

BACK TO BASICS...

Bevel Gear Development and Testing Procedure

The Gleason Works
Rochester, New York

The most conclusive test of bevel and hypoid gears is their operation under normal running conditions in their final mountings. Testing not only maintains quality and uniformity during manufacture, but also determines if the gears will be satisfactory for their intended applications.

Gears are checked in the testing machine for the following conditions: tooth size in relation to a master, or to the mating member, mounting distance of gear and pinion, the position of the tooth contact, the quality of the surface finish, the amount of TOPREM®, the amount of clearance, visual eccentricity, tooth spacing errors, and the general running qualities of the gear and pinion, as well as the axial displacement tolerances of the gear set. Gears are also checked for bias and profile on the test machine.

Definitions

It is important that certain terms be defined before any testing and development procedure for bevel gears is presented. (Fig. 1)

Gear — of two gears that run together, the one with the larger number of teeth is called the gear. It is the driven member of a pair of gears.

Pinion — the member with the smaller number of teeth. With miter gears it is the driving member.

Toe — the portion of the tooth surface at the inner end.

Heel — the portion of the tooth surface at the outer end.

Top — the upper portion of the tooth surface.

Flank — the lower portion of the tooth surface.

Top Land — the non-contacting surface at the top of the tooth.

Root Land — the non-contacting surface at the bottom of a tooth space.

Top Side and Bottom Side — in conventional machines for producing both straight and curved tooth bevel gears, the cutter or cutting tools always operate on the left hand side of the gear blank as viewed from the front. The term *top* refers to the upper side of the tooth in this position, and the

term *bottom* refers to the lower side.

Top Side of Tooth

Left hand spiral — convex side of tooth.

Right hand spiral — concave side of tooth.

Bottom Side of Tooth

Left hand spiral — concave side of tooth.

Right hand spiral — convex side of tooth.

The terms *bottom side* or *top side* would always apply to a specific side, regardless of the hand of spiral, and also with straight bevel gears. When the *forward* side in the testing machine is running, the rotation of the pinion spindle is clockwise when viewed from the source of power, and the *bottom side* of the pinion will contact the *bottom side* of the gear. When the pinion is running in the *reverse* direction, the rotation is counter-clockwise, and the *top side* of the pinion will contact the *top side* of the gear. It would, therefore, be better to refer to *bottom side* or *forward side*, and *top side* or *reverse side*.

When referring to a specific side of the tooth, the terms *drive side* or *coast side* are quite often used, but, unless a full knowledge of the application is available, these terms

