Design and Selection of Hobs

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Introduction

The following is a general overview of some of the different factors that lead to the specific design and the selection of the correct tool for a given hobbing application. There will be three main sections investigated:

A. Basic review of the generating process as it relates to gear hobbing, including general nomenclature of hob terms, and specific tooth modifications.
B. Hob error as it relates to gear accuracy.
C. Optimization of hob design.

Hob Nomenclature

The terms in Fig. 1, along with additional terms and their definitions follow.

Nomenclature of Hob Elements and Other Terms Relating to Hobbing

adjacent flute spacing – The variation from the desired angle between adjacent tooth faces measured in the plane of rotation.

adjacent thread spacing – The difference in the average variations obtained by traversing along the desired helical path of one thread, indexing and traversing in a similar manner on an adjacent thread.

approach – See preferred term **tip relief modification.**

approach distance – The linear distance in the direction of feed between the point of initial hob contact and the point of full hob contact.

arbor collar – A hollow cylinder which fits an arbor, and is used to position the hob.

auxiliary leads – A feature employed on some hobs, especially worm gear hobs, wherein both sides of the hob thread have leads different from the nominal hob lead; one side longer, the other side shorter. This results in the tooth thickness being successively less toward the roughing end of the hob.

axial feed – The rate of change of hob position parallel to the workpiece axis usually specified in inches per revolution of the workpiece.

axial plane – A plane containing the axis of rotation.

axial pressure angle – See definition under **pressure angle.**

back-off – See preferred term **cam relief**, under **relief.**

cam – The radial drop of the form in the angular distance between adjacent tooth faces.

centering device – A ground locating pin used to center a tooth or space of the hob on the centerline of the workpiece.

chamfer – A beveled surface to eliminate an otherwise sharp corner.

climb hobbing – Rotation of a hob in the opposite direction to the feed of the hob relative to the workpiece at the point of contact.

clutch keyway – See term **keyway.**

common factor ratio – In multiple thread hobs, the condition wherein the **gear tooth-hob thread ratio** is not a whole number, but there is a common factor of the number of gear teeth and the number of hob threads.

conventional hobbing – Rotation of a hob in the same direction as the feed of the hob relative to the workpiece at the point of contact.

cutting face width – The axial length of the relieved portion of the hob.

cutting speed – The peripheral lineal speed resulting from rotation, usually expressed as surface feet per minute. [sfm]

depth of cut – The radial depth to which the hob is sunk into the workpiece.

drawbar – A rod which retains the arbor, adapter or hob shank in the spindle.

even ratio – In multiple thread hobs, the condition wherein the **gear tooth-hob thread ratio** is a whole number.

feed – The rate of change of hob position while cutting.

fillet – 1 – A curved line joining two lines to eliminate a sharp internal corner. – 2 – A curved surface joining two surfaces

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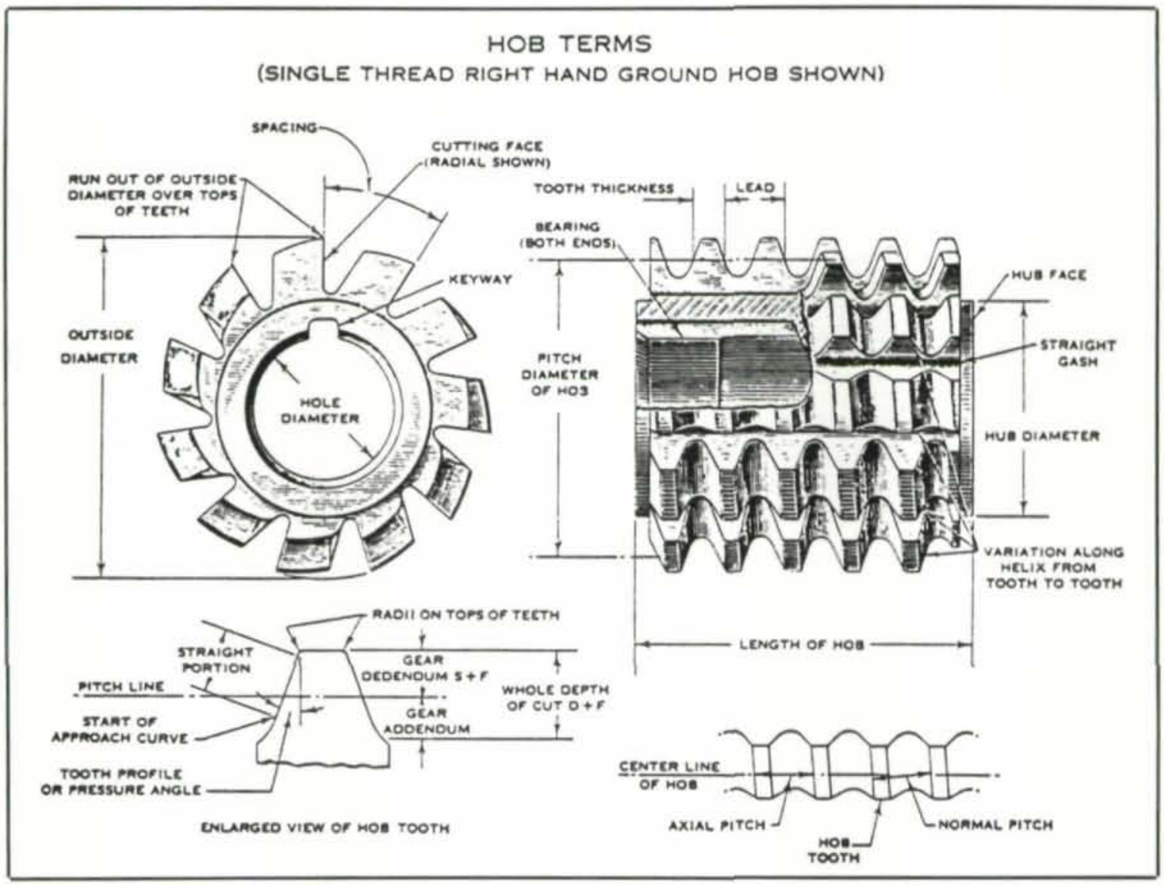


