Analysis of and Solution to Slewing Ring Gear Failures

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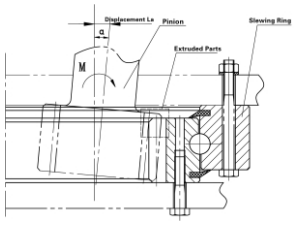
Abstract
This article illustrates and analyses failures of slewing ring inner ring gears in service. To reduce failures the first solution was to control the backlash between the slewing ring and pinion gears to be no less than 0.06 x module. Later a 37 deg angled chamfer made some further improvements. Based on theoretical work and experimentation, the slewing ring with gear hardness gradient is presented as a solution to inner ring gear failure which has now been applied to over 2000 slewing rings still in service.

Key words
Slewing ring; Gear failure; Backlash; Gear hardness gradient

Introduction
The author has 30 years' experience in the design and manufacture of domestic excavator slewing rings, as well as 15 years' experience with foreign, after-market excavator slewing rings. The problem of slewing ring gear failure occurs mainly in hardened inner ring gears (hardness > 50 HRC) operating in excavators, rotary drill rigs, crawler cranes etc. The problem is rarely seen in unhardened outer ring gears (hardness < 30 HRC).
According to statistics the failure rate of domestic excavator slewing ring gears is about 1% - 2% (varying between periods and brands), while the gear failure rate of aftermarket rings reaches 5% - 6%. In particular, double digit failure rates have been found in 5 ton, 7 ton and 8 ton domestic brand excavator slewing rings.

Analysis of excavator gear failure
The author clearly states in "Slewing Ring Early Stage Gear Failure Analysis" (Hou and Liang, 2002) that most gear failures occur within one year of delivery and are caused by radial tilt extrusion (Figure 1). The concept of a floating transmission shaft is employed to illustrate the engagement between gear and pinion. Tilting moment 'M' would be generated in service due to the existence of clearance between the inner and outer ring. The centre line of the pinion will be displaced by angle A with radial displacement La, changing the center distance and the backlash of the gear system.

Figure 1 Title: An illustration of the gear and pinion system

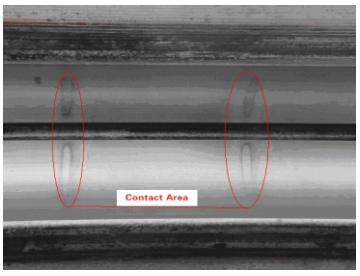


Source: Hou N and Liang W (2002), Slewing Ring Early Stage Gear-Broken Analysis & Solution, Construction Machinery, No.7 pp. 58-59

The usual radial internal clearance of a slewing ring is less than 0.20mm, which may increase in service (due to wear) to around 0.30mm. The raceway will deform (elastically) under normal operating conditions. For example, assume a slewing ring raceway is deformed by 0.2mm on one side, or 0.4mm on both sides as the contact area changes under load. (Figure 2). Combined with additional deformation of the machine frame and other factors, the radial displacement of the upper part of the pinion may reach

1mm. Based on this displacement, force analysis by Hou and Liang (2002) shows how the resultant forces are transmitted through the gear teeth which will break under repeated loading.

Figure 2 Title: The contact area of steel ball and raceway after 125% overloading applied



Source: Adopted from the Quality Report of Maanshan Tongli Slewing Ring Co., Ltd.

Characteristics of failure

Slewing ring gear failures usually occur in the upper part of the gear face. The fractured surface intersects the slewing ring top surface at between 45 – 60 degrees (Figure 3, Figure 4). On occasion the crack extends across the entire tooth face. The tooth is plastically deformed, more so on the upper sides. The width of the gear groove (or distance between teeth) increases from bottom to top.

Figure 3 Title: Traditional gear failure

Source: Adapted from Maanshan Tongli Slewing Ring Co. Ltd Quality report.

Figure 4 Title: Failure of gear with 37 degree chamfer

Source: Adapted from Maanshan Tongli Slewing Ring Co. Ltd Quality report.

