

Understanding Spur Gear Life

TRSM0913

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Introduction

Warnings and Precautions



Before starting a vehicle always be seated in the driver's seat, place the transmission in neutral, set the parking brakes and disengage the clutch.

Before working on a vehicle, place the transmission in neutral, set the parking brakes and block the wheels.

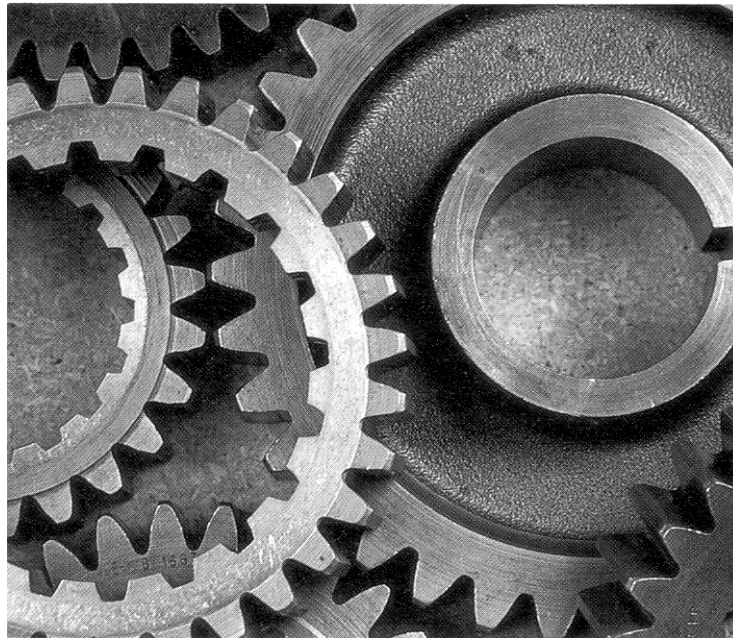
Before towing the vehicle, place the transmission in neutral, lift the rear wheels off the ground, remove the axle shafts, or disconnect the driveline to avoid damage to the transmission during towing.

General Information

Often, transmission gearing has been unnecessarily replaced because it was thought to have failed, when in fact, it could have been reused and provided many more miles of trouble-free service. This guide will help you determine if gearing should be replaced, what caused a failure if one has occurred and, if possible, what can be done to prevent a failure from reoccurring.

To determine if a gear should be replaced during a rebuild requires a degree of technical knowledge. Some gears must be checked with highly sophisticated equipment in a laboratory. This guide deals only with the type of gearing which can be visually checked and evaluated in the field.

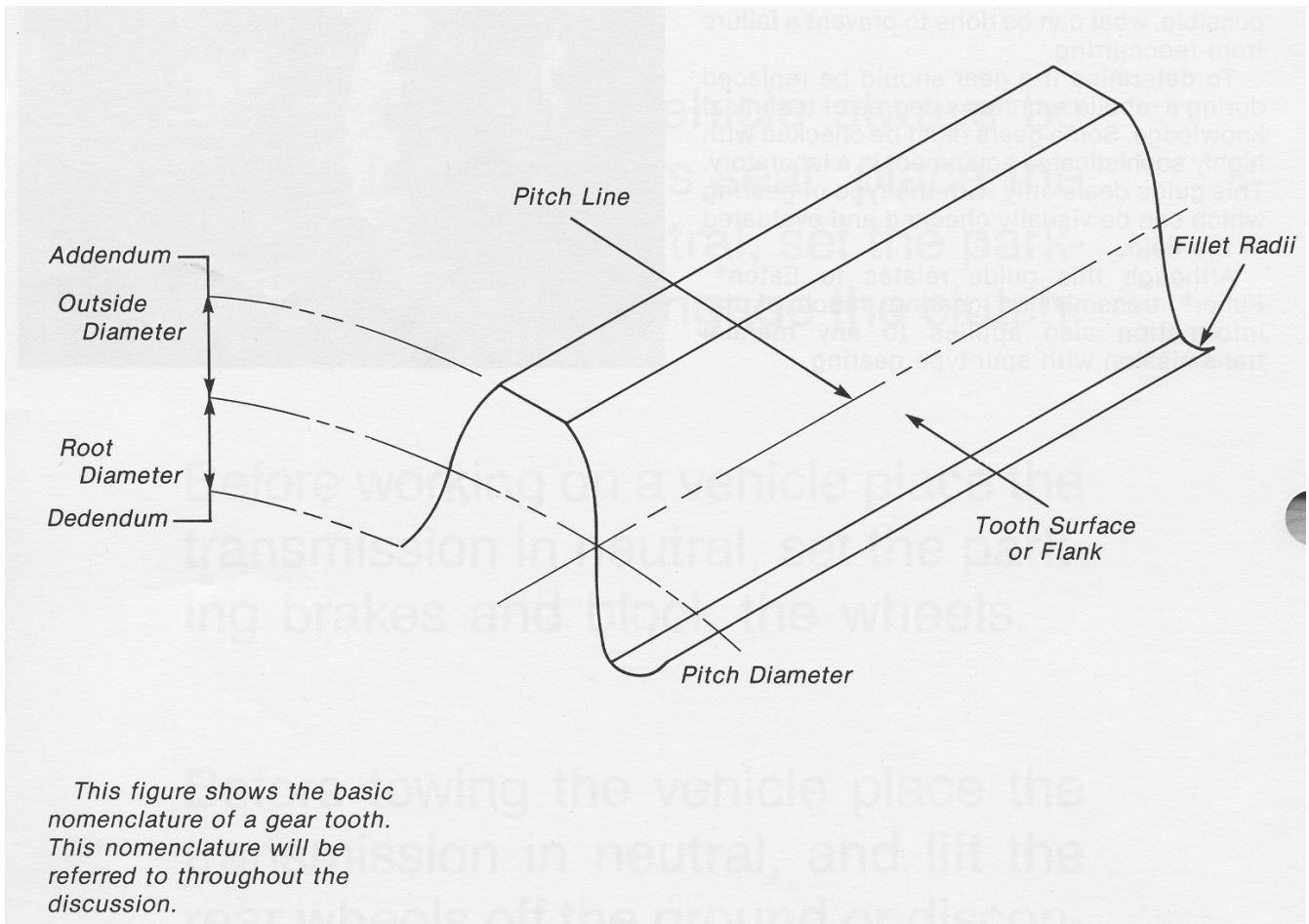
Although this guide relates to Eaton® Fuller® transmission gearing, much of the information also applies to any manual transmission with spur-type gearing.



