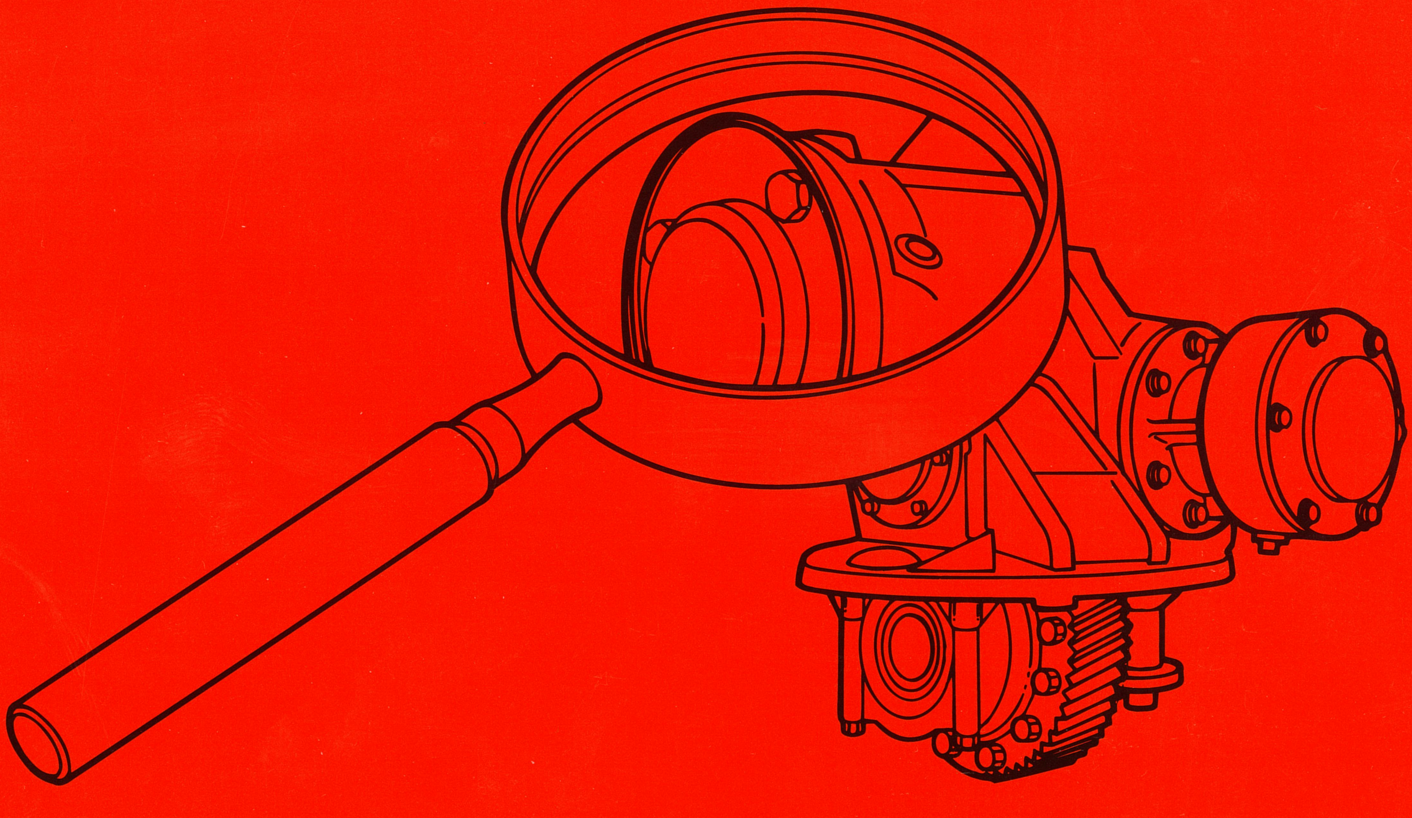
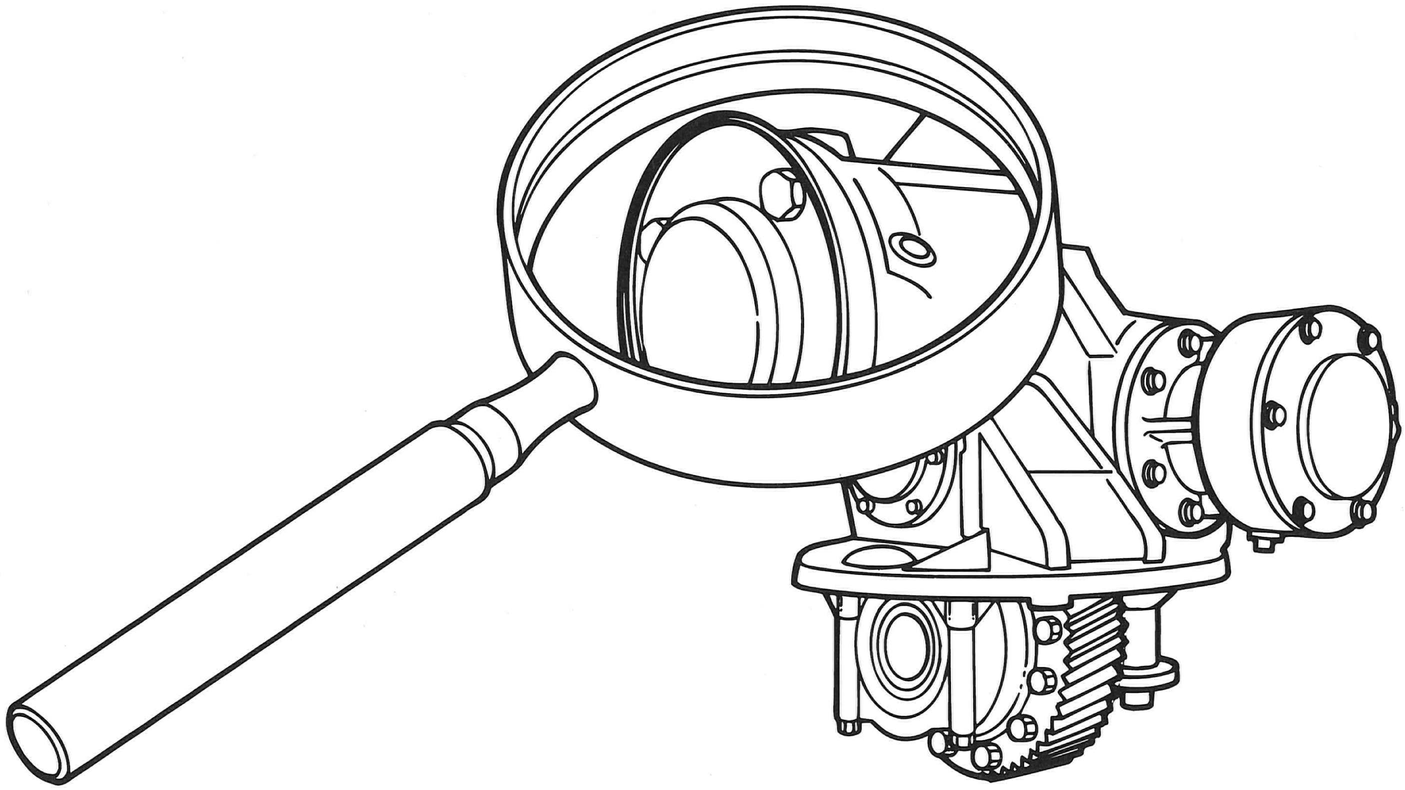
CARRIER GEAR FAILURE ANALYSIS



JULY 1995
(NEW ISSUE)

FAILURE ANALYSIS
21-201

CARRIER GEAR FAILURE ANALYSIS



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21-201

ATTENTION

The information in this manual is not all inclusive and cannot take into account all unique situations. Note that some illustrations are typical and may not reflect the exact arrangement of every component installed on a specific chassis.

The information, specifications, and illustrations in this publication are based on information that was current at the time of publication.

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NOTES

EXPLANATION OF 3-DIGIT NUMERICAL CODE

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EXPLANATION OF NUMERICAL CODE

The organization of Mack service manuals has been upgraded to standardize manual content according to a reference system based on component identification. The new reference system will help to link the information contained in this publication with related information included in other Mack service-warranty publications, such as associated service bulletins, warranty manuals, and the TS477 Labor Time Standards Manual.

The system is based on a numerical code, the first digit of which identifies the general component grouping as listed here:

GROUP 000 — INSPECTIONS
GROUP 100 — CHASSIS
GROUP 200 — ENGINE
GROUP 300 — CUTCH, TRANSMISSION, TRANSFER CASE, PTO
GROUP 400 — STEERING, AXLES, WHEELS & TIRES, DRIVELINE
GROUP 500 — BRAKES, AUXILIARY SYSTEMS
GROUP 600 — CAB, TRUCK BODY
GROUP 700 — ELECTRICAL

The complete 3-digit code is used to identify the **system**, **assembly** or **subassembly**, as appropriate, within each of the groupings. The codes applicable to this publication are shown at the TOP OF EACH PAGE as necessary, and may also appear in the TABLE OF CONTENTS, to guide you to specific component information.

SAFETY INFORMATION

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Advisory Labels

Cautionary *signal words* (Danger-Warning-Caution) may appear in various locations throughout this manual. Information accented by one of these signal words must be observed to minimize the risk of personal injury to service personnel, or the possibility of improper service methods which may damage the vehicle or render it unsafe. Additional Notes and Service Hints are utilized to emphasize areas of procedural importance and provide suggestions for ease of repair. The following definitions indicate the use of these advisory labels as they appear throughout the manual:

CAUTION

Directs attention to unsafe practices which could result in damage to equipment and possible subsequent personal injury or death if proper precautions are not taken.

WARNING

Directs attention to unsafe practices which could result in personal injury or death if proper precautions are not taken.

DANGER

Directs attention to unsafe practices and/or existing hazards which will result in personal injury or death if proper precautions are not taken.

NOTE

An operating procedure, practice, condition, etc., which is essential to emphasize.

SERVICE HINT

A helpful suggestion which will make it quicker and/or easier to perform a certain procedure, while possibly reducing overhaul cost.

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GLOSSARY

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Abrasion - The process of rubbing, grinding, or wearing away of material from a surface by friction.

Beach Marks - Contour lines on a somewhat smooth failed surface that indicate fatigue. These features are created as a part successfully resists, for a time, the advance of a fatigue crack.

Bending Fatigue - Characterized by "beach marks" on the fractured area. The phenomenon leading to fracture under repeated or fluctuating stress having a maximum value less than the tensile strength of the material. Fatigue fractures are progressive, beginning as minute cracks that grow under the action of the fluctuating stress. Fatigue results from load and time.

A. High Cycle Bending Fatigue - A fatigue break having a large area of beach marks that are close together, and a small final fast fracture zone.

B. Low Cycle Bending Fatigue - A fatigue break having a small area of beach marks that are not close together, and a large final fast fracture zone.

Brinelling, False - Depressions produced when rolling element bearings are subjected to vibration or low-radial-angle oscillation, or to both while not rotating. The bearing surfaces are either polished or show a characteristic red-brown stain.

Brinelling, True - Indentation produced by plastic flow when rolling elements are forced against bearing raceway surfaces by stationary overload or, especially, by impact during mounting. Original surface features such as machine marks are usually visible at the bottom of the indentations.

Burning - Permanent damage to metal or alloy by heat, causing either incipient melting or intergranular oxidation.

Erosion - Destruction of metals or other materials by the abrasive action of moving fluids, usually accelerated by the presence of solid particles or matter in suspension. When corrosion occurs simultaneously, the term erosion-corrosion is often used.

Fatigue Strength - The maximum stress that can be sustained for a specified number of cycles without failure.

Final Fast Fracture Zone - That part of a break through a cross section that has a rough, crystalline appearance. It could be the entire area in a shock failure or a small part of the cross section area in a fatigue failure.

Flaking - *See Surface Fatigue Progression.*

Fretting - An action that results in surface damage, especially in a corrosive environment, where there is a relative motion between solid surfaces in contact under pressure.

Frosting - *See Surface Fatigue Progression.*

Gear - The larger member of a gear set. *See Pinion.*

High Cycle Bending Fatigue - *See Bending Fatigue.*

Inadequate Lubrication - Any situation where the lubricant fails to maintain a barrier between metal parts.

Low Cycle Bending Fatigue - *See Bending Fatigue.*

Oil Contamination - Pollution of lubricating oil by a foreign substance.

Overheating - Heating a metal or an oil to such a high temperature that its properties are impaired.

Overloading - A load or torque that is greater than the design load or torque specification of a particular component.

A. Shock Load (Instantaneous Overload) - A very rapidly applied force that causes component damage immediately.

B. Sustained Overload - A consistent application of force that is greater than the part can withstand.

Pinion - The smaller member of a gear set. *See Gear.*

Pitting - *See Surface Fatigue Progression.*

Plastic Deformation (Plastic Flow) - Deformation that remains permanent after removal of the load which caused it. Metal flow on the surface (often over the tips and ends of the gear teeth). This condition can quickly become destructive pitting.

Ratchet Marks - Steps that indicate multiple fatigue initiations on different planes. These steps disappear as the fatigue fronts merge.

Scarring - Component damage caused by metal flakes under compression due to dynamic loading that indent the component surface without embedding.

Scoring - Damage caused by embedded particles of metal. Scoring may show up as either deep wide grooves or narrow shallow grooves.

Scuffing - Adhesive wear from progressive removal of material from a rubbing surface caused by localized welding and tearing.

Shock Loading - A rapidly applied load or force that is severe enough to exceed the strength of the component and cause it to crack or fail instantly.

Spalling - *See Surface Fatigue Progression.*

Stress - Force per unit area, often defined as force acting through an area within a plane (i.e., pounds per square inch).

Stress Risers - Changes in contour or discontinuities in structure that cause local increases in stress.

Surface Fatigue Progression

A. Frosting - Superficial material displacement on gear teeth that presents a non-destructive burnished appearance.

B. Pitting - This surface fatigue condition occurs when the endurance limit of a material is exceeded. Fatigue of this kind depends on surface contact stress and the number of stress cycles.

