Sumitomo Drive Technologies

WHAT ARE YOUR BEARINGS & GEARS TELLING YOU?

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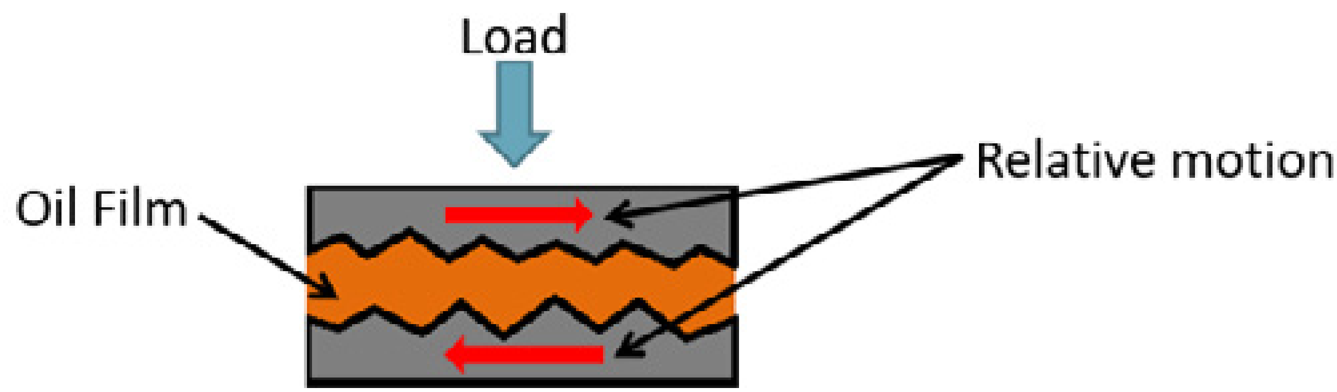
PREFACE

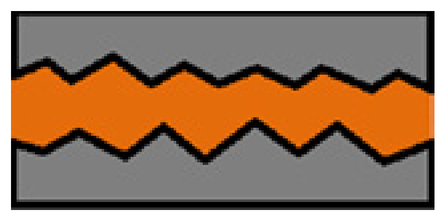
LUBRICATION

A lot of the damage that will be discussed will mention oil film, so let's look at it.

Graphic representation of oil film formation:

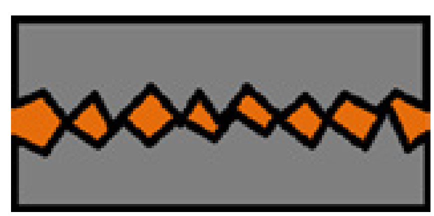


Full EHL film - The oil film is thicker than the sum of the amplitude of the roughness of both surfaces.



Mixed Lubrication - The oil film is generally thicker than the sum of the amplitude of the roughness of both surfaces, but occasional contact takes place.

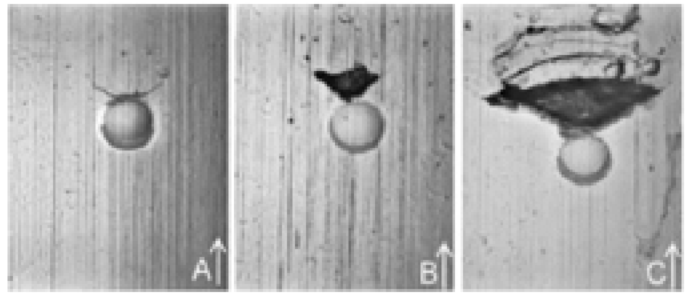
Boundary Lubrication - The oil film is thinner than the sum of the amplitude of the roughness of both surfaces and as a result there is significant contact between the mating surfaces.



BEARING STORIES

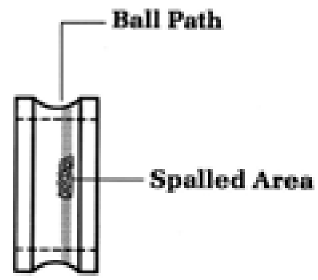
A LOOK AT TYPICAL BEARING FAILURES, DAMAGE, AND CAUSES IN GEARBOXES

NORMAL FATIGUE FAILURES

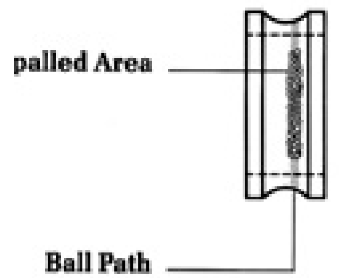


Sometimes called spalling.
This is characterized by fracture of the running surface and subsequent removal of small, discrete particles of material.

Moderately spalled areas indicate the bearing has reached the limits of its useful life.
This can occur on balls, rollers, inner rings, or outer rings.



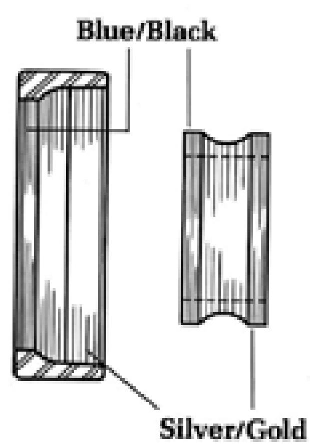
EXCESSIVE LOAD FAILURES



Symptoms are the same as normal fatigue, although showing heavier ball wear paths, greater evidence of overheating and a more widespread deeper spalling (fatigue area).

When the spall damage appears deeper and over a larger area you should suspect excessive load being the culprit, especially if it happens quickly. The damage may include signs of overheating.