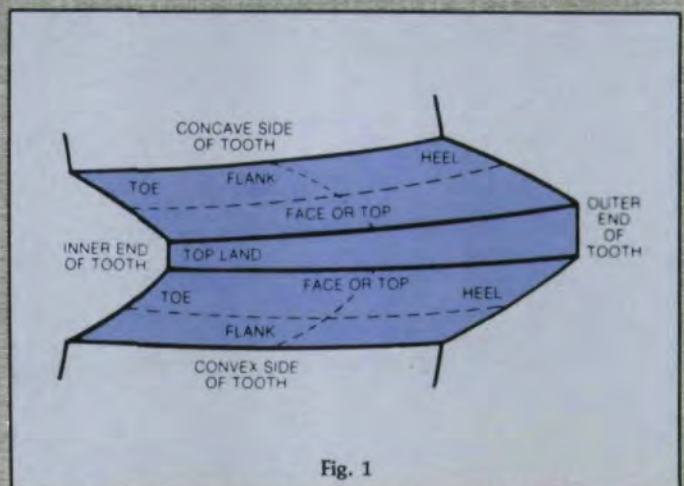


Fig. 1

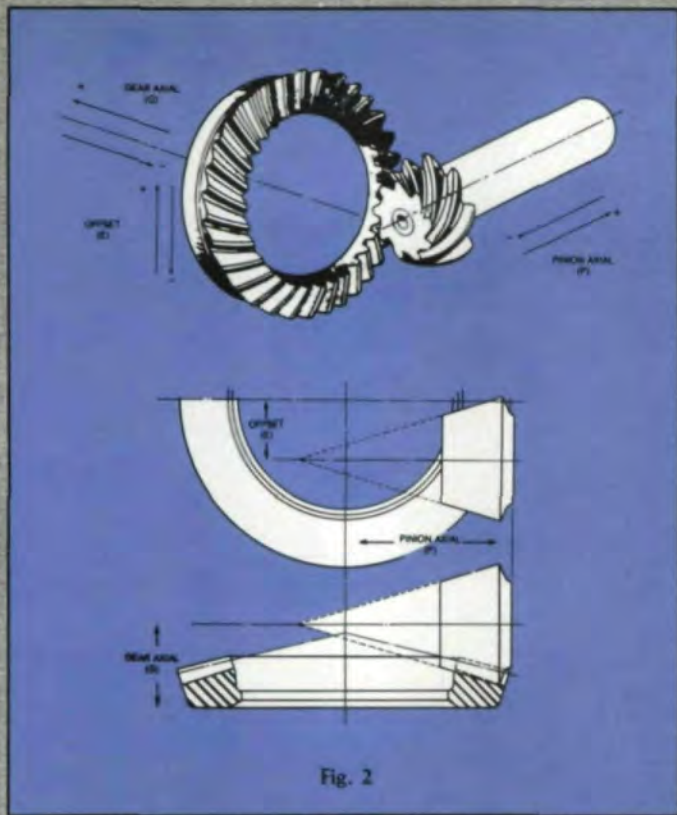


Fig. 2

would not be specific. Normally the concave side of the pinion is called the *drive side* and the convex side of the pinion is called the *coast side*, but in many cases either side may drive. Also, with straight bevel gears, there is no concave or convex side, so it again would be difficult to correctly specify by *drive side* or *coast side*.

Right Hand Spiral — when viewed from the front, above center, the spiral angle of a bevel gear curves to the right.

Left Hand Spiral — when viewed from the front, above center, the spiral angle of a bevel gear curves to the left.

Clockwise Rotation — the pinion rotates clockwise when viewed from the back.

Counter-clockwise Rotation — the gear rotates counter-clockwise when viewed from the back.

Tooth Contact — the summation of all instantaneous lines of contact on a tooth surface. Also, the area on a tooth surface from which marking compound is removed when the gears are run together in a test machine.

EPG

Tooth contact of mating gear teeth can be positioned by manipulation of tester machine adjustments. The directions of these movements and their designating letters are shown in Fig. 2. This sketch is of a hypoid pair, but the directions of the movements are equally applicable to spiral, or straight bevel gears.

(E) = movement perpendicular to the gear and pinion axes. A change in offset (E) can be made by moving the pinion relative to the gear. Or, it can be made by moving the gear relative to the pinion, depending upon

the design of the testing equipment used.

(P) = pinion axial movement. A change in the pinion axial distance (P) can be made by moving the pinion relative to the gear. Or, it can be made by moving the gear relative to the pinion, depending upon the design of the testing equipment used. (P) is commonly known as a pinion cone change or a pinion mounting distance change.

(G) = gear axial movement. A change in the gear axial distance (G) can be made by moving the pinion relative to the gear. Or, it can be made by moving the gear relative to the pinion, depending upon the design of the testing equipment used. (G) is commonly known as a backlash change, a gear cone change or a gear mounting distance change.

EPG Sign Conventions

The readings on all dials on testing machine E, P and G adjustments should be considered "zero" readings, when the gears are mounted at the mounting distances and hypoid offset specified on the Summary.

- (E+) indicates an increase in offset.
- (E-) indicates a decrease in offset.
- (P+) indicates an increase in pinion axial distance.
- (P-) indicates a decrease in pinion axial distance.
- (G+) indicates an increase in gear axial distance.
- (G-) indicates a decrease in gear axial distance.

V & H

The E & P check accomplishes the same thing as the former V & H check. "V" is equivalent to (E) and "H" is equivalent to (P).

Testing Procedures

A. The E & P Check

The E & P (offset and pinion axial) check is used as a method of measuring the axial displacement movement required in the test machine, to move the contact from a *central profile contact shading out at the toe to a central profile contact shading out at the heel*.

The following can be determined by analysis of the E & P check:

1. The total length of contact.
2. The amount and the direction of bias (bias in or bias out).
3. Position of the tooth contact in relation to correct testing machine centers.
4. By visual observation of the tooth contact, when the heel and the toe E & P checks are on the tooth at the same time, the relative length of the heel and toe contact is determined and the width of profile can be observed.
5. The approximate amount of displacement that the gear will withstand without causing load concentration.

