Contact Surface Topology of Worm Gear Teeth

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Abstract:

In a mating worm and worm gear set, the inspection of the worm member is accomplished by available analytical inspection procedures. The mating enveloping worm gear with its warped tooth surfaces is generally accepted by the contact pattern developed while running the gear with a qualified worm. These patterns will only show that area with a minimal separation between the worm and worm gear tooth surfaces and the actual separation beyond the contact area are unknown.

A mathematical modelling procedure has been developed to predict the initial contact pattern, as well as the surface separation topology over the entire worm gear tooth surface. Equations and procedures are presented to permit an analysis for any gear set.

Gear and tool design parameters can be studied in relation to the computed results in advance of actual cutting of the components.

Introduction

Among the various types of gearing systems available to the gear application engineer is the versatile and unique worm and worm gear set. In the simpler form of a cylindrical worm meshing at 90° axis angle with an enveloping worm gear, it is widely used and has become a traditional form of gearing. (See Fig. 1.) This is evidenced by the large number of gear shops specializing in or supplying such gear sets in unassembled form or as complete gear boxes. Special designs as well as standardized ratio sets covering wide ratio ranges and center distances are available with many as stock catalog products.

This type of gearset has broad capabilities and can range in center distance sizes from as little as .3" to as much as 100"

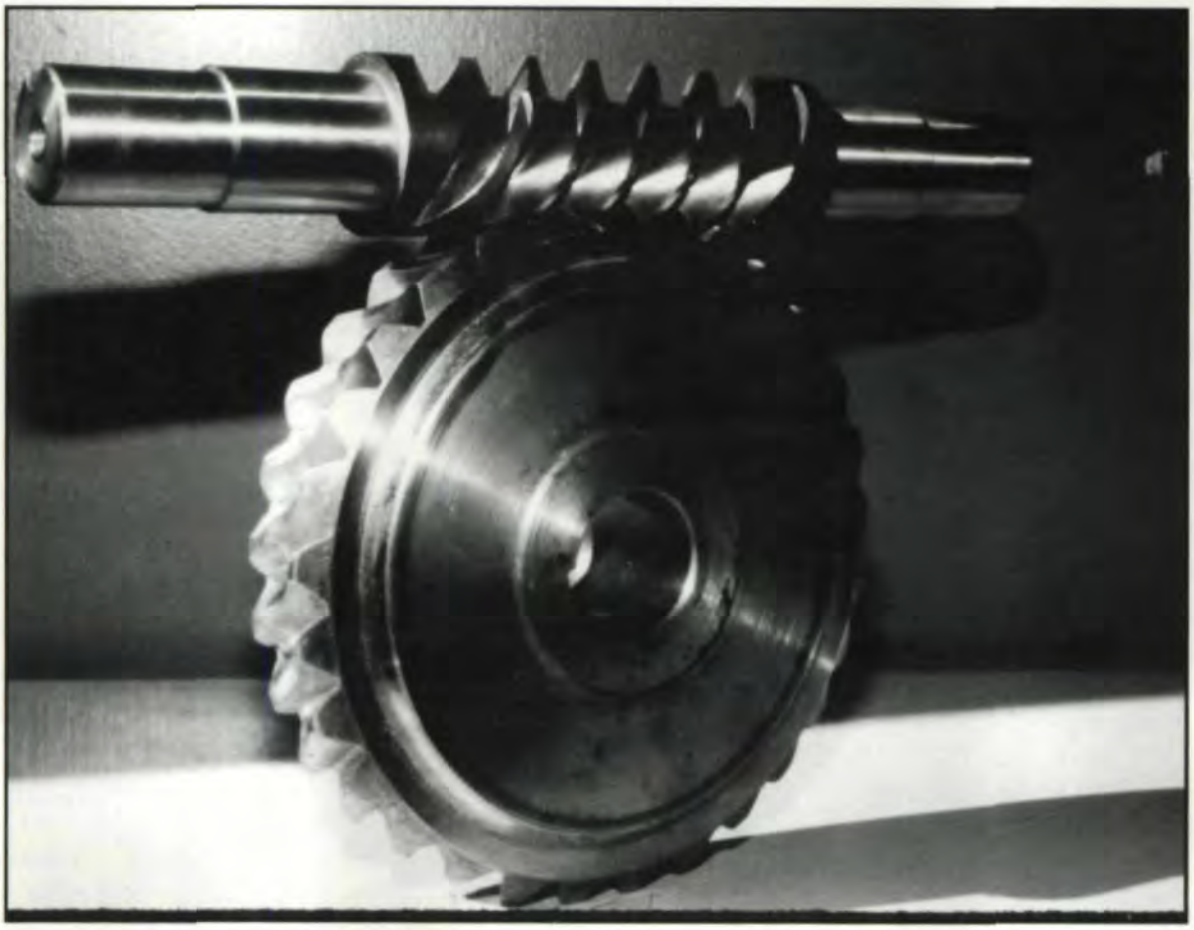
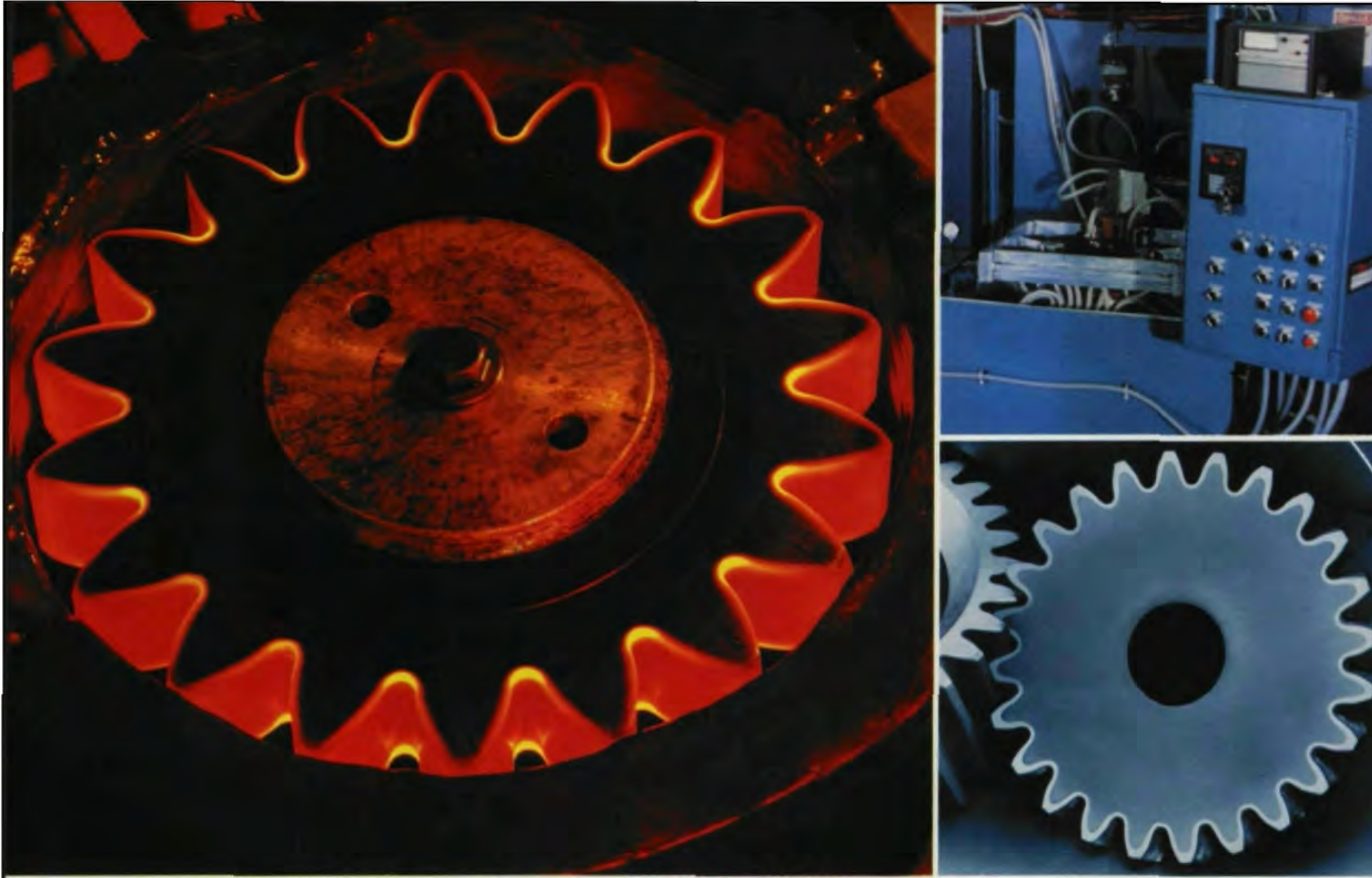


Fig. 1 – A typical industrial speed reducer gear set using a ground form worm and a bronze gear.



or more. Reduction ratios in the range of 4 to 1 and 400 to 1 are possible. While a large percentage of the worms are single thread or single start, it is not uncommon to see ten or more threads in the worm. Applications range from very precise drives, such as dividing heads and indexing tables, through power drives and the less precise situations requiring motion direction changes or adjusting purposes.