OVERHEATING FAILURES



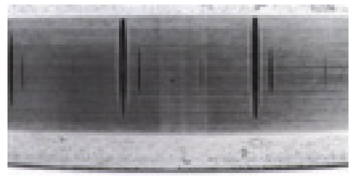
Symptoms

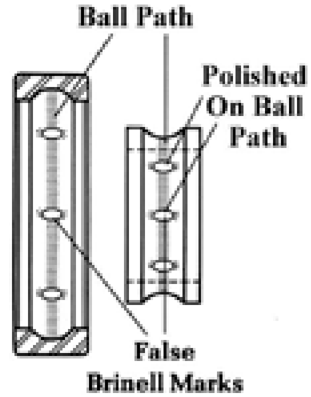
- discoloration of the rings, balls/rollers and cages from gold to blue.
- Temperatures in excess of 400°F anneal the rings and balls, making them soft.
- Extreme cases show deformation of balls/rollers and rings.
- Look for blue/black and silver/gold discoloration.
- Balls will usually be blue/black.

OVERHEATING FAILURES CONT

You'll see discoloration associated with tempering is usually the first indicator. If the heat is severe enough you will see signs of molten deformation. The lubrication supply needs to be investigated to make sure it's adequate and cool. Bearing clearances need to be validated and speeds verified as not being excessive.

FALSE BRINELLING FAILURES



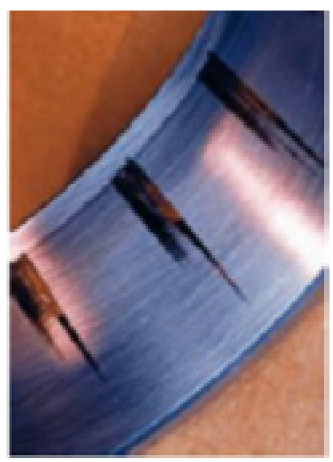


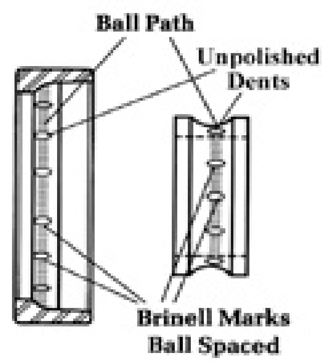
Characterized by elliptical wear marks in the axial direction at each ball/roller position. Sometimes surrounded by debris.

Occurs when there is small relative motion between the balls/rollers and raceways during non-rotation times.

When the bearing isn't turning, an oil film cannot be formed to prevent raceway wear. Created by small relative motion between rollers and races when it's not rotating. Usually, a storage or transportation issue due to lack of lubrication. Bearings need something to dampen the contact between the rollers and race.

TRUE BRINELLING FAILURES





Brinell marks show as indentations in the raceways which can increase bearing noise or even cause premature bearing failure. Occurs when loads exceed the elastic limit of the ring material. Any static overload or severe impact can cause brinelling.

Examples of true brinelling failures

- Using a hammer to install a bearing
- Dropping a bearing
- Pressing a bearing onto a shaft by applying force through the rolling elements

Need to review how the bearings are being installed. Especially noting if significant force is being used.

INSTALLATION DAMAGE FAILURES

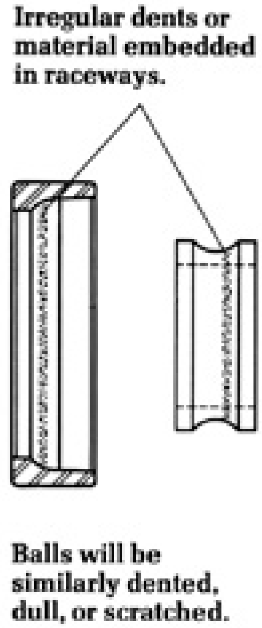
Occurs when a sharp impact is applied incorrectly to a bearing during mounting or dismounting. Installation damage often results in fracturing off pieces of a bearing. Again, review the installation technique and see if there needs to be tooling or process changes that minimize the risk. Lack of training for proper installation can contribute to the cause of damage.

CONTAMINATION FAILURES

One of the leading causes of bearing failures. Symptoms are dents or scratches embedded in the bearing raceways and balls/rollers resulting in bearings with high vibration and wear.

Contaminants include airborne dust, dirt, or any abrasive substance that can get into the bearing.

Principal sources are dirty tools, contaminated work areas, dirty hands and foreign matter in lubricant or cleaning solutions. Small pits form from contamination that with time and subsequent roller passes create larger areas of spalling. Investigate the storage and installation practices to make sure areas are clean. Make sure proper sealing is occurring on the unit to prevent ingress of damaging particles.



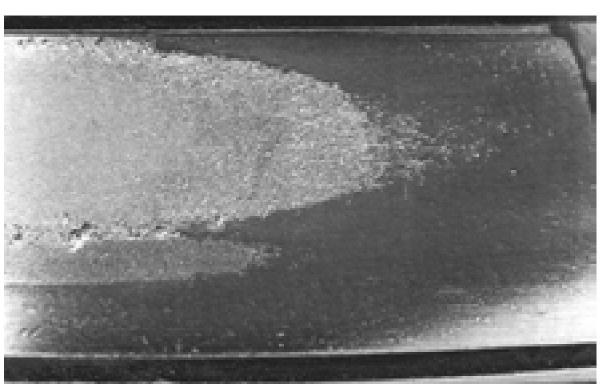
LUBRICANT FAILURES

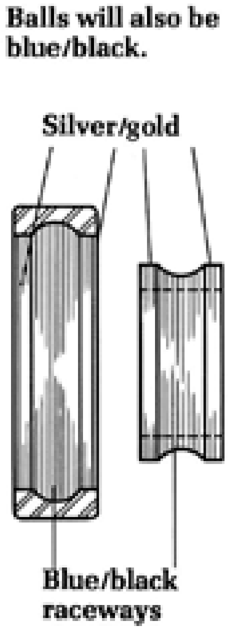
Symptoms include discolored raceways and balls/rollers.

Failures are typically caused by restricted lubricant flow or excessive temperatures that degrade the lubricant's properties.

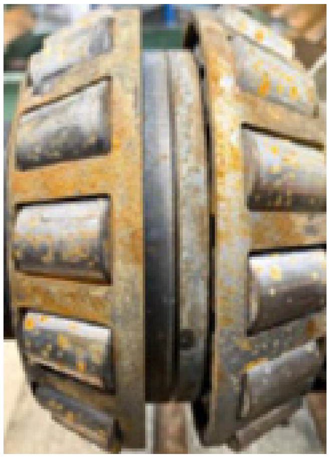
Lubricant failure will lead to excessive wear, overheating and subsequent bearing failure.

