Assessing and Monitoring Girth Gearing Wear

Bill Hankes, A-C Equipment Services, USA, explains why it is essential to minimise wear to girth gearing in order to achieve proper operation and maximise service life, and discusses the importance of an assessment and monitoring program.

Introduction

The operators of large gear driven equipment including kilns, coolers, and grinding mills are frequently addressing wear issues. Some of the components in these machines are designed to function properly as they wear. Examples of this include the support rings and carrying rollers on a kiln or the liners in a grinding mill. Most components are not designed to wear and therefore their performance deteriorates over time. Examples of this include seals (which leak as they wear), the shell (which can catastrophically fail), and the girth gearing (the topic of this article). The question for all of these components ultimately becomes how much wear is too much? Answering this question with certainty is difficult, but an assessment and monitoring program will prevent unscheduled downtime and costly interruptions of production.

Kilns, coolers, and grinding mills are critical pieces of equipment in any processing plant. One of the most important components of these machines is the main girth gear and mating pinion(s). This gearing is typically custom made for each application and therefore the lead time for replacement is measured in months, not weeks. The cost of a girth gear set ranges from US$75 000 to over a US$1 million. With such a long lead time and high cost, girth gearing is designed to last many decades with proper maintenance.

Under ideal conditions, the gear and pinion teeth should not wear. Ideal conditions include adequate lubrication of the correct type, perfect alignment, constant

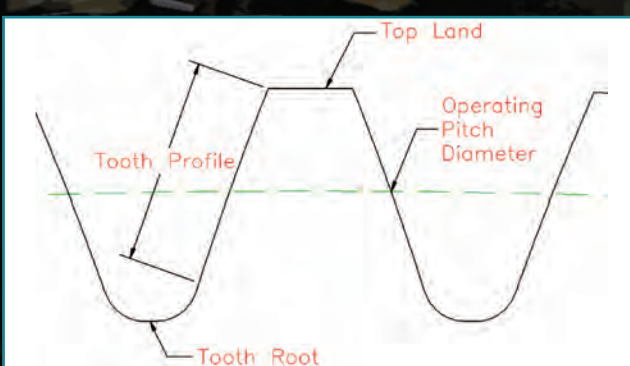


Figure 1. Tooth features.

Figure 2. Pinion with original cutting tool marks. Polishing on right side is caused by misalignment.

Figure 3. Severe gear profile wear.

Figure 4. Mild pinion wear and edge plastic flow.

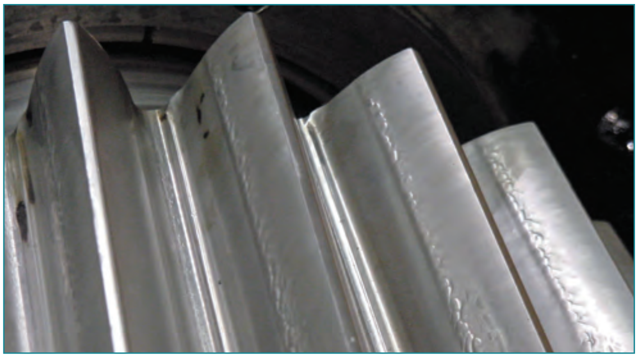


Figure 5. Rippling and wear step. Note operating pitch diameter is clearly visible.

Figure 6. Mild gear profile wear and corrosion.

loads, infrequent starts, and no contamination. However, instead of using the term 'ideal conditions' it would be more accurate to say 'conditions impossible to achieve in the real world'. Despite this, it is possible to assess, monitor and minimise tooth wear.

Since wear generally occurs slowly, the exact moment when tooth failure will occur cannot be predicted. Severely worn teeth may operate for years until a slight increase in load or small change in alignment ultimately causes tooth failure. This means methods of assessing and monitoring wear are needed to avoid tooth failure.

To aid in the understanding of tooth wear, it is helpful to know the major tooth features: Figure 1 shows the top land, tooth profile, operating pitch diameter, and the tooth root. Knowing these tooth features will assist the reader to monitor the tooth condition.

