Computerized Hob Inspection & Applications of Inspection Results

Part II

Yefim Kotlyar
Global Gear
Downers Grove, IL

Editor's Note: *The first half of this article appeared in our May/June 1994 issue.*

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).

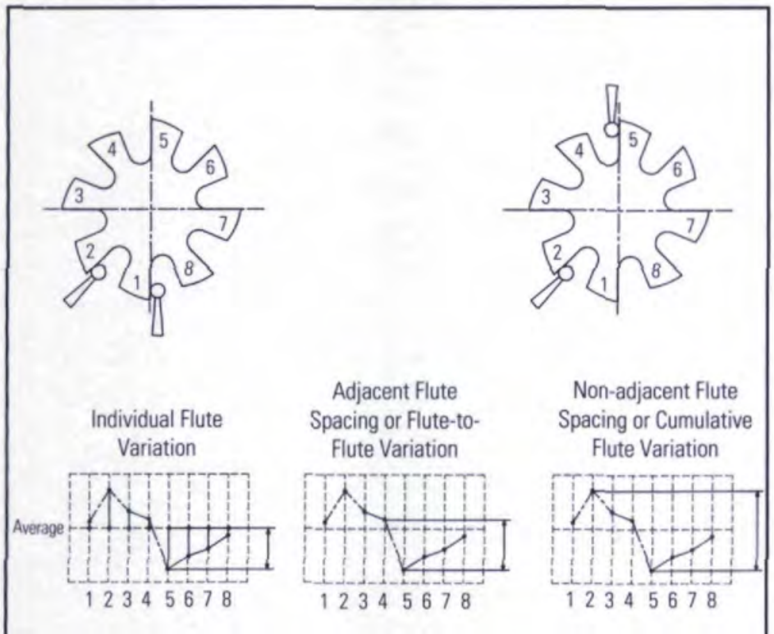
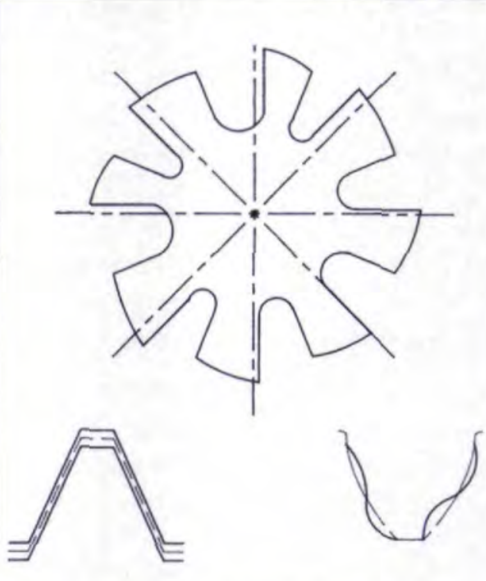


Fig. 1



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:

$$\text{Radial misposition} = (\text{cumulative spacing error}) \cdot (\text{cam size}) \cdot (\text{number of flutes}) \cdot \text{correction}/[\pi \cdot (\text{index measuring diameter})]$$

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:

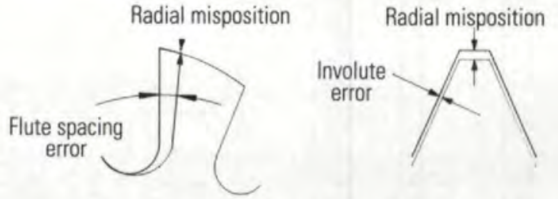
$$\text{Gear profile variation} = (\text{radial misposition}) \cdot \sin(\text{axial pressure angle})$$

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



$$\text{Radial Misposition} = \frac{\text{Cumulative Error} \cdot \text{Cam Size} \cdot \text{Number Flutes} \cdot \text{Correction}}{\pi \cdot \text{Measuring Diameter}}$$

Gear Profile Error = Radial Misposition • Sin(Axial Pressure Angle)

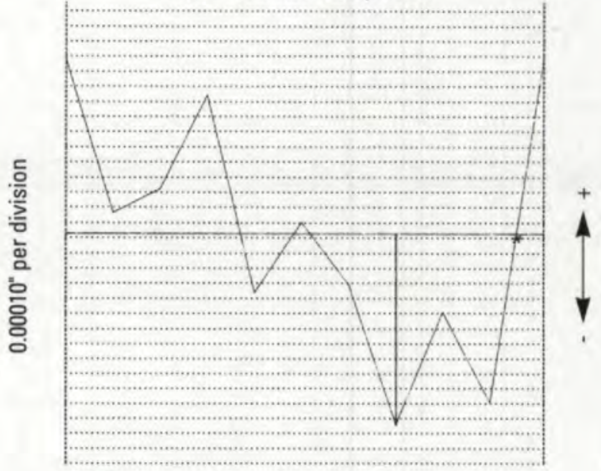
Correction = 1 — for Straight Flute Hobs
HN/(HN ± H) — for Helical Flute Hobs
HN = Flute Lead H = Thread Lead
(–) is used when flute and thread have the same hand.