Examples of the applications of this type of gearing are: Speed reducers, indexing tables, positioning tables, screw jacks, hoists, passenger and freight elevators, machine tools, capstans, conveyors, tensioners, actuators, stoker drives, printing machines, antenna drives, electric clocks, floor polishers, food processors, irrigation drives, speedometer drives, washing machines, waste water processors, valve operators and mining machines.

The enveloping worm gear tooth surface that is required in the set creates a rather unusual manufacturing problem. The warped tooth surface must comform very closely in conjugate action with the worm so that good load support, long wear life and smooth transmission of motion are maintained. In fact the one advantage of the worm gear set over a simple crossed axis set of helical gears, is load carrying ability. A throated worm gear set can carry some 15 to 20 times the load of a comparable set of crossed axis helicals. This is attributable solely to the larger area of contact available with enveloping worm gears.

The Worm Member

There are five popular ways to make a worm.

Thread chasing. A straight sided tool is positioned in a lathe and tranversed axially through the turning worm blank. If the tool cutting edge lies in the worm normal plane that is normal to the worm lead angle, a "chased helicoid" will be formed. If the cutting edges of the tool lie in the axial plane of the worm, an Archimedean or common screw thread is formed. This method is not too popular if a ground worm surface is needed, since the grinding wheel shape becomes geometrically complex and difficult to dress.

Thread milling. This method utilizes a special lathe which has a milling cutter drive head set in place of the tool post. As the worm is turned the milling head is passed axially through the worm, developing a lead. The double conical vee form of the cutter produces a worm called the "thread milled helicoid." This method is far more productive than thread chasing, but still lacks somewhat in accuracy or finish on the worm.

Thread grinding. In place of the relatively small cutter used in thread milling, a larger double conical vee shaped grinding wheel is used. The machine motions are the same as above, and a "thread milled helicoid" is produced. With the need in many cases for a good smooth finish on the worm member, this is a popular way to produce worms. Besides good finish, accuracy is also available with the worm surface in a fully hardened state.

It is possible to use a special dressed form on the grinding wheel other than the straight vee form, so that an involute helicoid will be developed on the worm. Or alternately, a single flank grind could be used with the flat side of a grinding wheel generating the involute helicoid. The involute helicoid is chosen sometimes as the design basis of the worm, and in some countries it is the standard form.

Hobbing. If the worm has two or more starts, it becomes possible to consider regular hobbing practices for manufacture. A gear hobbing machine and a hob are employed to cut the worm, and the result is a generated involute helicoid worm. Considerations for the resulting hobbed finish and accuracy must be made. This is a productive way of making multiple start worms.

Roll forming. With the capability of very high productivity the use of roll forming of worms has become popular. Because of the large relative size of the rolling dies compared to the

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worm, the resulting worm is usually a very close fit to an involute helicoid form. However, since roll forming relies on the plastic deformation of the worm material, some rolling die development work might have to be done to produce the desired results. While the surface finish is usually quite acceptable, the chance of distortion after heat treat does exist.

The Worm Gear Member

The worm gear member is almost exclusively produced by one of the gear hobbing processes:

Radial feed. This is also known as the infeed method and uses a multiconvolution full face width hob and a gear hobber with a power infeed or radial feed cycle. This is the most common way of producing the worm gear and is the fastest method if it can be used. Almost all single thread applications are made this way. The hob is plunged to depth into the blank and is dwelled until full final cutting is completed.

Tangential feed. Whenever it is not possible to use the radial feed method, either because of the worm thread versus gear teeth relationship or because of the need for a smoother finish, the tangential feed method is used. It requires a gear hobbing machine with a tangential feed capability which travels the tool tangentially past and through the worm gear throat. The long path of tool travel requires longer cutting times than radial feeding. There are four different designs of tooling that can be used in this process.

- Multiple convolution cylindrical hob. This hob uses the machine cycle of a radial feed followed by at least one axial pitch of tangential travel.
- Multiple convolution tapered end hob. This hob is fed only in the tangential direction leading into the cut with the tapered roughing section and following with the finishing section. This combined roughing and finishing hob is favored for use with the coarser pitch gears starting at about .600 axial pitch or bigger. This hob requires more time to cut the gear than the radial-axial feed.
- Pancake hob. Pancake hobs are tangential feed tools which permit lesser tool costs, having a narrow face and only one or two finishing teeth lying in each thread. Because of fewer cutting edges tool wear is higher and gear cutting time is increased.
- Fly cutters. Having a hobbing machine capable of tangential feed permits the cutting of worm gears with very minimal tool costs as only a single finishing hob tooth or tool point is required. Of course, it also requires the maximum machine time, and the wear demands on the single point tool are high. For development work, short delivery demands or limited production of parts the method is ideal. Contact pattern is not locked in and is more controllable.

Inspection of the Worm

The accuracy of the worm thread lead and the thread spacing on multiple thread worms is sensed by a lead measuring instrument. The worm profile can be checked by using a worm and hob profile checker with a co-ordinate system, or if the worm is an involute helicoid, by a straight line check along the generatrix. The worm can be readily checked for accuracy and compared to specified values and tolerances.

Fig. 2—Basic gear rolling inspection unit with fixed 90° axis angle.

Fig. 3—Floor model instrument with a rotatable swivel feature allowing deviation from 90° axis angle.

Fig. 4—Close up view of unit in Fig. 3.

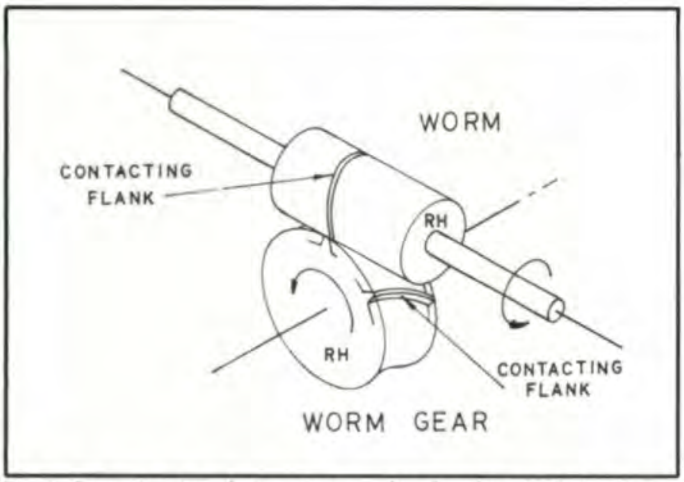


Fig. 5—Isometric view of conventions used in describing contact patterns.

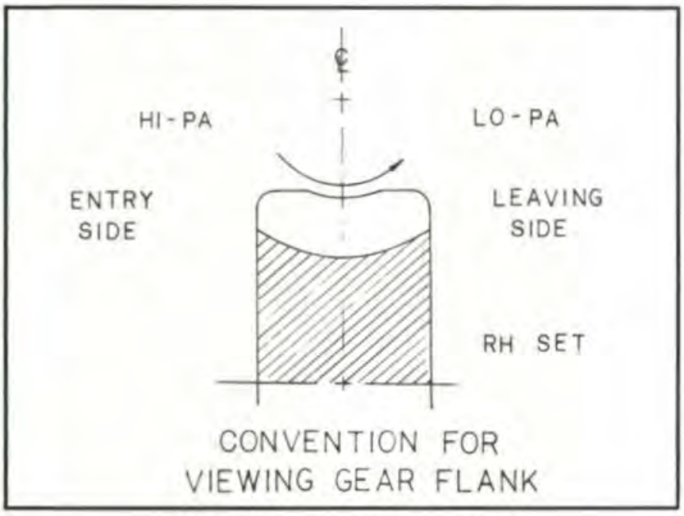


Fig. 6—Plan view of gear tooth flank.