1. Initial - The mildest stage of pitting. It consists of definite pits from pinhole size to 0.03 inches (0.76mm) in diameter. Initial pitting continues until the tooth is able to carry the load without further distress. A gear with initial pitting does not have to be replaced because it will not cause noise and will provide substantial additional service.
2. Moderate - In this stage the pits are approximately double the size of the initial pitting. The gear teeth have not been weakened and there is no danger of breakage. Moderate pitting of a gear will not cause noise and may give additional service.
3. Destructive - At this stage the pits are considerably larger and deeper than those with moderate pitting. Gears found in this stage should be replaced. Fatigue fractures may develop and noise may also occur.

C. Flaking - An advanced type of pitting resulting from contact fatigue. Material falls away from the surface in the form of shallow flakes or scale-like particles.

D. Spalling - Deterioration of a highly stressed surface by surface fatigue producing irregularly shaped, sharp-edged, deep cavities. Spalling may be referred to as a severe form of flaking.

Torsion - A twisting action resulting in shear stresses and strains.

NOTES

INTRODUCTION

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MANUAL OBJECTIVE

The objective of this manual is to assist the skilled technician to assess the extent of axle carrier failures. This will better enable him to identify all the contributing causes of failure. The technician will not only be able to repair the carrier successfully, but also pinpoint any conditions that may need to be changed to prevent a repeat failure.

FAILURE ANALYSIS

Failure analysis is the process of determining the **original cause** of a component failure in order to keep it from happening again. Too often, when a failed component is replaced without determining its cause, there will be a recurring failure. If a carrier housing is opened, revealing a bevel gear with a broken tooth, it is not enough to settle on the broken tooth as the cause of the carrier failure. Other parts of the carrier must be examined. Look at the pinion that mates to the bevel gear and also look at the lubricant. In some instances, the service records need to be checked. The overall condition of the vehicle and other components of the truck may need to be examined.

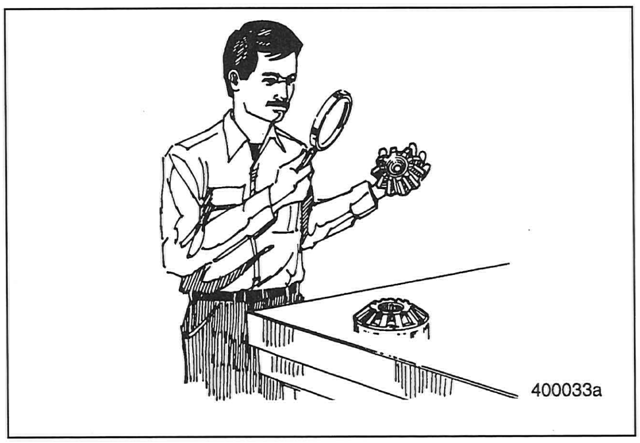

Figure 1 - Overall Condition of the Vehicle

No one benefits when a failed component goes on the junk pile with the cause unknown.

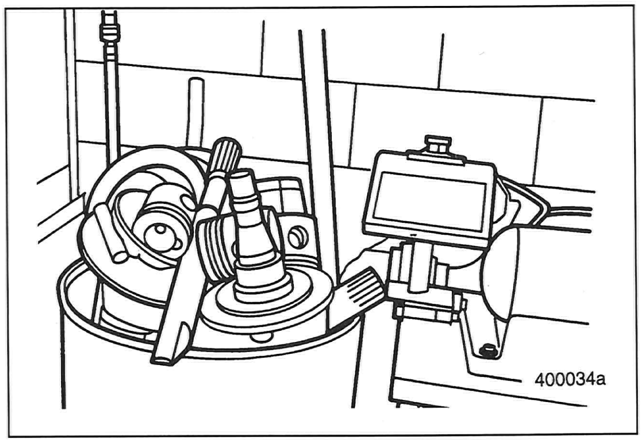

Figure 2 - Failed Components Provide No Benefit

Nothing is more disturbing to a customer than a repeat failure. If a carrier fails in exactly the same way twice, the customer will likely become upset.

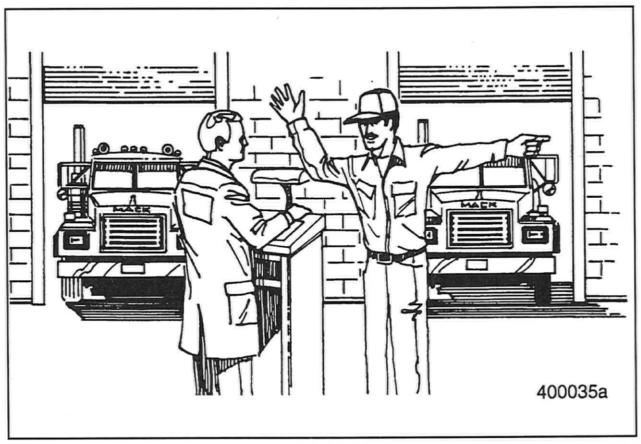

Figure 3 - Avoid Repeat Failures

Systematically analyzing a failure assures quality service by avoiding unnecessary downtime and further expense for the customer caused by a repeat of the same failure.

Many clues can be gathered by carefully examining the failed components. By knowing what to look for, how a piece of equipment was running, and what previous problems existed, the true cause of failure can be determined.

In some cases, the part itself is at fault (gears may have been improperly cut). In the case of a rebuilt rear axle, mismatched gears may have been installed.

Also, correctly spec'ing the drive axle for the vehicle and its job is a very important factor in preventing axle failures. The drive axle must be selected with strength capable of withstanding the duty cycle of a loaded truck in operation.

Mack Trucks, Inc. has established recommended maintenance and specification practices and procedures to ensure the carrier(s) in a vehicle will perform to give optimum service. Evaluation of a carrier failure should start with a knowledge of the vehicle application or usage, vehicle specification and maintenance.

Reasons for failure to drive axle carriers usually fall into four categories:

- Vehicle application or usage
- Vehicle operation
- Maintenance
- Design or manufacturing

It is important to understand proper selection of vehicle components is necessary for the anticipated operating conditions. If vehicle operations exceed carrier design limitations, premature failures and reduced life can be expected. To avoid failures due to misapplication or specification, it is important for the owner to understand the GCW/GVW rating of their vehicle and the terrain over which the vehicle will be operated. For straight trucks, Gross Vehicle Weight (GVW) is the weight of the vehicle plus its payload. For tractor trailer combinations, GCW is the Gross Combined Weight of the tractor, trailer and payload.

Each straight truck or tractor trailer combination must be operated within Mack Trucks, Inc. approved maximum loaded weight rated capacity. Exceeding the maximum rated capacity will reduce the life of the carrier. GCW/GVW may never be greater than the GCW/GVW specified when the vehicle was ordered from Mack Trucks, Inc.

Road grades and surfaces also affect carrier performance. It takes more effort to move a vehicle up a hill than on level ground. The amount of effort required to move a vehicle up a grade is directly proportional to the steepness of the grade. When ordering a vehicle, the order should include an estimate of the highest grade over which the vehicle will be operated. As an example, vehicles should not be ordered stating the maximum grade the vehicle will be operated is 3% when it is known the vehicle will operate over terrain that contains grades in excess of 3%. Operating a vehicle on grades higher than specified on the vehicle order to Mack Trucks, Inc. may reduce carrier life.

The type of road surface the vehicle will operate over also determines what carrier should be ordered for a vehicle operation. Harder road surfaces require lower rolling resistance than softer and rougher surfaces. Soft surfaces increase the carrier effort to move any vehicle when compared to moving a vehicle of equal weight over a hard surface. It is important when ordering a vehicle to give an accurate estimate of the percent of vehicle usage that will be on-highway versus off-highway. Due to rolling resistance, carrier life will be reduced on equally spec'd and weighted vehicles for the vehicle operated on softer and rougher surfaces versus a vehicle operated on hard surface highway.

All Mack truck carriers are designed to give years of trouble-free service, provided they were properly spec'd for the usage, operated according to Mack guidelines and maintained to Mack's procedures. When vehicles are being ordered or placed in service, it is the responsibility of the customer and the delivering Mack Sales Facility to ensure the vehicle is properly spec'd to match the job it is required to do. Care in supplying the customer with the proper carrier(s) for his operation is one of the most important steps toward ensuring the carrier(s) will provide satisfactory performance and life.

The more successful shops prevent repeat equipment failures by developing good failure analysis practices. Knowing how to diagnose the cause of a premature failure is becoming one of the main prerequisites of a good heavy-equipment technician. In addition to just replacing failed parts, the technician must determine and correct the cause of the failure. This is successful failure analysis.

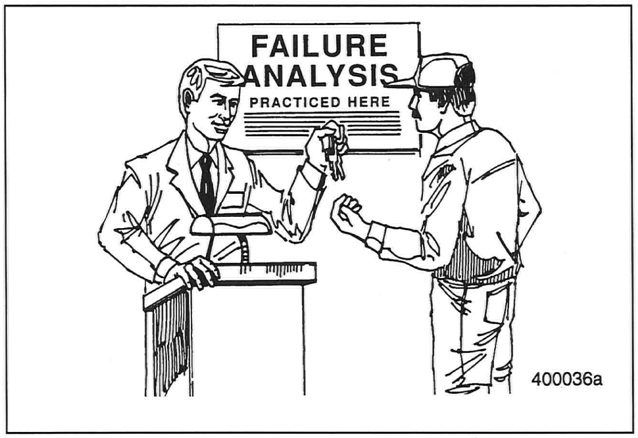

Figure 4 - Failure Analysis

Often, a failure may seem obvious but this is generally the exception rather than the rule. Good failure analysis techniques require that the technician follow a definite procedure, or Systematic Approach.

SYSTEMATIC APPROACH

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SYSTEMATIC APPROACH

The following steps are recommended as an effective approach to good failure diagnostics.

1. Document the problem.
2. Perform a preliminary investigation.
3. Prepare the parts for examination.
4. Find the exact cause of the failure.
5. Correct the cause of the problem.

Document the Problem

Talk to the operator of the truck. Look at the service records. Find out when the truck was last serviced. In what type of service is the unit being used? Has this particular failure occurred before? How was the truck working prior to the failure?

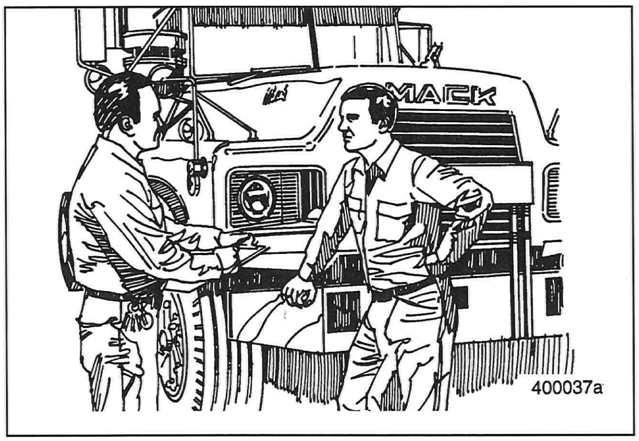

Figure 5 - Document the Problem

Be a good listener. Sometimes, insignificant or unrelated symptoms can point to the cause of the failure. Was the vehicle at normal operating temperature? Were the gauges showing normal ranges of operation? Was there any unusual noise or vibration?

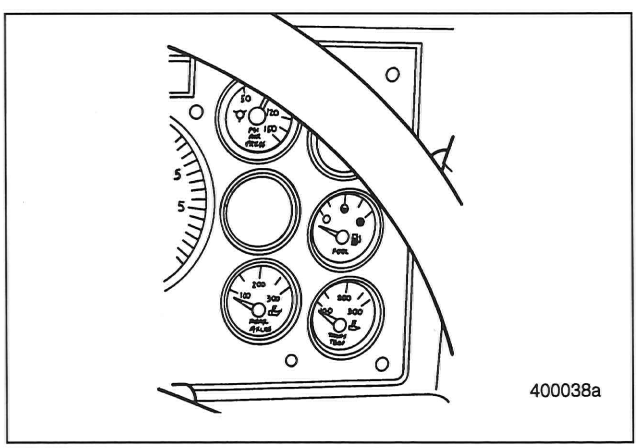

Figure 6 - Record Gauge Readings

After listening, review the previous repair and maintenance records. If there is more than one driver, talk to all of them and compare their observations for consistency with the service and maintenance records. Verify the chassis serial number from the vehicle identification plate, as well as the mileage and hours on the vehicle.

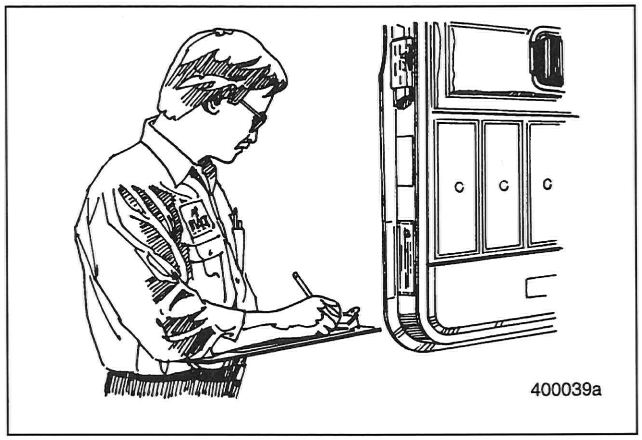

Figure 7 - Chassis Serial Number

Preliminary Investigation

A brief visual external inspection may reveal leaks, cracks or other damage that can point to the cause of the failure.

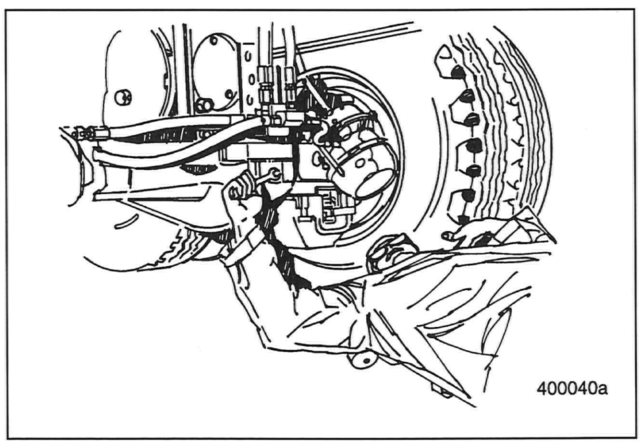

Figure 8 - Visual External Inspection

Make note of obvious leaks around plugs and seals. A missing fill or drain plug would be an obvious cause for concern. Harder to see, but sometimes visible, are actual cracks in the carrier housing.