Fig. 1

to eliminate a sharp internal corner.

flute – A longitudinal groove either straight or helical that forms the tooth face of one row of hob teeth and the backs of the preceeding row. It also provides chip space.

flute helix angle – The angle which a helical tooth face makes with an axial plane, measured on the hob pitch cylinder.

flute lead – The axial advance of helical tooth face in one turn around the axis of a hob.

flute lead variation – The deviation of a hob tooth face from the desired helical surface.

former – See preferred term **sharpening guide.**

full top radius – Continuous radius tangent to top and side cutting edges.

gear tooth-hob thread ratio – The ratio of the number of teeth in the workpiece to the number of threads in the hob.

generated fillet – At the bottom of the hobbed form a fillet joining the root diameter with the desired generated form. This fillet is not a true radius.

generated fillet height – On the hobbed workpiece, the radial distance from the root diameter to the point where the generated fillet joins the desired generated form.

grinding cracks – Fractures in the hob caused by improper grinding techniques in sharpening.

high point – See preferred term **protuberance.**

hob addendum – Radial distance between the top of the hob tooth and the **pitch cylinder.** Do not confuse with gear addendum.

hob arbor – A device to mount in or on the spindle of a hobbing machine, which is designed to carry and drive an arbor-type hob.

hob dedendum – In **topping hobs,** the radial distance between the bottom of the hob tooth profile and the **pitch cylinder.** Do not confuse with gear dedendum.

hob length – Overall length of hob.

hob runout – The runout of hob when mounted in hobbing machine, measured radially on hub diameter, and axially on hub face.

hob shift – The axial movement of a hob along its axis to engage a different section with the workpiece.

hub – A qualifying surface at each end of an arbor type hob which is provided for checking diameter and face runout.

hub diameter runout – The total variation in radial distance of the hub periphery from the axis.

hub face – The side surface of the **hub.**

hub face runout – The total axial variation of the hub face from a true plane of rotation.

hunting ratio – See preferred term **prime ratio.**

infeed – The radial rate of change of hob position, relative to the workpiece axis, usually specified in inches per revolution of the workpiece.

key – A mechanical member through which the turning force is transmitted to the hob.

keyseat – The pocket, usually in the driving element, in which the key is retained.

keyway – A slot through which the turning force is transmitted to the hob. May be either a longitudinal slot through the hole or a transverse slot across the hub face. If the latter, it is called a **clutch keyway.**

lead – The axial advance of a thread for one complete turn, or convolution.

lead angle – The angle between any helix and a plane of rotation. In a hob, **lead angle** usually refers specifically to the angle of thread helix measured on the **pitch cylinder**.

lead variation – The axial deviation of the hob teeth from the correct thread lead.

leader – See preferred term **sharpening guide.**

linear pitch – See preferred term **axial pitch,** under **pitch.**

linear pressure angle – See preferred term **axial pressure angle,** under **pressure angle.**

lug – An extension of hob tooth profile above the nominal top cutting edge. Sometimes called **spurs** or **prongs.**

non-adjacent flute spacing – The variation from the desired angle between any two non-adjacent tooth faces measured in the plane of rotation.

normal circular pitch – See definition under **pitch.**

normal diametral pitch – See definition under **pitch.**

normal plane – A plane perpendicular to a pitch cylinder helix.

normal pressure angle – See definition under **pressure angle.**

number of threads – In multiple thread hobs, the number of parallel helical paths along which hob teeth are arranged, sometimes referred to as **number of starts.** Should not be confused with the term, **number of threads per inch,** which is commonly used in designating the axial pitch of screw threads.

offset – See preferred term **rake offset.**

outside diameter – The diameter of the cylinder which contains the tops of the cutting edges of the hob teeth.

outside diameter runout – The total variation in the radial distance from the axis to the tops of the hob teeth.

overtravel – The linear distance in the direction of feed of the hob beyond the last point of contact of the hob with the workpiece.

pilot end – On shank type hobs, a cylindrical or conical bearing surface opposite the driving end.

pin measurement – The measurement taken over pins of equal diameter placed in specified tooth spaces in the workpiece.

pitch – The distance between corresponding, equally spaced hob **thread** elements along a given line or curve. The use of the single word **pitch** without qualification may be confusing. Specific terms such as **normal diametral pitch, normal circular pitch,** or **axial pitch** are preferred.

Axial Pitch – The pitch parallel to the axis in an axial plane between corresponding elements of adjacent hob thread sections. The term *Axial Pitch* is preferred to the term *Linear Pitch.*

Circular Pitch – The distance along the pitch cylinder between corresponding elements of adjacent hob thread sections.