Inspection of the Worm Gear

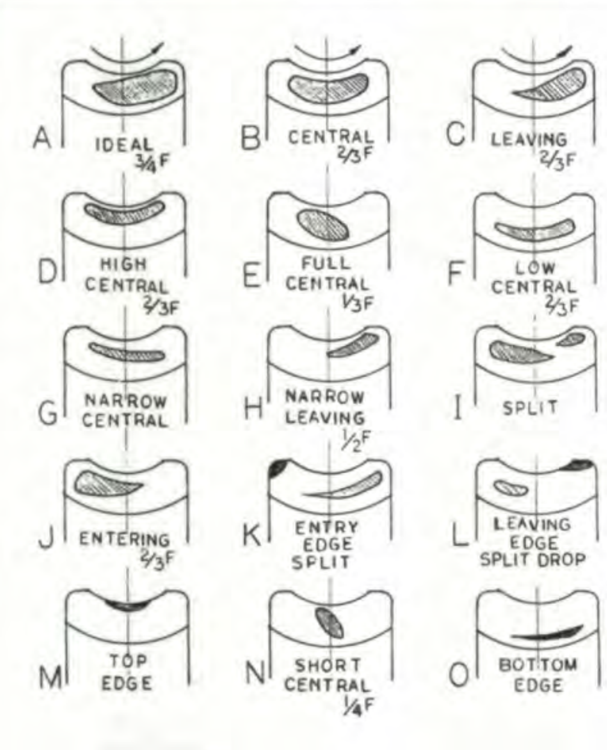
Although tooth spacing and pitch diameter runout can be readily checked analytically, there are no simple analytical methods for checking the worm gear tooth surface. Functional methods are commonly used for two reasons: to make a composite check, rolling the worm gear in mesh with a qualified production part or a master worm, measuring the total composite action and tooth to tooth action, and to develop a contact pattern. The latter check is done at a fixed center distance, with backlash, under light load, rolling in both directions. The contact pattern is enhanced by using a marking medium such as a colored pigment, coating the worm and rolling, thus, transferring the pigment to the gear to develop the contact pattern. Usually this check is performed with the gear axes at right angles, but some rolling instruments can swivel the worm support for a measure of the amount of readjustment for the hob swivel setting. For those gearsets that are sensitive to the swivel setting, this feature can reduce the trials and recuts necessary to close in on an acceptable contact pattern.

Fig. 2 shows a basic gear rolling unit with a fixed 90° axis angle. Fig. 3 shows a more complex gear rolling unit that includes a rotatable and measurable swivel, which permits departures from the 90° axis angle setting. Fig. 4 is a close up of the same instrument and shows a motor drive attachment for turning the worm.

Contact Pattern Analysis

The convention for viewing the contact pattern on a gear set is shown in the isometric view on Fig. 5 and the plan view in Fig. 6. The entering and leaving sides are identified.

Fig. 7 displays some of the contact patterns that may be encountered.



CODE: F – Face width
A – Acceptable
MA – Marginally acceptable
NA – Not acceptable

A. The ideal accepted contact pattern with clearance on the entering side which allows for the lubricant film to be carried into mesh. The contact is about 2/3 of the gear face, is mostly located on the leaving side of center and has no edge contact.

B.	Center contact	A
C.	Leaving side contact	A
D.	High central contact	A
E.	Full central contact	A
F.	Low central contact	A
G.	Narrow central contact	MA
H.	Narrow leaving contact	MA
I.	Split contact	MA
J.	Entering side contact	NA
K.	Entry edge - split	NA
L.	Leaving edge - split/drop	NA
M.	Top edge	NA
N.	Short central	NA
O.	Bottom edge	NA

Fig. 7—Description of various contact patterns.

Edge contacts are usually considered unacceptable because of possible lubricant diversion or blockage on the entering side, or because of probable broken contact or a poor rolling action on the leaving side. Top and bottom edge contacts are unacceptable and also may be accompanied by a poor rolling action.

Narrow areas of contact can cause heating and, depending on loading, may be destructive. Welding of material between gear and worm may occur. Worm gear sets involve a significant degree of sliding in the contact zone and lubrication is highly important.

For high precision drives not only is good rolling action desired, but also a substantial area of contact to assure long consistent accuracy.

The Worm Gear Cutting Procedure

The initial set up of the worm gear hobbing machine is always tentative until the first piece can be inspected and passed. If necessary, adjustments are made in the hobbing machine settings. For inspection, the gear is transferred from the gear cutting machine to a gear rolling tester where it is run against a test worm. Observing the contact pattern on both flanks can help decide if a centering or hob swivel change is necessary. Traffic continues between the cutting and checking machines until an acceptable pattern is established. The process starts over if the cutting tool is sharpened or changed.

A New Approach to Contact Pattern Planning

We have now seen the framework in which most worm gear sets are manufactured. If a problem arises with the contact pattern, a good amount of time can be spent in deciding on a course of corrective action. The information seen in the paint markings may leave many unanswered questions as to the future prospects for the gear set. An analysis solely by the contact pattern can be a very frustrating matter on certain gear set configurations.

If a part of the surface does not contact, one cannot tell just how much separation exists. Thin coatings of marking materials may only sense separations of .0003 to .0005". Use of shims or feelers has proven unreliable because contact separation is a dynamic thing. Correct placement of the shim is difficult to estimate. Accelerated wear testing is expensive. Full load run in tests usually leaves questions too.

A mathematical modelling procedure is presented here to help in describing the clearances that exist between the worm and gear teeth as they rotate through mesh. Naturally this involves the cutting tool, as this is the part that establishes the worm gear tooth contacting surface. If the tool is a hob, it involves the exact design, whether based on normal or axial pitch, and includes profile modifications. The results of this procedure are called the contact surface topology of the worm gear tooth. The calculated data can be mapped along equal separation lines so contact areas may be predicted and observations of future contact prospects may be made. As with all mathematical modelling, the relationships are rather exact, and in reality this is seldom true. Experience has shown a good correlation between this model and real life experiences, and it can be used as a basis for some logical and practical decisions.

The Mathematical Approach

As mentioned earlier there are several different families of worms and the first step is to identify that family. We have done work on these three:

1. Archimedian or screw helicoid
2. Thread milled helicoid
3. Involute helicoid

Because of the individual geometry characteristics of each different worm family, separate programs are used for each, *but the procedure is the same. The equations will only be* given for the screw helicoid, but examples will be shown for screw and involute helicoid. Figs. 8-14 illustrate various aspects of this gear geometry. Following is a list of the nomenclature used in the calculations.

