GEAR TECHNOLOGY

THE JOURNAL OF GEAR MANUFACTURING

JULY/AUGUST 1994

IMTS PRE-SHOW ISSUE

EFFECT OF EXTENDED TOOTH CONTACT ON THE MODELING OF SPUR GEAR TRANSMISSIONS

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EVERY REASON IN THE WORLD TO GO

IMTS 94, the Association for Manufacturing Technology's biennial machine tool extravaganza opens September 7 at McCormick Place in Chicago. As always, the size of this show is astonishing. Over 100,000 visitors, enough to populate a medium-sized town, will converge on Chicago's lakefront to visit more than 1,200 exhibits spread over the entire McCormick Place complex.

IMTS is a major marketplace. On-site sales at the 1992 show reached $407 million, and the majority of visitors at IMTS 94 are expected to be decision-makers ready and able to buy. Exhibitors have come prepared to do business, and the show, with the latest equipment on display, is a good place to research your next purchase and, perhaps, close a deal.

Business in many areas of the manufacturing sector seems to be picking up. You may wish to consider making the upgrades in your equipment that you put off during leaner times. There are few places besides IMTS where you will find more of the latest equipment and information all gathered in one place. In this issue we have included some suggestions to help you maximize your returns from visiting the show. A carefully planned fact-finding trip can save both time and money.

Gear Technology will be at IMTS for the first time this year. We are looking forward to meeting and talking with you, about your interests and concerns regarding our industry. Drop by at Booth N2-7193 (on the same floor with most of the gear manufacturing equipment exhibitors) and say "hello."

PUBLISHER'S PAGE

Information has never been more important to success in manufacturing than it is today. The people who know the most about what's happening in their industry are in the best position to prosper. IMTS is a great place to gather some of that information.

See you at the show . . .

Michael Goldstein,

Editor-in-Chief

IMTS – Big Trade Show for the CITY OF BIG SHOULDERS

The biggest industrial trade show in the world this year—and the manufacturing machinery industry's most important marketplace—will be at McCormick Place in Chicago September 7-15.

The Association for Manufacturing Technology, the sponsor of IMTS 94, expects more than 1,000 exhibitors and more than 100,000 visitors at the biennial event. All of McCormick Place, nearly one million square feet, will be turned into "a factory of the future" for the nine days. Visitors from all over the world will walk the aisles, reviewing billions of dollars' worth of cutting-edge technologies.

The following *Gear Technology* advertisers will be showing a wide variety of the latest equipment and processes at their booths.

American Pfauter Limited Partnership of Loves Park, IL (Booth E3-4700) will feature the PE150C hobbing machine, the PSA300 shaping machine, the PHS254 hob sharpener, the Pfauter Mikron A15 gear hobbing machine, the CTX twin spindle machine, the GM16AC automatic lathe, the GLD20 sliding head automatic, the GAC65, the Hessapp DVH25 vertical turning machine, the Kapp VAC61 and GAS51 grinding machines, along with Pfauter-Maag cutting tools.

Bourn & Koch Machine Tool Company, Rockford, IL (Booth E2-2003) will feature the CBN gear grinder, a remanufactured Cincinnati 12C slant bed lathe with a NUM CNC Plus control and a multitude of other manufacturing solutions.

Fellows Corporation, Springfield, VT (Booth N2-7182). Fellows Corporation, J&L Metrology and Bryant Grinder Corporation are featuring advanced technology at the VT USA booth. Stop by our booth for the latest gear shaping machinery, gear cutting tools and CNC optical comparators with internal edge sensing. See the new Bryant Ultraline UL2 high-speed precision bore grinder.

Fette Tool Systems Inc., Brookfield, WI (Booth N2-6503) will feature Fette cobalt roughing and finishing end mills for end and center cutting, profiling and pocket milling. Also, they will have carbide indexable tools, including Univex and Twincut developments, heavy duty roughing and finishing hobs, hobs with interchangeable segments and thread rolling axial, radial and tangential heads for faster output than thread cutting.

The Gleason Works, Rochester, NY (Booth N2-6921) will demonstrate the latest CNC hobbing, gear grinding and honing machines, as well as CNC gear cutting, lapping and chamfering/deburring machines, plus innovative tooling and workholding. Come see 15-second hob changes, totally automatic dressing and grinding and more. Complete gear processing technology for spur, helical, bevel or hypoid gears.

GMI, Independence, OH (Booth N1-5228) will display the GFB-250/CNC-5 five-axis hard gear finishing machine, with new features to satisfy the requirements of gear manufacturers for super-fine surface finishes on gears.

Inductoheat Inc., Madison Heights, MI (Booth N2-6455) will feature an interactive, multi-media display system showcasing a wide variety of our induction heating capabilities, including standard and custom equipment and power supplies for heat treating, hardening, tempering, brazing, annealing and more. Our flexible, self-contained statiscan for vertically scan-hardening a wide variety of parts will also be on display.

Kanzaki Kokyukoki Manufacturing Co., Ltd., Amagaski, Hyogo, Japan (Booth N1-5228) will display the GFB-250/CNC-5 five-axis hard gear finishing machine, with new features to satisfy the requirements of gear manufacturers for super-fine surface finishes on gears.

Liebherr, Saline, MI (Booth N2-6953) will feature the revolutionary LC82 CNC gear hobbing machine from Liebherr, designed for dry cutting at high speeds. Also on display at the booth will be a Klingelnberg gear inspection station, a Lorenz gear shaper, an LS154 CNC and Oerlikon equipment.

Mitsubishi Machine Tool USA Inc., Itasca, IL (Booth E3-4299) will be introducing their new CNC gear grinding machine. It uses either CBN or vitrified wheel technology along with optional dressing capability. Also, they will display their new GC20 CNC gear hobber with state-of-the-art automation and carbide cutting.

Pfauter-Maag Cutting Tools, Loves Park, IL (Booth E3-4700) will display its line of hobs (including the Wafer Hob and Opti-Gash Hob), shaper cutters (including the Wafer Shaper Cutter), milling cutters and shaving cutters.

Sala & BLM Corp., Elk Grove Village, IL (Booth N2-6782) will feature CNC tube bending and endforming equipment; tube loading, sawing and deburring systems; circular saws for solid steel and tubing; and high-speed saws for aluminum and plastic.

WMW Machinery Company, Inc., West Nyack, NY (Booth E3-4298). NILES Berlin, exclusively represented by WMW Machinery Company, Inc., will exhibit the new Profile gear grinder. Its two independent CNC-controlled grinding wheel slides, menu-driven CNC control and integrated software guarantee highest productivity. For additional information, please visit WMW Booth E3-4298. ■

IMTS EXHIBITOR INDEX

(as of May 27, 1994)

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Booth N2-6782

WMW Machinery Co., Inc.
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(914) 358-3330
Fax (914) 358-2378
Booth E3-4298

Making the Most of Your Trade Show Visit: Avoid These 18 Common Mistakes

Phillip M. Perry

Going to IMTS? Beware. It's easy to make any number of common mistakes that can turn your productive buying trip into an expensive bomb.

"Attending a trade show is an investment in time," says Steve Miller, who runs a consulting firm called Adventure of Trade Shows in Federal Way, WA. "And time is the currency of the 1990s."

How true. Given the business opportunities you forgo to attend the show, the hours you spend navigating the aisles can be more expensive than the actual cash outlay for flight and hotel room.

So how can you get a solid return on all this investment in time and money? Seven trade show consultants pinpoint the most common errors made by trade show visitors — then tell you how to avoid making them.

Phillip M. Perry
is a New York-based writer specializing in business management and law. His business articles have appeared in publications such as World Trade *and* International Business. *He is the former computer and finance editor of a major industry newspaper.*

1. ***Neglecting advance planning.*** "I would really stress the importance of preparing for your visit far in advance," says Richard J. Brunken, president of Human Resources Development, Milwaukee, WI.

Indeed, most consultants cite the lack of sufficient advance planning as the number one reason why trade show visitors spin their wheels. They advise marking your calendar a month prior to the trade show. That's when you should start thinking about two things: your goals for attending the show and your strategy for reaching those goals.

2. ***Defining goals that are too general.*** When deciding what you want from the show, avoid general statements such as "seeing what's new" or "seeing our suppliers." If you don't set specific goals, the show may end with you feeling as though you failed to accomplish all you could.

Steve Miller suggests a better way: "Ask yourself what is the biggest problem you have in your business. Write this down in the form of a question. Then take this question to the show with the idea of getting answers from the staffers in the booths."

For example, how can I get greater cutting accuracy and longer tool life? Who offers the highest productivity with the lowest per piece cost? From which manufacturer can I get the best support and customer service?

One question or a series of similar questions will keep you focused on what you really need to accomplish at the show.

3. ***Not developing a strategy to reach goals.*** You may fail to reach your goals because you did not plot a detailed strategy. "Define a game plan so all your steps are laid out before you arrive at the show," says JoAnn R. Hines, who attends close to 20 shows every year as president of the consulting firm of Hines & Associates, Ackworth, GA.

The steps in the strategy should result in achieving your stated goals. Example: See *x* number of vendors to find the best sources for a specific product or type of equipment.

Part of a successful strategy is to allocate tasks among coworkers who will be attending the show. Do this early enough to avoid the duplication of effort that would otherwise result when different people plan to accomplish the same goals.

4. ***Failing to get a floor plan and booth directory in advance.*** Most shows have floor plans that list booths numerically and directories that list exhibitors alphabetically. Well in advance of the show, ask the managing company to send you both.

"Cross-reference the directory with the floor plan to lay out a walking plan which maximizes the time you spend at the show," says Hines. The savings in hours will ensure that you reach your goals. "Most people just turn to the right and go down the aisle to start the show," says Hines.

And what if an advance copy of the directory is not available? "Many shows that don't send out directories will send you their exhibitor registration lists," advises Hines.

Industry trade publications will usually include advance directory and booth information (see p. 9).

5. *Not prioritizing sections of the floor plan.* Try to estimate how many booths you will be able to visit during the time you have at the show. "The average attendee spends about 13 minutes at each exhibit targeted for a visit," says Brett Fisher, marketing manager of the Trade Show Bureau, a Denver, CO, association that studies the industry. He adds: "To that you must add your walking time, eating, resting and the chance encounters with peers."

Considering that slack time, figure you can visit maybe three booths each hour. These are booths run by exhibitors you specifically want to see, not unknown booths where you stop for quick looks while walking up and down the aisles.

Okay. That comes to 18 booths in a six-hour period. Select these booths as your "Priority 1" selections and mark them with a green marker. Write general guidelines for seeing *x* number of these booths per hour. You want to see these exhibitors without fail.

Select a number of "Priority 2" booths and mark them with yellow. You see these booths during slack time between the green booths. Then use a red marker for the new vendors in whose products you might be interested and for those whom you'd like to see if the opportunity arises.

Now you have a visual aid for walking the floor. You can check off the booths as you see them and monitor your progress in getting through your top priority stops.

6. *Making too many appointments.* Don't get carried away when you make appointments. Trying to squeeze too many in one day can actually make you less effective on the floor. That's because you can easily fall behind and start rushing from one appointment to another before you have all the information you intend to gather.

"Rather than setting definite appointment times, I suggest you tell the booth staffers you will drop by during certain windows of time," says Hines. "Say something like, 'I'll drop by between this and that time. . . .'" If the staffer is busy when you drop by, don't waste time hanging around. Leave word about the next window of time in which you'll drop by, then move on.

7. *Carrying too much.* Travel light. Hauling a briefcase and other unnecessary items can slow you down and tire you out, making you less effective in the booths. If possible, carry only what you need to take notes, along with your specific questions and your floor plan.

And don't weigh yourself down with lots of product literature from the booths. Take advantage of whatever facilities the show has to check your pile of literature. Some shows also have shipping services, even providing the cardboard boxes.

8. *Wearing the wrong shoes.* More of a problem than you might think, wearing the wrong shoes was universally cited as a damaging error that can erode productivity.

"Select a good walking shoe that has a compliant outsole," advises Steven I. Subotnick, a podiatrist in Hayward, CA. "That means that the sole is not hard leather, but is soft and rubber-like so that it absorbs shocks easily."

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You should also select a shoe that has arches that match your foot, especially if your arches are either unusually low or high. Better quality shoe stores have certified shoe fitters to advise you.

"Women should avoid pointed shoes," says Subotnick. "Their shoes should have leather that stretches over the toes and is not so firm that it will cause corns and callouses."

9. *Omitting an "early bird" visit.* If you visit the show building early in the morning prior to the official opening time, you will find lots of magazines and product literature waiting in bins. "Gather it up, pack it in a box, and check it before the show begins," says Hines. "Then it's out of the way." The show may also ship it to your office for you. You haven't missed anything, and you won't weigh yourself down with material nonessential to buying.

Some literature, such as the market publications, you can review right away. "Scan them to see if there are any interesting product announcements," advises Bob Donath, a trade show consultant in White Plains, NY. "If so, mark where the booths are and hit them at an appropriate time."

10. *Not previewing the show.* Schedule some time to "scope" the show before you start the walk that you have laid out. Walk the entire show floor quickly, looking for unexpected exhibitors or products. Take notes on what looks interesting. Then sit down and adjust your color-coded floor plan and walking path to include them.

11. *Following the crowd.* You are showing your independence from the mob by planning a productive trade show visit. Take that one step further: Walk the show in reverse. "You will get faster attention from the booth staffers if you walk against the traffic," says Donath. "Most visitors start in the front of the show and crowd the booths. If you start in the back, you will be talking with staffers who are not already crowded by other buyers. You will be able to cover a lot more booths right off the bat."

12. *Ignoring the newer booths/lines.* While you don't want to spend too much time at them, the smaller and newer booths can provide leads for new products that can make your visit even more successful. "You'll see lots of interesting products from exhibitors who are new to the show," says Donath. "These booths are great for generating ideas."

Don't make the mistake of ignoring them. The trick is to cover a lot of them fast. Get in and get out quickly, taking notes on new products you can use.

13. *Attending too many seminars.* Be judicious when attending workshops. Ask two questions: "Is the material covered by the workshop so unique that I cannot obtain it elsewhere?" and "Does the subject matter relate directly to my job and to why I have come to the show?"

A seminar on time management may be appealing to you, but you will likely answer "no" when you ask the two questions. Unless there is another compelling reason for you to attend the workshop (like your boss ordered you to), avoid it.

14. *Not steering the conversation at the booths.* "As the buyer, you are the one in control," says Robert F. Dallmeyer, president of R. D. International, a Los Angeles, CA, consulting firm. "Never forget that. Don't be afraid to exercise your control by steering the conversation at the booths."

That means interrupting a booth staffer who is waxing eloquent on some features of his product that don't concern you and navigating the conversation toward benefits that will help you make more money.

Here's where your goal questions really come in handy. Miller suggests writing the questions on several dozen 3 x 5 inch cards. When you get

IMTS Survival Guide

On September 7, the equivalent of a medium-sized town will be dropped on Chicago's lakefront. Finding your way around this small city will require more than strong legs and a good sense of direction. *Gear Technology* has assembled some basic information about IMTS to help you get the most from your show visit.

IMTS Basics

Show Dates: September 7-15

Location: McCormick Place, Chicago, IL

Hours: 9:00 a.m. to 5:00 p.m. except Sunday, Sept. 11, 10:00 a.m. to 4:00 p.m. and Wednesday, Sept. 15, 9:00 a.m. to 4:00 p.m.

Registration Information: Call 800-322-IMTS.

The Complete Traveler

Getting There from Here. Shuttle buses, taxis and the CTA all will have routes between McCormick Place, downtown Chicago and both O'Hare and Midway airports. Costs run from $1.50 for a CTA Rapid Transit ride from O'Hare to downtown to $28.00 for taxi service.

Shuttles will be leaving McCormick Place for O'Hare approximately every 30 minutes during the show. You may also reserve a ride from the show to and from Midway Airport.

Special bus service has also been arranged between McCormick Place and all official IMTS hotels. Discount passes are available. For more information, call 800-322-IMTS.