E & P Check (Left Hand Spiral Pinion)

Increase the gear offset and decrease the pinion axial distance to move the contact to the toe on the concave side of the pinion or to the heel on the convex side of the pinion.

When moving the contact to the heel on the concave side of the pinion or to the toe on the convex side of the pinion, the gear offset is decreased and the pinion axial distance is increased.

E & P Check (Right Hand Spiral Pinion)

To move the contact to the toe on the convex side of the pinion or to the heel on the concave side of the pinion, the gear offset is increased, and the pinion axial distance is increased. To move the contact to the heel on the convex side of the pinion or toe on the concave side of the pinion, the gear offset and the pinion axial distance are decreased.

E & P Example:

TOE	HEEL	TOTAL
E +3	E -13	16
P -2	P +12	14

The preceding example refers to the *bottom side* because decreasing the offset of the gear in relation to the pinion (E-) will always move the contact toward the *bottom heel* position. (If the heel value was E +13, the reference would be to the top heel position and the offset of the gear would be increased in relation to the pinion).

A *Bias In* contact is indicated in the previous E & P example because the total offset value is greater than the total pinion axial value. In a *Bias Out* contact the total offset value is less than the total pinion axial value. The example also illustrates that the contact would be near the toe, in the center of the tooth profile, and would have a slight *bias in* direction.

L.H. Pinion

Concave Side			Convex Side		
TOE	HEEL	TOTAL	TOE	HEEL	TOTAL
E(+)	E(-)	—	E(-)	E(+)	—
P(-)	P(+)		P(+)	P(-)	

R.H. Pinion

Concave Side			Convex Side		
TOE	HEEL	TOTAL	TOE	HEEL	TOTAL
E(-)	E(+)	—	E(+)	E(-)	—
P(-)	P(+)		P(+)	P(-)	

B. Adjusting Gear Centers for Development

It is recommended that extra pinion blanks be made available for development purposes. One of these should have teeth cut to *finish* size for the first test. When testing the tooth contact between the gear and the pinion teeth, the gear is set to its correct mounting distance and held in this position throughout the development.

1. As the pinion tooth thickness is reduced, the backlash will increase, without affecting the nature of the tooth contact. This holds true only if the base on the gear cutting machine has not been adjusted during development.
2. On right-angle test machines, this is done by keeping the pinion cone stationary. On universal testers the gear cone is kept in a fixed position.

If no extra pinions are available, the development must be made on pinions which are not cut to finish tooth size. This is done by increasing the testing machine mounting distances on both members by moving the gear and pinion cone out until the desired amount of backlash is obtained. *The gear and pinion cone must be moved out in proportion to the numbers of teeth in the two members.*

Example #1:

20 x 40 combination — 90° shaft angle — Opening in proportion to the ratio being tested would give a .002" increase on the gear cone for every .001" increase on the pinion cone.

Example #2:

10 x 30 combination — 90° shaft angle — Increasing the testing machine mounting distances in proportion to the ratio being tested would give a .003" increase on the gear cone for every .001" increase on the pinion cone.

On universal test machines (arranged to test gears at any shaft angle), the method for increasing the mounting distances is controlled by the formula below.

X_G = amount to increase gear axial distance (G+)

X_P = amount to increase pinion axial distance (P+)

$$X_P = X_G \left[\frac{\text{cosine of gear pitch angle}}{\text{cosine of pinion pitch angle}} \right]$$

Example:

21 x 25 combination, 142° shaft angle —

Gear Pitch Angle = 85°10'; cosine = 0.0843

Pinion Pitch Angle = 56°50'; cosine = 0.5471

If the gear axial is moved *out* 0.013", the pinion axial

$$\text{must be moved out } 0.013" \times \frac{0.0843}{0.5471} = 0.002".$$

If the pitch angle exceeds 90° (internal gear), the cosine of the gear pitch angle will be negative, causing the pinion axial to be moved *in* and the gear axial to be moved *out*.

