Controlling Tooth Loads In Helical Gears

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Helical gears can drive either nonparallel or parallel shafts. When these gears are used with nonparallel shafts, the contact is a point, and the design and manufacturing requirements are less critical than for gears driving parallel shafts. With parallel shafts, the theoretical contact is a line (at an angle to the gear axis) that sweeps across the face of the teeth. Most problems with parallel-shaft helical gears can be traced to the fact that this theoretical contact is difficult to produce.

As with any gear drive, the performance and capacity of helical gears depend on the nature and extent of the contact between mating gear teeth. With helical teeth, and a wide enough face, multitooth contact is possible, but the load will not be shared equally among the teeth. Factors that prevent equal load distribution include: 1. Form, spacing, and lead errors. 2. Elastic deformation of the teeth and blanks under load. 3. Thermal distortion of the gears, shafts, and housing.

Despite these problems, properly designed and manufactured helical gears make effective drives. Good gear operation is a function of the action between mating teeth (approach or recess) and how well the gear leads match. Gear action is determined by geometry and can be controlled by design. Lead accuracy, on the other hand, is restricted by the quality of the gear generating machinery and cannot be controlled directly. But lead accuracy can be controlled indirectly by properly specifying the lead and by ensuring the gears are produced on "exact-ratio" cutting machines.

Cutting Machine Limitations

Helical gears are generated by shaping or hobbing, and they are finished by shaving, grinding, or honing. Both generating mnethods have disadvantages in that they introduce forming errors that are difficult to correct with a finishing operation. Close monitoring while cutting is the only way to minimize these errors.

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Shaping uses a pinion shaped cutter in conjunction with a helical guide to produce the helix. But, this technique leaves tool marks (perpendicular to the direction of sliding) that must be removed by a finishing operation. The only factor controlling lead accuracy is the accuracy of the guide.

Hobbing, on the other hand, uses an indexing drive train to produce the helix. Most helical gears are hobbed because new shaping guides do not have to be built for each new gear design. With this technique, each stage of manufacturing must be closely monitored to ensure quality gears. Errors in tooth form, spacing, or lead produced during rough-cutting may remain after final grinding. To assume that grinding corrects all hobbing errors is poor practice.

Gear generating equipment that may be adequate to hob other gear forms usually is not adequate for helical gears. The nature of the action in the other forms tends to correct errors introduced by the generating equipment. This correction results from cold-working of the contact surfaces. But, because of the cross-sliding action in helical gears, cold-working occurs to a much lesser degree, if at all.

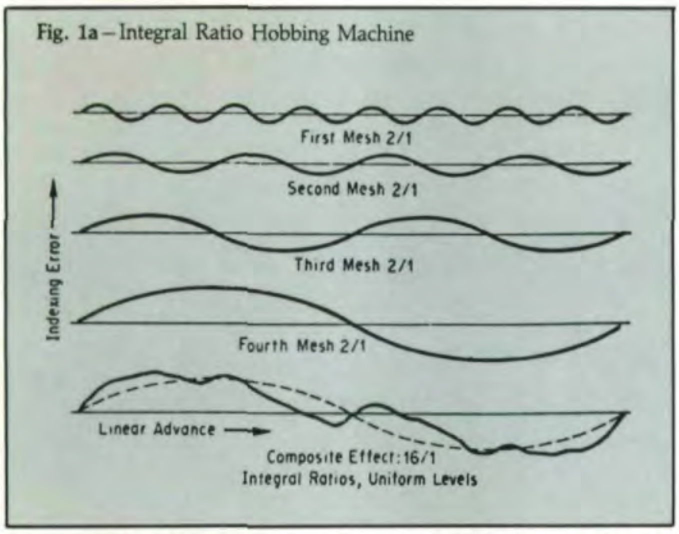
For example, a spur gear may be "free-wheeled" on a grinder with a threaded grinding wheel. (Free-wheeling means the drive train to work the spindle is disconnected, and the wheel drives the work.) If this method is handled properly, form and spacing errors on a spur gear can be reduced from one-half to one-third the errors produced when the work is driven through the indexing gear train. Unfortunately, free-wheeling does not work on helical gears.