Discoloration associated with tempering, along with micro-pitting damage, means the lubrication delivery needs to be reviewed. Look to see if the unit is starving the bearing of oil or determine if the oil viscosity is too thin.





CORROSION FAILURES



Corrosion results from the chemical attack on the metal by hostile fluids or atmospheres.

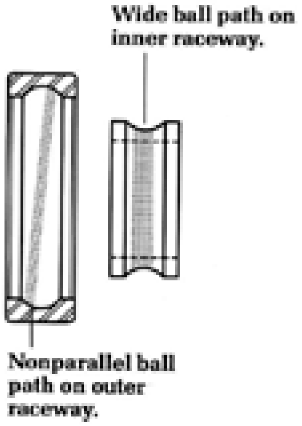
Symptoms include red/brown areas on rolling elements, raceways, and cages.

Corrosion usually results in increased vibration followed by wear, with subsequent increase in radial clearance or loss of preload.

Usually caused by contamination from water. Look for possible sources and try to eliminate. For example, for washdown requirements that may require a different seal design, for condensation—use a desiccant breather. Of course, there may be corrosive environments that have to be evaluated at the time of design to ensure components are protected from corrosion, which may include stainless steel components or the use of metal coating processes for protection.

MISALIGNMENT FAILURES

Can be detected on the raceway of the stationary ring by a rolling element wear path that is not parallel to the raceway edges. Excess misalignment can cause abnormal temperature rise and/or heavy wear in the cage pockets.

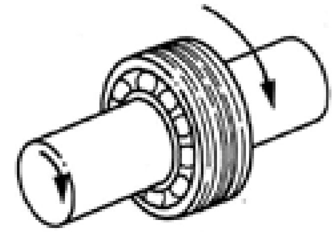


The most prevalent causes of misalignment

- bent shafts / misaligned housings
- burrs or dirt on the shaft or housing shoulders
- shaft threads that are not square with shaft seats
- locking nuts with faces that are not square to the thread axis

You can see roller paths that are at an angle which is evidence that the bearings are operating at an angle not perpendicular to the axis of rotation. You can consider bearing backing shoulders not being square, bent shafts, housing or shaft deflections. These are just a few areas to consider and evaluate. Some bearing designs handle misalignment better than others.

FRETTING CORROSION



Outer ring slippage caused by improper housing fits.

Fretting is defined as external wear damage to bearing rings due to micromovements between the bearing bore and shaft or bearing OD and housing. It is caused by microscopic relative motion between these mating parts during dynamic conditions (usually occurs in loose-fitted or poorly-fitted rings). Fretting corrosion occurs when fine metal particles oxidize, leaving a distinctive brown color.

Normally occurs through outer race slippage in the housing due to improper fits. Discoloration and scoring will appear on the outside of the outer race.

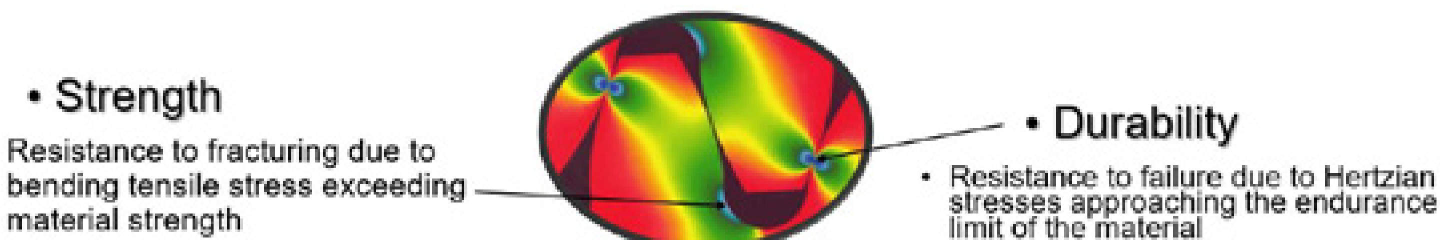
Look for an area that looks like it's been hammered and brown due to oxidation. Typically, either the outer race OD to housing bore fit is too loose or the inner race ID to shaft OD is too loose. The fits need to be evaluated and either fixed or redesigned to a more applicable fit.

