When a Good Gear Drive System

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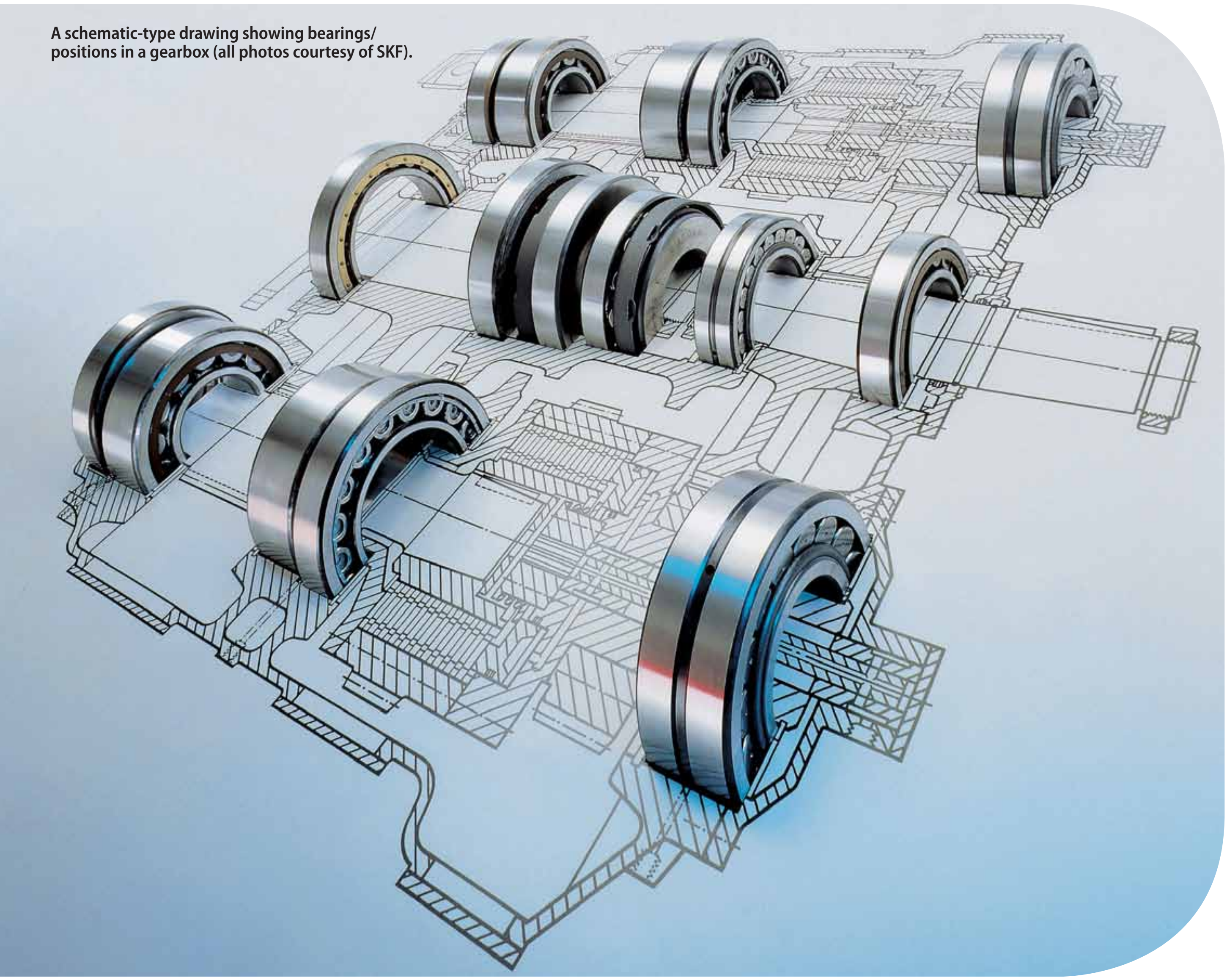
Even when the critical components of industrial power transmission gear drive systems are properly designed, specified and manufactured consistent with application requirements, performance problems can develop over time and failure may follow.

Typical causes range from improper loading or installation to misalignment and poor maintenance practices, among other usual suspects. No component (gears, shafts, or bearings) will be immune from the potential for distress. However, when early warning signs of trouble are detected and corrective actions subsequently follow, catastrophic failure can be avoided. In addition, a sustained preventive maintenance program—including visual monitoring—can contribute to overall efficient operation and longest possible service life of a gear drive system.