3. Running at increased mounting distances, the gears will show a contact similar to that which they will have when cut to size, only it will be nearer the heel of the tooth. *The final check should be made with both the gear and pinion at their specified mounting distances and backlash.*

Checking Backlash

The term backlash, used in these instructions, refers to normal backlash (backlash in a direction perpendicular to the tooth surface). To obtain backlash in the plane of rotation, the (normal) backlash must be divided by the cosine of the spiral angle times the cosine of the pressure angle.

Bevel gears are cut to have a definite amount of backlash which varies according to the pitch and operating conditions. This backlash is necessary for the safe and proper running of the gears. If there is insufficient backlash, the gears will



Fig. 3

be noisy, wear excessively, and possibly score on the tooth surfaces, or even break. In production testing, backlash measurement is used as a gage of tooth thickness.

Backlash should be measured at the tightest point of mesh with the gears mounted on their correct centers. To make this measurement on the testing machine, hold the pinion solidly against rotation, rigidly mount a dial indicator against a gear tooth being sure that the indicator stem is perpendicular to the tooth surface at the extreme heel. (See Fig. 3.) The backlash will then be shown by the indicator when the gear is turned back and forth by hand.

Backlash variation is measured by locating the points of maximum and minimum backlash in the pair gears and obtaining the difference. For precision gears this variation, in general, should not exceed 0.001".

After checking backlash by the above method on the finally approved pair of gears, the production control of backlash may be checked more easily by the following method:

The approved pair of gears (control gears) are mounted in the testing machine on their correct centers. The gear is then moved axially into metal-to-metal contact with the pinion. The amount of movement from its initial position is observed. Then, when testing the production gears, move past the correct centers by this same amount.

The axial movement of the gear for 0.001" change in backlash varies with the pressure angle approximately as follows:

Pressure Angle	14½°	20°	25°
Axial Movement of Gear	0.002"	0.0015"	0.001"

The following table gives the recommended backlash for gears assembled ready to run. Backlash for pitches, other than those listed, may be obtained by interpolation.

TABLE OF BACKLASH

Diametral Pitch	Backlash
1	0.020" to 0.030"
2	0.012" to 0.016"
3	0.008" to 0.011"
4	0.006" to 0.008"
6	0.004" to 0.006"
10	0.002" to 0.004"
20 and finer	0.001" to 0.003"

In certain applications, the backlash tolerance may have to be altered to meet specific requirements.

Procedure for Checking the Amount of TOPREM®

TOPREM is a decrease in the pressure angle at the tip of the cutter blades. This decrease in pressure angle causes more stock to be removed in the fillet of the tooth when the blades cut. TOPREM is usually applied to the pinion member to prevent interferences at the top of the gear tooth during lapping.

Use a dummy pinion that has been cut to the correct tooth depth, small in tooth size, and developed to a full profile contact. Run the gear and pinion together at the correct theoretical mounting distances and note the distance between the top edge of the contact and the top edge of the tooth. This is the amount of effective TOPREM.

To measure the amount of effective TOPREM, the following sequence should be followed:

Increase the gear axial distance +.010" and run the gears.

If the contact is not to the top edge of the gear tooth, increase the gear axial distance $+ .010''$, check again, and if necessary, increase the gear axial distance at increments of $.010''$, until the contact is just to the top edge of the gear tooth. The amount of increase in the gear axial distance, from the theoretical mounting distance, is the amount of effective TOPREM. The normal amount of effective TOPREM is between $.025''$ and $.035''$.

NOTE:

If, after following the above procedure, the check shows that additional TOPREM is required, use a cutter that has been ground to give a greater amount of TOPREM. This should be done before changing the depth of the tooth slot because of a possible interference in the root.

If less than $.025''$ effective TOPREM is noted, recut the pinion with the depth decreased by $.010''$. Check the pinion and gear with the gear axial distance decreased to $-.030''$ or $-.035''$ and rotate the gear and pinion slowly. Look for interference at the pinion root radius. If no interference is noted, the pinions may be cut at the decreased depth. This will give the maximum amount of effective TOPREM that has been ground onto the cutter.

