Remedies for Cutting Edge Failure of Carbide Hob due to Chip Crush—Some Results of Evaluation by this Method in the Automotive Industry

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Management Summary

This is the second of two related articles on cutting edge failure of carbide hobs due to chip crush. The first article was published in *Gear Technology*'s September/October 2004 issue.

The earlier article introduced a hobbing simulation program for clarifying the clearance between hob cutting edge and work gear tooth flank.

In this article, the simulation is applied to some practical industrial problems of dry hobbing, i.e. chipping failure of a carbide hob's cutting edge.

Influencing factors are investigated, and the bases for finding countermeasures against chipping are shown. This method has been applied to some practical cases of problems in the mass production of automotive gears, and good results were obtained.

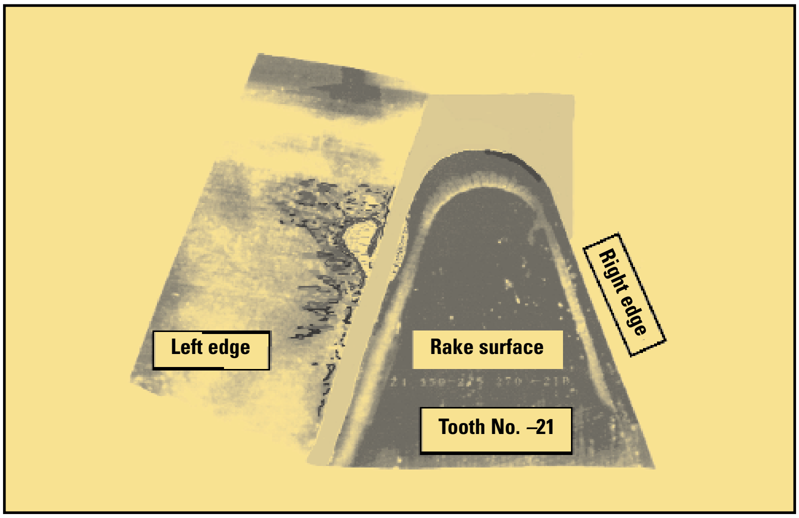

Figure 1—Chipping of carbide hob cutting edge under dry cutting.

Abstract

Dry hobbing is friendly to the environment, increases productivity and decreases manufacturing cost, but it often suffers failure of the hob cutting edge or problems with the surface quality of manufactured gears' tooth flanks. In the previous report, a simulation method to calculate the clearance between hob cutting edge and work gear tooth flank during hobbing was developed. In this report, this simulation is applied to some practical industrial problems of dry hobbing, i.e. chipping failure of a carbide hob's cutting edge and coarse, scratched surface finishes on hobbed gears' tooth flanks—perhaps due to chip crush. The simulation explains the mechanism of such actual failures in detail. Based on the simulation, the Distance of Single Edge Cutting (DSEC) of a hob tooth is proposed to be an index of pinching and crushing of chips that could intrude into the clearance between hob cutting edge and work gear tooth flank. Influencing factors on DSEC are investigated, and the bases for finding countermeasures are shown. This method has been applied to some practical cases of problems in mass production of automotive gears, and good results were obtained.

Introduction

Dry hobbing often has problems, such as chipping of hob cutting edge and coarse surfaces on manufactured gears' tooth flanks. Chip crush between hob cutting edge and work gear tooth flank is considered a major cause of these problems. However, the mechanisms of chip crush and influencing factors on it have not been clarified, so we know of no method today to prevent or solve the problems caused by chip crush.

In the previous report (Ref. 1), a simulation method to evaluate conditions of chip formation and clearance between hob tooth cutting edge and work gear tooth flank was proposed, where the trace of each hob cutting edge relative to the work gear is calculated. This proposed method explains the mechanism of chip crush between hob cutting edge and work gear tooth flank and enables evaluation of probability of chip crush.

In this report, the influence of gear dimensions, hob dimensions and cutting conditions on chip crush is investigated by the proposed method. A countermeasure to prevent chip crush is clarified and its effect is confirmed by applying it to actual industrial cases of hobbing.

Comparison of Simulation Result and Actual Hobbing

It is possible to evaluate the changing conditions of generated chips and clearance between hob cutting edge and work gear tooth flank by comparing tooth groove shape before one revolution of the work gear, the trace of the previously acting cutting edge, and that of the object cutting edge, which are calculated by the proposed hobbing simulation (Ref. 1). The hob tooth for generating the center of the work gear's tooth groove is defined as tooth No. 0. The teeth acting before No. 0 have a minus sign, those acting after it have a plus sign. The side edge on the left is called the hob's left edge and the side edge on the right is called the hob's right edge (compare with Fig. 1).

Figure 1 shows chipping failure of a hob cutting edge when a right-hand helical gear (module 2.75, pressure angle 20°, number of teeth 62, helix angle 30° and addendum modification factor –0.6) is dry cut by a right-hand carbide hob (four threads and outer diameter 100 mm) under a climb feed of 2.5 mm/revolution.

Figure 2 shows the simulation results for the cutting edge of hob tooth No. –21, which is expressed by traces on each normal-to-axis slice of a work gear by regular intervals as shown in Figure 3(b). The object tooth groove is behind the work gear body and is observed from a viewpoint below the work gear, as shown in Figure 3(a). In Figure 2, the inclined line on each slice for different z_s positions represents the work gear's tip circle and the vertical line shows the trace of each point on the cutting edge of hob tooth No. –21.