Relation Between Flute 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

Hob Gash Index Inspection



Gash/Tooth	Toler.	1/2
Total	0.00500	0.00242:A
Variation		–0.00127
Adjacent Gash	0.00150	0.00228:D
Actual Quality		D

Fig. 4

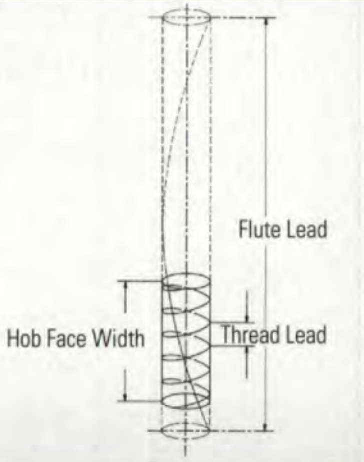


Fig. 5

Yefim Kotlyar
is a manufacturing engineer with Global Gear in Downers Grove, IL. He has also worked for American Pfauter, L. P., Loves Park, IL, and Roto-Technology, Inc., Dayton, OH. He is the author of numerous papers on gearing subjects.

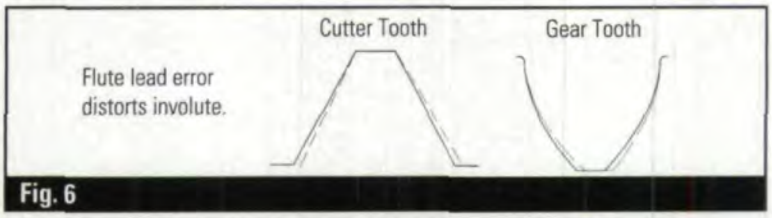
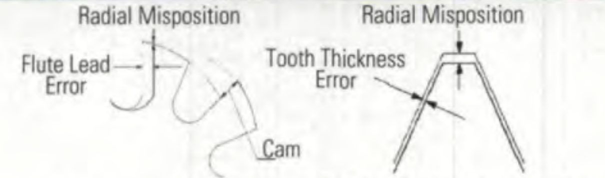


Fig. 6



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

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

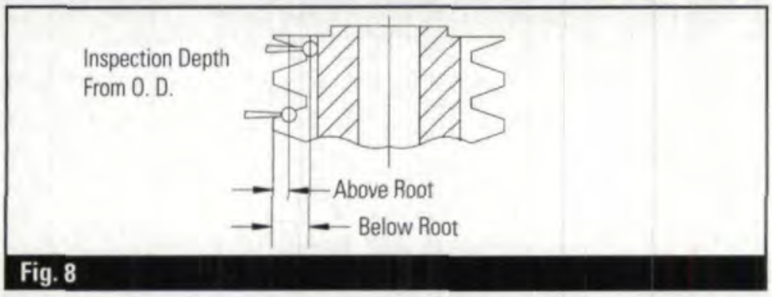
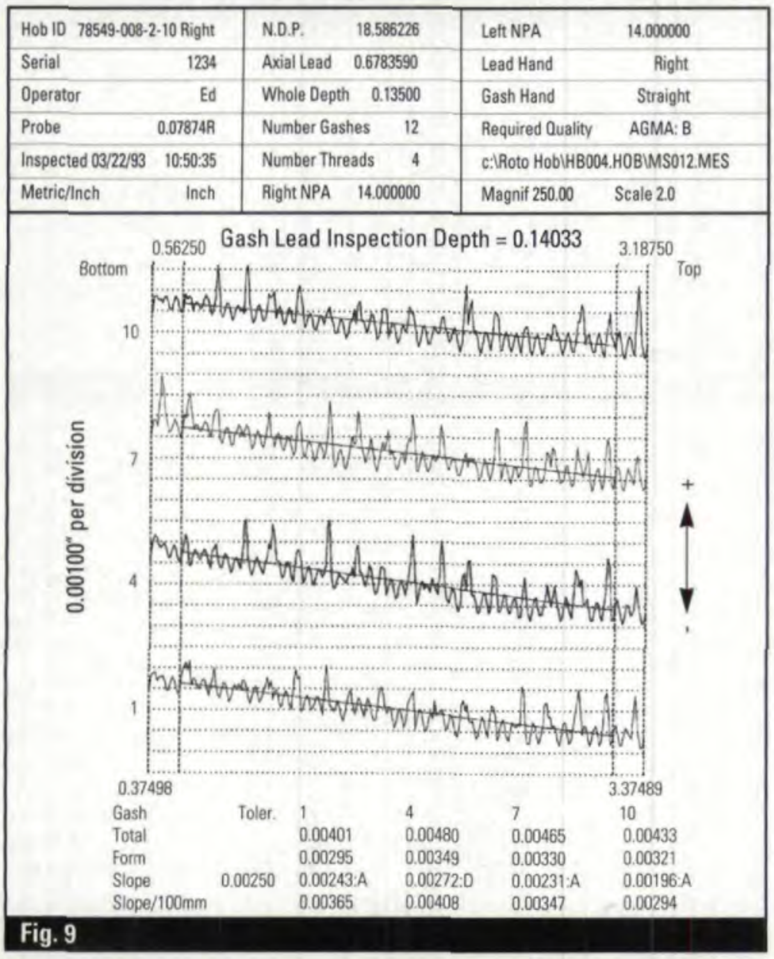