Mechanics of a Spur Gear

Tooth Nomenclature

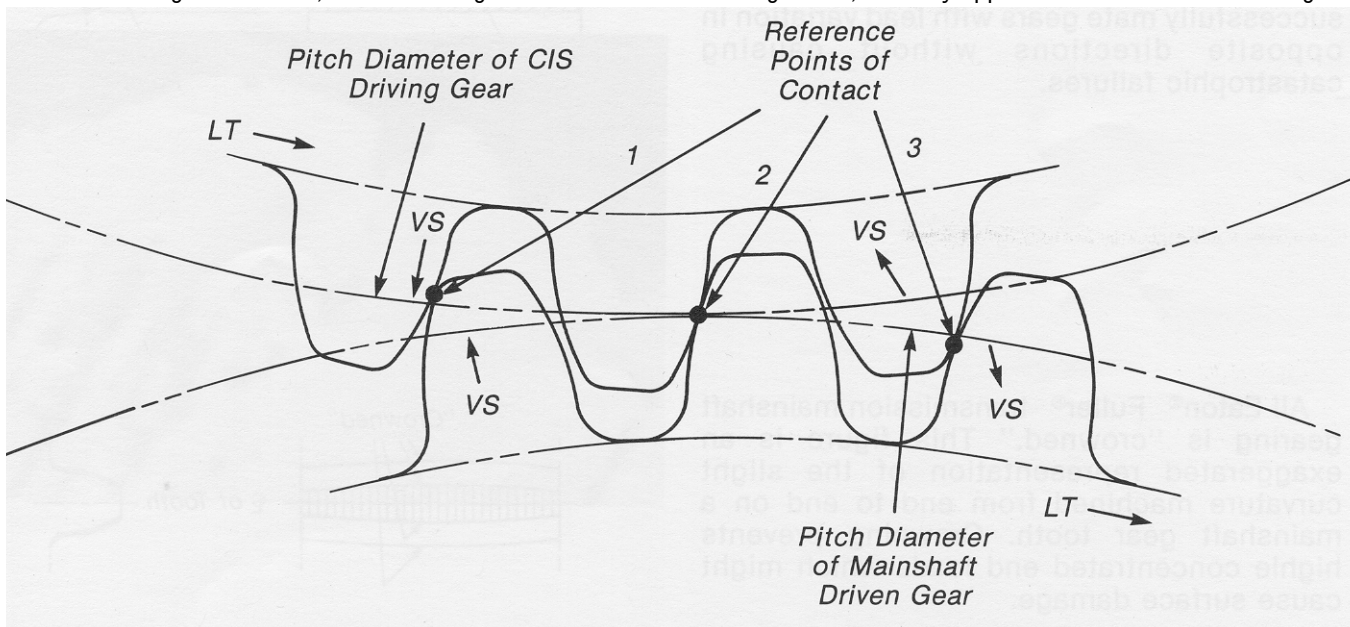
To better understand the following sections of this guideline, a description of tooth nomenclature and operation, as well as tooth design and manufacturing considerations, is provided.