The thin broken curves represent the tooth groove shape formed before the work gear's last revolution. The thin curves represent the trace of the cutting edge of hob tooth No. –22 acting before No. –21's cutting edge. The bold lines represent the trace of the cutting edge of No. –21.

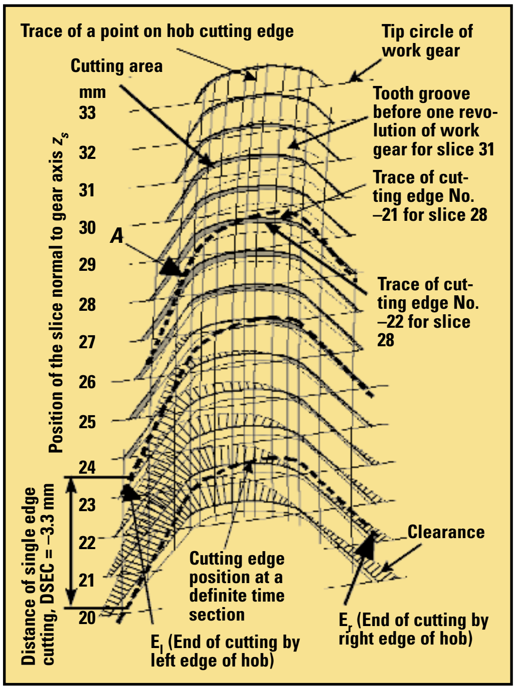

Figure 2—Cutting area (gray area) and clearance (hatched area) on each slice of tooth groove normal to gear axis, which are expressed by traces of hob cutting edges.

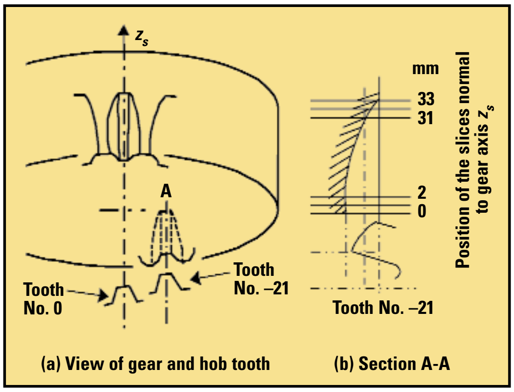

Figure 3—Definition of slices normal to gear axis.

The gray area, where the trace of No. –21's cutting edge is deeper than any other trace, shows the cut area with No. –21's cutting edge.

On the other hand, at the hatched area, where the tooth groove before one revolution of the work gear or trace of the cutting edge of hob tooth No. –22 is deeper than that of tooth No. –21, there is clearance between hob cutting edge and work gear tooth flank.

Figure 4 shows traces of the hob cutting edge on the normal-to-gear-axis slice at z_s = 28 mm and 24 mm. The whole cutting edge acts on the slice at z_s = 28 mm. At the slice near z_s = 24 mm, the upper left edge has finished cutting and the cutting area is divided in two. At the end of cutting by hob tooth No. –21, the right cutting edge acts alone, also seen in Figure 2. The two-dimensional expression on the normal-to-gear-axis slice shown in Figure 4 enables easy recognition

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Remedies for Cutting Edge Failure of Carbide Hob due to Chip Crush

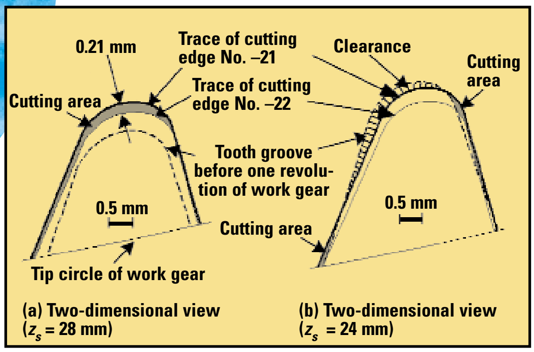

Figure 4—Expression of cutting area and clearance between cutting edge of hob tooth No. –21 and the work gear's tooth flank.

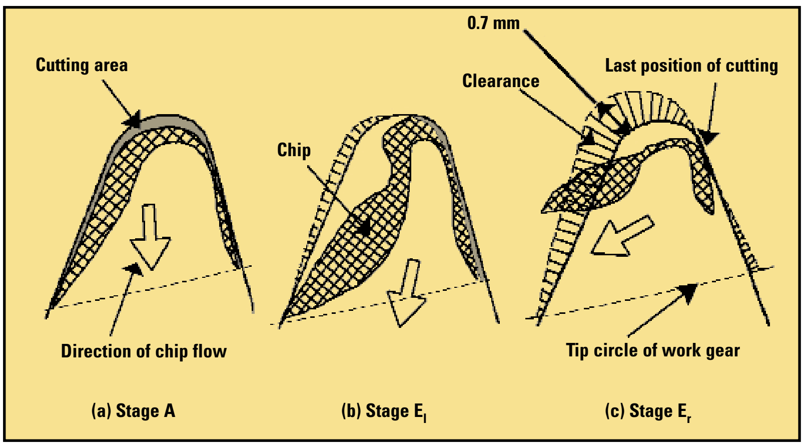

Figure 5—Direction of generated chip flow on rake surface of hob tooth at each cutting stage.