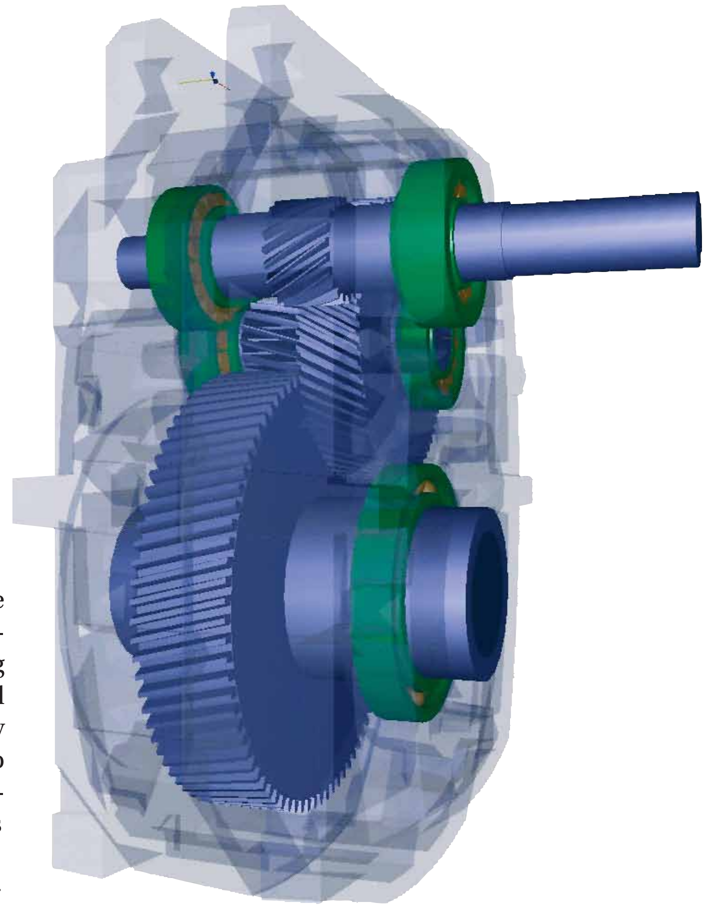
Gearing up

Distress (or failure) of gears historically has been classified into sev-

A schematic-type drawing showing bearings/ positions in a gearbox (all photos courtesy of SKF).



Goes Bad



A semi-transparent view of a gearbox.

eral categories: *surface fatigue, wear,* and *breakage. Surface fatigue* occurs when the material of the gear fails as a result of repeated surface or sub-surface stresses beyond the endurance limit. The visual effects of surface fatigue will be evident in a variety of ways and, most obviously as *"pitting"* (either initial or destructive), which will often arise shortly after gear drive operation gets under way.

Both in through-hardened and surface-hardened gearing, *initial (or corrective) pitting* will be caused by uneven surfaces on the gear teeth placing high stress on local areas (the shape of a classical pit appears as an arrowhead pointing to the direction of oncoming contact). While initial pitting is considered normal for most through-hardened gears, it can be reduced by special tooth finishing or, in some cases, reducing loads and speeds during the running-in period.

In contrast, *destructive (or progressive) pitting* usually results from overload conditions, starting below the tooth pitch line and increasing in both size and number of pits until the surface is destroyed. Among recommended corrective measures: reducing the drive loading, improving lubricant type and viscosity, upgrading the gearing, and/or increasing the gear drive size.

Abrasive wear can occur when hard particles slide and roll under pressure across a gear's tooth surface. Sources of these contaminants can include dirt in the housing, sand or scale from castings, metal wear particles from gear teeth or bearings, and/or ingress of particles into the housing during maintenance operations. Safeguards to help prevent this type of wear include proper lubrication in the right amount at the right time and effective seals to prevent the infiltration of contaminants. Flushing the gearbox with oil prior to assembly is recommended to remove as many machining particles as possible.

Breakage is perhaps the most dramatic type of gear failure, when stresses exceed the endurance strength of the tooth material, eventually developing fatigue cracks that will progress and cause the tooth to break away from the rim material. In fatigue fractures, system overloads would be suspect if the tooth contact pattern appears evenly across the entire face, while an alignment problem of the gearing would be suspect if the contact pattern is confined in the region of the fracture and at one end of the tooth.

In some instances a singe overload may break out a tooth or several teeth, which can be prevented by protecting the gearing from high-impact or transient loadings. In other cases, a severely uneven distribution of load on gear teeth can occur from damage to associated parts. (For example, a bearing failure can cause the load to shift to one end of the teeth, resulting in breakage, or fractures can occur from a shaft that is severely bent or broken.) Visual inspection can help tell the story and suggest an appropriate resolution.