Three Stages of Tooth Contact

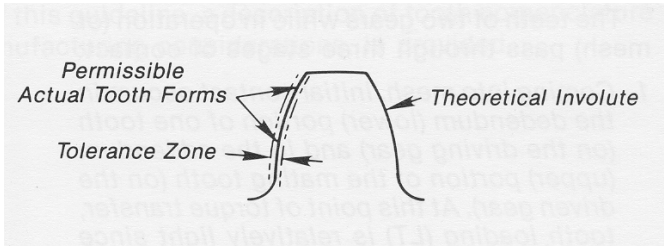
The teeth of two gears during operation (or mesh) pass through three stages of contact:

1. Coming into mesh, initial contact occurs in the dedendum (lower) portion of one tooth (on the driving gear) and in the addendum (upper) portion of the mating tooth (on the driven gear). At this point of torque transfer, tooth loading (LT) is relatively light, since most of it is carried by the teeth in full mesh and a portion by the teeth going out of mesh. Contact between the two teeth moves in a sliding action as they proceed through mesh. The sliding velocity (VS) decreases until it is zero when the contact points reach the intersection of their common pitch lines.
2. At full mesh, the two teeth meet at their common or "operating" pitch line, there is only a rolling motion, no sliding. However, this stage produces the greatest tooth loading.
3. Coming out of mesh, the two mating teeth also move in a sliding action, basically opposite of the initial contact stage.

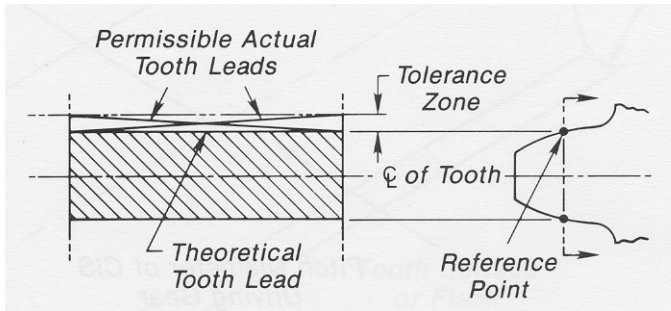


Mechanics of a Spur Gear

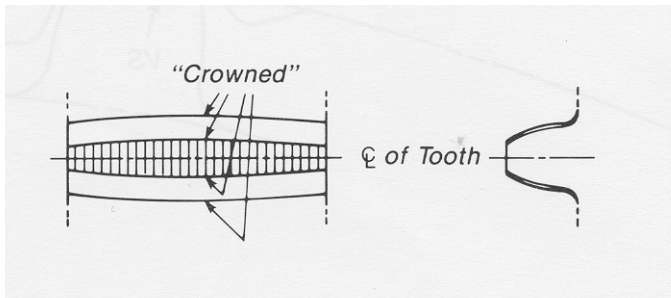
Gear Tooth Shape



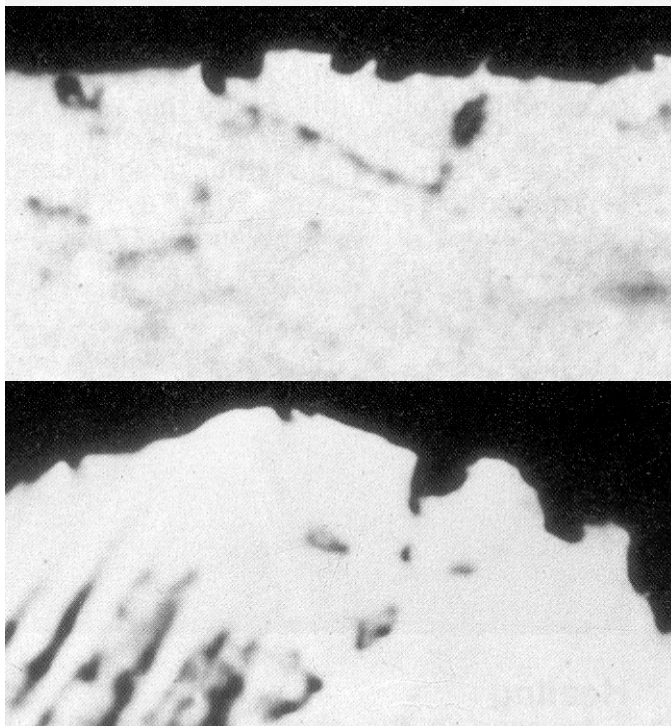
An ideal tooth shape is designed for each gear. Since it is impossible to make a perfect part, Eaton Transmission Division Engineering has determined manufacturing tolerances that will not shorten a gear's life. This figure is only an example of these tolerances, as the tooth form will change according to various design limitations. The actual tooth profile can fall anywhere with the tolerance band.



