Effects of Hob Quality and Resharpening Errors on Generating Accuracy

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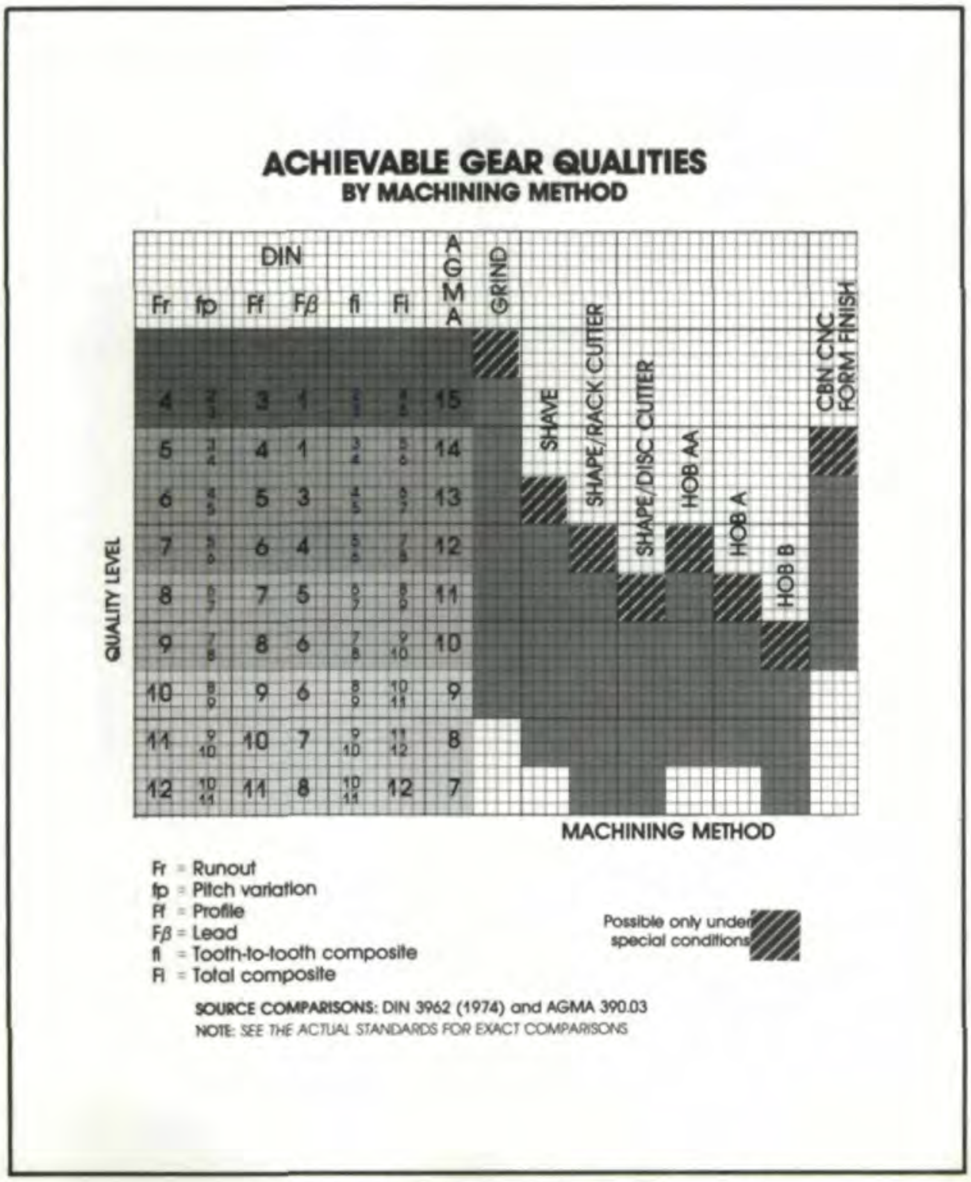

Fig. 1 – Achievable accuracies by machining method.

Introduction

The modern day requirement for precision finished hobbed gears, coupled with the high accuracy characteristics of modern CNC hobbing machines, demands high tool accuracy.

Modern CNC hobbing machines are capable of producing gears with lead and pitch accuracies of AGMA 14-15, but are still limited by the manufactured accuracy of the hob to a lower quality level on the involute profile (Fig. 1). For high accuracy hobbed profiles, high accuracy hobs are necessary.

The geometric peculiarities of the involute worm, from which the hob is derived, must be clearly understood to avoid loss of hobbed accuracy. Purchased tool accuracy and tool resharpening maintenance bear scrutiny in order to preserve hobbed accuracy.

Geometrical Peculiarities of Hobs

A hob is derived from the involute helicoid worm. A hob is a rotating cut-

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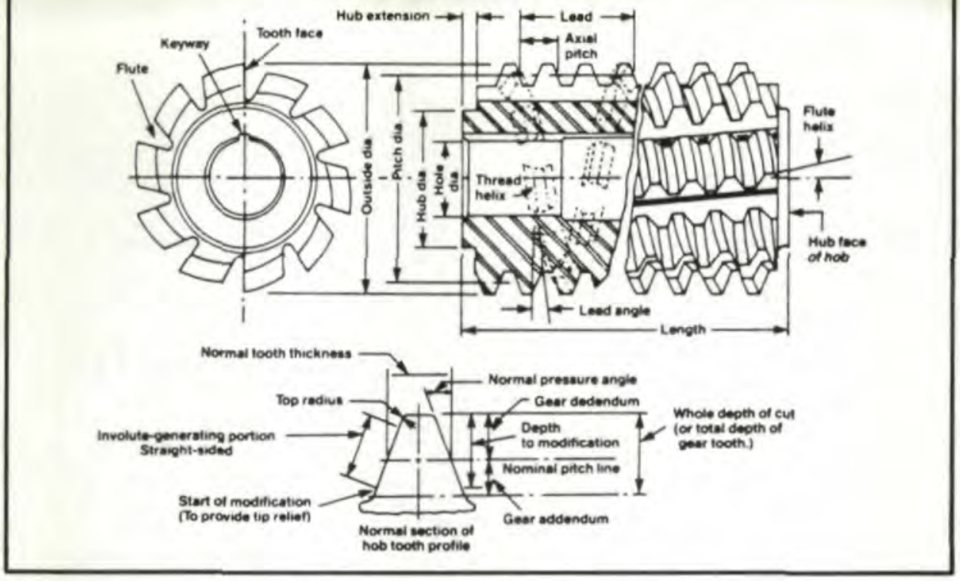


Fig. 2 – Geometrical elements of a typical cylindrical hob.

ting tool with its cutting edges arranged along a helix. It is used for generating gear teeth or other forms in a cylindrical workpiece (Fig. 2).