Does the general mechanical condition of the vehicle indicate proper maintenance or are there signs of neglect? Are the tires in good condition and have matched sizes? If equipped with a torque limiting device, is it working properly?

During the preliminary investigation, write down anything out of the ordinary for later reference. Something of little significance now may take on more importance when the subassemblies are torn down.

Prepare the Parts

After the preliminary investigation, locate the failure and prepare the parts for examination. In carrier failure analysis, it may be necessary to disassemble the unit.

SERVICE HINT

When disassembling subassemblies and parts, do not clean the parts immediately since cleaning may destroy some of the evidence.

When breaking down the rear axle, do it in the recommended manner. Minimize any further damage to the unit. Ask a few more questions when examining the interior of the carrier. Does the lubricant meet the manufacturer's specifications regarding quality, quantity and viscosity? As soon as you have located the failed part, take time to analyze the data.

Determine Cause of Failure

The challenge begins here to determine the exact cause of the failure. Again, there is no benefit to replacing a failed part without determining the cause of failure. Determine the specific type of failure. The following sections show different types of failures and explore possible causes. Use this as a guide in determining types of failures and in correcting problems.

For example, after examining a failed part, it is found that the failure is caused by a lack of lubrication. Determine if there was an external leak. If this is the cause, just replacing the failed gear is not going to correct the situation.

Correct the Cause of the Problem

Once the cause of the problem has been determined, you may refer to the appropriate service manuals to perform the repairs. Then complete the repairs to the failed components.

CARRIER GEAR TYPES

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EXPLODED VIEWS

The following illustrations are to be used as a guide. They show exploded views of typical carrier assemblies for Mack trucks. Some parts may appear slightly different as improvements to components are introduced in successive models. Remember to use the illustrations as a general guide only.