A gear tooth is also designed to be parallel with the centerline of the shaft. As with the tooth profile, certain acceptable tolerances have been determined, as shown in this figure. These close tolerances make it possible to successfully mate gears with lead variation in opposite directions without causing catastrophic failures.



All Eaton® Fuller® transmission mainshaft gearing is "crowned". This figure is an exaggerated representation of the slight curvature machined from end to end on a mainshaft gear tooth. Crowning prevents highly concentrated end loads which might cause surface damage.

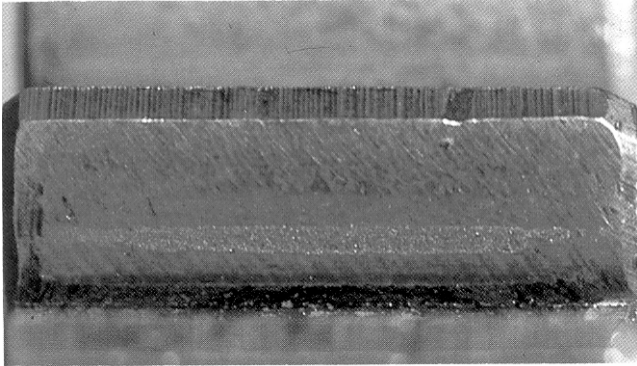


Under magnification, even the smoothest looking surface has irregular hills and valleys. This is illustrated by the two comparative photos magnified 600 times. The top photo shows the pilot bearing surface of the input shaft (.127 mm).

The bottom photo shows the surface of a gear tooth. In both photos, the width of the surface shown is approximately .005 inches

Tooth Distress - Minor Forms

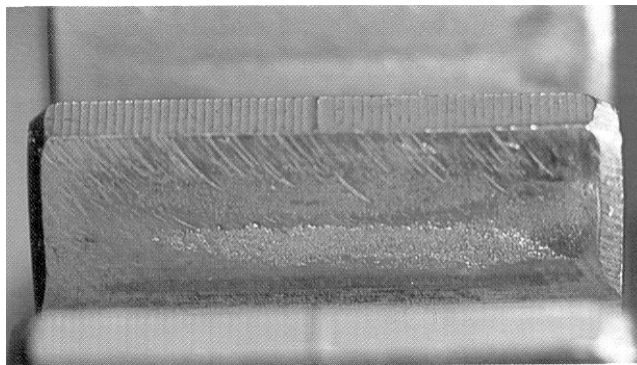
The technical use of the term “distress” in this guideline relates to any changes that may occur on the gear tooth surface; it does not necessarily denote a failure



Frosting

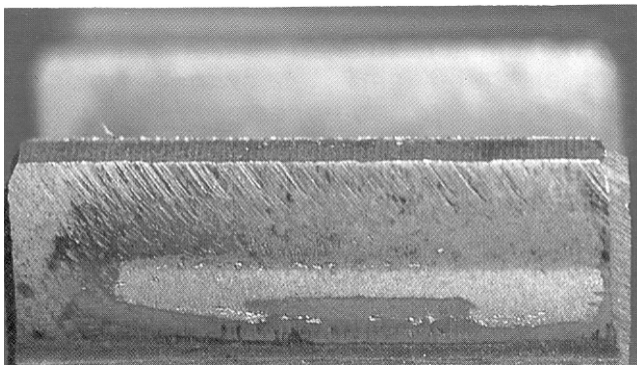
As noted before, during mesh specific areas of the tooth surface are in contact during each stage. However, variations in the tooth form between mating teeth may produce a slight change in the contact pattern. This will result in light wear as the mating gears seek to adjust to a common pitch line. Since this wear is in a sliding zone starting near the root of the gear, it causes a form of micro-pitting. Magnification is required to see the pits. To the eye, it looks like a band of off-white discoloration called “frosting”. There is a lack of sheen at this stage.

A gear should not be replaced simply because of frosting. But if it also shows other signs of distress, such as tip loading, misalignment, severe surface irregularities, etc., then further investigation is needed. These signs will be discussed later.