Controlling Hobbing Machine Errors

In a hobbing machine, the positional or indexing error of the output shaft is a composite effect of the indexing errors of all the gear pairs in the machine drive. For example, Fig. 1a shows the composite effect of a hobbing index drive where each gear pair is an exact ratio. If the indexing error is the same for each pair, the total error has an amplitude greater than that of any of the individual errors, but less than the sum total of all the errors. The curves close at the end of each revolution of the slow-speed shaft, so the total indexing error is fixed and repeats for each revolution.

But, for the nonintegral (or hunting-tooth) ratio, Fig. 1b, the maximum indexing error is greater, and the curves do not close at the end of each revolution. Thus, the indexing error is constantly changing.

Hobbing machines with long gear trains or differentials are hunting-tooth drives. When these drives produce a helical gear, the indexing error causes "drunkenness" (nonuniformi-



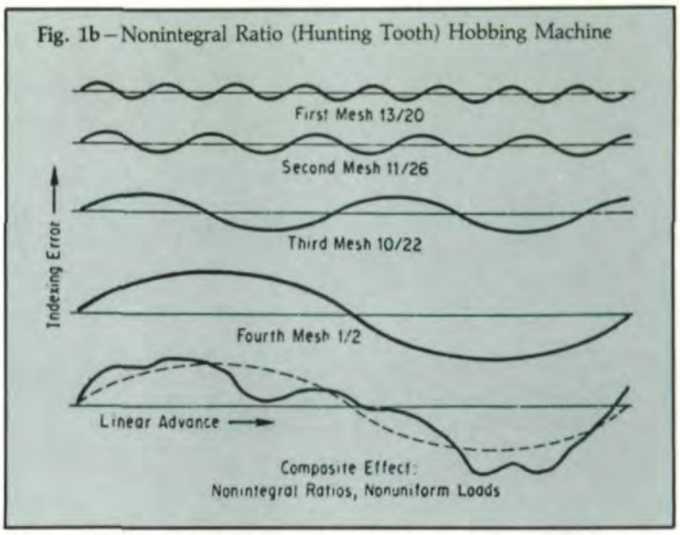


Fig. 1 – Hobbing machine indexing errors. With short-gear train, integral ratio drives, *a*, hobbing machines generate more uniform, better matched helical gears. Indexing error is uniform and repeats for every revolution of the slow-speed shaft. With nonuniform, hunting-tooth drives, *b*, indexing error varies for each revolution, producing less accurate gears.

ty) in the lead. For example, compare the lead profiles in Fig. 2. The first gear was produced with no effort to ensure a short gear train or integral ratios, and the second gear was produced on a machine using exact ratios. The second gear has a more uniform lead. Therefore, to minimize lead errors, use a cutting machine with an exact-ratio indexing drive.

Specify Lead

The lead, advance of the helix in one revolution, is one of the most important design parameters of a helical gear. For helical gears to contact properly, the leads must be exactly proportional to the number of teeth; that is, $L_1/L_2 = N_1/N_2$, where L_1 and L_2 = gear leads and N_1 and N_2 =

Table 1—Conventional Design vs. Exact-Lead Designs

Design Parameter	Conventional Design	Exact Leads: Standard Form	Exact Leads: Full Recess
Number of Driver Teeth	60	60	60
Number of Follower Teeth	120	120	120
Hob Pressure Angle (°)	*20*	*20*	*20*
Hob Diametral Pitch	5	5	5
Operating Center Distance (in.)	18.75	18.75	13.75
Face Width (in.)	3.54	3.54	3.54
Helix Angle (°)	16.26020470	16.5946787	16.5946787
Driver Lead	134.6396851	132.0	132.0
Follower Lead	269.2793703	264.0	264.0
Driver OD (in.)	12.90	12.90	13.30
Driver Pitch Diam (in.)	12.50	12.50	12.50
Follower OD (in.)	25.40	25.40	25.00
Follower Pitch Diam (in.)	25.00	25.00	25.00
Contact Ratio			
Plane of Rotation	1.715	1.610	1.452
Face Contact	1.577	1.609	1.609
Total	3.292	3.219	3.061

By specifying exact leads, helical gears can be produced more easily on conventional hobbing machines. Exact leads can be generated and measured more readily than leads calculated to eight places by a machinist. And a drive with exact leads has nearly the same helix angle and contact ratio as conventional designs.

