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Point–Surface–Origin, PSO, Macropitting Caused by Geometric Stress Concentration, GSC

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Point-Surface-Origin, PSO, macropitting occurs at sites of Geometric Stress Concentration, GSC, such as discontinuities in the gear tooth profile caused by micropitting, cusps at the intersection of the involute profile and the trochoidal root fillet, and at edges of prior tooth damage such as tip-to-root interference. When the profile modifications in the form of tip relief, root relief, or both are inadequate to compensate for deflection of the gear mesh, tip-to-root interference occurs. The interference can occur at either end of the path of contact, but the damage is usually more severe near the start-of-active-profile, SAP, of the driving gear.

An FZG-C gearset (with no profile modifications) was tested at load stage 9 and three pinion teeth failed by PSO macropitting. It is shown that the root cause of the PSO macropitting was GSC created by tip-to-root interference.

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Introduction

Stewart Way [1] first described what later became known as point-surface-origin, PSO, macropitting. The macropits are relatively shallow but large in area. The fatigue crack grows from a surface origin in a fan-shaped manner until thin flakes of material break out and form a triangular crater. The arrow-head-shaped crater points opposite to the direction of rolling (direction of load approach). Crack propagation can extend over large portions of a gear tooth. Way [1] also proposed the theory of hydraulic-pressure-propagation to explain the growth of PSO macropits. Lubricant viscosity is an important parameter influencing PSO macropitting, and it has been shown [2] that low viscosity lubricants promote PSO macropitting by hydraulic-pressure-propagation. PSO macropitting is promoted by the combination of low viscosity lubricant, low specific film thickness, and tangential shear stresses from sliding [2]. PSO macropitting can originate from surface flaws such as:

- Tip-to-root interference
- Debris dent
- Handling nick
- Edge of macropitting
- Edge of micropitting
- Surface flaws from manufacturing
- Surface non-metallic inclusion
- Surface carbide
- Corrosion pit

This paper discusses PSO macropitting originating from tip-to-root interference. If involute gear teeth were perfectly rigid and without manufacturing errors they would begin contact at the ideal start-of-active-profile, SAP, point and end contact at the ideal end-of-active-profile, EAP, point. However, real gears are not rigid, and even without manufacturing errors, tooth deflection causes the teeth to start contact earlier than the ideal SAP, and end contact later than the ideal EAP. In the areas of extended contact at the ends of the path of contact a

gear tooth is loaded on its tip corner (intersection between the tooth flank and tooth top-land) and the contact stresses are very high because of geometric stress concentration, GSC. Therefore, to avoid corner contact and the associated high contact stresses, it is common practice to design gear teeth with tip relief that is sufficient to compensate for tooth deflection and manufacturing errors. However, FZG type C test gears, FZG-C, spur gears are manufactured accurately but without tip relief. Consequently, they inevitably have corner contact when they are tested at high loads. FZG-C gears are discussed in this paper because they demonstrate the consequences of inadequate tip relief.

Objective

This paper demonstrates how gears without tip relief suffer tip-to-root interference that causes GSC and PSO macropitting.

Corner contact

Figure 1 shows the path of contact for FZG-C gears that was calculated with KISSsoft software [3]. It shows corner contact occurs when early contact occurs between the gear tip and the pinion involute at point A' and continues along the gear tip circle to point A on the line of action. The path of contact between points A' and A is non-conjugate and is known by many names such as:

- Tip-to-root interference
- Corner contact
- Contact outside the normal path of contact
- Early contact
- Edge contact
- Extended contact
- Non-conjugate action
- Premature contact
- Prolonged contact
- Top contact
- Tooth interference