Offset Frosting

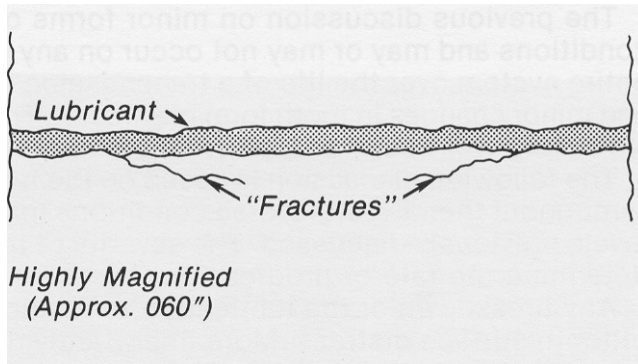
As previously stated, there are acceptable tolerances in tooth lead. Mating gear teeth can successfully operate with lead variation in opposite directions. However, a small amount of load shifting may occur. Slight wear may take place until the load is again evenly distributed across the entire tooth width. This may also result in frosting in the dedendum portion and sometimes in the addendum portion of the tooth, offset from the tooth center. Again, under normal conditions, healing will take place and gear life will not be lost.



Healing

As seen in the photo, the pitch line is generally well defined. The balance of the frosting will take the shape of the contact area, no matter what it might be. Under normal conditions, the contact zone wears away; the rate of wear decreases until the point is reached where it polishes itself out and the frosting is totally replaced by a very shiny area. No further wear takes place. This is called “healing” and absolutely no gear life is lost at this stage.

Tooth Surface Distress



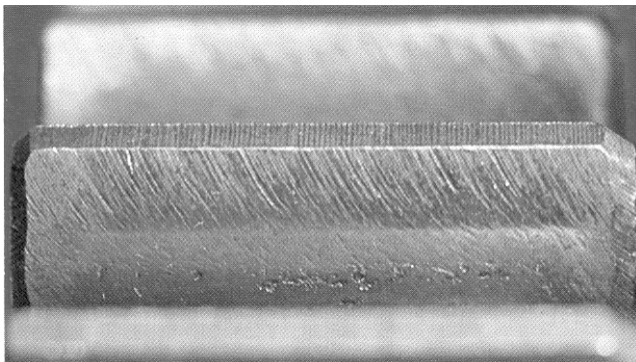
Gear Pitting

There is another surface condition which is normal in the early life of a gear and common in any carburized involute spur gear. It is the result of microscopic variations in tooth form and surface material microstructure.

Lubricant normally fills the irregularities of both teeth while in mesh. Lubricant builds a film of oil and no metal-to-metal contact takes place. Under load, oil pressures and surface stress develop between the teeth. The specific cause of this stress is debatable. One theory is that repeated high horsepower applications may cause oil pressures sufficient to overstress the microscopic areas of the tooth surface. Small surface fractures may start, and repeated loading may increase the fracture until the area is weak enough to break out, forming a pit.

The pit size will vary, depending on the depth of the initial fracture and how far the pitting has progressed. The pitting will progress until the tooth can carry the load without further distress. This rarely exceeds "initial" pitting and the distressed areas can heal

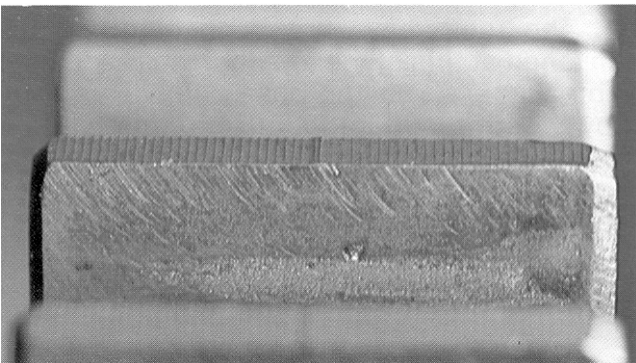
over.



Initial Pitting

"Initial pitting" is the mildest stage of pitting. It consists of definite pits from pin hole size, just larger than frosting and barely noticeable to .030 inches (.762mm) in diameter.

Generally, initial pitting continues until the tooth is able to carry the load without further distress. Do not replace a gear because of initial pitting, as it will not cause noise and in many cases will heal over.



Combinations

You can see under normal operation, a gear can have a "combination" of tooth distress, frosting and/or initial pitting. Again, all are likely to heal over.

Conclusion

So far, we have been discussing tooth distress caused when there are two gears in mesh. However, Fuller twin countershaft transmissions have three gears in a set. This can result in combinations of minor distress forms or acceleration of healing, not normally associated with single countershaft transmissions.