Procedure for Soft Testing

1. Have a pinion cut small enough to permit running it with a mating gear at correct mounting distances for both the gear and pinion.
2. With the gears properly installed in the test machine, carefully jog the machine and apply a suitable marking compound to the teeth. Run the machine carefully without any brake load, noting the position of the tooth contact. If the contact is too far out of position, any further amount of running could damage the tooth surfaces.
3. Adjust the test machine, if necessary, to obtain a central toe contact with central profile. The amount of offset and pinion axial movement required to properly position the contact should be recorded. This information is used in making the corrective changes on the cutting machine. Recut the pinion. The tooth contact should be in proper position before making an E & P check.
4. Check the gears for E & P and record the values. Observe center, heel and toe contacts for width of profile, bias contact, fillet interference and TOPREM. Also make sure that

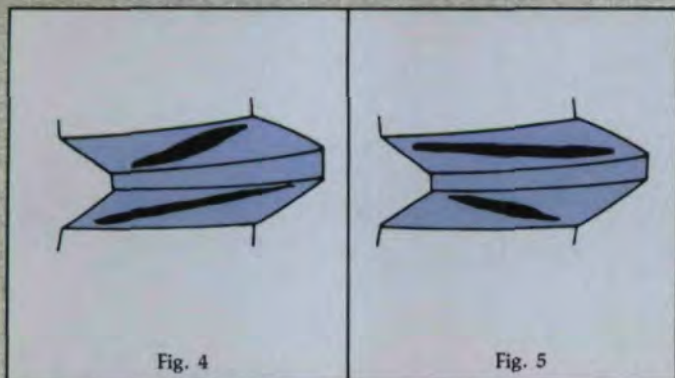


Fig. 4

Fig. 5

they are finish cut completely to the ends of the teeth (rolled out in cutting).

5. Set the test machine to the *Average Contact* values and note the lengthwise positioning of the contact on the tooth. If the contact is closer to the heel, this will show that the heel portion of the contact is longer than the toe portion.
6. When the final positioning of the contact has been made in cutting, the gears must be checked for the following:
 - a. Whole depth of both pinion and gear.
 - b. Fins or steps in the root of both pinion and gear.
 - c. Interference at radii of both pinion and gear.
 - d. Surface finish on both pinion and gear.
 - e. Amount of effective TOPREM.
 - f. Possible tooth defects and visual eccentricity.
 - g. Length of contact at toe and heel checks.
 - h. Final E & P check for length of contact and proper bias.
 - i. Profile adjustment and sound at toe, center, and heel.
7. When a production piece is finish cut on one side, it is important that enough stock be left to completely clean up the remaining side when it is finish cut to the proper backlash at the correct mounting distances for both pinion and gear.

Hardening-Effects on the Tooth Contact

When gears are hardened, the spiral teeth have a tendency to straighten. Since this condition applies to both the gear and the pinion, the effect is not extreme when the two hardened members are run together. Although the pinion is likely to change more than the gear, in hypoids, due to having a longer face and higher spiral angle, compensating position changes can be allowed in cutting to maintain a correct position and bias after hardening.

Since *bias in* is introduced in hardening, it is usually desirable to have a slight amount of *bias out* in soft gears. Also due to the straightening tendency of the spiral teeth, it is sometimes necessary to have the contact central on the concave side of the pinion and favoring the toe on the convex side of the pinion.

The amount of change can only be determined by trial, but generally the length of the contact will show approximately one-third less E & P movement and the profile will normally change from a full width profile to a narrower profile. This will produce a satisfactory contact with a normal amount of adjustment.

The contact on the convex side of the pinion will also be higher after hardening, therefore, it may be desirable to have the contact deeper on the convex side of the soft pinion to compensate for that change.

Conditions That Can Be Determined by a Test Machine

1. Bias in and Bias Out

Bias In (Fig. 4)

The total *offset value* in the E & P check is greater than the total pinion axial value.

A visual check of *bias in* can be made as follows:

The contact is diagonal to the pitch line, and on the con-

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Main Specifications

Maximum part diameter 6", optional 8"
Maximum pitch 6DP
Maximum hob diameter 4.7"
Maximum hob length 7"
Hob shift 5"
Hob speed 150 to 1000 rpm
Hob head swivel +/- 45 deg.
Table speed 150 rpm
Main motor 7.5 hp