Linear Pitch – See preferred term *Axial Pitch.*

Normal Circular Pitch – The distance between corresponding elements on adjacent hob thread sections measured along a helix that is normal to the *Thread Helix* in the *Pitch Cylinder.*

Normal Diametral Pitch – π [3.1416] divided by the *Normal Circular Pitch.*

pitch circle – A transverse section of the hob **pitch cylinder.**

pitch cylinder – A reference cylinder in a hob from which design elements, such as lead, lead angle, profile, and tooth thickness are derived.

pitch diameter – The diameter of the **pitch cylinder.**

pitch point – The point at which a **tooth profile** intersects the **pitch cylinder.**

pressure angle – The angle between a tooth profile and a line perpendicular to the **pitch cylinder** at the **pitch point.** In hobs, the **pressure angle** is usually specified in the **normal plane** or in the **axial plane.**

Axial Pressure Angle – The *Pressure Angle* as measured in an *Axial Plane.* The term *Axial Pressure Angle* is preferred to the term *Linear Pressure Angle.*

Normal Pressure Angle – The *Pressure Angle* as measured in a *Normal Plane.*

prime ratio – In multiple thread hobs, the condition wherein the **gear tooth-hob thread ratio** is not a whole number and there is no common factor of the number of gear teeth and the number of hob threads.

protuberance – A modification near the top of the hob tooth which produces **undercut** at the bottom of the tooth of the workpiece.

rake – The angular relationship between the tooth face and a radial line intersecting the tooth face at the hob outside diameter measured in a plane perpendicular to the axis.

Negative Rake – The condition wherein the peripheral cutting edge lags the tooth face in rotation.

Positive Rake – The condition wherein the peripheral cutting edge leads the tooth face in rotation.

Zero Rake – The condition wherein the tooth face coincides with a radial line.

rake offset – The distance between the tooth face and a radial line parallel to the tooth face. Used for checking rake.

ramp – A modification at the bottom of the hob tooth which produces a chamfer at the top corners of the tooth of the workpiece.

relief – The result of the removal of tool material behind or adjacent to a cutting edge provide clearance and prevent rubbing [heel drag].

Cam Relief – The relief from the cutting edges to the back of the tooth produced by a cam actuated cutting tool or grinding wheel on a relieving [back-off] machine.

Side Relief – The relief provided at the sides of the teeth behind the cutting edges. The amount depends upon the radial cam, the axial cam, and the nature of the tooth profile.

scallops – The shallow depression on the generated form produced by hob action.

setting angle – The angle used for setting hob swivel to align the hob thread with the workpiece teeth.

shank – That projecting portion of a hob which locates and drives the hob in the machine spindle or adapter.

sharpening allowance – The amount by which the pitch diameter of a worm gear hob exceeds that of the worm, to allow for the reduction in diameter by sharpening.

sharpening guide – A cylindrical part with flutes, having the same lead as the hob flutes, used for guiding the hob along the correct lead when sharpening.

short lead – A feature employed on some hobs to obtain generated fillet or undercut conditions not obtainable with nominal lead.

side relief – See definition under **relief.**

stock allowance – The modification of the hob tooth to leave material on the workpiece tooth form for subsequent finishing.

tangential feed – The rate of change of hob position along its own axis, usually specified in inches per revolution of the workpiece.

thread – A helical ridge, generally of constant form or profile. In a hob, unlike a worm or screw, the thread is not continuous and exists only at the cutting edges of the hob teeth. Therefore, it is sometimes referred to as the **thread envelope.**

thread envelope – See preferred term **thread.**

thread helix – The helix of the hob thread in the **pitch cylinder.**

tip relief – A modification in which a small amount of material is removed from the basic profile near the tip of the gear tooth.

tip relief modification – A modification on the sides of the hob tooth near the bottom which produces a small amount of **tip relief.** Such modification is usually incorporated in **finishing hobs** except in the finer pitches.

tooth – A projection on a hob which carries a cutting edge.

tooth face – The tooth surface against which the chips impinge.

tooth profile – Outline or contour of hob tooth cutting edges.

tooth thickness – The actual width or thickness of the hob thread at the **pitch cylinder.** The use of the single term **tooth thickness** without qualification may be confusing. The specific terms **normal tooth thickness** and **axial tooth thickness** are preferred.

Axial Tooth Thickness – The tooth thickness as measured in an axial plane.

Normal Tooth Thickness – The tooth thickness as measured along a helix normal to the thread helix.

top radius – Radius of the arc joining the top and a side cutting edge of a hob tooth.

total indicator reading [tir] – See preferred term **total indicator variation.**

total indicator variation [tiv] – The difference between maximum and minimum indicator readings during a checking cycle.

undercut – The condition at the base of a hobbed workpiece form wherein additional material beyond the basic form is removed. Under certain conditions this may occur naturally, while in other cases it may be produced by intentional modification of the hob tooth.

wear land – A cylindrical or flat land worn on the relieved portion of the hob tooth behind the cutting edge.

Fig. 2

wobble – The motion of a hob when the radial runout varies along the hob length.

worm gear hob oversize – See preferred term **sharpening allowance.**

For varying specific reasons, it is possible to alter the straight sided rack form in order to achieve a modified generated gear tooth form.

The hob in Fig. 2 was designed to eliminate sharp corners at the tops of gear teeth. It can be made to produce a desired amount of chamfer or radius, but to do this the number of teeth in the gear must be known. Obviously, the form of such a modification produced by a given hob will vary with the number of teeth in the gear, just as the width of the top of the gear tooth varies.

The topping gear hob shown in Fig. 3 is used for cutting spur gears and helical gears. This hob finishes the tops of gear teeth, holding the outside diameter of the gear to a given dimension in relation to the pitch line and root diameter.

Several advantages accompany the use of topping hobs that in many cases result in material savings. For instance, the finish-hobbed gears may be chucked on the outside diameter in subsequent operations for hole finishing when necessary. Moreover, their use eliminates an accurate finish-turning operation on gear blanks before hobbing. Additionally, gears hobbed with topping hobs may be quickly inspected for pitch line thickness to ordinary commercial limits by measuring the outside diameter with a micrometer.

