Avoiding Interference In Shaper-Cut Gears

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In the process of developing gear trains, it occasionally occurs that the tip of one gear will drag in the fillet of the mating gear. The first reaction may be to assume that the outside diameter of the gear is too large. This article is intended to show that although the gear dimensions follow AGMA guidelines, if the gear is cut with a shaper, the cutting process may not provide sufficient relief in the fillet area and be the cause of the interference.

In 1982, J. Colbourne presented an ASME paper entitled "Gear Tooth Interference," which described the possibility of this type of interference and gave a mathematical analysis showing that it could exist. He also suggested that there probably would not be interference if the minimum root clearance was .25 m (module) (.25/dp). This condition is too restrictive when designing gears for maximum strength or high contact ratio. Frequently the inner bore of a gear also limits the depth of the root. The Colbourne paper also describes the mathematics of the relationship of a shaper cutter and a gear that can be used to predict interference. This article extends the discussion by showing that a very important criterion is the number of teeth, or diameter, of the shaper cutter.

In the design of custom gears, it is the usual procedure to incorporate the dimensions of the cutter in the design. When designing gears for high contact ratio or high pressure angle requirement, the AGMA standards no longer apply. The actual point of contact of the mating gear must be studied to prevent interference, primarily at the point where the involute and fillet join.

Since hobbing is the most desirable method of cutting gear teeth, a basic rack, usually the rack of a hob already available, will be assumed for the design process. However, when the gear goes into production, it may be cut with a shaper cutter for various reasons. When this happens, even though the gears may be operating on a standard center distance, it is possible that the tip of the mating gear will drag in the fillet of the small gear. This condition results in noise and high stresses and is evidenced by a shiny area near where the fillet and involute join. This article discusses possible reasons for this and illustrates the phenomenon with computer graphics. The writers do not know of any empirical equation that will predict this condition.

The basic design rule to prevent interference in the fillet applies to all gears. These rules specify that the tip of a mating gear involute profile must make contact between the tangent points on the line tangent to the two base circles. A basic rack represents a gear with an infinite number of teeth, and a hob with this profile and the usual standard proportions will provide "run out" clearance in the fillet area for gears with finite numbers of teeth. An interference exception would be a mating gear tooth with a very large chamfer, which could still bottom out in the root. This should always be checked. If the outside diameter of the mating gear exceeds the above criteria, it may drag in the fillet.

When it is decided to cut the gear with a shaper cutter, it is not too difficult to design the shaper cutter profile to generate the required involute curve. The process is similar to designing a mating gear. The outside diameter of the shaper cutter is calculated to give the same root diameter, and the assumption is that the fillet will be recessed enough to prevent interference.

It is difficult to predict if a design will lead to dragging in the fillet. To better understand what is going on, we need to study the generating path of the cutter. A computer program has been developed to graphically represent a point-by-point

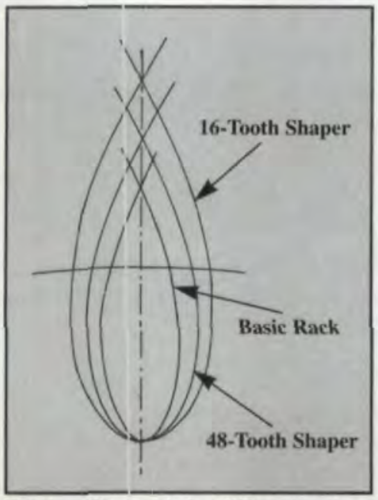

Fig. 1 — Trochoids for different cutters generating an 18-tooth gear.

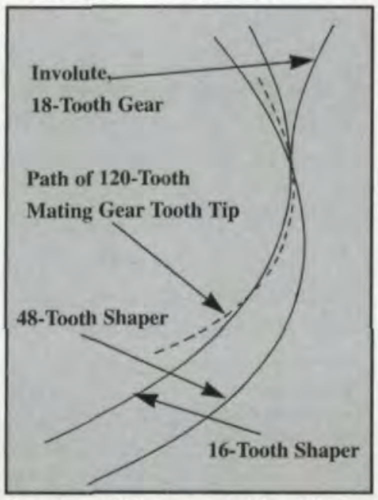

Fig. 2 — Fillets generated by different sized shapers.

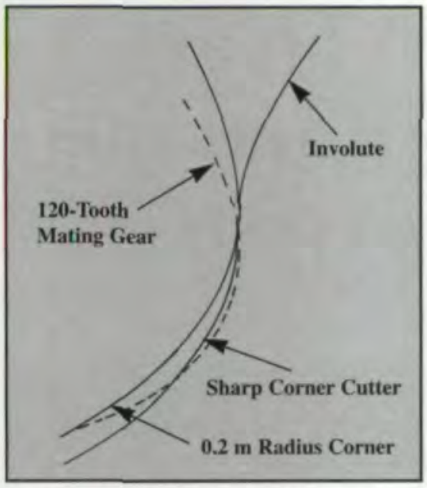

Fig. 3 — Effect of radius added to corner of shaper tooth compared to sharp corner.