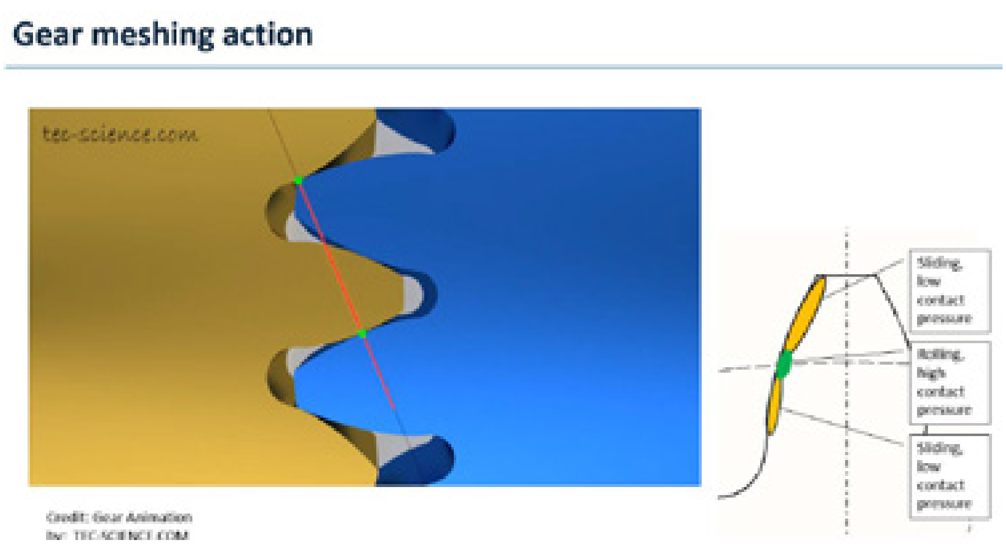
GEARING STORIES

A LOOK AT TYPICAL GEARING FAILURES, DAMAGE, AND CAUSES IN GEARBOXES

GEAR TOOTH STRESS

Gear tooth distress comes from load transmission across teeth



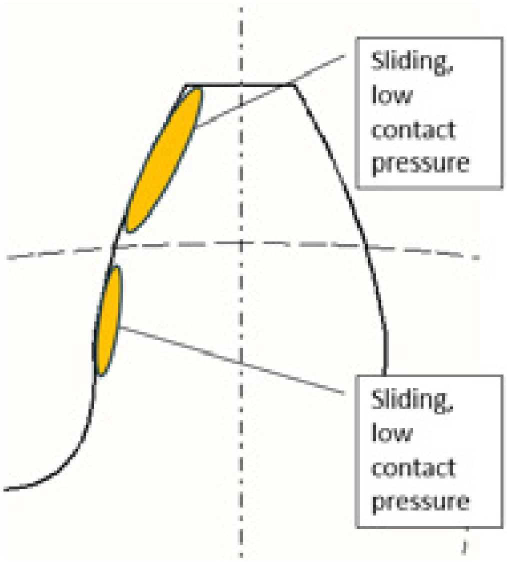


SURFACE DURABILITY- SLIDING

BOTH: sliding and contact pressure has to be taken into account when selecting gearing

Typical failures due to heavy sliding

- Wear / Polishing: wear at tip / root
- Spalling: begins below the pitch diameter, looks like pitting but is caused by sliding + moderate contact pressure. crack initiates from the surface, sliding + contact pressure tends to "open" the crack until the particle is removed from teeth.
- Scoring (Scuffing): Tooth surface asperities instantaneously "weld" together then tear causing heavy wear marks on tooth tip



WEAR

A LOOK AT TYPICAL GEARING WEAR

NORMAL WEAR

Normal wear is what you see occur over the life of a gear set. Visually you'll see on the flank of the tooth, smooth areas top and bottom and a defined line running along the flank at the pitch point where pure rolling takes place. Again, this should occur over many years if the unit is properly designed. If caught early enough and the damage is not too severe, the flanks can be reclaimed and the part be put back in service.

Characteristic

- Tooth flanks on sliding surfaces smooth out over time.
- Pronounced pitch line
- Normal wear does not influence the life and proper functioning of the gear train.

Causes

- Tooth flank surface has tall asperities making it rough but smooth out during operating life
- Viscosity of oil too low
- Sliding and rolling velocities of the tooth flanks are not sufficient to allow a cohesive lubricant film to be built up between the tooth flanks.

ABRASIVE WEAR

This is when the wear occurs excessively and much quicker than intended. The tooth flanks exhibit a uniformly matte surface with radial scratches. Often a sharp edge of metal is present on the tip of the tooth's loaded flank. The original flanks are largely removed and you can feel the indentations in the tooth with your finger running up the profile. Operators need to review and evaluate recommended oil viscosity, oil temperature, oil cleanliness, age of the oil. Have the oil periodically tested. Determine if the load that is being transmitted matches the design load.

Characteristics

- The tooth flanks exhibit a uniformly matte surface exhibiting radial scratches.
- The original tooth flank surface is largely eliminated with increasing running time.
- At an advanced stage changes in the tooth profile form and an increase in backlash are detectable. A sharp edge usually forms on the tip of the tooth flanks

Causes

- Metal-to-metal contact of loaded surfaces
- Original oil recommendation is incorrect viscosity
- Viscosity of the oil changes
- High temperature
- Contaminated oil: water, dirt, metal
- Oil oxidized
- Excessive load

POLISHING WEAR

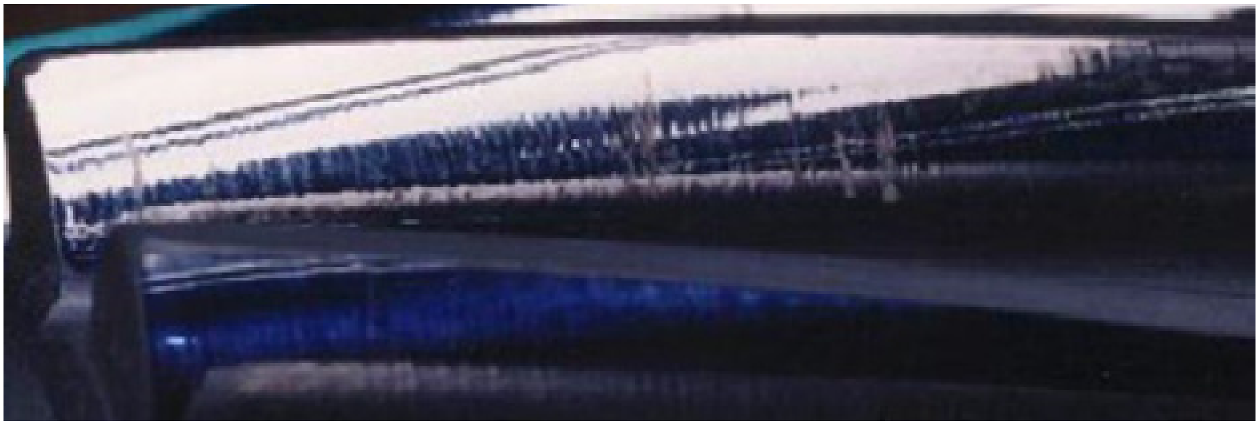
Polishing is a special wear that is deceptive because of its lustrous appearance. It is created by very fine particles that lap the flanks of the teeth creating a shiny appearance. However, as this polishing takes place it degrades the involute profile of the tooth creating rough transmission between the mating parts. Make sure the oil is clean and filtered along with verifying it's the right viscosity.