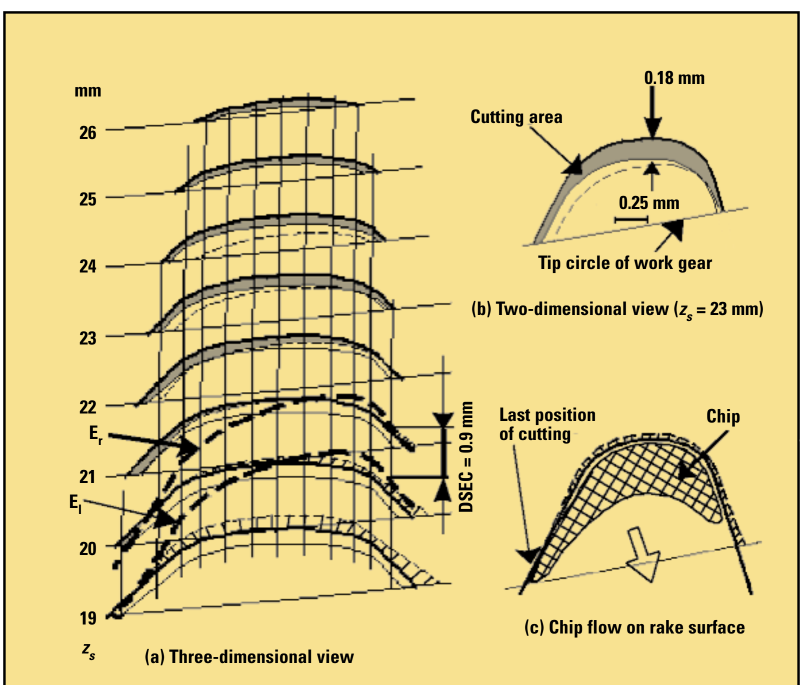

Figure 6—Cutting area, clearance and chip flow on rake surface for tooth No. –14 under standard conditions.

of the accurate size of cutting area and clearance.

Figure 2 also presents the chip formation process. The bold broken curve shows the cutting edge position at a definite time section. The hob's left cutting edge begins cutting each slice earlier than the right cutting edge because of the hob set angle, in this case. Edge position E_l corresponds to the end of cutting by the left edge and E_r to the end of cutting by the right edge. The tooth groove is cut only by the hob's right cutting edge in the axial range between E_l and E_r. That range is –3.3 mm (a plus sign means that the right edge finishes cutting before the left edge). This axial distance is defined here as DSEC (Distance of Single Edge Cutting).

Figure 5 shows a supposed movement of a generated chip on the hob's rake surface from the simulation for stages A, E_l and E_r in Figure 2. The whole tooth groove is cut simultaneously in Figure 5(a), so the chip moves toward the hob's tooth root. The hob tip and left cutting edge finish their work at stage E_l (compare with Fig. 2) in Figure 5(b), the right cutting edge acts alone at stage E_r (compare with Fig. 2) as shown in Figure 5(c). At that stage, the chip moves toward the hob's left edge. A large part of the already generated chip can surely reach the position near the hob's left cutting edge. However, the clearance between the left cutting edge and the work gear tooth flank appears in the process between A and E_l (compare with Fig. 2) and becomes larger. In such a situation, a generated chip could intrude into the clearance and chip crush could occur. The chipping position of the hob cutting edge in Figure 1 corresponds well to the position of

Table 1—Standard Specifications of Gear, Hob and Cutting Conditions.

a) Specifications of Gear		
Module	m	2.5
Pressure angle	α	20°
Number of teeth	z	59
Helix angle	β	30° RH
Cutting depth		5.875 mm
Addendum modification factor	x	0
Outside diameter	d_a	175.32 mm
(b) Specifications of Hob		
Module	m_0	2.5
Pressure angle	α_0	20°
Outside diameter		85 mm
Number of threads	z_1	4 RH
Lead angle		7.57°
Number of gashes	G_n	16
Amount of protuberance		0 mm
Radius of top corner		0.90 mm
(c) Cutting conditions		
Feed of table revolution		2 mm/rev.
Direction of feed		Climb
Hob set angle	Γ	22.43°

clearance in Figure 5(c). That means a main cause of that chipping is judged to be chip crush.

Chip crush does not always occur even if there is clearance and a generated chip moves toward the clearance. A chip might not intrude into the clearance or might pass through the clearance without crush. Chipping of the cutting edge is not actually observed on tooth No. –21's neighboring hob teeth, although there is no big difference in simulated results for the condition of chip formation and the behavior of clearance for hob tooth No. –21 and for its neighboring hob teeth.

The occurrence of chip crush may also be influenced by chip curl and work gear tooth flank surface condition, and it is difficult to predict exactly whether chip crush occurs or not. The proposed simulation is able, however, to evaluate the probability of chip crush. Evaluating this probability is industrially useful.

Influence of Gear Dimensions on Chip Crush

The cutting of a gear whose dimensions are shown in Table 1(a) by the hob in Table 1(b) under the cutting conditions in Table 1(c) is provided as an example. Figure 6 shows the simulation result for hob tooth No. –14. The result of the investigation in the following section confirms that general characteristics of chip crush are not much influenced by the difference in hob cutting edge, and it can be seen from the analysis by taking cutting edge No. –14 as a representative cutting edge. Figure 6(b) shows traces of the cutting edge on the normal-to-gear-axis slice at z_s = 23 mm.

Failure of a cutting edge often becomes a problem when a large chip is generated. Figure 6(c) shows the chip condition on a hob's rake surface before the end of cutting. DSEC is short (0.9 mm) in this case, although only the left cutting edge remains in work at that stage. That means the time when a chip moves toward the hob's right cutting edge is short and the distance of the chip's movement is short as well. In addition, the clearance near the right cutting edge is small due to the short DSEC. There is therefore little probability of chip crush under those conditions.