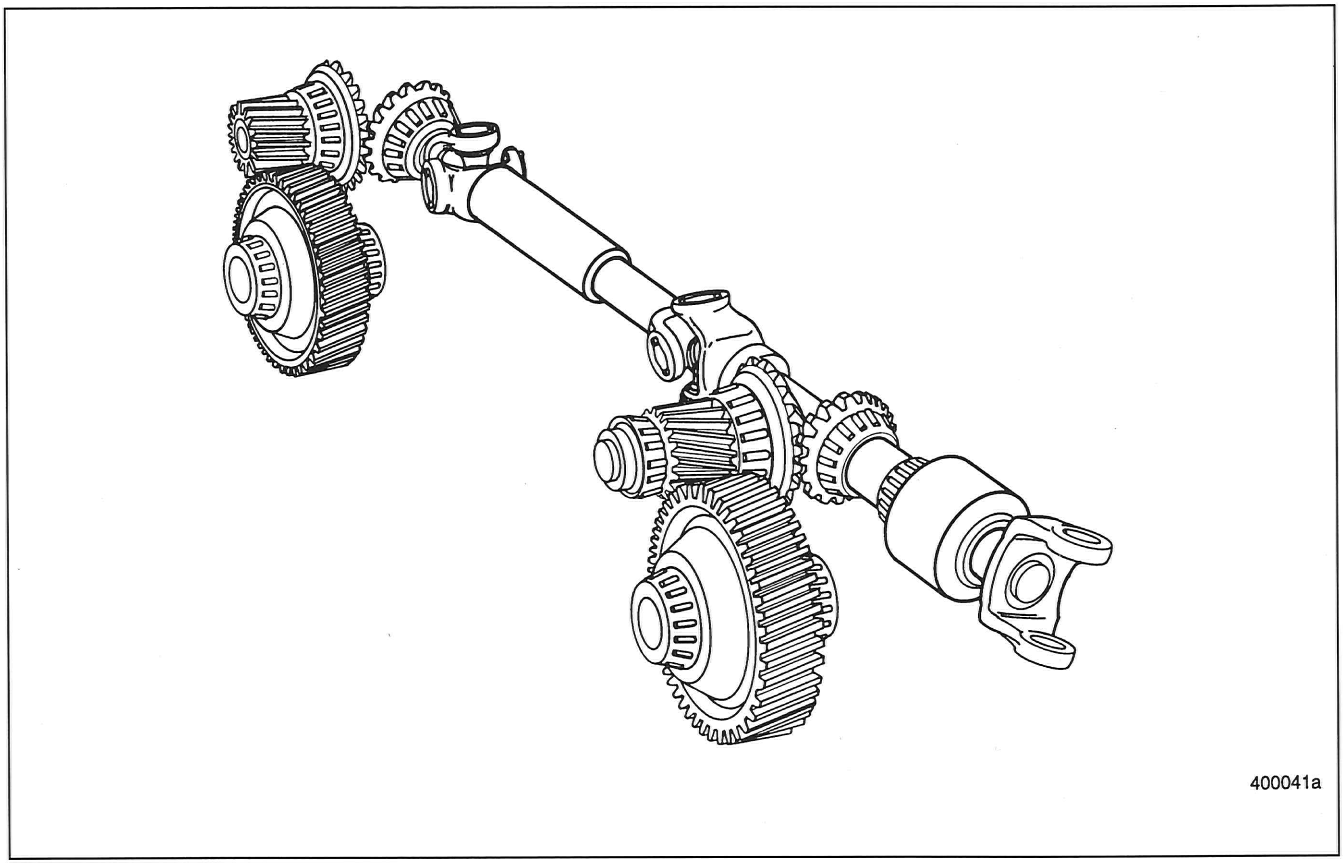

Figure 9 - Carrier Drive Team

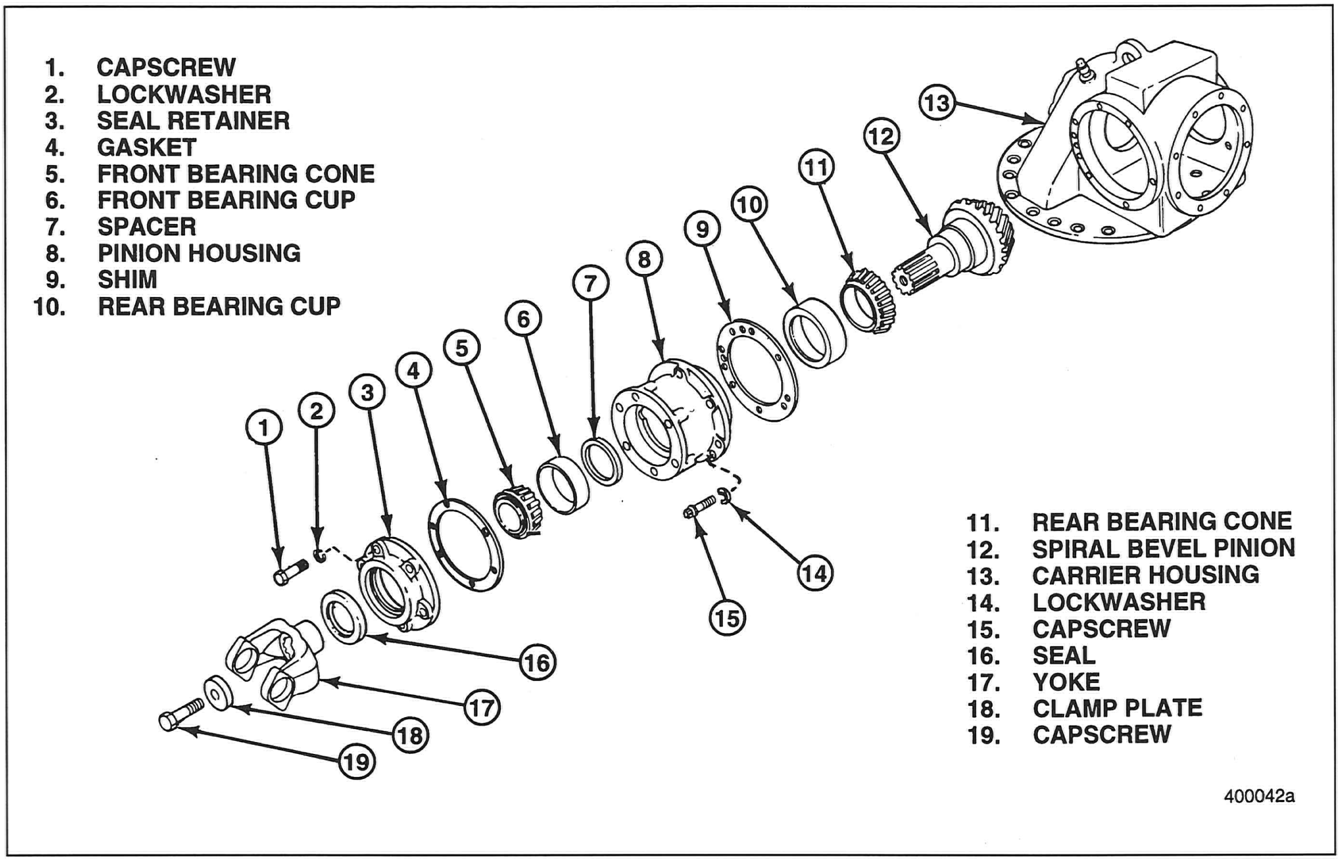

Figure 10 - Spiral Bevel Pinion Assembly

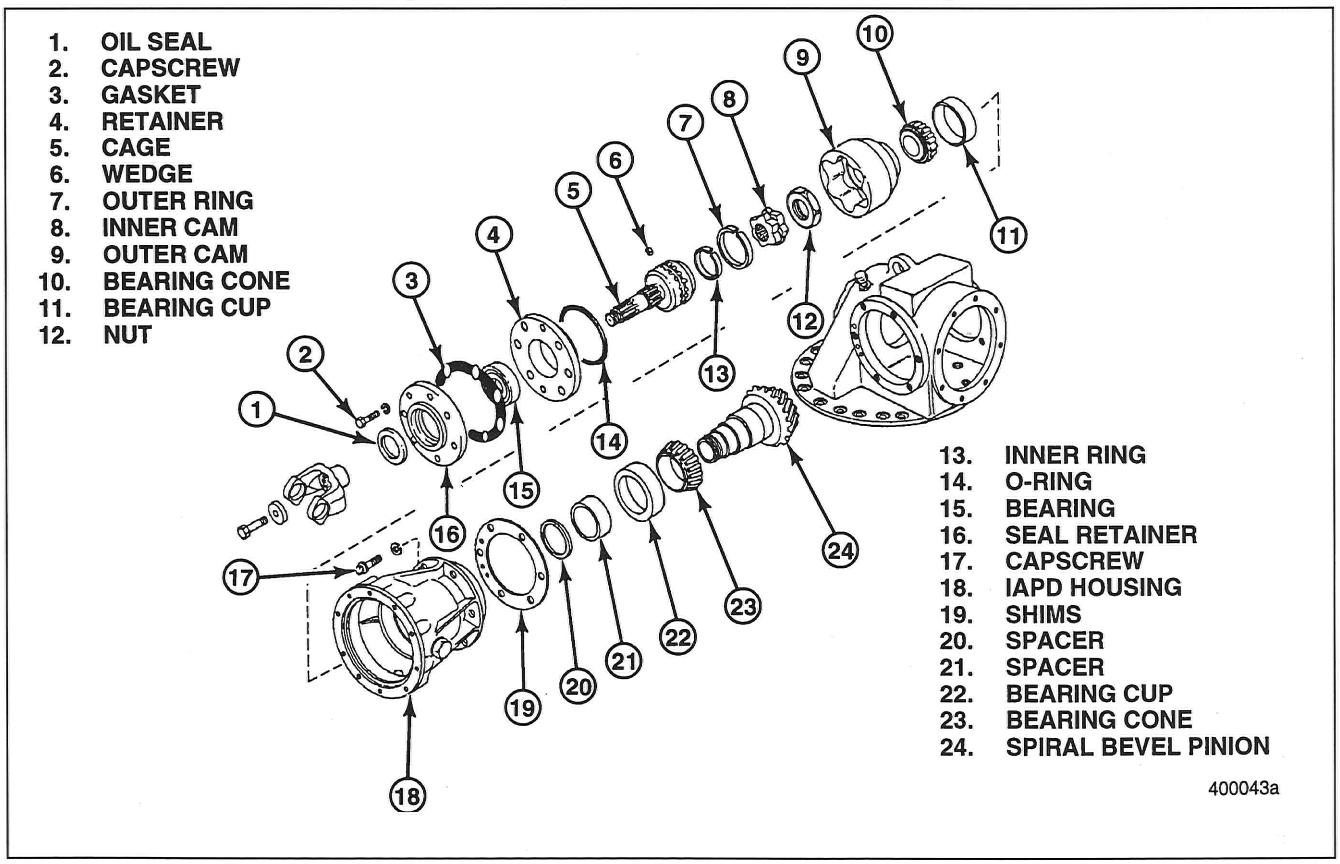

Figure 11 - Spiral Bevel Pinion Assembly with Interaxle Power Divider

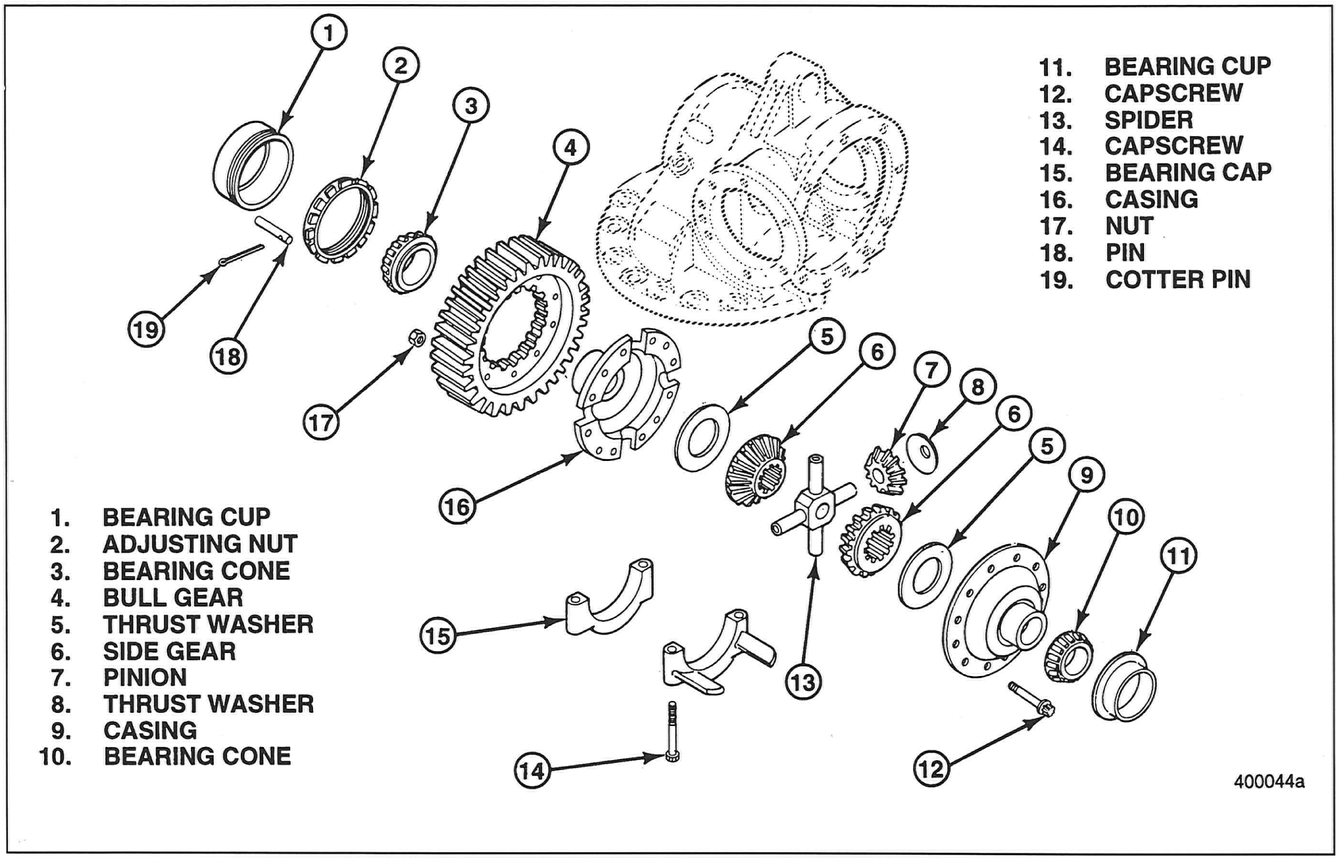

Figure 12 - Differential Assembly

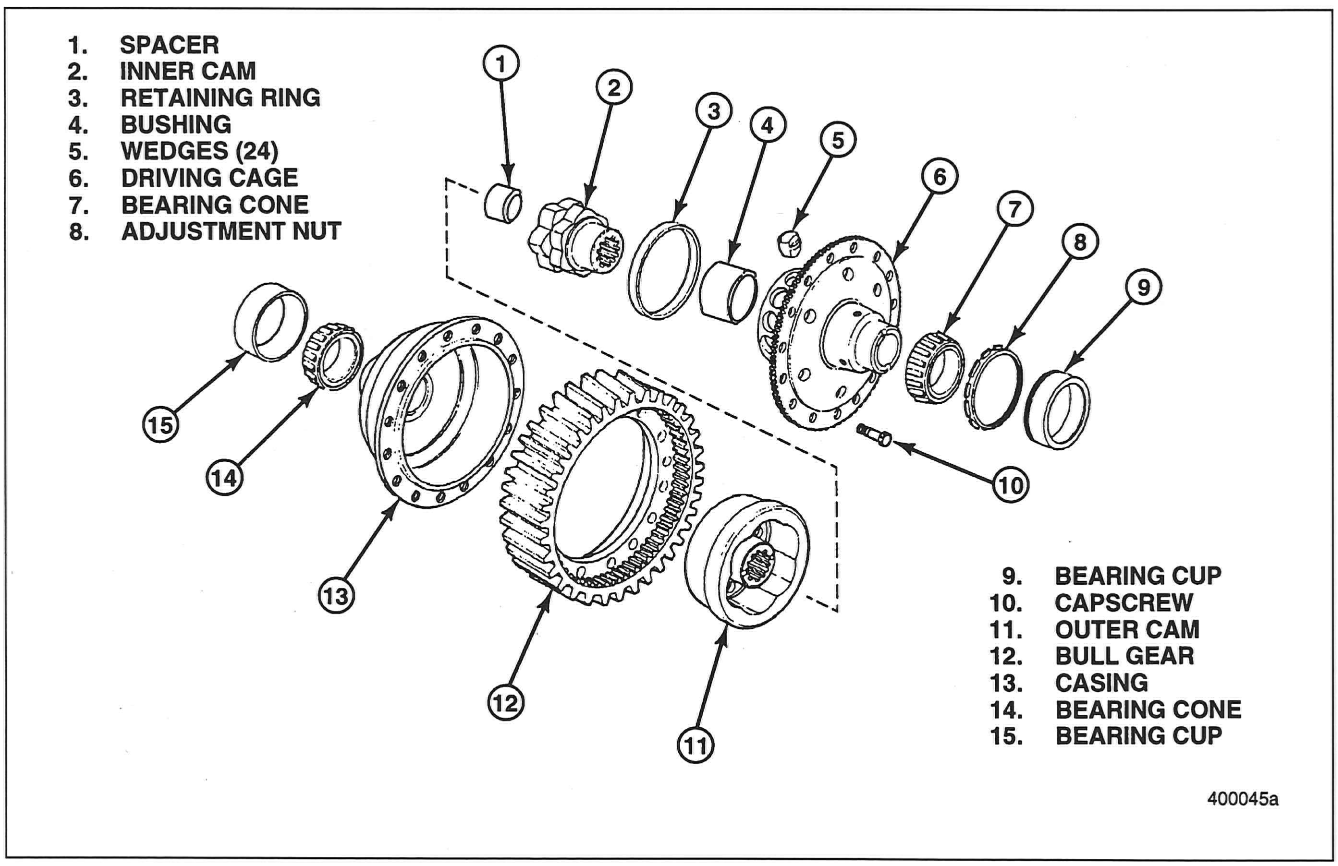

Figure 13 - Interwheel Power Divider Assembly

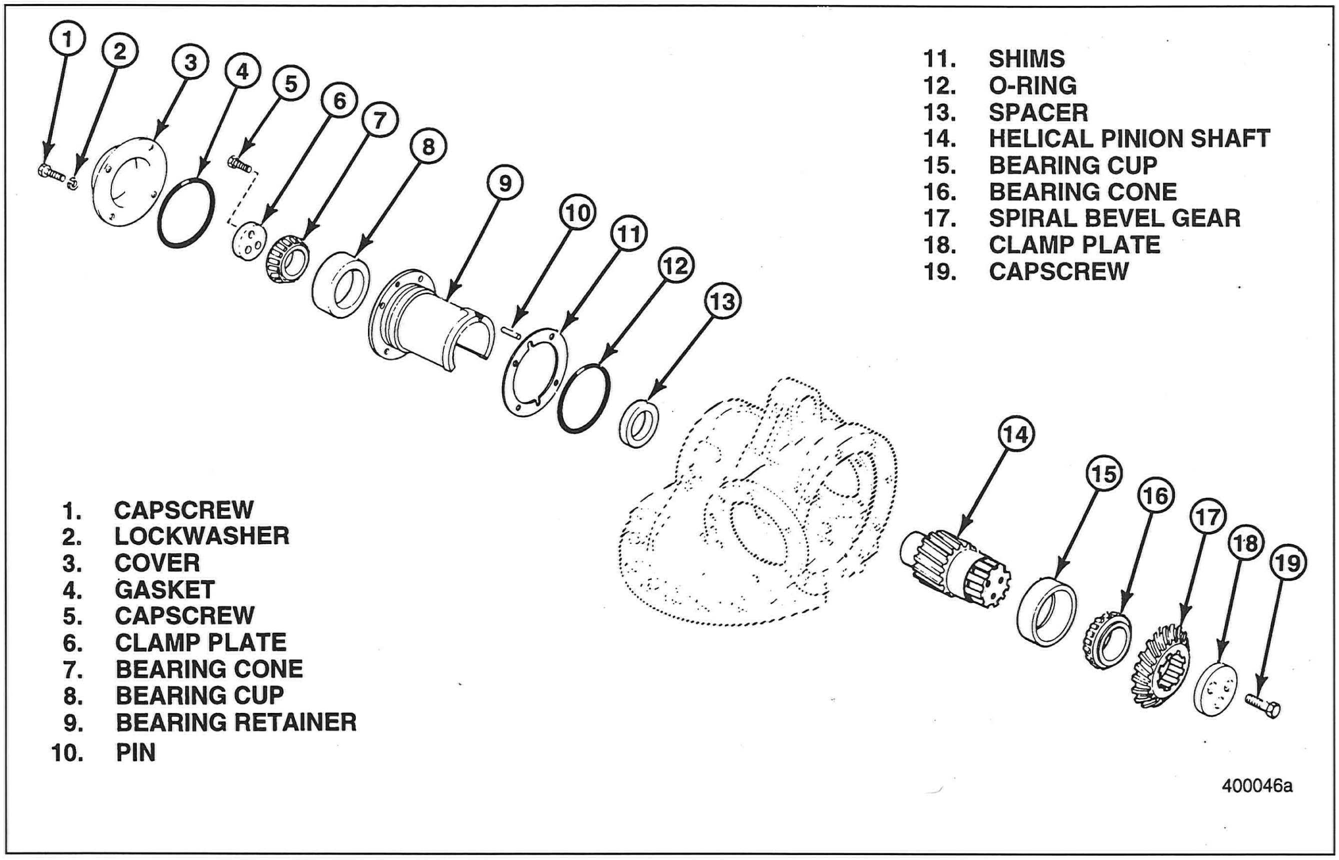

Figure 14 - Helical Pinion Shaft Assembly

SPIRAL BEVEL GEARS

Bevel gears transfer motion between shafts at a right angle to each other. Spiral bevel gears have curved teeth that are set at an angle. The load is distributed over more than one pair of teeth, allowing the gear set to run at higher speeds and loads than a similar straight bevel gear set.

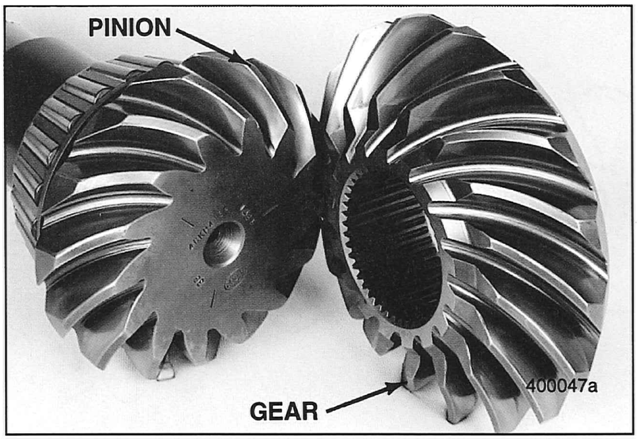

Figure 15 - Spiral Bevel Gear Set

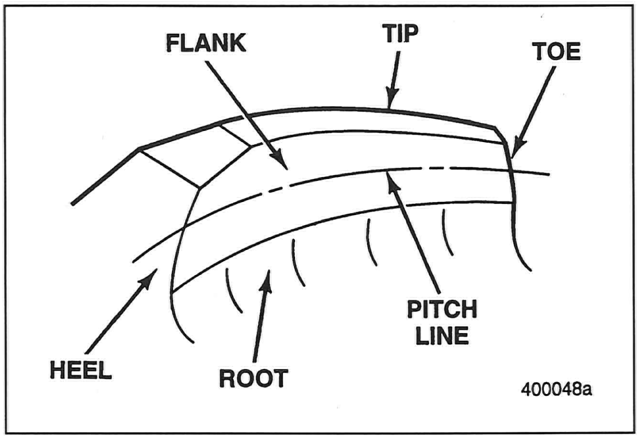

Figure 16 - Spiral Bevel Gear Tooth

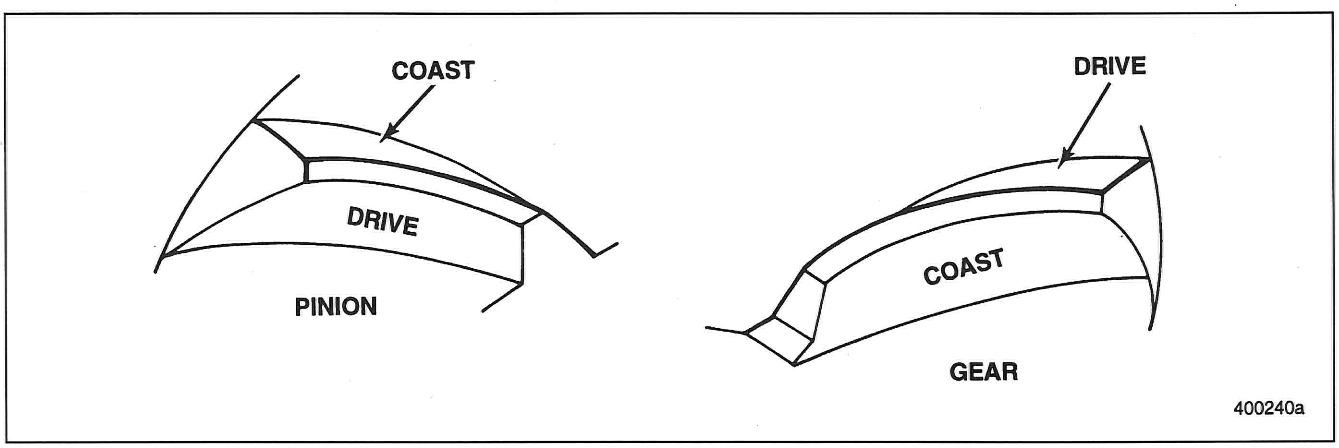

Figure 17 - Spiral Bevel Gear Teeth

STRAIGHT BEVEL GEARS

Bevel gears transfer motion between shafts that are at a right angle to each other. Straight bevel gear teeth have no curvature or angle from toe to heel. They have durability and manufacturing economy similar to spur gears. Differential gears are straight bevel gears.