Characteristics

- Fine-scale abrasion that causes gear teeth to have a bright mirror-like finish.
- The gear tooth surface may be smooth or wavy with local bumps.
- Looks nice but the tooth profile is being degraded. Acts as an aggressive and uncontrolled super finish.
- Under magnification the surface appears to be covered in fine scratches in the direction of sliding.
- This type of wear may reduce life if the profile of the tooth is damaged before the cause of the wear is eliminated.

Causes

- Promoted by chemically active lubricants that are contaminated with fine abrasives.



WEAR PREVENTION

Prevention Recommendations

- Make certain you are using the correct viscosity oil
- Buy oil from a reputable supplier who sells gear lubricants from major manufacturers with knowledge and experience
- Do not mix oils
- Maintain the correct lubricant temperature
- Maintain clean oil
- Use synthetic oil if oil temperatures are excessive
- Manufacture teeth with proper surface finish
- Supply the right material hardness
- Effective sealing to prevent contamination

SPALLING

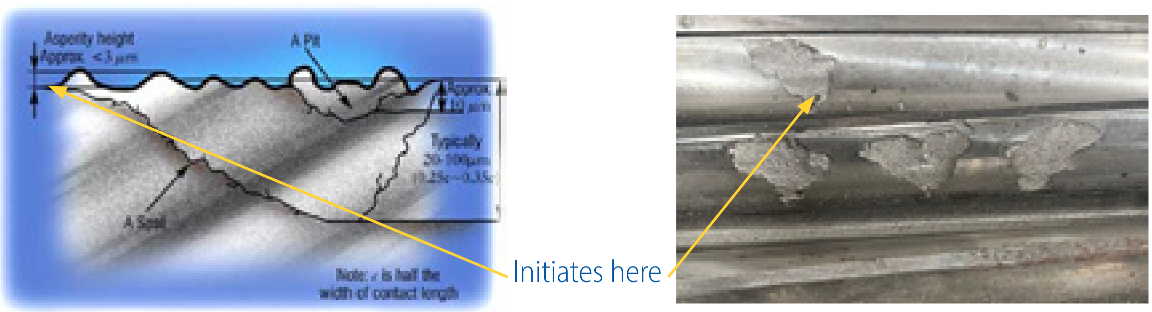
Spalling consists of pits that initiate low in the tooth profile in the area of high sliding. Cracks initiate from the surface and moves inward. Review material certs for correct material and the heat-treating lab results and verify that hardness and case depth are correct. Review surface finish requirements and oil viscosity to make sure an adequate oil film is being produced. Make sure gear design doesn't introduce excessive sliding.

Characteristics

- Spall fatigue consists of pits that initiate low on the tooth profile from areas of high load and high sliding
- As the tooth slides through mesh areas of metal flake off or peel away usually in a triangular shape
- Crack initiates from the tooth surface and propagates inward

Causes

- Attributable to defective material or shortcomings in heat treatment
- Inadequate lubrication
- Overstressing of the core material. The thickness of the layers which break out is usually greater than the hardness depth
- Poor surface finish on tooth flanks



SCORING DAMAGE

Scoring damage occurs when the combination of pressure, lubricant temperature, sliding velocity and friction cause the lube film to vaporize and the mating tooth surfaces weld together. As the parts rotate the welds tear apart leaving radial scratches along the tooth flanks. Proper lubricant and gear design need to be reviewed. Gear geometry changes, specified lubricant and surface finish requirements may all need to be modified

Characteristics

- Rough edge radial scratches

Causes

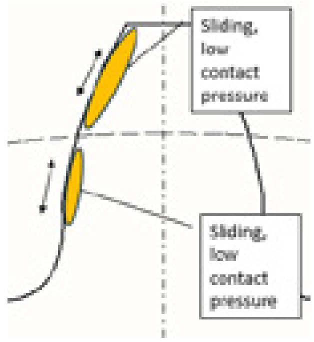
- Combination of pressure, lubricant temperature, sliding velocity and friction cause the lube film to vaporize and the mating tooth surfaces weld together.
- As the parts continue to rotate, the welded areas tear apart leaving radial scratch marks. Poor surface finish on tooth flanks

Prevention

- Select proper lubricant for operating conditions and provide high-quality surface finish.
- Design with high sliding action should be avoided.

SLIDING DURABILITY DAMAGE PREVENTION

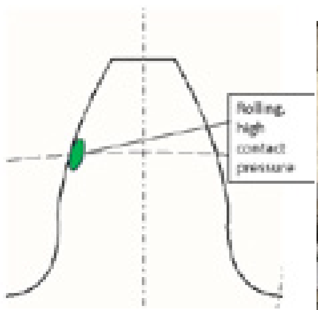
Actions to avoid sliding-based damage



- Gear geometry => select geometry to minimize unnecessary sliding (Specific sliding)
- Tip relief => reduce contact pressure during sliding
- Oil selection => Use the right oil viscosity
- Use only EP (& AW) additive oils!
- Smooth surface finish on tooth flanks
- Proper oil temperature
- Clean oil

SURFACE DURABILITY- ROLLING FAILURES

Typical failures due to heavy rolling



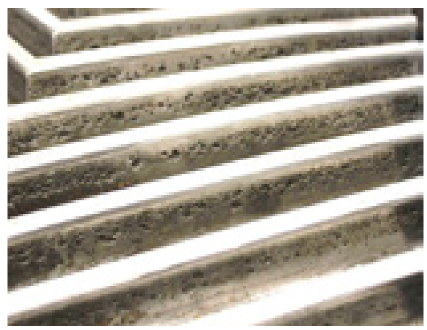
Pitting fatigue: Pockets of metal removal near the pitch line of the tooth flank surface in through-hardened gears

Case crushing

Similar to pitting, case crushing begins near the pitch diameter where the contact pressure is high. Looks like pitting but is a case-hardening failure phenomenon.

The two most common damage due to rolling contact pressure are pitting for through hardened gear and case crushing for carburized gears.

MACRO-PITTING



When the cracks have grown long enough to separate a piece of the surface material, a pit is formed.

