From linear to circular maintenance management

Downtime in a plant rarely pleases colleagues in the accounting department in particular - after all, nothing is produced during these phases that can be sold later. While planned maintenance work can still be easily integrated into the processes, unexpected downtimes are highly unpleasant. With regard to girth gear drives, the guest authors from three companies describe from their own practical experience how the service life and performance of drives can be maximized. The authors specialize in special lubricants, on-site mechanical processing and condition monitoring.

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Large girth gear drives have proven effective in plant engineering for many decades and their reliability and operational safety is of utmost importance. Given the total cost of such equipment as well as their impact on production performance, steel manufacturers and metal processors should adopt the right maintenance strategy for each life stage of a gear. Four maintenance strategies can be distinguished:

1. Curative: repair after damage to return to normal operation
2. Preventive: perform routine maintenance for sustainable operation
3. Predictive: minimize unplanned shutdown
4. Proactive: implement a Total Productive Management (TPM) system for continuous improvement

To achieve the highest possible return on investment, all of these strategies should be implemented at the right time and with the appropriate resources in terms of people, systems used and organizational aspects. How does one make the right decision? Maintenance managers must often reconcile the views of internal experts and third parties with conflicting interests. For ease of understanding, Klüber Lubrication (Global Leader in Speciality Lubricants), Novexa (Global Leader in on-site Machining) and Dalog (Global Leader in Condition Monitoring) have joined forces to provide an overarching view of how to maximize the lifetime and performance of gear drives.

Machine Monitoring

An objective machine health assessment of the drive system is the foundation for a cost efficient TPM system (**Figure 1**). The goal is to prevent any unwanted surprises during the operation and to plan maintenance interventions based on the condition of the drive. Online condition monitoring systems can give detailed information about the health of the machine in real time. Their main task is an early failure detection of wear and cracks at bearings and gears. In addition, even slight changes in the gear meshing can be detected and the effects of repair works (e.g. repair lubricants, reprofiling) can be evaluated. Conventional vibration analysis at low speeds generally fails to detect vibrations caused by a faulty bearing due to its low energy, high and variable loading conditions and the high noise levels from the mechanical components of other low-speed machines, such as gear systems, in the vicinity.

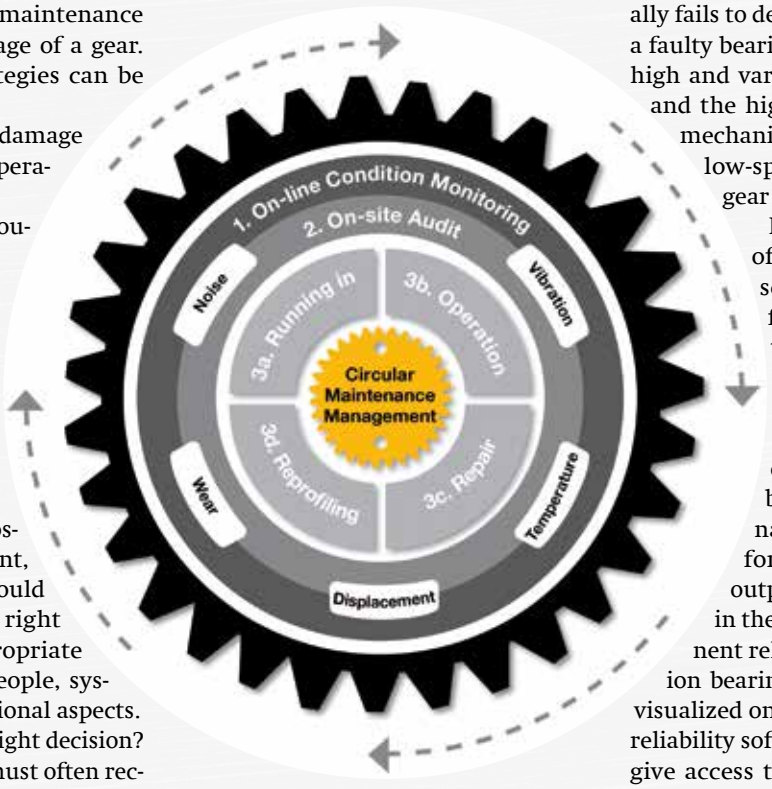

Figure 1: Open gear circular maintenance management

Dalog uses a combination of acceleration and speed sensors with a high-performance online condition monitoring system to detect early-stage failures at low speed girth gears and bearings. The data logger system must be able to sample the signals at a high rate and perform signal filtering. The output of the Dalog system is in the form of intuitive component related indicators (e.g., pinion bearing indicator) that can be visualized on the operator screen in a reliability software and in the cloud to give access to all stakeholders. This gives time to act and plan. Plants benefit from less unplanned stoppages and