A hob is a reducing cylinder. Over its usable lifetime its diameter gets smaller due to repeated sharpenings. Each time it is resharpened it changes size relative to the amount of outside (tip) clearance and flank clearance (cam or backoff).

Every hob is designed with a basic (generating) rack profile which defines the pressure angle, the addendum and dedendum, the fillet radius, design modifications of the addendum profile, and design modifications for preshave, pregrind, preroll and prehard finish.

The Nature of the Enveloping Cut

Deviations from the theoretical or design generating helix of the hob (Figs. 3 and 4) effect the polygonal path of the enveloping cut along the gear tooth profile.

Figs. 3 and 4 show a single thread hob. In one revolution of the hob each of the 12 cutting edges removes metal from the tooth space enveloping the profile. The profile is made up of a series of individual cuts. The more cutting edges in a hob, the finer the network of enveloping cuts. The fewer the number of cutting edges in the hob, the rougher the involute profile.

If the hob is manufactured with deviations along its generating helix (thread error) or is resharpened so as to displace one or more cutting edges from the nominal pitch line cylinder of hob, the effect is a deviation in the network of enveloping cuts. This deviation manifests itself as profile error (Fig. 5).

Incorrect resharpening of the hob produces deviations in the design geometry which effect the basic rack tooth form of the hob, the position of one cutting edge to another, the rake of the hob cutting edge, and the lead of the gash (whether straight or spiral). These deviations are reproduced in varying magnitudes on the involute profile of the gear.

Mounting a theoretically perfect hob on an eccentrically running arbor causes the hob cutting edges to advance and retract in one revolution. This causes an advance and retreat of the network of enveloping cuts from the nominal, producing a "wandering" involute profile.

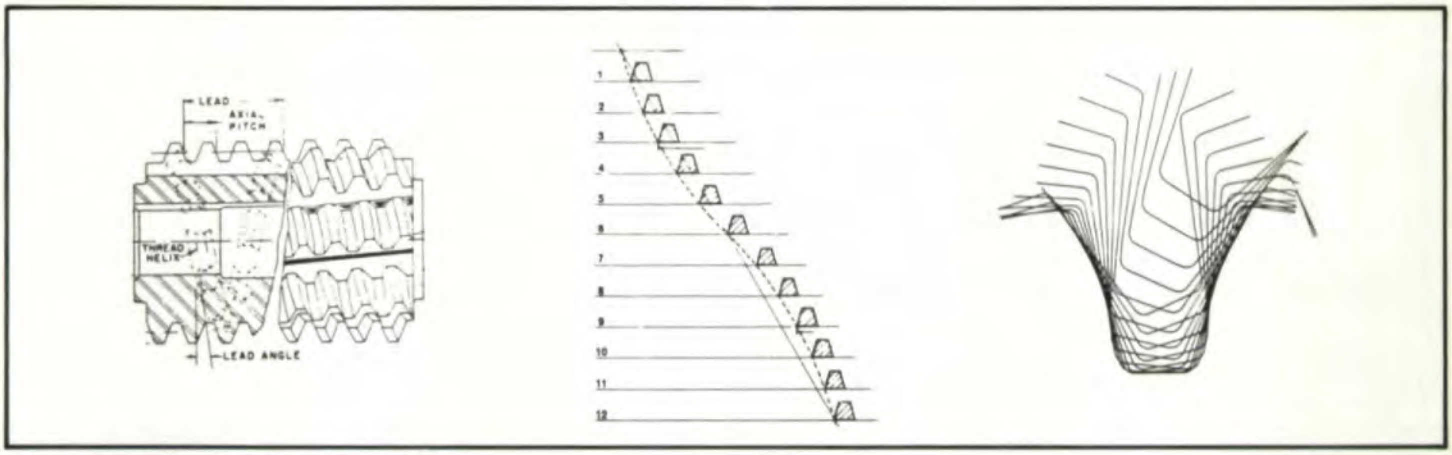


Fig. 3 – A single thread hob in one revolution envelopes a tooth space with a series of polygonal cuts. (In this instance 12 gashes are shown.)

Achievable Profile Accuracies by Finish Hobbing

For most CNC hobbing machines the burden for involute accuracy rests with the hob. Pitch and lead accuracy are built into the machine kinematics and alignment characteristics as machine manufacturing tolerances.

Finish hobbed gear profile accuracies are directly related to manufactured hob class accuracy, mounting accuracy on the hobbing machine and resharpening accuracy.

Typically, a Class AA single thread hob can produce an AGMA Class 12 profile, a Class A hob can produce an AGMA Class 11 profile, and a Class B hob can produce an AGMA Class 10 profile in 10" to 20" PD gears, 3 DP to 20 DP (Fig. 6). This assumes a hob with adequate gashes, correctly resharpened to the tolerance requirements for its accuracy class (Figs. 7 and 8) and correctly mounted on the hob arbor in the hobbing machine within the runout value tolerance for its manufactured class accuracy.

To determine the profile accuracy to which a specific accuracy class hob can produce, read the tolerance value in tenths from the AGMA Hob Standard 120.01 for the characteristic "Lead. . . . In Any One Turn of Helix" (Fig. 7). The value "Lead. . . .In Any One Turn of Helix" refers to the accuracy to which the hob manuacturer produces the thread of the hob. It is the manufacturer's allowed deviation along the generating helix of the hob. It is the allowed wandering of the cutting flanks of the hob in one

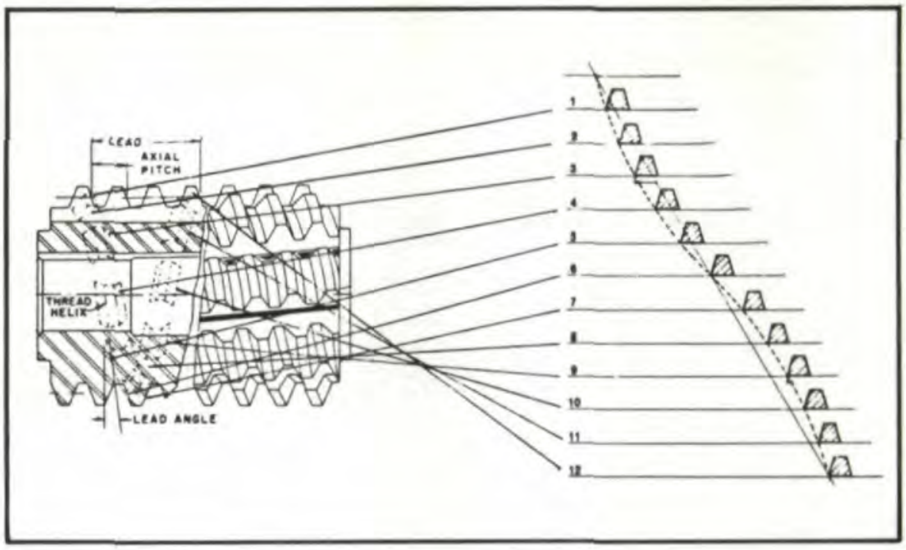


Fig. 4 – The unwound generating helix of a 12 gash single thread hob, shown here, displays a deviation of the cutting edges (dotted line = thread lead error) from the nominal (solid straight line).