Influence of addendum modification factor. Figure 7 shows the simulation result for hobbing a gear in which addendum modification factor x is changed from 0 to 0.5 or –0.5. The tip diameter of the work gear is changed from that of Figure 6 according to the change of addendum modification factor x. For a gear of x = 0.5, DSEC becomes longer (3.4 mm) and the clearance between cutting edge and work gear tooth flank is larger. The lower illustration in Figure

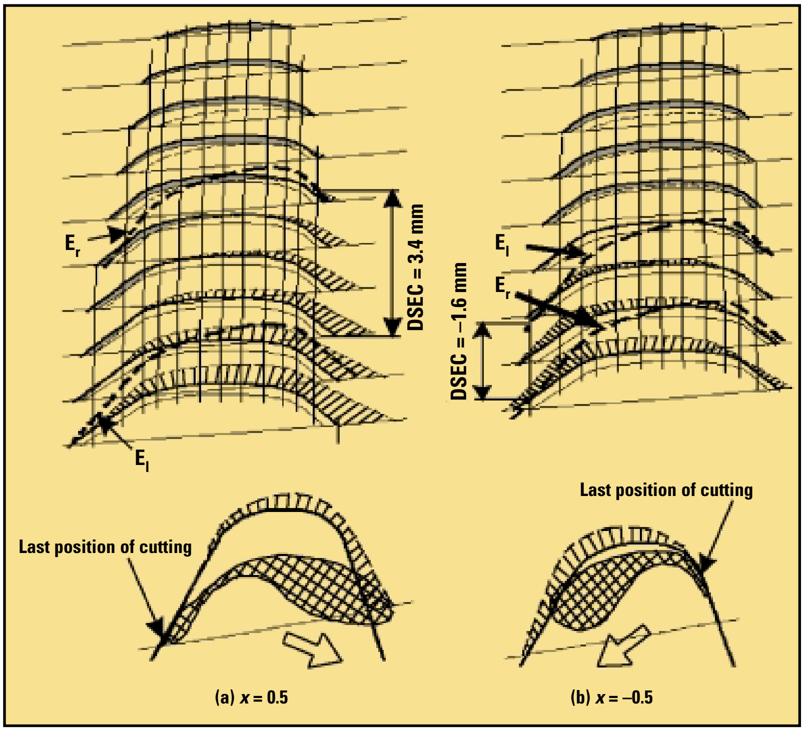

Figure 7—Influence of addendum modification factor x of gear.

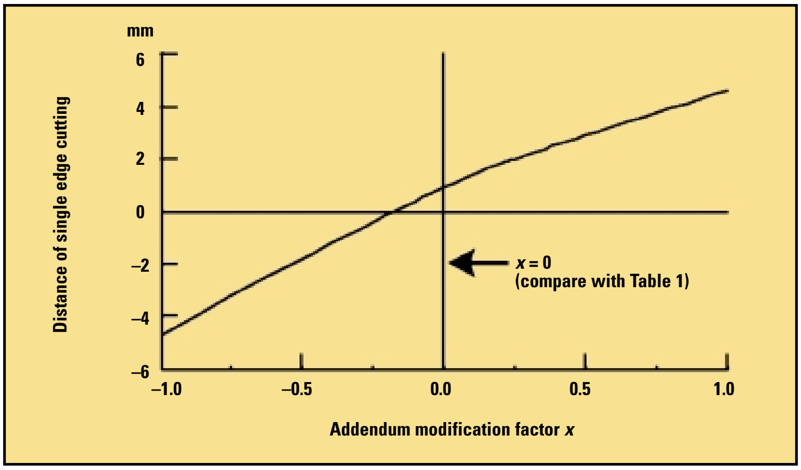

Figure 8—Effect of addendum modification factor of gear on DSEC.

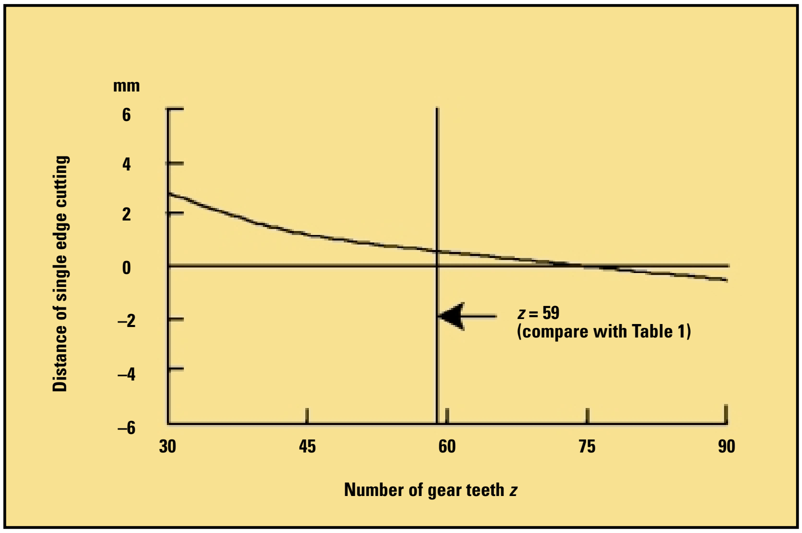

Figure 9—Effect of number of gear teeth on DSEC.

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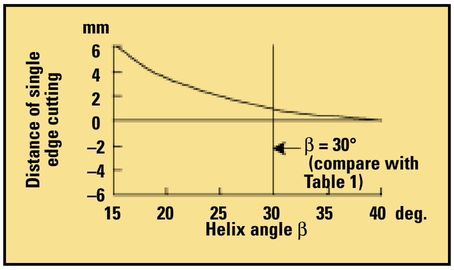

Figure 10—Effect of gear helix angle on DSEC.

