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Industrial Wear Modes and Failure Analysis
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This webinar discusses the various modes of wear that occur in industrial equipment, followed by examples of failure modes and how to identify them.

First, a refresher: Even a surface that appears and feels smooth has roughness when magnified sufficiently. Asperities are the peaks of material that extend above the average surface finish.

In addition to minimizing friction, the goal of lubrication is to reduce wear. A lubricant performs both of these functions by building a load-carrying film to keep surfaces apart.

The nine most common wear modes are as follows: abrasive, adhesive, fatigue, erosive, corrosive, cavitation, polishing, fretting, and electrical discharge.

Abrasive wear is due to hard particles or hard protuberances forced against and moving along a solid surface. It can be in the form of two-body or three-body abrasion.

Adhesive wear is due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface. It is characterized by cold welding of asperities.

Fatigue wear of a solid surface is caused by fracture arising from material fatigue. This is the normal wear mode.

Erosive wear is the progressive loss of original material from a solid surface due to impact damage caused by particles in a liquid or gas.

Corrosive wear occurs when a chemical or electrochemical reaction with the environment is significant. Corrosion debris and surface irregularities can lead to abrasive and adhesive wear.

Cavitation wear occurs when vapor bubbles in the fluid form in low-pressure regions and are then collapsed (imploded) in the high-pressure region of the system.

Polishing wear involves the removal of surface material by very fine hard particles in the lubricant, producing a brightly polished surface.

Fretting wear arises as a result of small amplitude oscillatory motion between two solid surfaces in contact. Small wear particles are formed through the mechanism of adhesive wear.

Electrical discharge wear is characterized by the removal of metal by high amperage electrical discharge or spark between two surfaces. It often results in fluting on the surfaces. It can be prevented by proper grounding.

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Failure analysis involves the examination of failed parts – primarily bearings and gears – to determine the cause of the failure. There are many modes of failure. For rolling element bearings, the failure modes include fretting corrosion, inadequate lubrication, contamination, radial preload, axial preload, misalignment, improper lubrication, corrosion, brinelling, false brinelling, electrical discharge, ring fractures, overheating, and cage damage.

Fretting corrosion is characterized by brownish-black spots on bearing seats and wear at fitting surfaces. It is often caused by micro-motion between fitted parts where fits are too loose, among other causes. The best remedy for fretting corrosion is to provide the correct fit and surface finish for each bearing ring.

Inadequate lubrication is typically caused by either insufficient lubricant or too low of a viscosity for the operating conditions. It shows up as dull roughened tracking patterns or bright, pressure-polished tracks. Remedies include providing sufficient volume of lubricant and using a lubricant of the recommended viscosity.

Contamination can be either solid or liquid contamination. Solid contamination typically causes indentation damage on bearing surfaces. Liquid contamination can be water, lubricants other than specified, or other foreign liquids. Water degrades the lubricating properties of the lubricant and can cause corrosion. The wrong lubricant or solvent can result in inadequate lubrication. Contaminants should be excluded from bearings with proper sealing, clean mounting conditions, and flushing after installation or maintenance.

Radial preload is characterized by circumferential tracks on both the inner and outer rings of a bearing. It is typically caused by improper fit on the shaft or in the housing, excessive temperature difference between the inner and outer rinds, or too small of bearing clearance. It can be remedied by checking and correcting the fit or changing the clearance to suit the operating conditions.

An out of round conditions is characterized by separate tracking patterns on the circumference of the stationary ring. It can be caused by an oval shaped housing or shaft, poor housing rigidity, or storing bearings in a vertical position. Remedies include checking the fit and roundness of the housing and shaft, improving the rigidity of the housing, or storing bearings according to the manufacturer's guidelines.

Axial preload shows as an off-center load track on both the inner and outer ring of the bearing. It is often found on the locating bearing in locating-floating bearing arrangements. It can be caused by a disturbance of the floating bearing function or unexpectedly high axial loading. One remedy is the use of cylindrical roller bearings in the floating bearing position.

Misalignment is a common problem, characterized by a tracking pattern that does not run parallel with the raceway. It is caused by such issues as shaft deflection, out-of-square abutment surfaces, dirt trapped between abutment surface and bearing rings, or too high of bearing clearance combined with moment load. Remedies include ensuring cleanliness during mounting and setting a suitable bearing clearance.

Other signs of misalignment include material flaking, asymmetric tracking to bearing center, and fatigue damage on the edges of raceways or rolling elements. Causes include misalignment of the housing or shaft, bending or tilting loads, and balls running of the shoulder edge. Remedies include strengthening the shaft, correcting misalignment, and the use of self-aligning bearings.