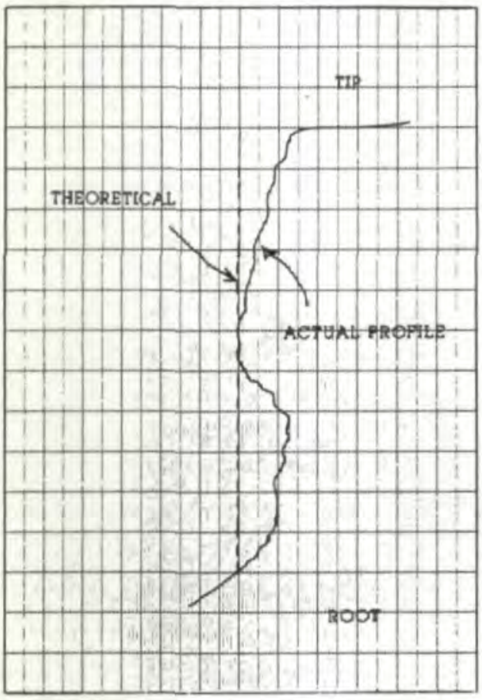


Fig. 5 – Profile error produced by manufactured deviations of the hob generating helix (thread).

Fig. 6 – Single thread hob error in one turn of the helix relative to hob class accuracy required to produce involute to AGMA 10 and AGMA 12 tolerances for 10" to 20" pitch diameter gears.

SINGLE THREAD HOB ERROR IN ONE TURN OF HELIX RELATIVE TO HOB CLASS ACCURACY REQUIRED TO PRODUCE INVOLUTE TO AGMA 10 & 12 TOLERANCES FOR 10" TO 20" DIAMETER GEARS.

Fig. 7 – Single-Thread Coarse-Pitch Gear Hob Tolerances[1] (In ten thousandths of an inch)

Hob Element	CLASS	NORMAL DIAMETRAL PITCH[2] 1 Thru 1.99	2 Thru 2.99	3 Thru 3.99	4 Thru 4.99	5 Thru 5.99	6 Thru 8.99	9 Thru 12.99	13 Thru 19.99
RUNOUT[3]									
Hub Face	AA	–	–	2	2	2	1	1	1
	A	8	5	2	2	2	2	2	2
	B	10	8	4	4	3	3	2	2
	C	10	8	4	4	3	3	2	2
	D	10	8	5	5	4	4	3	3
Hub Diameter	AA	–	–	2	2	2	1	1	1
	A	10	5	4	3	3	3	2	2
	B	12	8	6	5	4	4	3	2
	C	12	8	6	5	4	4	3	2
	D	15	10	8	8	6	6	5	5
Outside Diameter	AA	–	–	5	4	3	3	3	3
	A	30	20	15	15	10	10	10	10
	B	40	30	25	20	15	15	15	10
	C	50	45	40	25	20	17	17	12
	D	60	55	50	45	35	35	30	25
LEAD[3]									
Tooth to Tooth	AA	–	–	4	3	2	1.7	1.7	1.7
	A	7	5	4	3	2	2	2	2
	B	10	8	6	4	3	3	3	3
	C	15	12	8	6	5	4	4	4
	D	25	20	16	14	12	10	10	8
In Any One Turn of Helix	AA	–	–	8	6	4	3	3	2
	A	25	18	10	8	6	5	5	4
	B	35	25	17	11	9	7	7	6
	C	45	35	22	14	11	9	9	8
	D	60	50	40	30	25	20	20	18
In Any Three Turns of Helix	AA	–	–	12	9	6	5	5	4
	A	38	26	15	12	9	8	8	7
	B	53	38	22	16	12	11	10	9
	C	70	50	30	21	16	14	13	12
	D	120	100	80	60	50	40	35	25
TOOTH									
Pressure Angle[3,4]	AA	–	–	2	2	1.7	1.7	1.7	1.7
	A	10	5	3	3	2	2	2	2
	B	16	8	5	5	4	3	3	3
	C	25	15	10	5	4	3	3	3
	D	80	55	30	18	12	8	8	6
Thickness (minus only)	AA	–	–	15	15	10	10	10	10
	A	30	20	15	15	10	10	10	10
	B	30	20	15	15	10	10	10	10
	C	35	25	20	20	15	15	15	15
	D	40	35	30	25	20	20	20	20
Start of Tip Relief Modification (plus or minus)	AA	–	–	100	80	70	60	60	40
	A	200	180	160	140	120	100	80	60
	B	220	200	180	160	140	120	100	80
	C	220	200	180	160	140	120	100	80
	D	260	240	220	200	180	160	140	120
Symmetry in Start of Tip Relief Modification	AA	–	–	70	60	50	40	40	25
	A	150	130	120	100	90	80	60	50
	B	180	150	130	120	100	90	80	70
	C	180	150	130	120	100	90	80	70
	D	200	180	160	140	120	110	100	90

Fig. 8 – Single-Thread Coarse-Pitch Gear Hob Tolerances[1] (In ten thousandths of an inch)

Hob Elements	CLASS	NORMAL DIAMETRAL PITCH[2] 1 Thru 1.99	2 Thru 2.99	3 Thru 3.99	4 Thru 4.99	5 Thru 5.99	6 Thru 8.99	9 Thru 12.99	13 Thru 19.99
FLUTES									
Adjacent Flute Spacing[5]	AA	—	—	20	15	10	8	8	6
	A	40	30	25	20	15	10	10	10
	B	50	45	40	30	20	15	15	10
	C	50	45	40	30	20	15	15	10
	D	60	60	50	50	30	25	25	20
Non-Adjacent Flute Spacing[5]	AA	—	—	40	35	25	15	15	15
	A	80	60	50	40	30	30	30	25
	B	100	90	80	60	50	50	50	40
	C	100	90	80	60	50	50	50	40
	D	120	120	100	100	80	80	70	60
Rake To Cutting Depth[6]	AA	—	—	10	8	6	5	5	3
	A	30	15	10	8	6	5	5	3
	B	50	25	15	10	8	7	7	5
	C	50	25	15	10	8	7	7	5
	D	100	75	50	40	30	20	20	15
		CUTTING FACE WIDTH in inches							
		Up to 1	1.001 to 2	2.001 to 4	4.001 to 7	7.001 & Up			
Flute Lead Over Cutting Face Width	AA	8	10	15	20	20			
	A	10	15	25	30	50			
	B	10	15	25	30	50			
	C	10	15	25	30	50			
	D	15	23	38	45	75			
HOLE		HOLE DIAMETER in inches							
		2.500	2.000	1.500	1.250	0.750	0.500 & Smaller		
Hole Diameter (plus only)	AA	—	—	—	2	2	2		
	A	8	8	5	2	2	2		
	B	10	10	8	3	2	2		
	C	10	10	8	3	2	2		
	D	10	10	8	5	4	3		

NOTE: 1. Tolerances apply only to standard hob sizes.
2. For combination pitch hobs, the coarser of the two pitches shall apply.
3. Total indicator variation.
4. Exclusive of Tip Relief Modification.
5. Compared against master index plate.
6. Radial (zero rake) tooth faces are standard.