Sources: Klüber Lubrication

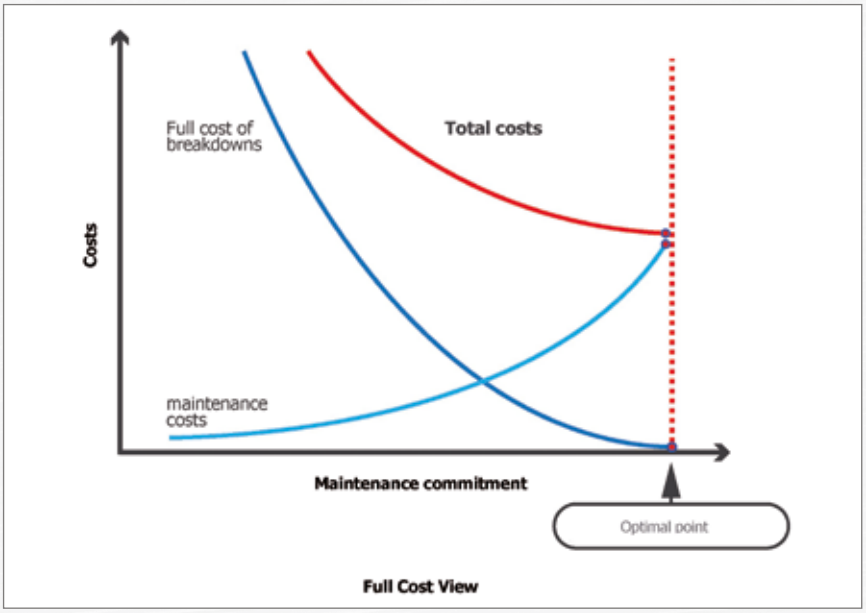

Figure 2: Full cost view

a minimization of consequential damage (**Figure 2**).

The assessment of the failure is backed by experts in the Dalog Diagnostic Center. Besides detecting the failure, their job is to evaluate its criticality and determine consequential actions. Many failures can be rectified before they turn into a bigger problem. Klüber Lubrication and Novexa can quickly intervene and verify the findings of Dalog with an on-site inspection.

Field Inspection

Visual inspection is inseparable from the accurate establishing of a diagnosis on a girth gear. Regardless of the warning mechanisms available to a maintenance team, only an on-site inspection will confirm or rule out the indicated cause of the fault.

Vibration and temperature are indicators of the proper functioning of an equipment, but they are also warning indicators that allow to plan an on-site audit when the warning thresholds are reached. In itself, the Dalog expertise and the level of technology they can develop makes it possible to ensure technical monitoring of the equipment and to react as quickly as possible.

For example, a recurring speed variation detected on a gear by a sensor should trigger an immediate visual inspection. This variation may be caused by excessive deformation of the tooth profiles due to a high wear rate. By reacting quickly to the first warning signals, wear can be better controlled, maintenance costs and the risk of unplanned downtimes are reduced.

A complete inspection of the girth gear must take into account several parameters, including:

- lubrication conditions (quality, consumption, lubricant distribution, lubrication system, etc.)
- meshing conditions (root clearance, contact pattern, pinion and gear alignment, etc.).
- gear surface faults (pitting, spalling, scuffing, etc.)
- vibration measurements
- temperature measurements
- the kinematic wear state (bearing clearances, pinion/gear box alignment, etc.)

The on-site inspections carried out by Klüber Lubrication and Novexa are complementary as they combine all parameters of an inspection. While both types of inspection share common parameters (vibrations, load distribution, temperatures), Klüber Lubrication's inspections are mainly focused on analyzing the lubrication conditions, whereas Novexa's focus is on the geometry of gears and shafts.