CNC GEAR HOBBER



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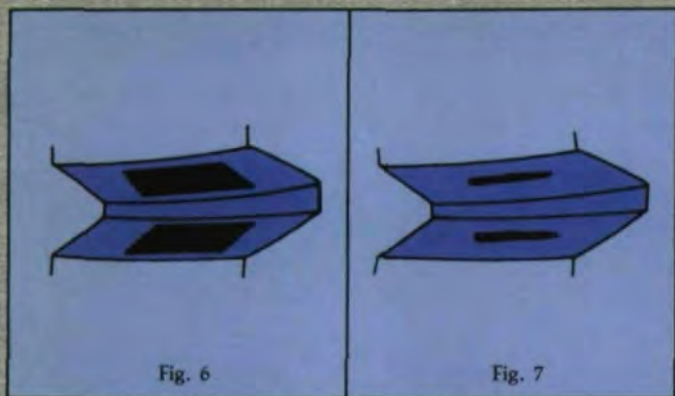
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vex side of the gear tooth it runs from the flank at the toe to the top at the heel. On the concave side of the gear tooth the contact runs from the top at the toe to the flank at the heel.

Bias Out (Fig. 5)

The total offset value in the E & P check is less than the total pinion axial value.

A visual check of *bias out* can be made as follows:

The contact is diagonal to the pitch line, and on the convex side of the gear tooth it runs from the top at the toe to the flank at the heel. On the concave side of the gear tooth, the contact runs from the flank at the toe to the top at the heel.

Bias out is often required, in developing the tooth contact, due to the normal changes that take place during hardening, and to allow for the deflections in the mountings when the gears are in operation. A slight amount of *bias in* is desirable after lapping in automotive gears to give a quieter operating pair of gears. The line of contact as the tooth rolls into and out of engagement on the concave side of the pinion, starts in the flank at the heel and rolls out at the top at the toe, therefore, *bias in* increases the line of contact, but it will also decrease the amount of pinion mounting adjustment if the amount of *bias in* is too great.

Figs. 4 and 5 illustrate bias contacts. Regardless of the hand of spiral on the pinion, *bias in* will always run from the flank at the toe to the top at the heel on the convex side, and from the top at the toe to the flank at the heel on the concave side.

2. Profile Tooth Contact

The width of the contact (tooth profile) is as important as the length of the contact. A wide profile contact, Fig. 6, shows a contact covering the full depth of the tooth. Quite often there is a heavier concentration at the top of the tooth and in the flank of the tooth with the center of the tooth profile showing a lighter contact.

Too wide a profile contact is not desirable because even a slight amount of change in mounting distance would cause a definite concentration of load either high or deep on the tooth and may result in noisy gears which might also scuff or score along the area of concentration.

An extremely narrow profile contact, Fig. 7, shows a narrow concentration of contact in the center of the working

depth. This condition permits a greater variation in mounting distance, but results in a noisier pair of gears which will also have a tendency to scuff or score at the concentrated contact points.

In general, gears which have a wide profile before hardening will show a narrower profile after hardening. However, lapping will generally widen the profile, therefore an attempt should be made to obtain a profile width in cutting that will result in the hardened and lapped gears having a good profile adjustment and still be quiet in operation.

3. Interference Along Top Edge of Teeth

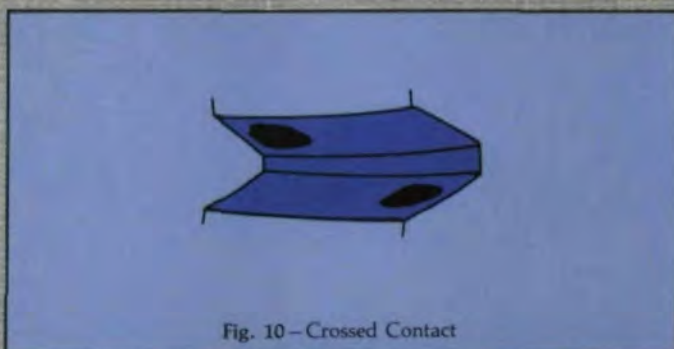
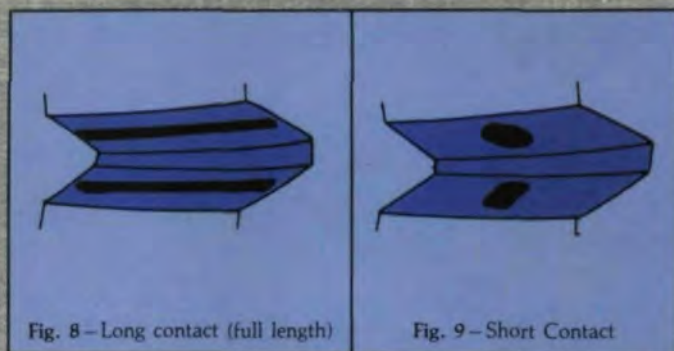
This condition is caused by an insufficient amount of backlash. It can be changed by adjusting the backlash when testing. Care must be taken not to decrease it too much because TOPREM interference will be introduced. Decreasing the backlash will also move the contact to the toe on both sides; on hypoid gears, it will cause the reverse side contact to be slightly lower on the gear (lameness) after testing.