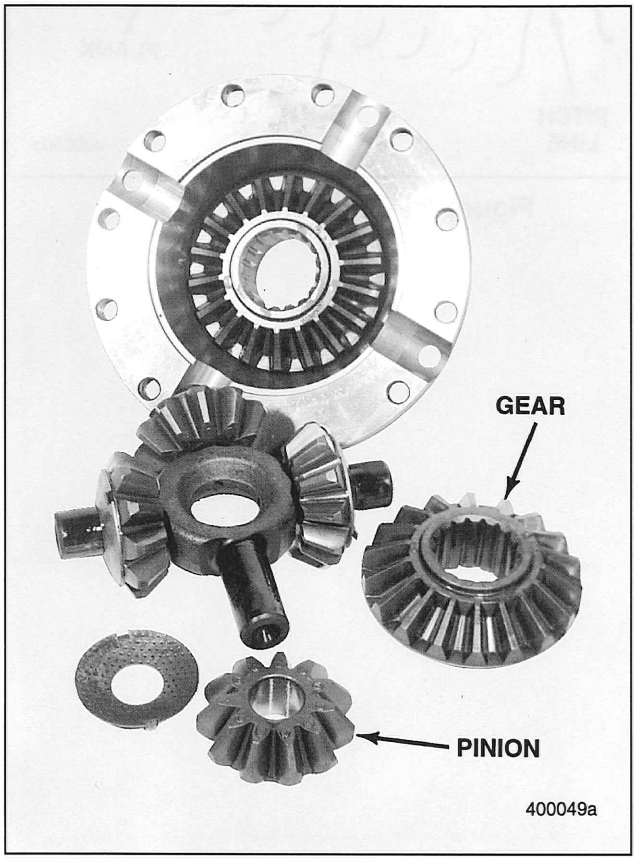

Figure 18 - Straight Bevel Gear Set

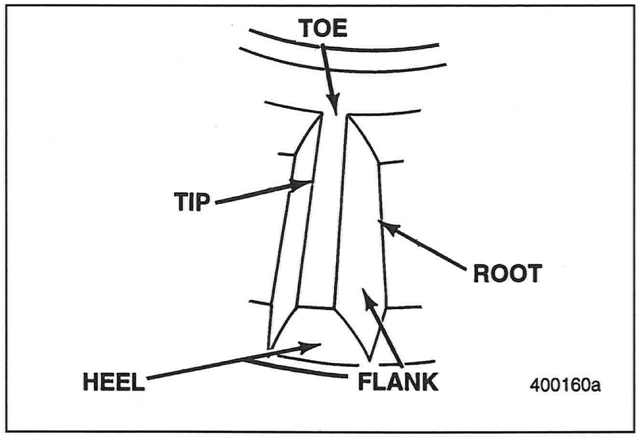

Figure 19 - Straight Bevel Gear Tooth

HELICAL GEARS

Helical gears are modified versions of spur gears. Spur gears have straight teeth that engage two teeth at a time. Helical gears have teeth set at an angle that engage more than two teeth at a time. This permits increased loads, while the more gradual meshing of the gears results in quieter operation at higher speeds. Helical gears are used primarily in carriers where high speeds and heavy loading must be combined with silent operation.

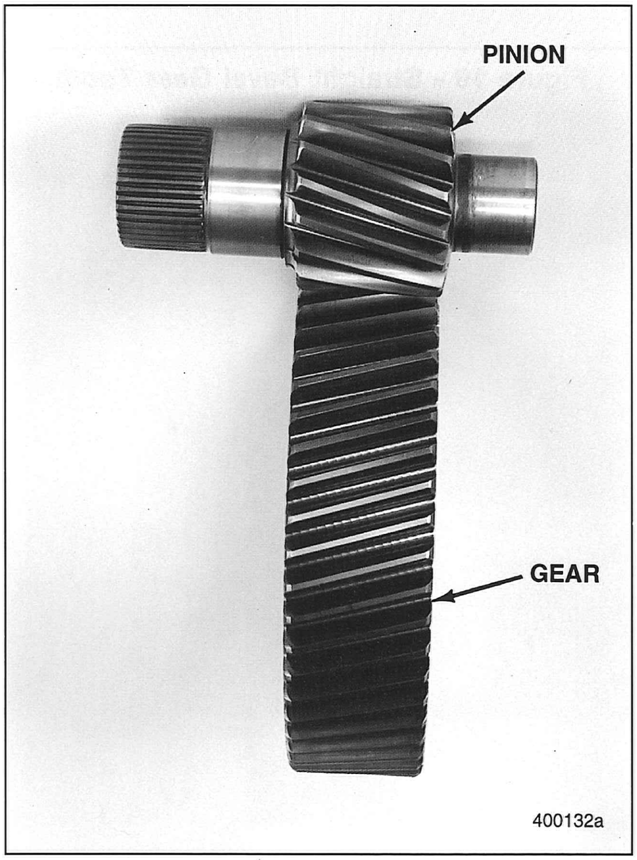

Figure 20 - Helical Gear Set

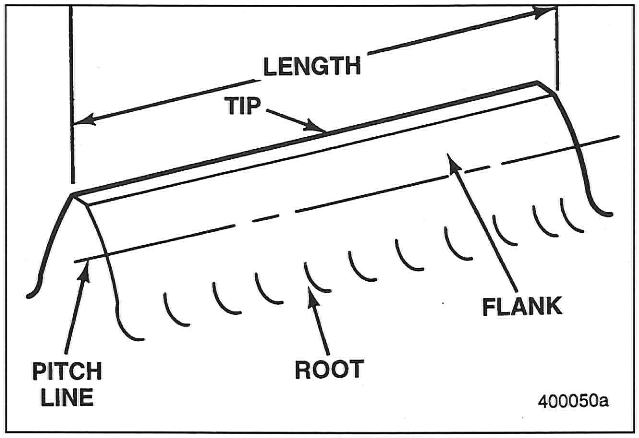

Figure 21 - Helical Gear Tooth

GENERAL TYPES OF FAILURE

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OVERLOAD

Virtually every failure is a type of overload. This word presents the potential for misunderstanding. The word overload conveys a fundamental, technical concept used by educators, engineers and manufacturers in failure analysis. Generally, it means **the application of a force to a structure greater than the structure can withstand without sustaining permanent damage.** Overload is an effect. It results from an endless list of causes or combinations of causes.

There are two general categories of overload. The first is **instantaneous** overload, and the second is **sustained** overload.

Instantaneous overload is **shock** loading. Shock failures result from a rapidly applied force that is severe enough to exceed the strength of the structure and to cause it to crack or break instantly.

If it breaks completely and instantly, it is referred to as **pure shock** loading. It is characterized by a single, uninterrupted break.

If the shock loading is of lesser magnitude and if the structure cracks but does not break instantly, the structure may eventually fail in the fatigue mode initiating from the crack site. This is referred to as **shock-initiated fatigue**.

Sustained overload is the result of application of force to a structure that eventually causes the structure to change shape and suffer surface and sub-surface fatigue effects. Frosting, pitting, flaking, spalling and collapse of the structure are the eventual effects of sustained overload. This type of overloading exceeds the structure's elastic limit (ability to spring back to its original shape) and causes the material to flow (plastic deformation) until fragments crack and break away from the structure.

LUBRICATION PROBLEMS

Contaminated Lubricant

Any lubricant which contains moisture, dirt, or wear particles is defined as a contaminated lubricant. Contaminated lubricant is a common cause of geared unit failure.

There are a number of ways that the lubricant in a geared unit may become contaminated.

- Moisture and dirt can enter the unit through a faulty oil seal or a breather.
- By not cleaning the unit thoroughly around the drain or level plugs, dirt and moisture can enter the unit when checking or refilling lubricant level.
- Wear particles can build up through normal wear while the unit is in service.

Mack carriers utilize magnetic drain plugs as a standard feature. These plugs are used to remove ferrous metallic particles from the lubricant and should be cleaned in accordance with the instructions outlined in the Maintenance and Lubrication manuals.

The latest production Mack top-mounted dual reduction carriers have a trough with magnetic strips attached to the cover. The magnetic strips and the trough should both be cleaned whenever the oil is changed or the cover is removed.

Figure 22 - Contaminated Lubricant Failure

This bearing cup has deterioration in the load zone due to water in the lubricant.

Lubrication Failure

Lubrication failure can be caused by:

- low oil level
- improper oil quality
- contaminated oil
- oil leaks
- clogged passages
- lack of an Extreme Pressure (EP) additive

Failures resulting from improper lubricants or from EP additive depletion will show up on the gear teeth as unusual wear patterns. As the condition worsens, wear particles from the gear teeth will cause contamination of the lubricant and may result in secondary damage to the unit.

⚠WARNING

Do not mix brands or types of lubricant. The chemical additives may not be compatible and, as a result, may cause sludge, acid formation, or hardening of the lubricant.

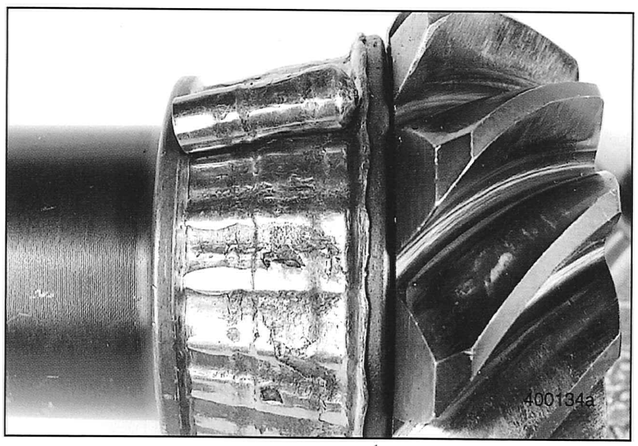

Figure 23 - Lack of Lubrication

This spiral bevel pinion and bearing exhibit over-heating, localized metal transfer, and extreme plastic deformation. These effects have been caused by an inadequate volume of oil to keep metal parts separated and to carry heat away.

As the lubricant level in any geared unit gets too low, the friction between parts will generate heat. If the temperatures are allowed to get hot enough, the lubricant will become burned and the parts will become galled.

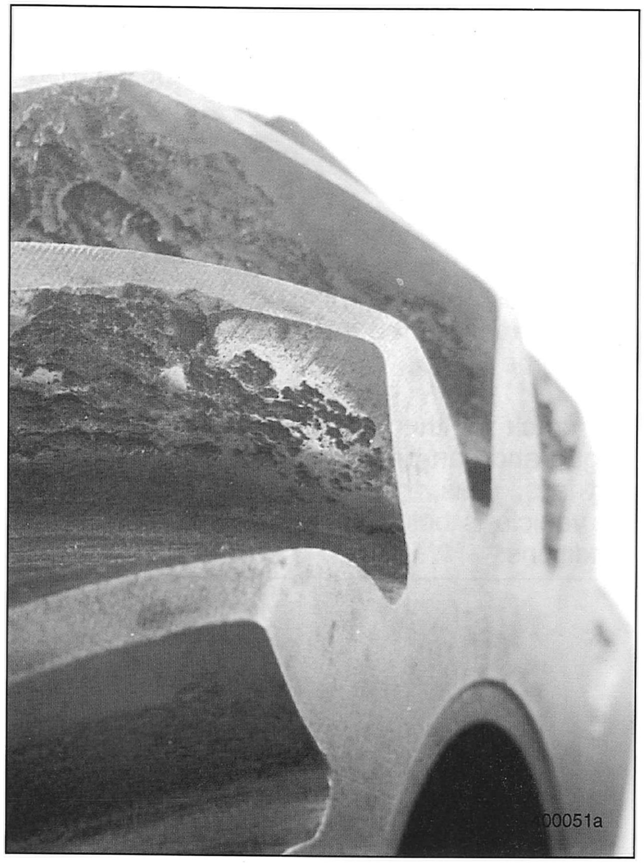

Figure 24 - EP Additive Failure

In this example, the EP additive has been exhausted due to lack of maintenance. The pitting shown here extends over the entire surface of the tooth, which is typical of a lubrication failure. Oil maintenance is covered in the Lubrication and Maintenance manuals.

Improper Lubricant Maintenance

Using the Wrong Oil

Improper lubricant or lubricant with depleted additives can cause gear set failures. The wrong gear lube will not provide adequate lubricant film protection and gear failure may occur.

Lack of Adhering to the Required Maintenance Schedule

It is important to understand that additive packages break down as mileage increases. If the lubricant is overheated, the additive package breaks down faster. Keeping the lubricant at its proper level and changing it at proper intervals prevents wear caused by broken down or depleted additives.

SHOCK LOAD

Shock load results from a rapidly applied load or force that is severe enough to exceed the strength of the component and will cause immediate damage.

If the failed part separates into two or more pieces, the operator will usually notice immediately. But if the part is only cracked, the operator may not be aware of the damage until some time later.

The crack will then become a point of origin for fatigue and can progress in fatigue until the part fails. Thus, the failure could happen while the vehicle is being operated under normal conditions.