Fig. 8



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 Lead Inspection Depth = 0.14033

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:

Radial misposition
= (flute lead error) • (cam size)
• (number of flutes) • correction
/[π • (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:

Tooth thickness error
= 2 • (radial misposition)
• sin(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:

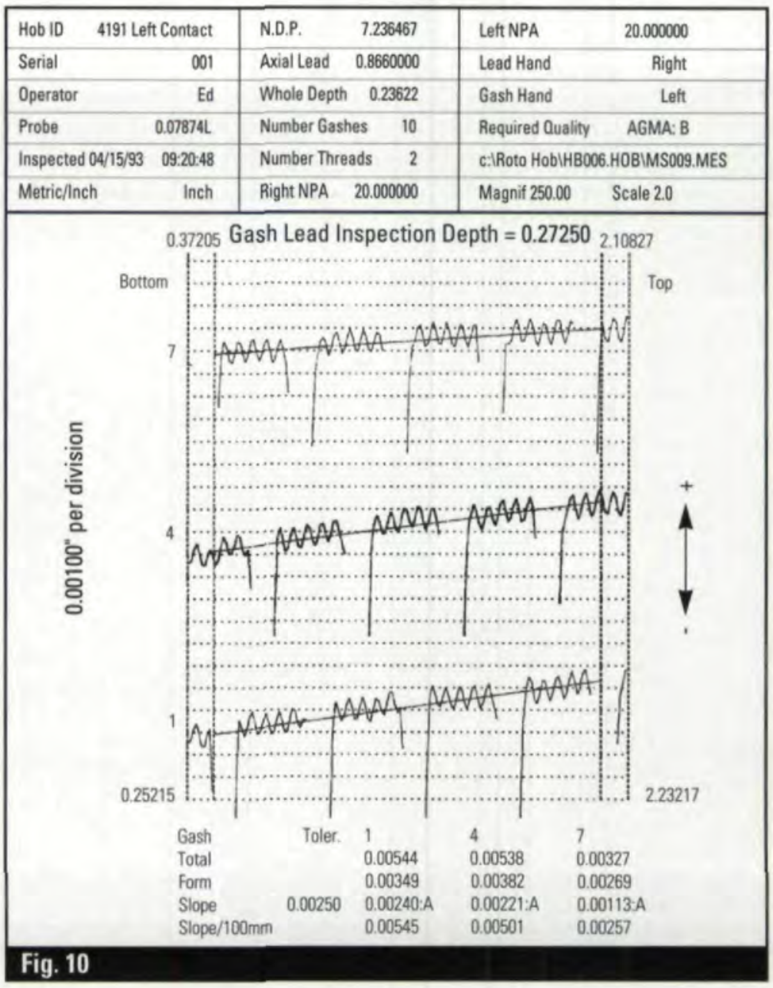
Total profile error
= (lead error within generating zone)
• cos(axial pressure angle)

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



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 250.00	Scale 2.0

Gash	Toler.	1	4	7
Total		0.00544	0.00538	0.00327
Form		0.00349	0.00382	0.00269
Slope	0.00250	0.00240:A	0.00221:A	0.00113:A
Slope/100mm		0.00545	0.00501	0.00257