The tooth profile is the working surface of the tooth. Hence, the tooth profile is the area of the tooth that wears. Mating gear teeth slide while in contact up and down the tooth profile except at the operating pitch diameter. The operating pitch diameter is the only location on the tooth profile at which rolling occurs. The tooth profile at the operating pitch diameter will wear at a different rate than the rest of the tooth. One of the first visual clues to the presence of tooth wear is a distinct line at the operating pitch diameter (Figures 5, 11 and 12) and a wear step developing in the tooth root.

Effects of wear

The effects of wear range from minor to catastrophic. In general, some wear is expected in girth gearing applications such as kilns, coolers, and grinding mills. This is because the ideal conditions mentioned above never exist in these applications. Girth gearing always has a combination of misalignment, varying load and contamination resulting in at least mild wear. In addition, the material being processed at most sites is abrasive, chemically active, or both.

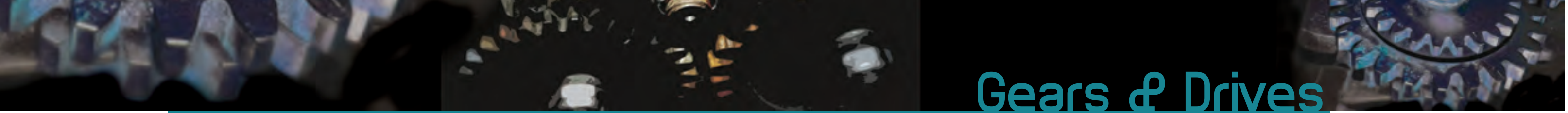
The effects of wear include:

- Increased vibration.
- Increased noise.
- Loss of efficiency: increased power draw (amps).
- Reduced load carrying capacity.
- High localised stresses.
- Cracking.
- Catastrophic tooth failure.

Typically, the effects of wear take years to develop into a condition of major concern. Occasionally, wear occurs very quickly as in the case of the gear and pinion shown in Figures 11 and 12, respectively. This gearing has only been in operation for four months and has already experienced significant tooth profile wear.

Unfortunately, once wear has occurred there is very little that can be done to correct it. The best that can be done is to detect wear early and prevent it from progressing. Ultimately, the only solution to severe wear is to reverse the gearing (use an unworn tooth flank) or to replace the gearing.

It should be noted that while it is typical to mesh an unworn pinion with a worn gear, it is strongly discouraged to operate a new gear with a worn pinion. The reason for this is that the pinion wears faster than the gear (due to the difference in rotating speed between the pinion and gear). The pinion and gear wear into each other over time resulting in tooth profiles that become matched mating surfaces. A new pinion profile wears to mate adequately with a worn gear tooth profile. In fact, a new pinion has been shown to heal or improve the appearance of worn gear tooth profiles. However, meshing a new gear with a



worn pinion profile will quickly result in the destruction of the gear tooth profile.

Types of tooth wear

The *American Gear Manufacturers Association (AGMA) Standard 1010-E95*, 'Appearance of Gear Teeth – Terminology of Wear and Failure'[1], provides standard definitions for types of gear tooth wear. The following is excerpted from *AGMA 1010-E95*.

"Wear is a term describing change to a gear tooth surface involving the removal or displacement of material, due to mechanical, chemical, or electrical action.

"Wear can be categorised as mild, moderate or severe. Mild wear is considered normal in many applications. Moderate and even severe wear may be acceptable in some applications."

Girth gear applications are those where mild tooth wear is considered normal. There are many different types of wear. From *AGMA 1010-E95*, Table 1, the types of wear include:

- Adhesion.
- Abrasion.
- Scaling.
- Polishing.
- Corrosion.
- Rippling.
- Cavitation.
- Erosion.
- Electrical discharge.
- Fretting corrosion.

The first five types listed are typically observed on girth gear and pinion teeth. Actual examples of these are presented in Figures 2 through to 12.

There are many other types of tooth distress that also occur. These include plastic flow, debris denting, contact fatigue (pitting), scoring, cracking, fracture and bending fatigue. It is beyond the scope of this article to discuss in detail all of these surface distress issues. However, it is important to note that pitting is a contact fatigue issue and is not considered a wear phenomenon.

In service, gear teeth almost always experience several types of tooth distress simultaneously. It is not unusual to observe abrasion, polishing, pitting and plastic flow on the same tooth as the photographs in this article demonstrate.