Fig. 9 – AGMA 390.03 coarse pitch involute gear tolerance table for AGMA quality levels 8 through 12. Reprinted by permission of the AGMA, Arlington, VA.

AGMA QUALITY NUMBER	NORMAL DIAMETRAL PITCH	PROFILE TOLERANCE – PITCH DIAMETER (INCHES) 3/4	1½	3	6	12	25	50	100	200	400
8	1/2					42.6	47.7	53.1	59.1	65.7	73.1
	1				28.3	31.5	35.3	39.3	43.7	48.8	54.1
	2			18.8	21.0	23.3	26.1	29.0	32.3	36.0	40.0
	4		12.5	13.9	15.5	17.2	19.3	21.5	23.9	26.6	29.8
	8	8.3	9.3	10.3	11.5	12.8	14.3	15.9	17.7	19.7	21.9
	12	7.0	7.8	8.6	9.6	10.7	12.0	13.3	14.8	16.5	18.4
	20	5.6	6.2	6.9	7.7	8.6	9.6	10.7	11.9	13.2	14.7
9	1/2					30.4	34.1	37.9	42.2	46.9	52.2
	1				20.2	22.5	25.2	28.1	31.2	34.7	38.6
	2			13.5	15.0	16.7	18.6	20.7	23.1	25.7	28.6
	4		8.9	10.0	11.1	12.3	13.8	15.3	17.1	19.0	21.1
	8	5.9	6.6	7.4	8.2	9.1	10.2	11.4	12.6	14.1	15.6
	12	5.0	5.5	6.2	6.9	7.6	8.6	9.5	10.6	11.8	13.1
	20	4.0	4.4	4.9	5.5	6.1	6.8	7.6	8.5	9.4	10.5
10	1/2					21.7	24.3	27.1	30.1	33.5	37.3
	1				14.5	16.1	18.0	20.0	22.3	24.8	27.6
	2			9.6	10.7	11.9	13.3	14.8	16.5	18.3	20.4
	4		6.4	7.1	7.9	8.8	9.9	11.0	12.2	13.6	15.1
	8	4.2	4.7	5.3	5.9	6.5	7.3	8.1	9.0	10.0	11.2
	12	3.6	4.0	4.4	4.9	5.5	6.1	6.8	7.6	8.4	9.4
	20	2.9	3.2	3.5	3.9	4.4	4.9	5.4	6.1	6.7	7.5
11	1/2					15.5	17.4	19.3	21.5	24.0	26.7
	1				10.3	11.5	12.9	14.3	15.9	17.7	19.7
	2			6.9	7.6	8.5	9.5	10.6	11.8	13.1	14.6
	4		4.6	5.1	5.6	6.3	7.0	7.8	8.7	9.7	10.8
	8	3.0	3.4	3.8	4.2	4.6	5.2	5.8	6.4	7.2	8.0
	12	2.5	2.8	3.1	3.5	3.9	4.4	4.9	5.4	6.0	6.7
	20	2.0	2.3	2.5	2.8	3.1	3.5	3.9	4.3	4.8	5.4
12	1/2					11.1	12.4	13.8	15.4	17.1	19.0
	1				7.4	8.2	9.2	10.2	11.4	12.7	14.1
	2			4.9	5.5	6.1	6.8	7.6	8.4	9.4	10.4
	4		3.3	3.6	4.0	4.5	5.0	5.6	6.2	6.9	7.7
	8	2.2	2.4	2.7	3.0	3.3	3.7	4.1	4.6	5.1	5.7
	12	1.8	2.0	2.2	2.5	2.8	3.1	3.5	3.9	4.3	4.8
	20	1.5	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.4	3.8

enveloping revolution of the hob.

By comparing the lead tolerance in any one turn of the helix for a specific hob to the AGMA 390.03 profile tolerance table for gears (Fig. 9) it can be predetermined whether or not a particular profile tolerance can be finish hobbed.

The Effect of Hob Mounting Errors

Even if a hob is hypothetically perfect and manufactured error-free, it can produce profile errors if mounted eccentrically on the hobbing machine arbor.

Hob runout error due to either careless mounting or to improper sharpening is the greatest contributor to poor hobbed involute profiles. Figs. 10, 11 and 12 illustrate the effects three types of hob runout have upon the gear tooth form. These effects are created most often by:

1. Failure to true up the hob arbor
2. Failure to true up the hob on the hob arbor by indicating the hubs on the ends of the hob
3. Bent hob arbor
4. Oversize hob bore or undersize hob arbor
5. Non-parallel hob clamping spacers
6. Misaligned or worn outboard support bearing for hob arbor.

Often hob runout error is introduced at the first hob resharpening. If a hob is mounted carelessly – that is, without truing – on the sharpening arbor, runout can be sharpened into the hob by sharpening off progressively greater amounts of material from the hob gashes for half its rotation. The sources of this error in the sharpener are similar to those in the hobber.

In some precision gear manufacturing shops, the hob is sharpened on the hob arbor after careful alignment to insure optimum gear tooth profile accuracy.

