

Schmitt Industries, Inc., Booth 734. Schmitt's SBS Dynamic Balance System is a dynamic balancing device used on gear grinding machines which substantially improves the quality of work, reduces cost and setup time and extends grinding wheel life. Schmitt Industries balance systems are the premier automatic balancing systems available in the marketplace today.

Star Cutter Company, Booth 501, a leading manufacturer of cutting tools and tool grinding equipment will feature precision hobs and milling cutters, shaper cutters, gun drills, gun reamers, PCD tools and CBN and diamond-coated tools and dressers. They will be demonstrating their new UTG600 machine, developed for precision grinding of cutting tools.

SU America, Inc., Booth 515, provides a full line of gear cutting tools, plus chamfering and grinding machines, resharpening of shaving cutters and CNC thread grinding.

Therm Alliance Co, Booth 251, engineers and manufactures heat treating furnaces for gear carburizing. New technology will be presented which achieves high quality case depth across the root, pitch and top of gear teeth, reduces distortion, shortens carburizing time dramatically, requires no endothermic gas generator, is environmentally cleaner and costs less to operate.

WMW Machinery, Inc, Booth 309, will spotlight the new Niles gear profile grinding machine, the only profile grinder to feature two independently CNC-controlled grinding wheels. The 8-axis CNC control with CNC dresser ensures grinding any profile. Niles will demonstrate programming and setup, the operator guidance system and time studies in Booth 309.

Carl Zeiss, Inc. IMT Division, Booth 331, is a leading supplier of high-quality CNC gear inspection centers, coordinate measuring machines and related products and services. IMT offers Hofler gear inspection centers and Zeiss high-precision manual and CNC coordinate measuring machines. ■

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Rules of Engagement

Exporting – Part IV

"Doing the right thing" may be different overseas. The basics of etiquette abroad will help smooth your path to successful dealing.

Lawrence M. Kohn

MANAGEMENT MATTERS

Putting one's best foot forward is important for successful business communication. And successful business people know the "rules" of the game, what to say and do in business situations, to make the best impression. However, these rules change from country to country, and what is appropriate behavior here may appear rude to someone from Latin America, Europe or Asia. To help you become more familiar with some of the different rules of engagement in other countries, *Gear Technology* spoke with three businessmen who have had extensive contacts in various parts of the world.

Simpatico in Latin America

According to Ed Cherry, partner in the law firm of Farella, Braun & Martel, San Francisco, who was born and raised in Latin America, the overriding factor when doing business there is *simpatico*. He says: "You have to get along well on a personal level with someone with whom you are going to do business consistently. That's very different from the U.S., where we tend to be much more oriented toward the bottom line. Here, so long as the person gets the job done, it doesn't matter if he or she is someone you'd like to spend time with. That's not the case in Latin America."

The Well-Bred Traveler in Latin America

Names: In Latin America it is customary not to use a person's first name until invited to do so. This may not happen until you have met two or three times or even longer. Using titles such as *señor, señora* or *señorita*, is also important.

Meals: The long lunch (2-3 hours) with several courses and wine or drinks is traditional. This is the big meal of the day, and much business entertaining is done over lunch. Many businesses close for the afternoon, but beware: no matter how big the lunch, Latin Americans go back to work afterwards.

Gifts: Giving gifts is always welcome, especially at first meetings, but not mandatory. If one is invited to a person's home, a gift is always appropriate, but be careful of color choices in flowers. Yellow, for example, is a symbol of death or contempt in some Latin American countries. Gifts should be brand names and high quality.

Personal Space: Latins are more "touchy-feely" than Americans, putting an arm around a shoulder or using a double-handed handshake. They stand closer, within "kissing distance," and make strong eye contact. Try to avoid the almost instinctive reaction of backing away.

Conversation: Avoid the subjects of religion or politics. Base compliments on personality or character, not on possessions. Tell your host he has attractive children or that his wife is an excellent cook, rather than comment on his expensive car.

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Lawrence M. Kohn
is president of Kohn Communications, a Los Angeles-based marketing and management consulting firm. His firm specializes in helping clients develop stronger business relationships through quality communication.

According to Cherry, this *simpatico* does not mean you have to be best friends with your business partner, but you will have a much closer relationship than you would develop with a business acquaintance in the U.S. "It doesn't need to be a lasting social friendship, but it does need to be a very comfortable and personable relationship. You will develop a closeness. Your business partners will be people you enjoy being with and they will enjoy being with you."

The importance of *simpatico* is reflected in the way that business negotiations are conducted in Latin America. Cherry explains it this way: "In both the U.S. and Latin America, there's a kind of dancing that occurs when negotiating a deal, but it's a different kind of dance." In the U.S., the dance occurs on business terms. Both sides put up proposals and go back and forth, with people playing their cards close to their chests, until an agreement is reached. In Latin America what Cherry calls "the relationship dance" occurs first. The purpose of this process is to discover whether the other person is one with whom you want to do business; whether you and the other person are *simpatico*. If the answer to that question is "yes," then you go on to the details of the deal.

Another reflection of this *simpatico* is that in Latin American countries, there is much less emphasis on the written documentation of business deals. Says Cherry, "[In Latin America] a joint venture agreement could easily be just three or four pages long, whereas in the U.S., the terms sheet would be 20 pages long, and the actual documentation would typically be 100 or more pages."

The Many Faces of Europe

For advice on the rules of engagement in Europe, we spoke with Richard L. Philson, managing director of Heller Europe, a firm based in London that controls joint ventures in 11 European countries.

His first general observation is that: ". . . other than the differences in language, the business people are not that much different than they are in the U.S. Business is business just about anywhere you go, and everyone's looking to do anything that makes good business sense. What you have to be sensitive to, though, are the subtle differences, and these you pick up over time as you work in these countries."

He goes on to explain some of these subtle differences: "In the Benelux countries, especially Belgium, their business attitude is very soft-spoken. They're very willing to negotiate and compromise, and they are perhaps more driven by the quality of life than by the bottom line. On the other hand, Holland and the U. K. are very much like us. If anything, the Dutch are more aggressive than we are. They're true internationalists. In Southern Europe, France and Spain, you find a much more nationalistic attitude. They are very protective of their own traditions and business values, but, again, they are willing to accept anything that makes good business sense."

Roots are very important in continental Europe, more so in some countries than in others. People are reluctant to relocate, having lived sometimes for generations in the same area if not in the same house. This sense of permanence is reflected in business attitudes. It is important for Europeans to know well the people with whom they do business. Says Philson, "They're going to want to get to know you, spend some time with you and understand your thinking before they're really willing to open up and discuss a possible business relationship."

Because of this, Americans need to learn to control their impatience to "cut to the chase" in a business discussion. As Philson points out, "If you were doing business in, say, France, you probably would have your early-on

MANAGEMENT MATTERS

The Well-Bred Traveler in Europe

Names: Using first names is okay everywhere in Europe, except in German-speaking countries. There, you should never use a person's first name unless invited to do so. This invitation implies that you have developed a personal and social relationship that goes beyond business.

Meals: As in the U.S., much business is done over meals. The attitude about alcohol with meals will vary. In southern Europe, wine and aperitifs are served with most meals. The Benelux countries and the U.K. tend to follow the American custom of not mixing alcohol with lunch meetings. They save it for evening entertaining. WARNING: Southern Europeans HATE breakfast meetings. Schedule something for the evening instead, and note that in Spain, dinner may be as late as 10:00 or 10:30 in the evening.

Gifts: Giving small gifts is appropriate. Something reminiscent of the U.S. — say a souvenir of the World Series — is acceptable. If invited to someone's home, flowers are always a safe choice. Don't bring wine. It suggests you don't trust the host to choose one appropriately, and he will feel obligated to serve yours.

Personal Space: Most Europeans share the same concept of personal space as Americans.

Conversation: Politics is an appropriate subject; religion is not. Outside interests, cultural matters, hobbies, etc. are all good topics of conversation.

negotiations and meetings over a meal. This meal would include discussion of both American and French politics, personal interests, all the liberal arts subjects, and this could go on for the better part of an hour before you would even begin to think about discussing the possible business relationship."

On the other hand, in countries like Holland or the U.K., people are apt to be much more direct and ready to get to the point.

Perhaps because of the sense of stability mentioned earlier, a person's age may play some role in success in negotiation. Philson suggests that a younger American will find it to his or her advantage to defer to the advice of older, more seasoned European colleagues when possible. Rightly or wrongly, they are perceived as having wisdom and experience beyond that of younger people.

This same respect for history will apply to a European's analysis of your company. He or she will have studied not just the last two or three years' performance, but will probably have researched it back fifteen or twenty years, and is not apt to be impressed with just a few good years.

The attitude toward documentation varies in Europe from north to south. In northern Europe, the documents will relate more to the business than the legal aspects of the arrangement, and they will be the law that governs your relationship. In southern Europe, while the documents are important, your personal understanding with the individual with whom you're doing business is even more important. Philson says, "No matter how carefully the documents have been prepared, I'd rather have a handshake."

Asian Observations

For advice on Asian cultural differences, we went to John A. Taylor, Valuation & Realty Consulting Group Director for Japanese and Client Services at the Los Angeles offices of Deloitte & Touche, an international professional services firm. He has travelled extensively in Japan, and his wife is a Japanese national.

Taylor suggests that basic to doing business in Asia is the understanding that business relationships are for the long haul. Once an Asian has committed to a relationship with you, he expects it to be one that will last for years; therefore, he may not be eager to quickly decide to work with you. "We need to understand that there is a certain amount of commitment in terms of time and resources which may be necessary for doing business with them," he says. "The benefit of that factor is, once you become a vendor or a supplier, you will find that they are outstanding clients."

Taylor organized his

advice for developing such successful, long-term business relationships under five categories, which could apply equally well in any culture: language, speaking, listening, follow-up and thoughtfulness.

He advises readers to remember that while most Japanese are taught English, they are not taught American English; therefore, one should avoid colloquialisms, double negatives or contractions.

When giving oral presentations, it is important to make your points individual and clear. Taylor says, "Structure your presentation like a term paper. First introduce the concepts, give a full description and then go back and revisit the general issue, summing up a section at a time."

Listening is also important. First, as with any conversation, discipline yourself to hear what is really being said, not what you wish were being said.

Then, if something really is unclear to you, be sensitive to the fact that Japanese and other Asians tend to be very concerned about their English language skills. Ask for clari-

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The Well-Bred Traveler in Asia

Meals: The celebrated Asian custom of the drinking bout as part of a business relationship does exist. Casual drinking in the evenings with business associates is still very common. Being invited to a colleague's private club is a high compliment. Note: it is customary to pour drinks for one another.

Gifts: Giving gifts to those with whom you wish to do business is customary. The inference in Asia is that you are assigning value to the relationship or the future potential of the relationship. The gift does not have to be expensive, but it should be a thoughtful one and of U.S. origin (the fact it was brought into the country implies effort, therefore enhanced appreciation). The gift should indicate that you have been listening to the recipient, that you have taken time to find out something about him or her and that you value this relationship.

Personal Space: Personal space in Asia is about the same or a little more distant than it is here. The things to be wary of are extended eye and casual physical contact. These may be considered confrontational.

Conversation: Religion, politics and controversial cultural issues are not taboo, but they should be approached from an informational rather than a dogmatic viewpoint. It is more common to talk about family or personal matters or outside interests in a restaurant or bar than in a business setting. Japanese do not invite people into their private offices. They have separate meeting rooms where business is conducted.

MANAGEMENT MATTERS

fication in a tactful way. Taylor suggests: "Try to turn the issue into a conceptual question rather than a language question. If you say 'I did not understand what you said,' that puts up a barrier. If you say, 'That is an important concept. I want to make sure I understand it fully,' it makes for a much more productive exchange of words."

Taylor also recommends sending follow-up memos after meetings. "There are generally a lot of issues you wanted to make sure they understood which they have not. It is always nice to offer, 'We have covered a lot of topics today, and what I would like to do is send a follow-up stating some of the key issues we discussed, and giving some important definitions which may be different from what you are accustomed to, and what goals and resolutions were arrived at.'"

> **"... the basis of any good, professional business understanding...is a learning process on both sides."**

Thoughtfulness is important to all your customers and is a basic of good manners in any culture, but it is especially appreciated by Asians, who regard small courtesies as very important. Show by small, sincere gestures that you are interested in the other person and concerned for his comfort. Taylor tells the story about his father-in-law who was entertaining a Korean client in an exclusive Japanese restaurant. He arranged for an order of kimchee, a Korean dish, to be delivered to the restaurant, so that the gentleman would have at least one familiar dish in front of him. Not a difficult or complicated gesture, but one that was greatly appreciated.