Nomenclature

AX	– Axial pitch of worm
TH	– Number of worm threads
L	– Lead of worm
D2	– Worm pitch diameter
LA	– Worm lead angle
R2	– Worm pitch radius
PN	– Normal circular pitch of worm
OS	– Hob design oversize on diameter
D7	– Hob pitch diameter
NH	– Number of hob threads
HL	– Hob lead angle
LH	– Hob lead
CD	– Actual center distance of gear set
CH	– Hobbing center distance
NW	– Number of gear teeth
R5	– Theoretical gear pitch radius
CC	– Theoretical center distance of gear set
D	– Offset plane distance
RX	– Radius to a point in offset plane
TA	– Turning angle of worm
AP	– Axial pressure angle of worm
XX & YX	– Co-ordinates of point in offset plane
PP	– Axial pressure angle at point XX, YY in offset plane
Q	– Interim value
RT	– Interim value - radians
RW	– Interim value - radians
RZ & RQ	– Polar co-ordinates of point on worm gear flank
RG	– Interim value - radians
C	– Parametric value - radians
SA	– Swivel angle of hob
AL	– Interim value - radians
DH	– Interim value
RB	– Interim value - radians
BB & X2	– Co-ordinates of trace in hob axial section
XC & YC	– Co-ordinates of trace rotated to hob axial PA

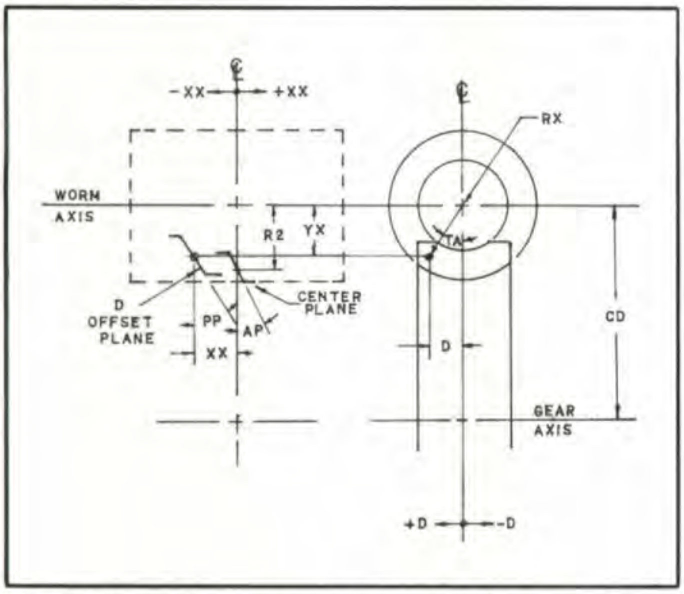


Fig. 8 – Diagram of geometry and dimensions on the worm and gear.

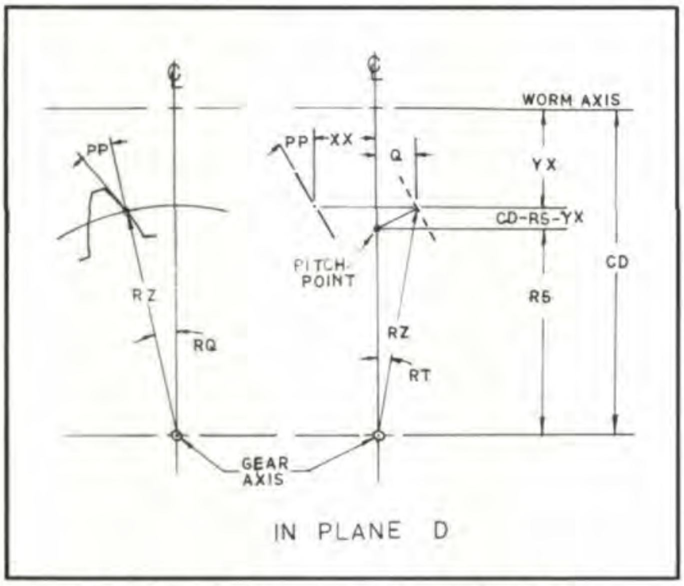


Fig. 9 – Diagram of geometry on the set in the "D" plane.

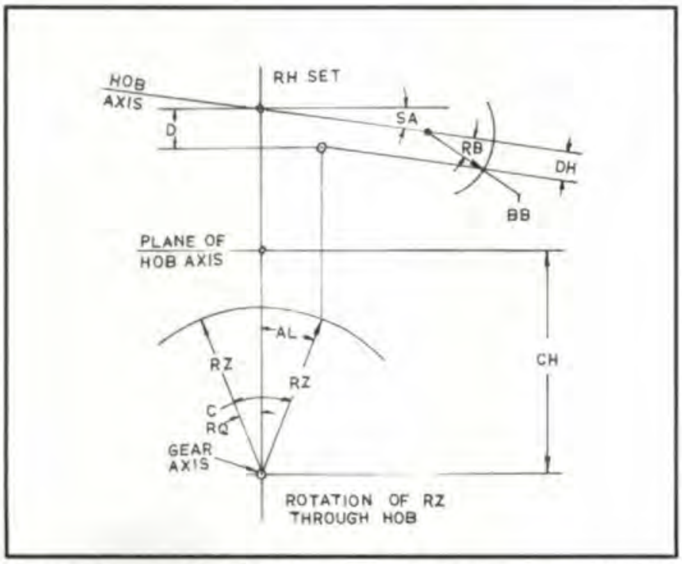


Fig. 10 – Diagram of the relationship of a point on the worm gear and the hob.

These equations are for a right hand worm and right hand gear at 90° axis angle and utilizing the normal pitch hob design method.

$L=AX*TH$ (1)

$\text{Tan } LA=L/(D2*PI)$ (2)

$R2=D2/2$ (3)

$PN=AX*\text{Cos } LA$ (4)

$D7=D2+OS$ (5)

$\text{Sin } HL=NH*PN/(D7*PI)$ (6)

$LH=NH*PN/\text{Cos } HL$ (7)

$CH=CD+OS/2$ (8)

$R5=NW*AX/(2*PI)$ (9)

$CC=R5+R2$ (10)

$YX=\text{sqr}(RX^2-D^2)$ (11)

$\text{Tan } TA=D/YX$ (12)

$XX=(RX-R2)*\text{Tan } AP-TA*L/(2*PI)$ (13)

$\text{Tan } PP=(2*PI*YX*\text{Tan } AP*RX+L*D)/(2*PI*RX^2)$ (14)

$Q=(CD-R5-YX)/\text{Tan } PP$ (15)

$\text{Tan } RT=Q/(CD-YX)$ (16)

$RZ=\text{sqr}(Q^2+(CD-YX)^2)$ (17)

$RW=(XX-Q)*2*PI/L$ (18)

$RG=RW*TH/NW$ (19)

$RQ=RG+RT$ (20)

$AL=RQ+C$ (21)

$DH=D*\text{Cos } SA-RZ*\text{Sin } AL*\text{Sin } SA$ (22)

$\text{Tan } RB=DH/(CH-RZ*\text{Cos } AL)$ (23)

$BB=\text{sqr}(DH^2+(CH-RZ*\text{Cos } AL)^2)$ (24)

$X2=LH*(RB-NW*C/NH)/(2*PI)+RZ*\text{Sin } AL*\text{Cos } SA+D*\text{Sin } SA$ (25)

$YC=(BB-D7/2)*\text{Cos } WAP+X2*\text{Sin } WAP$ (26)

$XC=(BB-D7/2)*\text{Sin } WAP-X2*\text{Cos } WAP$ (27)

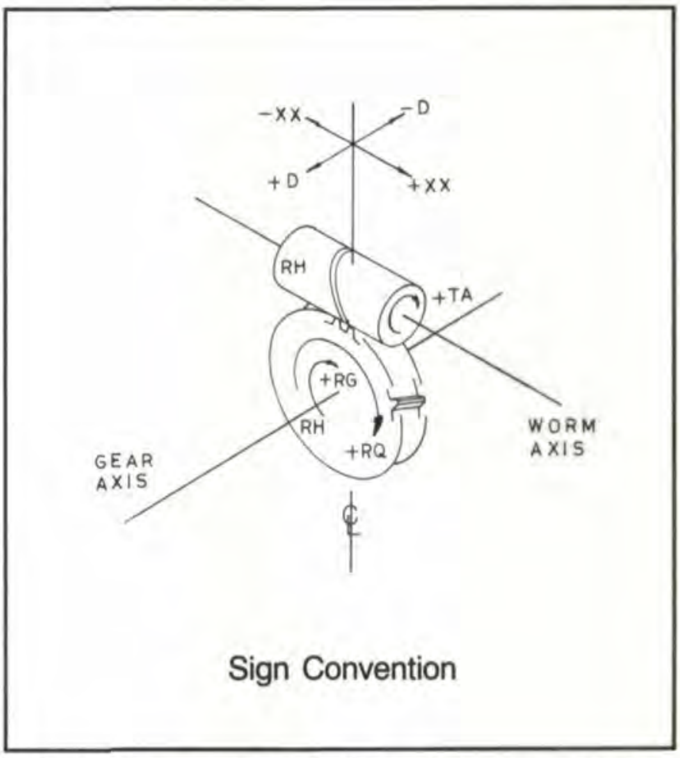


Fig. 11 – Sign convention used in the equations for worm and gear.