The mainshaft gear in a Fuller twin countershaft transmission may have to adjust to both countershaft gears. Any change on the teeth of the mainshaft gear that may occur from meshing with one countershaft gear may also affect its operation with the other. If observed, the result will be combinations of surface distress beyond previous discussion but still minor in nature. Wear and distress will, again, eventually cease and likely heal over. Further, if variations from theoretical design are of the same forms and locations on the gearing, break-in and healing will be accelerated. This due to the mainshaft gear being subjected to the condition twice each revolution (during mesh with both countershaft gears).

Since all torque loads in a Fuller twin countershaft transmission are distributed across two countershafts, the actual loads applied to the gear teeth in mesh are lower. Therefore, under normal operating conditions, break-in wear or other forms of distress are typically of the most minor nature, when found.

Tooth Surface Distress

Tooth Distress - Progressive Forms

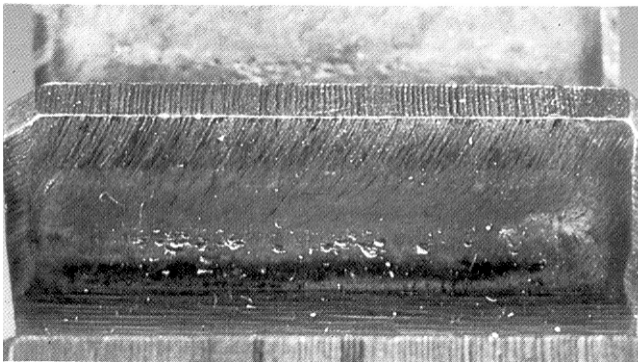
The previous discussion on minor forms of distress is based on gearing operation under normal conditions, which may or may not occur on any gear in the life of a transmission. Subtle changes in the entire system over the life of a transmission (as it breaks in) can affect how the gears mesh together, which may change tooth form. This is why frosting may be found at relatively high mileage. No failure will occur and, after adjustment, the distress is likely to heal over.

The following discussion is based on the fact that not all transmissions operate under normal conditions throughout their lives. Adverse conditions may exist which can result in distress progressing beyond levels previously discussed. The severity of the conditions, including the length of time involved, will determine the rate of progression.

Any breakdown of the lubrication, or reduced oil film, can increase the possibility or acceleration of tooth surface distress. More importantly, inadequate lubrication for a sustained period will likely cause the distress to advance to a more severe stage.

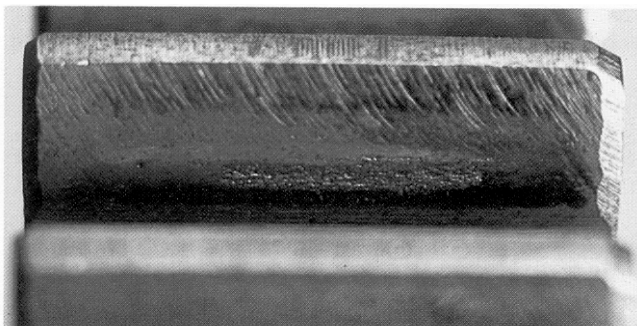
Common causes of inadequate lubrication are:

- Low lube level
- Inadequate lube viscosity
- Use of incorrect lube
- Use of oil beyond its functional life

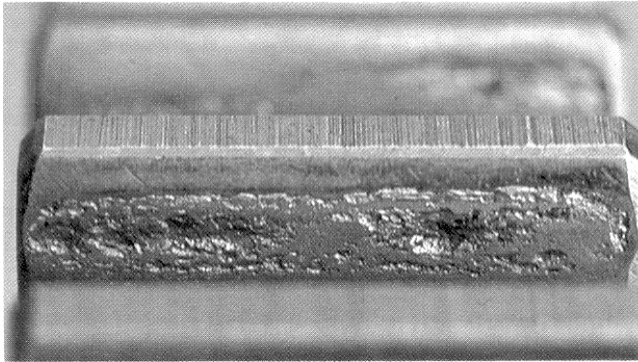


Moderate Pitting

This gear shows pit craters approximately .060 inches (1.524mm) in diameter and .005 to 010 inches (.127mm to .254mm) deep, about twice the size of craters in initial pitting. The pits are widely distributed across the face of the tooth. This gear has lived about 50% of life. The teeth have not been significantly weakened at this stage and there is no danger of breakage. As in the case with gears that show frosting and initial pitting, this type of “moderate pitting” will not cause noise. This gear can give many more miles of useful service.