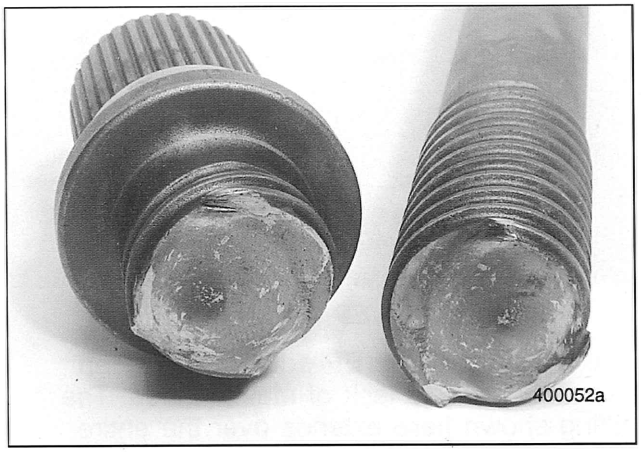

Figure 25 - Impact Failure

METAL FATIGUE

Metal fatigue is probably the most common type of specific failure. Failure due to fatigue occurs when parts are subjected to repeated "stress."

Stress is a force acting upon a particular material which resists being deformed. When a load is applied, it tends to produce deformation, and it is restricted by the stress it creates within the material. The maximum stress a metal will withstand for an infinite number of cycles without failing is known as the fatigue limit.

There are several different types of mechanical forces. In metal fatigue there are a few main types to consider.

- Shear stress
- Tensile stress
- Compression stress
- Torsion stress

Shear stress is a force applied parallel to a surface. It is also known as tangential stress because the force is applied on a tangent to the axis of the part. Parts subject to shear stress include gear teeth and axle spindles.

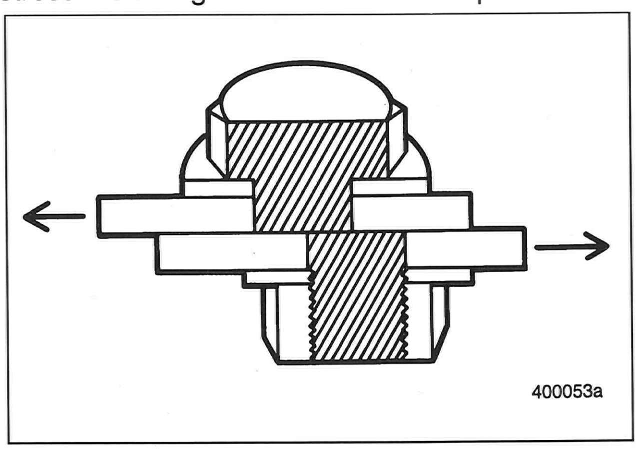

Figure 26 - Shear Stress

Tensile stress is a stretching or pulling force applied parallel to the axis of a part. A common test of material strength is a tensile test, in which a sample of material is stretched until it fractures. Parts commonly subjected to tensile stress include capscrews and bolts.

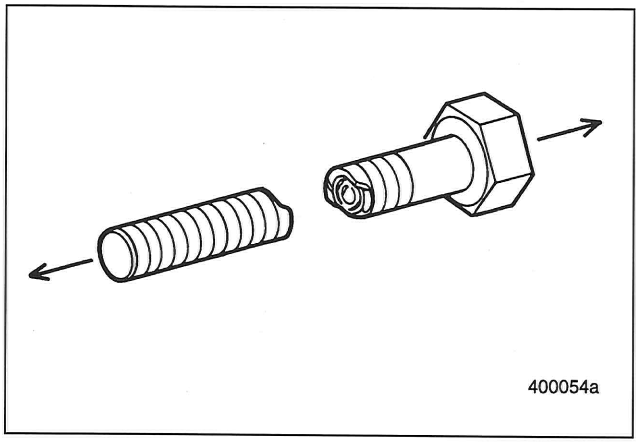

Figure 27 - Tensile Stress

Compression stress is a force applied parallel to the axis in the direction of its center. A compression test is also commonly used to determine material strength. Parts commonly subject to compression forces include tapered roller bearings and races.

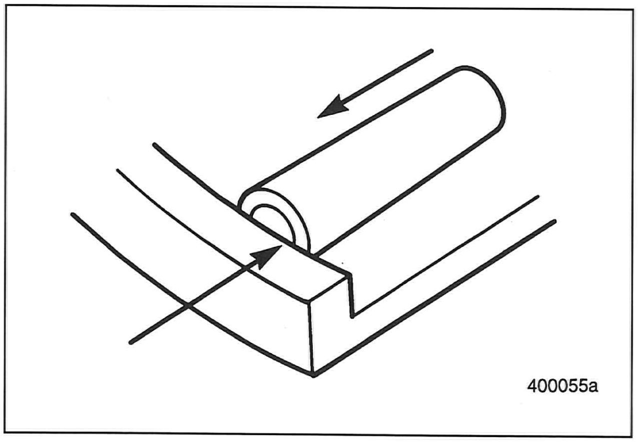

Figure 28 - Compression Stress

Torsion stress is a force that acts in rotation around the axis of a part. The area of final failure is usually a rough crystalline surface, typical of this torsional failure.

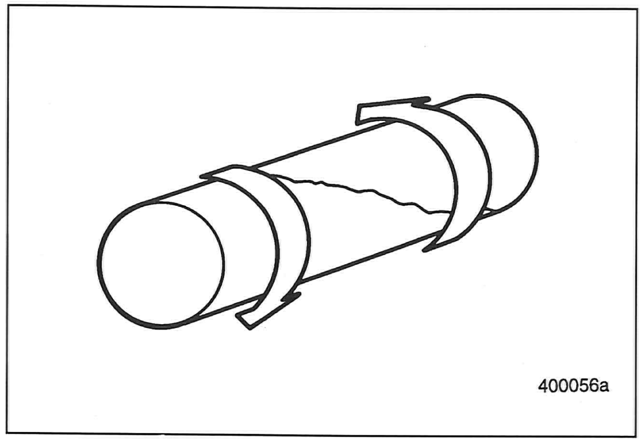

Figure 29 - Torsion Stress

PROBABLE CAUSES OF FAILURE MODES

Differential Assembly failures are typically associated with:

A. Startup conditions including excessive vehicle weight, soft road surfaces and grades that are too steep.

B. Spinout conditions which produce uncontrolled loss of traction and result in seizure and shock loading.

Helical Gear Set failures are associated with:

A. Sustained torque overloading caused by too-high vehicle weight and road conditions that result in excessive torque demands.

B. Shock loading caused by sudden changes in torque loading like impacting a stationary object or a spinning wheel suddenly gaining traction.

Spiral Bevel Gear Set failures usually result from:

A. Sustained high torque loads at road speeds possibly caused by too-high vehicle weights, steep grades and low oil fill.

B. Shock load impact often caused by coast side impact – i.e., backing into a dock.

Common Misconceptions

A common perception is that one carrier fails and the other does not. Although in some applications, one carrier is seen to fail first, general experience shows either carrier can fail first and, if the overloading is substantial, the second carrier fails in a short period of time.

Another common perception is that one tooth spalls while the others do not. If this condition is found and no other distress is evident on the other teeth, the condition was caused by a probable manufacturing fault. Typically, multiple teeth spall with additional teeth being severely worn. Occasionally, a single tooth spalls out and other teeth will show wear and plastic deformation with sharpened tips. This condition is not indicative of a manufacturing fault.

SPECIFIC FAILURE ANALYSIS

400195a

DIFFERENTIAL ASSEMBLY

Extreme Overload

This differential failure is primarily due to extreme overload and to lubrication breakdown. The actual chipping of the metal leads to debris and lubricant contamination. Also, there is plastic deformation and pitting.

Additionally, extreme overloading also produces gear separation forces capable of flowing and impressing or even breaking differential pinion washers. These separation forces coupled with those of the bull system can cause differential roller bearings to lock up. The bearing inner race then actually turns on the differential case trunnion and machines into this cast steel component under these excessive loadings.