4. Contact Too Long or Too Short on Either Side

This can be corrected by changing the cutter diameter on the pinion machine. When lapping, the value of the toe and heel swing cam settings or E & P settings should be increased on the side that is to be corrected for a long contact. To make a correction for a short contact the value should be decreased. (Fig. 8 & Fig. 9)

5. Crossed Contact

Changing the offset setting in the testing machine will cause the contact to move toward the toe on one side of the tooth and toward the heel on the opposite side. At the same time the contact will move high or deep on the tooth profile in



the case of spiral bevel or hypoid gears. The movement will follow along the tooth in the *bias out* direction. (Fig. 10)

6. Incorrect Shaft Angle

The tooth contact on both sides of the tooth will be concentrated at the same end of the tooth. If the contact is concentrated at the toe the shaft angle is too large. If the contact is concentrated at the heel, the shaft angle is too small. It will be necessary in either case to correct the shaft angle to obtain the proper tooth contact. (Fig. 11, Fig. 12)

7. Incorrect Pinion Mounting Distance

Changing the pinion mounting (axial) distance will cause the contact to move high or deep on the tooth profile. See Figs. 13 and 14. Increasing the pinion mounting distance will move the contact toward the flank of the pinion and high on the gear. In the case of spiral bevel, or hypoid gears, the contact may also move toward the heel or toe.

8. Desired Tooth Contact

A localized tooth contact is desirable because it allows for displacement of the gear under operating loads without causing concentration of the load at the ends of the teeth. It also permits some variation in the final mountings without effecting the running qualities.

Fig. 15 shows a central toe contact. The contact extends along approximately one-half the tooth length and is nearer the toe of the tooth than the heel. The contact is also relieved slightly along the top and flank of the tooth. Under light loads the contact should be in this position on the tooth.

Fig. 16 shows the same tooth with a contact as it should be under full load. It should show slight relief at the ends and along the top and flank of the teeth with no load concentration at the extreme edges of the tooth.

A. Runout

Runout is characterized by a periodic variation in sound during each revolution and by the tooth contact shifting progressively around the gear from heel to toe and toe to heel.

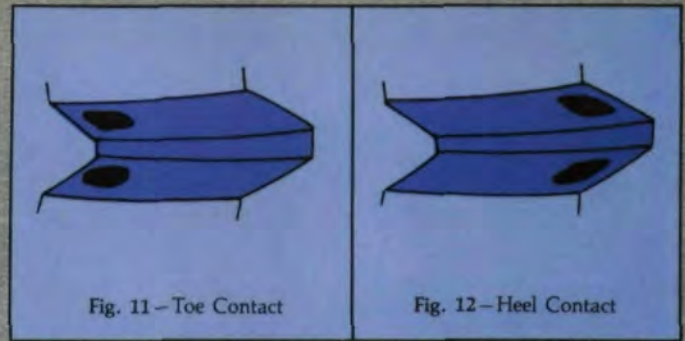
B. Tooth Spacing

Tooth spacing error is a cumulative error which can build up around the gear, often causing a large error between the first and last tooth cut. These are known as tooth defects and are indicated by a knocking sound or a light or heavy tooth contact on one or more teeth.

Error in spacing and concentricity usually is the result of faulty arbor equipment, improper chucking or inaccurate gear blanks. These items should be checked before any changes are made on the cutting machine.

C. Noise

A poor finish usually results in vibration and increased noise when the gears are run together. A visual check will show a rough or uneven tooth contact. A poor finish is usually due to improper normalizing of the steel or to a steel of poor machinability. Poor finish can also result from improper cutting speeds or from dull cutters.