Phoning Home. Messages may be left at the Message Center on the mezzanine level of McCormick Place North. The number there is 312-808-2055. The exhibit halls have no paging facilities, and messages can only be checked and picked up at this location.

Full-service business centers are located in both the East and North buildings. They offer secretarial and postal services, photocopy machines, fax facilities and package handling. Souvenir and gift shops are located near both centers.

Meat and Drink. Levy Restaurants has several restaurants inside McCormick Place, featuring a variety of items from pizza and hot dogs to full-course dinners. Specialty carts selling tacos, oriental food and snacks will be located throughout the exhibition halls.

Cash Crop. An ATM Money Machine is located on Level 2 of McCormick Place East. Lakeside Bank is located at the corner of 22nd Street and King Drive, west of the North Building.

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Getting to the Good Stuff

Many, but not all, of the exhibitors of gear-related products and services will be located in either the Metal Forming & Fabricating Pavilion or the Tooling Systems Focus Area, both on the upper level of McCormick Place North.

To make sure you don't miss any exhibits of interest, use the Electronic Product Directory. Just insert your Expocard (part of your registration packet) in one of the computers located throughout McCormick Place, select the products of interest to you and get a printed list.

And to help you keep your bearings, the carpets in the exhibition hall are color-coded to indicate pavilion and focus area boundaries.

Hot Times

Over 100,000 visitors are expected at IMTS, but there are ways to keep ahead of the crowd. The first and last 90 minutes of each day at the show are less crowded than the rest of the time. "Slow" days are the opening and closing days and Saturday and Sunday.

Manufacturing '94

The Society of Manufacturing Engineers is cosponsoring and managing *Manufacturing '94—the Machining, Tooling and Fabricating Conference*, which will run concurrently with IMTS. Seminars will cover a wide variety of manufacturing subjects, including gear-related issues such as cutting tool materials, tool management, remanufacturing machine tools, EDM and lasers.

The conference will run from September 7–14. Hours are 8:30 a.m. to 2:30 p.m. Meetings will be held in McCormick Place North, Lower Level.

For more information, contact SME at 800-763-2734 or 313-271-1500.

to each booth, hand the cards to a rep and ask how the company's products can solve your problem. That narrows down the dialogue to basic matters pronto. If the staffer doesn't have an answer right away, say you'll return later for the information.

Alternatively, use a statement such as, "I need to make a business decision" to shift the booth staffer's pitch away from product features and toward your needs. Explain what the business decision is; then ask how the products at the booths can help you make that decision.

"If you find you know more about the products than the salesman does, move on quickly to another booth," says Human Resources Development's Richard Brunken. You may jot down the name of a better qualified person who is expected later.

"Also find a way of verifying what the staffers say the product can do," says Brunken. "Get the name of designers or other technical people whom you can call after the show."

15. *Writing sloppy notes.* Jotting notes on the back of business cards . . . in the margins of show directories . . . along the top of product literature sheets. . . . Show visitors can think of as many ways to confuse themselves later as there are blank spots on papers. Avoid them all. If you return home with a bunch of sloppy notes on all kinds of paper, you'll never get them organized enough to achieve the goals you set for the show.

"If you need to take a lot of notes, then a tape recorder is good," says JoAnn Hines of Hines & Associates. "If you want to jot down short personal responses to what you see, then use a small note pad that fits in your pocket."

16. *Not exploiting "slow" hours.* Every show has its hours when the aisles are as calm as a country pond at midnight, and the booth staffers stand around yawning and staring at each other like owls. "This is the best time to make appointments," says Adventure of Trade Shows' Steve Miller, "especially with your high-priority companies whom you really must see. Find out when the slow times are by calling ahead and asking the exhibitors or others who have attended the show."

Hines recommends Sunday as the least crowded day if the show starts that day. "A lot of buyers don't come in on Sunday, so you have more time to talk with the booth staffers," she says. "It's also a good time to scope out the show."

17. *Not monitoring promises to follow-up.* Don't let the exhibitor forget to contact you with requested information. According to Miller 80% of exhibitors fail to follow up as promised after the show has closed its doors. That means a lot of wasted time. You may never get the informa-

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tion that you need to make better buying decisions.

To solve the problem, Miller has developed what he calls a "buyers guide." This is a long vertical card roughly 4 x 8 inches. The buyers carry a couple of dozen such cards as they walk the show. At each booth they pull out a card and fill it in with answers that the representative gives to their questions.

Lines are included for information such as specific products or services seen, type, quantity and delivery terms. Way down at the bottom is a question: "What is the action step agreed to after the show?" Answers may include making a telephone call, a personal visit or sending literature.

Trade shows are busy times for exhibitors and visitors alike. With hundreds (or thousands) of people coming and going at each booth, it's easy for records to get lost in the shuffle. "By using such a card, you have a personal record of what the exhibitor promised to do," says Miller. Two weeks after the show, go through your cards and call anyone who did not follow up with whatever action or information you requested.

18. ***Not updating coworkers.*** Prepare a brief report for your coworkers. What are the trends you spotted? The applications you saw? The new products and technology introduced? "Your sharing will not only spread useful and enlightening information, but will reinforce your learning process as well," says Brett Fisher of the Trade Show Bureau.

In summary, to get the most from your visit to a trade show, think of it as a research project rather than a recreational browse through a shopping mall. Have clear goals in mind when you go, a clearly thought-out strategy for achieving those goals, and a specific plan for follow-up after the show is over. That is the best way to make your investment of time, money, and effort pay off. ■

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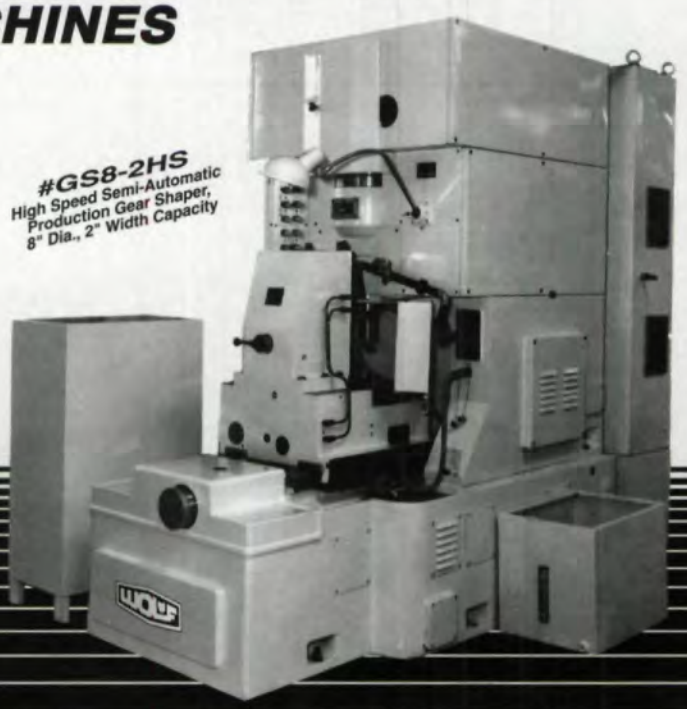

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Effect of Extended Tooth Contact on the Modeling of Spur Gear Transmissions

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Abstract

In some gear dynamic models, the effect of tooth flexibility is ignored when the model determines which pairs of teeth are in contact. Deflection of loaded teeth is not introduced until the equations of motion are solved. This means the zone of tooth contact and average tooth meshing stiffness are underestimated, and the individual tooth load is overstated, especially for heavily loaded gears.

This article compares the static transmission error and dynamic load of heavily loaded, low-contact-ratio spur gears when the effect of tooth flexibility has been considered and when it has been ignored. Neglecting the effect yields an underestimate of resonance speeds and an overestimate of the dynamic load.

Nomenclature

E_d	gear error due to tooth deflection, mm (in)
E_s	tooth spacing error, mm (in)
E_p	tooth profile error or profile modification, mm (in)
E_t	static transmission error of gear pair, mm (in)
K_g	stiffness of gear mesh, N/mm (lb/in)
Q^a, Q^b, Q^c	meshing compliance of tooth pairs *a*, *b* and *c*, mm/N (in/lb)
R_{a1}, R_{a2}	addendum radii of gear 1 and gear 2, mm (in)
R_{b1}, R_{b2}	base radii of gear 1 and gear 2, mm (in)
R_1, R_2	pitch radii of gear 1 and gear 2, mm (in)
S_a, S_r	separation distance in approach and recess, mm (in)
W	total static transmitted load, N (lb)
W^a, W^b, W^c	static transmitted load on tooth pairs *a*, *b*, and *c*, N (lb)
Δ_1	separation angle: rotation of gear 1 (gear 2 fixed), rad
Δ_2	separation angle: rotation of gear 2 (gear 1 fixed), rad
Subscripts:	
j	contact point of meshing tooth pair
1	driving gear
2	driven gear

Introduction

It is well known that the dynamics of gear systems can be influenced considerably by the stiffness of the meshing gear teeth (Refs. 1-5). A principal excitation for gear dynamics and vibration is the variation of this stiffness caused by teeth entering and leaving mesh. This stiffness variation is a primary cause of the time-varying component of static transmission error. The static transmission error is defined as relative displacement of the driving gear with respect to the driven gear along the line of action. The static transmission error also can be affected by gear errors such as tooth profile and spacing, runout, alignment and deflection under load.

An important task for developing a gear dynamic model is the determination of which pairs of teeth actually are in contact at any instant. In some models, the gear teeth are treated as rigid when contact conditions are determined (Refs. 3, 4, 6-9). However, in an actual transmission, the load-carrying teeth deform elastically. This causes the incoming tooth pair to enter contact earlier than the theoretical start of contact. Similarly, the loaded outgoing teeth will leave contact later than the theoretical end of contact. This extends the

tooth contact zone and increases the average mesh stiffness.

In this article the effect of extended tooth contact on heavily loaded spur gears is examined. The static transmission error and dynamic load were calculated for gears of moderate contact ratio (1.64) as well as for somewhat higher contact ratio (1.95). The calculated results were compared to evaluate the influence of extended tooth contact on the static and dynamic loads of a low-contact-ratio spur gear transmission. The findings may form the basis for improvements in the spur gear dynamic analysis code DANST (Dynamic ANalysis of Spur gear Transmissions).

Theory and Analysis

Two sets of low-contact-ratio gears were considered for an analytical study. The two sets are the same except for the tooth addendum, which was adjusted to provide contact ratios of 1.64 and 1.95. Parameters for the gears are given in Table 1. The analyses were performed using the NASA gear dynamic code DANST. The analytical procedures are described in the following sections.

Gear System Model

Fig. 1 shows a four-degree-of-freedom, lumped-mass model for a typical gear transmission. The model includes driving and driven gears, connecting shafts, motor and load. The equations of motion were derived from basic gear geometry and elementary vibration principles. The dynamic process is studied in the rotating plane of the gears, and gear tooth contact is assumed to be along the line of action. The model and differential equations of motion are described in more detail in Refs. 10 and 11.

Meshing Stiffness and Transmission Error (Neglecting Extended Tooth Contact)

To study the static transmission error and meshing stiffness of a low-contact-ratio gear system, we designate three consecutive tooth pairs — *a*, *b* and *c* — and begin our analysis at the moment in which pair *a* is carrying the entire load (single contact zone) and tooth pair *b* is just about to enter contact. The initial contact of tooth pair *b* occurs at the point where the addendum circle of the driven gear intersects the line of action. At this instant, double contact begins. As the gears rotate, the point of contact moves along the line of action. When

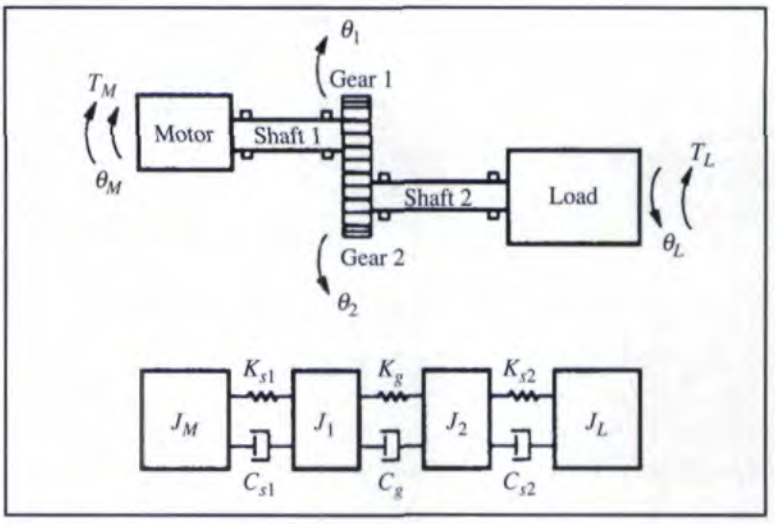

Fig. 1 — Gear transmission model.

tooth pair *b* reaches the theoretical point of transition between double and single contact, the leading tooth pair *a* disengages, leaving only pair *b* in single contact. When tooth pair *b* reaches the next theoretical transition point for single and double contact, tooth pair *c* comes into contact and begins to share the load (double contact); thus, the meshing action alternates between double and single contact zones as the gears rotate.

To investigate the effect of tooth flexibility on the zone of tooth contact, we will examine in detail the first double tooth contact zone (where tooth pairs *a* and *b* are in contact). With these two tooth pairs in contact, the static transmission error E_t and the shared tooth load W_j for each individual tooth pair at contact point *j* may be expressed as:

$$\left(E_t^a\right)_j = \left(E_{d1}^a\right)_j + \left(E_{d2}^a\right)_j + \left(E_{p1}^a\right)_j + \left(E_{p2}^a\right)_j \quad (1)$$

$$\left(E_t^b\right)_j = \left(E_{d1}^a\right)_j + \left(E_{d2}^b\right)_j + \left(E_{p1}^b\right)_j + \left(E_{p2}^b\right)_j + \left(E_{s1}^b\right)_j + \left(E_{s2}^b\right)_j \quad (2)$$

$$W = W_j^a + W_j^b \quad (3)$$

The tooth spacing errors above are determined with reference to tooth pair *a* (which is therefore assumed to have no spacing error). These spacing errors are due to manufacturing. The error terms are expressed as linear displacements along the line of action. The static transmission error E_t is the total relative displacement of the driven gear with respect to the driving gear along this line. As long as they are both in contact, the static transmission error of tooth pairs *a* and *b* must be the same. There-

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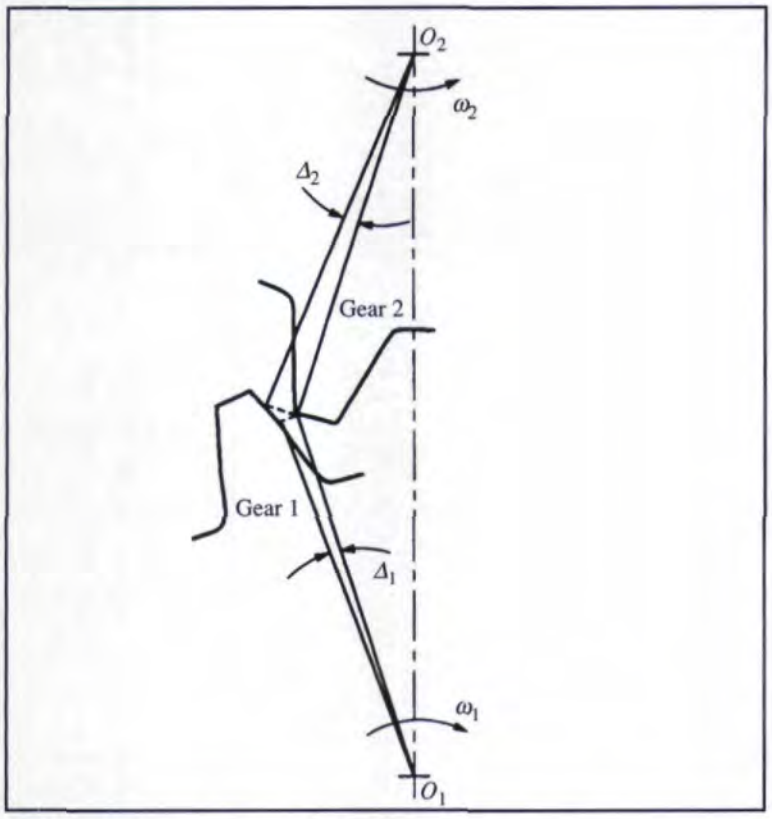


Fig. 2 — Separation angles of a tooth pair in approach.