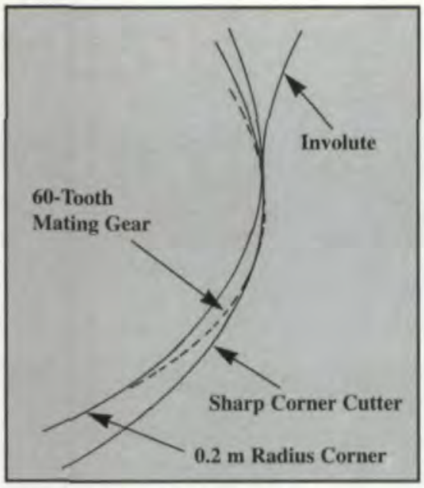

Fig. 4 — Effect of radius added to corner of shaper tooth compared to sharp corner when mating gear has 60 instead of 120 teeth.

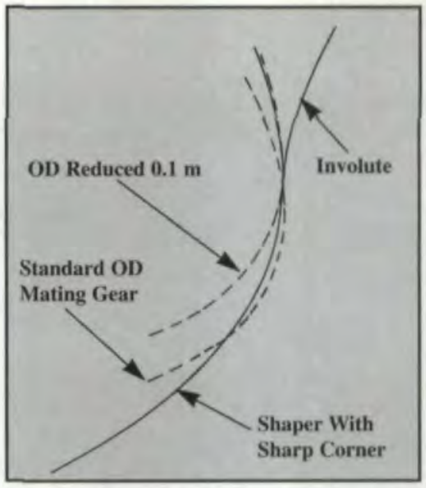

Fig. 5 — Effect of reducing the diameter of the mating gear by 0.1 m.

path of the cutter for comparison with a point-by-point plot of the path of the tip of the mating gear. An overlap in the fillet area indicates interference.

The trochoidal path of the tip of a basic rack (hob) will be quite narrow, depending upon how deep it goes below the generating pitch circle. For shaper cutters and mating gears, the trochoids will be wider, assuming the same depth below the generating pitch circle. The fewer the number of teeth in the mating gear or the shaper cutter, the wider the trochoid (Fig. 1). Also, the greater the addendum of the cutter, the wider the trochoid. Since the trochoid of a shaper cutter will be wider than that of a hob, the expectation is that there will be more clearance in the fillet area when using a shaper cutter.

However, the orientation (centerline) of the trochoid will not be the same for a shaper and hob. The shaper tooth is thinner than a hob tooth at the tip; therefore, the centerline of the trochoid for the shaper tooth tip that cuts the fillet is further from the center of the tooth of the gear, and this feature thickens the gear tooth in the fillet area (Fig. 2). The smaller the number of teeth in the shaper, the thinner the tooth tip and the thicker the gear tooth fillet profile. The higher the pressure angle of the cutter, the thinner the tooth is at the tip and, again, the thicker the shaper-generated tooth is in the fillet area. For emphasis, the plots in all figures have been expanded horizontally four times.

To demonstrate the effect of a radius on the tip of the shaper cutter, Fig. 3 shows that the overlap (interference) of the path of the mating gear is significantly greater than for a fillet generated by a sharp-cornered cutter. Most shaving cutters have some form of tip modification, frequently a sloped surface, which may be the best choice for least interference.

Fig. 4 illustrates the effect of the size of the mating gear. By reducing the number of teeth from 120 in Fig. 3 to 60 in Fig. 4, the interference shown in Fig. 3 becomes borderline when fillet-cut with a shaper with sharp corners at the tip. Significant interference exists when the tip of the cutter has a radius.

Fig. 5 shows the result when the outside diameter of the mating gear is reduced by 0.1 m. This minor change in outside diameter results in a trochoid for the mating gear that is a little shorter and narrower. It no longer interferes with a fillet generated with a sharp-cornered shaper; however, it may for a cutter with a radius.

To summarize, the following conditions may create a condition for interference in the fillet of a gear cut with a shaper cutter.

1. A gear set with a large ratio. In this situation, the large gear may travel a considerable distance below the base circle with a trochoid loop that is narrow and nearly straight toward the center of the gear. It will tend to intersect the fillet of the shaper-cut small gear that does not have a sufficiently recessed fillet.

2. A gear cut with a shaper cutter with a small number of teeth, a large tip radius and a short addendum. All these parameters contribute to a thicker fillet in a small gear.

When recycling shaper cutters, sometimes only a small shaper is available. In such cases, the possibility of interference should be investigated. ○

Reference:

1. Colbourne, J. R. "Gear Tooth Interference," ASME Paper 82-DET-128. Presented at the Design & Production Engineering Conference, Washington, D.C., Sept., 1982.

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