Adequate lubrication and faultless gear geometry (including correct alignment setting) are two essential parameters in the efficient monitoring of a piece of equipment. Without the right lubrication, equipment wear progression will be rapid and exponential. Likewise, without good meshing conditions ensuring sufficient load distribution, equipment lubrication while meshing will not operate optimally.

From Running-in To Repair

Large girth gear drives are ubiquitous in steel processing. The reliability and operational safety of the drives, and in consequence their lubrication, is of utmost importance. Functional reliability and damage-free operation of large gear drives highly depend on correct lubrication. An outstanding gear protection starts long before the actual first revolution, i.e. during transportation, storage and assembly, and accompanies the gear set over its entire lifetime. To ensure optimum lubrication at all life stages, Klüber Lubrication has developed a systematic five-step lubrication method for large gear drives, which is known under the name of A-B-C-D-E system lubrication (**Figure 3**).

Priming lubricants protect the tooth flanks in the first life stage from damage during storage and initial alignment of the gears. Lubricants can be applied manually by brush or spatula. Running-in lubricants are applied to new gears drives or after repair lubrication. Due to their special additives, they cause a controlled, minimum amount of chemical wear. Thereby, they improve the surface condition by smoothening rough surfaces and enlargement of the contact pattern. Both reduces the possibility of gear damage in subsequent stages. During the regular operation of a large girth gear drive, operational lubricants are the

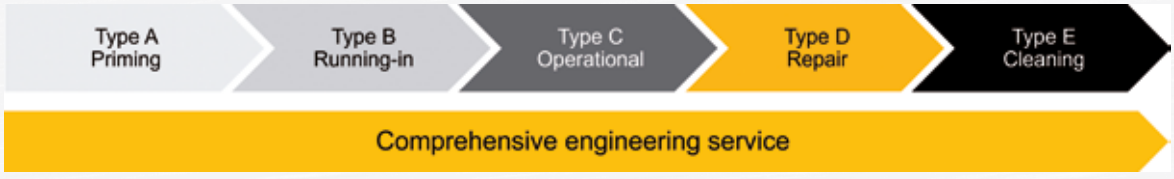

Figure 3

Figure 4: Pinion / girth gear with Klüberfluid C-F 3 Ultra: inspection and documentation made easy with strobe light or high-resolution digital camera while running.

lubricants of choice. They are modern adhesive lubricants tailored to suit the operational conditions of girth gear drives. They meet all extreme pressure requirements of gear drives at very low consumption rates while keeping up wear protection. Hereby, two different lubricant technologies are distinguished:

High viscosity fluids

To meet the demands of large girth gear drives, Klüber Lubrication has developed a range of transparent open gear lubricants. With a wide range of available viscosities, the Klüberfluid C-F Ultra series can be used in spray, circulation, and immersion systems in all climates. The modern high-viscosity fluids offer low consumption in combination with the best gear protection on the market. Inspections can be conducted easily with strobe light or a high-resolution digital camera while running of the gear drive (**Figure 4**).

Gear greases containing solid lubricant

These lubricants for open gearboxes are soap thickened and contain mineral or semi-synthetic base oils and solid lubricants. They offer operating reliability in different environments around the world that has been proven by decades of experience. Furthermore, these lubricants are the first choice if cost efficiency is a target. Another advantage is that the contact pattern can be easily visualized in contrast to the gear material.

Flank surfaces may become damaged for a variety of reasons, which can lead to an inadequate contact pattern. To prevent breakdowns, Klüber Lubrication has a solution to repair the gear while remaining in operation under full load. Repair lubricants re-condition the tooth flank surface (Figure 5). They remove incrementally and evenly asperities, scratches and scorings, which improves the contact pattern and helps avoid peak loads. Even pittings and plastic deformation can be smoothened up to a certain level.

However, when the tooth flank damage is too excessive, chemical smoothening is often no longer sufficient and a mechanical intervention is required (in order to restore the initial involute profile and right meshing conditions) as load and lubricant distribution and lubricant circulation deteriorate. This condition is present, for instance, if profile deformation, vibration level and/or temperature difference between fixed bearing and loose bearing side, on pinion and/or girth gear exceed certain levels. In such critical situations, reprofiling is one of the few applicable options.