Sizing up shafts

The strength and fits of shafting for gear elements will play vital roles in shaft operation, performance and longevity. Shafting must be rigid enough to prevent excessive deflection (which would result in abnormal load distribution on the gear teeth), and shafts must be strong enough to resist permanent yield from shock loads and the reverse bending fatigue loads. In turn, the fits between shafts and bearings—as well as between the shaft and the mounted gears —must be neither too loose nor too tight for fear of contributing to shaft failure. In general, confirm shaft strength, rigidity, fits and appropriate loads for the application at the outset to prevent serious operational problems down the road. These issues often are very difficult to change once the gearbox is completed and in service.

Rolling to bearings

With few exceptions, rolling bearings will almost exclusively be specified to support the shafts and gear wheels of industrial gearboxes—and for good reasons. Among them:

- Good location capabilities with minimum radial and axial play to enable optimum meshing;
- High specific load carrying capacity with low friction;
- Many bearing types can accept both radial and axial loads.
- Relative insensitivity to misalignment compared with plain or journal bearings;
- Unaffected by direction of load or rotation;
- Axially compact for use with short and stiff shafts.

In some gearbox designs, several different rolling bearing types will function in one gearbox. Regardless, at every turn demands on bearings during system operation potentially can lead to damage linked most often to the following modes warranting close monitoring and scrutiny:

- **Fatigue** defines a change in the bearing's material structure caused by repeated stresses in the contacts between rolling elements and raceways. *Subsurface fatigue* shows as micro-cracks at a certain depth under the surface and *surface initiated fatigue* is flaking that originates at the rolling surfaces.
- **Wear** is the progressive removal of material from the bearing's sliding or rolling contact surfaces during service. *Abrasive wear* usually can be linked to inadequate lubrication or ingress of contaminants and *adhesive wear* (or *smearing*) follows transfer of material from one surface to another.

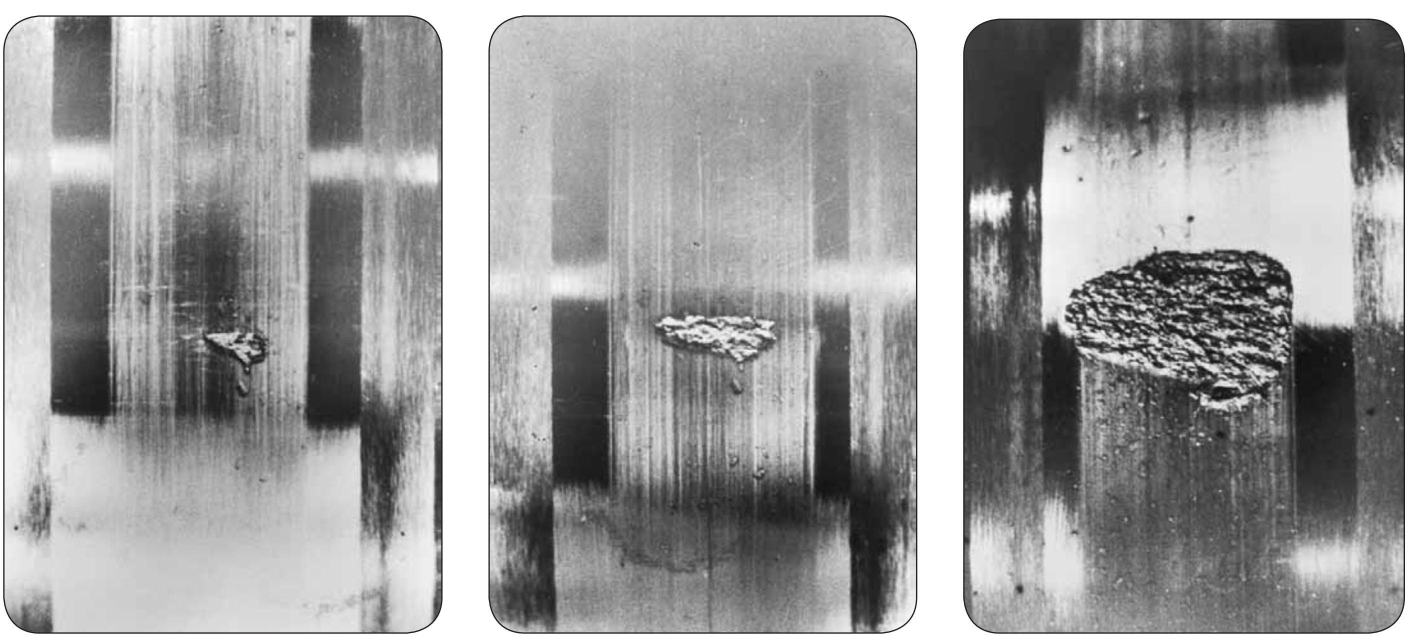
The first visible indication of *abrasive wear* is usually a fine roughening or waviness of the bearing's surface. Fine cracks can then develop and spalling (or surface-initiated fatigue) will occur. If there is insufficient heat removal, the temperature may rise high enough to cause discoloration and softening of the hardened bearing steel.