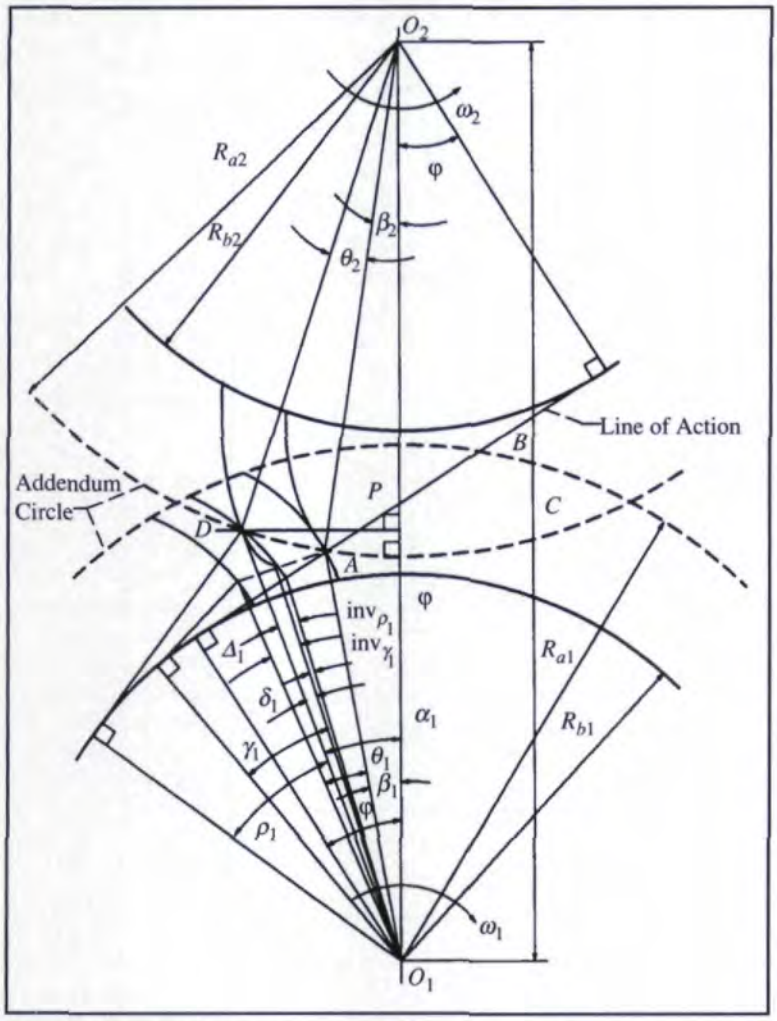


Fig. 3 — Separation distance calculation for a tooth pair in approach (gear 2 fixed).

fore, from Eqs. 1 – 3,

$$Q_j^a W_j^a + \left(E_p^a\right)_j = Q_j^b W_j^b + \left(E_p^b\right)_j + \left(E_s^b\right)_j \quad (4)$$

where

$$\left(E_s\right)_j = \left(E_{s1}\right)_j + \left(E_{s2}\right)_j \quad (5)$$

$$\left(E_p\right)_j = \left(E_{p1}\right)_j + \left(E_{p2}\right)_j \quad (6)$$

$$\left(E_d\right)_j = \left(E_{d1}\right)_j + \left(E_{d2}\right)_j = Q_j W_j \quad (7)$$

The gear meshing stiffness K_g at contact point j is then

$$\left(K_g\right)_j = \frac{W_j^a}{\left(E_t^a\right)_j} + \frac{W_j^b}{\left(E_t^b\right)_j} \quad (8)$$

In the analyses above and those to follow, the position of the contact point j on the gear teeth is expressed in terms of the roll angle of the driving gear tooth. In the single contact zone, the transmission error and meshing stiffness equations are much simpler and can be derived by similar procedures.

Gear Teeth Separation Distance

We define the tooth separation distance as the distance between a pair of teeth just out of contact during approach or recess if there is no elastic deformation. This distance, expressed along the line of action, is equal to the product of separation angle and base radius of the gear. The separation distance will be compared with the static transmission error to determine the contact condition.

To calculate the separation distance, we introduce the separation angle (exaggerated for clarity in Fig. 2) for a pair of teeth (pair *b*) in approach, where gear 1 represents the driving gear and gear 2 the driven gear. The separation angle is not the same for the two mating gears. If gear 1 is held stationary, the separation angle Δ_2 is the angular rotation required for gear 2 to close the gap between the teeth of pair *b*. Likewise, Δ_1 is the required rotation of gear 1 while gear 2 is held stationary. The actual tooth contact will start at a point where the separation angle of the incoming tooth pair is equal to the angular deflection of the preceding tooth pair(s).

The equations for the separation distance as a function of the separation angle can be

derived for a tooth pair in approach using Fig. 3. In Fig. 3, the driven gear (gear 2) is regarded as fixed. Point A represents the theoretical start of contact of a tooth pair, point B the theoretical end of contact, and point P the pitch point, when no load is applied. To find the separation angle Δ_1, the two gears were rotated backward to a position just before contact at θ_1 and θ_2, respectively. The tooth pair will make contact at point D if the elastic deformation of the preceding tooth pair(s) caused the driving gear (gear 1) to rotate an angle of Δ_1. The equivalent separation distance along the line of action, S_1, between the incoming tooth pair due to the rotation of gear 1 can be found from:

$$S_1 = \Delta_1 \, R_{b1} \tag{9}$$

where

$$\Delta_1 = \theta_1 + \beta_1 - \alpha_1 + \delta_1 \tag{10}$$

$$\theta_1 R_1 = \theta_2 R_2 \tag{11}$$

$$\delta_1 = \text{inv}\,\rho_1 - \text{inv}\,\gamma_1 \tag{12}$$

$$\beta_1 = \tan^{-1}\left(\frac{R_{a2}\sin\beta_2}{C - R_{a2}\cos\beta_2}\right) \tag{13}$$

$$\beta_2 = \cos^{-1}\left(\frac{R_{b2}}{R_{a2}}\right) - \phi \tag{14}$$

$$\alpha_1 = \tan^{-1}\left(\frac{R_{a2}\sin(\theta_2+\beta_2)}{C - R_{a2}\cos(\theta_2+\beta_2)}\right) \tag{15}$$

$$\rho_1 = \cos^{-1}\left(\frac{R_{b1}}{DO_1}\right) \tag{16}$$

$$\gamma_1 = \cos^{-1}\left(\frac{R_{b1}}{AO_1}\right) \tag{17}$$

$$DO_1 = \sqrt{[R_{a2}\sin(\theta_2+\beta_2)]^2 + [C - R_{a2}\cos(\theta_2+\beta_2)]^2} \tag{18}$$

$$AO_1 = \sqrt{[R_{a1}\sin\beta_2]^2 + [C - R_{a2}\cos\beta_2]^2} \tag{19}$$

Similar expressions can be derived for the linear separation distance S_2, where gear 1 is fixed and gear 2 rotates to close the gap. Likewise, expressions can be derived for the separation distances S_1 and S_2 of a tooth pair in recess, where S_1 and S_2 are defined for tooth pair a.

Fig. 4 shows the variation of the separation distance during approach and recess as a function of the rotation angle (θ_1 in Fig. 3) for a 1:1 ratio gear pair as described in Table 1 and with contact ratio 1.64. The zero rotation angle in the abscissa refers to the gear position at the theoretical start (or end) of tooth contact in approach (or recess). The separation distances S_1 and S_2 differ, and the difference grows larger as the rotation angle increases. The magnitude of S_1 is less than S_2 in approach and greater than S_2 in recess. Since there is no particular reason to consider either the driving or the driven gear to be fixed, an average value of S_1 and S_2 has been taken as the separation dis-

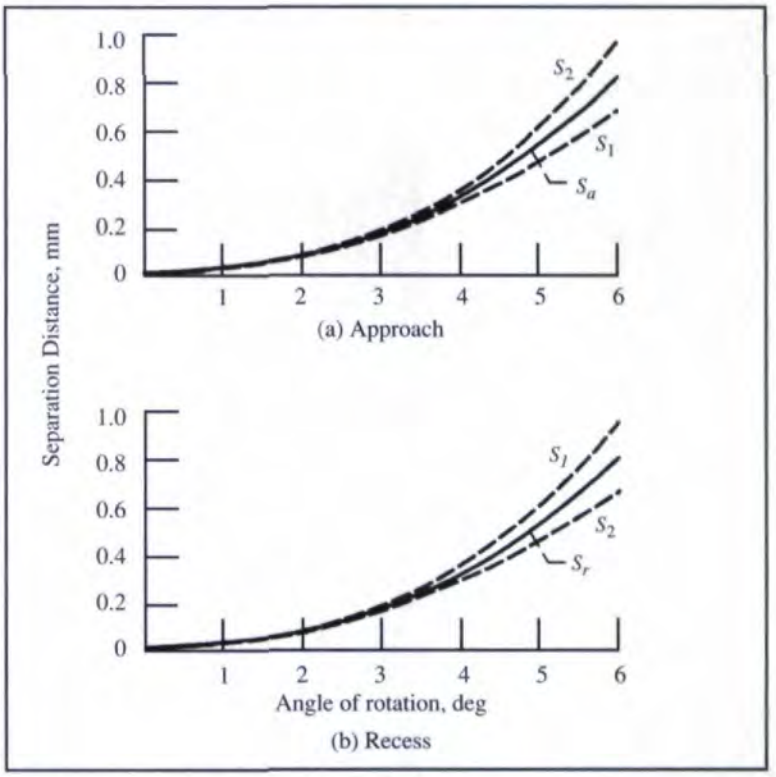


Fig. 4 — Separation distance calculated for approach and recess.

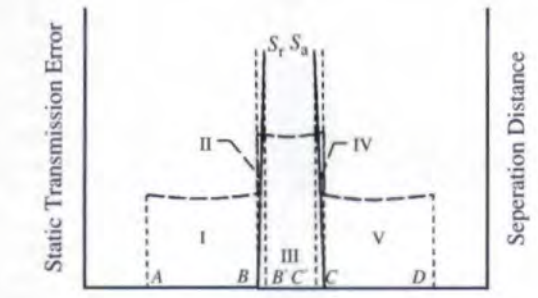
Table 1 — Sample Gear Parameters

Number of teeth	28, 28
Pressure angle, deg	20
Module, mm (diametral pitch, 1/in)	3.18 (8)
Backlash, mm (in)	0.05 (0.002)
Face width, mm (in)	25.4 (1.00)
Design torque, N-m (lb-in)	373 (3290)
Normalized tooth addendum	1.00 or 1.20
Theoretical contact ratio	1.64 or 1.95

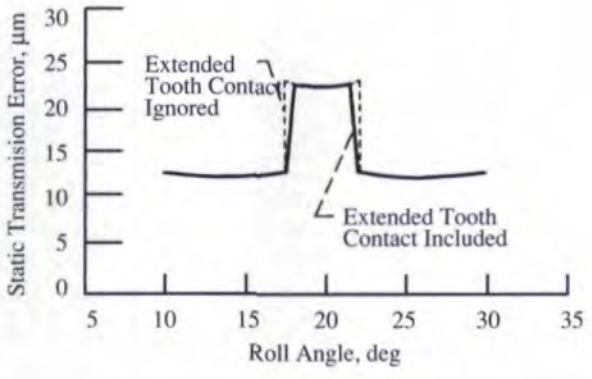
tance. S_a is designated as the separation distance during approach and S_r is that for recess.

The computer program DANST was used to calculate the static transmission error for the gear system described in Table 1. To simplify the analysis, only unmodified gears are considered here. DANST is based on algorithms developed in Refs. 10 and 11.

Fig. 5(a) shows the theoretical (extended contact ignored) static transmission error for gears of contact ratio 1.64. The static transmission error consists of manufacturing errors added to the deflection due to load. In this study manufacturing errors, such as spacing and profile errors and runout, are neglected. This is a reasonable assumption for high-quality, heavily loaded gears; therefore, the static transmission error represents the elastic deflection of the gear teeth and gear blank. The horizontal axis in Fig. 5(b) is calibrated in terms of the roll angle for tooth b. This is the same as the rotation angle (used in Fig. 4) except for a constant offset.



(a) Theoretical Static Transmission Error and Separation Distance



(b) Comparison of Static Transmission Error with Effect of Extended Tooth Contact Both Included and Ignored

Fig. 5 — Static transmission error and separation distance for gears with contact ratio = 1.64.

Meshing Stiffness and Transmission Error (Including Extended Tooth Contact)

Superimposed on the transmission error curve in Fig. 5(a) are separation distance curves S_a and S_r. The actual point where the approaching tooth pair b makes contact is the point labeled C', where the separation distance equals the static transmission error. Likewise, tooth pair a, in recess, leaves contact at the point labeled B'.

Five regions (designated I to V) are identified in Fig. 5(a). Regions I (AB) and V (CD) represent double contact zones; region III ($B'C'$) is the single contact zone; and regions II (BB') and IV ($C'C$) represent the increased double (or reduced single) contact regions due to the effect of tooth flexibility. This effect increases the contact ratio of the gear pair about 5% (from 1.64 to 1.72).

To evaluate the static transmission error of region II, we adopt an analysis similar to that presented above. We begin at the moment when tooth pair b is in contact at the point labeled B in Fig. 5(a). (This is the end of the theoretical double contact zone.) Elastic deflection causes tooth pair a to remain in contact until b reaches B'. The total transmitted load W shared by tooth pairs a and b in this region is:

$$W = \frac{(E_t^a)_j - (S_r^a)_j}{Q_j^a} + \frac{(E_t^b)_j}{Q_j^b} \qquad (20)$$

where the first term at the right-hand side of the equation represents the load on tooth pair a, and the second term represents the load on tooth pair b at an arbitrary contact point j.

The static transmission error of all tooth pairs in contact must be equal; therefore, the transmission error of b in this region can be calculated from Ref. 13:

$$(E_t^b)_j = \frac{Q_j^b (S_r^a)_j + Q_j^a Q_j^b W}{Q_j^a + Q_j^b} \qquad (21)$$

When E_t^b, the static transmission error of tooth pair b, is less than the separation distance, S_r^a, tooth pair a leaves contact. This occurs as tooth pair b reaches B'. (This is the beginning of region III, where b is the only tooth pair in

contact.) The gears remain in single contact until tooth pair b reaches point C'.