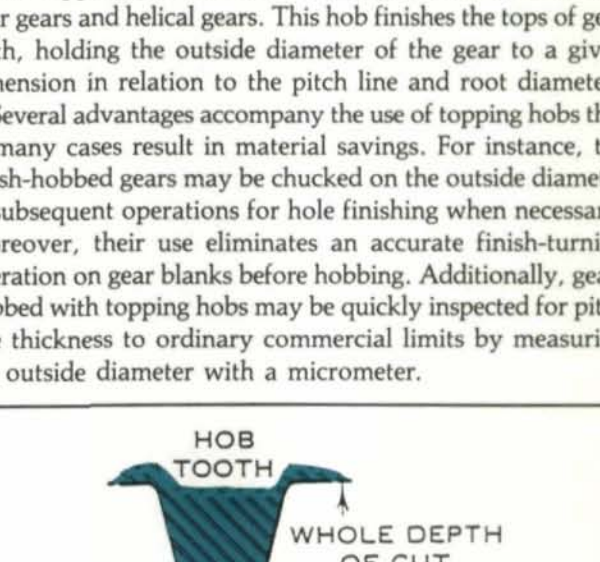


Fig. 3

Gears are frequently hobbed and then finished by shaving or grinding. Hobs for producing such gears are referred to as semi-finishing hobs. The hobbing of such gears has not been considered a roughing operation because of the accuracy required for leaving a minimum and uniform amount of finishing stock. (Fig. 4)

The protuberance type hob shown in Fig. 5 generates undercut at the bottom of the gear tooth to provide clearance for the shaving cutter and to prevent the formation of an abrupt change in profile with its resulting stress concentration. With small numbers of teeth, the tooth form cut with a hob without protuberance is often undercut enough, but a protuberance is required for larger numbers of teeth to eliminate contact between the tip of the shaving cutter and the fillet on the gear tooth.

Hob Error vs. Gear Accuracy

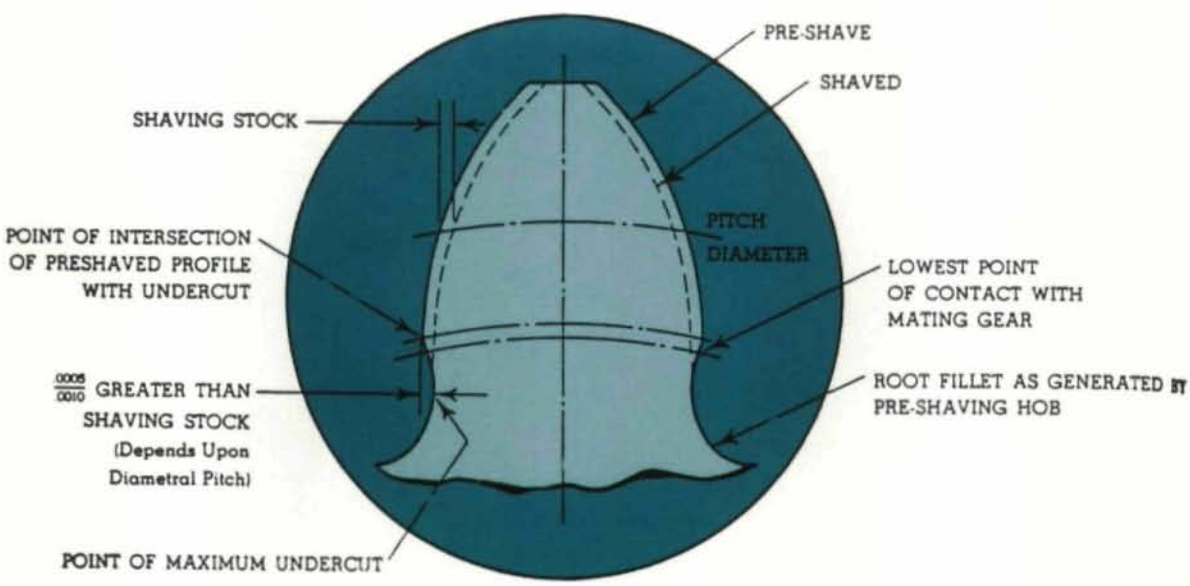
All hob manufacturers work to a given set of standard tolerances. A reprint of tolerances from the Metal Cutting Tool Institute Standards are as follows. It should be noted, these tolerances pertain to standard outside diameter sizes only. (Table of standard hob sizes—see pages 40-43) Tolerances for lead on oversized hobs can be increased proportionally to the diameter increase.

Tolerance Definitions

Hole

diameter—The basic diameter of the hole in the hob.

tolerance—The amount that a hole may be oversize from the basic diameter of the hole.



Comparison between hobbed and shaved profiles.

Fig. 4

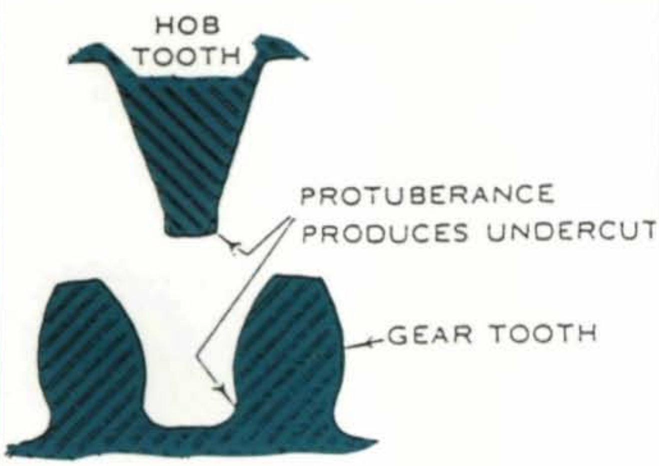


Fig. 5

bearing contact – The area of contact obtained using a plug gage that makes contact over the full length of the hob.