The Effect of Hob Resharpening Errors

Fig. 13 illustrates the effects hob sharpening errors have on the basic rack profile of the hob and the resultant workpiece tooth profile. Figs. 14, 15, 16 and 17 illustrate diagrammatically typical resulting involute profiles. Figs. 9 through 11 illustrate the effects three types of hob runout have upon the involute profile due to careless mounting. Careless mounting of the hobs on the sharpening arbor can introduce the same error. A hob mounted on a bent resharpening arbor, for example, will be resharpened eccentrically, introducing the same error even if the hob is mounted concentrically on the hobbing machine arbor in the machine. Apart from runout errors four other errors can be introduced at the time of resharpening:

1. The hob cutting faces sharpened with incorrect lead (Fig. 14)

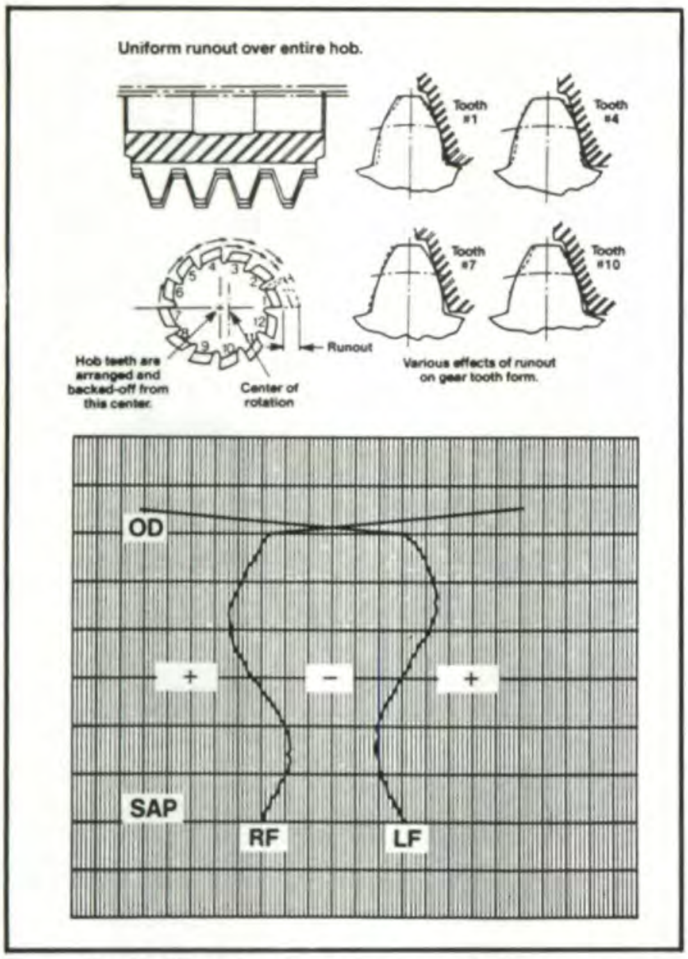


Fig. 10 – Effect of uniform hob runout on hobbed profile.

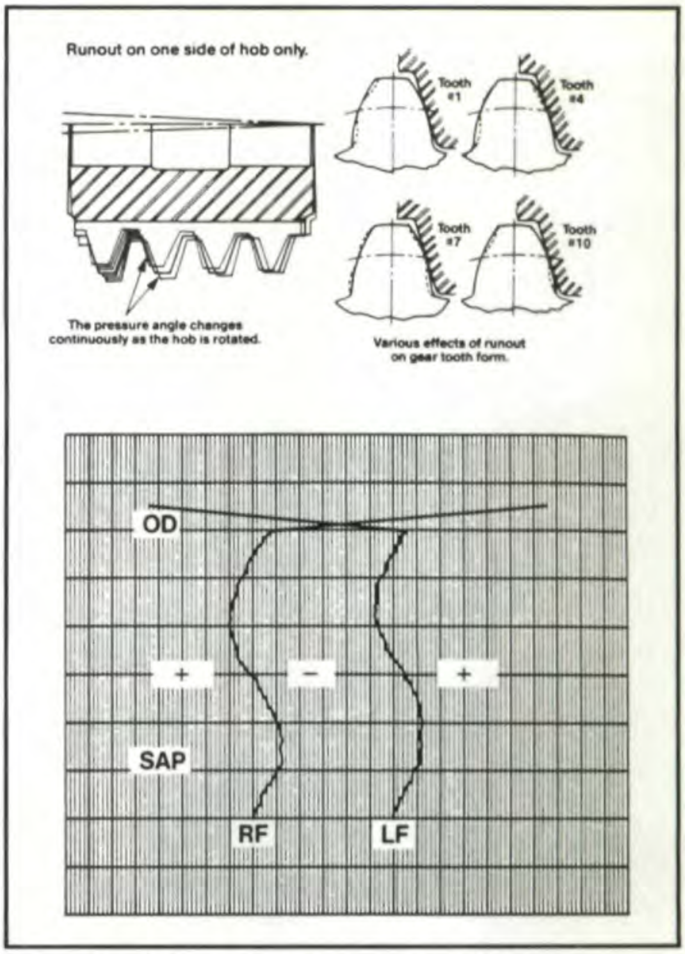


Fig. 12 – Effect of runout on one side of the hob only.

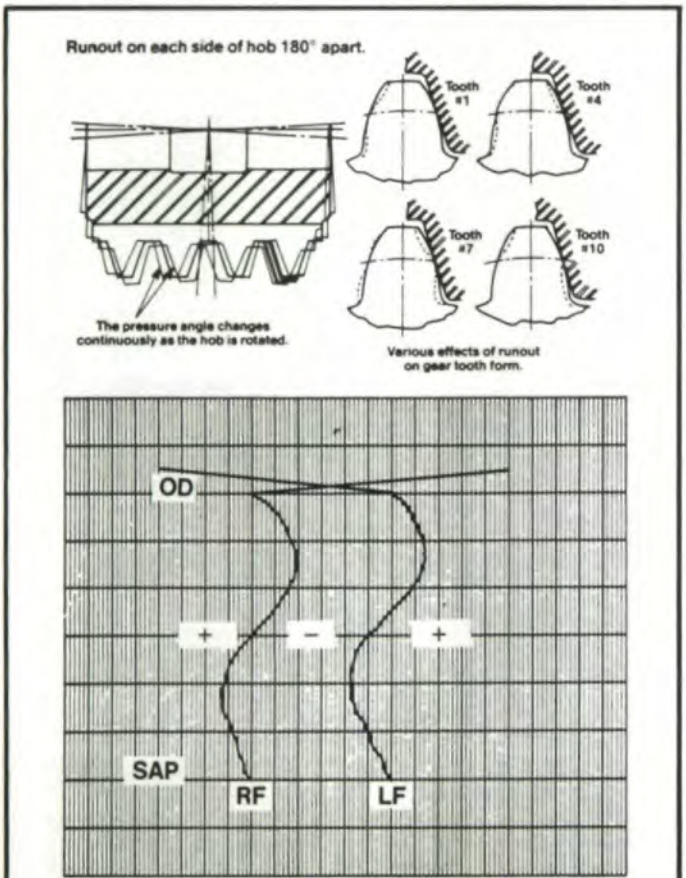


Fig. 11 – Effect of runout on each side of hob, 180° apart.