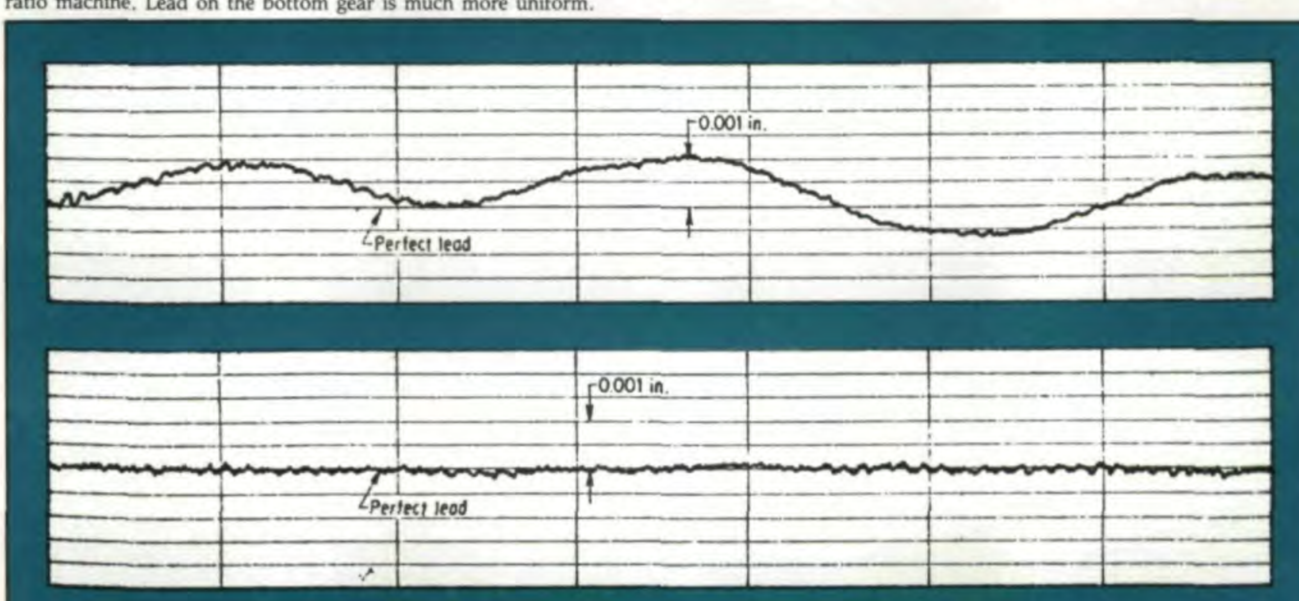
number of gear teeth. If this relationship is not maintained, then the two helixes will not be parallel, resulting in unequal contact across the face and high unit loading.

For shaped gears, the helix and lead are controlled by the mechanical guide. Provided the guide is accurate, this system produces leads that are proportional to the number of teeth. But most helical gears are hobbed, the helix angle is specified, and the lead often is not even listed on the print.

Helix angle cannot be measured by conventional equipment and cannot be set on the hobbing machine. The lead, however, can be measured easily and also can be set on the equipment. But, if the lead is not specified, the machinist must calculate it from $L = \pi N / P_{nc} \sin \psi$, where P_{nc} = hob diametral pitch and ψ_1 = helix angle. To ensure proper tooth contact, L should be accurate to eight places. But, unless L is a simple number (an integer, common decimal, or ratio of two integers less than 100), it cannot be manufactured or measured accurately to eight places. Therefore, leads should always be exact numbers.