An outgrowth of this kind of thoughtfulness is the final component in Taylor's scheme — understanding, which is the goal of any communication. He says, ". . . the basis for any good, professional business understanding is getting a very good familiarity with the other person's business, what his needs and goals are, and helping him understand how he can best accomplish those in our culture. Part of it is being aware of his culture, part of it is also helping him become educated in our culture, so it is a learning process for both of us." ■

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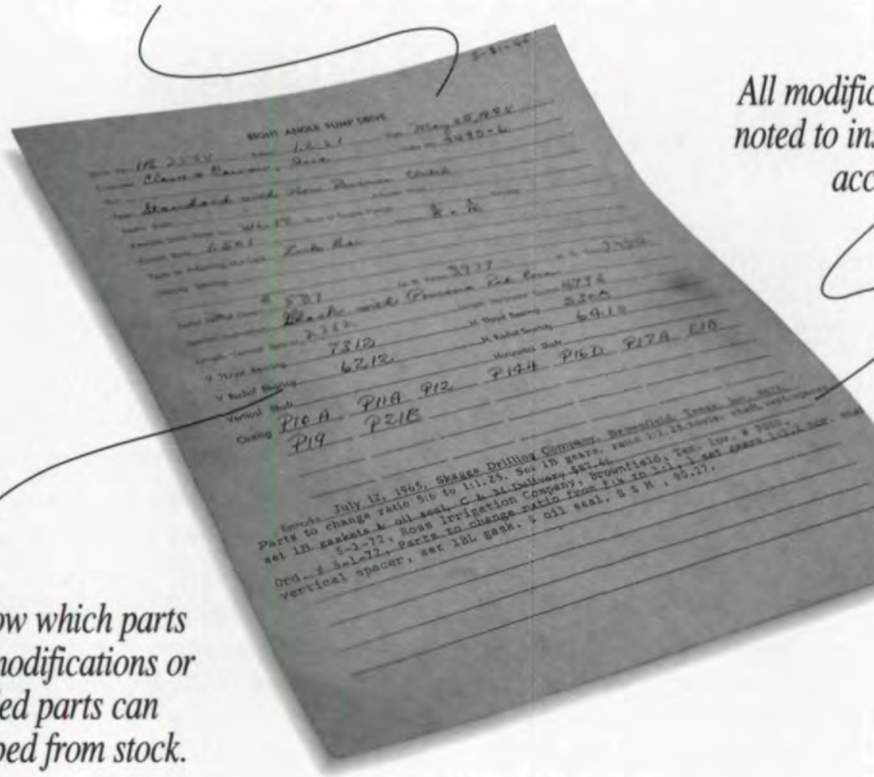

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Maximum Life Spiral Bevel Reduction Design

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Summary

Optimization is applied to the design of a spiral bevel gear reduction for maximum life at a given size. A modified feasible directions search algorithm permits a wide variety of inequality constraints and exact design requirements to be met with low sensitivity to initial values. Gear tooth bending strength and minimum contact ratio under load are included in the active constraints. The optimal design of the spiral bevel gear reduction includes the selection of bearing and shaft proportions in addition to gear mesh parameters. System life is maximized subject to a fixed back-cone distance of the spiral bevel gear set for a specified speed ratio, shaft angle, input torque and power. Significant parameters in the design are the spiral angle, the pressure angle, the numbers of teeth on the pinion and gear and the location and size of the four support bearings. Interpolated polynomials expand the discrete bearing properties and proportions into continuous variables for gradient optimization. After finding the continuous optimum, a designer can analyze near-optimal designs for comparison and selection. Design examples show the influence of the bearing lives on the gear parameters in the optimal configurations. For a fixed back-cone distance, optimal designs with larger shaft angles have larger service lives.

Introduction

Spiral bevel gears are complex machine elements which operate kinematically in three dimensions to transmit power at high speeds between intersecting shafts. The spiral angle enables the gears to transmit power more quietly than straight bevel gears, just as helical gears operate more quietly than spur gears. Bevel gears convert the high-speed power of horizontal gas turbine engines into the nearly vertical power of the main rotor masts in all helicopter transmissions. Aircraft transmissions are one of the more critical applications of bevel gearing due to the high speed, high power and light weight requirements.

Although the design of bevel gears has evolved over several centuries (Ref. 1), it has focused recently on the load capacity, meshing kinematics and manufacturing requirements of the gears (Refs. 2-12). A significant effort has been expended to model the meshing kinematics of spiral bevel gears because of their importance and complexity (Refs. 3, 4, and 6-8). Although the design of a spiral bevel gear set must include this information, it also should include considerations of gear tooth (Refs. 9-11) and bearing load capacity. In this article, considerations of the support bearing capabilities are included at the time the gear parameters are chosen.

Optimization theory offers designers this capability (Ref. 13). One approach to optimization is to find the intersections of the active design constraints. The optimal design is often found at a trade-off point on the constraint boundaries. A constraint intersection technique has been applied to design lightweight spur gear sets (Ref. 14). Although powerful, this technique is limited to problems with only two or three active design variables.

More recently, a modified feasible directions gradient search technique has been applied to the same spur gear design problem with equal success (Ref. 15). One significant advantage of the gradient technique is its multi-dimensional search capability. Larger problems which include simultaneous optimization of interacting components can be treated with this technique.

This article applies the modified feasible directions gradient search technique to the problem of designing a spiral bevel reduction to transmit a specified power at a specified input speed with a given reduction ratio, shaft angle and reduction size. The optimization criterion is maximum system life based on a two-parameter Weibull system life model which includes the lives of the bearings and the gears (Ref. 16).

In the model, each gear is supported by a ball and a straight roller bearing mounted behind the gear with the roller bearing being closest to the gear. The independent design parameters include the mesh face width, the number of pinion teeth, the normal pressure angle, the mesh spiral angle and the shaft diameters. The diametral pitch of the gears is dependent on these parameters. Inequality constraints restrict the gears to having adequate tooth bending and pitting strengths, tooth scoring resistance, avoidance of involute interference and adequate contact ratios. Adequate room for the bearing envelopes and consistency of shaft sizes for the gears and bearings provide additional constraints for the model.

The gradient search occurs in a continuous design space which is generated by polynomial fits to discrete bearing data and the mathematical willingness to have fractional teeth on the gears. Once a continuous mathematical optimum is found, the optimization program allows the designer to enter one or several alternate designs with more practical proportions for comparative evaluations. A full analysis is conducted for the initial optimal design and all selected alternative designs.

To demonstrate the procedure, the shaft angle is varied for a bevel gear design problem of fixed speed and power level at a fixed gear ratio with the same back-cone distance and shaft lengths. Optimum designs at different

Nomenclature

A	distance from inboard roller bearing to gear or pinion, in.
a	addendum, in.
A_o	back-cone distance, in.
B	distance from outboard ball bearing to gear or pinion, in.
b	Weibull slope
C	dynamic capacity, lb
Co	design constant vector
D	shaft diameter, mm
d	dedendum, in.
e_l	goodness of fit error limit
F	force, lb
f	gear face width, in.
∇f	unit gradient in the feasible direction
∇h	unit gradient in the violated constraints
J	AGMA bending strength tooth form factor
K_v	dynamic load velocity factor
l_{av}	mean service life, hr
l_{10}	90% reliability life, hr
M	merit function
∇M	gradient in the merit function
∇m	unit gradient in the merit function
N	number of teeth
n	gear reduction ratio
P_d	diametral pitch, in.$^{-1}$
p	load life factor
ΔS	optimization step size
V	inequality constraint vector
∇V	gradient in an inequality constraint
∇v	unit gradient in an inequality constraint
X	independent design parameter
Y	scaled independent design parameter
Γ	cone angle, deg
Γ	gamma function
Σ	shaft angle, deg
σ	stress, psi
ϕ	pressure angle, deg
ψ	spiral angle, deg
Subscripts:	
a	active
g	gear
j	optimization step index
k	constraint index
p	pinion
t	tangential

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shaft angles are compared.

Spiral Bevel Reduction Model

Fig. 1 is a schematic of the spiral bevel model for this design study. The figure includes most of the basic parameters which define a bevel gear set. It shows the geometry of this study in which both gears are supported in overhung configurations. The gears are described by:

1. The shaft angle, Σ;
2. The gear ratio, n;
3. The number of teeth on the pinion, N_p;
4. The back-cone distance of the mesh, A_o;
5. The face width, f;
6. The normal pressure angle, ϕ; and
7. The mesh spiral angle, ψ.

The bearings are described by:

1. The type;
2. The series;
3. The distances from the supported gear, A and B; and
4. The shaft size, D.

The bearings may be either ball or straight roller, and the series may be extra-light, 100; light, 200; or medium, 300. For the examples of this work, the bearings closest to the gears are straight roller bearings, and the far bearings are ball bearings. The roller bearings are placed directly behind the gears with a small axial clearance equal to a proportion of the bearing and gear widths, and the ball bearings are placed at the ends of the support shafts. Both bearings on the same shaft have the same bore, which is kept smaller than the inside rim of the gear. This places the stronger roller bearings at the positions of higher radial load, while allowing the ball bearings to support the thrust loads in combination with the lower radial loads on both shafts.

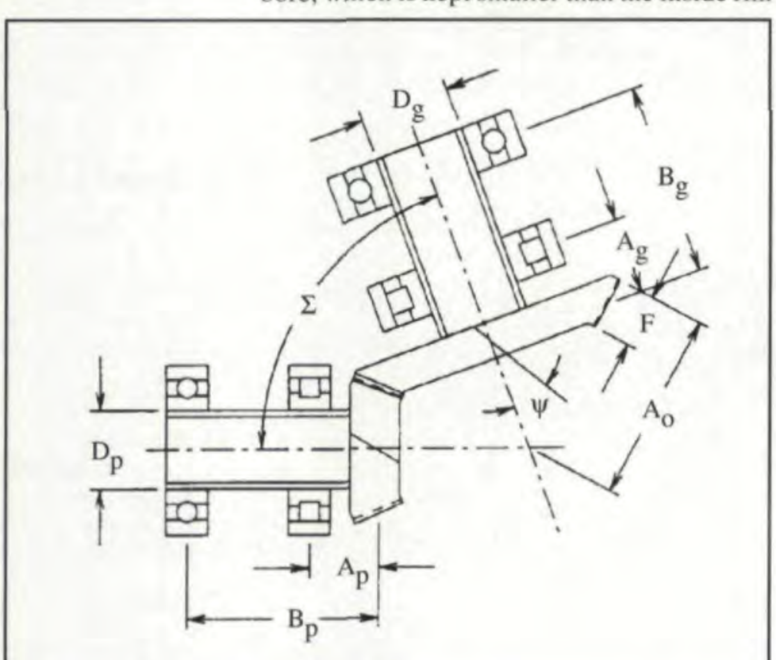

Fig. 1 — Spiral bevel reduction parameters.

For a given shaft angle, reduction ratio, size, input torque and input speed, the design objective is to maximize the life of this reduction as measured by the anticipated mean time between service overhauls (Ref. 16). Expected overhauls are based on predictions of pitting fatigue failures in the bearings and gears for steady loads and good lubrication. Under these conditions, a two-parameter Weibull reliability model predicts the service life of the reduction.

Pitch Cone Angles

At any combination of gear ratio and shaft angle, the pinion and gear pitch cone angles are defined. The gear ratio, n, has an absolute value greater than 1. For a positive gear ratio, the pinion and gears turn in opposite directions as viewed from the backs of the gears, while a negative gear ratio indicates that the pinion and gear rotate in the same direction as viewed from the backs of the gears. The shaft angle, Σ, can have a value between 0° and 180°. In terms of these two parameters, the tangent of the pinion cone angle Γ_p, which is less than 90°, is given by the absolute value:

$$\tan \Gamma_p = \left| \frac{\sin \Sigma}{\cos \Sigma + n} \right| \qquad (1)$$

And the tangent of the gear cone angle, Γ_g, which may have a value between 0° and 180°, is given by:

$$\tan \Gamma_g = \left| \frac{\sin \Sigma}{\cos \Sigma + 1/n} \right| \qquad (2)$$

If the gear cone angle, Γ_g, is less than 90°, then the gear is an external gear, as the pinion is. If this angle is equal to 90°, the gear becomes a crown gear with all its teeth in a single plane perpendicular to the axis of the gear. When the gear pitch cone angle is greater than 90°, the gear becomes an internal gear, with its teeth on the inside of the pitch cone.

Gear Tooth Geometry

The addenda and dedenda of the pinion and gear teeth follow standard bevel tooth proportions (Ref. 17). In terms of the back-cone diametral pitch, P_d, and the gear ratio, n, these tooth

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(Continued from p. 26.)
heights are:

$$a_g = \frac{0.46}{P_d} + \frac{0.39}{P_d \cdot n^2} \quad (3)$$

$$a_p = \frac{1.7}{P_d} - a_g \quad (4)$$

$$d_g = \frac{1.888}{P_d} - a_g \quad (5)$$

and

$$d_p = \frac{1.888}{P_d} - a_p \quad (6)$$

The cutter radius, R_c, is calculated as a polynomial fit to the suggested proportions for spiral bevel manufacture (Ref. 12). To match this cutter radius, the maximum face width is limited to be equal to or less than 30% of the back-cone distance.