Runout

hub face – The total indicator variation on the end face in one revolution of the hob.

hub diameter – The total indicator variation on the hub diameter in one revolution of the hob.

outside diameter – The total indicator variation on the tops of the hob teeth in one revolution of the hob.

Sharpening

spacing between adjacent flutes – The total indicator variation obtained between two successive flutes when a hob is indexed.

spacing between non-adjacent flutes – The total indicator variation obtained between any two flutes when the hob is indexed through one complete revolution.

rake to cutting depth – The total indicator variation when traversing the tooth face from the top to the cutting depth.

flute lead – The total indicator variation when traversing the faces of all of the teeth in any one flute following the specified lead.

Lead Variation

tooth-to-tooth – The total indicator variation on successive teeth when traversing along the true helical path.

any one axial pitch – The total indicator variation in one complete revolution along the true helical path (360 degrees) on a single thread hob.

any three axial pitches – The total indicator variation in three revolutions along the true helical path (1080 degrees) on a single thread hob.

total – The total indicator variation on teeth when traversing along true helical path of all teeth in hob.

Tooth Profile

pressure angle or profile – The departure of the actual tooth profile from the correct tooth profile as denoted by total indicator variation or by magnified layout comparison.

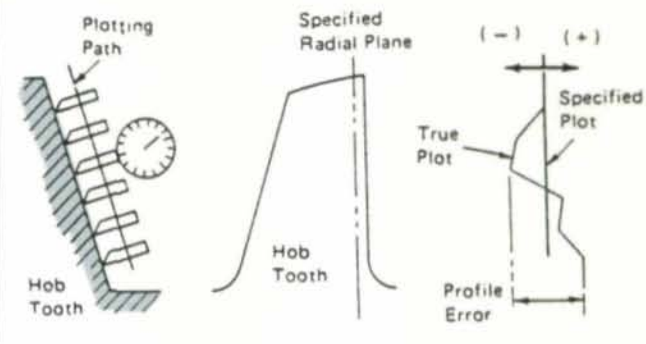


Fig. 6

Tolerances shown apply to straight side profiles in the axial or normal section.

Hobs with curved profiles are special and subject to individual consideration.

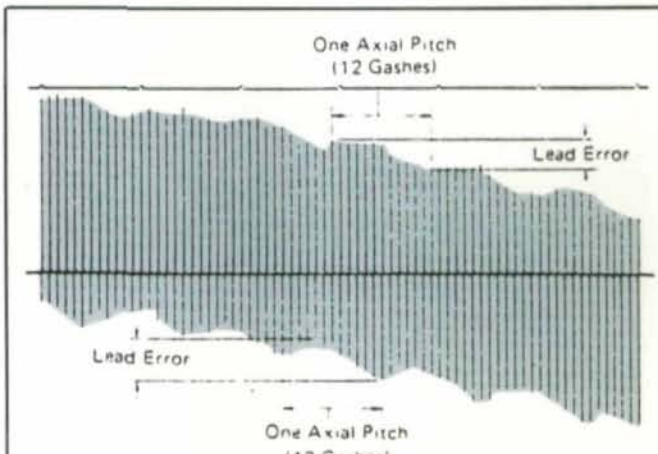
tooth thickness – The difference between the measured thickness and the specified thickness at the hob pitch cylinder.

start of tip relief modification – The tolerance permitted in locating the point on the hob tooth, plus or minus, at which a profile modification begins.

symmetry in start of tip relief modification – The radial tolerance for the start of the modification with reference to the start of the modification on the opposite hob tooth profile.

Hob profile error

The actual hob profile is allowed to vary from the specified hob profile entirely in the plus direction, entirely in the minus direction or split and divided in any ratio, provided the total deviation does not exceed the specified value. This maximum value can occur anywhere along the hob profile, and the variation of the profile on one side of the thread has no relationship to the variation on the other side of that same thread. (See Fig. 6)



Recording Lead Checker Chart for a 12 Gash, 1 Thread Hob Illustrating Lead Error in One Axial Pitch

Fig. 7

SINGLE-THREAD AND MULTITHREAD GEAR HOB TOLERANCES

(All readings in tenths of a thousandth of an inch)

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

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

(All readings in tenths of a thousandth of an inch)