Analysis Procedure

To make a contact analysis all the pertinent worm, worm gear and hob data necessary to describe the set is listed. The face of the gear is sectioned by a plane offset a distance D from the centerline. To cover the entire gear face some planes are taken both to the right and left of center; that is, plus and minus D values. For a particular value of D, various values of RX, an arbitrary radius on the worm, are selected beginning with the worm outside radius. Radius RX is gradually reduced observing the value of RZ, which is on the worm gear, seeing that it remains within the limits of the gear outer radius. This point is then rotated back into the gear hob by varying the value C, tracing the point path until it passes near or through the hob helicoid surface. If a point penetrates the hob surface, material will be removed at that radius point, RZ. If the trace passes outside the hob surface, excess material will be left. Thus for each value of D & RX, a value RZ is calculated and an associated separation value is determined. Fig. 15 shows the trace of several points as they are tracked back into the hob surface. On a magnified basis the separations are easily measured, and the profile separation based on actual hob profile is determined as is shown in Fig. 16. Data is plotted in an array format as D & RZ on a gear face layout according to the convention in Fig. 17. It yields a field which can be contoured into a topological map.

The sample data (Table 1) was used in this presentation

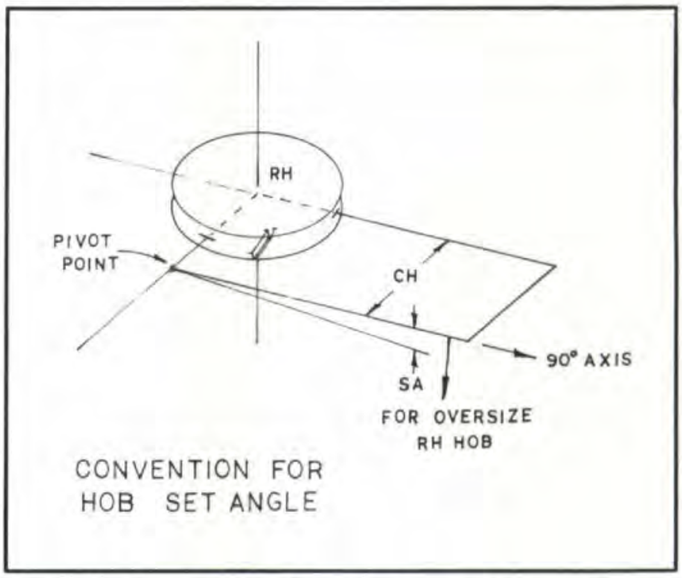


Fig. 12 – Diagram of the hob swivel or setting angle convention.

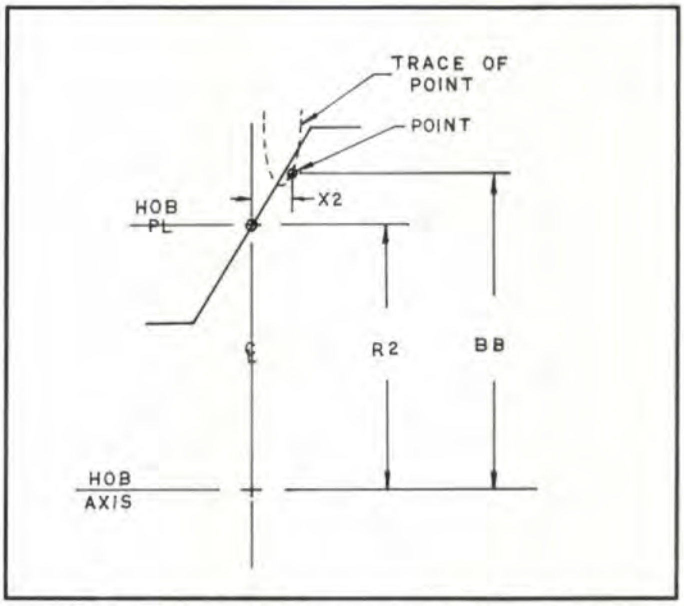


Fig. 13 – Co-ordinates of the point trace path in the axial hob section.

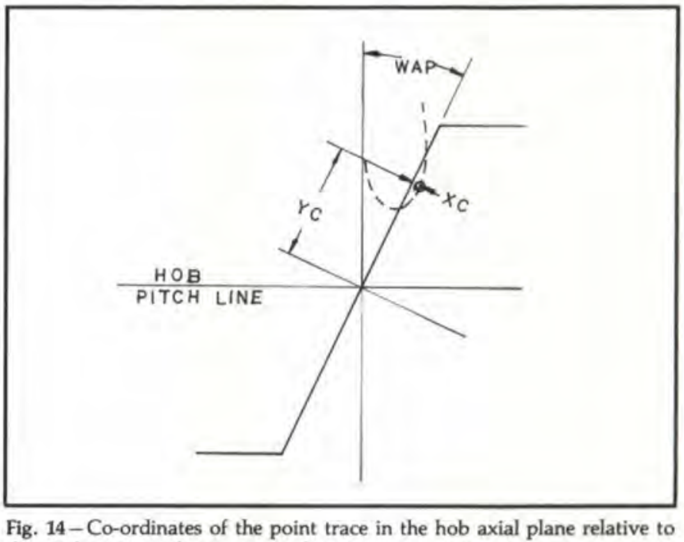


Fig. 14 – Co-ordinates of the point trace in the hob axial plane relative to the pitch point and pressure angle.

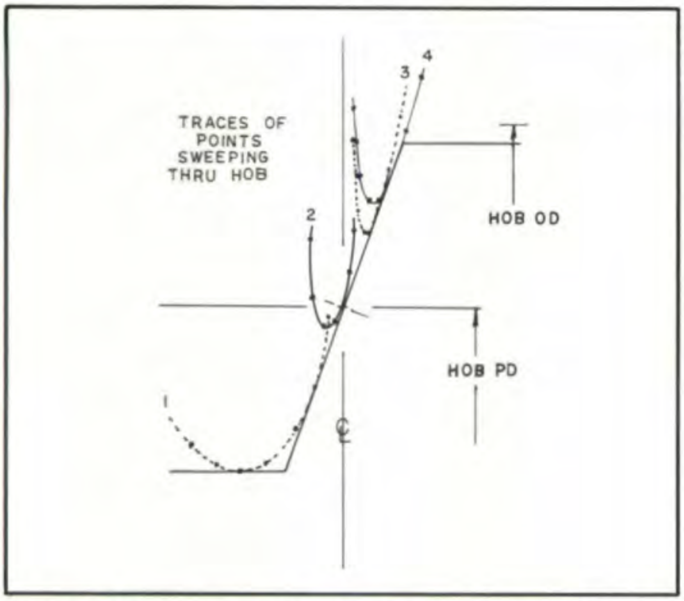


Fig. 15 – Trace of several different points sweeping through the hob.

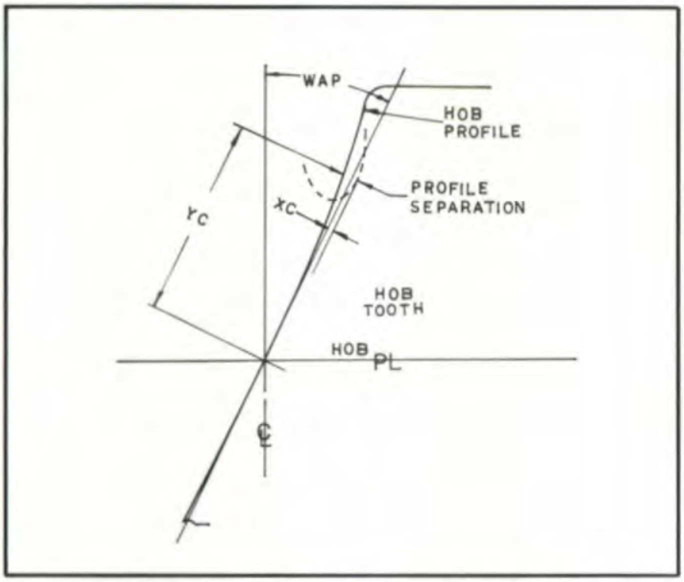


Fig. 16 – Determination of the profile separation value for a point.