This gear also has pitting on approximately 50% of the tooth surface, but unlike the previous gear shown, this gear should be replaced. The pitting is concentrated and at the pitch line, which changes the involute form. Although the teeth have not been significantly weakened, noise can be generated because the involute form no longer falls within the tolerance band discussed earlier.



Destructive Pitting

The pitting on this gear is well advanced into a “destructive” stage. The pit craters are considerably larger and deeper than those in moderate pitting. Gears in this stage of pitting should be replaced, or noise and fatigue fractures may occur.

Decision Factors

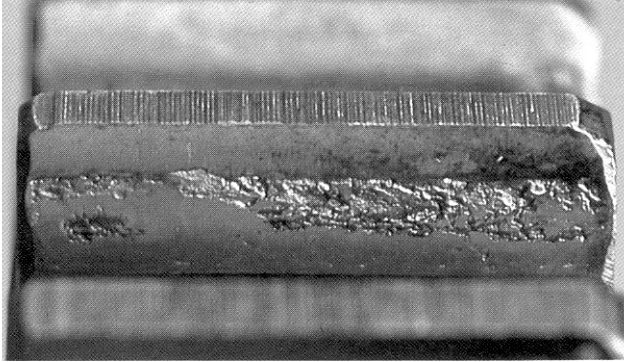
When deciding if a particular gear should be replaced because of pitting, the following variables must be considered:

- How much longer is the transmission expected to be in service? For example, in a transmission expected to give 500,000 miles of service, you find moderate pitting of the main drive gear at 300,000 miles. If there is not a noise complaint and the transmission is going back into the same operation, there should be no reason to replace the gear.
- Is the transmission going back into the same application? If the transmission was used previously under moderate operating conditions, but in the future will be used under more severe conditions, then the questionable gearing cannot be expected to wear at the same rate as in the past.
- Has a noise complaint been isolated to a particular gear set? If so, the gear set should be replaced, regardless of its appearance.
- If the past history of the transmission is not known (application, previous noise complaint, expected life of transmission), then a questionable gear should be replaced.

Tooth Surface Distress

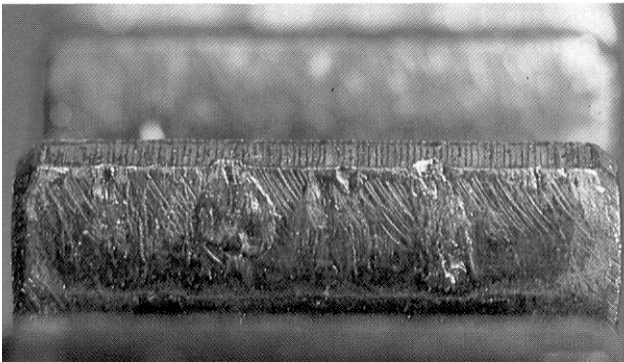
Tooth Distress - Major Factors

Major forms of distress are primarily caused by a severe case of the factors given for minor and progressive forms of distress. These forms can occur at any time in the gear's life. Whenever they occur, all gears in the set must be replaced.



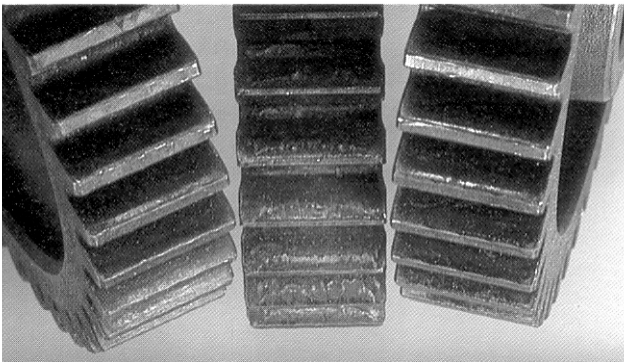
Spalling

“Spalling” is similar in appearance to destructive pitting except the craters are larger in diameter and shallower in depth. Spalling occurs over a short period of time when a gear is subject to an extreme overload condition.



Scoring

“Scoring” is caused by an insufficient oil film between mating gear teeth, resulting in very high surface temperatures. This results in an alternate welding tearing of metal which is rapidly torn from the tooth surface. Insufficient oil film can be caused by: Low oil level, excessive transmission operating angles, high operating temperatures, poor quality, incorrect viscosity oil, and by mixing types of oil.