At the beginning of region IV, when b arrives at point C', tooth pair c engages and gradually increases its share of the total transmitted load. The shared tooth load and static transmission error of tooth pairs b and c change with respect to the rotation of gears. They can be determined from the following expressions:

$$W = \frac{(E_t^b)_j}{Q_j^b} + \frac{(E_t^c)_j - (S_a^c)_j}{Q_j^c} \qquad (22)$$

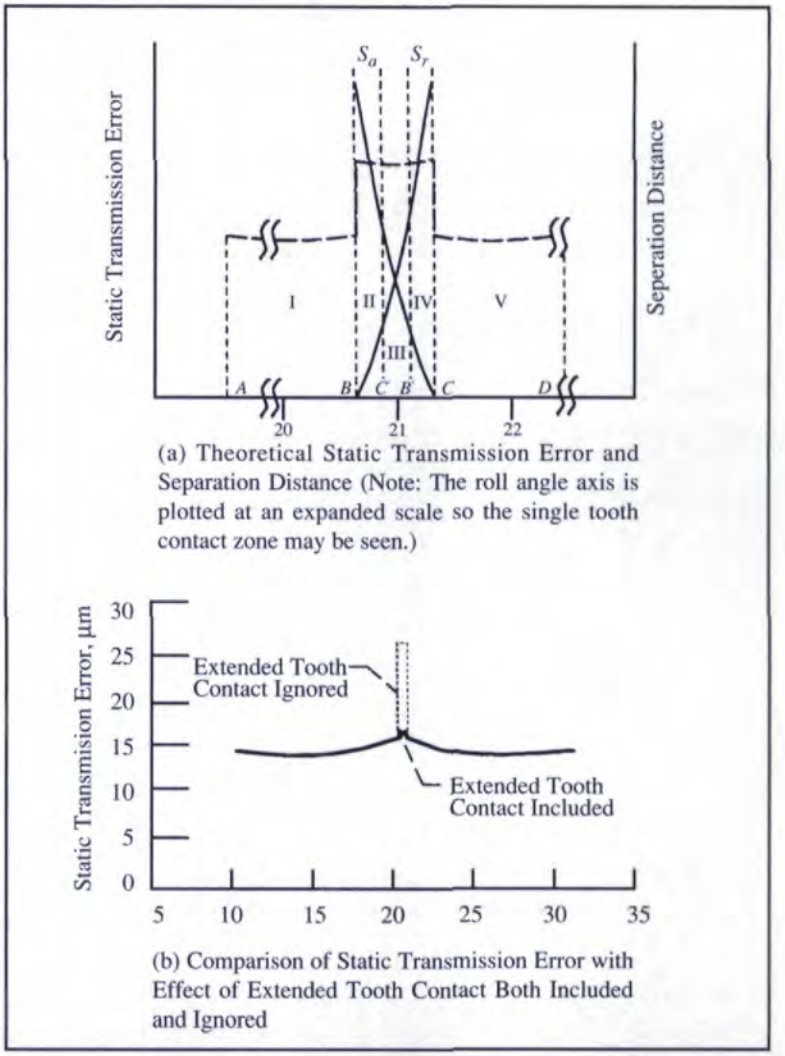
$$(E_t^b)_j = \frac{Q_j^b (S_a^c)_j + Q_j^b Q_j^c W}{Q_j^b + Q_j^c} \qquad (23)$$

Fig. 5(b) compares the transmission error calculated with extended tooth contact included (solid line) and ignored (dashed line).

If the tooth addendum (and hence the height of the teeth) is increased, the contact ratio becomes greater. The increase in the contact ratio reduces the zone of single contact. The width in the step in the static transmission error curve will be reduced as the separation distance curves S_a and S_r approach each other. These effects can be seen in Fig. 6(a).

If the theoretical contact ratio is increased to slightly less than 2.00, the increase in contact length due to extended tooth contact may cause the single contact zone to completely disappear. This is illustrated in Fig. 6(b), in which the tooth addendum of the gears was increased by 20% over the standard value to increase the theoretical contact ratio to 1.95. The actual contact ratio (after consideration of tooth flexibility) is 2.02.

Fig. 6(a) shows the static transmission error for the gears with theoretical contact ratio of 1.95. The single tooth contact zone (regions II to IV) is so narrow compared to regions I and V that the figure was plotted at an expanded scale. (Only portions of regions I and V are shown.) For regions I (AB) and V (CD), the static transmission error curve is similar to Fig. 5(a). Regions II (BC') and IV ($B'C$) are extended zones of double tooth contact (similar to the corresponding regions in Fig. 5(a)). The transmission error in these regions can be found from Eqs. 18-21 as in the previous case.



(a) Theoretical Static Transmission Error and Separation Distance (Note: The roll angle axis is plotted at an expanded scale so the single tooth contact zone may be seen.)

(b) Comparison of Static Transmission Error with Effect of Extended Tooth Contact Both Included and Ignored

Fig. 6 — Static transmission error and separation distance for gears with contact ratio = 1.95.

In region III ($C'B'$), tooth pair b is carrying most of the load, but pairs a and c are also in contact; hence, this is a triple contact zone. The transmitted load shared by the tooth pairs a, b and c is given by:

$$W = \frac{(E_t^a)_j - (S_r^a)_j}{Q_j^a} + \frac{(E_t^b)_j}{Q_j^b} + \frac{(E_t^c)_j - (S_a^c)_j}{Q_j^c} \qquad (24)$$

The transmission error of the three tooth pairs in contact must be equal, therefore:

$$(E_t^b)_j = \frac{Q_j^a Q_j^b (S_a^c)_j + Q_j^b Q_j^c (S_r^a)_j + Q_j^a Q_j^b Q_j^c W}{Q_j^a Q_j^b + Q_j^b Q_j^c + Q_j^a Q_j^c} \qquad (25)$$

In Fig. 6(b) the magnitude of the transmission error was significantly reduced because the single contact region was entirely eliminated.

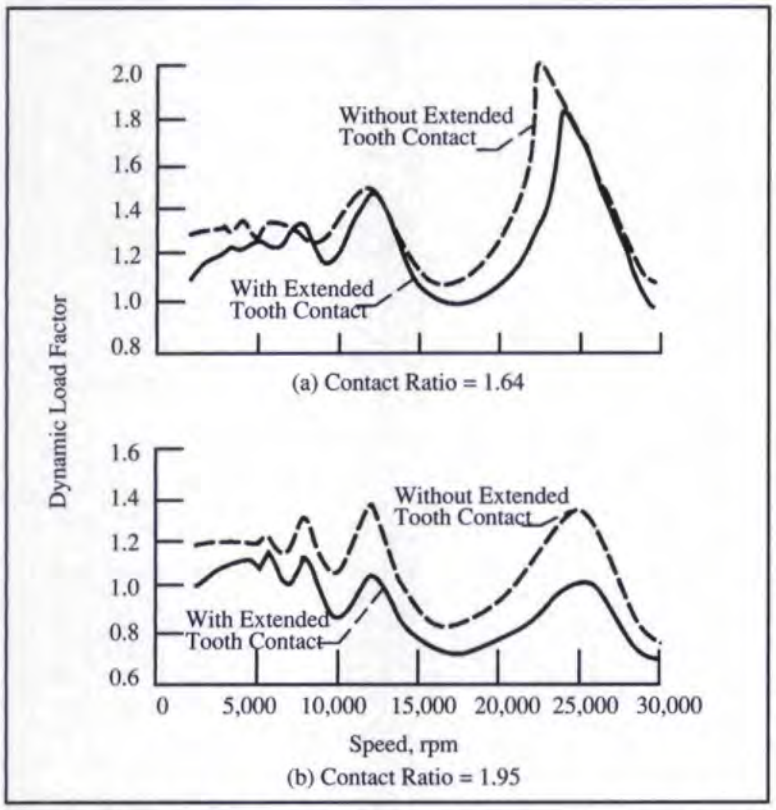


Fig. 7 — Predicted dynamic load factor of gears as a function of speed, with and without the effect of extended tooth contact.

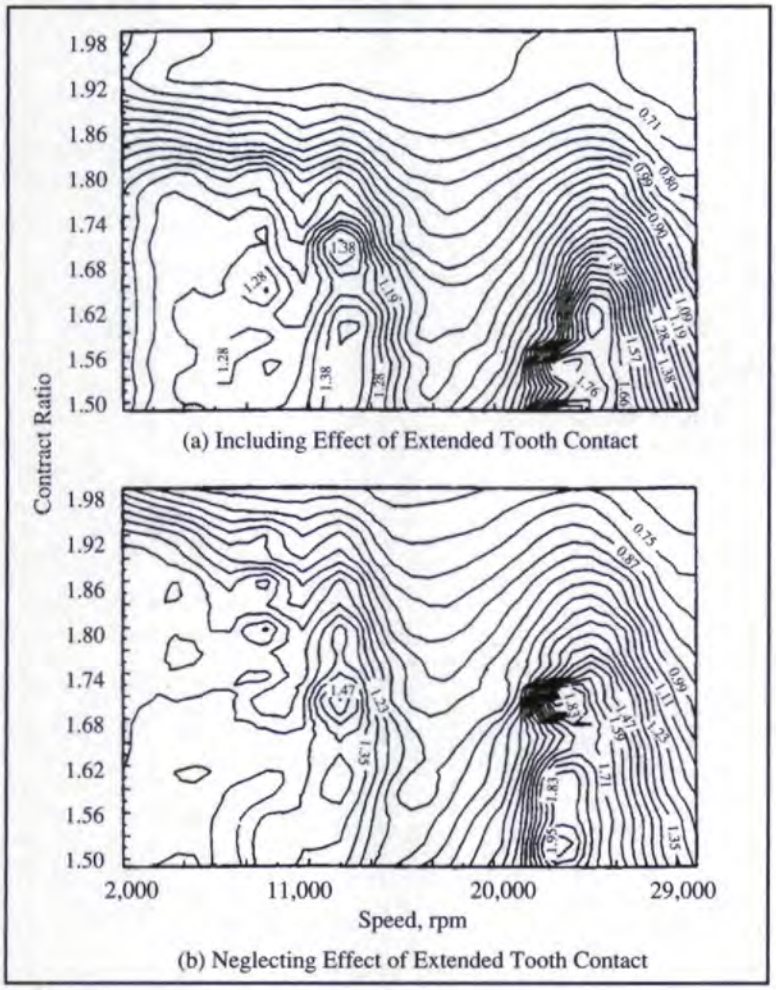


Fig. 8 — Predicted dynamic load factor of gears as a function of speed and contact ratio.

The predicted dynamic excitation of this gear pair will be similarly reduced from that calculated with the extended tooth contact neglected. The difference is greater for gears with a higher contact ratio (which generally have more flexible teeth), especially at heavy load.

Results and Discussion

DANST was used to calculate the dynamic load for our sample gear system. To compare the dynamic load predicted under different conditions, we define a non-dimensional term called the dynamic load factor. This is the ratio of the maximum dynamic load divided by the total static load. The total static load is the torque divided by the base circle radius. For gears with contact ratio greater than 2, the dynamic load factor may be less than 1.

Figs. 7(a) and (b) contain many individual solutions for the dynamic load factor arranged in the form of speed surveys. The speed surveys are shown two ways — with the effect of extended tooth contact neglected and included. Fig. 7(a) is for a set of sample gears with standard tooth addendum (1/DP). The theoretical contact ratio (neglecting extended tooth contact) is 1.64. The response of the gear system peaks at the resonant speed near 25,000 rpm. There are also smaller peaks at submultiples of the resonant speed.

Including extended tooth contact in the model increases the predicted system resonant speed from approximately 23,250 to 24,600 rpm, while the predicted dynamic load factor at resonance is reduced from about 2.02 to 1.84, a 9% reduction in dynamic load. Extended tooth contact results in greater load sharing (increasing the length of double or triple contact zones), which, in turn, increases the average mesh stiffness. Other effects include an increase in the system resonant speed and a reduction in the maximum dynamic load.

Fig. 7(b) illustrates the results for a set of gears with tooth addendum increased by 20% (to 1.2/DP) over the standard value. This increases the theoretical contact ratio to 1.95. Including extended tooth contact in the analysis reduces the predicted dynamic factor at resonance from 1.42 to 1.10, a reduction of nearly 23%. Unlike the example above, there is little change in the predicted system resonant speed (25,000 rpm). Apparently, elimination of the very narrow single contact zone

(Fig. 6) has little effect on the average gear meshing stiffness.

Figs. 8(a) and (b) are contour plots which illustrate the effects of both speed and contact ratio on the predicted dynamic load factor. The speed was varied over the range 2,000 to 30,000 rpm, and the theoretical contact ratio was varied from 1.50 to 1.98. (As above, the contact ratio was varied by adjusting the tooth addendum.) These figures show how both factors affect spur gear dynamics.

Fig. 8(a) shows the predicted results if extended contact is neglected. The resonant response at 23,000 rpm shows the highest dynamic loads for contact ratios of 1.52 and 1.70. In Fig. 8(b) the analysis was repeated with extended tooth contact included. Fig. 8(b) shows an overall lower level of dynamic response than Fig. 8(a). The resonant response has shifted to about 25,000 rpm, and there is less effect from changes in the contact ratio.

Conclusions

The NASA gear dynamic code DANST was used for an analytical study of the influence of tooth flexibility to extend the zone of tooth contact for heavily loaded spur gears. This effect was both neglected and included as the static transmission error and dynamic load were calculated for low-contact-ratio spur gears. The following conclusions were drawn from the investigation:

1. Neglecting the extension of the contact zone results in underestimating resonant speeds and overestimating the dynamic load, especially for heavily loaded gears.

2. The effect is more significant for gears with a theoretical contact ratio nearly (slightly less than) 2.00. For these gears, the increased zone of tooth contact may extend the actual contact ratio beyond 2.00.

3. For the cases studied in this article, ignoring the effect results in an underestimate of the contact ratio by about 3 to 5%. ■

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GEAR FUNDAMENTALS

Computerized Hob Inspection & Applications of Inspection Results Part II

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Flute Index

Flute index or spacing is defined as the variation from the desired angle between adjacent or nonadjacent tooth faces measured in a plane of rotation. AGMA defines and provides tolerances for adjacent and nonadjacent flute spacing errors. In addition, DIN and ISO standards provide tolerances for individual flute variation (Fig. 1).

There is a slight inconsistency in the ANSI B94.7 definitions of flute spacing variation and flute spacing tolerance. The variation refers to an angle variation; however, the tolerance refers to a linear displacement.

A flute index error caused by inaccurate sharpening creates unequal height and thickness of cutting edges. Unequally positioned cutting edges produce a "drunk" involute (Fig. 2). The effect of a flute index error can be calculated (Fig. 3).

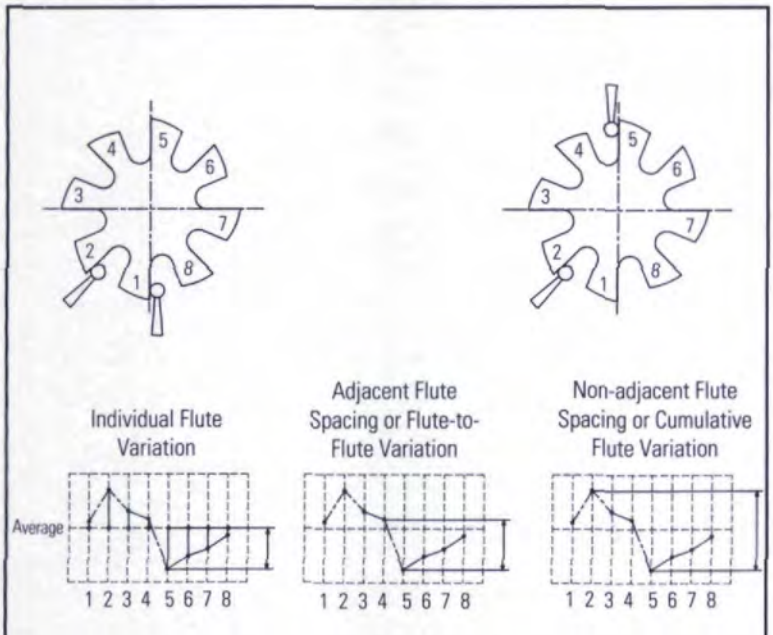
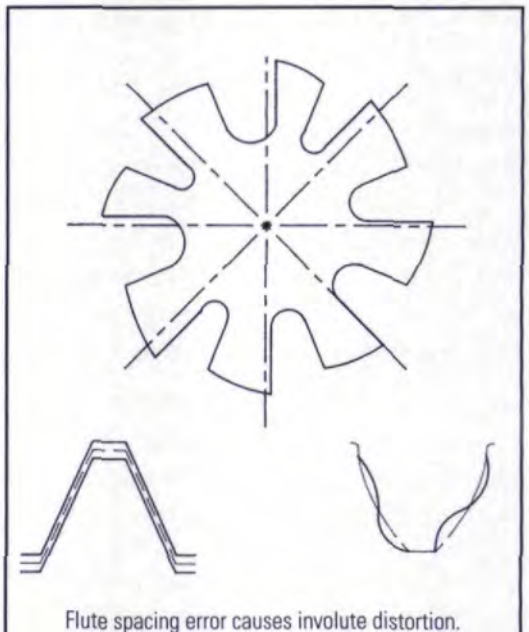


Fig. 1



Flute spacing error causes involute distortion.