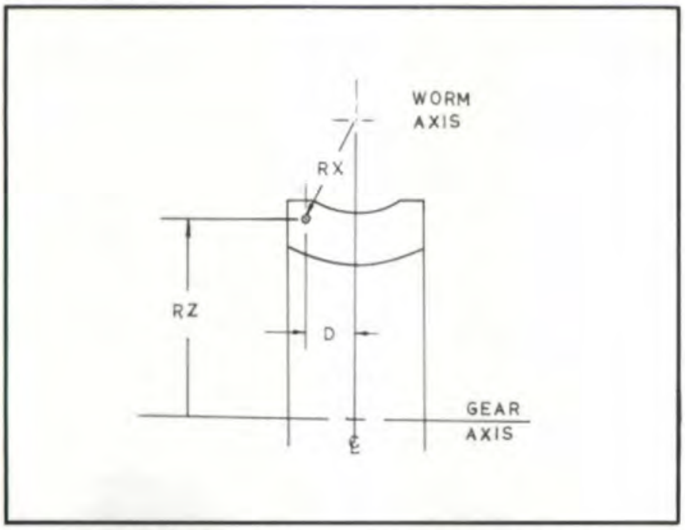


Fig. 17 – The location of the separation values on the gear flank.

Table 1 – Sample Data for Contact Analysis

Worm Data:

Thread form – screw helicoid
Axial C.P. – 1.0000
Normal C.P. – .96907
Threads – 2
Lead – 2.0000
Worm O.D. – 3.136
Worm P.D. – 2.5000
Axial P.A. – 20.0000°
Lead angle – 14.2866°

Gear Data:

Teeth – 25
Pitch radius – 3.9789
Face – 2.000
Outside radius – 4.430
Throat radius – 4.297
Actual center distance – 5.2289
Theo. center distance – 5.2289

Hob Data:

Normal C.P. – .96907
Axial C.P. – .99645
Hob oversize – .150
Hob pitch diameter – 2.65
Hob lead – 1.9929
Axial pressure angle – 19.9346°
Hobbing center distance – 5.3039
Hob lead angle – 13.46223°
Hob set angle – 0.82°
Theo. hob set angle – 0.82438°
Profile mod. – .0015 hollow

and uses a gear hob specified according to the normal circular pitch design method. The plot of separations resulting from a sequence of calculations using this data is shown in Fig. 18, displayed as an array. In Fig. 19, equal levels of separation measured from the high point are connected by lines to create the map.

Some observations concerning the expected contact area and its location can be made as well as noting the degree of separation across the entire gear face. With light test load and color transfer a .0005 level is used. With some "running-in" the .001 level can be considered. The progressive potential for future contact patterns can be assessed, either by plastic deformation or, later, by normal wear. The opportunity to see the amount of entry side easement in consideration of lubrication can be particularly helpful.

An additional cross sectional plot is useful graphically and represents the separation plot along the worm mid form trace. This is plotted just below the topological map.

The first contour map shown in Fig. 19 is for a hob with .150 oversize. Fig. 20 and Fig. 21 show a series of maps with

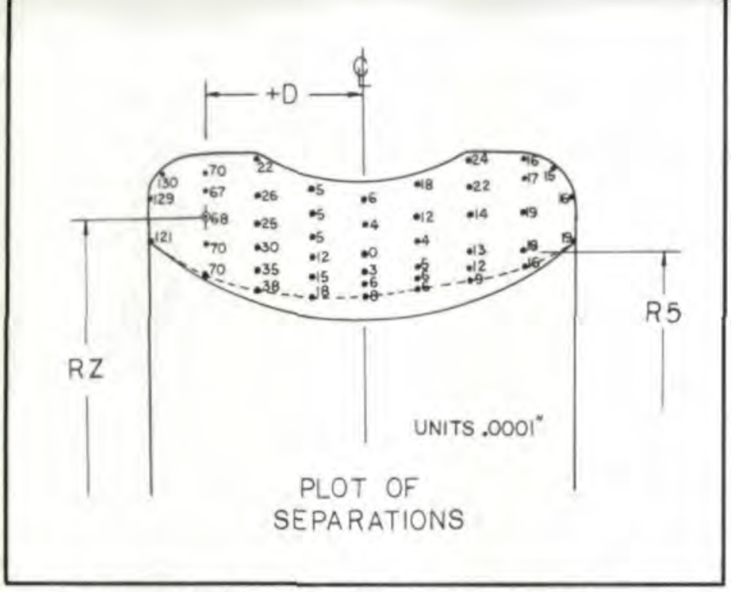


Fig. 18—Array of separation values plotted for the sample case.

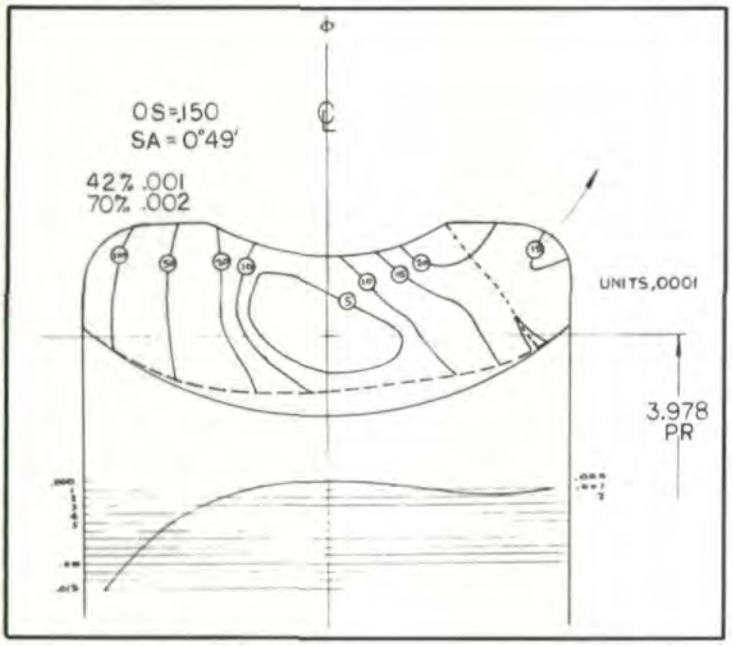


Fig. 19—Point of equal separation are delineated, creating the separation map for .150 oversize.

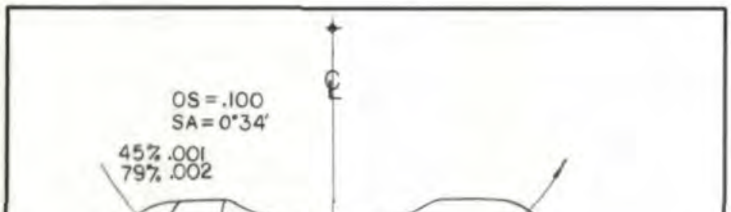


Fig. 20—Map for same case data with hob oversize .100.

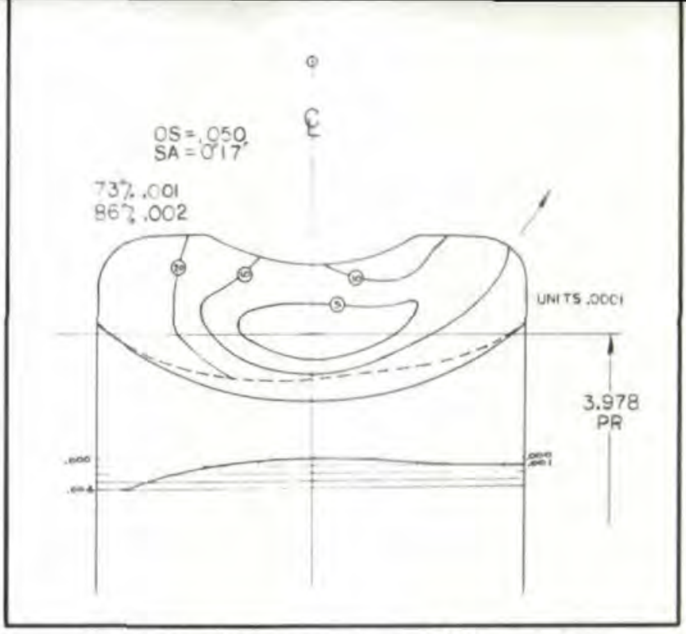


Fig. 21—Map for same case data with hob oversize .050.