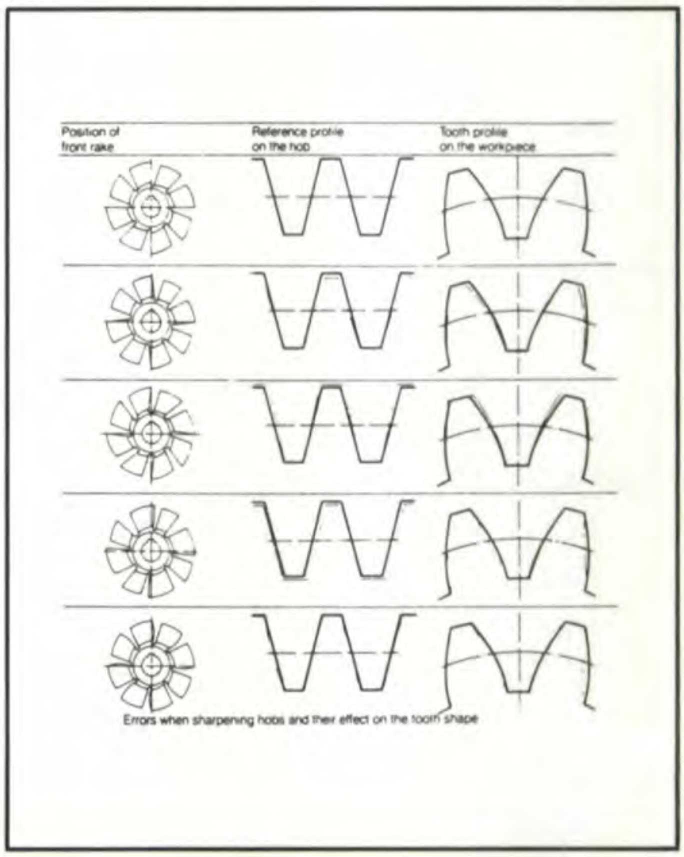


Fig. 13 – Effect of hob resharpening errors on the hobbed tooth profile relative to the basic rack profile of the hob.

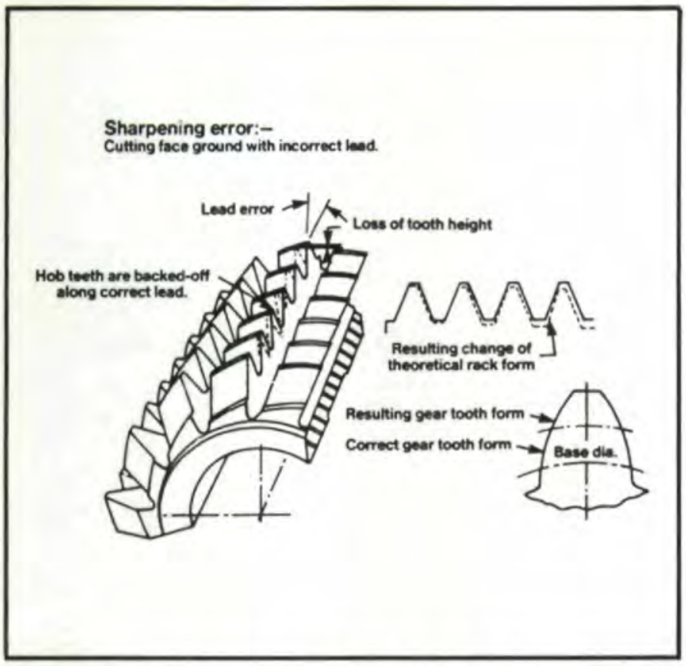


Fig. 14 – Effect of hob flute lead error. Since the hob is a reducing cylinder, incorrect flute lead resharpening destroys the integrity of the hob cylinder end to end, typically causing changes in workpiece size as the hob is shifted across its length.

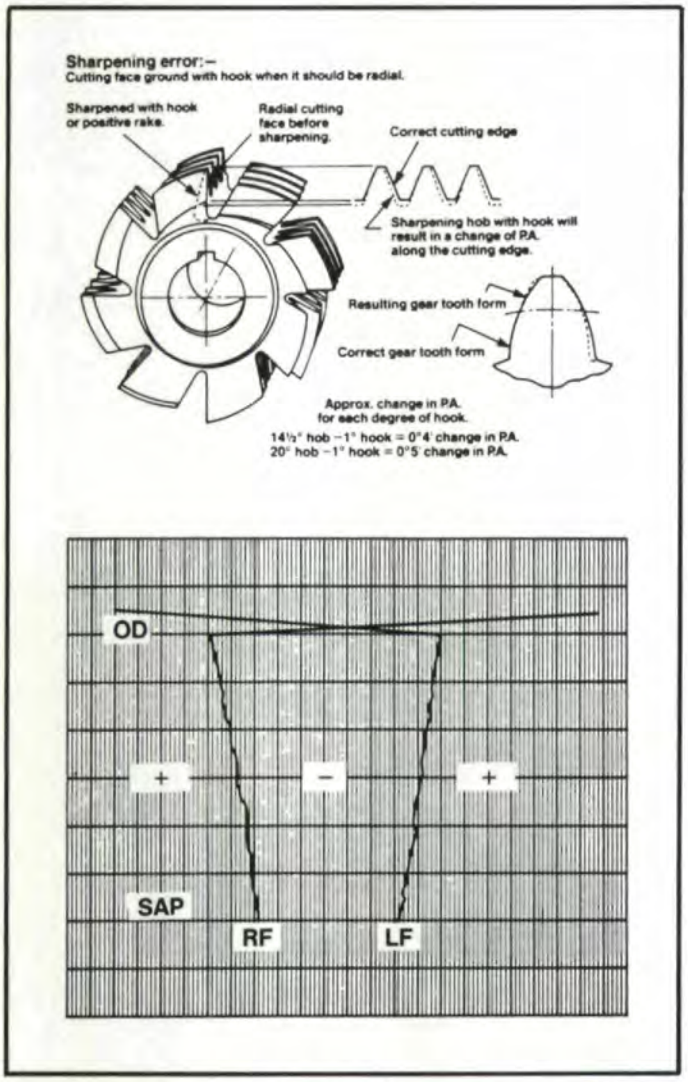


Fig. 15 – Effect of negative rake resharpening error on profile.