DIAMETRAL PITCH		1 Thru 1.999	2 Thru 2.999	3 Thru 3.999	4 Thru 4.999	5 Thru 5.999	6 Thru 8.999	9 Thru 12.999	13 Thru 19.999	20 Thru 29.999	30 Thru 50.999	51 and Finer
LEAD VARIATION (con't.)	**CLASS**											
	A	38	30	15	12	9	8	8	7	7	5	5
Any Three Axial Pitches*	B	53	38	22	20	15	12	12	10	10	7	
2 - 4 Thread	C	70	50	30	28	20	18	16	14	14	12	8
	D	120	100	80	60	50	40	35	25	22	18	
Adjacent Thread to	A	11	9	8	7	6	5	4	3	3	3	3
Thread Spacing*	B	14	12	11	10	9	8	6	5	5	5	
2 Thread	C	20	17	15	13	11	10	9	8	7	6	5
	D	26	22	19	17	15	13	12	11	10	9	
	A	13	11	10	8	7	6	5	4	4	4	3
3 Thread	B	16	14	12	11	10	9	7	7	6	6	
	C	22	19	16	14	13	11	10	9	8	7	6
	D	28	24	20	18	16	15	13	12	11	10	
	A	15	13	12	9	8	7	6	5	4	4	3
4 Thread	B	18	16	14	12	11	10	8	7	7	6	
	C	24	21	18	15	14	12	11	10	9	8	7
	D	30	26	22	20	18	16	14	13	12	11	
TOOTH PROFILE												
	AA			2	2	1.7	1.7	1.7	1.7	1.7	1.5	1.5
Pressure Angle	A	10	5	3	3	2	2	2	2	2	2	2
or Profile*	B	16	8	5	5	4	3	3	3	3	2	
1 Thread	C	25	15	10	5	4	3	3	3	3	3	3
	D	80	55	30	18	12	8	8	6	5	4	
	A	12	7	5	4	3	3	2	2	2	2	2
2 Thread	B	18	10	7	5	5	4	3	3	3	2	
	C	27	16	11	7	5	4	3	3	3	3	3
	D	80	55	30	18	12	8	8	7	6	5	
	A	15	8	5	4	3	3	3	2	2	2	2
3 - 4 Thread	B	20	10	7	5	5	4	4	3	3	2	
	C	27	16	11	7	5	4	4	3	3	3	3
	D	80	55	30	18	12	8	8	7	6	5	
	AA			100	80	70	60	60	40	40	30	
Start of Approach	A	200	180	160	140	120	100	80	60	40	30	
(Plus or Minus)	B	220	200	180	160	140	120	100	80	50	40	
1 Thread	C	220	200	180	160	140	120	100	80	60	50	
	D	260	240	220	200	180	160	140	120	100	80	
	A	200	180	160	140	120	100	80	60	50	40	
2 - 4 Thread	B	220	200	180	160	140	120	100	80	60	50	
	C	220	200	180	160	140	120	100	80	60	50	
	D	260	240	220	200	180	160	140	120	100	80	
	AA			70	60	50	40	40	25	25	25	
Symmetry of Approach*	A	150	130	120	100	90	80	60	50	35	25	
1 Thread	B	180	150	130	120	100	90	80	70	45	35	
	C	180	150	130	120	100	90	80	70	55	45	
	D	200	180	160	140	120	110	100	90	80	60	
	A	150	130	120	100	90	80	60	50	40	30	
2 - 4 Thread	B	180	150	130	120	100	90	80	70	60	50	
	C	180	150	130	120	100	90	80	70	60	50	
	D	200	180	160	140	120	110	100	90	80	60	

*Total indicator variation.
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Tolerances apply only to standard or recommended hob diameters.

(All readings in tenths of a thousandth of an inch)

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

	FACE WIDTH	0 to 1"	1" to 2"	2" to 4"	4" to 7"	7" and up
Accuracy of Flutes, Straight And Helical*	AA	8	10	15	20	20
	A	10	15	25	30	50
	B	10	15	25	30	50
	C	10	15	25	30	50
	D	15	23	38	45	75

BORE (1-4 Thread)

	BORE DIAMETER	2.500"	2.000"	1.500"	1.250"	.750"	.500" & smaller
Diameter, Straight Bore (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

	ALL DIAMETERS	LENGTH
Percent of Bearing Contact, Straight Bore	AA	75
	A	75
	B	75
	C	60
	D	50

	ALL TAPERS	CIRCUMFERENCE	LENGTH
Percent of Bearing Contact, Taper Bore	AA	95	75
	A	90	60
	B	90	60
	C	90	60

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

STANDARD HOB SPECIFICATIONS & TOLERANCES
RECOMMENDED HOB SIZES

Single Thread Coarse Pitch Hob Sizes
for Ground and Unground Hobs

(1-19.99 Normal Diametral Pitch)

For Spur and Helical Gears

Normal Diametral Pitch	Nominal Hole Diameter	Outside Diameter	Overall Length
1	2½"	10¾"	15"
1¼	2"	8¼"	12"
1½	2"	8"	10"
1¾	2"	7¼"	9"
2.00-2.24	1½"	5¼"	8"
2.25-2.49	1½"	5½"	7½"
2.50-2.74	1½"	5"	7"
2.75-2.99	1½"	5"	6"
3.00-3.49	1¼"	4½"	5"
3.50-3.99	1¼"	4¼"	4¾"
4.00-4.99	1¼"	4"	4"
5.00-6.99	1¼"	3½"	3½"
7.00-7.99	1¼"	3¼"	3¼"
8.00-11.99	1¼"	3"	3"
12.00-13.99	1¼"	2¾"	2¾"
	¾"	2"	2"
14.00-19.99	1¼"	2½"	2½"
	¾"	1⅞"	1⅞"

Single Thread Fine Pitch Hob Sizes
for Ground and Unground Hobs

(20 Normal Diametral Pitch and Finer)

For Spur and Helical Gears

Normal Diametral Pitch	Nominal Hole Diameter	Outside Diameter	Overall Length
20-21.99	1¼"	2½"	2½"
	¾"	1⅞"	1⅞"
22-23.99	1¼"	2½"	2"
	¾"	1⅞"	1⅞"
24-29.99	1¼"	2½"	2"
	¾"	1⅞"	1⅞"
	½"	1¼"	1¼"
30-55.99	¾"	1⅞"	1½"
	½"	1⅛"	1⅛"
	.3937 (10 mm)	1⅛"	¾"
	.315 (8 mm)	⅞"	½"
56-85.99	¾"	1⅝"	1⅛"
	½"	1⅛"	1⅛"
	.3937 (10 mm)	1⅛"	¾"
	.315 (8 mm)	⅞"	½"
86-130.99	¾"	1½"	¾"
	½"	1⅛"	⅞"
	.3937 (10 mm)	1"	¾"
	.315 (8 mm)	¾"	½"
131-200	¾"	1⅜"	⅝"
	½"	1⅛"	½"
	.3937 (10 mm)	1"	½"
	.315 (8 mm)	¾"	½"

Multiple Thread Course Pitch Hob Sizes
for Ground and Unground Hobs

(2-19.99 Normal Diametral Pitch)