With these proportions, the contact ratio of the spiral bevel gear mesh has two orthogonal components: a face advance contact ratio and the radial contact ratio of the equivalent back-cone spur gears. The total contact ratio is the square root of the sum of the squares of these two contact ratios. Fig. 2 shows the face advance contact ratio, which is the ratio of the spiral advance of the gear tooth at the back-cone radius, A_o, to the circular pitch of the gear teeth at the back-cone radius. In this article, this ratio is limited to be greater than 1.3 to provide some spiral engagement of the gear teeth.

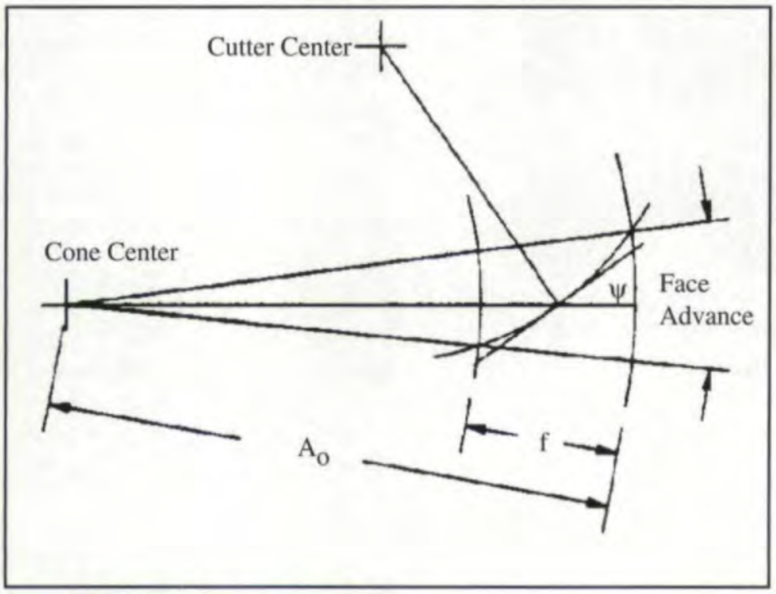

Fig. 2 — Face contact ratio geometry.

Kinematic interference is modeled with the kinematic interference model of the equivalent back-cone spur gears. For the addendum and dedendum proportions of the standard, this does not appear as an active constraint in the design searches. All potential designs have adequate involute contact. One possible extension of this work is to improve the kinematic interference model and make the addendum and dedendum ratios independent parameters in the design problem. For this article, these ratios are held to the standard values of Equations 3-6.

Gear Strength

Tooth loading can cause bending, pitting and scoring failures in bevel gear teeth as well as in spur gear teeth. A major difference in loading between the two gear types is that the load on a spiral gear tooth is a point load which travels across the tooth, instead of a line load carried by the full width of the tooth, as for a spur gear. Standard geometry factors for the bending strength of spiral bevel gear teeth are available in chart form for a 90° shaft angle and two or three pressure angles (Ref. 18). To permit the optimization to deviate from these conditions, the gear tooth width is taken as the width of the contact ellipse, and the spur gear geometry factor is used along with a dynamic load velocity factor.

$$\sigma_b = \frac{K_v F_t P_d}{f_a J} \quad (7)$$

For the examples in this article, the velocity factor increases the load about threefold. A low stress limit of 25,000 psi is used to provide a high design factor for bending strengths.

The contact ellipse size and location and the maximum contact pressure are modeled using a three-dimensional Hertzian contact stress analysis (Ref. 19). The cutter radius and the tooth involute curvatures are used to determine the principal curvatures. For most of the examples, the contact ellipse covers about one-third the width of the tooth, and the localized maximum Hertzian contact pressure is significantly higher than the two-dimensional equivalent spur gear contact stress calculation. The higher contact ellipse

(Continued on p. 30.)

(Continued from p. 28.)

pressure is used in the gear tooth life model and the scoring failure limit calculation of pressure times sliding velocity.

Reduction Life

Both bearings and gears are modeled with a linearly decreasing log-strength with log-life relationship. Dynamic capacities, C, at a life of one million cycles are used to determine the 90% reliability lives, l_{10}, of the components. The basic relationship is:

$$l_{10} = \left(\frac{C}{F}\right)^{p} \qquad (8)$$

For gears, the dynamic capacity value, C, is a function of the gear material strength and tooth geometry (Refs. 14-15). Since the natural log of life is inversely proportional to the contact stress, the load-life factor of 8.93 (Ref. 10) for spur gear teeth which see two-dimensional Hertzian contact stress is corrected to 6.0 for the spiral bevel teeth which see three-dimensional Hertzian contact stress. Bearing lives have a similar load-life relationship (Refs. 20 and 21) in which the load life factor is lower due to the higher contact stress. The bearing load-life relationship is often modified with life and load adjustment factors. The life adjustment factors are for lubrication and speed effects, while the load adjustment factor converts the applied load to an equivalent radial load.

Describing both gear and bearing life scatter with two-parameter Weibull distributions enables the statistical combination of these lives into a system life at the same 90% reliability level (Ref. 16). The gamma function converts the 90% reliability life into a mean life for the reduction:

$$l_{av} = \frac{l_{10}\,\Gamma\,(1 + 1/b)}{[\mathrm{Ln}(1/0.9)]^{1/b}} \qquad (9)$$

In these calculations, the Weibull slope, b, differs for the bearings, gears and system. The mean life of the reduction is an estimate of the mean time between overhauls for the units in service or the mean service life.

Interferences

In combining the components into a system, one needs to be concerned with the spatial compatibility of the components. As a design develops, shaft configurations and mounting details enable improved combinations of the components. However, only basic interactions of the components are considered in this study, so each gear and its two support bearings are constrained to have the same shaft diameter. This forces the bore of the bearings to be less than the gear diameter at the root of the bevel teeth on the inside edge of the gear. The geometry also forces the near bearing to be placed behind the gear by a clearance proportional to the widths of the bearing and the gear.

An additional spatial limit in the study is that between the outside diameters of the near bearings on the two shafts. For small shaft angles, the inside corners of the bearing outside diameters must be separated by a sufficient clearance to allow proper mounting.

Optimization Method

The modified feasible direction gradient search technique uses several vectors. These vectors are the independent design variables, X; the inequality constraints, V; the parameters of the merit function, P; and the constants which define the specific problem, Co. An optimization solution is the design variable values, X, which minimize or maximize the merit function value while maintaining all constraint values, V, inside their specified limits. A procedure starts with a guess for the design variable, X, and iterates to find the optimal design.

To maintain balance among the independent design parameters, the design space is scaled into a continuous, dimensionless design space. The scaled design parameters, Y, vary from - 1.0 to +1.0 as specified by upper and lower bounds on the independent design parameters, X. By setting the upper and lower bounds on the design parameters, the user has control over the relative sensitivity of the design variables in the optimization search. Increasing the range between limits for a variable increases the sensitivity of that variable in the search.

Gradients

For minimization, the direction of change in Y which reduces the merit function, M, at the greatest rate is determined by the unit vector, ∇m:

$$\nabla m = -\,\frac{\nabla M}{|\nabla M|} \qquad (10)$$

(Continued on p. 34.)

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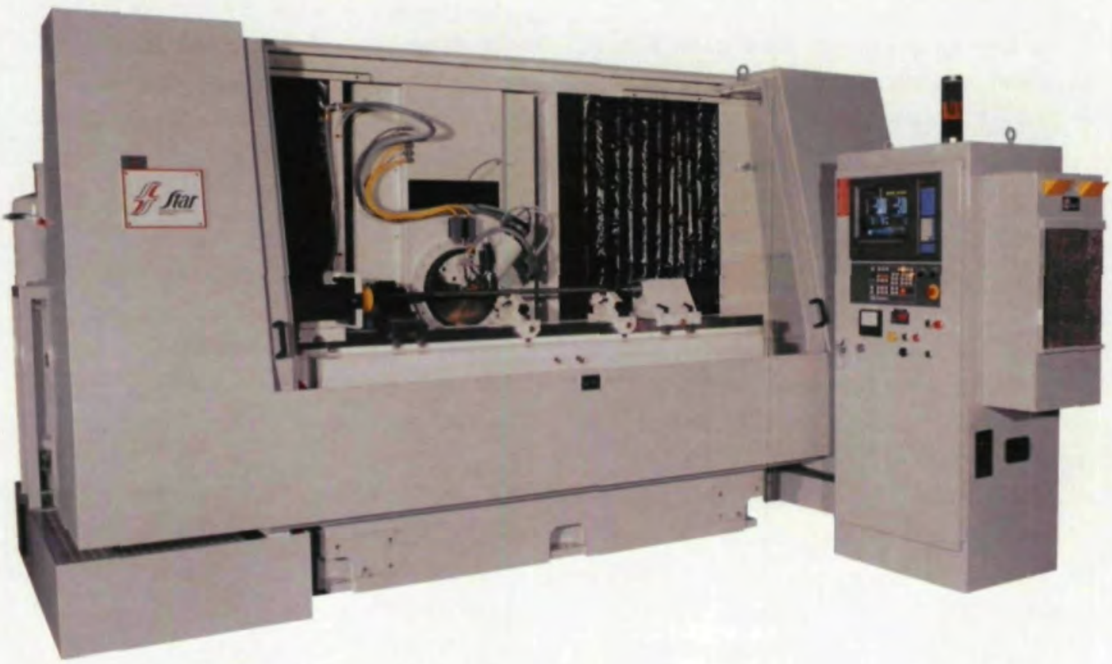

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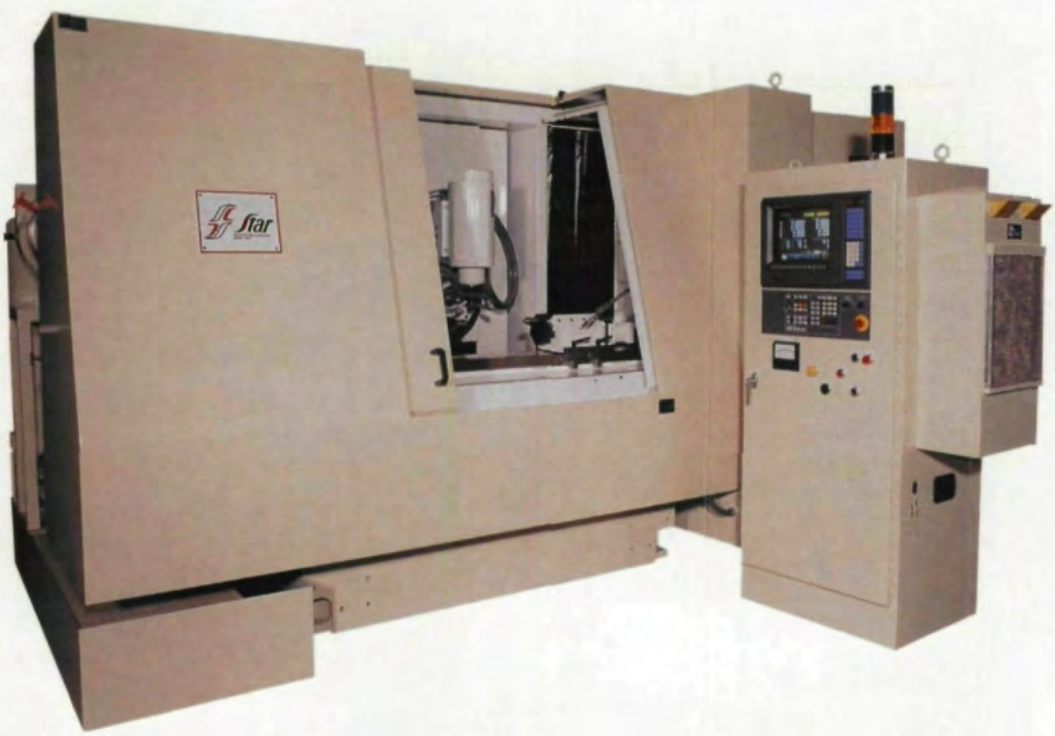

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(Continued from p. 30.)
For maximization, the sign in Equation 10 reverses.

In the simple gradient search which occurs free of the design constraints, Equation 10 defines the direction for the step change in the scaled design vector.

$$Y_{j+1} = Y_j + \Delta S \; \nabla m \qquad (11)$$

where ΔS is the scalar magnitude of the step. If no constraints are violated, this will be the next value for Y in the search.