Causes of excessive wear

There are many causes of the wear types listed above. Below is a summary of the most common causes of girth gearing wear. In most cases, there will be multiple causes of wear occurring simultaneously.

- Inadequate lubrication quantity/delivery.
- Incorrect grade of lubricant (viscosity too low).
- Incorrect lubricant additives.
- Contamination (debris, water).
- Misalignment.

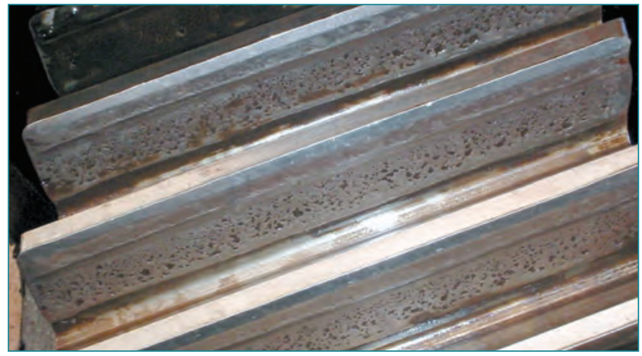


Figure 7. Moderate wear and top land plastic flow.

Figure 8. Severe plastic flow results in top land material separation. This material should be removed immediately to prevent debris going through mesh.

Figure 9. Very severe gear profile wear meshing with newer pinion. This gear should be replaced as soon as possible.

- Frequent starts.
- Variable speed operation.
- Gear design (tooth geometry, rating).
- Gear manufacturing (hardness, quality).
- Overload.

Experience has shown that the gear design or manufacture is rarely the root cause of a tooth wear problem. The maintenance practices of the site have much more influence on the wear rate and therefore the operating life of the gearing.

Solutions to wear

Each of the causes listed above can be investigated rela-

Figure 10. Polishing, debris denting, moderate wear.

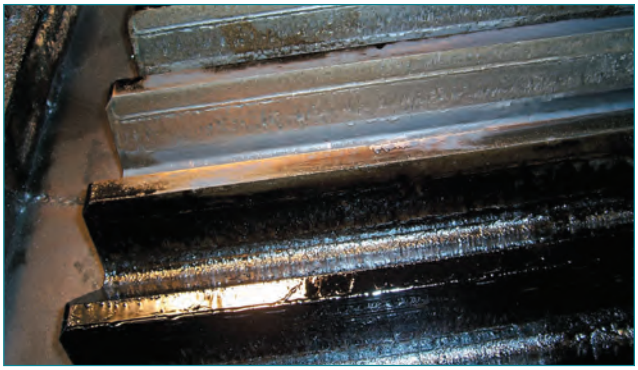


Figure 11. Gear active tooth distress.

tively easily as to its role in causing wear. The corrective action needed ranges from simple adjustments of the lubrication system, changing the lubricant used or the complete replacement of the gearing, guarding and lubrication system.

Solutions to the causes of wear include:

- Visual inspection of lubricant spray patterns and/or level.
- Work with a reputable lubricant supplier to ensure the proper lubricant additive package is used.
- Realign the gearing to the manufacturer's specifications.
- Reduce load and/or speed variations.
- Perform an Elastrohydrodynamic (EHD) Analysis to determine the correct grade of lubricant needed.
- Prevent the ingress of contaminants by sealing the guard.
- Review the gearing design and rating.
- Review manufacturing records.

In cases of extreme pinion wear and when other solutions have not been effective, a pinion can be replaced in kind with one that has been case hardened. An induction hardened or carburised pinion is significantly harder than a typical through hardened pinion. The increased hardness and carbon content in the surface of a case hardened pinion dramatically increases the wear resistance. The reader is advised that case hardening a pinion can more than double its cost. The increased cost may be offset by reduced replacement costs and the associated downtime that is avoided.

The solutions listed may range in cost and complexity from being essentially free (lube system adjustments) to being quite expensive (a new gear guard with improved sealing). Of course, the best solution is to avoid the causes of wear at the design stage of the equipment. This option is not available to a site already in operation. Therefore, identifying the causes of wear as soon as possible will minimise the impact on uptime and maximise the service life of the gearing.