For Spur and Helical Gears

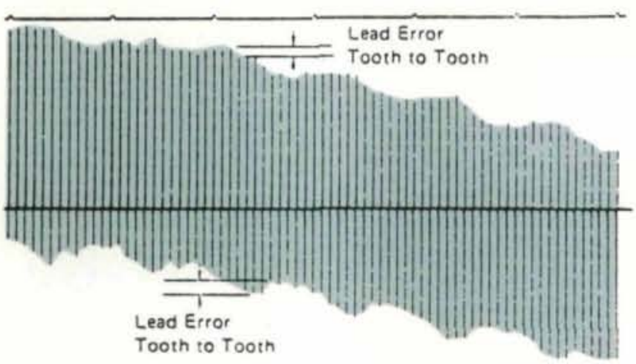
Normal Diametral Pitch	Number of Threads	Nominal Hole Diameter	Outside Diameter	Overall Length
2-2.99	2	1½"	6½"	8"
3-3.99	2	1½"	5½"	5½"
4-4.99	2 or 3	1½"	5½"	5½"
5-6.99	2, 3 or 4	1½"	5"	5"
7-7.99	2, 3 or 4	1¼"	4"	4"
8-8.99	2, 3 or 4	1¼"	3¾"	3¾"
9-11.99	2, 3 or 4	1¼"	3½"	3½"
12-13.99	2, 3 or 4	1¼"	3¼"	3¼"
14-15.99	2, 3 or 4	1¼"	3"	3"
16-19.99	2, 3 or 4	1¼"	2¾"	2¾"

Multiple Thread Fine Pitch Hob Sizes
for Ground and Unground Hobs

(20 Normal Diametral Pitch and Finer)

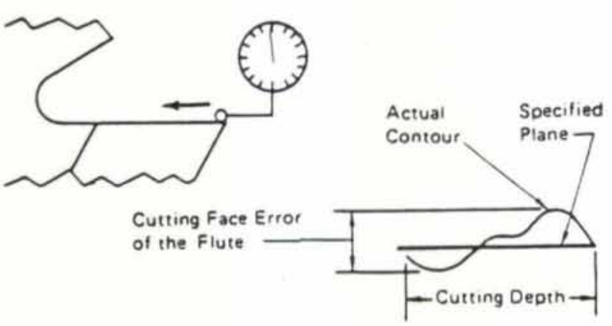
For Spur and Helical Gears

Normal Diametral Pitch	Number of Threads	Nominal Hole Diameter	Outside Diameter	Overall Length
20-29.99	2, 3 or 4	1¼"	2½"	2½"
30-50	2, 3 or 4	¾"	1⅞"	1½"



Recording Lead Checker Chart for a 12 Gash, 1 Thread Hob Illustrating Lead Error Tooth to Tooth

Fig. 8



Method of Measuring the Cutting Face Error of the Hob Flute

Fig. 9

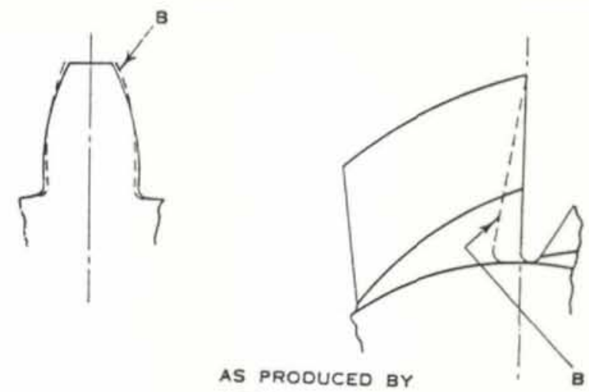


Fig. 10

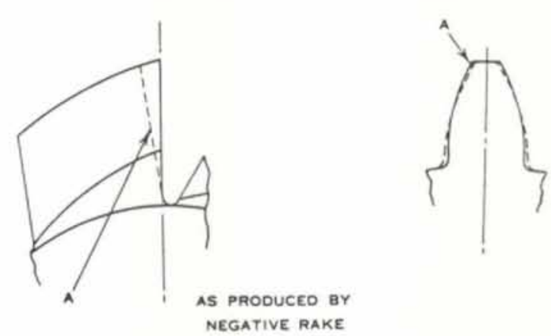


Fig. 11

Lead error — one axial pitch

Lead error in one axial pitch is the maximum deviation from the theroretical thread helix in any group of hob teeth equal to the number of hob teeth in one axial pitch. This number of hob teeth may be selected anywhere in the length of the hob and is equal to the number of hob gashes divided by the number of hob threads. (See Fig. 7)

Lead error — tooth-to-tooth

Tooth-to-tooth lead error is the maximum deviation between any two consecutive hob teeth from their relative position as measured at any point along the thread in the entire hob length. Fig. 8 illustrates this error as read from an automatic lead checker chart.

Cutting face error

The cutting faces of the hob flute are usually designed to lie in a given radial plane in the case of straight flute hobs and in a specific helicoidal surface for helical flute hobs. However, in straight flute hobs the plane can be radial or can be inclined in either direction from radial providing either positive or negative rake. When the cutting faces are designed to lie in a plane, the variation of the actual hob flute cutting faces from that plane is considered to be a flute cutting face error. (See Fig. 9)

Positive rake in sharpening increases depth and decreases pressure angle of the hob tooth. The resulting gear tooth is too heavy at the top and too thin at the bottom as shown in Fig. 10.

Negative rake in sharpening decreases the depth and increases the pressure angle of the hob tooth. This results in a cutting drag and makes the gear tooth lighter at the top and heavier at the bottom. (See Fig. 11)

Optimizing Tool Design

Multiple thread hobs

The two primary considerations in determining the number of threads on the hob are the production requirements and the accuracy and finish requirements. Increased production is the outstanding advantage of multithread hobs.