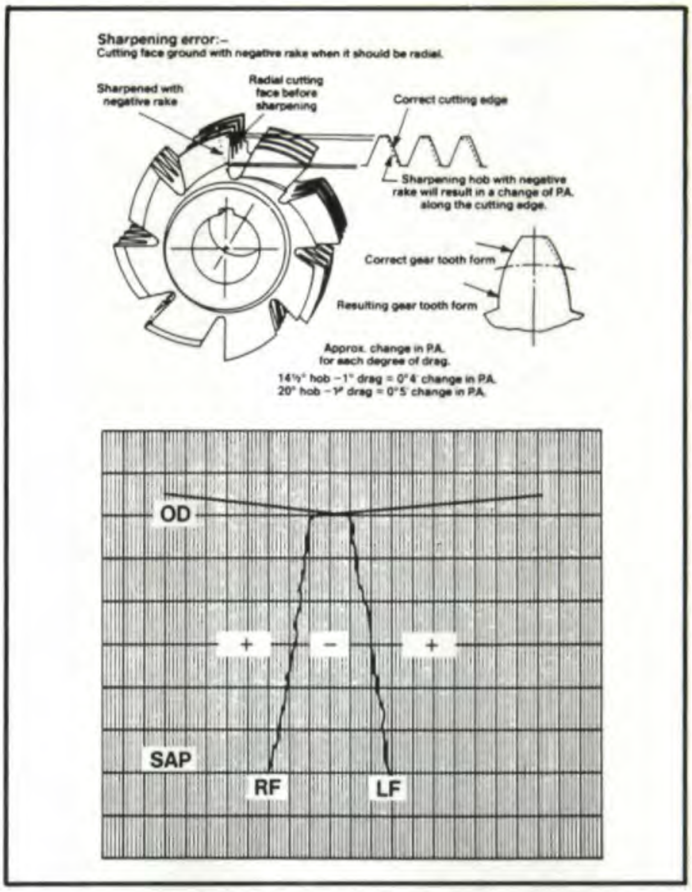


Fig. 16 – Effect of positive rake resharpening error on profile.

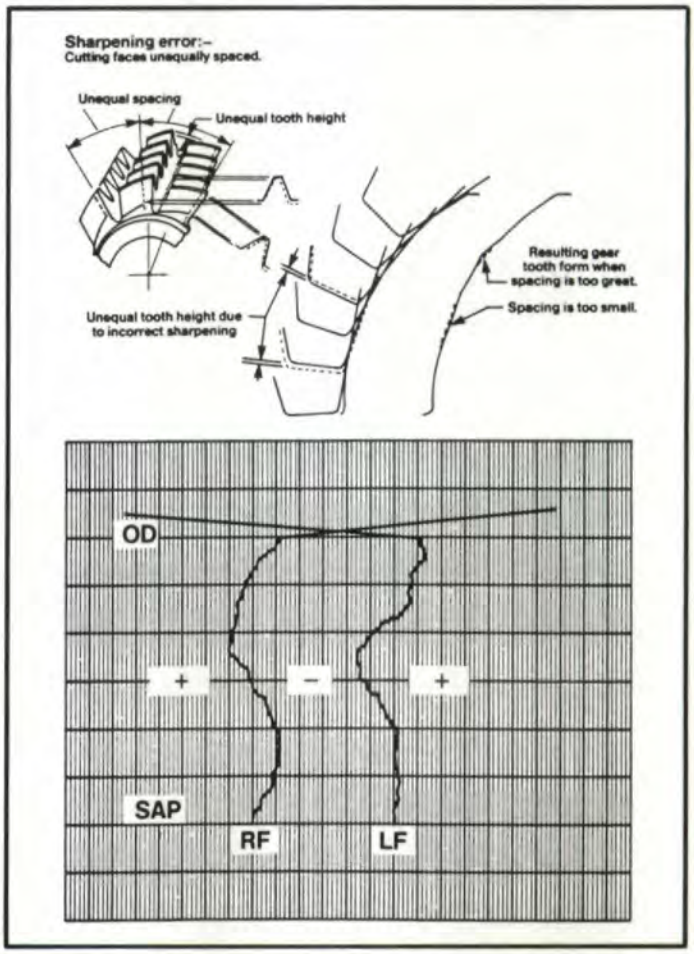


Fig. 17 – Effect of accumulated flute spacing error on profile.

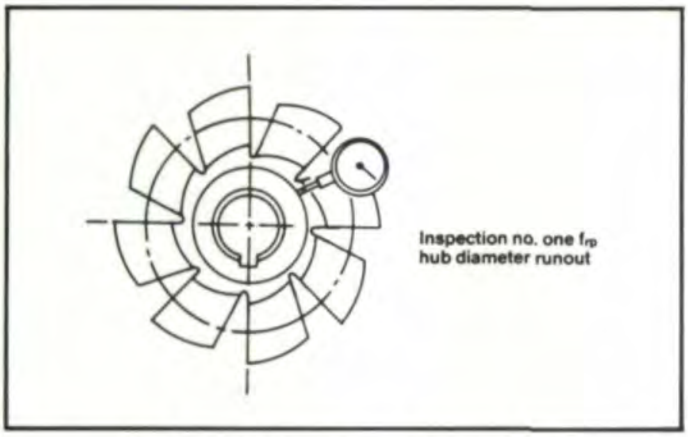


Fig. 18 – Hob diameter runout inspection check.

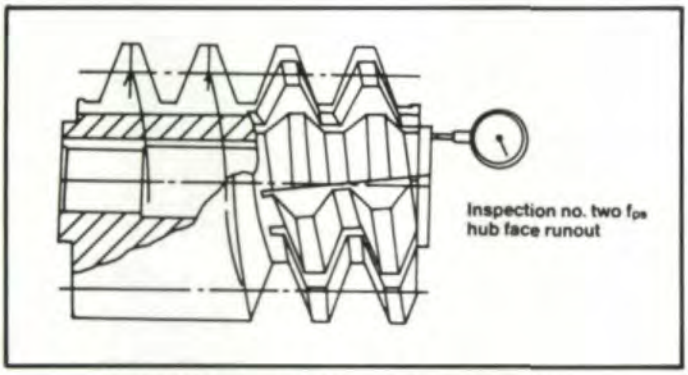


Fig. 19 – Hob clamping face runout inspection check.

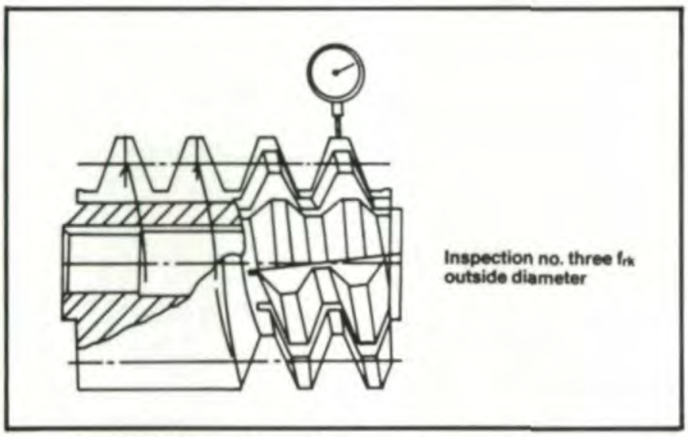


Fig. 20 – Hob outside diameter inspection check.