From *adhesive wear* a bearing's surface assumes a "frosty" appearance and will feel smooth in one direction but distinctly rough in the other. Or, smearing damage may be apparent. One type of smearing develops between sliding surfaces, whereby minute pieces of one surface tear away and re-weld to either surface. (Areas subject to sliding friction, such as locating flanges and the ends of rollers in a roller bearing, are usually the first parts to be affected.) Another type of smearing is called "skid-smearing," which can be detected as patches. This condition can result when rolling elements slide as they pass from the unloaded to the loaded zone and there is insufficient lubrication in the load zone.

Fractures occur when the ultimate tensile strength of bearing material is exceeded, causing a complete separation of a part of the bearing. *Forced fractures* result from a stress concentration in excess of the bearing material's tensile strength; *fatigue fractures* occur when the fatigue strength limit of the material is frequently exceeded; and *thermal cracking* (or *heat cracking*) will form cracks due to high frictional heating.

Definitive signs in "reading" the damage will suggest particular damage mode causes. Two of the primary suspects include *ineffective lubrication* and *ineffective sealing*. Here's what to look for when attempting to ascertain whether one of these causes is culpable:

Lubricant for a rolling bearing separates the rolling elements, cage, and raceways in both the rolling and sliding regions of contact. Without



These three successive images show the fatigue progression on a bearing.

The TKSA 20 laser shaft alignment tool from SKF.

effective lubrication, metal-to-metal contact occurs between the rolling elements and the raceways, causing wear of the internal rolling surfaces. Most cases of "lubrication failure" will result either from insufficient or excessive lubricant viscosity, over-lubrication, contamination of the lubricant, or inadequate quantity of lubricant.

The effects of contaminants on bearings without *effective sealing systems* can also be devastating, even affecting lubricant performance. When debris is trapped between a bearing's raceway and rollers, *plastic deformation* depressions, or particle denting, can develop. When spalling debris causes this condition, the effect is known as fragment denting. Each type of these small dents can be viewed as the potential origin of premature fatigue. In addition to abrasive matter, non-particle corrosive agents can invade. Water, acid and many cleaning agents deteriorate lubricants and lead to corrosion. Effective sealing will help keep contaminants out and keep lubricant intact.

Monitoring for maintenance

Proper gearbox bearing maintenance begins by monitoring both the operating conditions and the bearings for early identification of trouble. Among the important parameters to monitor:

- **Lubrication.** Lubricant supply in oil bath systems can be checked using simple technology (such as a dipstick). For circulating oil lubrication, however, complex systems will be required to check oil pressure, flow rate, and temperature at each lubrication point. Often, an alarm system can add timely value. Oil samples can be taken and analyzed for contamination levels and oil deterioration.
- **Load.** The power consumption of a gearbox drive is sometimes used as a measure of the load, but will be unsuitable for monitoring bearing loads. Better information will be obtained by measuring torque at the root of gear teeth.
- **Temperature.** Measuring bearing temperature usually will apply to bearings operating at high speeds—and then only as an indication of trends—with temperature preferably measured directly on the bearing rings. In addition, temperature measurements of bearings, gearbox and oil will help determine the operating viscosity of the oil, which then can open a window into operating conditions.
- **Wear.** A clear indication that particles of bearing steel are among perceived wear particles will suggest that a bearing has already become damaged. If so, the gearbox should be inspected to determine the source of the wear and remedial action should be implemented to prevent further damage. (Wear particle analysis also enables gear wear and seal efficiency to be monitored.)
- **Vibration.** Depending on extent, the presence of vibration, especially in excess, may indicate system trouble. Suitable procedures to monitor vibration include comparative measurements on similar gearboxes under the same operating conditions (allowing differences to be observed) or trend measurements on one gearbox at given intervals to uncover differences.

Inspection and analysis of all critical components in a gearbox drive system can offer practical insights into whether damage and failure are on the horizon. Whenever possible, evidence from a failed component should be collected and interpreted to establish what went wrong and why—with the ultimate goal to avoid unproductive and costly recurrences and increase system uptime. **PTE**

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