Fig. 10

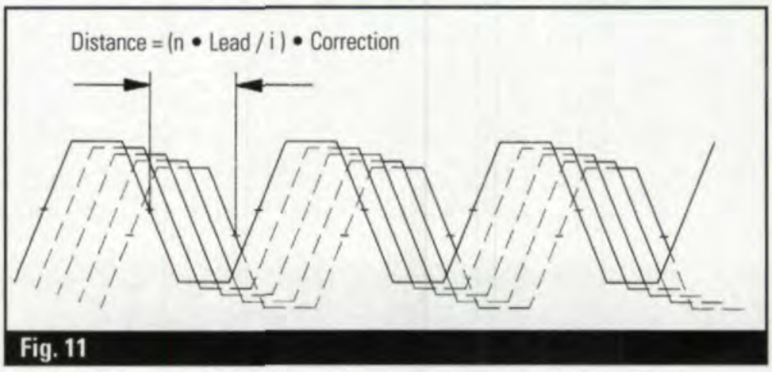
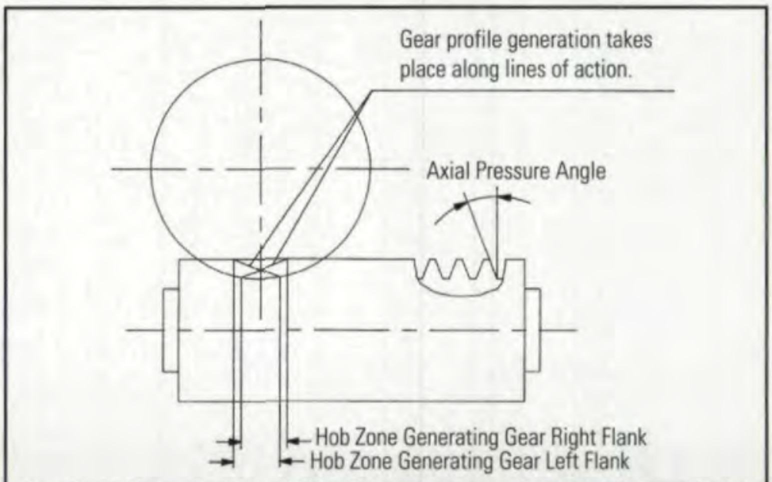
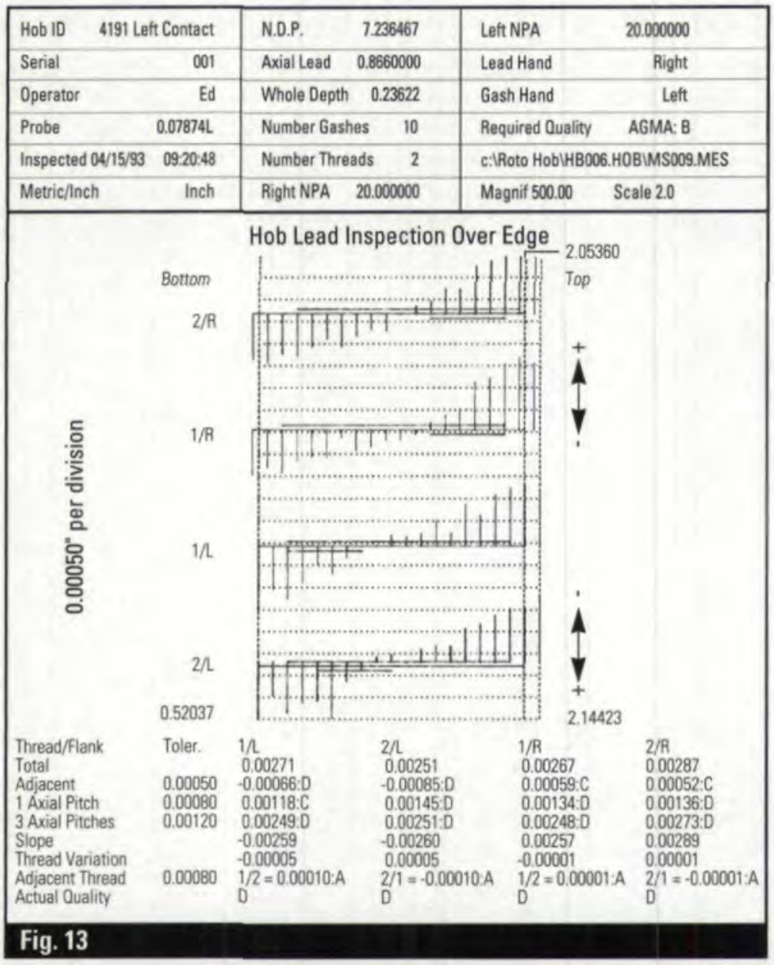


Fig. 11



Gear Profile Error = Lead Error Within Generating Zone • Cos (Axial Pressure Angle)