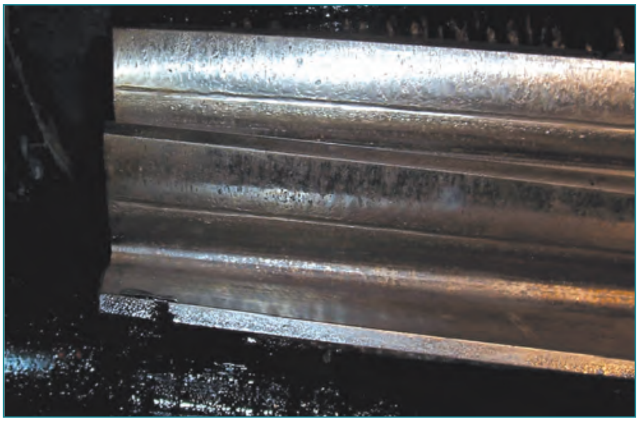


Figure 12. Pinion active tooth distress.

Monitoring wear

Properly installed and maintained girth gearing teeth will have a smooth, dull, aluminum or brushed nickel appearance. There should be no signs of surface distress and the original tool marks from the tooth cutting (left side of Figure 2) should remain visible for many years.

Tooth wear can be monitored by numerous methods. Tooth wear monitoring methods include:

- Visual inspection.
- Digital photographs.
- Infrared temperature measurements and thermal photographs.
- Straight edge test.
- Tooth caliper measurements.
- CAD plots of the original tooth form.
- Tooth moulds.
- Oil sample analysis (element and particulate count).

Physical measurements of the teeth using a tooth caliper are the most precise method of monitoring wear. A tooth caliper is a special type of micrometer used to very accurately measure tooth thickness. It is difficult and costly (increased downtime) to perform repeatable tooth thickness measurements in the field. Sites have actually reported teeth increasing in size!

Infrared temperature measurements provide a direct indication of alignment and areas of high localised stress. Many manufacturers recommend using infrared temperature data to ensure proper alignment. Thermal images provide a far more comprehensive indication of alignment and high localised stress. The thermal image plots will pinpoint areas of concern quickly.

It should be noted that temperature monitoring methods are typically more effective on grinding mills than kilns or coolers. The slow operating speed of most kilns and coolers reduce the effectiveness of the temperature

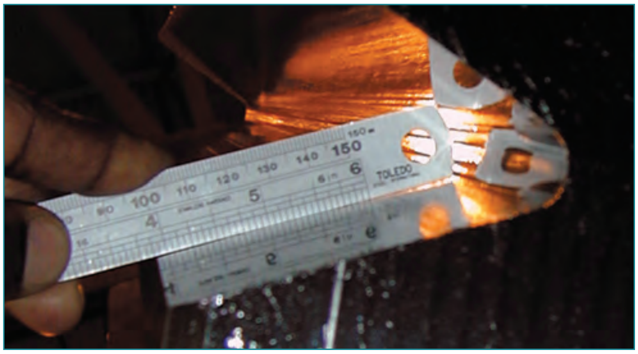


Figure 13. New gear profile with straight edge showing convex shape. (Photo courtesy of The Falk Corp., Milwaukee, WI.)

Figure 14. Worn tooth profile with straight edge showing concave shape. (Photo courtesy of The Falk Corp., Milwaukee, WI.)

gradient across the face width to identify misalignment. For kilns, the heat radiated from the shell can interfere with temperature monitoring equipment producing erroneous results.

One of most useful and easiest monitoring methods is to take digital photographs at regular intervals. A photographic record of the tooth condition every week, month or quarter, provides detailed evidence of the onset and progression of wear. Reliance on the memory of site personnel is inconsistent at best and frequently unreliable. It is not unusual for someone to look at the girth gearing after a period of weeks and state that it did not look like that last time. However, it is then impossible to quantify the scope and magnitude of the change.

New tooth profiles are outwardly curved or convex (Figure 14). Worn tooth profiles are recessed or concave. A simple straight edge can be placed against the tooth profile to determine if the profile is convex or concave (Figure 14). Some sites have even taken feeler gauge measurements to more accurately determine the magnitude of wear.

A more sophisticated method than using a straight edge is to use a CAD plot of the original tooth form. A scale CAD drawing can be plotted of the original tooth profile. This tooth profile is then cut out or copied onto an overhead and fitted against the tooth (Figure 15). Gaps can be easily identified providing a clear visual indication of a worn tooth profile.