A single-thread hob rotates once for each tooth on the part, a double-thread hob rotates once for every two teeth on the part, a triple-thread hob rotates once for every three teeth, etc. Therefore, the workpiece rotates faster in relation to the hob speed, depending upon the number of threads on the hob.

The increase in the speed of indexing, however, does not usually result in a proportional gain in production. The diameter of a multithread hob is larger than a corresponding single-thread hob but does not increase in proportion to the number of threads. Therefore, the number of flutes does not increase in direct proportion to the number of threads.

Material

When considering the total manufacturing cost per metal cutting operation the price of the tool is, in fact, minor in percentage. It is not uncommon that the purchase cost of a tool will amount to only about 5% of the total cost per part. With this in mind, it follows that simply buying the cheapest tool is not an effective way of reducing cost.

If the purchase price of the tool is combined with the cost of resharpening the tool, we find that the total tool cost is approximately 15% of the metal cutting cost per part produced. The balance, or about 85%, is considered machining cost. This will be discussed in detail later. The percentage stated above are for gear cutting tools such as hobs and shaper cutters. Less expensive tools will have different ratios. Table 1 shows the relative cost of tools made of different steels as they are related to the base price of an M2 tool.

Table 1 takes into account both the increase due to material cost (premium steels because of manufacturing process and alloying elements generally are more expensive) and the additional machining cost encountered by the tool manufacturer.

The life of any particular tool is directly related to the following factors:

a. Crater wear
b. Corner/flank wear
c. Chipping

Crater wear is largely a function of red hardness and abrasion resistance of the tool steels being examined. The usual causes of cratering are cutting conditions (speed and feed) too high for the tool material.

Corner/flank wear depends on micro-chipping due to lack of toughness or abrasive wear due to lack of hardness. Under normal conditions, it is flank wear that puts the limit on the life of the tool.

Chipping occurs when the tensile strength of particular tool steel is exceeded. This type of wear is due to brittle tool materials subjected to excessive mechanical loads.

TABLE 1

M2	M2HC	M3	M4	M35
100	100	125	2125	140
M42	REX 20	REX 25	REX 76	T1
150	–	170	200	150
T15	ASP23	ASP30	ASP60	
180	110	125	160	

% Relative Price (To M2 Material)

TABLE 2

M2	M2HC	M3	M4	M35
100	100	110	125	120
M42	REX 20	REX 25	REX 76	T1
120	120	130	130	100
T15	ASP23	ASP30	ASP60	
130	110	120	135	

% Relative Life (To M2 Material)

TABLE 3

M2	M2HC	M3	M4	M35
100	100	110	115	110
M42	REX 20	REX 25	REX 76	T1
125	125	125	125	100
T15	ASP23	ASP30	ASP60	
125	110	110	135	

% Relative Feed (To M2 Material)

TABLE 4

M2	M2HC	M3	M4	M35
100	100	100	100	120
M42	REX 20	REX 25	REX 76	T1
125	125	140	200	100
T15	ASP23	ASP30	ASP60	
200	100	120	160	

% Relative Speed (To M2 Material)

As pointed out earlier, there is a definite trade-off between wear resistance/red hardness (flank wear and cratering) vs. toughness (chipping and flank wear). It is due to this trade-off that in most instances, the cutting conditions will change in relation to the tool material being used.

Table 2 lists some relative extended life values for different tool steels as they are related to an M2 tool. Example: You can expect an estimated 25% more parts per tool if you compare M4 to M2.

In the tool cost section it was stated that approximately 85% of the total manufacturing cost is due to machining cost. This machining cost is directly related to feeds and speeds in any given application. To effectively decrease machining cost, it is required that the volume of stock removal per unit

(continued on page 47)

DESIGN AND SELECTION OF HOBS . . .
(continued from page 45)

time be increased by increasing the feed and/or speed. Maximum values in this area are sought with regard to:

a. Tolerances specified.
b. Surface finished required.
c. Stability and design of machine.

Some typical figures for relative feeds and speeds are shown in Table 3 and 4. As with the other comparison tables, all the materials are shown in relation to an M2 tool. It should be pointed out that these figures are only approximations. Actual results may vary according to how aggressively the original M2 tool is being applied.

Titanium Nitride Coatings

To develop the proper tool design for a specific application, yet another variable must be given consideration – titanium nitride coatings.

In an effort to improve tool life and increase the productivity of the gear cutting process, extensive research and development has taken place in the past few years to successfully apply titanium nitride coatings to high speed steel tools.

The intent of this section is to suggest the importance of proper selection of high speed steels used in combination with titanium nitride coatings.

There are two modes of failure directly related to the substrate material used with titanium nitride coated tools, cratering, and lack of adherence.

After a coated tool (hob, shaper cutter) is sharpened, the titanium nitride layer is removed from the cutting face of the tooth. This exposes the substrate material and thus, the cratering resistance is only as good as the base metal. If the primary mode of failure on an uncoated tool is cratering, simply coating the tool with titanium nitride is not the solution. Another point to keep in mind is that although cratering was not a problem with the uncoated tool, with increased feeds and speeds and more pieces per sharpening being cut, it is likely that cratering may become a problem. Whether cratering was a problem with the uncoated tool or developed after titanium nitride coating, it would be suggested to try a higher alloy steel (one high in abrasion resistance). If cratering continues to be a problem after trying different tool steels, it may be necessary to revise (slow down) the operating conditions.

Occasionally, the wear pattern of coated cutting tools can be flaking close to the cutting edge. Consequently, the tool

(continued on page 48)

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.

CONTROLLING TOOTH LOADS . . .
(continued from page 33)

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 . . .
(continued from page 47)

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.