Fig. 12

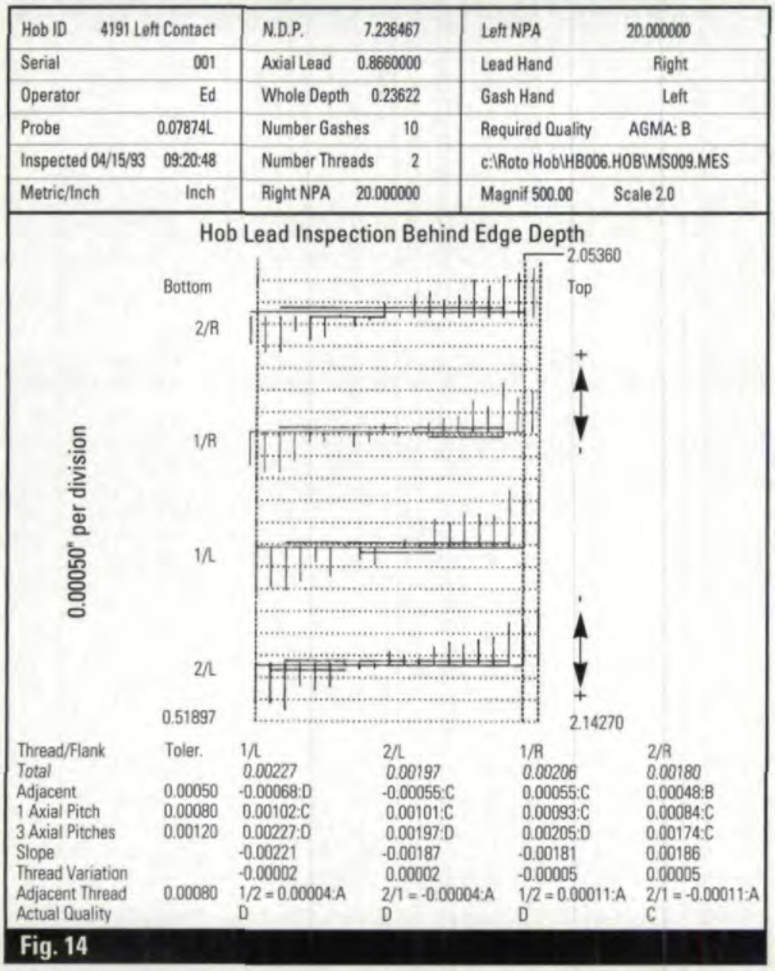


Hob ID	4191 Left Contact	N.D.P.	7.236467	Left NPA	20.000000
Serial	001	Axial Lead	0.8660000	Lead Hand	Right
Operator	Ed	Whole Depth	0.23622	Gash Hand	Left
Probe	0.07874L	Number Gashes	10	Required Quality	AGMA: B
Inspected 04/15/93	09:20:48	Number Threads	2	c:\Roto Hob\HB006.HOB\MS009.MES	
Metric/Inch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

Hob Lead Inspection Over Edge

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

Hob Lead Inspection Behind Edge Depth

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

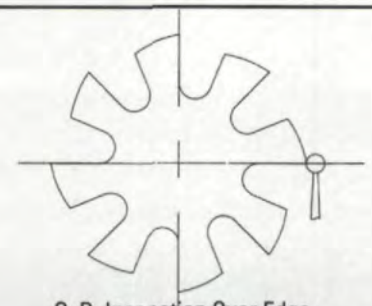
Pressure angle inspection is the inspection of a hob tooth profile (Fig. 20). Frequently, the hob tooth profile angle is the same as the gear pressure angle at the pitch diameter.

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.