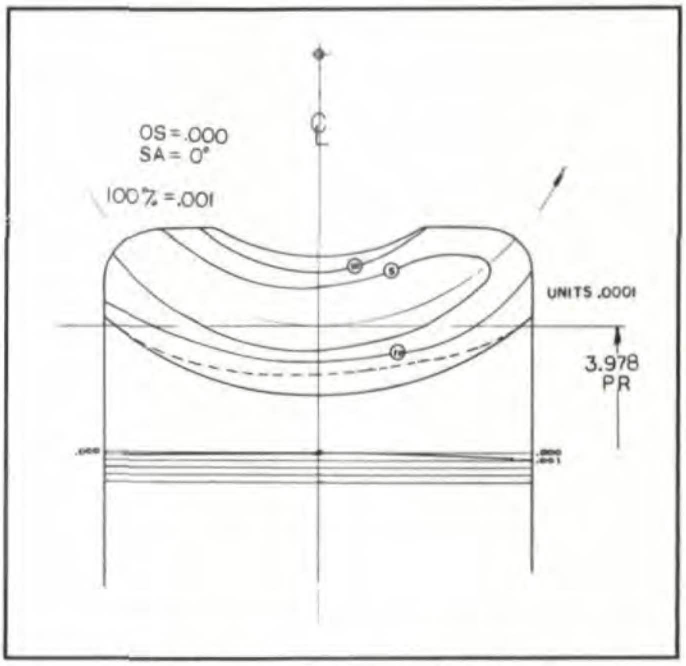


Fig. 22—Map for same case data with .000 oversize.

.100 and .050 oversize respectively. Fig. 22 shows the results from a hob with no oversize.

General Comments

- As the oversize is reduced, the longitudinal easement reduces.
- The curvature geometry favors the entry side with increased separations.
- The leaving side frequently exhibits a cusp or valley phenomenon, which inhibits the attempt to get the contact pattern toward the leaving side of center. Small swivel adjustments may get a split or leaving edge contact.
- Low oversize hobs make for critical swivel settings, and subsequently, gear alignment in assembly will be sensitive too.

Fig. 23 is an additional case in the series in which the hob is undersize .015 on diameter, and the contact pattern develops into the well-known split.

Using an Extra Thread in the Hob

Occasionally a worm gear hob will be made with one more thread than is in the worm, as when a seven thread hob is used to cut a worm gear that mates with a worm of six threads. The hob is labelled as one thread oversize. The actual amount of oversize in this case is one-sixth of the worm pitch diameter. By usual standards this amount of oversize would be considered rather large and a significant amount of crowning or ease-off will be developed on the gear tooth. Such a case was investigated and the results are shown in the contour separation plot in Fig. 24. In this case, the hob oversize is .500 and, while the area of contact at the .002 level appears good, the entry side easement is high at .030. It will take substantial wear to develop a broad contact.

Another case of a three-thread hob being used to cut a gear mating with a two-thread worm was also investigated. The oversize is one-half of the worm pitch diameter and is quite excessive and is unusable in most applications. The contour separation plot is shown in Fig. 25. This hob has the equivalence of 1.250 oversize; the contact is a narrow band, and it will not widen very quickly with progressive wear. If loaded comparably with other throated worm gear sets, a failure is likely.

At times it would be advantageous to use the concept of the extra hob thread, particularly when the worm threads and gear teeth are of an even ratio, and where tangential feed might be required. For example, in the case of a six-thread worm mating with a 30 tooth gear, using a seven-thread hob would permit using the faster infeed hobbing method, providing the reduced area of contact is acceptable.

The extra thread design is unique in that both the axial and normal pitch and the axial and normal pressure angles are matched between the worm and hob. The hob swivel angle is normally set at zero.

Involute Worms

One of the other thread forms used is the involute helicoid. The calculations are more complex due to the curvature of the worm form and there is a greater sensitivity on the worm gear profile on the leaving side. In Fig. 26 a map of the contact is shown for a hob set at the theoretical swivel setting angle, and then to the right the same gear is mapped for a slightly smaller swivel setting. A significantly different contact pattern is produced for only an eleven minute angular change. With the first setting the gear is unacceptable, and after the adjustment, it is acceptable. The results shown here are typical of the higher lead angle worms of both involute and "thread milled" helicoids.

APPENDIX

Worm Gear Hob Oversize

With the concept that a hob should duplicate the worm in the set exactly, a problem arises as soon as the hob is sharpened and goes undersize. Besides the impractical or uneconomical aspect of a very limited hob life, the result of

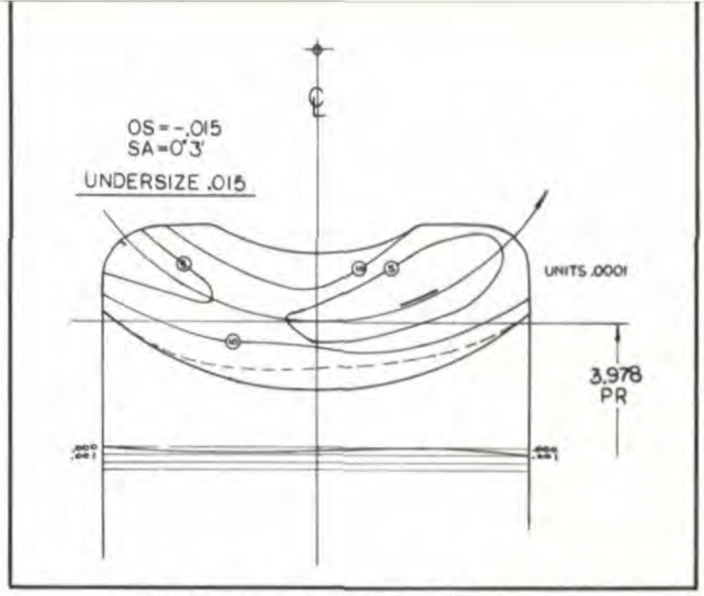


Fig. 23 – Map for same case data with .015 undersize.

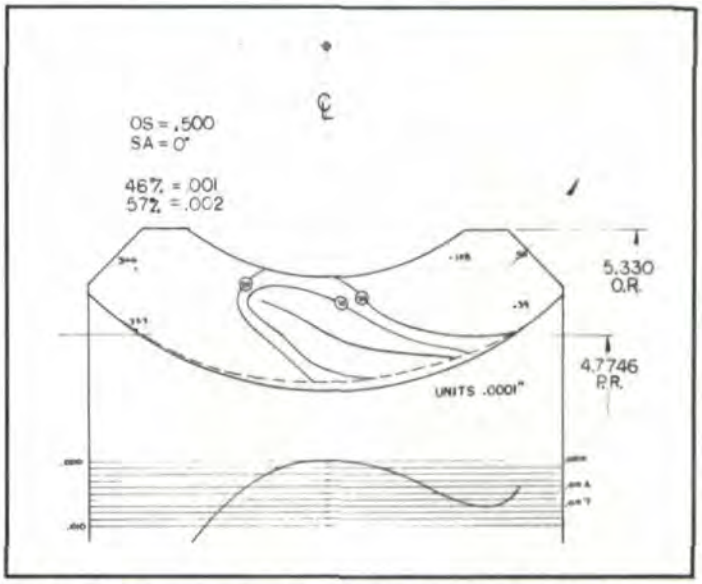


Fig. 24 – Map of one thread oversize hob. Seven thread hob, six thread worm.