Fig. 2

Adjacent or nonadjacent flute spacing errors will affect changes in the radial position of a cutting edge:

Radial misposition
= (cumulative spacing error)
• (cam size) • (number of flutes)
• correction/[π • (index measuring diameter)]

Correction = 1 for straight flute hobs.

For helical flute hobs, the correction could be determined as follows:

Correction = HN/(HN ± H)
Where: HN is the flute lead,
H is the thread lead,
(-) is used when flute and thread lead have the same hand.

The gear's involute variation caused by hob flute index error can be calculated as follows:

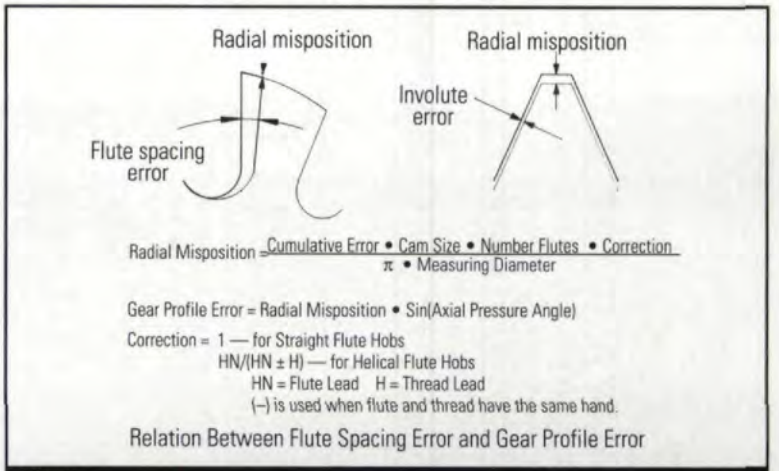
Gear profile variation
= (radial misposition)
• sin(axial pressure angle)

Fig. 4 shows the result of the inspection. It shows the total flute spacing variation (nonadjacent by AGMA definition, cumulative by DIN definition), adjacent flute spacing and individual spacing variation (specified only by the DIN standard). The inspected errors, tolerances and actual quality are displayed.

Flute Lead

Flute lead is the axial advance of a tooth face helix in one turn around the axis of the hob (Fig. 5). The amount of flute lead is usually a very large number or even an infinity in the case of a straight flute hob; therefore, only a fraction of flute lead is usually inspected. In any case the inspection length cannot be greater than hob length. DIN and ISO standards, for instance, prorate flute lead tolerance in relation to 100 mm of hob face width. The AGMA standard specifies lead tolerance in steps relative to hob face.

Flute lead error causes involute distortion (Fig. 6). It can also cause an inconsistency in gear tooth size during hob shifting, but only a fractional amount, depending on radial relief. Fig. 7 illustrates the relation between flute lead



Relation Between Flute Spacing Error and Gear Profile Error

Fig. 3

Hob ID	4191 Left Contact	N.D.P.	7.236467	Left NPA	20.000000
Serial	001	Axial Lead	0.8660000	Lead Hand	Right
Operator	Ed	Whole Depth	0.23622	Gash Hand	Left
Probe	0.07847L	Number Gashes	10	Required Quality	AGMA: B
Inspected	04/15/93 09:20:48	Number Threads	2	c:\Roto Hob\HB006.HOB\MS009.MES	
Metric/Inch	Inch	Right NPA	20.000000	Magnif 2000.00	Scale 0.40

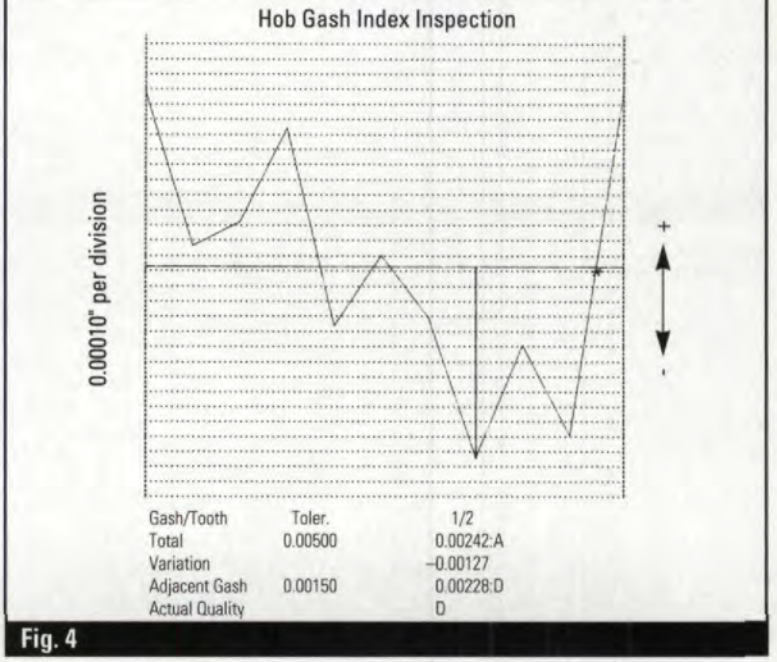


Fig. 4

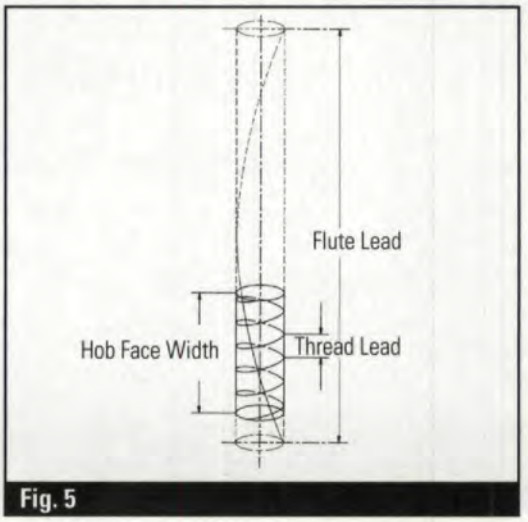


Fig. 5

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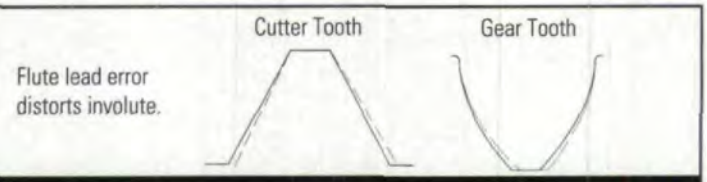
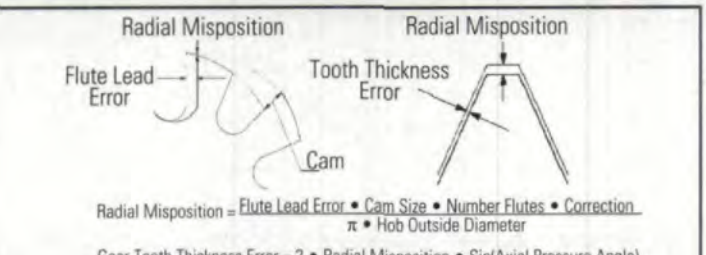


Fig. 6



$$\text{Radial Misposition} = \frac{\text{Flute Lead Error} \bullet \text{Cam Size} \bullet \text{Number Flutes} \bullet \text{Correction}}{\pi \bullet \text{Hob Outside Diameter}}$$

Gear Tooth Thickness Error = 2 • Radial Misposition • Sin(Axial Pressure Angle)
Correction = 1 — for Straight Flute Hobs
HN/(HN ± H) — for Helical Flute Hobs
HN = Flute Lead H = Thread Lead
(–) is used when flute and thread have the same hand.

Relation Between Flute Lead Error and Generated Gear Tooth Thickness

Fig. 7

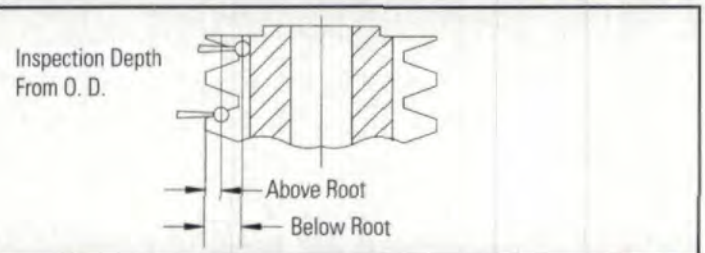
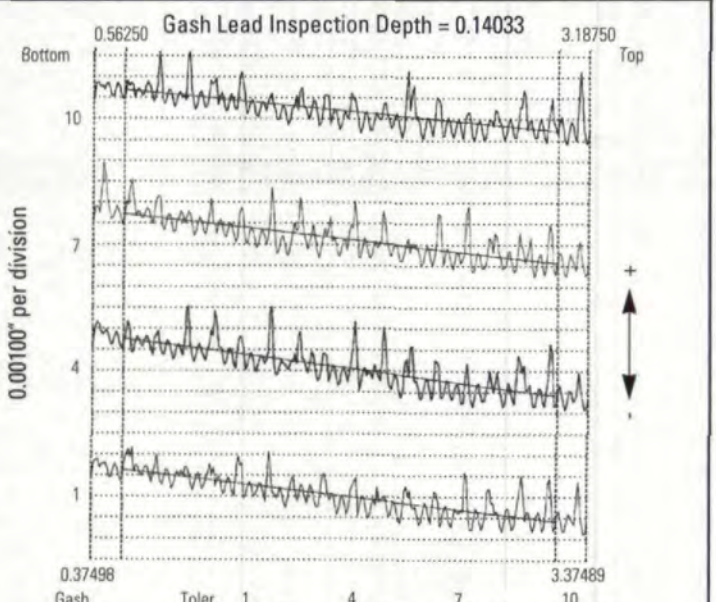


Fig. 8

Hob ID	78549-008-2-10 Right	N.D.P.	18.586226	Left NPA	14.000000
Serial	1234	Axial Lead	0.6783590	Lead Hand	Right
Operator	Ed	Whole Depth	0.13500	Gash Hand	Straight
Probe	0.07874R	Number Gashes	12	Required Quality	AGMA: B
Inspected	03/22/93 10:50:35	Number Threads	4	c:\Roto Hob\HB004.HOB\MS012.MES	
Metric/Inch	Inch	Right NPA	14.000000	Magnif 250.00	Scale 2.0



Gash	Toler.	1	4	7	10
Total		0.00401	0.00480	0.00465	0.00433
Form		0.00295	0.00349	0.00330	0.00321
Slope	0.00250	0.00243:A	0.00272:D	0.00231:A	0.00196:A
Slope/100mm		0.00365	0.00408	0.00347	0.00294

Fig. 9

error and gear tooth thickness. Flute lead error changes the radial position on a cutting edge:

$$\text{Radial misposition} = (\text{flute lead error}) \bullet (\text{cam size}) \bullet (\text{number of flutes}) \bullet \text{correction} / [\pi \bullet (\text{hob outside diameter})]$$

Correction = 1 for straight flute hobs.

For helical flute hobs, the correction could be determined as follows:

Correction = HN/(HN ± H)
Where: HN is flute lead,
H is the thread lead,
(-) is used when flute and thread lead have the same hand.

Tooth thickness error caused by hob flute lead error:

$$\text{Tooth thickness error} = 2 \bullet (\text{radial misposition}) \bullet \sin(\text{axial pressure angle})$$

The flute lead inspection could be done above or below the root (Fig. 8), where the probe can have an uninterrupted check, or both. Fig. 9 shows a plot of an inspection below the root. The inspection results identify flute number, inspection depth from tooth tip, inspection range relative to hob length, evaluation range relative to hob length, magnification and scale, required standard, quality and tolerance if specified.

A CNC hob checker should be able to check any number of flutes of either straight or helical flute hobs. Evaluation results of every single flute can include total variation, slope error, slope error relative to a 100 mm hob length, form error (valid only for the below-root inspection) and actual quality per AGMA, DIN or ISO standards for every flute inspected.

A slope error prorated for a 100 mm hob length is used for determination of actual DIN or ISO quality. An evaluation range can be changed within the limits of measuring length in order to analyze different portions of flute lead if required. The resulting charts could be presented in a superimposed format. Fig. 10 shows the results of a flute lead inspection

above the root.

Lead and Thread-to-Thread Errors

Lead error is most commonly checked by a hob manufacturer since it is a very important characteristic that affects hob performance. Hob lead is an axial advance of one revolution of hob thread (Fig. 5). Axial distance between cutting edges can be calculated as shown in Fig. 11. In this figure, n = number of cutting edges, i = number of gashes, correction = gash helix correction factor (see section on flute index). The task of hob lead inspection is to find variation of cutting edges in relation to their theoretical positions.

Lead inspection over cutting edges shows the combined effect of any runout, flute lead, flute index and lead error itself. Lead error, measured over the cutting edges within the generating zone, reflects the potential gear involute variation almost directly. The only additional factor influencing gear profile variation is the quality of hob pressure angle. The effect of lead error on gear profile accuracy (Fig. 12) can be calculated as follows:

Total profile error
= (lead error within generating zone)
• cos(axial pressure angle)

Sometimes it is important to analyze the lead variation in different hob sections, since different hob sections generate right and left flanks. If one needs to pinpoint a lead error itself, a behind-the-edge lead inspection should be performed. This type of inspection would help to find out the inherent lead error introduced during manufacturing without the effect of sharpening errors.

Lead inspection is perhaps the most comprehensive inspection after the action line. The only missing link to the complete understanding of hob performance is accuracy of hob pressure angle.

A CNC inspection machine may combine lead inspection with thread-to-thread inspection for the multi-start hobs. The adjacent thread-to-thread error and thread variation can be mathematically determined within the specified hob section.

Lead averages of all threads are compared for the thread spacing determination. Threads between which the maximum adjacent error