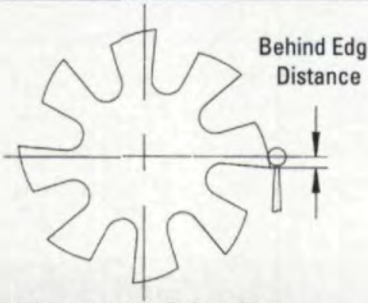
Line of Action

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

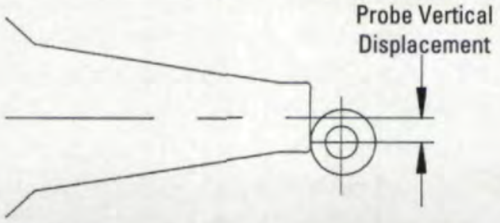
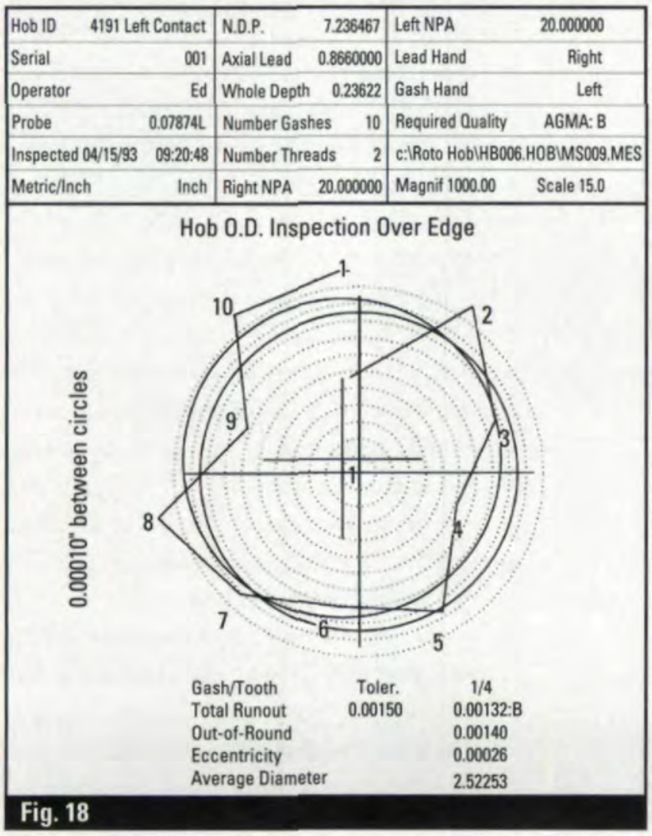


Fig. 17

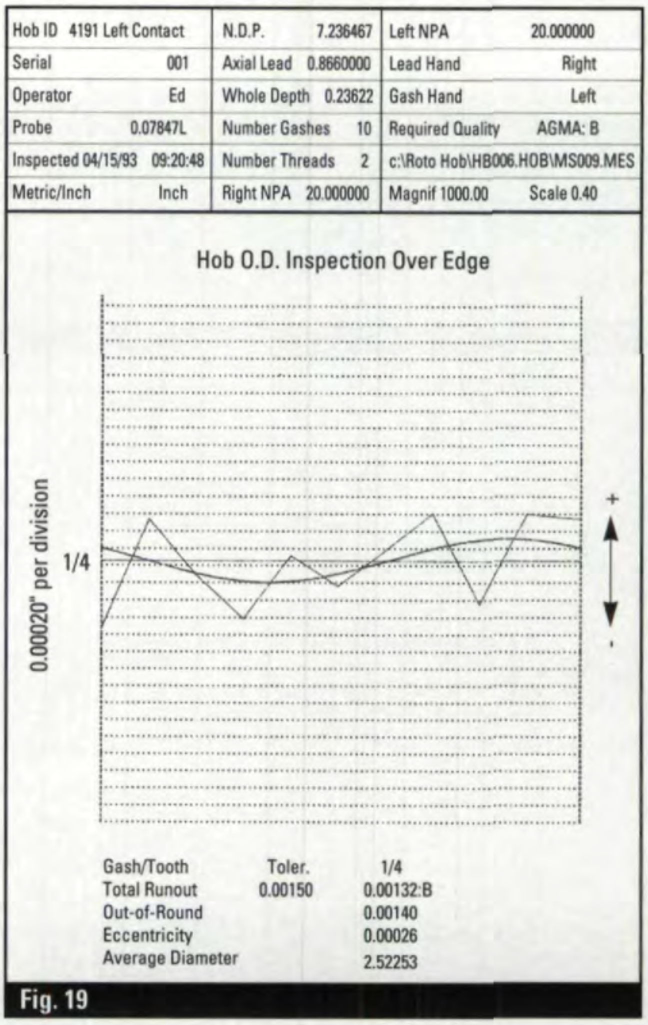


Hob ID 4191 Left Contact	N.D.P. 7.236467	Left NPA 20.000000
Serial 001	Axial Lead 0.8660000	Lead Hand Right
Operator Ed	Whole Depth 0.23622	Gash Hand Left
Probe 0.07874L	Number Gashes 10	Required Quality AGMA: B
Inspected 04/15/93 09:20:48	Number Threads 2	c:\Roto Hob\HB006.HOB\MS009.MES
Metric/Inch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

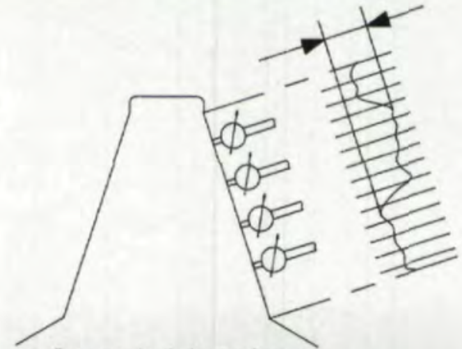


Hob ID 4191 Left Contact	N.D.P. 7.236467	Left NPA 20.000000
Serial 001	Axial Lead 0.8660000	Lead Hand Right
Operator Ed	Whole Depth 0.23622	Gash Hand Left
Probe 0.07847L	Number Gashes 10	Required Quality AGMA: B
Inspected 04/15/93 09:20:48	Number Threads 2	c:\Roto Hob\HB006.HOB\MS009.MES
Metric/Inch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