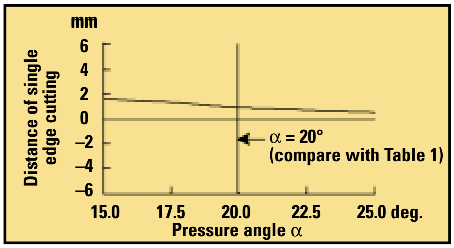

Figure 11—Effect of gear pressure angle on DSEC.

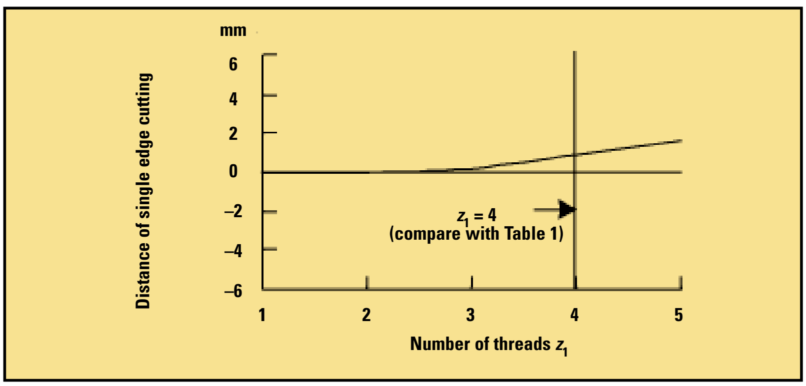

Figure 12—Effect of number of hob threads on DSEC.

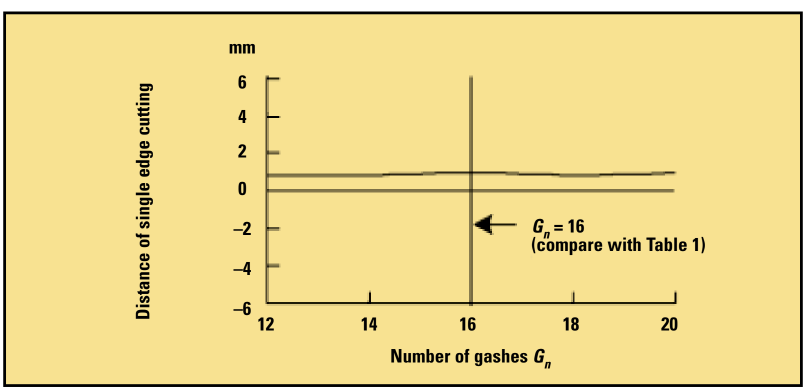

Figure 13—Effect of number of hob gashes on DSEC.

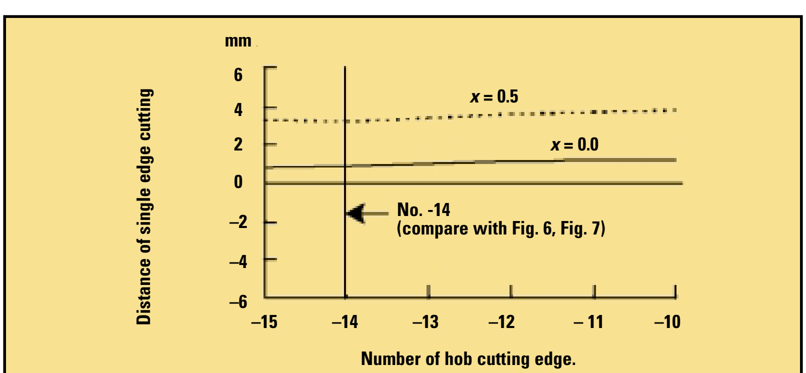

Figure 14—Difference in DSEC at different hob cutting edges.

7(a) shows the condition of chip formation on the hob tooth's rake surface. The chip moves toward the clearance near the right cutting edge because the left cutting edge acts alone for a long time. Those conditions imply a high probability of chip crush.

DSEC is –1.6 mm for a gear of $x = -0.5$ (see Fig. 7(b)). That means that only the right cutting edge acts at the end of cutting, which is opposite to the previous examples. A large clearance appears near the left cutting edge, and a chip could crush between the cutting edge and the work gear's tooth flank.

The large absolute value of DSEC implies large clearance and large chip movement on the hob tooth's rake surface—in other words, a high probability of chip crush. DSEC can therefore be taken as an index for evaluating the probability of chip crush.

It can be difficult to determine a clear DSEC threshold for chip crush. But, in the above two cases, a DSEC with an absolute value of 0.2 or 0.3 would be considered small enough.

DSEC increases according to an increase of the addendum modification factor, as shown in Figure 8). The DSEC value changes from a minus to a plus. That means that whether the cutting edge at the end of cutting is left or right depends on the addendum modification factor of the work gears.

DSEC becomes 0 when $x = -0.2$. That is, the left and right cutting edges finish cutting at the same time and there is little probability of chip crush under such conditions. The change of addendum modification factor from 0.2 increases the probability of chip crush. In actuality, it is known that small differences in gear dimensions result in large differences in the difficulty of dry hobbing. This fact is partly confirmed by the simulation result shown in Figure 8.

Influence of tooth number, helix angle and pressure angle. Figure 9 shows the influence of a gear's tooth number on DSEC. DSEC is approximately 0 when tooth number is large, but the value changes somewhat when the tooth number is small.