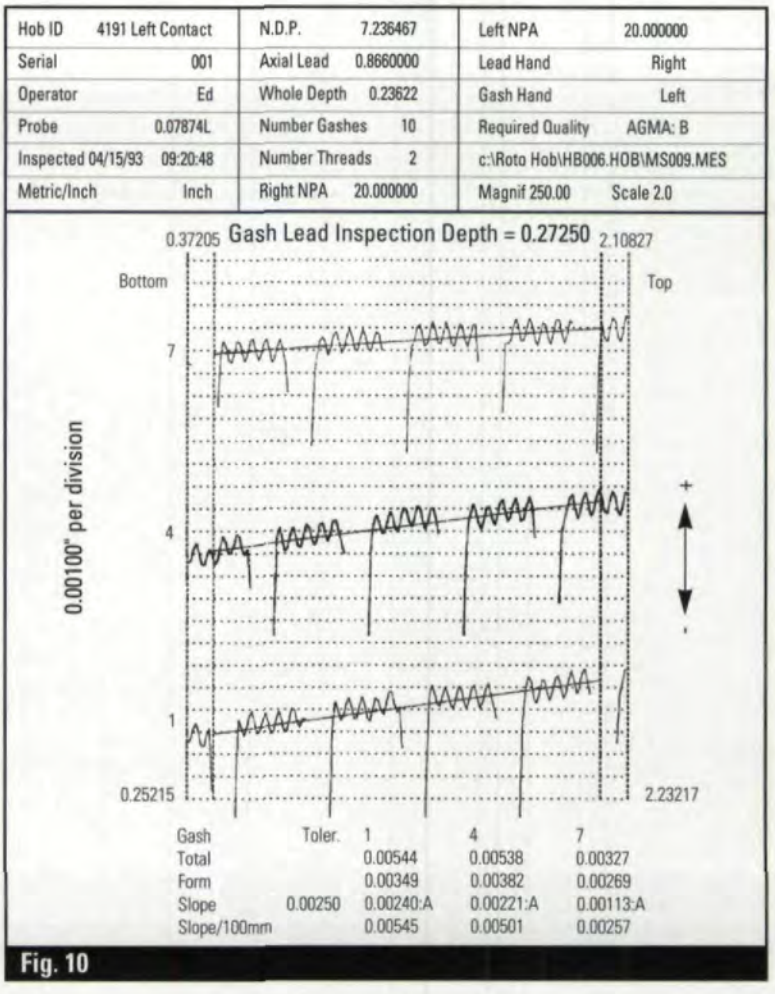


Fig. 10

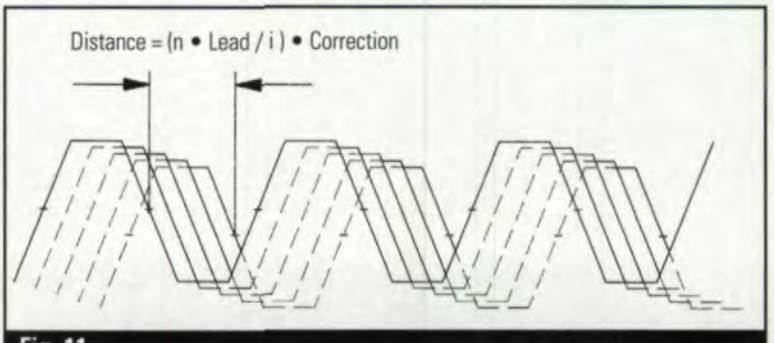


Fig. 11

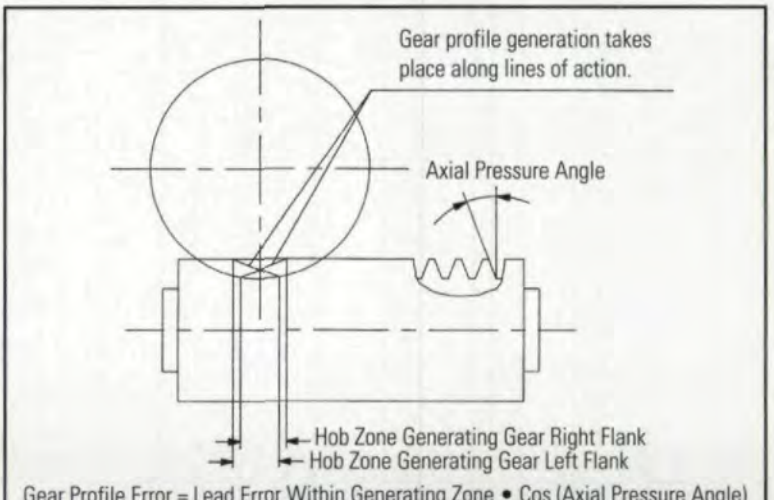
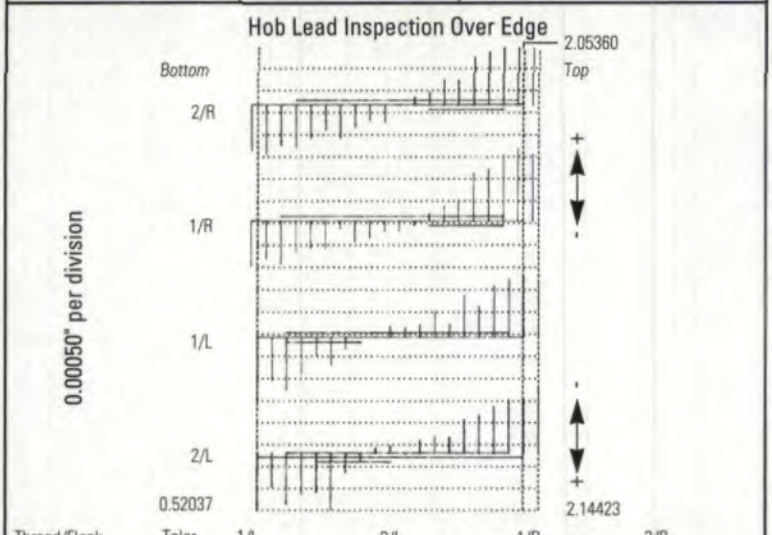


Fig. 12

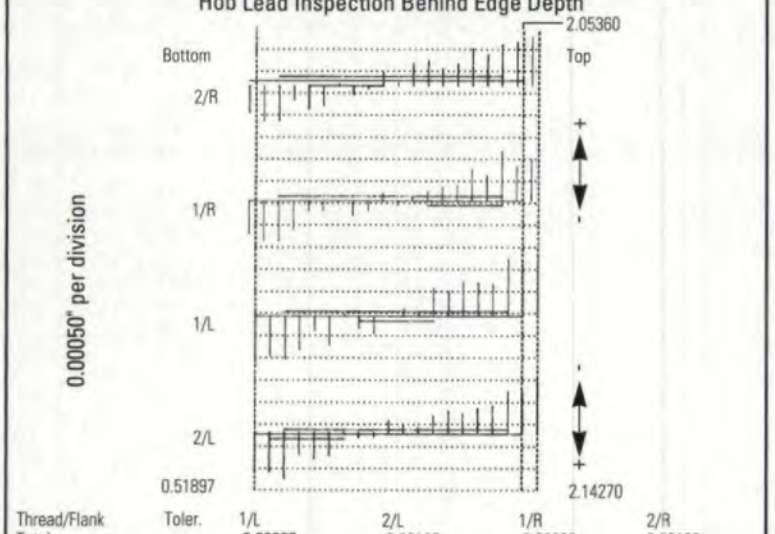
Hob ID	4191 Left Contact	N.D.P.	7.236467	Left NPA	20.000000
Serial	001	Axial Lead	0.8660000	Lead Hand	Right
Operator	Ed	Whole Depth	0.23622	Gash Hand	Left
Probe	0.07874L	Number Gashes	10	Required Quality	AGMA: B
Inspected 04/15/93	09:20:48	Number Threads	2	c:\Roto Hob\HB006.HOB\MS009.MES	
Metric/Inch	Inch	Right NPA	20.000000	Magnif 500.00	Scale 2.0



Thread/Flank	Toler.	1/L	2/L	1/R	2/R
Total		0.00271	0.00251	0.00267	0.00287
Adjacent	0.00050	-0.00066:D	-0.00085:D	0.00059:C	0.00052:C
1 Axial Pitch	0.00080	0.00118:C	0.00145:D	0.00134:D	0.00136:D
3 Axial Pitches	0.00120	0.00249:D	0.00251:D	0.00248:D	0.00273:D
Slope		-0.00259	-0.00260	0.00257	0.00289
Thread Variation		-0.00005	0.00005	-0.00001	0.00001
Adjacent Thread	0.00080	1/2 = 0.00010:A	2/1 = -0.00010:A	1/2 = 0.00001:A	2/1 = -0.00001:A
Actual Quality		D	D	D	D

Fig. 13

Hob ID	4191 Left Contact	N.D.P.	7.236467	Left NPA	20.000000
Serial	001	Axial Lead	0.8660000	Lead Hand	Right
Operator	Ed	Whole Depth	0.23622	Gash Hand	Left
Probe	0.07874L	Number Gashes	10	Required Quality	AGMA: B
Inspected 04/15/93	09:20:48	Number Threads	2	c:\Roto Hob\HB006.HOB\MS009.MES	
Metric/Inch	Inch	Right NPA	20.000000	Magnif 500.00	Scale 2.0



Thread/Flank	Toler.	1/L	2/L	1/R	2/R
Total		*0.00227*	*0.00197*	*0.00206*	*0.00180*
Adjacent	0.00050	-0.00068:D	-0.00055:C	0.00055:C	0.00048:B
1 Axial Pitch	0.00080	0.00102:C	0.00101:C	0.00093:C	0.00084:C
3 Axial Pitches	0.00120	0.00227:D	0.00197:D	0.00205:D	0.00174:C
Slope		-0.00221	-0.00187	-0.00181	0.00186
Thread Variation		-0.00002	0.00002	-0.00005	0.00005
Adjacent Thread	0.00080	1/2 = 0.00004:A	2/1 = -0.00004:A	1/2 = 0.00011:A	2/1 = -0.00011:A
Actual Quality		D	D	D	C

Fig. 14

occurs should be identified for both right and left flanks.

In addition to the lead characteristics specified by DIN, AGMA and ISO standards (total variations, adjacent variations and variations within 1 and 3 axial pitches), a lead slope error can be determined. This value can help to correct a setup on a hob grinding machine.

The automatic lead inspection and evaluation can be performed on any section of the hob. The inspection plot should provide references to the inspection and evaluation area (Figs. 13 and 14).

Outside Diameter

Runout of hob outside diameter may not be important for some applications. The tip of the hob tooth does not generate a gear involute. But when the gear root form is a consideration, the hob O.D. inspection may be useful. Fig. 15 shows hob inspection at the tip of the hob. Sometimes it is important to check hob runout behind the edge (Fig. 16). This type of inspection would show O.D. runout without the effects of hob wear and sharpening inaccuracies. Sometimes for special form hobs, it is necessary to offset the probe position from the tooth center (Fig. 17).

Figs. 18 and 19 show the outside diameter inspection results in circular and linear formats. Results of the inspection and evaluation may include total runout, out-of-round, concentricity errors and average diameter. The average hob diameter may be helpful for setup adjustments of a hobbing machine.

Pressure Angle

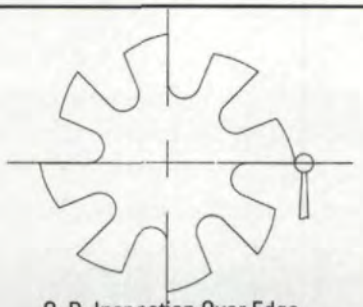
Pressure angle inspection is the inspection of a hob tooth profile (Fig. 20). Frequently, the hob tooth profile angle is the same as the gear pressure angle at the pitch diameter.

Usually the tooth profile is measured in the axial direction (Fig. 21). However, sometimes results may be presented normal to the axial pressure angle (Fig. 20).

Pressure angle accuracy directly affects the gear profile. The task of inspection is to find out the profile deviation from the specified geometry. Most straight gash hobs have a straight line profile. Some coarser pitch hobs may have an exvolute profile.

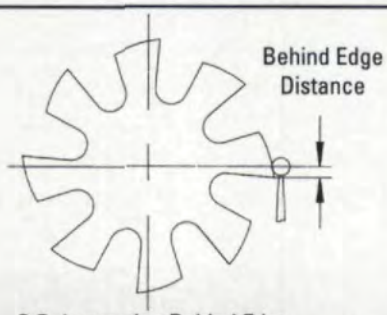
Line of Action

The action line is the line that crosses generating points on the hob cutting edges within



O. D. Inspection Over Edge

Fig. 15



O.D. Inspection Behind Edge

Fig. 16

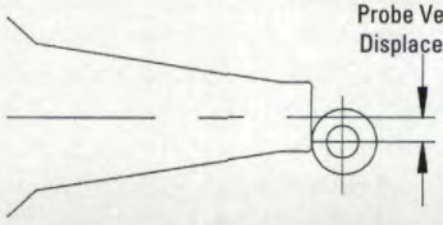
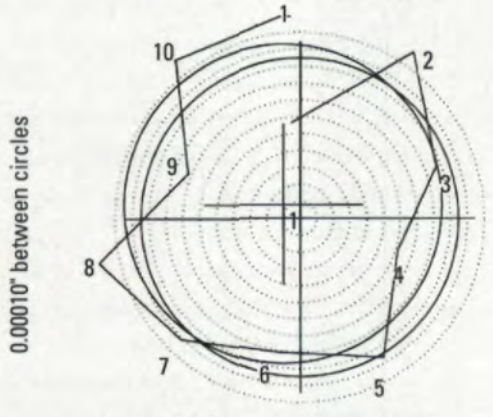


Fig. 17

Hob ID	4191 Left Contact	N.D.P.	7.236467	Left NPA	20.000000
Serial	001	Axial Lead	0.8660000	Lead Hand	Right
Operator	Ed	Whole Depth	0.23622	Gash Hand	Left
Probe	0.07874L	Number Gashes	10	Required Quality	AGMA: B
Inspected 04/15/93	09:20:48	Number Threads	2	c:\Roto Hob\HB006.HOB\MS009.MES	
Metric/Inch	Inch	Right NPA	20.000000	Magnif 1000.00	Scale 15.0

Hob O.D. Inspection Over Edge

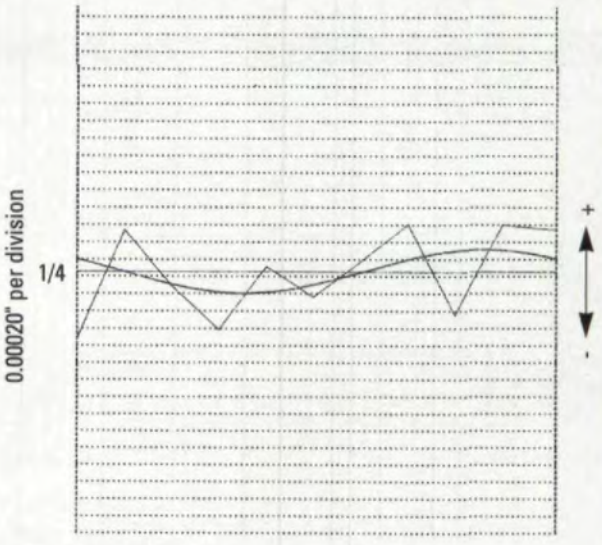


Gash/Tooth	Toler.	1/4
Total Runout	0.00150	0.00132:B
Out-of-Round		0.00140
Eccentricity		0.00026
Average Diameter		2.52253

Fig. 18

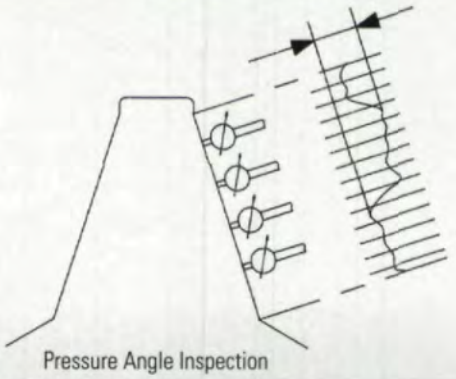
Hob ID	4191 Left Contact	N.D.P.	7.236467	Left NPA	20.000000
Serial	001	Axial Lead	0.8660000	Lead Hand	Right
Operator	Ed	Whole Depth	0.23622	Gash Hand	Left
Probe	0.07847L	Number Gashes	10	Required Quality	AGMA: B
Inspected 04/15/93	09:20:48	Number Threads	2	c:\Roto Hob\HB006.HOB\MS009.MES	
Metric/Inch	Inch	Right NPA	20.000000	Magnif 1000.00	Scale 0.40

Hob O.D. Inspection Over Edge



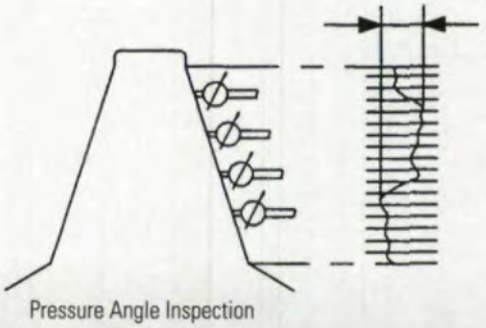
Gash/Tooth	Toler.	1/4
Total Runout	0.00150	0.00132:B
Out-of-Round		0.00140
Eccentricity		0.00026
Average Diameter		2.52253