Burned Head Set

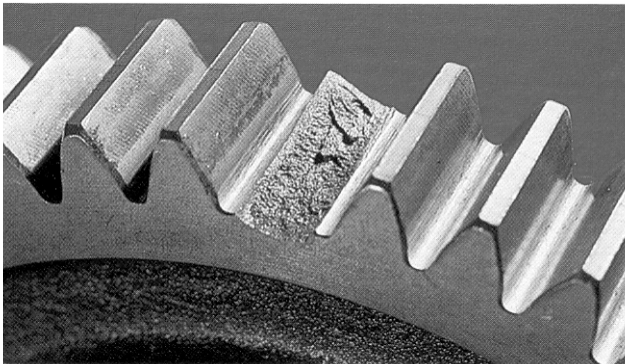
When inspecting a transmission with a “burned head set”, it is not unusual to find the main drive gear badly scored, with only slight visible damage to the mating countershaft drive gears. This occurs because the teeth of the main drive gear make contact almost three times as often as the teeth of the mating countershaft drive gears. When replacing a burned main drive gear, also replace the countershaft drive gears, even if there is no visible damage.

Gear Tooth Breaking

The actual breaking of a tooth is a serious failure. Not only will the broken gear fail, but serious damage may occur to other gearing as a result of the broken tooth running through the transmission.

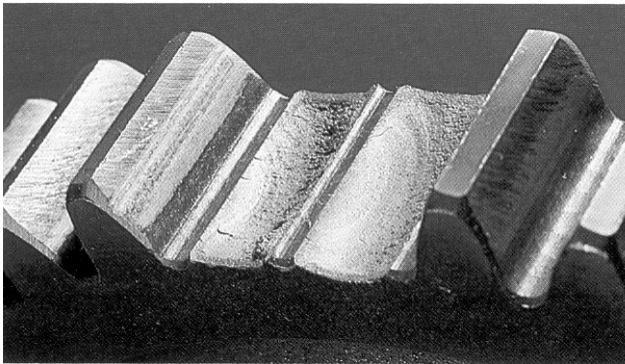
There are three basic types of gear tooth fractures:

- Impact Fractures
- Fatigue Fractures
- “Stringers” or “Gas Pockets”



Impact Fractures

“Impact fractures” are caused by a severe shock load or a foreign object passing through the gear mesh. They are identified by a “bump” on the compression side of the fractured area. The more cycles the gear has run after the fracture, the smaller the bump will be. In addition to the gear which has a tooth fracture, the other two gears of the set should also be replaced, even though they may look undamaged. All gearing in the transmission should be inspected for possible damage caused by the broken tooth running through the transmission.



Fatigue Fractures

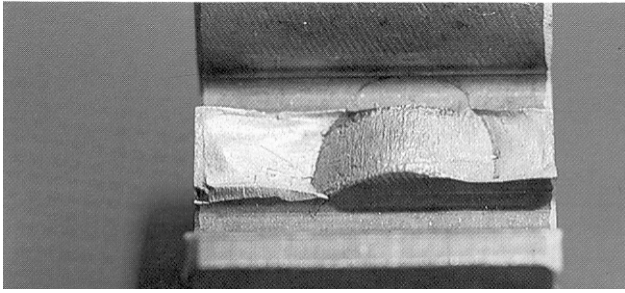
“Fatigue fractures” are caused by extremely high stresses on a gear tooth over a period of time.

Possible causes of such stresses could be:

- Shock loads causing a small crack in the tooth.
- Tooth damage from objects going through the gear mesh.
- An overload condition.
- Forging imperfections, excessive machining marks, or improper heat treatment.
- Severe pitting or surface fatigue.

Fatigue fractures are identified by “beach” marks on the fractured area. These marks are made as the tooth progressively cracks under a load heavy enough to enlarge the crack but not great enough to break the entire tooth off at one time.

Gear Tooth Fractures



Stingers or Gas Pockets

Gears made from base metal which contain “stringers” or “gas pockets” have weak points at those areas. These fractures can be identified by the difference in fracture shape and metal texture in the break surface. Again, as with other fractures, inspect all gearing in the transmission for possible damage.

User Information

Using the information presented in this guide along with your mechanical skills will help to determine if gear replacement is necessary, as well as the reason for the condition. Sometimes, variations or combinations of conditions may make determination of the primary cause difficult and confusing. In these situations, or for more information, call or write:

EATON CORPORATION
TRANSMISSION DIVISION
P.O. Box 4013
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1-800-826-HELP (4357)

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Eaton Corporation

Vehicle Group
P.O. Box 4013
Kalamazoo, MI 49003 USA
800-826-HELP (4357)
www.eaton.com/roadranger

Printed in USA

For parts or service call us
Pro Gear & Transmission, Inc.



1 (877) 776-4600

(407) 872-1901

parts@eprogear.com

906 W. Gore St.

Orlando, FL 32805