Figure 10 shows the result of investigating helix angle. It is clear that DSEC approaches 0 when the helix angle increases. That suggests a rather high probability of chip crush in the case of hobbing gears with small helix angles.

The result of investigating pressure angle is shown in Figure 11. There is no big influence from pressure angle on DSEC.

Influence of Hob Dimension and Cutting Condition

Figure 12 shows the relationship between number of hob threads and DSEC, where the number of threads is changed from the value shown in Table 1 and a parameter, such as hob set angle, is adjusted according to that change for the simulation. The probability of chip crush is very low for hobs with one or two threads because DSEC is near 0, but the probability of chip crush increases when a hob with a large number of threads is used.

The result concerning number of hob gashes is shown in Figure 13. It is clear that number of gashes has little influence on the probability of chip crush.

Figure 14 shows the change in DSEC at different hob cutting edges, where work gears of addendum modification factors of 0 and 0.5 serve as examples. It is clear that the DSEC changes very little for each hob cutting edge. That means that any hob cutting edge can be taken to analyze the probability of chip crush.

Figure 15 shows the influence of hob set angle. The values in parentheses show the amount of modification to the hob set angle from its original value. DSEC changes much due to the change in hob set angle. Arrangement of hob set angle is considered a powerful way of changing the conditions of chip formation and the behavior of the clearance.

A short pitched hob or a long pitched hob has a different pressure angle and module but has the same normal pitch compared with the original standard hob. The same gear can be cut by such a short/long pitched hob. Figure 16 shows the change in DSEC by such a short/long pitched hob under fixed normal pitch. DSEC decreases according to an increase of module and pressure angle. That result means a short/long pitched hob can change the condition of chip formation and the behavior of the clearance to prevent chip crush.

Method to Solve Problems due to Chip Crush

Problems concerning chip crush often occur in the trial-cut stage or early stage of mass production. The problem must be solved by changing parameters unrelated with gear dimension because gear dimension cannot be changed at that time. The condition shown in Figure 7(a) is taken here as an example, and the trouble due to chip crush at the right cutting edge is to be solved. DSEC must be decreased because DSEC

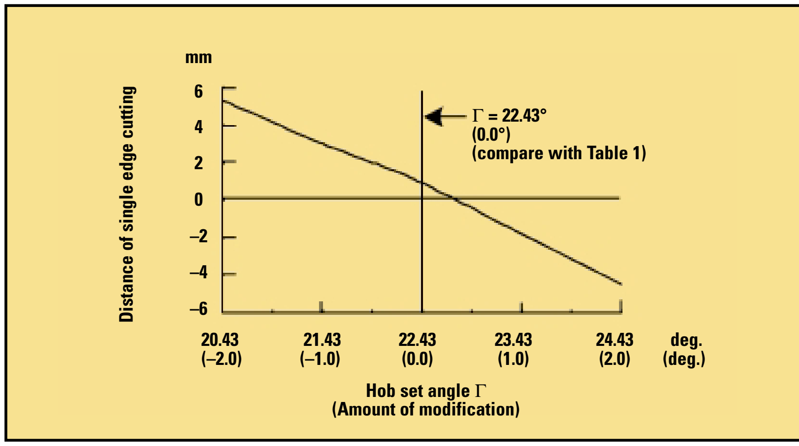

Figure 15—Effect of hob set angle on DSEC.

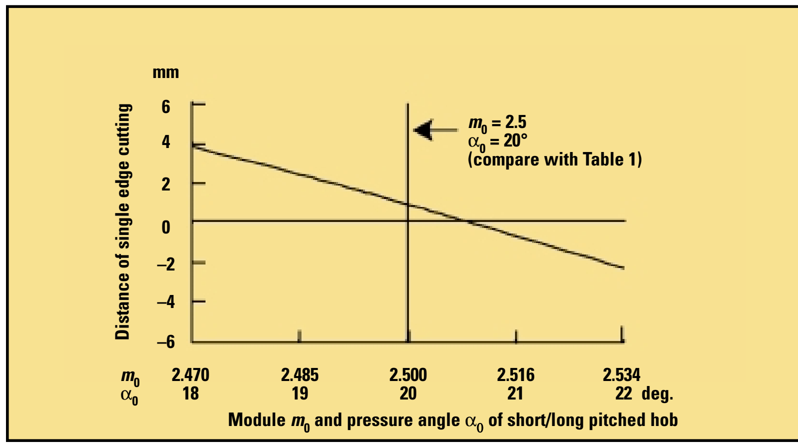

Figure 16—Effect of short/long pitched hob on DSEC.