Fig. 19



Pressure Angle Inspection

Fig. 20



Pressure Angle Inspection

Fig. 21

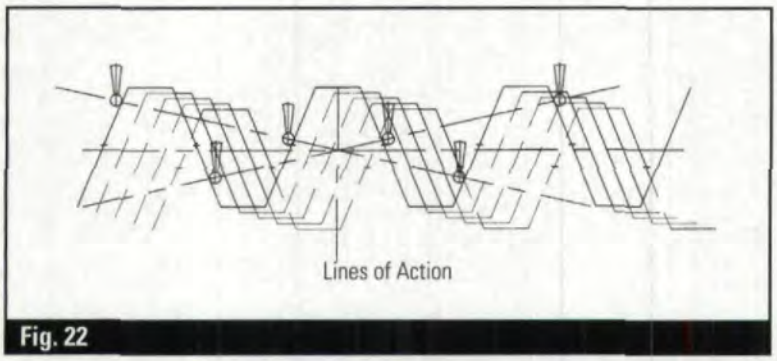


Fig. 22

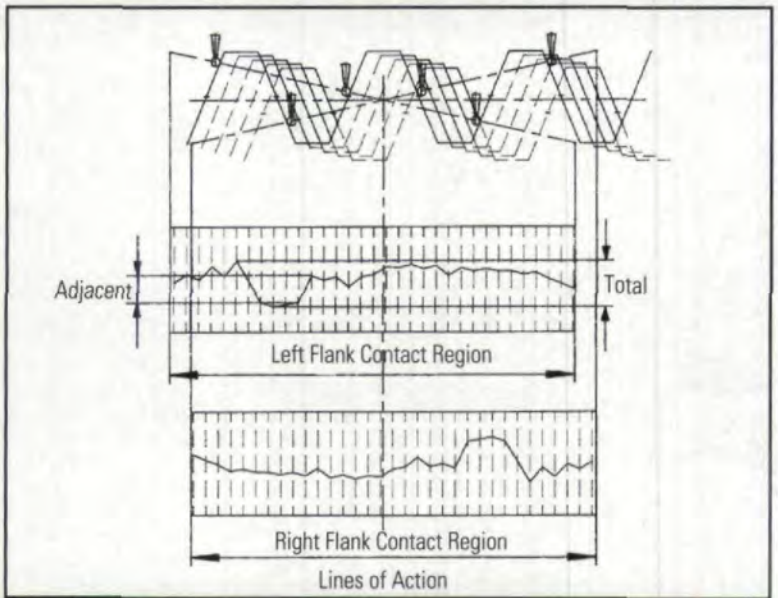


Fig. 23

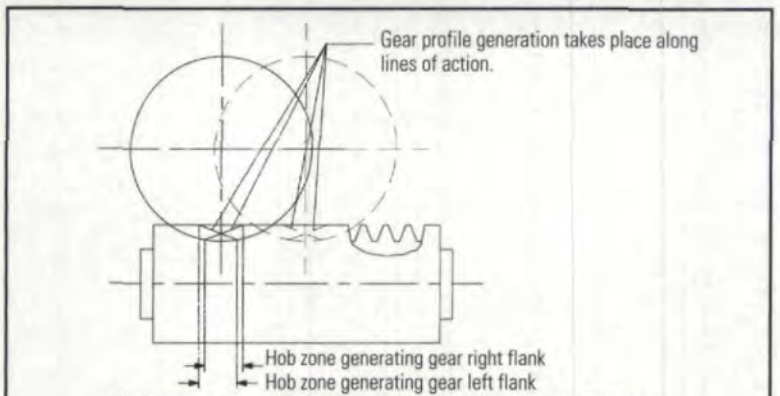


Fig. 24

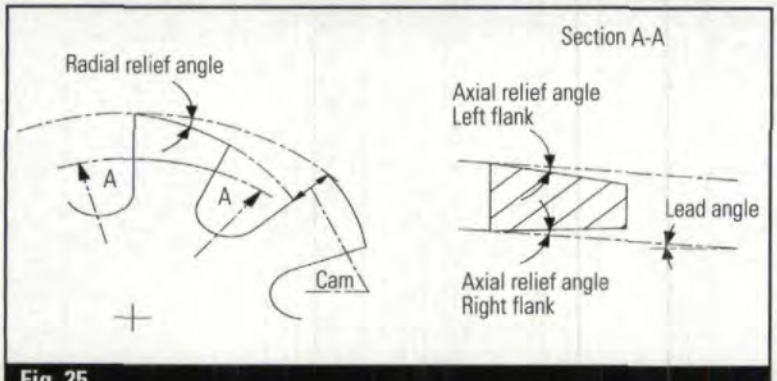


Fig. 25

the contact region (Fig. 22). A variation between theoretical positions of these points and their real positions is the action line error. DIN and ISO standards specify tolerances for variation between two adjacent cutting edges and the total variation within a contact region (Fig. 23). Some specifications use the term "base pitch" rather than "action line."

Action line is perhaps the most significant inspection. This inspection combines the effects of all single hob accuracy characteristics that influence the gear accuracy. For gears that were cut with a low feed rate, there is a direct relation between the accuracy of the hob action line and the generated involute. The following single geometrical characteristics are combined in an action line check: any runout caused by mounting or manufacturing, rake, flute lead, flute index, hob lead and pressure angle. Thus, the combined effect of the above characteristics on gear involute can be determined in one action line inspection.

Sometimes, in order to reduce overall inspection time, only line of action is inspected. However, in order to locate the source of a specific hob problem, the inspection of the line of action only is not sufficient. In this case, inspections of other hob characteristics have to be performed. There is another drawback in inspecting just a line of action. Line of action inspection can only show variation of cutting edges in one specific hob position. When the hob is shifted, different cutting edges or different points on cutting edges generate the involute. Since all the hob characteristics affect line of action variation, the inconsistency of errors at different hob positions can be rather large when the line of action is inspected. In contrast, the error inconsistency of other hob characteristics is usually of lesser magnitude. For example, a rake error on different hob teeth is likely to be more consistent. In short, the line of action inspection can be very effective if performed at the apex point as the hob is mounted on the hobbing machine (Fig. 24).

Radial and Axial Relief

Axial and radial reliefs, shown in Fig. 25, provide clearance during the cutting action. These characteristics are not classified by any known standards. Nevertheless, some people check these characteristics for various purposes, mostly research and development.

Tooth Thickness

Hob tooth thickness, shown in Fig. 26, is usually specified in reference to the tip of the tooth. That is why the current tip diameter of the hob has to be determined prior to tooth thickness measurement. Hob tooth thickness is an important characteristic if gear root diameter is to be controlled precisely or if the gear tooth has a tip or root modifications. Otherwise, a small variation of hob tooth thickness has no significant effect on gear involute as long as that variation is consistent. The consistent tooth thickness variation can be compensated for by adjusting the center distance between the hob and the gear blank.

CNC and Mechanical Hob Inspection Machines

Prior to the introduction of CNC machines, there were various types of mechanical machines available for hob inspection. They were usually limited to inspection of only a few hob characteristics. Data acquisition and analysis were tedious and very much dependent on operator skills. Nowadays, there are systems that perform all inspection and evaluation tasks automatically.

Data Processing

The ultimate goal of data processing features is to make the inspection and evaluation system more capable and simpler to use.

Only ten to fifteen years ago, computerized data processing techniques for hob inspection were either nonexistent or very primitive. Today there is an explosion of data processing features developed for hob inspection that were inspired by the latest advancements in computer and software technology. Some of these features are discussed below.

An assortment of evaluation capabilities. These include (1) the ability to select or modify an evaluation range within the inspection zone; (2) the ability to determine tolerances based on a selected class and to determine quality level based on the inspection results; (3) a built-in library for AGMA, DIN and ISO standards; (4) the breakdown of surface variation into basic components — total, form and slope; (5) the ability to present results in the superimposed format; (6) the ability to switch between metric and inch measurement; and (7) the ability to automatically select magnification and scale.

Full screen editing. This includes the ability to go forward and backward through the fields and screens; full cursor control — up, down, left, right, delete, and insert; clear and separate screens for the part geometry and the inspection and evaluation conditions; and multiple language support for descriptive text.

Data entry validation feature that detects growth errors and advises corrections. This feature tests every parameter entered and provides the validation range on the screen. Every logical combination of the data can also be tested for compatibility on every screen. Incompatible fields can be displayed.

Default features to minimize data entry. These include the capability to override default inspection and evaluation criteria.

Off-line analysis. This feature opens an immense opportunity for data manipulation and enables the reevaluation of the previously performed inspections. It provides capability for (1) storing, sorting, and displaying the list of stored inspection results; (2) moving the inspection data to another computer for reevaluation; (3) applying different evaluation criteria after the completion of the inspection, including a circular, linear or superimposed graphical presentation, an evaluation range, magnification, scale, output devices, tolerance systems, etc.; and (4) paperless storing and filing of inspection results.

Data output. Many systems provide a choice of output — printer, plotter, screen or file. Some systems have the capability to print or plot several characteristics on a single page.

Part storage and retrieval. This feature should include storing, sorting and displaying the list of parts for selection.

Back up/Restore. This feature provides the operator with a tool for complete or partial copying or deleting of files.

Communication with external computers and networks.

Automation of Inspection

Automatic inspection has obvious benefits. However, in order to facilitate the automatic inspection, the system needs to know hob vertical position, current outside diameter, angular and vertical positions of cutting edges and gashes, etc. In order to do that, some advanced hob inspection systems have hob orientation, an automatic procedure during which the machine

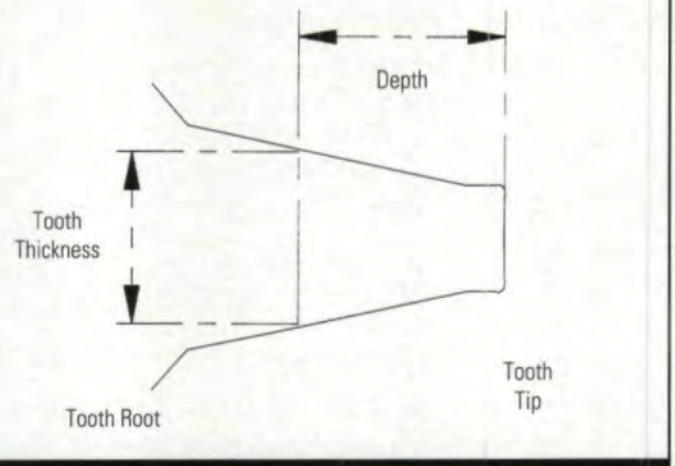


Fig. 26

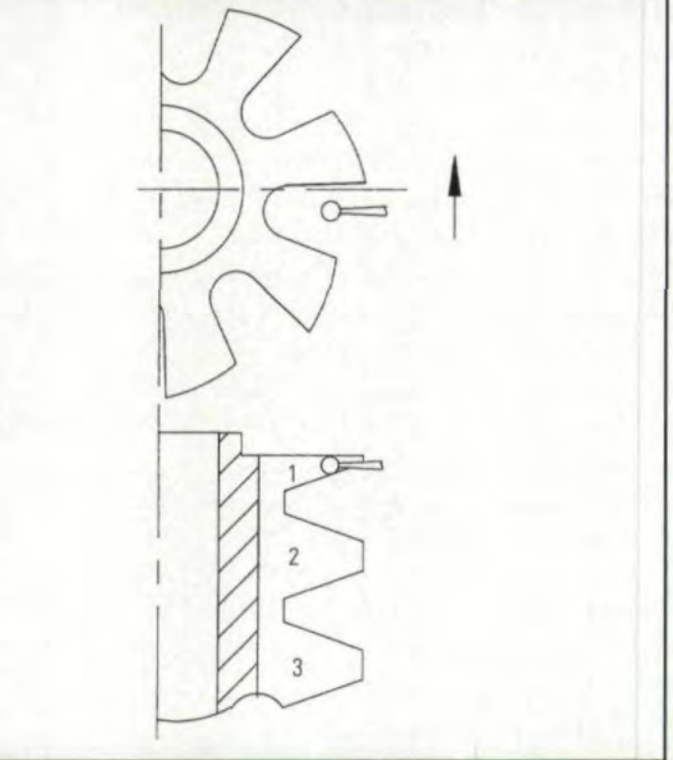
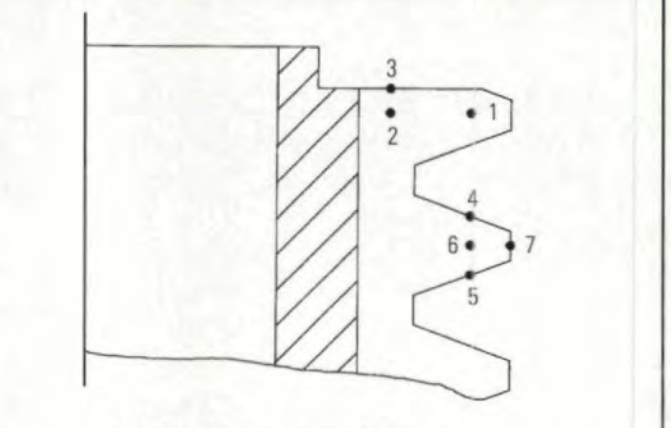


Fig. 27



Data Points Gathered During Orientation

Fig. 28

gathers all necessary information for automatic inspection. Fig. 27 presents an example with only one operator requirement — bringing the probe into the vicinity of the first tooth. Fig. 28 shows the sequence and data points gathered during orientation. These data points provide sufficient information for automatic inspection of all hob characteristics.

Conclusion

Hobs probably have the most sophisticated geometry of all gear cutting tools. In the past, few companies could check sharpening errors, let alone other characteristics, such as lead or pressure angle or line of action. It has not been unusual for hob users to rely on a "trust me" relationship with hob manufacturers. The user did not have much choice because of a lack of the equipment to prove or disprove a hob's accuracy.

Thanks to new computer technology, a comprehensive automatic hob inspection system is no longer a luxury — it is affordable to most hob and gear manufacturers. That is why there are more people in the industry who would like to have capabilities to question a supplier's claim about hob accuracy or be able to resolve tool related manufacturing puzzles.

However, the hob inspection itself will not mysteriously resolve all our manufacturing challenges. It can only supply additional and perhaps crucial information to help resolve our challenges. It is not enough to have the information. It is important to learn how to apply it. ■

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2. ANSI B94.7-1980
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4. VDI/VDE 2606
5. Kotlyar, Yefim, and John Lange "CNC Inspection and Evaluation of Gear Cutting Tools," AGMA, 1989.

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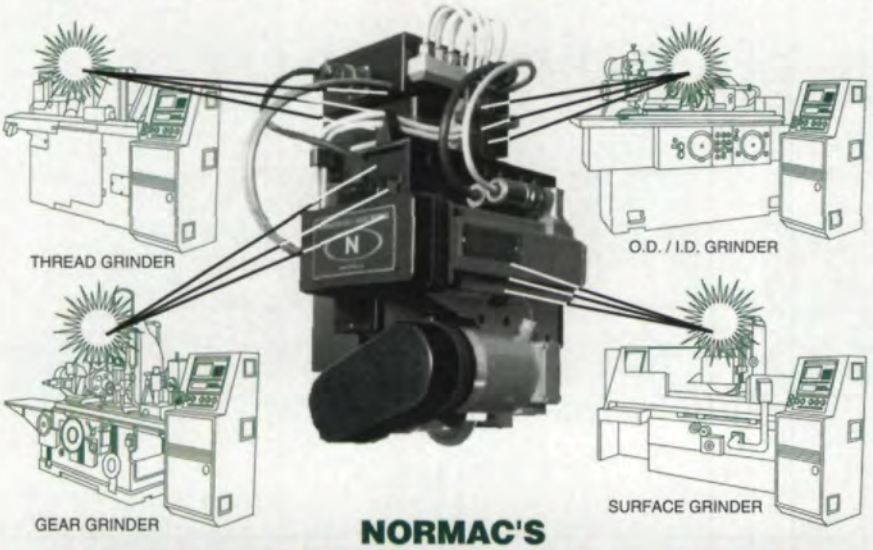

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The Frugal Certification Process

How to be ISO 9000-certified without losing your mind or emptying your wallet.

Amy Zuckerman

Much about ISO 9000 is the subject of noisy debate. But on one thing almost everyone, true believers and critics alike, agrees: Getting ISO 9000 certification can be expensive. Companies can expect to spend at least $35,000 for basic certification and six-month checkup fees over a three-year period. These figures do not include hidden costs like time and money spent on internal improvements required to meet ISO 9000 certification. But the really big-ticket items in the process are employee time and the cost of bringing in outside consultants. Many ISO 9000 consultants charge upwards of $1,800 a day.

However, there are ways to get an ISO 9000 certificate without blowing the top off your corporate budget. Certain "danger zones" that lead to increased spending appear during the certification process. Avoiding these can save your company thousands of dollars. These danger zones include initial panic, lack of information on ISO 9000, internal disorganization and reaching for outside help unnecessarily.