A unit gradient in a constraint variable is defined as:

$$\nabla v_k = - \frac{\nabla V_k}{|\nabla V_k|} \qquad (12)$$

where ∇v_k is a unit vector in the direction of decreasing value in the constraint, V_k. For upper bound constraints, moving through the design space in the direction of ∇v_k reduces the constraint value V_k. For lower bound constraints, a sign reversal in Equation 12 produces an increase in the constraint value, V_k, for motion in the gradient direction. The vector sum of the gradients in the violated constraints, ∇h, is the second gradient of the feasible direction algorithm:

$$\nabla h = \frac{\sum_k \nabla v_k}{|\sum_k \nabla v_k|} \qquad (13)$$

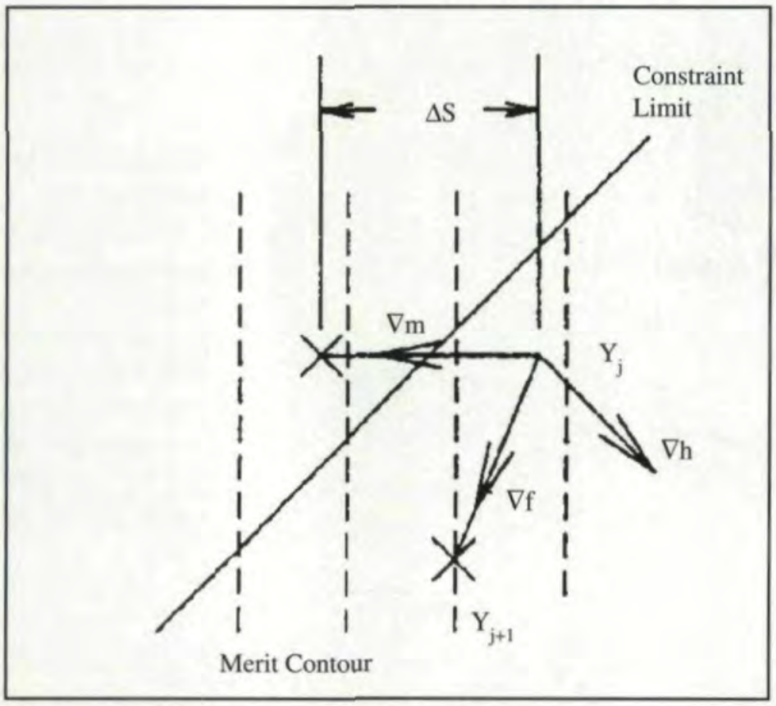

Fig. 3 — Feasible direction gradient vector.

The gradient in the violated constraints, ∇h, points towards the acceptable design space from the unacceptable design space. By itself, it enables the algorithm to turn an unacceptable initial guess into an acceptable trial design by a succession of steps:

$$Y_{j+1} = Y_j + \Delta S \; \nabla h \qquad (14)$$

Once inside the acceptable design region, the algorithm proceeds along the steepest descent direction until the calculated step places the next trial outside the acceptable design space. To avoid this condition, the algorithm selects a feasible direction for the next step. Fig. 3 shows a constraint limit intersecting contour lines of improving merit function values. The figure shows gradients in the merit function, ∇m, and the impending constraint, ∇h. The feasible direction selected, ∇f, is the unit vector sum of these two gradients:

$$\nabla f = \frac{\nabla m + \nabla h}{|\nabla m + \nabla h|} \qquad (15)$$

And the next design step becomes:

$$Y_{j+1} = Y_j + \Delta S \; \nabla f \qquad (16)$$

Solution

The step size, ΔS, is a significant element of any optimization procedure (Ref. 13). For stability and directness, the step size of this work normally is fixed. Initially, the step size is 5% of the range of a single design parameter. But the procedure halves the step whenever a local minimum is reached, or the search is trapped in a constraint corner.

To end the design search, the procedure declares a solution when the percent change in the merit function, M, is less than a pre-set limit.

$$\left| \frac{M_{j+1} - M_j}{M_j} \right| < e_l \qquad (17)$$

If this limit is not reached, a pre-set limit of optimization steps signals that the design search is at an end.

Computer Program

The spiral bevel design problem is incorporated in the program as a series of design analysis subroutines which evaluate the design constraint and merit function values for

(Continued on p. 36.)


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(Continued from p. 34.)

each design parameter vector. User interfaces to the optimizing routines include: an input file, an output file, terminal graphic output and terminal text output and input.

The program provides user control over its operation through the input file and through terminal interaction. The input file allows the designer to set the design constants, active constraints, the initial design parameter values and design parameter ranges for the design search. The design parameter ranges influence the relative sensitivities of the different design parameters in the search. By increasing the range between the low and high limits on a design variable, the designer makes that variable more active in the design search. The program does overcome poor initial design values and should find the same optimum with different parameter sensitivities, but adjustments in these values give the designer control in the optimization process.

Table I — Design Parameter Values

	Initial	Shaft angle	
		80 degree	100 degree
Face width, in.	**2.0**	**1.0**	**1.1**
Pinion teeth	**20**	**37**	**43**
Pressure angle, deg	**20.0**	**22.0**	**22.0**
Spiral angle, deg	**35.0**	**30.0**	**25.0**
Pinion shaft diameter, mm	**50.0**	**70.0**	**80.0**
Gear shaft diameter, mm	**60.0**	**75.0**	**80.0**

Table II — Property Values

	Shaft angle	
	80 degree	100 degree
Service life, hr	**5,870**	**18,260**
Bending stress, ksi	**19**	**18.9**
Contact pressure, ksi	**396**	**312**
Pressure x velocity, 10^6 psi-ft/min	**3.4**	**2.5**
Face contact ratio	**1.3**	**1.46**
Radial contact ratio	**1.34**	**1.48**
Pinion cone angle, deg	**24.37**	**28.33**
Pinion pitch diameter, in.	**4.13**	**4.75**

In the terminal interaction phase, the program summarizes the optimal design and its constraint values and offers the designer the opportunity to modify the design for a comparison analysis. If this option is chosen, the modified design is analyzed, and a full report of its properties is placed on the screen and in the output file. The opportunity to modify the last design continues until the designer chooses to end the program.

The program includes a graphic output routine which generates a scaled schematic view of the transmission similar to the drawing in Fig. 1. This view is of the plane of the input and output shafts. In the view, the basic components — gears, bearings and shaft proportions — appear in scale without the dimensions of Fig. 1. The drawing improves design awareness in this early stage of transmission evaluation.

Transmission Design

Consider the design of gear reductions to transmit an input torque of 600 lb-in. at 1,000 rpm at a power level of 9.5 hp with a ratio of 2:1. The back-cone distance of the designs is fixed at 5", as are the shaft lengths from the center of the gear to the center of the rear ball bearing. A series of designs is sought with shaft angles that vary from 60° to 120°. Extra-light, 100 series bearings are used throughout.

Six independent design parameters are sought for each design:

1. The mesh face width, f;
2. The number of pinion teeth, N_p;
3. The normal pressure angle, ϕ;
4. The mesh spiral angle, ψ;
5. The pinion shaft diameter, D_p; and
6. The gear shaft diameter, D_g.

The optimal design criterion is the maximum mean service life between overhauls for the reductions.

Among the design constraints active in the program are:

1. The tooth bending stress;
2. The tooth contact pressure;
3. The tooth pressure times the sliding velocity;
4. The face contact ratio; and
5. The back-cone contact ratio.

The design constraints include radial clearances between the bearings and gears which

(Continued on p. 38.)

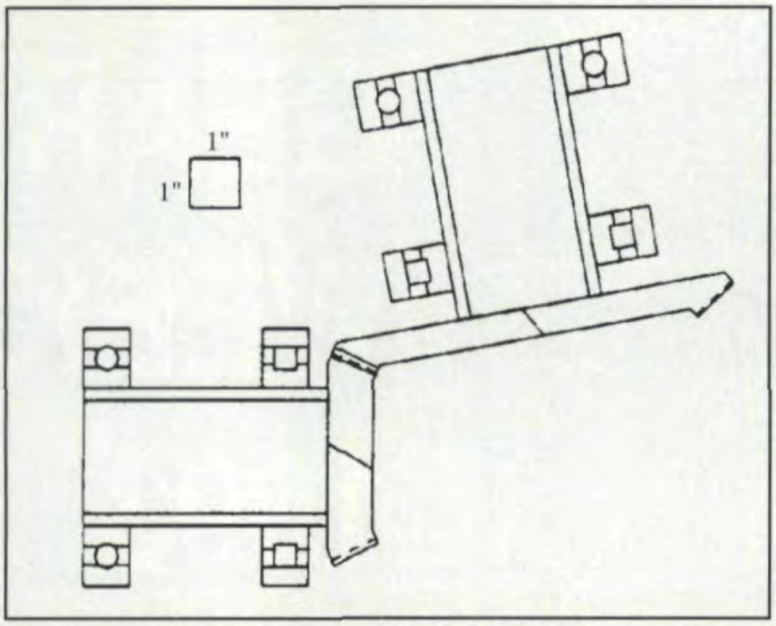

Fig. 4 — 80° shaft angle design with a life of 5,870 hrs.

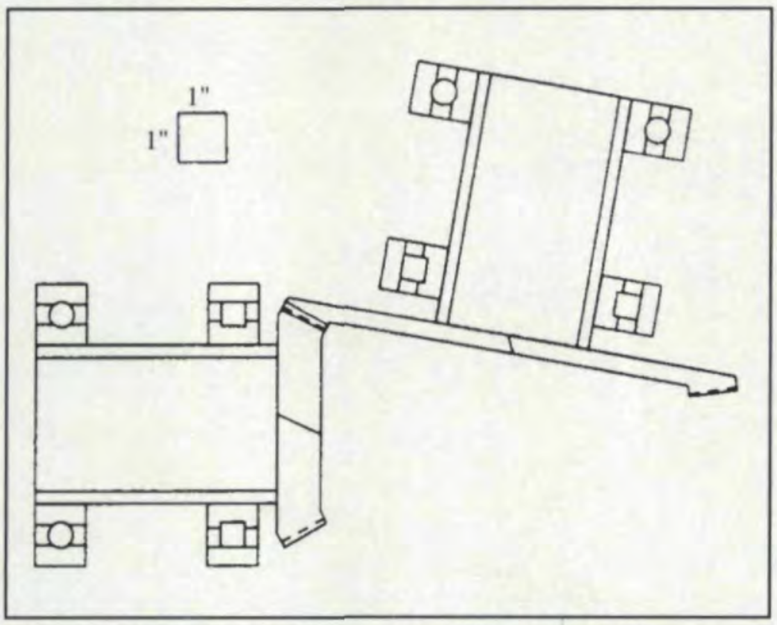

Fig. 5 — 100° shaft angle design with a life of 18,260 hrs.

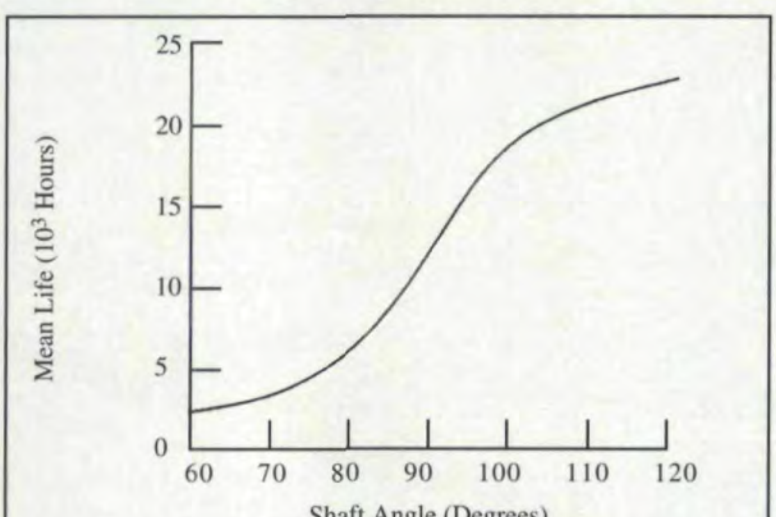

Fig. 6 — Reduction mean service life versus shaft angle for optimal designs.

(Continued from p. 36.)

key the interaction between these components in the designs. The inside bores of the bearings are held to be smaller than the inside rim of the supported gear at its small end. Several other factors such as contact ellipse shift, shaft stress, back-cone involute interference, cutter radius, dynamic load and roller bearing location are included in the constraint list, but are not listed for brevity's sake.

Table I lists the initial guess and optimal design values for the cases with shaft angles of 80° and 100°. Table II lists the values of the merit function, the five cited constraints and the pinion cone angle and pitch diameter for these designs. Fig. 4 is a schematic of the 80° design, and Fig. 5 shows the 100° shaft angle design. Both designs have a diametral pitch near 10. The two designs have nearly the same weight, but significantly different service lives of 5,870 hours for the 80° shaft angle design and 18,260 hours for the 100° shaft angle design. The service life difference is attributable to the increase in pinion size with the increase in shaft angle. The larger pinion has lower contact and bearing forces for the same transmitted torque as well as larger and stronger bearings. In all the designs, the weakest component from a life standpoint is the rear ball bearing on the pinion shaft.