In order to facilitate an inspection of the tooth flank condition or to provide a cleaned surface for further reprofiling, repair lubrication can be used. Thereby, the cleaning process is not only faster and more effective than manual cleaning, but can also be carried out during operation of the open gear. Additionally it enhances occupational safety.

Reprofiling

Even though the wear rate and lifespan of an open gear can be managed, mechanical wear is inevitable. Year after year, pinion and gear wear out due to metal-metal contact during meshing. Gear profiles are slowly deteriorating,

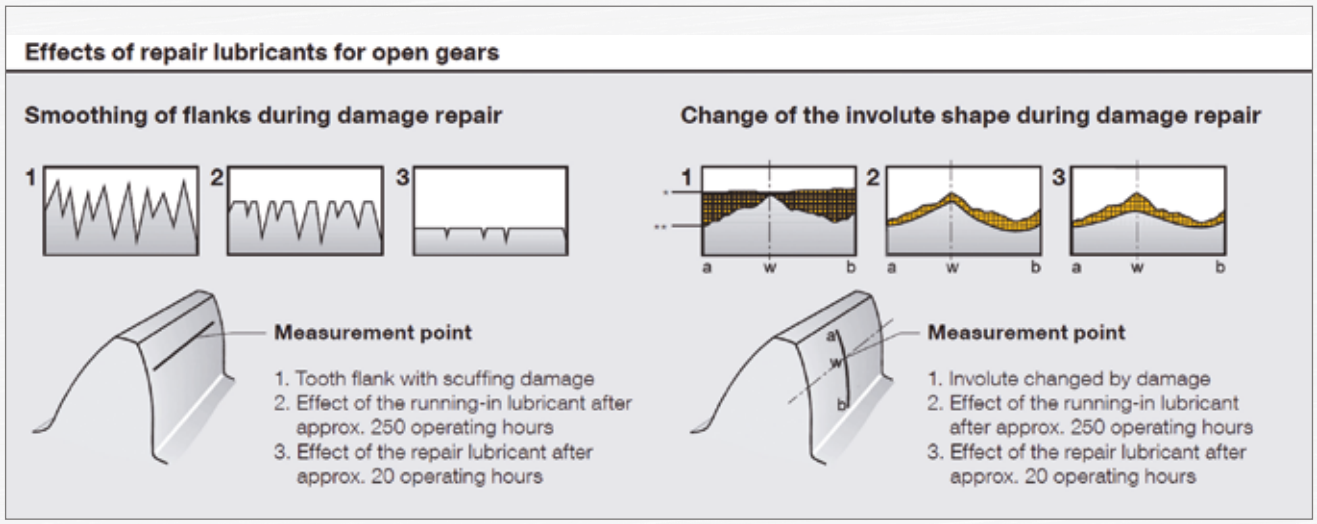

Figure 5: Repair lubricants are not applicable when profile deformation is excessive