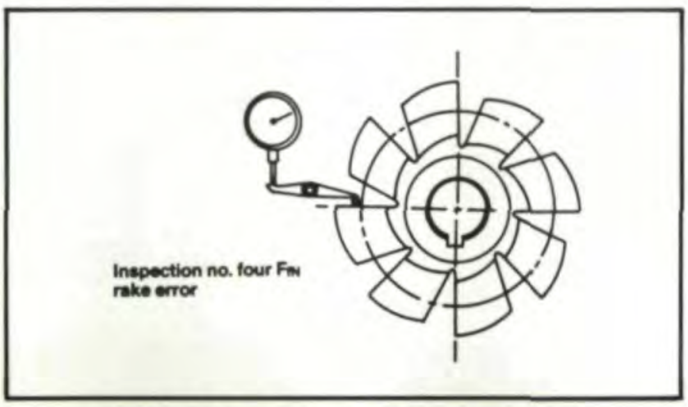
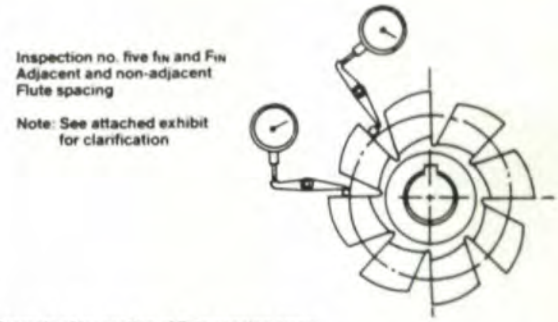


Fig. 21 – Hob rake to cutting depth inspection check.



Example of inspection of flute spacing error:

FLUTE NO. (N)	MEASUREMENT	CORRECTION	ftN	FtN
1	+.0004	−.0002	+.0002	+.0002
2	0	−.0002	−.0002	0
3	+.0004	−.0002	+.0002	+.0002
4	+.0001	−.0002	−.0001	+.0001
5	+.0002	−.0002	0	+.0001
6	−.0001	−.0002	−.0003	−.0002
7	+.0006	−.0002	+.0004	+.0002
8	0	−.0002	−.0002	0

Correction value = sum of measured errors divided by total number of flutes.

ftN = measured value minus correction value

fuN = maximum deviation between any two *adjacent* flutes. From above: fuN = deviation of −.0003 and +.0004
fuN = .0007

Ft(N+1) = Ftn = ft(N=1)
Note: This will give the particular value of FtN for one flute.
The decisive value will equal the maximum deviation between any two values of FtN. From above: FtN = deviation of +.0002 and −.0002
FtN = .0004

Fig. 22 – Hob adjacent and non-adjacent flute spacing check.

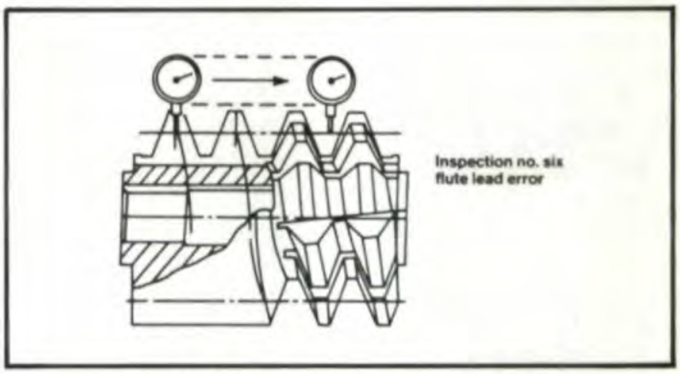


Fig. 23 – Hob flute lead error inspection check.

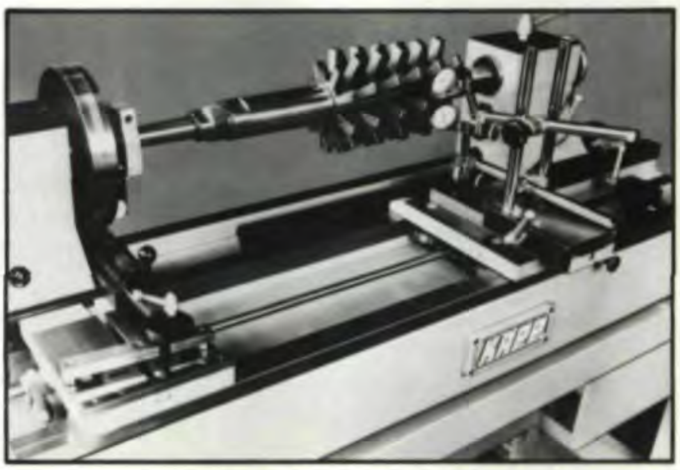


Fig. 24 – Hob checking unit.

2. The hob cutting faces sharpened with negative rake (Fig. 15)

3. The hob cutting faces sharpened with positive rake (Fig. 16)

4. The hob cutting faces sharpened with unequal spacing (Fig. 17).

Fig. 14 shows the effect of sharpening the reducing cylinder of a straight fluted hob with a lead error. This occurs often in older hob sharpeners with misaligned centers. Because the hob is a reducing cylinder, sharpening more off one end of the hob than the other results in a tapered hob. As the hob is shifted across its usable life in the hobbing machine, a change in the size of the workpieces will be evident. Often this error is assigned to the hobbing machine and valuable production hobs are wasted while maintenance crews attempt to find the source of the error.

The same error can exist in helically fluted hobs. Wear of the sine bar or misaligned centers contribute to this off lead problem.

Figs. 15 and 16 show two common resharpening errors on radial rake designed hobs – positive and negative rake. The effect of positive or negative rake sharpening on a radial rake designed hob is a change in the pressure angle of the basic rack form of the hob. This produces either a lesser or greater pressure angle on the gear tooth, which can result in excessive gear wear, gear noise and shock loading.

Some hobs are deliberately designed with hook (positive rake) or with negative rake and must be sharpened accordingly to prevent the introduction of pressure angle errors.

Fig. 17 illustrates the condition of unequally sharpened hob flutes, resulting in unequal spacing of the cutting edge positions relative to the thread helix. Due to the flank or cam relief on the hobs, unequally spaced flutes will cut either high or low from the nominal enveloping helix, producing a "wandering" profile.

Usually worn index plates or worn pawls are the source of this problem. Excessive stock removal during the resharpening can crowd the grinding wheel, also causing unequal flute spacing.

Inspecting the Resharpened Hob

Figs. 18 through 23 illustrate the six basic checks which can be performed to insure that the hob resharpening conforms to the tolerance level of the hob purchased class accuracy. These simple checks can be performed on bench centers or with a hob checking unit such as shown in Fig. 24.

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