As the shaft angle increases from 60° to 120°, the optimum design life increases as shown in Fig. 6 with the maximum rate of increase occurring at a shaft angle of 90°. Lower rates of increase in life occur at low and high shaft angles. The larger gear increased in cone angle from 40.893° for the 60° shaft angle to 90° for the 120° shaft angle. A cone angle of 90° makes the output gear a crown gear.

In the optimal designs, the gear face widths are less than the 30% back-cone distance limit of 1.5", and the number of pinion teeth is larger than expected. These results are due to interactions of the pinion shaft bearing life requirements with the face contact ratio and pinion bore to gear internal diameter clearance limits. The face contact ratio increases with increasing pitch for the same back-cone distance, face width and spiral angle. The bearing capacity increases with its bore which also increases with a decreasing gear face width for a fixed

(Continued on p. 40.)

(Continued from p. 38.)

back-cone distance and cone angle.

For these designs, the number of teeth on the pinion rose from 29 for a shaft angle of 60° to 45 for a shaft angle of 120°. The pinion pitch diameter increased from 3.27" for a shaft angle of 60° to 5.0" for a shaft angle of 120°. The pressure angle stayed nearly constant at 22°, and the spiral angle dropped from 30° for shaft angles below 90° to about 25° for shaft angles of 90° and above.

Summary and Conclusions

A modified feasible directions gradient search optimization procedure has been applied to the problem of designing a spiral bevel gear reduction with a fixed back-cone distance for a maximum life between service overhauls. The gear and pinion shaft lengths are equal to the back-cone distance, and each shaft is supported in a ball and roller bearing with the roller bearing close to the gear and both bearings behind the gear. The spiral bevel gear transmits a selected power at a selected input speed to a given output speed through a specified shaft angle.

The procedure finds six independent design parameter values: the mesh face width, the number of pinion teeth, the pressure angle, the spiral angle and the pinion and gear shaft diameters. The diametral pitch of the gears is a function of these parameters.

The optimization is performed by a program with user interfaces which allow control over the input parameters and enable the designer to check other designs with the program's analysis routines. Therefore, practical, near-optimal designs may be found with the program.

Examples at various shaft angles demonstrate a dramatic increase in service life with an increase in shaft angle. The service lives of the designed reductions are influenced strongly by the lives of the pinion shaft ball bearings, since the pinion shaft thrust load is a major load in these reductions.

In the optimal designs, the gear face widths are lower than the maximum allowed, and the numbers of pinion teeth are greater than the minimum allowed. The optimal pressure angles are close to 22° for most designs, and the spiral angles range from 30° to 25° as the shaft angle increases. ■

References:

1. Dudley, D.W. *The Evolution of the Gear Art.* American Gear Manufacturers Association, 1969.
2. Coleman, W. "Guide to Bevel Gears." *Product Engineering,* 1963, pp. 87-95.
3. Baxter, M. L., Jr. "Exact Determination of Tooth Surfaces for Spiral Bevel and Hypoid Gears." AGMA Paper 139.02, Oct. 1966.
4. Krenzer, T. J. "Tooth Contact Analysis of Spiral Bevel and Hypoid Gears Under Load." SAE Paper 810688, Apr. 1981.
5. Fort, P. "Computer Aided Design, Manufacturing and Inspection System for Spiral Bevel Gears." ASME Paper 80-C2/DET-127, Aug. 1980.
6. Litvin, F. L. *Theory of Gearing.* NASA RP-1212, Dec. 1989.
7. Litvin, F. L. et al. "Local Synthesis and Tooth Contact Analysis of Face Milled Spiral Bevel Gears." *Proceedings of the International Conference on Motion and Power Transmissions,* Hiroshima, Japan, Nov. 1991, pp. 721-724.
8. Gosselin, C. et al. "Tooth Contact Analysis of High Conformity Spiral Bevel Gears." *Proceedings of the International Conference on Motion and Power Transmissions,* Hiroshima, Japan, Nov. 1991, pp. 725-730.
9. *Standard for Spur, Helical, Herringbone and Bevel Enclosed Drives.* AGMA 6010-E88, AGMA Standard, Arlington, VA, Nov. 1988.
10. Drago, R. J. *Fundamentals of Gear Design.* Butterworth, 1988.
11. Dudley, D. W. *Handbook of Practical Gear Design.* McGraw-Hill, 1984.
12. Hotchkiss, R. G., McVea, W. R., and Kitchen, R. L. "Bevel and Hypoid Gear Manufacturing." *Dudley's Gear Handbook.* 2nd Edition, D. P. Townsend, ed., McGraw-Hill, 1991.
13. Vanderplaats, G. N. *Numerical Optimization Techniques for Engineering Design: With Applications.* McGraw-Hill, 1984.
14. Savage, M., Coy, J. J., and Townsend, D. P. "Optimal Tooth Numbers for Compact Standard Spur Gear Sets." *ASME Journal of Mechanical Design,* Vol. 104, No. 4, Oct. 1982, pp. 749-758.
15. Savage, M., Mackulin, B., Coe, H., and Coy, J. J. "Maximum Life Spur Gear Design." NASA TM-104361, June 1991.
16. Savage, M., et al. "Computerized Life and Reliability Modeling for Turboprop Transmissions." *AIAA Journal of Propulsion and Power,* Vol. 5, No. 5, Sept.-Oct. 1989, pp. 610-614.
17. Dean, P. M. "Gear Tooth Proportions." *Gear Handbook,* D. W. Dudley, ed., McGraw-Hill, 1962.
18. *Geometry Factors for Determining the Strength of Spur, Helical, Herringbone and Bevel Gear Teeth.* AGMA 226.01, AGMA Standard, Arlington, VA, Aug. 1970.
19. Savage, M., et al. "Tooth Contact Shift in Loaded Spiral Bevel Gears." *ASME Proceedings of the 1989 International Power Transmission and Gearing Conference,* Chicago, IL, Apr. 1989, pp. 203-212.
20. Zaretsky, E. V., et al. "Life Adjustment Factors for Ball and Roller Bearings." *ASME Engineering Design Guide,* ASME, New York, 1971.
21. Harris, T. A. *Rolling Bearing Analysis.* 2nd Edition, Wiley, 1984.

Lubricants and Lubrication of Plastics Gears

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Consultant
Charlotte, NC

Surface measurement of any metal gear tooth contact surface will indicate some degree of peaks and valleys. When gears are placed in mesh, irregular contact surfaces are brought together in the typical combination of rolling and sliding motion. The surface peaks, or asperities, of one tooth randomly contact the asperities of the mating tooth. Under the right conditions, the asperities form momentary welds that are broken off as the gear tooth action continues. Increased friction and higher temperatures, plus wear debris introduced into the system are the result of this action.

The basic function of a lubricant is to provide an oil film that will separate two mating surfaces that move relative to one another. In metal gearing, it is imperative that an adequate lubricant and lubrication system be provided to prevent contact of surface asperities. Once failure of the lubricant or lubrication system is initiated, ultimate failure of the gearing is likely.

Plastics Reactions

In plastics gearing, both molded and cut plastics gears have the peak-and-valley surface contour. This is the result of manufacturing, inherent machining equipment inaccuracies and allowable tolerances. Some studies indicate that under the right conditions, momentary welding can occur in plastics gears. A compressive stress is present as a set of gear teeth come into contact. The stress moves from the initial point of contact along the tooth profile until the teeth are no longer in contact. The compression causes the same subsurface stress as in metal gears. When relative sliding takes place at the mating point of contact, heat builds up at a localized point and material is removed due to the shear stress. These factors contribute to:

1. New, exposed surface irregularities;
2. Free debris particles and erosion;
3. Increased energy requirements to maintain constant speed;
4. Increased friction and wear;
5. Increased heat generation;
6. Erratic, sluggish system response; and
7. Accelerated tooth contact surface change reflected in output load fluctuations or motion transfer problems.

Significant lubrication differences and similarities are found between lubrication of metal and plastics gears. Applications, materials and design situations range in plastics gearing from the extreme of plastics gearing with no lubrication and unfilled material to gears operating immersed in water, oil, or chemical baths. Present-day usage consists of many combinations of lube/no-lube, filled/unfilled materials and like/unlike materials. The ideal low-cost gearing system is that requiring no lubrication and unfilled materials.

In a gear set that is designed, manufactured, assembled and operated correctly, the use of a lubricant is recommended during the run-in period. Continued lubrication serves primarily to help reduce friction and assist in heat dissipation at the tooth contact surfaces, since even the best quality standard gears cannot avoid some degree of sliding contact during operation. Other uses of a lubricant in the application are flushing wear particles, dirt, and moisture, providing corrosion protection to adjoining parts and lubrication of those parts. As in all plastics gearing applications, gears should be tested to determine design suitability. The lubricant and lubrication method should be tested at the same time using the identical systems of the intended application at the required service conditions.

Coefficients of friction, temperatures, stress levels and wear factors of mating materials are an indication of the necessity for use of a lubricant. A low coefficient of friction indicates that relatively small amounts of input energy are necessary to overcome sliding contact conditions. Small wear factors for unit load will provide longer wear life. When coefficient of friction and wear data are not available, substitute materials may be considered. This is particularly advisable in plastics gearing because much data have been generated for the commonly used and most successful gearing materials.

It is important to remember that lubricants are chemicals. Plastics are susceptible to chemical attack, so a major consideration is the type of lubricant selected for a particular application. This selection process is aided by tables provided by plastics material suppliers and texts containing results of chemical compatibility tests. Test samples of candidate plastics materials are immersed in the chemical of interest at a certain temperature for a period of time. Test samples are then weighed, and that weight compared with pre-test weights. Chemical attack of the plastic material has occurred if the sample weight has been reduced or if crazing of the material is evident. If the test sample weight is increased, the indication is that absorption has occurred. Remeasurement of the test sample can sometimes indicate the severity of the fluid absorption. In gearing, moisture or chemical absorption can be as severe a problem as chemical attack, because small clearances for backlash can easily be eliminated and wear initiated.

Discussion of chemical attack on plastics is not an indictment of the lubricant. Practically all types of lubricating oils contain at least one additive, and some oils contain several different types of additives. The amount of additive used varies from a few hundredths of a percent to 30% or more (Ref. 1). It is usually the chemical action of the additives that is responsible for the failure of plastics materials when in contact for a period of time, under stress conditions, subjected to adverse temperatures or in contact with combinations of other system materials.

Chemical compatibility data will usually indicate exposure time and temperatures. The question confronting the design engineer is the applicability of the data for his or her application. Operating stress levels are usually never the same as the stress level of the test sample. The same is true for the temperature and the time of exposure. For this reason, some material suppliers provide data generated at wide ranges of temperatures for extremely long periods of time. Regardless, gear life tests should always be run unless significant experience with a particular lubricant dictates otherwise.

Plastics Stress Level

The fact that lubricant attack is influenced by stress level is sometimes overlooked. Often samples submitted for chemical compatibility testing will be at a specific stress level due to normal sample preparation procedures. When a gear is produced either by molding or cutting, stresses are set up in the parts. These residual stresses may or may not be relieved with subsequent manufacturing processes. Nevertheless, operating stresses are also present during running of the gears in their application. The problem is that the reaction of the gear materials to the residual or operating stress levels and operating temperatures may produce significant lubricant and material incompatibilities. Fortunately, experience has shown that some lubricants work better with certain materials used in gears of common sizes, with typical loads, and limited to reasonable temperature levels. The result is that many material suppliers and gear houses are aware of the lubricant/plastics gear compatibility concern and can be of assistance in providing recommendations. However, since stress levels and applications can be substantially different, the recommendation is to test the gears with the intended lubricant in actual situations. Where testing is impossible or impractical, all available experience and reported data should be consulted and analyzed.

Clifford E. Adams
is a consultant specializing in plastics and fine-pitch gearing, gear design and analysis and mechanical components used in power transmission. He has over 35 years' experience in design and engineering.

Plastics gear lubrication is accomplished using the following methods or in combinations of the various methods:

1. Dry with no external or internal lubricant;

2. Initial application of external lubricant, usually grease;

3. Initial application, replenished at random or fixed intervals;

4. Continuous coverage by liquid bath;

5. Fillers such as carbon, graphite or molybdenum disulfide;

6. Gears filled with silicone or similar lubricants; and

7. Gears both filled with lubricants and externally lubricated.

Other Considerations

A problem often encountered is adherence of the lubricant to the tooth-contacting surfaces. Squeeze-out and throw-off by centrifugal action has plagued gear users and is a continual problem in many applications. Some innovative housing designs have provided deflectors that channel the oil or grease back into the gear contact area. Selection of an adhering type lubricant may resolve the problem in some applications. Nonspreading and nonmigrating lubricants or oil creep barrier films may also be possible if carefully selected for particular problems.