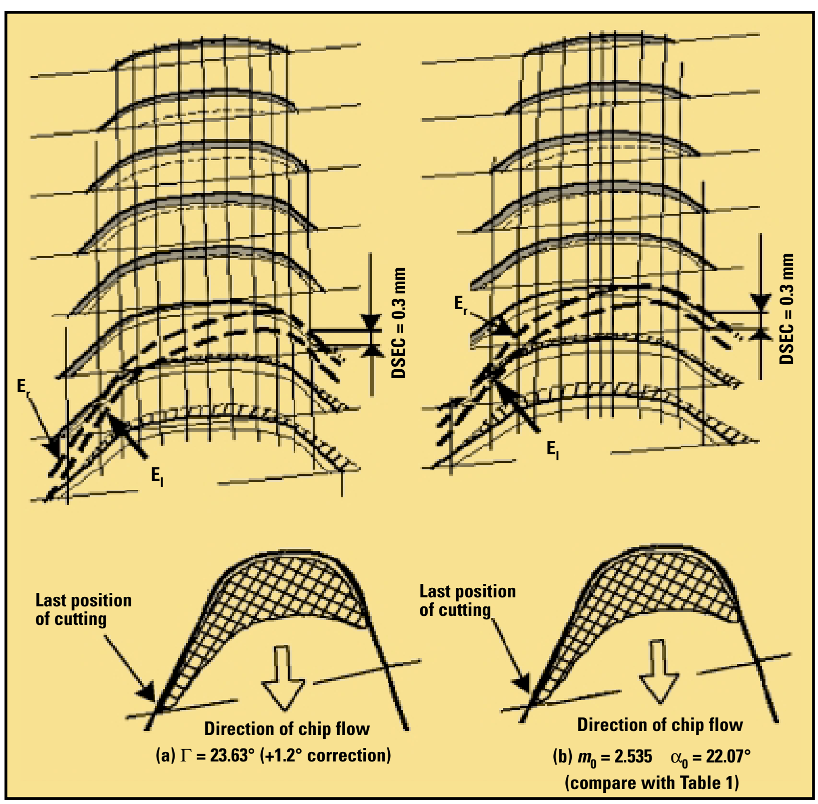

Figure 17—Improvement of cutting condition by modifying hob set angle or applying long pitched hob (m_0: hob module, α_0: hob pressure angle).

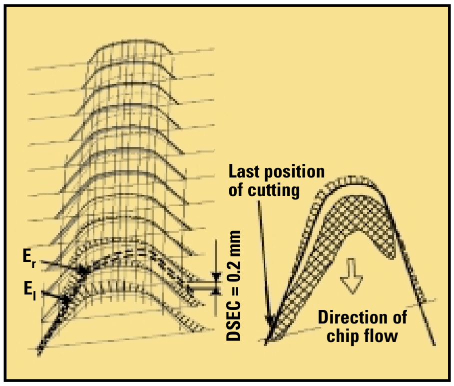

Figure 18—Simulation result when countermeasure against hob chipping is applied by providing a hob set angle modification of –0.75 degrees.

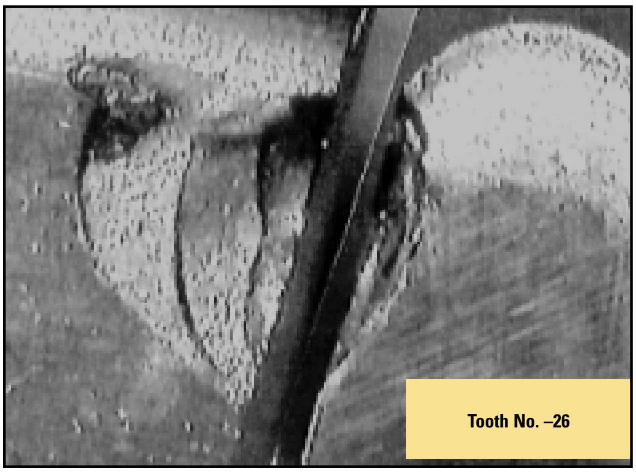

Figure 19—Chipping of carbide hob cutting edge (Example 2).

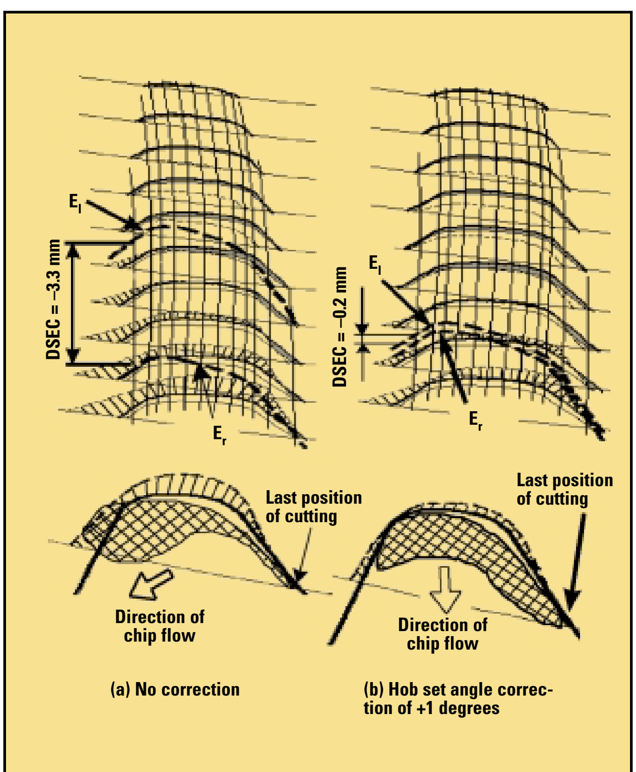

Figure 20—Simulation result for hob tooth No. –26 for Example 2, where hob set angle modification of +1 degree is provided.

is long (3.4 mm) under that cutting condition. An increase in hob set angle leads to a decrease in DSEC as shown in Figure 15. DSEC can also be decreased by applying a long pitched hob of larger module and pressure angle. Figure 17(a) shows the simulation result for +1.2 degree modification of hob set angle and Figure 17(b) shows the case of incorporating a long pitched hob of module 2.535 and pressure angle 22.07 degrees. It is clear that the DSEC value approaches almost 0 by the proposed methods and the probability of chip crush is expected to be lower.

Application to Actual Problems of Hobbing

Failure of hob left cutting edge (Example 1). The chipping shown in Figure 1 is used here, where simulation results are shown in Figure 2. Figure 18 shows the simulation result, where hob set angle is changed by –0.75 degrees. DSEC changes from –3.3 mm (see Fig. 2) to 0.2 mm. This countermeasure was applied to an actual case involving mass production of automotive gears, and the chipping problem was completely solved.