An even more accurate method is the use of tooth moulds. Tooth moulds provide the most positive method of monitoring wear. If a baseline mould is taken when the gearing is new, it can then be used to check the tooth condition throughout the life of the gearing. Moulds can be taken at any time to provide a very accurate representation of the tooth condition. Of course, taking tooth moulds involves significantly more time than taking digital photographs.

Oil sample analysis is a very valuable tool for all types of machinery. While it can be helpful for applications with sumps (e.g. systems with oiling pinions), many open gearing applications apply lubricant with an intermittent spray system. Oil sample analysis is therefore not possible with these systems.

Now to answer the ultimate question posed, how

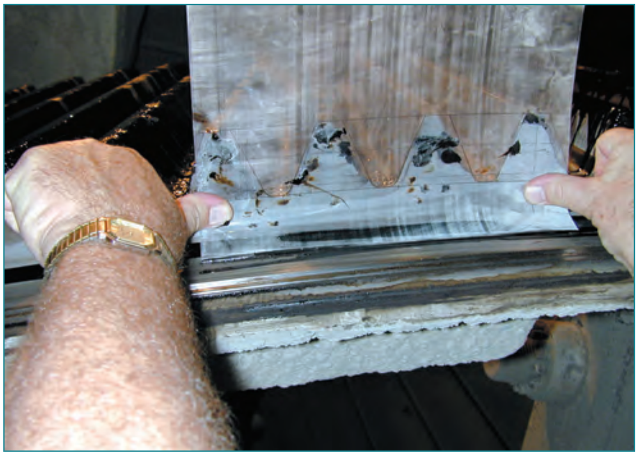


Figure 15. CAD plot comparison. (Photo courtesy of The Falk Corp., Milwaukee, WI.)

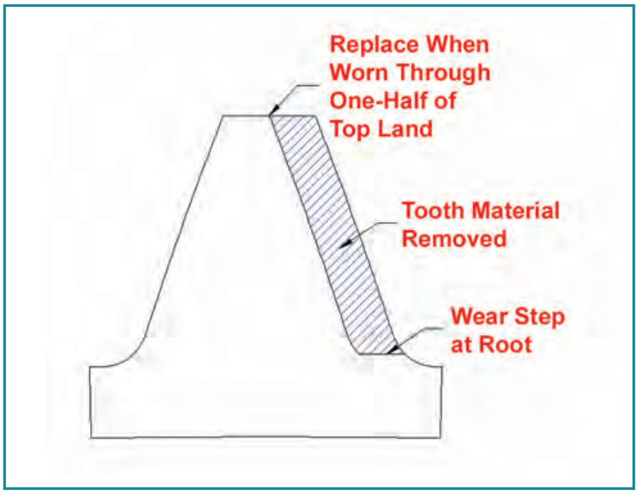


Figure 16. Worn tooth.

much tooth wear is too much? It has been previously stated that the exact moment cannot be predicted when tooth failure will occur. While this is true, it has been the authors' experience that teeth that have worn through one-half the original top land thickness (Figure 16) should be replaced as soon as possible.

When teeth are worn half-way through the top land thickness, the profiles will have become severely worn (Figures 3 and 9). These profiles no longer have the original involute form. This creates mesh incompatibilities resulting in vibration, noise and very high localised stresses.

Teeth worn half-way through the top land are also subject to catastrophic tooth breakage. If one-half of a tooth has been worn away, this means that one-half of the tooth support is also gone. Any misalignment, impact loads, or high starting loads could tear the teeth completely off. Because of this, wear beyond one-half of the top land thickness jeopardises the ability to reverse the gearing to use the unworn tooth flank. The reduced support increases the stress and deflection of the tooth, increasing the probability of catastrophic failure. This effectively halves the service life of a very valuable pinion or gear.

Conclusion

There are many types and causes of girth gearing tooth wear. It is critical to prevent or at least minimise tooth wear to ensure a long, trouble free service life. Once wear is detected, little can be done to correct it. The effects of wear can be minimised with a proactive assessment and monitoring program.

References

1. *ANSI/AGMA 1010-E95*, "Appearance of Gear Teeth - Terminology of Wear and Failure", published by the American Gear Manufacturers Association, Virginia, USA