Improper lubrication can cause diverse damage patterns to arise, including tiny superficial fractures and pitting. It is often caused by insufficient supply of lubricant, operating temperature too high, water in the lubricant, or very low or high loads. Remedies include increasing the lubricant quantity, using a higher viscosity lubricant with extreme pressure (EP) additives, decreasing the operating temperature, preventing water ingress, or using a softer consistency grease.

Corrosion is characterized by brownish, reddish, or black stains or rust spots with pits. It is typically caused by the ingress of water or other corrosive materials, such as acid fumes, into the bearing. Possible remedies include improving the bearing seals, using a lubricant with improved corrosion inhibition, or relubricating more frequently for grease-lubricated bearings.

Brinelling consists or indentations or dents at the ball or roller spacing. It can be caused by improper mounting during installation, supporting an excessive static load, or contamination with debris. Remedies include following the proper bearing mounting procedure, avoiding excessive static loads, and filtering oil.

False brinelling is characterized by shiny marks and recesses on the raceway surface at the rolling element pitch, with no raised edges or indentions. It is typically caused by vibration in stationary machines. The best remedy is to eliminate or absorb vibration, lock equipment to prevent movement during transportation, and to slowly rotate the shaft and bearings of out-of-service or spare equipment.

Electrical discharge can be characterized by either fluting or fusion craters. Fluting appears as brownish marks parallel to the axis on a large part or all of the raceway. It is caused by the constant passage of electrical current through the bearing. It is prevented by proper grounding or the use of electrically insulated bearings. Fusion craters have the appearance of welding beads, and are typically caused by welding that is not properly grounded or grounded through the bearing. They are prevented by properly grounding so that current does not pass through bearings during welding.

Ring fractures include partial or complete cracks of the inner ring in the axial direction, outer ring fractures in the circumferential direction, and inner ring lip fractures. Inner ring cracking can be caused by bearing slippage, rotation of the inner ring on the shaft, fit too tight on the shaft, a keyway or groove in the load zone, out of roundness, or unsuitable lubrication, among others. Possible remedies include improving lubrication, properly fitting the inner ring on the shaft, or using a bearing with case hardened rings. Outer ring fractures typically occur evenly in the circumferential direction beyond the middle of the raceway. They are most often caused by poor support of the ring in the housing and are remedied by providing proper housing support. Inner ring lip fractures are caused by an unsuitable design, inaccurate machining, or high axial loading. Possible remedies include changing the construction of the part or reducing the axial load.

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Overheating results in bearing parts being badly discolored, from light straw at 450°F to a bright shade of blue at 600°F. The bearing can also be deformed to a large extent. Causes include too low of bearing clearances in operation, inadequate lubrication, radial preload, over-lubrication, and impeded running due to cage fracture. Remedies include increasing the bearing clearance, improve lubrication, and avoid over-lubrication.

Cage damage can take multiple forms, including wear due to starved lubrication and contamination, wear due to excess speed, wear in ball bearing cages due to tilting, damage due to incorrect mounting, and cage fracture. Starved lubrication and contamination is characterized by wear in the pockets and poor rolling element guidance. Too little or unsuitable lubricant, or contamination with hard particles are the typical causes, and can be remedied by ensuring clean assembly conditions and filtering the oil. Excess speed wear causes excessive wear between the guidance surfaces, and is caused by excess speed (no surprise!) or unsuitable cage construction materials. Remedies include operating at lower speed or selecting the correct cage material. Wear die to tilting shows up as deformation or fracture of the cage. Excessive misalignment, high acceleration forces, and high stress due to poor lubrication can cause this to occur. It is remedied by avoiding tilting, using bearings with long hole pockets, or using self-aligning bearings. Incorrect mounting damage results in broken, melted, or cracked plastic cages or bent or warped metal cages. It is caused by incorrect heating during mounting or the use of incorrect tools for mounting. It is remedied by following the manufacturer's mounting instructions. Cage fracture is characterized by broken cage side edges or crosspieces. It is caused by mounting damage, excessive speed, poor lubrication, high moment load or tilting, or excessive clearance in tapered roller bearing pairs. It is remedied by careful mounting, filtering the lubricant, increasing lubricant flow, changing the lubricant viscosity, avoiding misalignment or shaft deflection, or reducing bearing clearances.

Failure analysis of gears is similar to that of bearings, involving careful examination of the failed parts to determine the root cause of the failure. The many modes of gear failure include mild wear, moderate wear, abrasion, polishing, corrosion, fretting corrosion, scaling, cavitation, erosion, electrical discharge, scuffing, indentation damage, plastic deformation, rippling, ridging, burr, pitting, spalling, micropitting, and cracking. Photos illustrating all of these failure modes are provided in the webinar slides.