Characteristics:

- Macro-pitting consists of pits visible to the naked eye resembling "craters" or "potholes". Easy to identify as they typically have sharp, angular edges.
- >1 mm in diameter
- Identified in two states: Initial and progressive

Formation

- Fatigue cracks initiate at a shallow depth below the tooth flank surface where localized points of subsurface compressive stress exceed the material strength.
- The crack propagates for a short distance in a direction roughly parallel to the tooth surface before turning or branching to the surface.

INITIAL PITTING

Starts out in the mixed lubrication regime and transitions into the full EHL regime. Once that occurs the unit operates just fine.

Characteristics

- Taller asperities wear down during initial operation and eventually smooth over.
- Doesn't affect operational life
- Visual halo effect around the pits
- Usually a transition from partial lube film to full EHL

Causes

- Rough tooth flank surface
- Tooth inaccuracy (lead error)
- Internal misalignment
- Thin oil

DESTRUCTIVE PITTING, PROGRESSIVE PITTING

More pits reduce the area carrying the load which means the contact stress goes up even more. Pits grow to the point that cracks form between them and ultimately the cracks lead to a fracture. Tooth material may be too soft. Load may be too high. Oil viscosity too thin. All of them need to be investigated.

Characteristics

- Pitting continues to develop from initial pitting even after initial surface asperities on the tooth flank have been worn down
- Leads to the formation of larger pits through the disruption of material from adjacent smaller pits.
- Self-propagating in that with each pit that forms there is less surface area on the tooth flank to carry the load creating more pits
- Rough surface impedes smooth transfer of load accelerating removal of material
- Continual removal of material can lead to tooth fracturing

Causes

- Metal-to-metal contact due to asperities taller than oil film thickness
- Soft material's endurance limit being exceeded as teeth roll through mesh
- Excessive load
- Oil viscosity too thin – wrong grade, too hot, oxidized oil, contaminated oil

MICRO-PITTING

Micro-pitting is similar to macro-pitting; micro-pitting originates from the same reasons— low oil film and tall asperities. This just happens to be damage you see in carburized teeth. This damage shown in the picture would lead you to question the alignment. You only see half of the tooth face carrying load. With proper alignment this damage may not have occurred.

Characteristics

- Micro-pitting gives the gear tooth a "frosted, or gray stained" appearance.
- Under magnification, the surface appears to be covered by very fine pits that are usually cover a large area but very shallow in depth.
- Micro-pitting is typical phenomenon for surface hardened gear teeth.
- The depth of cracks is typically in the 5-10µm range

Causes

- Asperity contact issue. Lubrication and surface roughness have the biggest influence for the situation.
- In addition, the same causes of macro-pitting may be valid.

CASE CRUSHING

Case crushing can be attributed to thin case depth, weak core strength due to bad material, or overload. Bottom picture you can see signs of tempering that would have softened the case. These pictures would justify verifying the alignment and calculating the deflection based on the shorter contact area. Material certs and carburizing records need to be reviewed for proper heat treatment.

Characteristics

- Metal removal near the pitch line
- Usually shallow and covers a larger area

Causes

- Case depth too shallow and allowing the endurance limit of the softer core to be exceeded.
- Case depth may be okay but loading may be excessive
- Inferior material that creates a softer core hardness
- High temperatures temper and soften the steel

FATIGUE FRACTURE INFLUENCERS

Loading

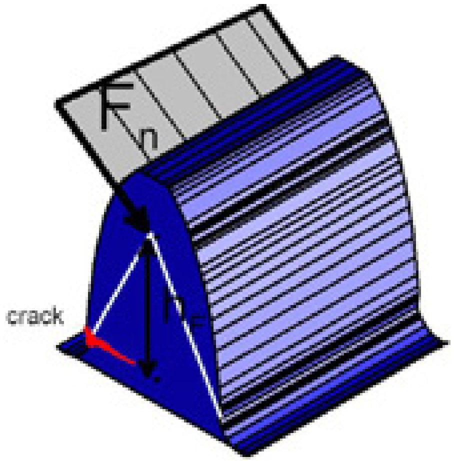
- Stress amplitude, mean stress, constant/alternating amplitude, residual stress

Material

- Material strength, purity, phase structure, chemical composition

Manufacturing technique

- Surface roughness, material inclusions, casting porosity, initial crack by welding and harmful residual stresses. Forging and rolling may have caused oriented structure that's not ideal.



Geometry of components

- Location and magnitude of the stress
- Root radius design

Ambient Environment

- Corrosion fatigue, thermal fatigue
- Thin oil

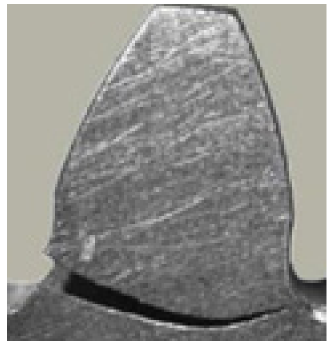
BENDING FATIGUE

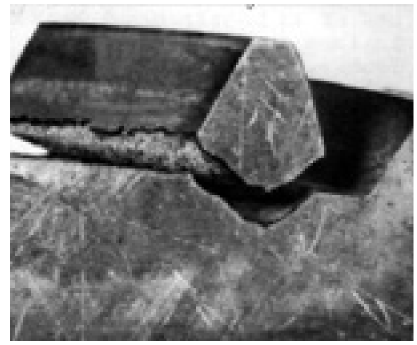
CAUSES OF FRACTURES

Destructive pitting initiating a fracture is the most common cause we see

General Cause:

- The bending stress of the tooth exceeds the ultimate strength of the tooth.
- Tooth wear that causes stress riser in root of tooth
- Destructive pitting and wear can initiate cracks due to bending cycles of a tooth and eventually the cross section of the tooth can no longer carry the load