Hob O.D. Inspection Over Edge

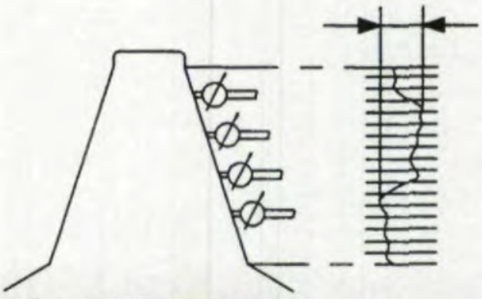
Gash/Tooth	Toler.	1/4
Total Runout	0.00150	0.00132:B
Out-of-Round		0.00140
Eccentricity		0.00026
Average Diameter		2.52253

Fig. 19



Pressure Angle Inspection

Fig. 20



Pressure Angle Inspection

Fig. 21

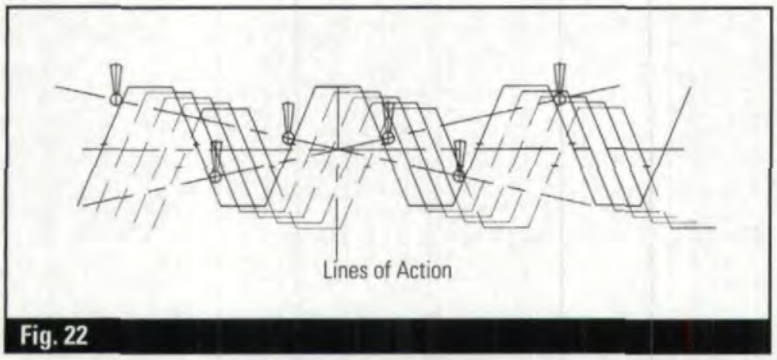


Fig. 22

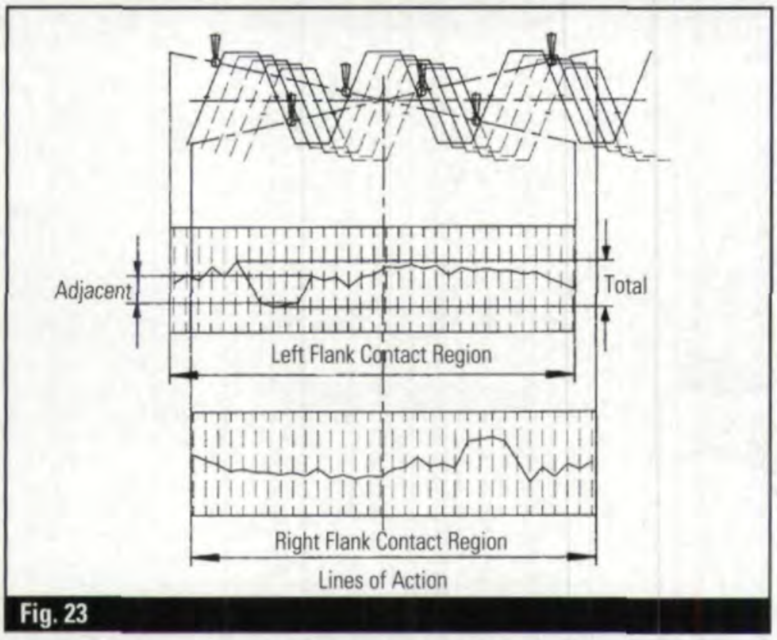
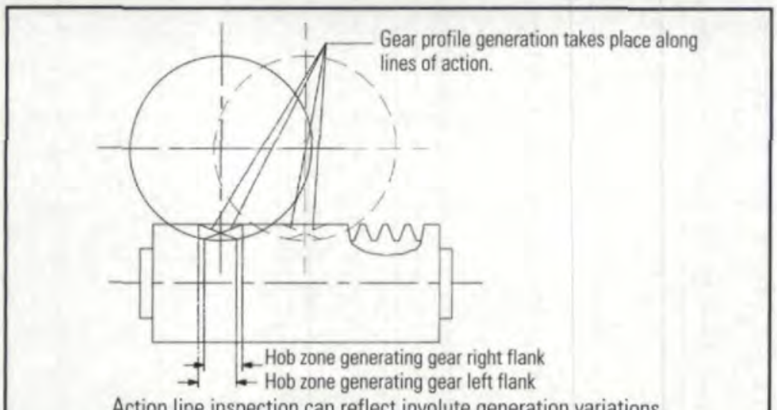


Fig. 23



Action line inspection can reflect involute generation variations only in a specific single hob position.