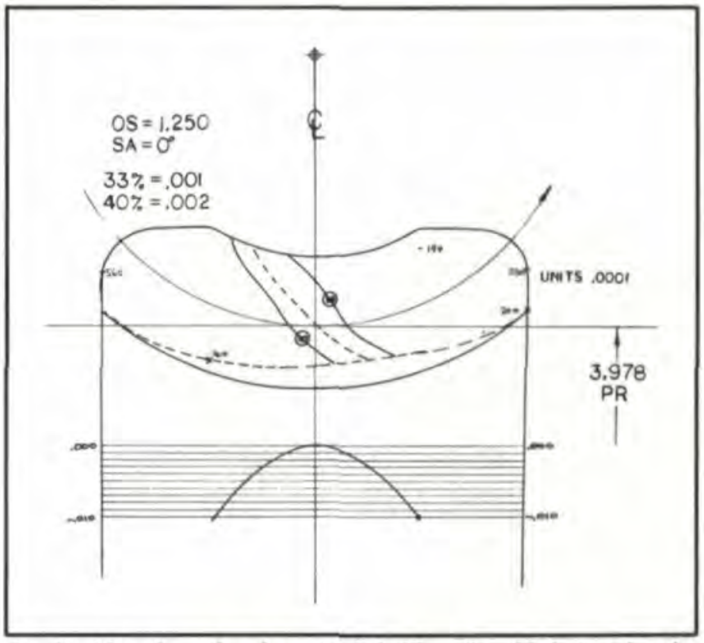


Fig. 25 – Map of one thread oversize hob. Three thread hob, two thread worm.

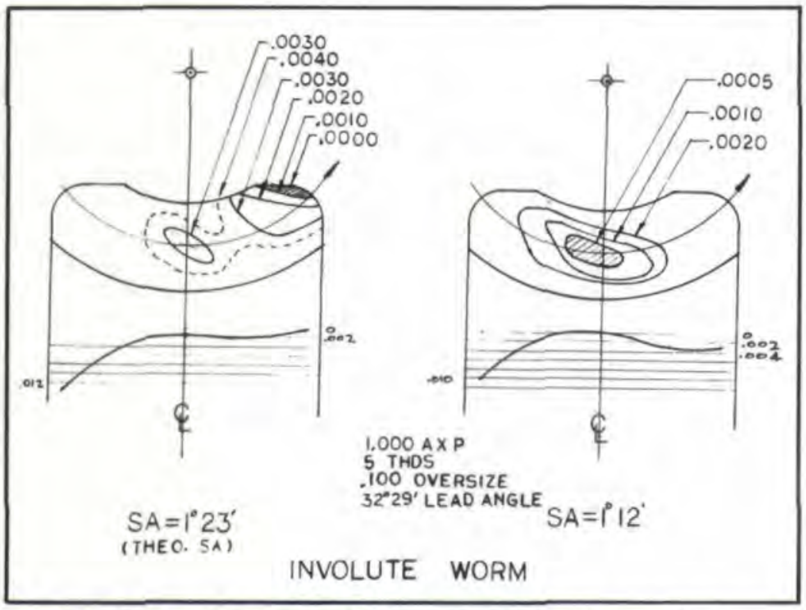


Fig. 26—Map of the same involute form worm flanks with two different swivel angles.

using an undersize hob is the development of one of the undesirable split contact patterns.

Although a duplicate design type hob can yield the full maximum available area of contact, there is little room for error and some edge contact will very likely occur. It is obvious that some hob oversize is needed. The demands for oversize selection are in opposite directions, one asking for maximum oversize to fully utilize the hob life, and the other demanding a significant area of contact.

The Axial Pitch Design Concept

One approach to designing a worm gear hob is to match the axial pitch, axial pressure angle and number of threads with that of the worm. In essence this has the hob matching the worm exactly only when the oversize is zero. Since some oversize is always used for a new hob, it is mismatched and is long on the normal circular pitch.

The oversize is an arbitrary choice guided by recorded experience. The oversize used is made as large as possible while still maintaining a passable contact pattern on the gear. Then as the hob is gradually sharpened back, it approaches an exact match, on both axial pitch and normal circular pitch, just as the hob is nearing the scrap point. Also the area of contact increases along with the possibility of an edge contact.

Initial contact with this design is usually narrow and high, and if a little too much oversize is used, a top edge contact will result. As the hob is sharpened the contact will widen and drop towards the pitch line.

Fig. 27 shows the results for an axial pitch designed hob beginning with .200 oversize and decreasing down to .000 oversize. These computed maps show the contact progressing from the top edge down to a full bearing. The swivel settings in these examples were only 75% of that calculated. The patterns were optimized.

The Normal Pitch Design Concept

Using this approach the worm gear hob is made to match the normal circular pitch and the normal pressure angle of the worm at a preselected amount of oversize. Again the amount of oversize is selected by the hob manufacturer on the basis of experience to yield some planned amount of face contact. This design method, which has become an industry standard, presents the best contact pattern on the gear when the hob is new. As the hob is sharpened back the contact will broaden and drop.

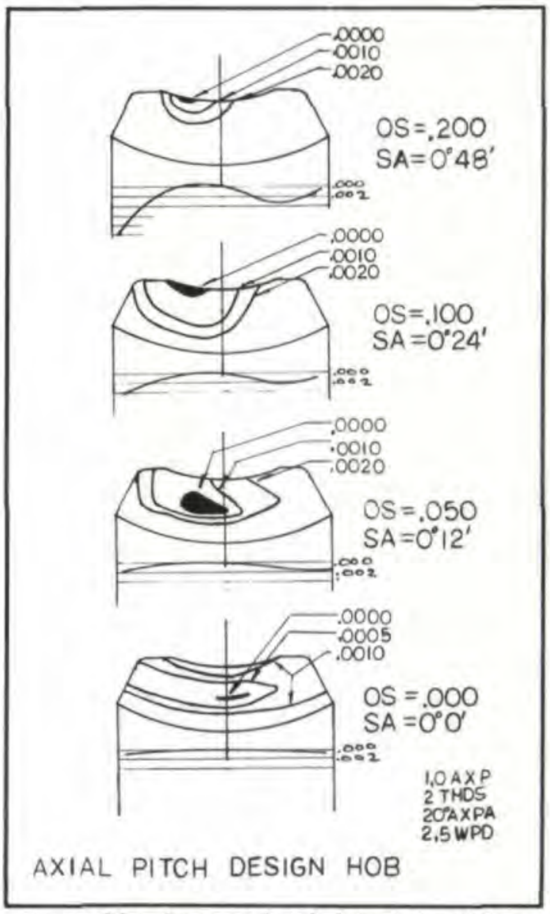


Fig. 27—Maps for an axial pitch design hob with four different amounts of oversize and the results.

Worm Gear Tooth Crowning

In other types of gearing it is not uncommon to apply some form of modification to the gear teeth surfaces to allow for minor errors, distortions or misalignment of axes. This crowning can also be applied to the worm gear tooth surface and is done in the longitudinal direction by the amount of hob oversize and in the radial direction by a hob profile modification to induce a tip and root flank easement.

Worm Gear Materials

With applications using a hardened steel worm and a bronze worm gear, the plasticity of the material permits a surface correction of some .002 inches during the initial break-in or loading period. Bronze has been called somewhat forgiving because of this. Other gear materials, such as cast iron or ductile iron, do not have this same property and can readily have material transfer or pick-up because of the iron against iron phenomenon. The initial contact area must be good for success with these latter materials.

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CONTACT SURFACE TOPOLOGY. . .

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Aluminum bronzes with higher strength and a work hardening property will also run-in better with larger contact area and less oversize.

Real Life Experience

Many variables exist in the gear cutting process and before examining the contact pattern on a cut gear one must feel assured that the cutting machine is reasonably accurate, that tool accuracy, sharpening and mounting are correct, and that heating from the cut and its effect on distortion are minimal.

Frequently one does not see a neat full patch of contact but a spotty area. Surface finish and in some cases generating cuts will upset the expected results. Experience will quickly get one to focus on the essentials.

Hob Oversize and Hob Life

Using the axial pitch design procedure the oversize can be considered to be equal to the life of the hob. When the hob is sharpened down below the worm size, it is considered no longer usable. With the normal pitch design procedure the oversize can be substantially more than the sharpening life of the hob. While this is not likely on single thread hobs, it can be expected on hobs with higher lead angles. Because of the manufacturing methods used for the hob, a change in the profile cut on the gear will take place. The hob is terminated when the contact pattern is no longer acceptable.

Future Inspection Techniques

With the arrival of the multi-axis analytical gear checking machines it appears inevitable that the computed conjugate worm gear surface will be compared with the actual cut tooth surface. Computer control of the axes of rotation and travel make it possible to measure other than regular leads or involutes.

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