There are times when lubricants may be considered to be contaminants. This may be particularly true where the lubricant is used on food handling equipment. Inadvertent contact with the food necessitates the use of certain types, such as the silicones.

Acetal (polyformaldehyde) is not vulnerable to solvation (attack by lubricant components) or crazing. However, it is quite sensitive to buildup of acidic constituents. The most popular gearing materials, acetal and nylon, are susceptible to chemical attack at temperatures above 150°F and in strong acids and strong alkalis, particularly at full strength (Refs. 3, 4).

The most versatile synthetic lubricant families are the silicones and hydrocarbons, where operating temperature ranges of -65°F to +250°F are not uncommon.

Chen and Juarbe (Ref. 5) discuss lubricants and MoS_2-filled nylon gears. Gear oils with an EP additive in the viscous range of 200-300cs at 40°C are suitable for nylon. This is equivalent to the AGMA mild EP lubricant #4EP. Loads tested were heavy and operation was low-speed.

Chemical equipment and chemical handling equipment can be sources of contamination by oils and greases. Lubricants can contaminate areas such as office equipment, where paper forms, bills and account ledger materials must pass through data processing machines. Care is necessary so that creep, splash-out, dripping or bleed do not become a problem.

What to Look For in a Plastics Lubricant

Items of importance are as follows:

1. *Correct viscosity.* Minimum oil film thickness, continual recreation of a lubricated surface, formation of a protective film, good distribution with minimum squeeze-out.

2. *Adequate temperature range.* Fluid film at low-temperature extreme, sufficient coverage and lubricating capability at high temperature extreme, minimum fluid breakdown at high temperature.

3. *Chemical stability.* Minimum oxidation under heat buildup may provide additional protection.

4. *Good lubricity.* Minimum friction that aids in control of operating temperature rise may have additive protection.

Lubricant and Plastics Compatibility (Ref. 2)

Materials not usually a problem are nylon, phenolic, diallyl phthalate, terephthalate polyesters, polytetrafluoroethylene, polyethylene and polypropylene.

Materials that can be a problem are polystyrene, polyvinyl chloride, ABS resins, polycarbonate, polysulfone, and polyphenylene oxides. ■

References

1. Wills, J. G. *Lubrication Fundamentals.* Marcel Dekker, Inc., New York, 1980.

2. *Nye Lubeletter.* William F. Nye, Inc., New Bedford, MA, 1977.

3. *DuPont Delrin Acetal Resin Design Handbook.* E. I. DuPont DeNemours and Co., Wilmington, DE, 1981.

4. *DuPont Zytel Nylon Resin Design Handbook.* Bulletin E-44971, E. I. DuPont DeNemours and Co., Wilmington, DE.

5. Chen, J. and Juarbe, F. "Tests of MoS_2-Filled Nylon Gears Provide Design Data." *Power Transmission Design,* Penton/IPC, Cleveland, OH, 1978.

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CIRCLE A-35 on READER REPLY CARD

CIRCLE A-36 on READER REPLY CARD

Hob Basics Part I

Keith Liston
Pfauter-Maag Cutting Tools, L.P.
Loves Park, IL

The Hobbing Process

The hobbing process involves a hob which is threaded with a lead and is rotated in conjunction with the gear blank at a ratio dependent upon the number of teeth to be cut. A single thread hob cutting a 40-tooth gear will make 40 revolutions for each revolution of the gear. The cutting action in hobbing is continuous, and the teeth are formed in one passage of the hob through the blank. See Fig. 1 for a drawing of a typical hob with some common nomenclature.

Fig. 2 shows the generating process of hobbing. This diagram shows the cutting action of consecutive teeth in a hob thread passing through the gear space as the gear space rotates past the hob. Each hob tooth cuts its own profile, which is straight-sided. It is the accumulation of these straight cuts that produces the involute form on the gear teeth. The gear profile is formed a little at a time in a series of cuts. This method is known as the generating process of cutting gears. As the number of flutes in a hob are increased, the number of cutting teeth also increases. Thus, given the same feeds and speeds, a hob with a higher number of flutes will generate a smoother profile.

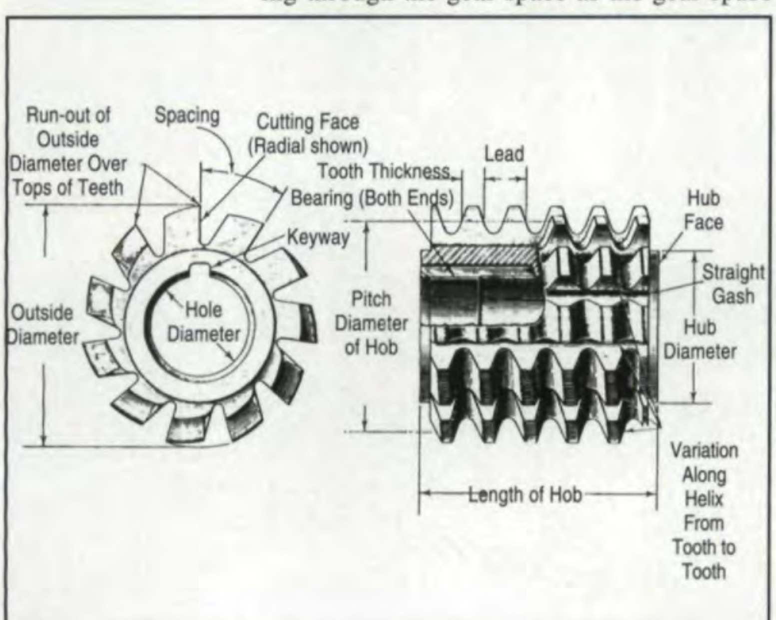

Fig. 1 — Hob nomenclature.

Selection of the Type of Hobbing Operation

The selection of the type of hobbing operation is dependent upon the class of gear required, the type of equipment available, the condition of the equipment, the experience of the work force or the personal preference of the gear designer. In some cases there may be more than one manufacturing method available to obtain the same end result.

Finish Hobbing. Finish hobs are used to put the final tooth form on a part. No secondary operations are performed on the tooth after hobbing, therefore, the hob cuts the part teeth to the finish tooth dimensions. Gears can be finish-hobbed if the quality level permits, and the machine and fixturing are accurate enough. See Fig. 3 for achievable gear qualities. Note that this chart is only a guideline, with actual results dependent upon the equipment and tooling available, the experience of the work force and the control of the heat treating process.

Semi-Finish Hobbing. Semi-finish hobbing differs from finish hobbing, since a secondary operation is performed on the tooth form after the hobbing operation. Secondary operations include shaving, grinding, rolling or skiving, to name the more common methods. Semi-finish hobs leave stock on the tooth form to be removed by the finishing tool. The stock remaining must be of a minimum and uniform amount; therefore, semi-finishing hobs must have the same accuracy as finishing tools. Hobs of ground accuracy are frequently used as semi-finishing hobs. This is especially true if multiple-thread hobs are used, because thread-to-thread inaccuracies in unground tools can deteriorate part quality.

The finishing operation can be performed on parts in the soft green state or can be performed after hardening the parts. Shaving and rolling are soft gear finishing methods, while grinding and skiving are used on hard gears.

Rough Hobbing. A rough hobbing operation is intended to remove metal stock quickly without concern for the final part tolerances. A second hobbing operation is always required. Roughing hobs are used on coarse pitch gears where a relatively large amount of metal removal is necessary. Roughing hobs are designed to remove metal faster with less tool wear and less machine strain. Higher production rates are obtained with lower overall tool cost.

Design Features

Topping. Topping hobs cut the outside diameter of the part to finish size (Fig. 4). The outside diameter is held concentric to the pitch diameter. The resulting tooth thickness is held to a constant relation to the outside diameter. The tooth thickness of the gears can be easily verified by measuring the outside diameter of the part. The use of topping hobs can often result in a cost savings for the user. Finish-hobbed gears can be chucked on the outside diameter in subsequent operations for hole finishing. Their use also eliminates the need for an accurate finish-turning operation on the gear blank prior to hobbing.

Semi-Topping. Semi-topping hobs have a ramp near the bottom of the hob tooth to provide a chamfer on the part tooth (Fig. 5). The purpose of this chamfer is to reduce the

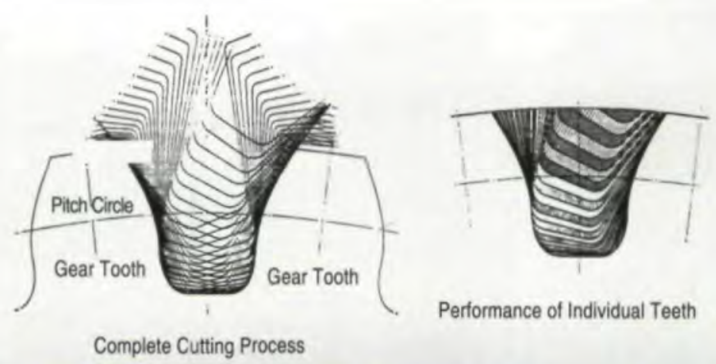

Fig. 2 — A) Generating action of a hob in cutting the profiles of gear teeth. B) Performance of an individual hob tooth.

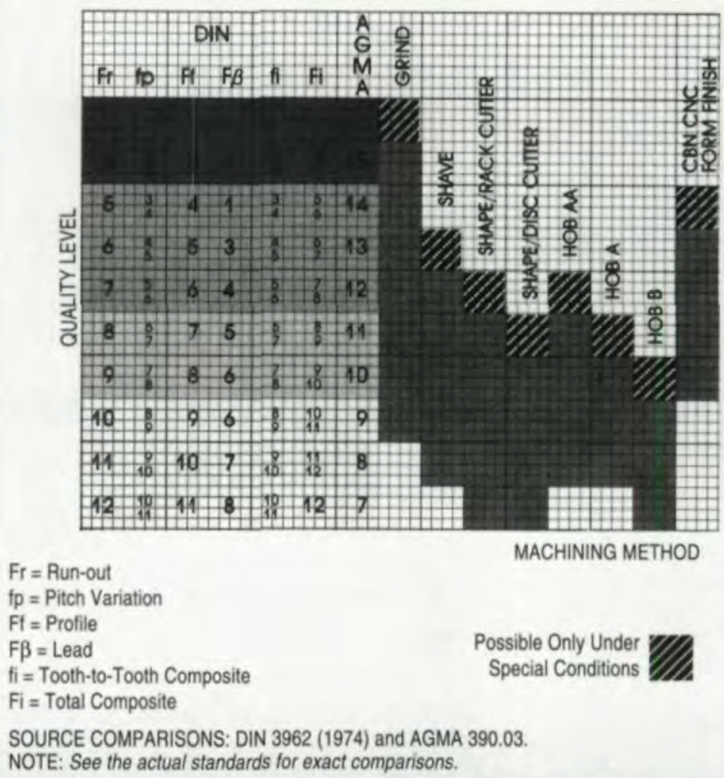

Fig. 3 — Obtainable gear qualities by machining methods.

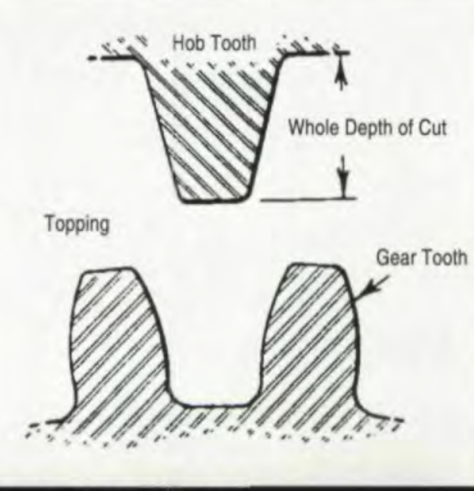

Fig. 4 — Topping hob.

Keith Liston

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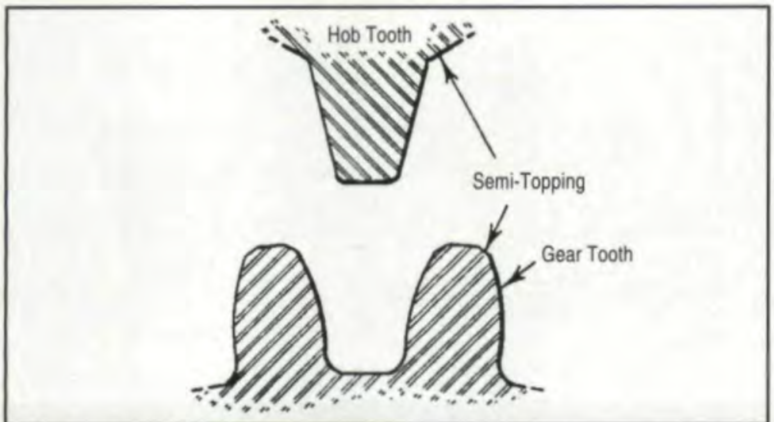

Fig. 5 — Semi-topping hob.