Poor finish should not be confused with interferences, which will also give a rough finish and noisy operation. Visual observation will show interference as a heavy tooth contact along the top edge of the teeth on one member and in the flank of the teeth on the mating member.

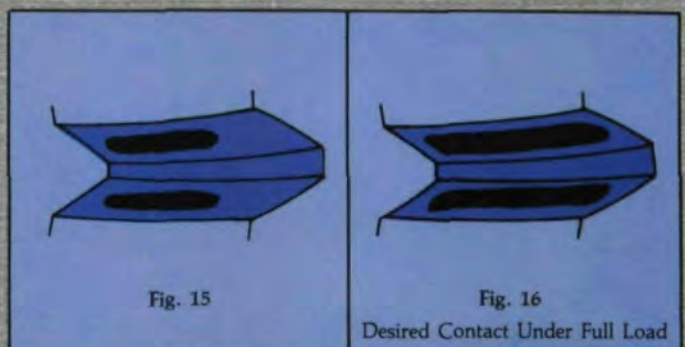
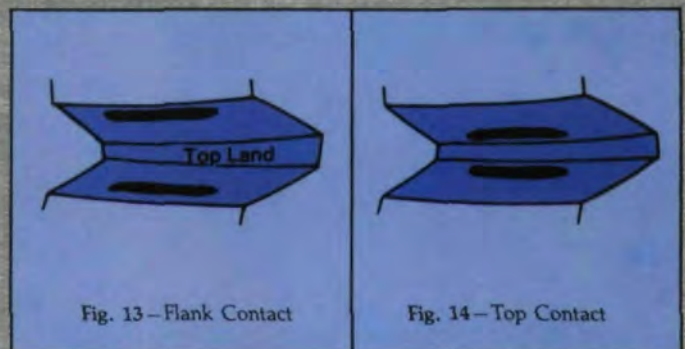
Interference is usually a result of one of the following conditions:

1. Teeth cut too shallow.
2. Blanks machined incorrectly.
3. Fillet radius too large.
4. Tooth profile not completely generated (insufficient generating roll on the cutting machine).

General Testing Information

Increasing the offset (E+) will move the contact in the *bias out* direction on all spiral bevel or hypoid gears regardless of the hand of the spiral.

Decreasing the offset (E-) in relation to the pinion will move the contact toward the heel on the bottom side and toward the toe on the top side.



Decreasing the pinion axial distance ($P-$) will move the contact higher on the pinion tooth and lower on the gear tooth.

Swing movement in the lapping machine will move the contact along the tooth from toe to heel in the *bias out* direction, the same as the offset movement in the E & P check.

Counter-clockwise swing movement in the lapping machine will move the contact toward the heel on either side; clockwise swing movement will move the contact toward the toe on either side.

Test Machine Adjustments and Their Effect on Tooth Contacts for Bevel Gears

Movements of the offset and pinion axial settings will move the tooth contact in the direction indicated in the following illustrations.

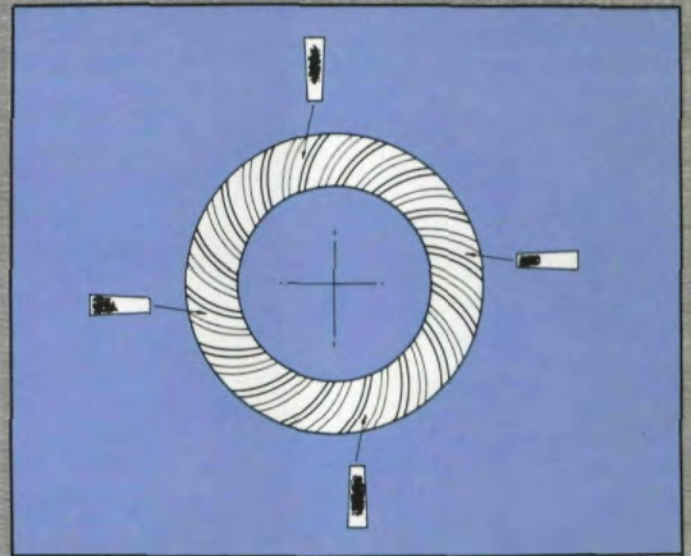


Fig. 17—Shifting of tooth contact shows presence of runout. Sound variation also characterizes the existence of runout.