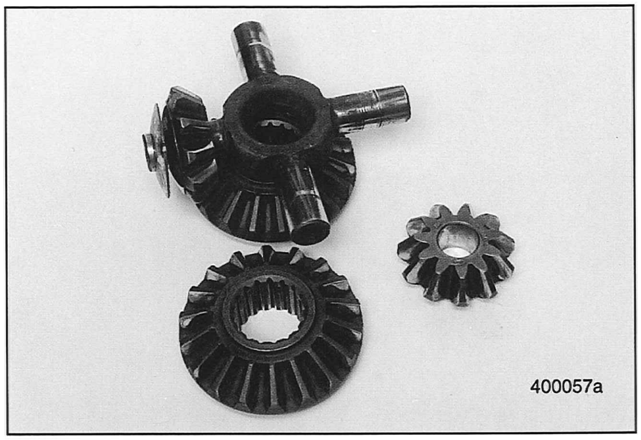

Figure 30 - Extreme Overload

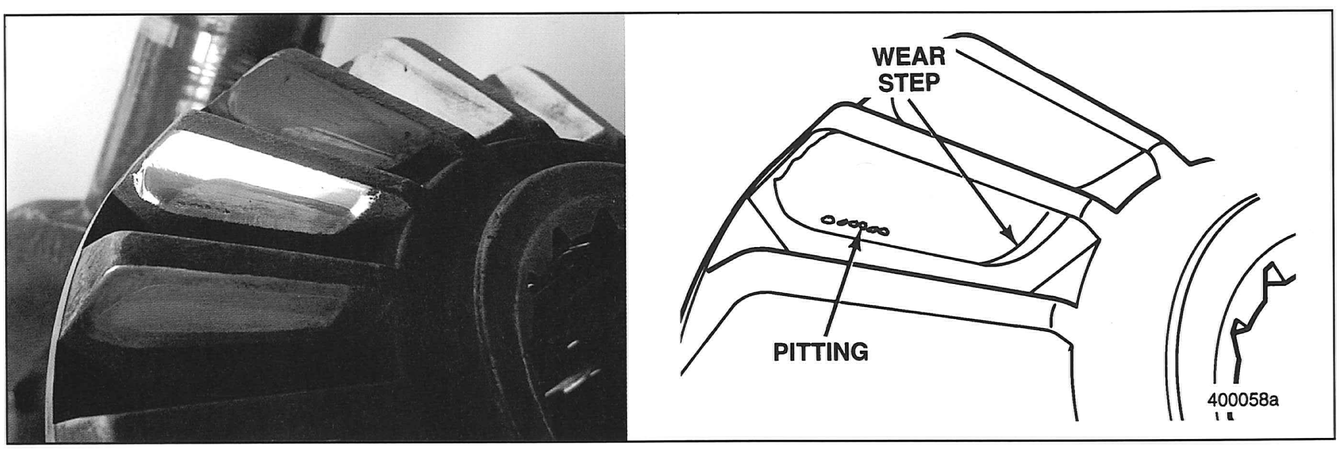

Figure 31

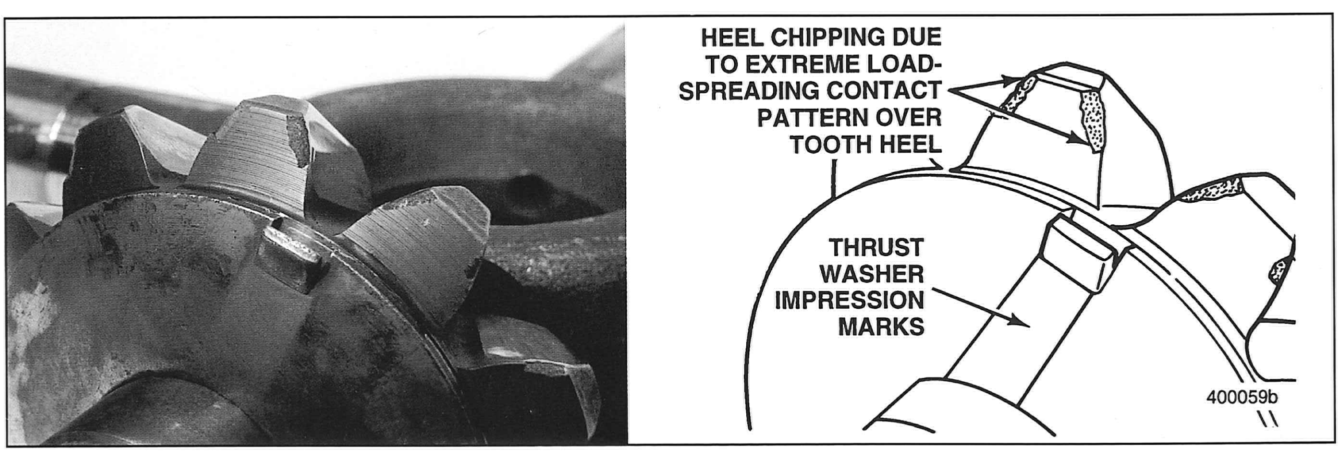

Figure 32

DIFFERENTIAL ASSEMBLY

Extreme Overload

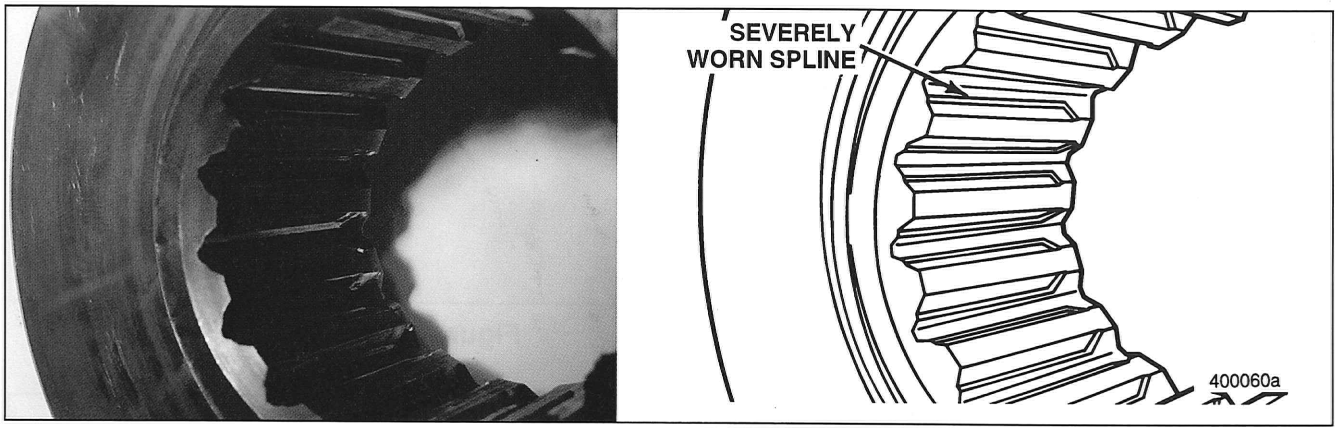

Figure 33

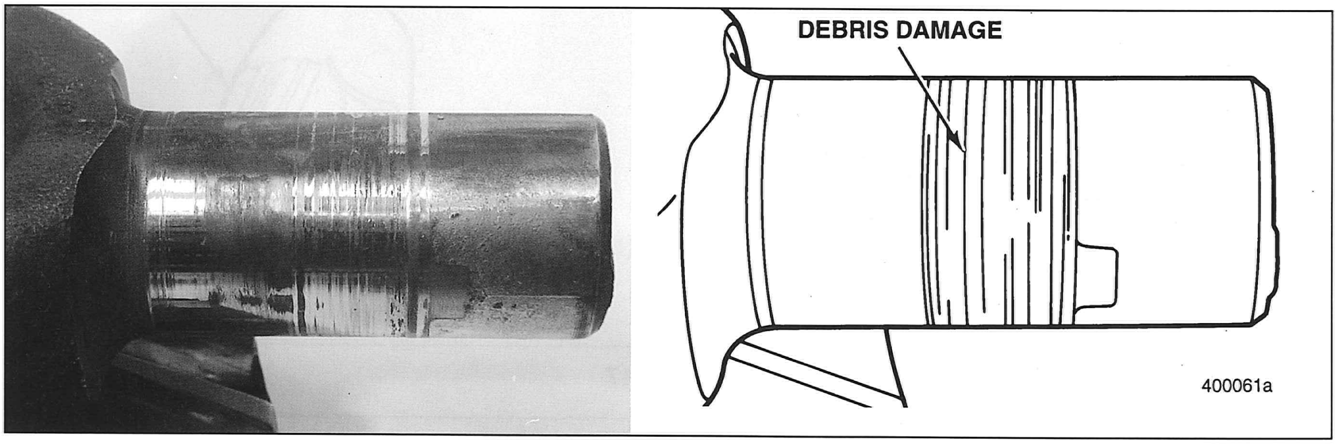

Figure 34

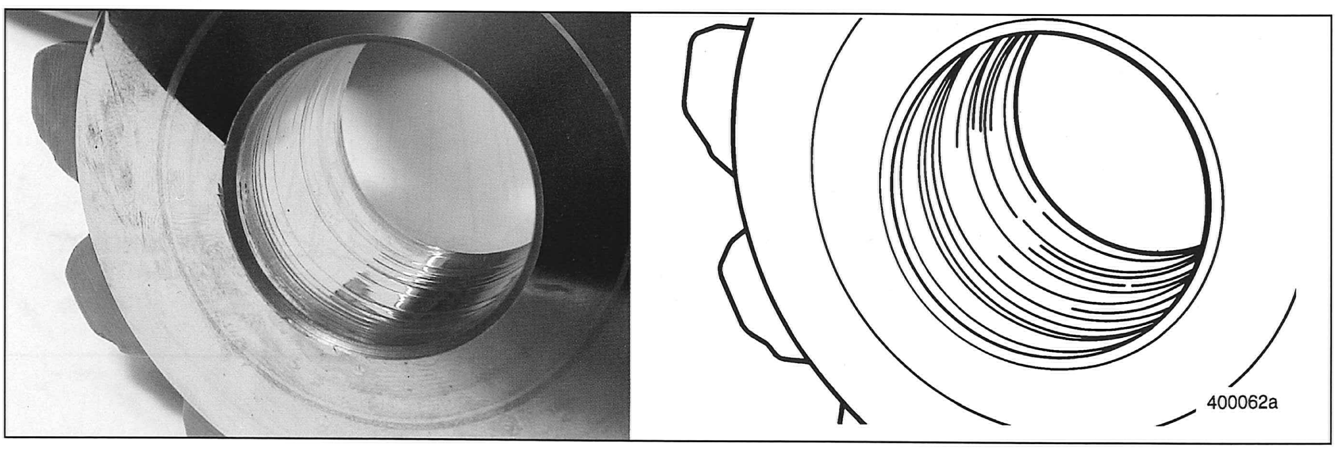

Figure 35

DIFFERENTIAL ASSEMBLY

Bending Fatigue

These pictures show an example of bending fatigue. The most likely cause of this kind of failure is a sustained torque overload.

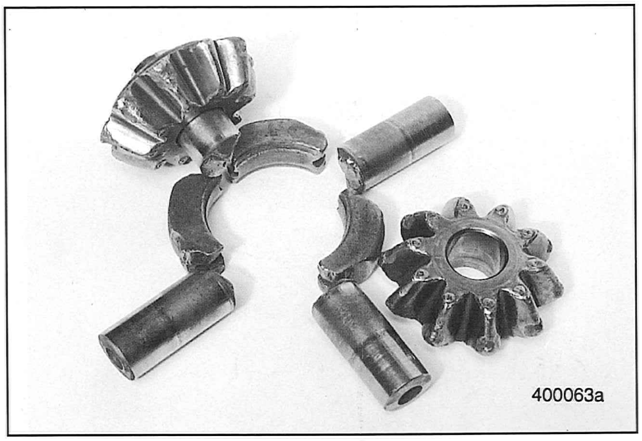

Figure 36 - Bending Fatigue

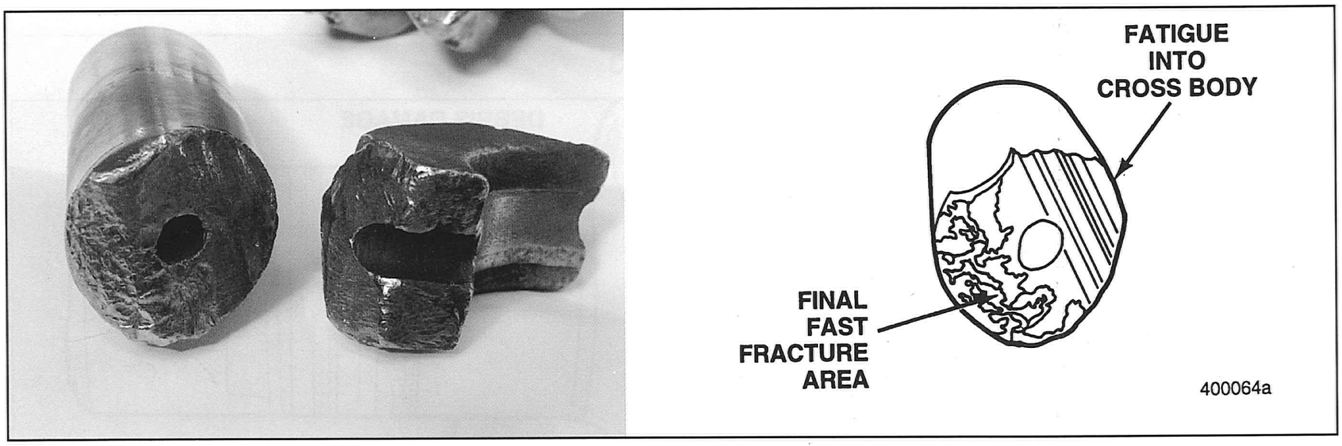

Figure 37

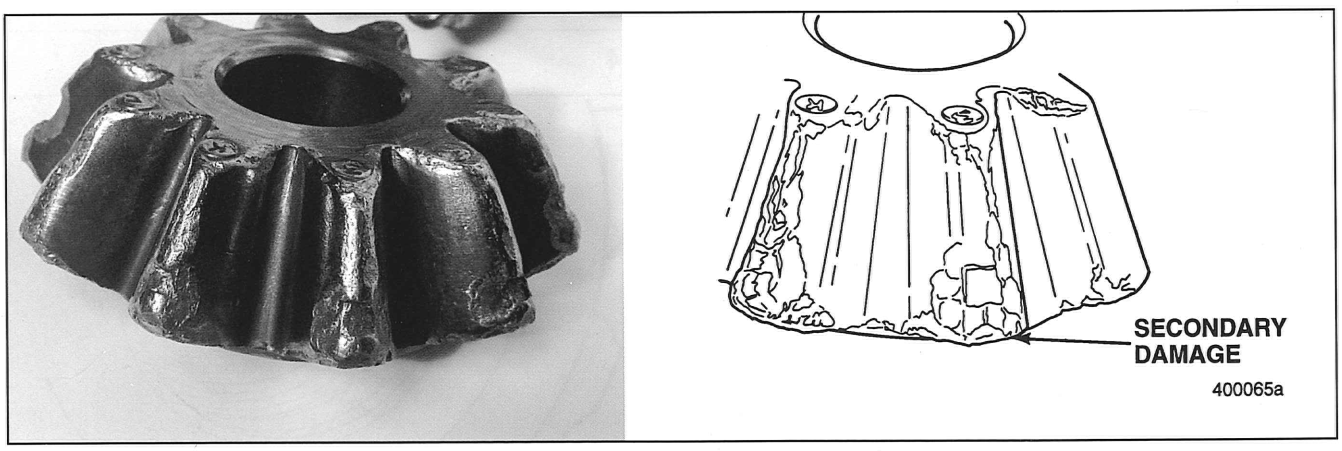

Figure 38

DIFFERENTIAL ASSEMBLY

Spinout

Spinout is an out-of-control loss of traction resulting in one or more wheels spinning. In this example the gears spun so fast that the lubricant broke down. Heat built up to the point of causing welding and metal transfer.

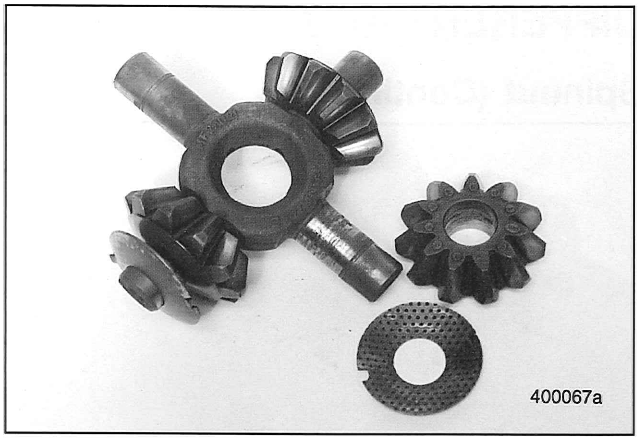

Figure 39 - Spinout

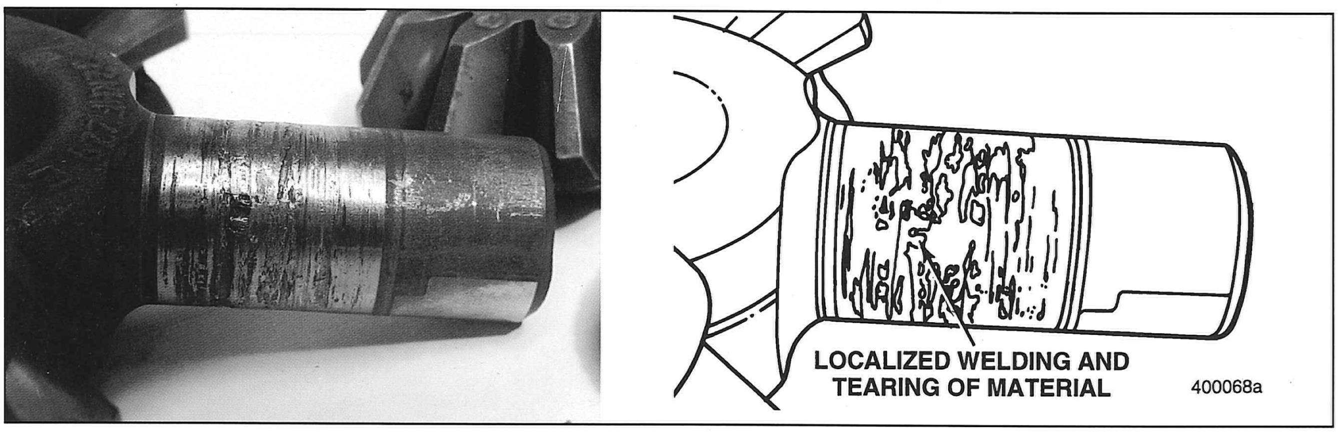

Figure 40

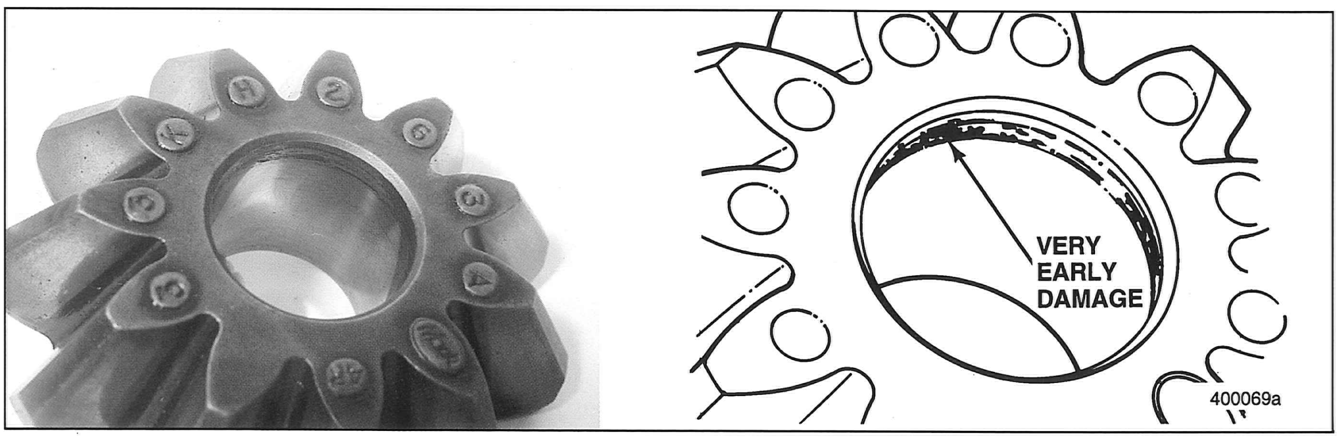

Figure 41

DIFFERENTIAL ASSEMBLY

Spinout (Continued)