Don't Panic

Your decision about whether to pursue ISO 9000 certification should be a rational one, based on a careful assessment of your company's needs. Don't be steam-rollered into certification by hype. You may not need to go through the process. Check with industry leaders and your major customers. Take your lead from them.

Companies with local or regional operations and no contact with multinationals or exporting may find little or no pressure to pursue ISO 9000 certification. Suppliers to the automobile and metal tooling industries, for example, are being told by industry leaders to hold on seeking ISO 9000 certification while their industries find ways of weaving ISO 9000 into a "one-stop shopping" approach that offers guarantees that a company is working efficiently and producing a quality product.

Don't embark on ISO 9000 unless you feel it's necessary for efficient operation of your company and will assist you to stay competitive. It may be worthwhile to assess where your company stands vis-à-vis these standards. In this case, either conduct an in-house audit using your own staff, or hire a consultant to help with this one task.

Many companies are seeking certification to increase acceptability to overseas markets, as a marketing tool and as a means of improving their products and internal performance. Companies that have succeeded in obtaining an ISO 9000 certificate claim increased productivity, fewer on-the-job accidents, higher employee morale and better communication. While ISO 9000 is still in its relative infancy and cer-

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tificate holders remain rare in many industries, the certificate can be used as a marketing tool and to get a leg up on the competition.

Don't Rush

Don't embark on ISO 9000 certification in a hurry. Know as much about ISO 9000 as possible before embarking on a certification program. If a customer is pressuring you to become certified, negotiate a realistic timetable given your company's resources. Some customers are willing to subsidize the cost of ISO 9000 certification, so check with your customer base before proceeding.

Next, appoint someone in-house to oversee your certification process. Make sure this individual is aware of all aspects of your operation. As much as possible, ISO 9000 should be a home-grown process involving employees throughout your company.

The more you can rely on your employees to oversee certification, the less you will need to rely on outside consultants—and the less you will need to pay them. Your own employees know the most about your company, its operating procedures and its culture. They can be assisted by consultants on an as-needed basis.

Plan Ahead

Lack of in-house preparation and coordination may cost a company thousands of extra dollars. ISO 9000 is oriented heavily towards documentation of procedures. Determine a system for collecting, processing and formatting documentation of your operating procedures *before* embarking on meeting a registrar's ISO 9000 demands. Companies that lack quality control manuals must devise a means of culling information from employees, recording that information and formatting it, all the while continuing to operate their business. Even those with quality control departments and manuals may find their systems require an overhaul.

Because few manufacturers or even service companies tend to involve employees in reporting and documenting their functions, ISO 9000 can seem bewildering and even overwhelming. How to organize the work that leads to certification while staying in business can seem daunting. Rather than take a pause and create a system, many companies hire outsiders to move the process along for them.

Up-front organization and creation of a documentation system that suits your company may save countless hours of confusion in the long run. Saving hours almost always equals saving dollars.

Use Teamwork

Organize your management and employees to work under an ISO 9000 team system. If you read between the lines, you can tell that ISO 9000 is employee-intensive, meaning that it encourages involvement by as many

employees as possible. Although employee input may be extremely positive and beneficial to a company in the long run, involving employees in unfamiliar tasks can prove difficult, confusing and costly in the short run.

Those who have succeeded in earning ISO 9000 certificates did so because management was firmly behind the process, but did not actively lead it. Management assisted in the creation of a team system that involved employees as ISO 9000 coordinators, data collectors and ultimately as in-house auditors. The person chosen to oversee ISO 9000 certification should be well respected by employees of all levels.

Choose Outside Help With Care

Don't hire outside help carelessly or unnecessarily, and use that help sparingly. Now that you have your employees organized and have set up a system for collecting and processing data, hire a "quality" registrar. Such a registrar will guide you through the ISO 9000 standards. When selecting a consultant, search hard for one who will offer a means of saving costs and streamlining your ISO 9000 certification system, rather than adding on possibly needless hours of work. A quality consultant can help interpret the ISO 9000 standards, determine where your company ranks vis-à-vis ISO 9000 standards, conduct pre-assessment audits, train employees in internal auditing and assist in creation of a quality manual that meets ISO 9000 regulations.

Shop for a registrar who fits your company's bureaucratic style. Negotiate the best price possible. Registrars operate in the free market and are facing tough competition in the United States and Europe.

While new standards are being designed and new guidelines for ISO 9000 implementation are being drawn up over the next five years or so, individual registrars will still serve as the "interpreters" of the ISO 9000 standards. For this reason, it's important that companies embarking on ISO 9000 find the right registrar to suit their own needs and the requirements of their overseas customers. Small companies report that it's best to pick a registrar who's aware of the needs of a smaller business and will not enforce needless work and bureaucracy where none is required.

Horror stories about Europeans rejecting American-based certification are becoming common. *Not all American registrars are unacceptable to overseas customers.* If you want to work with Americans, check first with customers to determine your registrar's acceptability. There's no need to avoid American registrars. But there's also

(continued on page 41)

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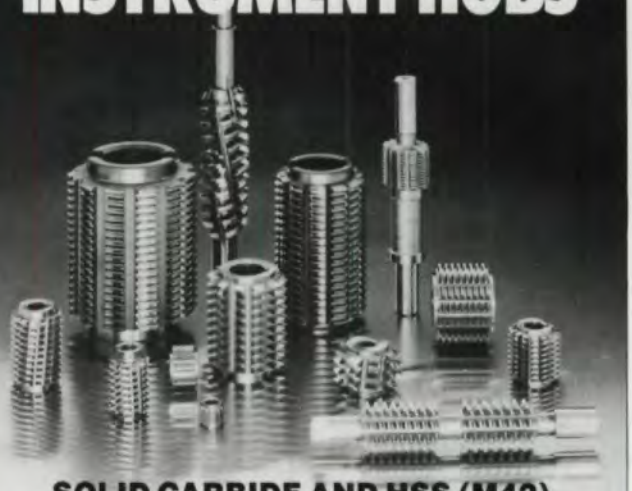

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AGMA Exec Speaks Out on ISO 9000

William R. Stott

With all the heated debate and hoopla surrounding ISO 9000 certification, everyone seems to have an opinion about whether to sign up. Executives in the gear industry are flooded with information and ideas that often seem at odds. *Gear Technology* asked AGMA executive director Joe T. Franklin, Jr. to give an industry perspective on the pros and cons of ISO 9000 certification.

AGMA itself is not directly involved with the ISO 9000 program or its implementation, nor has the organization taken an official stance on the program; however, AGMA is very vocal in its support of improving the quality of manufacturing worldwide, particularly as it may apply to gear manufacturing. Franklin says, "Our members would say that anything you do that improves the quality of your product and the confidence of the buyer in the quality of your product is something you should look at carefully."

Currently, fewer than a dozen AGMA members have become ISO 9000-certified. But those that Franklin has spoken with are almost unanimously in favor of the program. The ISO organization considers ISO 9000 a "quality management" standard, and one of the reasons for its popularity is that it is a highly disciplined process that forces companies to look more closely at their quality and the technical standards they use. "If somebody says they make grade II AGMA quality 10 gears, the ISO 9000 process simply makes them go back and validate every step," Franklin says. "For example, the incoming steel has to be good enough to support grade II loads, just as the tooth surface and the tooth tolerances at the end of the line have to be good enough for a quality 10 gear."

Regardless of the number of proponents who say the program improves quality, many detractors express concerns about the certification process. Chief among these concerns is the price tag. Many gear companies may not be able to afford the high cost of hiring a consultant, making the necessary changes and getting certified. In addition, it may be hard to measure how well the cost of certification is recovered. Some companies will be able to identify specific orders that were a result of certification, but generally certification will be only one of several factors that will lead to a sale.

"But for some companies, whether to become certified is largely a function of customer demand," Franklin commented. "It may be especially important when approaching new customers. Current customers already know a company's product and its quality, but for new customers, especially overseas, ISO 9000 certification may provide a level of assurance."

While there has been a lot of publicity about how ISO 9000 certification has become a booming business in its own right, that it's the latest flavor-of-the-month panacea and merely a cash cow for its marketers, nearly all of those AGMA members who are certified say that the program works. Quality has improved, they say.

Some have argued that the lack of regulation of the ISO 9000 certification program leads to a subjective certification process, that companies certified in America may not receive the same respect as companies certified in Europe. But of the companies Franklin has talked to, most say that the certification process is rigorous no matter who performs it. "They said ISO 9000 is to some extent subjective because it is a standard, but they totally disagreed that different assessors would rate you differently. They said that if you can pass one, you will pass all of them, and if you fail one, you will fail all of them."

While the certification process in America may be equivalent to the certification process in Europe, companies considering certification need to be wary of how their certifier is perceived by their customers. In the purchasing environment, the perception of quality may play an even larger role than quality itself.

Another criticism of the ISO 9000 program has been the concern over whether the program will become obsolete. Recently, the Commission of the European Community has unveiled plans for the creation of a European quality program. Although their program would use standards similar to ISO 9000, it would de-emphasize the certification process and focus more on the pursuit of quality for quality's sake.

But Franklin comments, "It is pretty astounding what people from Japan and Europe and other parts of Asia and the United States can do when we all sit down and agree first that we have a common objective. That objective is the best technology we can put together, as opposed to what sometimes comes across from the EC organization's formal position, which is the best way to keep business within the EC."

While he thinks the muscle flexing of the European Community may make people stop and think about whether ISO 9000 will last, the trend in industry is definitely toward some form of third-party certification. "Somebody, some third party, is going to stamp people 'good enough,' whatever that is," he explains, "and that is going to carry some weight within the purchasing community."

And when a program actually works to increase the quality of the product—as ISO 9000 proponents say it does—so much the better, says Franklin. "If you were evaluating hospitals in your neighborhood as to where you would go if you broke your leg or where you would go if you were going to have a child or your spouse were going to have a child, you would not ask, is this a clean hospital? That is an assumption. Part of the definition of being a hospital is being clean," he says. "I don't know when it will be, but at some point in the not-too-distant future, a basic assumption of being in the business means you are third-party certified by somebody to a quality standard.

"European gear manufacturers are virtually all ISO 9000-certified. During a recent meeting of the European gear industry, it was clear that they felt the customer expected ISO certification as a minimum condition."

As to whether that quality standard will be ISO 9000 or some other program, Franklin and AGMA have no ready answer. There are no easy choices regarding ISO 9000. The need for certification will have to be determined on a company-by-company basis, with each company evaluating its current quality standards and the requirements of its present and future customers. But for those who have made the investment, Franklin says, certification seems to be paying off. ■

(continued from page 40)

no need to find certification rejected after years of effort and money spent.

Finding an acceptable registrar will become more crucial as European national accreditation boards set higher standards. In recent weeks a report that may change the ISO 9000 landscape has been released by the Commission of the European Communities—an EC body. "Elements of a Community Quality Policy" calls for the creation of a pan-European quality program uniting the public and private sectors.

MANAGEMENT MATTERS

Although the ISO 9000 standards would be used as a basis for the program, the ISO 9000 certificates would be de-emphasized. This proposal is still in the discussion phase, but it bears watching and is one more reason why companies seeking certification need to be particularly cautious as they proceed.

Interview as many registrars as time permits. Use these interviews as a means of learning more about the ISO 9000 certification process. Do not hire a registrar until you are ready to start the ISO 9000 process.

Select outside help at a time in the process when that assistance is most needed. Learn as much about the ISO 9000 process as you can so you will get the most bang from your bucks when outside assistance appears beneficial.

And don't hire a consultant without checking all references thoroughly. This tip should seem unnecessary. But officials at the United States RAB report countless cases of companies that have rushed forward with ISO 9000 certification in a helter-skelter fashion. They hire someone to assist without checking his or her background, then complain later when the so-called consultant has overcharged them or proven otherwise deficient.

Richard Clements, director of the National ISO 9000 Support Groups, reports that a survey of roughly 800 ISO 9000 consultants indicates that less than a third of them had received formal ISO 9000 training. He agrees with the RAB that companies should be most selective when hiring outsiders. Take a little more time upfront and do proper screening. ISO 9000 preaches quality at all levels of an operation and a job. Checking references is the first step to doing this job—seeking ISO 9000 certification—properly.

It's true that the whole ISO 9000 plan is the suject of a good deal of controversy, but there is no need to leap on the bandwagon before you look or to refuse to ride along at all. Careful planning, research and implementation can make the process a positive one for your company. ■

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TO ERR IS HUMAN . . .

Three equations from "Minimizing Backlash in Spur Gears" by Richard L. Thoen, which appeared in our May/June issue were incorrectly printed. The correct versions are shown below.

The equation in the bottom left-hand column of page 26 should read:

$$\frac{S_b/2}{r_b} = \frac{S/2}{r} \text{ or } S_b = S\,\frac{r_b}{r}$$

The equation in the top right-hand column of page 26 should read:

$$\frac{S_b/2}{R_b} = \frac{S/2}{R} \text{ or } S_b = S\,\frac{R_b}{R}$$

Equation (7) on page 29 should read:

$$\text{inv } \phi = \text{inv } \Phi + \frac{\Delta T + \Delta t}{2C_b}$$

We apologize to Mr. Thoen and regret any inconvenience these errors may have caused our readers.

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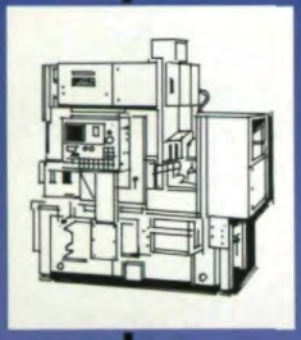

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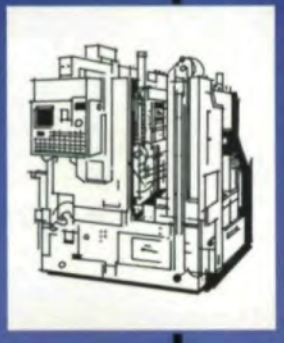

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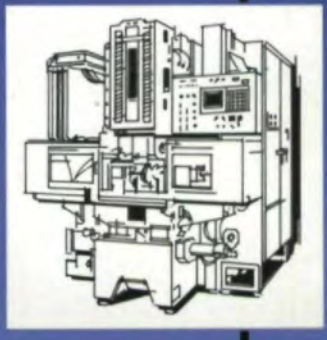

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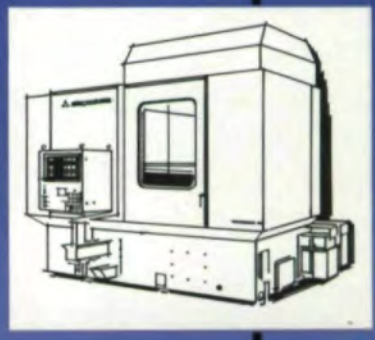

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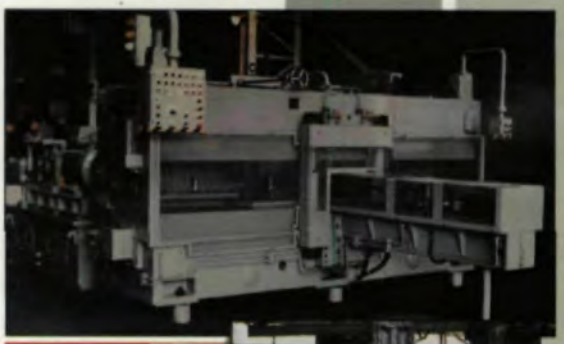
Blind Spline Broach Machines

SF Grinders

Single & Double-Die Gear Rollers

PGH Honers

GHH Honers



PFL Rack Rollers

Large Broach Machines

NACOM Broach Sharpeners

BVT Broach Machines

National Broach works rings around your tough gear applications...

...to help you ring up more profits through greater productivity.

National Broach, an industry leader in the gear finishing arena, now offers a complete line of gear manufacturing machines and tools.

From hobbing through honing, using the latest cell manufacturing techniques, you can now efficiently machine blanks into finished gears on Red Ring machines. You'll also add the convenience of a single-source for gear machines to the long list of traditional Red Ring advantages.

As with our quality-award-winning gear finishing tools, the full Red Ring line of machines is backed by our commitment to total customer support. To let us show you, just give us a ring.

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