Sources: Klüber Lubrication

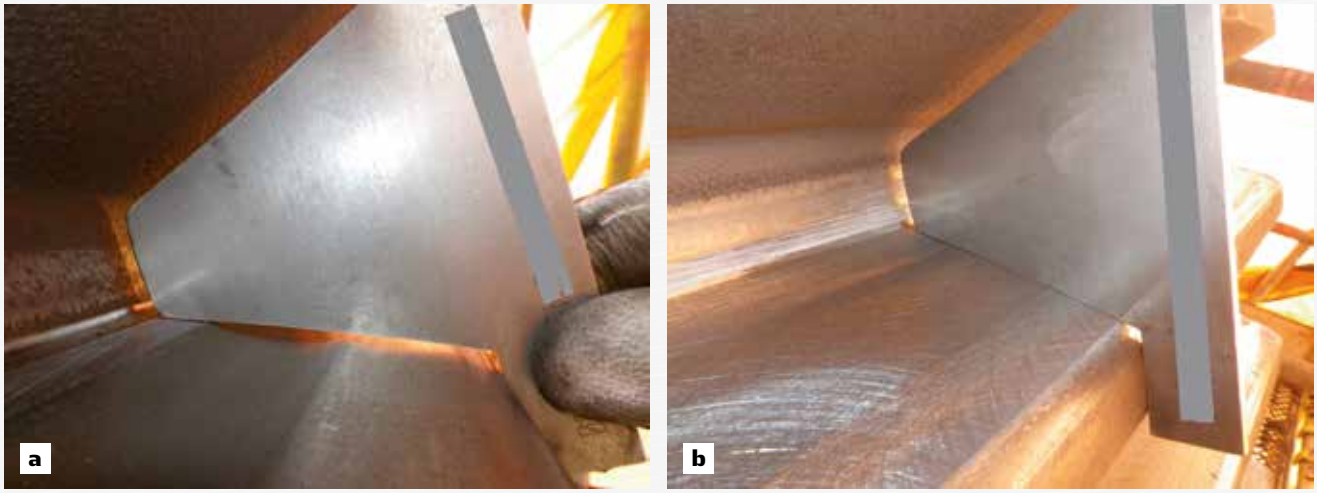

Figure 6: a) Profile deformation before intervention : 4,7mm; b) Profile deformation after reprofiling by Novexa : accuracy 0,07mm

thus creating similar wear on each tooth. Pinion / gear wear always shows in the form of:

- A pinion root notch
- A recess below the pitch diameter area
- A hump on the tooth's head, above the pitch diameter area

This profile deformation generates modifications in the meshing conditions and contact ratio. When wear reaches a critical level, one can also notice:

- An excessive vibration level
- In some cases, and without intervention: appearance of fatigue cracks with risk of tooth breakage

The replacement or reversal of damaged gears (when possible) is not the only available option. An intervention called "Reprofiling" represents an alternative solution (assuming that the remaining thickness is sufficient) which is faster and substantially less expensive than replacement or reversal.

During the last 20 years, Novexa has developed a unique reprofiling method which allows, in a few days only and without dismantling the gear, to restore the original gear's involute profile, with a machining accuracy of 0.07mm.

This on-site machining technique is specially recommended in cases of pinion replacement on a worn gear. Many clients do not take into account the girth gear's wear when replacing their pinion. In such situations, at restarting, meshing conditions are completely disturbed, and the contact pattern is very poor due to the incompatibility between the profiles of the new pinion and worn gear. This situation often generates very high vibrations coupled with shocks during rotation (mainly on mills which have an elevated rotation speed). As long as the pinion's and gear's profiles are not matched, vibrations will remain. The pinion's wear speed will drastically increase until the pinion's wear level reaches that of the gear so that their profiles will finally match. By this time, the pinion's wear will be almost as high as it was before its replacement and customer will face the same issues as before the replacement. In some cases, when the gear's maximum wear level does not exceed 0.5% of the module (i.e. 0.15mm for a module of 30), a chemical running in process by a running-in lubricant can be carried out. Otherwise, only a mechanical reprofiling intervention on the girth gear will allow to restore the perfect involute profiles and bring a sustainable solution (Figure 6).

After a reprofiling intervention including setting and alignment, all meshing conditions have to be maintained in their optimal state by means of perfect lubrication conditions and permanent remote monitoring in order to enable optimum running conditions over many years.

Summary

"Circular Maintenance Management" is a holistic approach to get the best out of rotary tubes in a more lasting and transparent way without the risk of unexpected shutdown. Beside the long-term gain of performance, this solution offers a large saving potential making the payoff extremely attractive.

- Cost of production: a reduction of energy consumption exceeding 3% through proper lubrication can be achieved and demonstrated using big data algorithms, a long-term reduction of lubricant consumption exceeding 50% compared to a conventional lubricant can be achieved without the risk of damage for the gear
- Cost of maintenance: remote monitoring and field inspection make the status of the large gear transparent and predictive. The system triggers ahead of time the need for Inspection, Repair, Reprofiling or Replacement to avoid costly emergency solutions. It also offers large possibilities for automation like condition-based lubrication systems to make Industry 4.0 a reality
- Cost of unexpected shutdown: this is likely to exceed 0.5 to 1 million € combining the cost of replacement of the gear (purchasing cost and installation), the loss of production (lead time until installation of the new gear) and various additional costs (labour, third party and others)

With the combined competences of Klüber Lubrication, Novexa and Dalog, each of them being an acknowledged global expert in their respective sectors, steel manufacturers and metal processors manufacturers are offered an innovative approach in maintenance management. The combination of machine monitoring, on-site inspection, repair lubrication and reprofiling helps to reduce costs, makes maintenance more efficient and thus supports the attainment of sustainability goals.