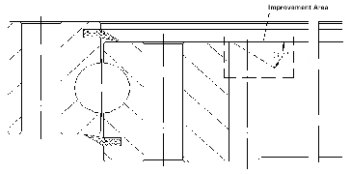
Solutions

Regarding excavator slewing ring failures, the following solutions have been employed:

Firstly, the backlash between gear and pinion was specified to be no less than 0.06 x module. For example, the module on a 20 ton excavator is 10, so the backlash was no less than 0.6mm. It is noted that in the aftermarket the end users ignore the importance of backlash during installation which results in the higher failure rate. The relationship between gear failure and backlash is well known and has been constantly pointed out by the manufacturers for many years, which may have resulted in a small decrease in aftermarket failures from 6% to 5%.

Secondly, the 37 degree chamfer gear design was adopted. The teeth on the non-mounting surface of the slewing ring are chamfered by 37 degrees (Figure 5). By purposely removing the easily fractured portion of the gear, the interference on the upper gear surfaces is avoided when the pinion is displaced. The slew ring gear would not be deformed and failure would be delayed. According to 2 year statistic data, the gear failure rate in aftermarket bearings improved from 5% to 4%.

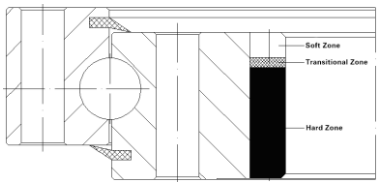
Figure 5 Title: Illustration of the 37 degree chamfer



Source: Adapted from Maanshan Tongli Slewing Ring Co. Ltd Quality report.

The slewing ring with gear hardness gradient is the latest patent intended to resolve this gear failure problem. The hardness of the hardened zone is 50-60 HRC, while the hardness of the soft zone is that of the quenched and tempered forged material. When the slewing ring gear and pinion engage and deform, the soft zone of the gear is elastically deformed only. No gear failures have been observed by the researchers in the excavator slewing ring aftermarket since the product was introduced into the market one year ago.

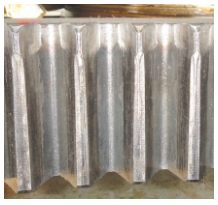
Figure 6 Title: The slewing ring with gear hardness gradient invented by Tongli



Source: Adopted from Maanshan Tongli Slewing Ring Co. Ltd Technical Document

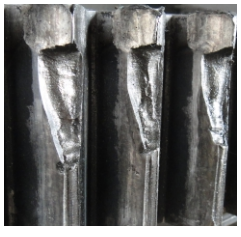
By experiment, when the elastic deformation of the soft zone reaches 2mm (Figure 7), the slewing ring with gear hardness gradient can still engage normally with the pinion and maintain transmission. The hardened zone and transition zone will break when the deformation of the soft zone reaches 3mm (Figure 8)

Figure 7
Title: In the circumstance when plastic deformation of “Soft Zone” reaches 2mm



Source: Adopted from Maanshan Tongli Slewing Ring Co. Ltd Technical Document

Figure 8
Title: In the circumstance when plastic deformation of “Soft Area” reaches 3mm



Source: Adopted from Maanshan Tongli Slewing Ring Co. Ltd Technical Document

Conclusion

Increasing gear backlash is one way to reduce gear failures, but this affects the swing zone of the boom. Excessive backlash is not advisable. The slewing ring with gear hardness gradient is the best solution. As explained above, the slewing ring with gear hardness gradient works well even if the deformation reaches 2mm, but the displacement of the pinion in excavators and rotary drill rigs will not normally reach these values in normal service. Thus the backlash can be reduced to limit the boom swing zone.

When the slewing ring gear is broken, the slewing reducer can break as well, but the rate of failure is effectively reduced by adopting the slewing ring with gear hardness gradient. Thus the gear hardness gradient reduces gear failures, limits the boom swing and reduces reducer failures – 3 targets at once. The slewing ring with gear hardness gradient was introduced to the market 12 months ago. Over 2000 units have now been sold and no failures in service have been recorded.

In conclusion, the slewing ring with gear hardness gradient is a revolutionary breakthrough in technology that eliminates the issue of gear failures in construction machinery such as excavators or rotary drilling rigs.

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