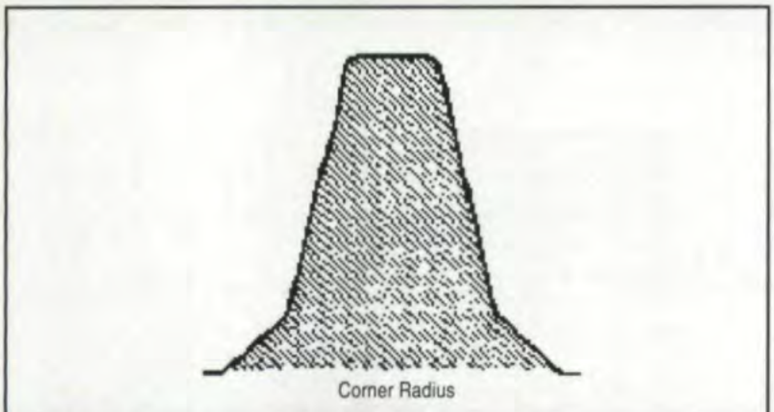

Fig. 6 — Corner radius hob tooth.

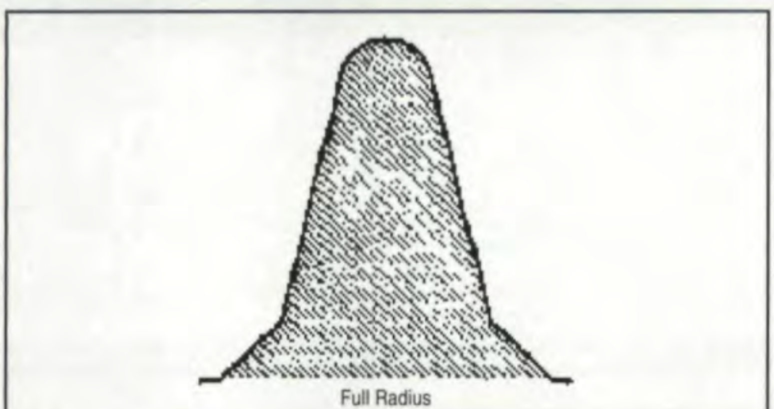

Fig. 7 — Full radius hob tooth.

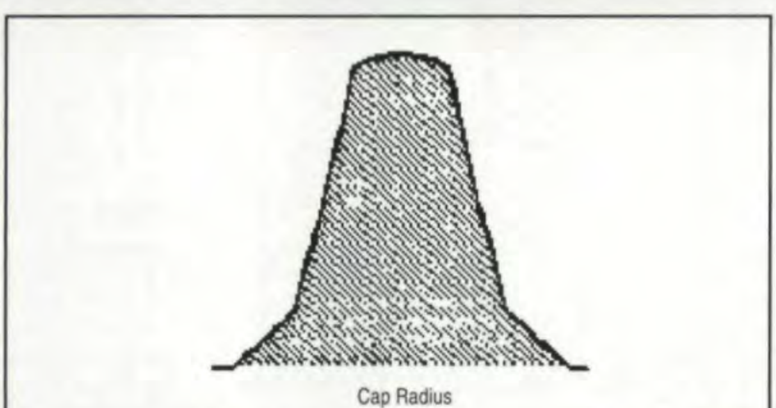

Fig. 8 — Cap radius hob tooth.

possibility of nicks on the involute profile when large numbers of gears are being handled. In addition, deburring operations are often eliminated or reduced because the burr is thrown away from the involute profile. The form of a semi-topping modification will vary with the number of teeth in the gear, just as the width of the top of the gear tooth varies.

Radius. The tops of hob teeth are designed with radii to help reduce the tip wear while providing greater strength to the gear teeth. The size of the radius is often dictated by the true involute form (T.I.F.) diameter and the root diameter. A standard finishing gear hob is designed with corner radii which are equal to 1/10 the tooth thickness. Semi-finishing hobs are usually given larger radii than finishing hobs. The deeper form is better able to accommodate a larger radius without violating the T.I.F. diameter.

Three types of radii are shown in Figs. 6-8. The corner radius (Fig. 6) is the most common type used on all standard hobs. The full radius (Fig. 7) provides the best wear characteristics, but is less likely to adhere to the root diameter and T.I.F. diameter constraints. The full cap radius (Fig. 8) is the poorest overall design because of its tendency to wear at the intersection points. This last option is only used when all other possibilities have failed.

Keep in mind that a true radius on a hob tooth does not generate a single radius in the gear fillet. Rather, a trochoid is produced. A trochoid is best described as a series of connecting fillet radii.

Hob Accuracies

Classes of Hob. Hobs are available in 5 different accuracy classes as follows:

- AA - Ultra Precision Ground
- A - Precision Ground
- B - Commercial Ground
- C - Accurate Unground
- D - Commercial Unground

The tolerances for classes A-D have been established by the Metal Cutting Tool Institute. Class AA tolerances were established by the Barber-Colman Company. The tolerances associated with these 5 classes are presented in Fig 9.

(Continued on p. 52.)

Fig. 9 – Single-Thread and Multi-Thread Gear Hob Tolerances
(All readings in tenths of a thousandth of an inch.)

Diametral Pitch		1 thru 1.999	2 thru 2.999	3 thru 3.999	4 thru 4.999	5 thru 5.999	6 thru 8.999	9 thru 12.999	13 thru 19.999	20 thru 29.999	30 thru 50.999	51 and finer
Run-out (1-4 Thread)	**Class**											
Hub Face*	AA			2	2	2	1	1	1	1	1	1
	A	8	5	2	2	2	2	2	2	2	2	2
	B	10	8	4	4	3	3	2	2	2	2	
	C	10	8	4	4	3	3	2	2	2	2	2
	D	10	8	5	5	4	4	3	3	3	3	
Hub Diameter*	AA			2	2	2	1	1	1	1	1	1
	A	10	5	4	3	3	3	2	2	2	2	2
	B	12	8	6	5	4	4	3	2	2	2	
	C	12	8	6	5	4	4	3	2	2	2	2
	D	15	10	8	8	6	6	6	5	4	3	
Outside Diameter*	AA			5	4	3	3	3	3	2	2	2
	A	30	20	15	15	10	10	10	10	10	7	5
	B	40	30	25	20	15	15	15	10	10	7	
	C	50	45	40	25	20	17	17	12	12	10	8
	D	60	55	50	45	35	35	30	25	20	15	
Lead Variation												
Tooth to Tooth* 1 Thread	AA			4	3	2	1.7	1.7	1.7	1.7	1.5	1.5
	A	7	5	4	3	2	2	2	2	2	2	2
	B	10	8	6	4	3	3	3	3	3	2	
	C	15	12	8	6	5	4	4	4	4	3	3
	D	25	20	16	14	12	10	10	8	6	5	
2 Thread	A	8	6	5	4	3	3	3	3	2	2	2
	B	12	10	7	6	5	5	5	4	3	2	
	C	18	14	10	9	7	6	6	5	5	3	3
	D	27	22	18	16	14	12	11	9	8	6	
3 Thread	A	9	7	6	4	4	4	3	3	3	2	2
	B	14	12	8	7	6	6	5	5	4	3	
	C	21	16	12	10	8	7	6	5	5	4	3
	D	29	24	20	18	16	14	12	10	9	7	
4 Thread	A	10	7	6	5	4	4	4	3	3	3	2
	B	16	13	9	8	7	6	6	5	4	4	
	C	24	18	13	11	9	7	7	6	5	4	4
	D	31	26	22	20	18	16	13	11	10	8	
Any One Axial Pitch* 1 Thread	AA			8	6	4	3	3	2	2	1.5	1.5
	A	25	18	10	8	6	5	5	4	4	3	3
	B	35	25	17	11	9	7	7	6	6	4	
	C	45	35	22	14	11	9	9	8	8	8	6
	D	60	50	40	30	25	20	20	18	16	14	
2-4 Thread	A	25	20	10	8	6	5	5	4	4	3	3
	B	35	30	17	12	10	8	8	7	7	4	
	C	45	35	22	18	15	12	12	10	10	8	6
	D	60	50	40	30	25	20	20	18	16	14	
Any Three Axial Pitches* 1 Thread	AA			12	9	6	5	5	4	4	3	3
	A	38	26	15	12	9	8	8	7	7	5	5
	B	53	38	22	16	12	11	10	9	9	7	
	C	70	50	30	21	16	14	13	12	12	12	8
	D	120	100	80	60	50	40	35	25	20	16	

(Continued Next Page)

Fig. 9 (cont.) – Single-Thread and Multi-Thread Gear Hob Tolerances (All readings in tenths of a thousandth of an inch.)												
Diametral Pitch		1 thru 1.999	2 thru 2.999	3 thru 3.999	4 thru 4.999	5 thru 5.999	6 thru 8.999	9 thru 12.999	13 thru 19.999	20 thru 29.999	30 thru 50.999	51 and finer
Lead Variation (con't.)												
Any Three Axial Pitches* 2-4 Thread	A	38	30	15	12	9	8	8	7	7	5	5
	B	53	38	22	20	15	12	12	10	10	7	
	C	70	50	30	28	20	18	16	14	14	12	8
	D	120	100	80	60	50	40	35	25	22	18	
Adjacent Thread to Thread Spacing* 2 Thread	A	11	9	8	7	6	5	4	3	3	3	3
	B	14	12	11	10	9	8	6	5	5	5	
	C	20	17	15	13	11	10	9	8	7	6	5
	D	26	22	19	17	15	13	12	11	10	9	
3 Thread	A	13	11	10	8	7	6	5	4	4	4	3
	B	16	14	12	11	10	9	7	7	6	6	
	C	22	19	16	14	13	11	10	9	8	7	6
	D	28	24	20	18	16	15	13	12	11	10	
4 Thread	A	15	13	12	9	8	7	6	5	4	4	3
	B	18	16	14	12	11	10	8	7	7	6	
	C	24	21	18	15	14	12	11	10	9	8	7
	D	30	26	22	20	18	16	14	13	12	11	
Tooth Profile												
Pressure Angle or Profile* 1 Thread	AA			2	2	1.7	1.7	1.7	1.7	1.7	1.5	1.5
	A	10	5	3	3	2	2	2	2	2	2	2
	B	16	8	5	5	4	3	3	3	3	2	
	C	25	15	10	5	4	3	3	3	3	3	3
	D	80	55	30	18	12	8	8	6	5	4	
2 Thread	A	12	7	5	4	3	3	2	2	2	2	2
	B	18	10	7	5	5	4	3	3	3	2	
	C	27	16	11	7	5	4	3	3	3	3	3
	D	80	55	30	18	12	8	8	7	6	5	
3-4 Thread	A	15	8	5	4	3	3	3	2	2	2	2
	B	20	10	7	5	5	4	4	3	3	2	
	C	27	16	11	7	5	4	4	3	3	3	3
	D	80	55	30	18	12	8	8	7	6	5	
Start of Approach (Plus or Minus) 1 Thread	AA			100	80	70	60	60	40	40	30	
	A	200	180	160	140	120	100	80	60	40	30	
	B	220	200	180	160	140	120	100	80	50	40	
	C	220	200	180	160	140	120	100	80	60	50	
	D	260	240	220	200	180	160	140	120	100	80	
2-4 Thread	A	200	180	160	140	120	100	80	60	50	40	
	B	220	200	180	160	140	120	100	80	60	50	
	C	220	200	180	160	140	120	100	80	60	50	
	D	260	240	220	200	180	160	140	120	100	80	
Symmetry of Approach* 1 Thread	AA			70	60	50	40	40	25	25	25	
	A	150	130	120	100	90	80	60	50	35	25	
	B	180	150	130	120	100	90	80	70	45	35	
	C	180	150	130	120	100	90	80	70	55	45	
	D	200	180	160	140	120	110	100	90	80	60	
2-4 Thread	A	150	130	120	100	90	80	60	50	40	30	
	B	180	150	130	120	100	90	80	70	60	50	
	C	180	150	130	120	100	90	80	70	60	50	
	D	200	180	160	140	120	110	100	90	80	60	

(Continued Next Page)

Fig. 9 (cont.) – Single-Thread and Multi-Thread Gear Hob Tolerances
(All readings in tenths of a thousandth of an inch.)