Failure of hob left cutting edge (Example 2). Figure 19 shows chipping of the cutting edge of hob tooth No. –26, which was observed when a left-hand helical gear (module 2, pressure angle 20 degrees, number of teeth 31, helix angle 35 degrees and addendum modification factor 0.33) is dry cut by a left-hand carbide hob (three threads) with a climb feed of 2.5 mm/rev. The same chipping failure occurred repeatedly at the same position on the hob tooth. Figure 20(a) shows the simulation result corresponding to the hobbing conditions of Figure 19. Chip crush at the hob's left edge is judged to be the cause of chipping because DSEC is long (–3.3 mm).

Figure 20(b) shows the result of the simulation where hob set angle is modified by +1 degree. The absolute DSEC value is decreased to 0.2 mm. In actual mass production, this correction of hob set angle was used. The chipping failure of the hob cutting edge disappeared.

Failure of hob right cutting edge (Example 3). (Ref. 2) Figure 21 shows chipping of hob cutting edge No. –14, which was observed when a right-hand helical gear (module 2.4, pressure angle 20 degrees, number of teeth 69, helix angle 30 degrees and addendum modification factor 1.0) is dry cut by a right-hand carbide hob (four threads) with a climb feed of 2 mm/rev. Figure 22(a) shows its simulation result. Chip crush is regarded as a main cause of the chipping shown in Figure 21 because DSEC is long (4.0 mm).

DSEC can be decreased to –0.2 mm by modifying hob set angle by +1.5 degrees, as shown in Figure 22(b). Clearance at the right edge becomes smaller as well. This remedy was applied to an actual case, and the problem of chipping failure was solved.

These actual cases confirm that the proposed remedies are useful at preventing hob failure due to chip crush.

Conclusion

Failures of hob cutting edge or problems with the surface quality of manufactured gears' tooth flanks are often problems in dry hobbing. These problems are usually caused by chip crush between hob cutting edge and work gear tooth flank. In this report, the behavior of chip formation and the changing state of clearance between hob cutting edge and work gear tooth flank is investigated by the proposed simulation method to develop the method to prevent chip crush. The following items are concluded:

(1) It is confirmed that the position of chipping on the hob cutting edge corresponds very well to the position of chip crush estimated from simulation. That means the probability of chip crush can be evaluated by utilizing the proposed simulation method.

(2) DSEC, i.e. the axial distance concerning a work gear where only a single edge cuts the tooth groove, can be taken as an index for evaluating the probability of chip crush: a larger absolute DSEC value means a higher probability of chip crush.

(3) Addendum modification factor, helix angle, number of gear teeth, hob set angle and short or long pitching of hob have a strong influence on DSEC. However, pressure angle, number of gashes, and hob tooth difference have little influence. Hobs with large numbers of threads, e.g. three or more threads, result in larger DSEC values.

(4) The solution for problems with chipping of hob cutting edges due to chip crush is to lower the DSEC. For that, we propose as follows: (1) using a short/long pitched hob of modified module and pressure angle or (2) changing the hob set angle. These methods make it possible to prevent chip crush without changing the dimensions of manufactured gears. The method has been applied to actual chipping problems in mass production of gears in some Japanese automotive companies and successful results have been achieved.

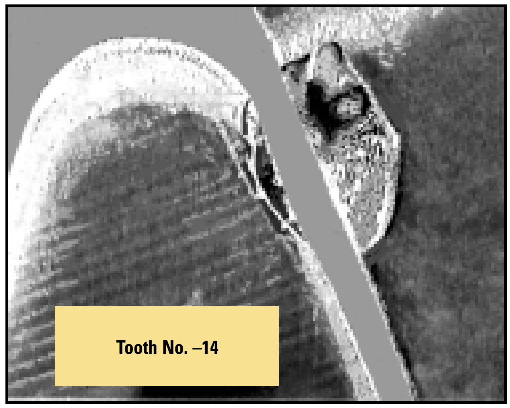

Figure 21—Chipping of carbide hob cutting edge (Example 3).

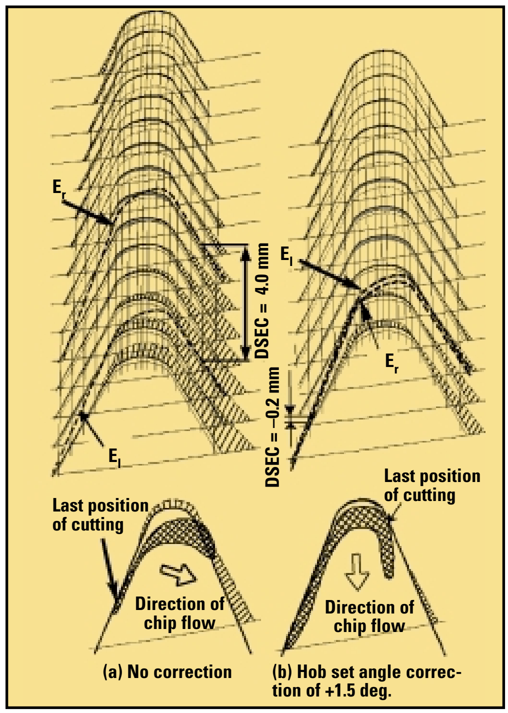

Figure 22—Simulation result for hob tooth No. –14 for Example 3, where hob set angle modification of +1.5 degrees is provided.

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