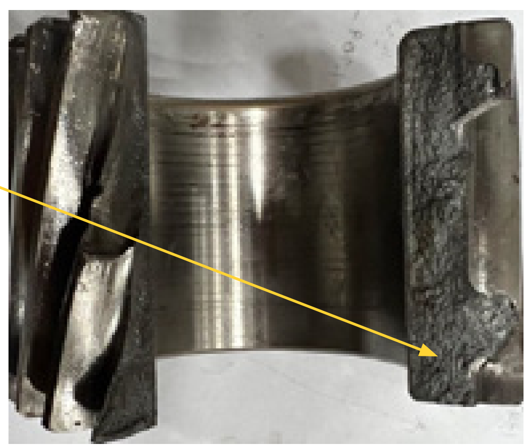


- A step in the root of the tooth created during the manufacture of the tooth
- Excessive load is more than the tooth section can carry
- Misalignment that overloads the area of a tooth
- Bad installation
- Failed bearing

TOOTH FRACTURE SURFACE CAN TELL A STORY

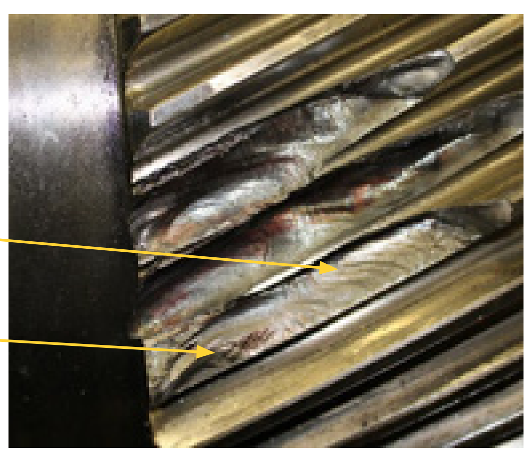
The fracture surface lets you identify an instantaneous failure or one that was created by cyclic loading. Beach marks of a bending fatigue fracture will lead back to the initiation point.

Instantaneous fracture (brittle) granular



Notice fatigue beach mark (cyclic) fracture surface

Initiation



OVERHEATING LEADS TO FAILURE

Overheating shows evidence of tempering of the material as exhibited by the color change. Extreme cases show deformation of the teeth and cracks. Softer material can't carry the forces, so the teeth fail. Investigate the oil delivery.

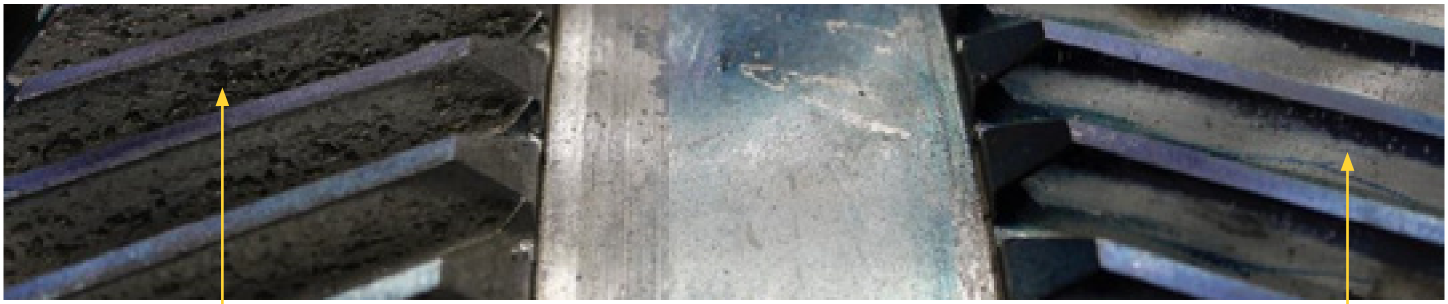
Did the oil pump fail? Oil level too low? Stopped up spray ports?

- Symptoms are discoloration of the gear teeth from gold to blue.
- Excessive temperatures can anneal the teeth and make them soft.
- Extreme cases show deformation of the teeth and fractures
- Consider oil level or low oil pressure as the cause

PITTING MAY OCCUR DUE TO AXIAL MISALIGNMENT

Axial misalignment. This double helical gear only ran on a single helix. They are designed so that one of the mating parts is able to float and center up in the mesh so the load is evenly distributed. In this case it should be investigated to see why the mating pinion did not run centered up on the gear. Wrong coupling gap? Over-greased coupling? Floating bearing was held? Proper axial alignment would have most likely prevented this failure.

- If caught soon enough, eliminate the thrust and the pitting may stop and even heal itself