Fig. 24

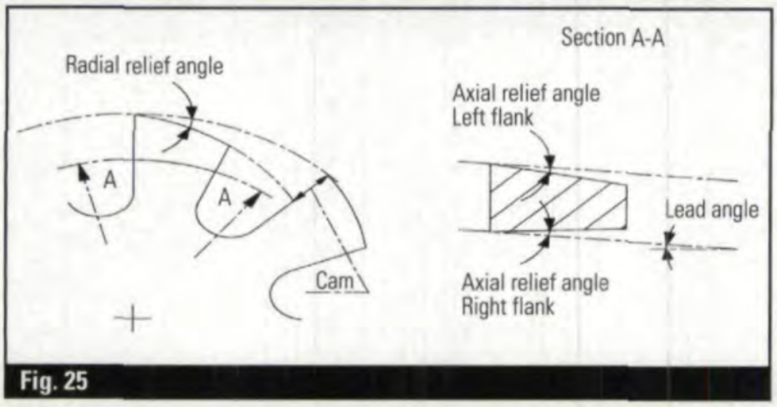


Fig. 25

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

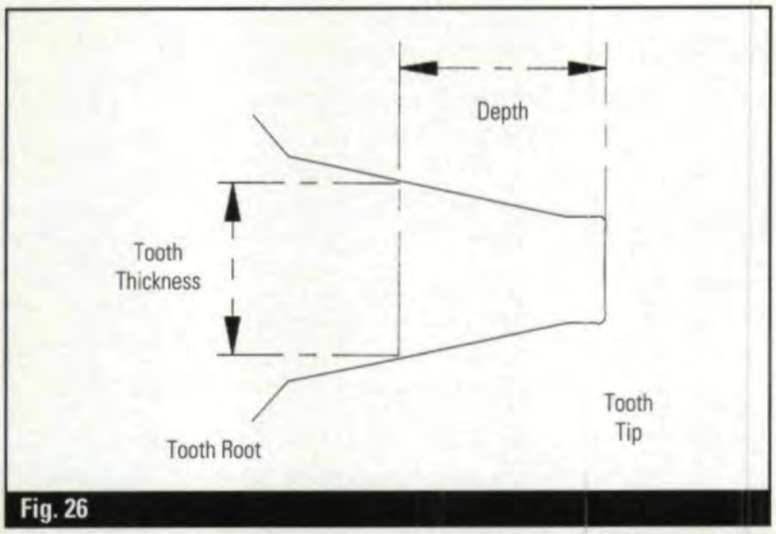
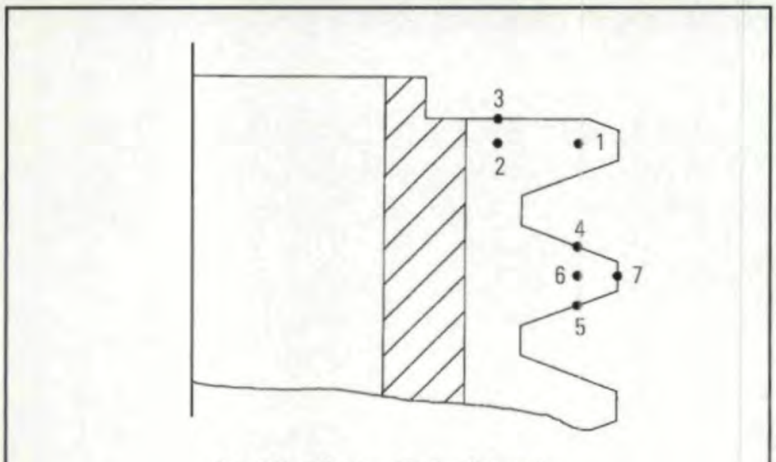


Fig. 26

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. ■

References:

1. AGMA Standards
2. ANSI B94.7-1980
3. DIN 3968-1069, 3000-1962, 3960-1980
4. VDI/VDE 2606
5. Kotlyar, Yefim, and John Lange "CNC Inspection and Evaluation of Gear Cutting Tools," AGMA, 1989.

Acknowledgements: *The author wishes to thank the following people for their help with this article: Ed Driscoll, who helped write many parts of this article; John Lange, for co-authoring a similar article on this subject; and Lauren Brombert and Esther Munsey for their editing help.*

Hob inspection charts are courtesy of Roto-Technology, Inc., Dayton, OH.

This article was first presented at the 1993 AGMA Gear Manufacturing Symposium.