Table 1 compares a set of helical gears cut by the conventional hobbing method (of simply specifying helix angle) with two gear sets designed to have exact leads. Note the small difference between the leads and helix angles. However, the

Fig. 2—Helical gear lead profiles. The top gear was hobbed on a nonintegral, hunting-tooth ratio machine, and the bottom gear on an integral-ratio machine. Lead on the bottom gear is much more uniform.



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TECHNICAL CALENDAR

March 23-25 **14th Annual AGMA Gear Manufacturing Symposium**
Holiday Inn, Airport
Indianapolis, Indiana

AGMS's 1986 Manufacturing Symposium will offer an open forum with industry experts and papers on topics of interest to everyone involved in gear manufacturing. The focus of this year's Symposium will he Hard Finishing, Heat Treatment, Process Control and Basic Gear Technology. As with past symposiums, the papers presented will provide the latest information on each of the subjects. Attendess will have the opportunity to ask questions of the speakers following each presentation.

For further information call: Polly MacKay, Meetings Coordinator, American Gear Manufacturers Association — (703) 684-0211.

April 7 **Deburring & Surface Refinement by Mass Finishing Methods**

Contact Anna Guy at SME, (313) 271-1500, ext. 370.

April 8-9 **Applying Modern Buff, Brush & Polish Techniques**

Contact Dianne Leverton at SME, (313) 271-1500, ext. 394.

April 10-11 **Nontraditional Deburring & Final Finish Machining Methods**

Contact Dianne Leverton at SME, (313) 271-1500, Ext. 394.

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last two designs are much easier to set up and measure. Also, $L_1/L_2 = N_1/N_2$ for the exact designs, but not for the conventional design.

If L is chosen to be $L = A/P_{nc}$, where A = any integer, then equating this expression for L with the previous equation for L and solving for sin ψ_1 yields sin $\psi_1 = \pi/A$. Table 2 lists ψ_1 for various values of A. If a helical gear pair is to be redsigned to use exact leads, then a value of A can be chosen from Table 2 to give approximately the same helix angle as the original design. (Refer to Table 1 and compare $\psi_1 = 16.26020470°$ for the original design to $\psi_1 = 16.26020470°$ for the improved designs.)

To accommodate the same center distance, one or both of the gears may be enlarged or reduced slightly. If, for some reason, the helix angle must be closer than those listed in Table 2, a decimal value for A can be used (9.1 or 9.3 for example). This approach is still preferable to trying to make L accurate to eight places.

Approach vs. Recess

Helical gears are best used in single pairs only. When the operating conditions are such that one gear is always the driver and the other always the follower, all recess action should be specified. This design places the pitch line of the driver at the bottom of the working tooth depth and the pitch line of the follower at the outside diameter. The result is low noise and friction, improved lubrication characteristics, and increased surface endurance. If the drive is used in an application where either gear is the driver, then the pitch line should be at the center of the tooth working depth.

E-2 ON READER REPLY CARD

DESIGN AND SELECTION OF HOBS . . .
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life is very much dependent on the adherence between the substrate and the titanium nitride layer.

Measuring the ability to adhere is a difficult problem. The most common method is the "scratch test". A small radius diamond is scratched across the surface of the titanium nitride coated sample. The load on the diamond is successively increased until flaking occurs. The load at which flaking occurs is referred to as the critical load. This critical load, however, is also dependent on hardness of the substrate material, cleaning process, and the method of titanium nitride application. It is not possible to rate present high speed steels according to adherence capability due to the measuring difficulty described above. It can be said, however, that generally the same tool life relation between the different high speed steels also exists after the titanium nitride coating, but at a higher level.

Once the titanium nitride begins to flake or abrade away, the wear resistance of a coated tool depends to a great extent on the substrate material. For this reason along with previous comments on crater resistance, it is suggested that the best results (tool life) of coated tools have been obtained using the high alloy powdered metal tools steels.

E-4 ON READER REPLY CARD

This paper was presented previously at the SME Gear Processing and Manufacturing Clinic, November 1985.