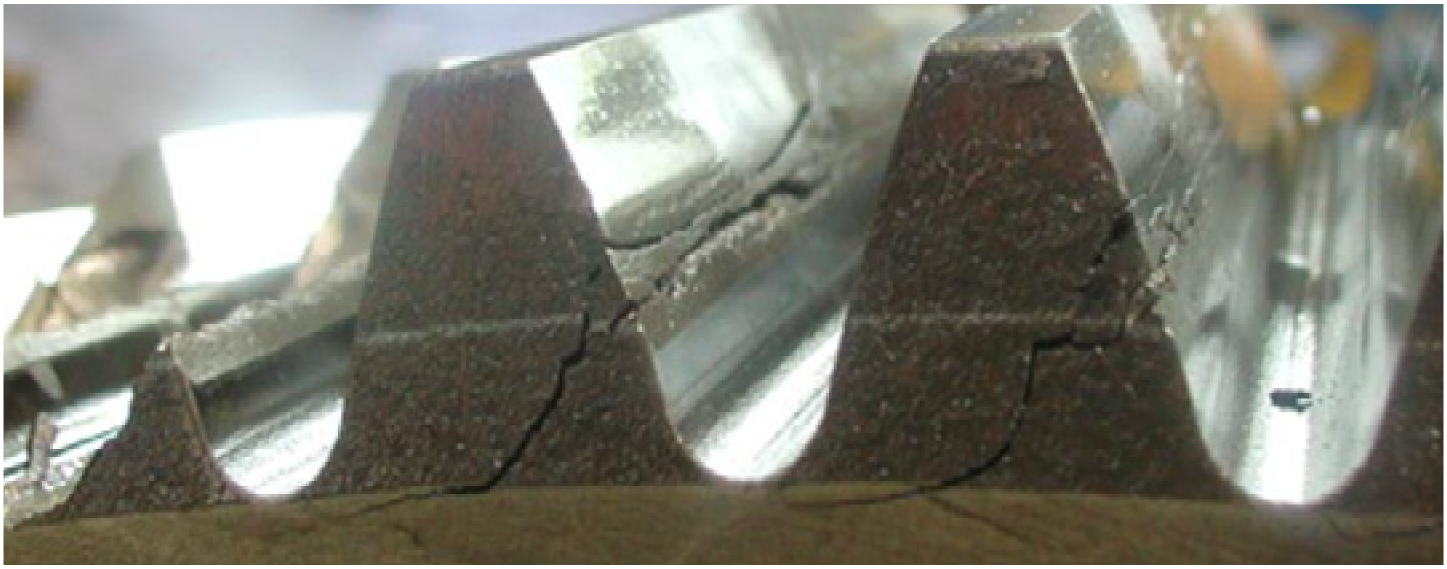
Destructive pitting on the left helix

No pitting on the right helix

CAUSES OF FRACTURES

The picture depicts that the gear was poorly aligned with the pinion.
That overloaded the teeth and it started pitting. The pits propagated toward
one another through flexural bending and formed a crack. Just a matter of time before the cracks would have caused the teeth to
fracture and deposit broken tooth debris in the mesh creating a
catastrophe. Evaluate the gearbox alignment and shaft deflection to
determine what to change to eliminate the poor contact.

- Poor load distribution overloaded the flank
- Overload caused pitting
- Pits connect creating a crack that typically leads to tooth fracture.
- This was caught before tooth separation.



For additional information regarding

What are Your Bearings & Gears Telling You

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- OR -

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Visit **https://us.sumitomodrive.com/en-us/gear-school**

A special thanks to the Schaeffler Group for supporting the presentation by providing additional information on bearings

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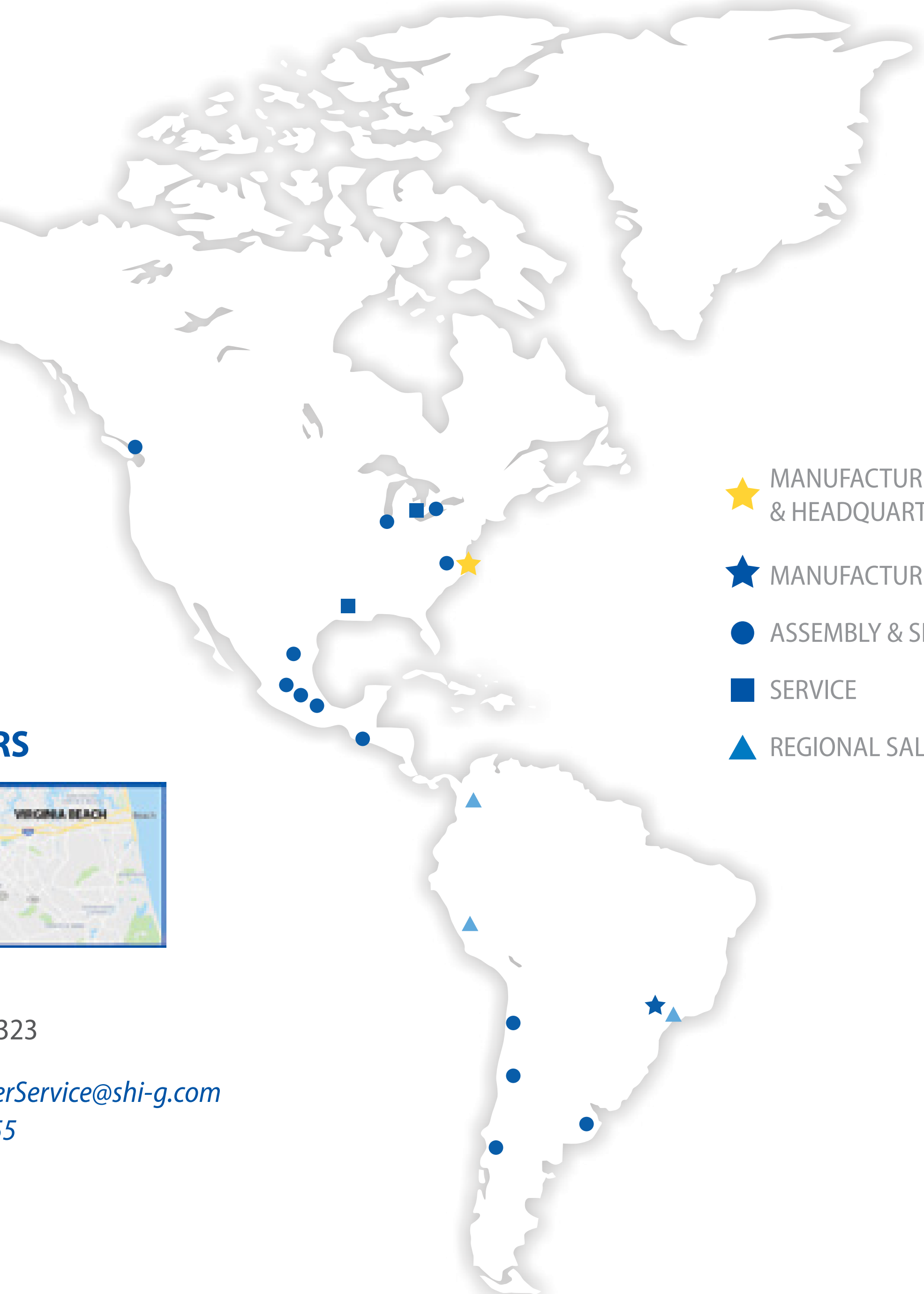

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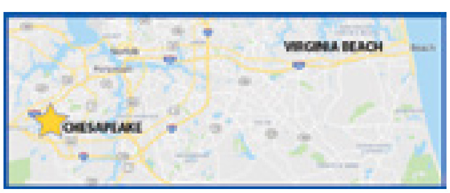

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