Diametral Pitch	Class	1 thru 1.999	2 thru 2.999	3 thru 3.999	4 thru 4.999	5 thru 5.999	6 thru 8.999	9 thru 12.999	13 thru 19.999	20 thru 29.999	30 thru 50.999	51 and finer
Tooth Profile (con't.)	**Class**											
Tooth Thickness (Minus Only) 1-4 Thread	AA			15	15	10	10	10	10	10	5	5
	A	30	20	15	15	10	10	10	10	10	5	5
	B	30	20	15	15	10	10	10	10	10	5	
	C	35	25	20	20	15	15	15	15	15	10	10
	D	40	35	30	25	20	20	20	20	20	15	
Sharpening (1-4 Thread.)												
Spacing Between Adjacent Flutes*	AA			20	15	10	8	8	6	6	6	6
	A	40	30	25	20	15	10	10	10	10	10	10
	B	50	45	40	30	20	15	15	10	10	10	
	C	50	45	40	30	20	15	15	10	10	10	10
	D	60	60	50	50	30	25	25	20	17	17	
Spacing Between Non-Adjacent Flutes*	AA			40	35	25	15	15	15	15	15	15
	A	80	60	50	40	30	30	30	25	25	20	20
	B	100	90	80	60	50	50	50	40	35	30	
	C	100	90	80	60	50	50	50	40	35	30	30
	D	120	120	100	100	80	80	70	60	50	40	
Cutting Faces Radial To Cutting Depth*	AA			10	8	6	5	5	3	3	3	3
	A	30	15	10	8	6	5	5	3	3	3	3
	B	50	25	15	10	8	7	7	5	5	5	
	C	50	25	15	10	8	7	7	5	5	5	5
	D	100	75	50	40	30	20	20	15	15	10	

Accuracy of Flutes, Straight And Helical*	Class	Face Width: 0-1"	1"-2"	2"-4"	4"-7"	7" & up
	AA	8	10	15	20	20
	A	10	15	25	30	50
	B	10	15	25	30	50
	C	10	15	25	30	50
	D	15	23	38	45	75

Bore (1-4 Thread.)

Diameter, Stright Bore (Plus Only)	Class	Bore Diameter: 2.500"	2.000"	1.500"	1.250"	.750"	.500" & smaller
	AA				2	2	2
	A	8	8	5	2	2	2
	B	10	10	8	3	2	2
	C	10	10	8	3	2	2
	D	10	10	8	5	4	3

Percent of Bearing Contact, Straight Bore	Class	All Diameters — Length
	AA	75
	A	75
	B	75
	C	60
	D	50

Percent of Bearing Contact, Taper Bore	Class	All Tapers — Circumference	Length
	AA	95	75
	A	90	60
	B	90	60
	C	90	60

*Total indicator variation.
Class AA Ultra Precision Hobs are made single thread only.
Tolerances apply only to standard or recommended hob diameters.

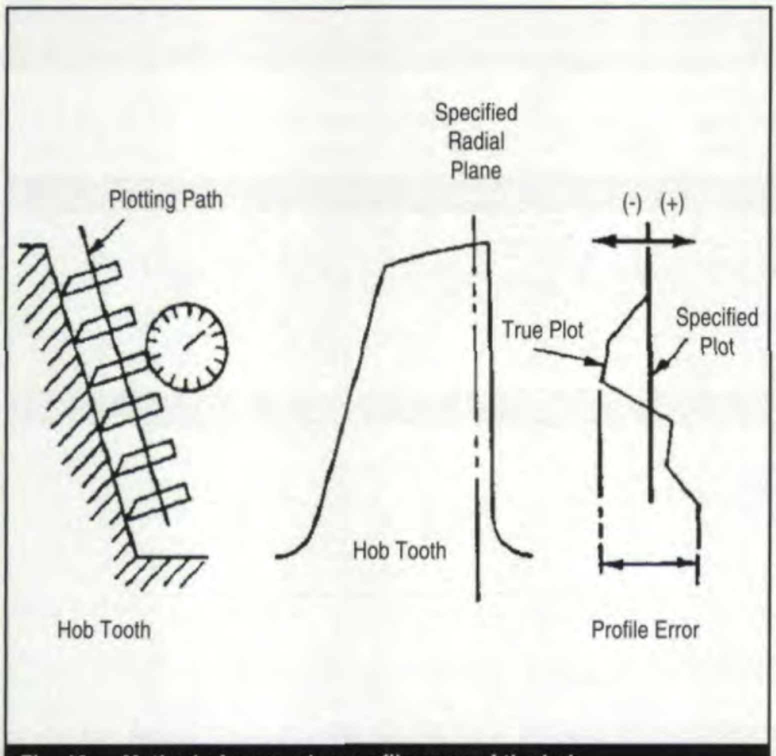

Fig. 10 — Method of measuring profile error of the hob.

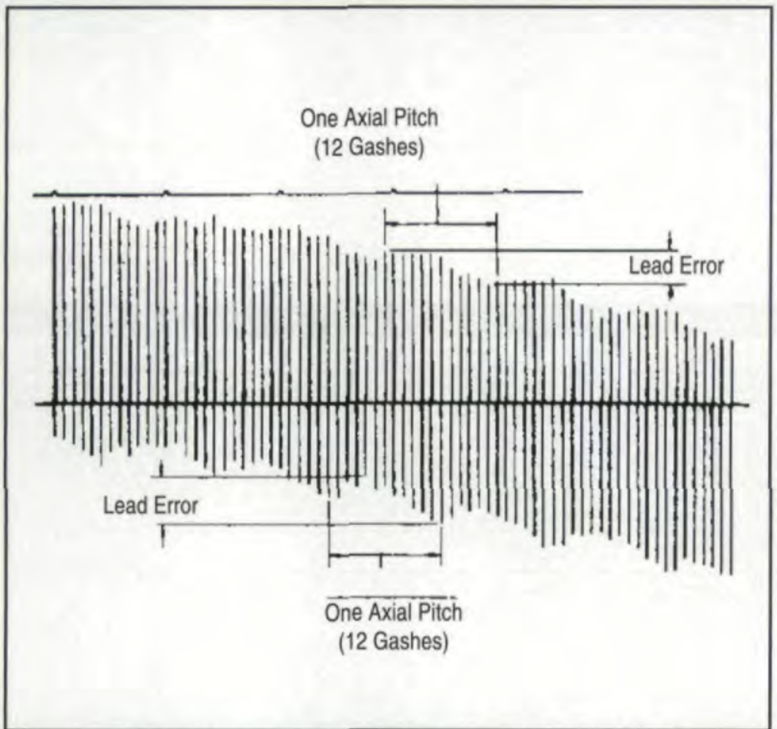

Fig. 11 — Hob lead chart measuring lead error in one axial pitch.

(Continued from p. 48.)

Hob Accuracy vs. Gear Accuracy. Hob accuracy has a direct relationship to the quality of the gears produced. It is generally accepted that the gear errors attributable to hob inaccuracies are the gear profile errors, and that gear profile errors are equal to the sum of the hob profile error and the hob lead error in one axial pitch. It should be noted that hob lead error is a composite of several elements.

Hob Profile Error. Pressure angle or profile error is the departure of the actual tooth profile from the correct tooth profile. The actual hob profile is allowed to vary from the specified hob profile entirely in the plus direction, entirely in the minus direction or split and divided in any ratio, provided the total deviation does not exceed the specified value. This maximum value can occur anywhere along the hob profile, and the variation of the profile on one side of the thread has no relationship to the variation on the other side of that same thread. The profile of either side can vary to the maximum positive or negative values independently. However, both must be within the specified tolerance. Fig. 10 is an illustration of the manner in which the hob profile error is measured by plotting. Hob tooth profile error is reproduced directly in the gear tooth profile.

Lead Error. Hob lead error (mispositioning of hob teeth along the thread) has varying effects. Tooth-to-tooth error produces small form or finish irregularities in a relatively localized spot. A hob lead error encompassing a whole axial pitch or more will change the gear tooth profile along the whole flank of the tooth from tip to root.

Lead error in one axial pitch is the maximum deviation from the theoretical thread helix in any group of hob teeth equal to the number of hob teeth in one axial pitch. This number of hob teeth may be selected anywhere in the length of the hob and is equal to the number of hob gashes divided by the number of threads. Fig. 11 illustrates the reading of the hob lead error in one axial pitch.

Part 2 of this article will appear in the next issue. It will cover sharpening errors and finish hob design considerations. ■

References:

1. American Pfauter, L. P. *Gear Process Dynamics*, Malloy Lithography, Inc. 1985.
2. Barber Colman Company. *Hob Handbook*, Rockford, IL, 1954.

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OOPS!
In our last issue, we omitted the credit line on the article, "CNC Bevel Gear Generators and Flared Cup Gear Grinding," by Theodore J. Krenzer, Director of Gear Theory at the Gleason Works, Rochester, NY. We regret any inconvenience to our readers.

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PUBLISHER'S PAGE

It's Still the Economy, Stupid!

(Continued from p. 7.)

more than one takes in indefinitely, and we have to stop pretending that the government can play by a different set of rules. We have to come to the collective realization that we will all have to take a hit on this one in order to get our economic house in order. We have to let our representatives know that we mean business about this, and that we expect them to mean it as well.

I have avoided using numbers in this editorial to describe the deficit. Frankly, I don't know what a trillion *really* means, much less four, five or six of them. I don't know if anyone else does either. Throwing such numbers around generates far more heat than light.

But I think I can sketch a picture of what our failure to get a handle on the deficit will mean — is already beginning to mean — for this country.

Over the last few weeks, like most of the rest of the country, I have watched with fascination, awe and horror the devastation that the flooding Mississippi and Missouri Rivers have brought to the Midwest. We have seen the very best that America is in these news clips: the courage, determination, charity and grit of its citizens in the face of what seems like overwhelming disaster, summed up by a dentist from somewhere in Iowa whose own home and business were safe, explaining why he was working to save yet another levee: "When your neighbors are in trouble, you help out. That's what neighbors do."

But a dark shadow looms over this bright picture, a shadow I fear will grow larger as time goes on. Agricultural and economic experts are trying to estimate the impact this devastation will have on a weak economy. (Summary answer: not a good one.) And we are already hearing the somber warnings from Washington that, given the deficit, the government will not be able to help as much as it would like to or even as much as it should.

Here is what the deficit is *really* costing us: our ability to respond to national emergency and to support the best instincts of our national character. This flood relief is not a pork barrel program. The people and cities behind the sandbags are not lazy welfare cheats, rich fat cats, PACs or the other villains on whom we usually blame our spending troubles. They're ordinary citizens just like us who, reasonably enough, look to the government for help to do what individually it is impossible for them to do themselves.

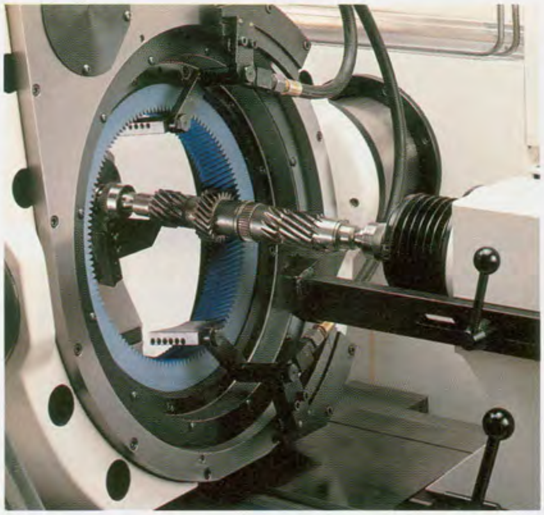
We as a nation want to help, and surely we will. But we have to know that the money we use to help will be borrowed money. As a nation we have saved nothing for this very rainy day.

And the Flood of '93 is only the beginning: There will be other natural disasters requiring attention. Sooner or later another international crisis will arise to which we will have the political and moral obligation to respond. Our allies will expect it of us, and we will expect it of ourselves.

Only we won't be able to because the national debt is like some evil growth, sapping our energy, will and the best part of our character.

The common warning about the deficit is that we are spending our children's and our grandchildren's inheritance. True enough. But we are also in danger of spending our collective ability to be the kind of people and the kind of nation we wish to be. That's what the debt is beginning to cost us, and that is the price we should all be unwilling to pay.

Michael Goldstein,
Editor-in-Chief

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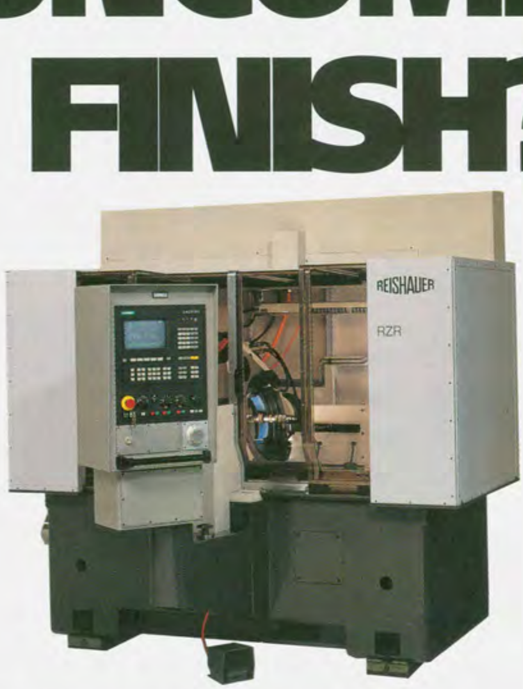
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