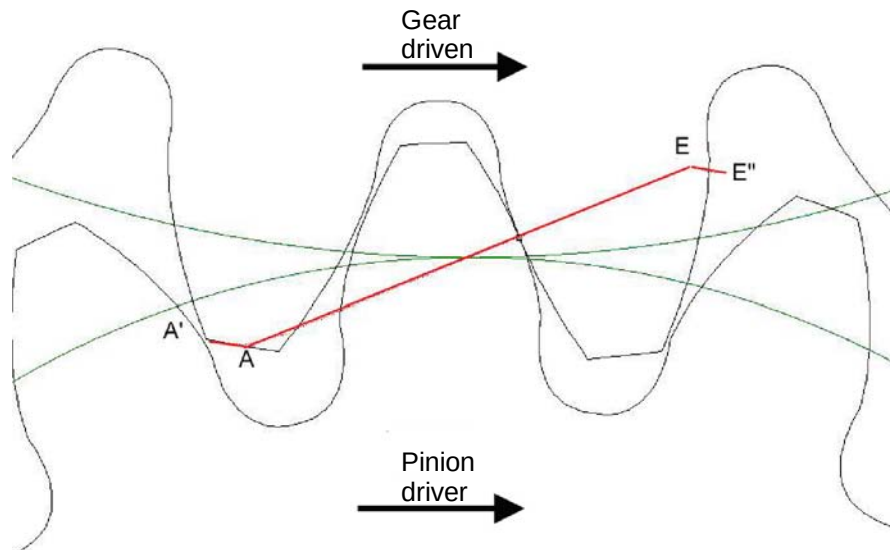


Figure 1. Gear tip approaching pinion involute

Mechanism of tip-to-root interference

Figure 2 shows how the gear tip corner approaches the pinion involute along a trochoidal path that intersects the pinion involute at a point above the usual pinion SAP. Contact between the gear corner and the pinion involute results in very high Hertzian stress especially if the gear has sharp corners at the tips of its teeth. The high stress and scraping action of the gear corner undercuts the pinion involute by removing the material shown shaded in Figure 2 and plowing material toward the pinion root. The intersection between the undercut and involute forms a cusp on the pinion flank at point A'. In this paper, damage caused by corner contact will be called tip-to-root interference.

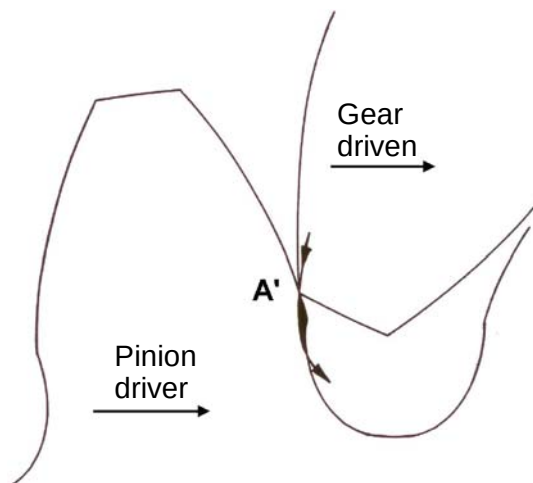


Figure 2. Mechanism of tip-to-root interference

Contact on pinion cusp

Corner contact undercuts the pinion involute and removes the usual SAP (point A) and delays the contact between the pinion and gear until they contact at point A'' on the line of action as shown in Figure 3. The edge contact that occurs on the pinion cusp causes GSC as shown by the local maximum Hertzian stress shown in Figure 4.

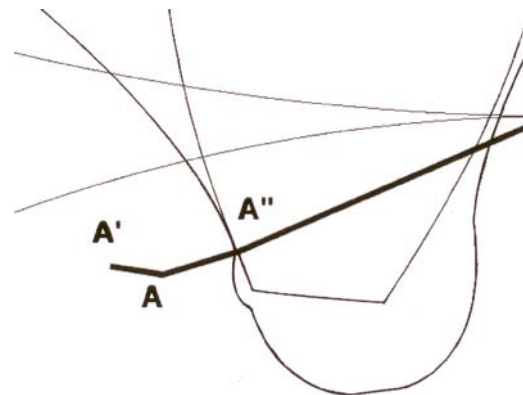


Figure 3. Contact on the pinion cusp

FZG-C test gears

An FZG-C gearset was tested at load stage 9 in accordance with the FZG pitting test PT C/9/90 procedure [4] except the oil temperature was set to 120°C. Table 1 gives the lubricant properties. The lubricant prevented adhesive and abrasive wear. However, after only 60 hours, the test had to be stopped because macropitting occurred on teeth 1, 9, and 15.