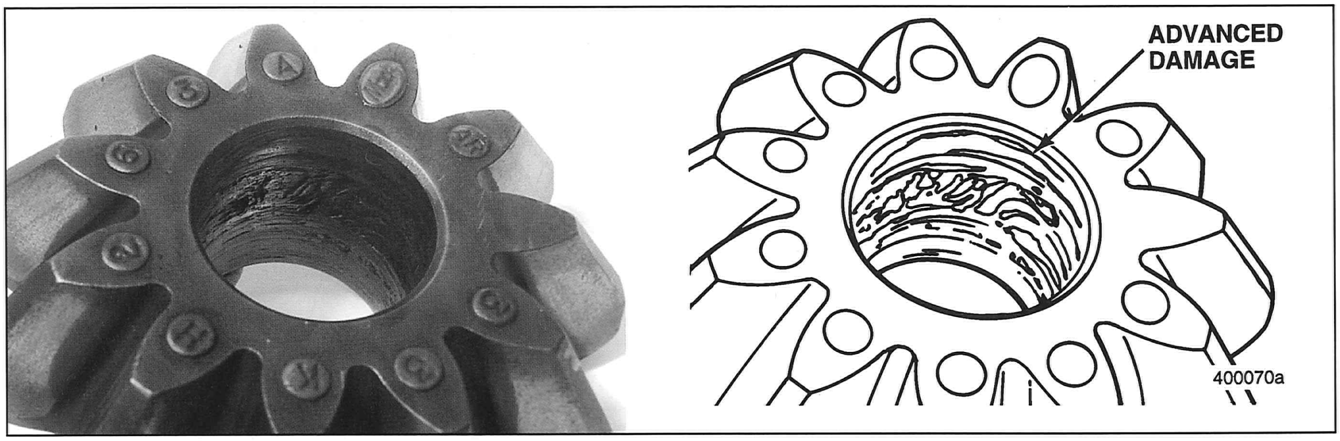

Figure 42

DIFFERENTIAL ASSEMBLY

Advanced Spinout

In this case the spinout is so severe that the differential pinion locked up on the trunnion causing it to twist off.

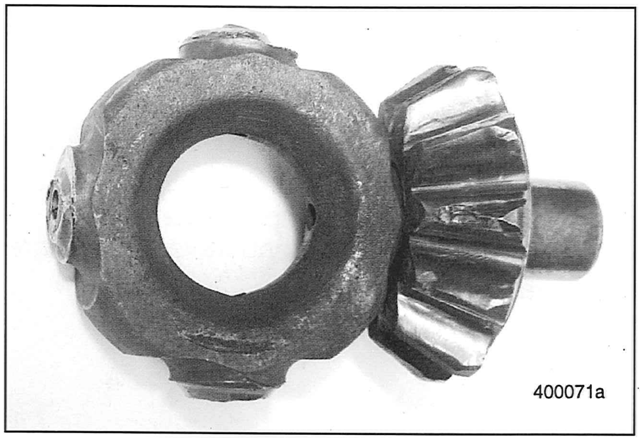

Figure 43 - Advanced Spinout

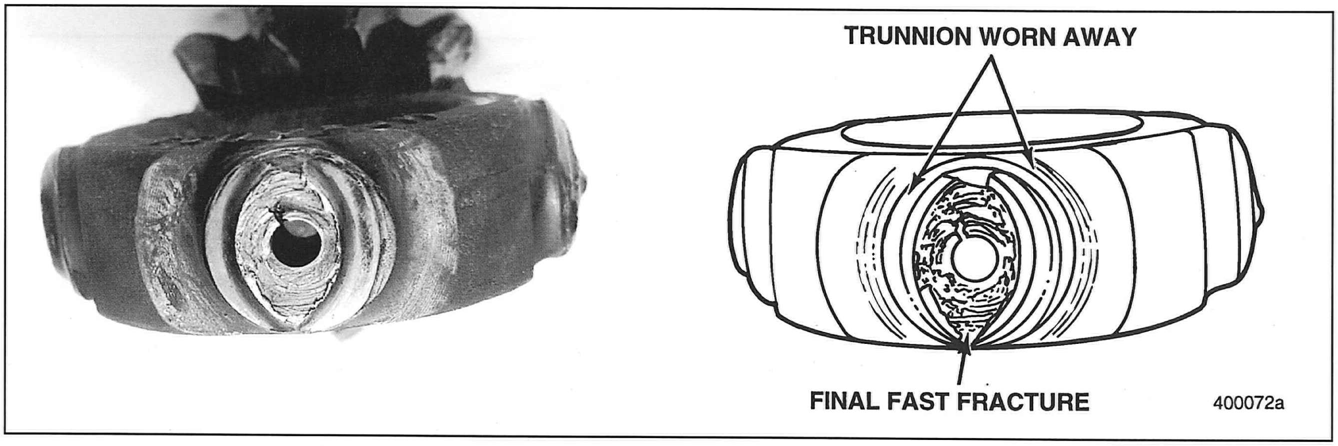

Figure 44

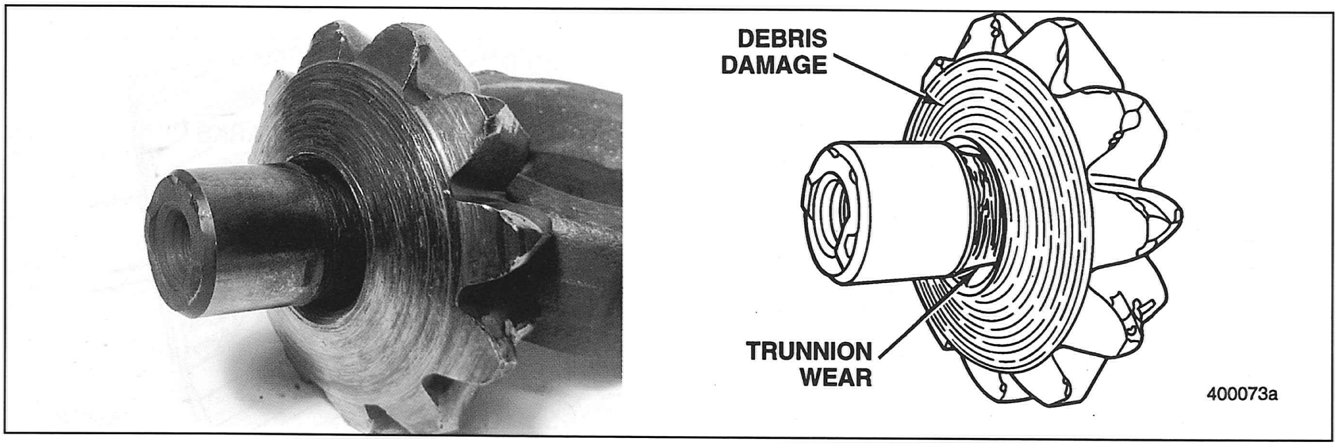

Figure 45

HELICAL GEAR SETS

Surface Fatigue with Shock-Initiated Bending Fatigue

Helical pinion failure due to overload is shown here. This example also shows extensive spalling on the gear teeth and several teeth are broken by bending fatigue.

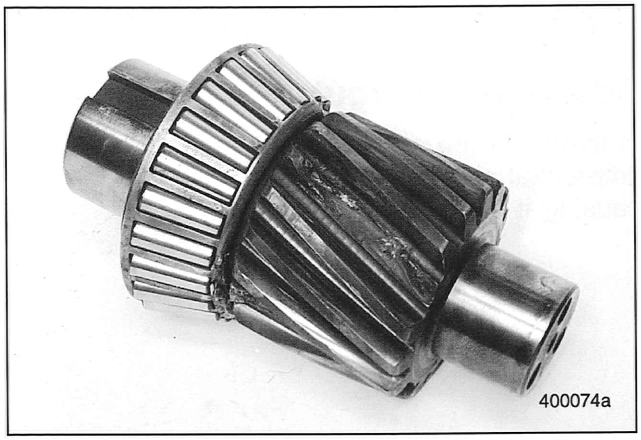

Figure 46 - Contact Fatigue with Shock-Initiated Bending Fatigue

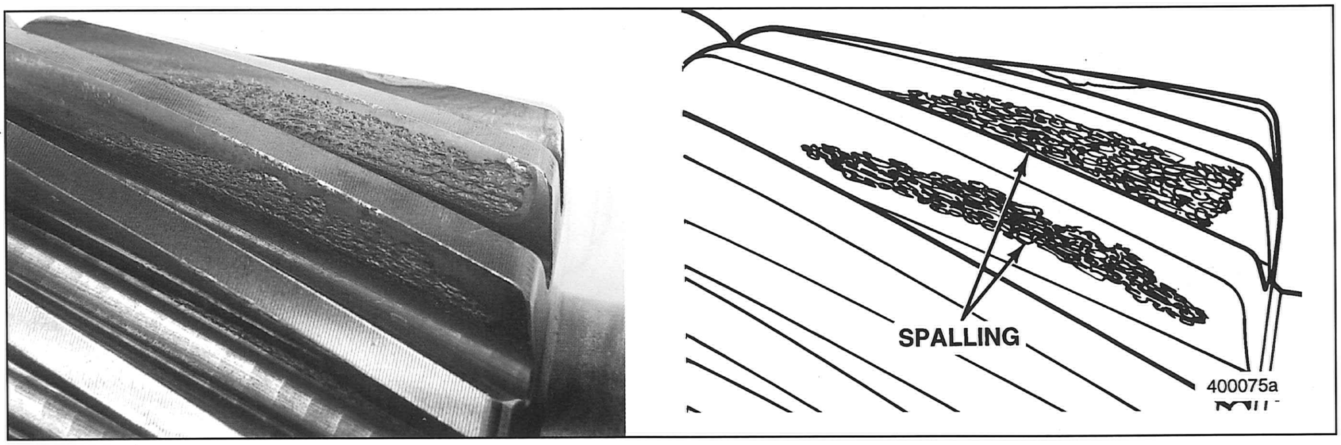

Figure 47

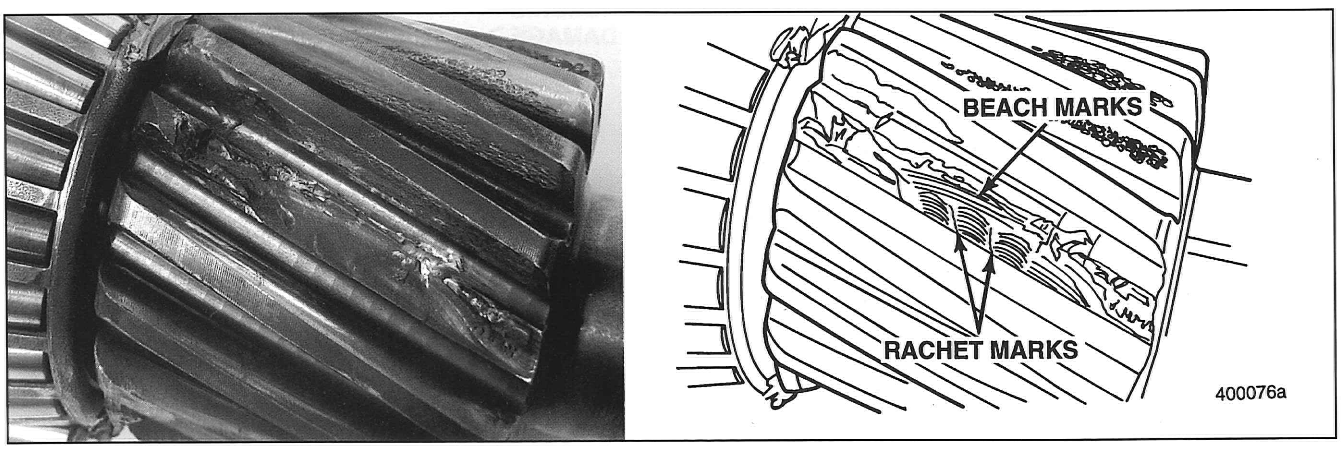

Figure 48

HELICAL GEAR SETS

Surface Fatigue

Here, overload has caused wear, plastic deformation, pitting and spalling across all pinion tooth flanks.

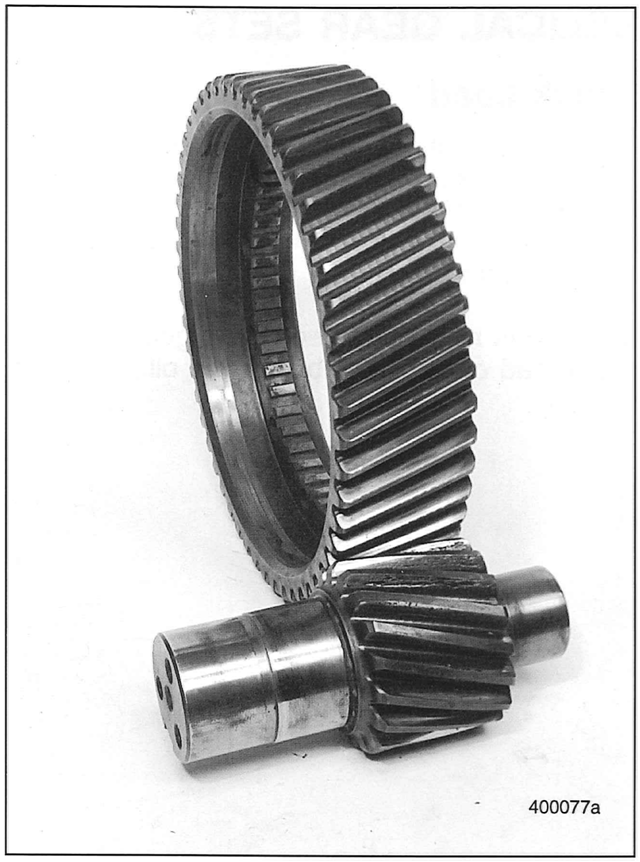

Figure 49 - Surface Fatigue

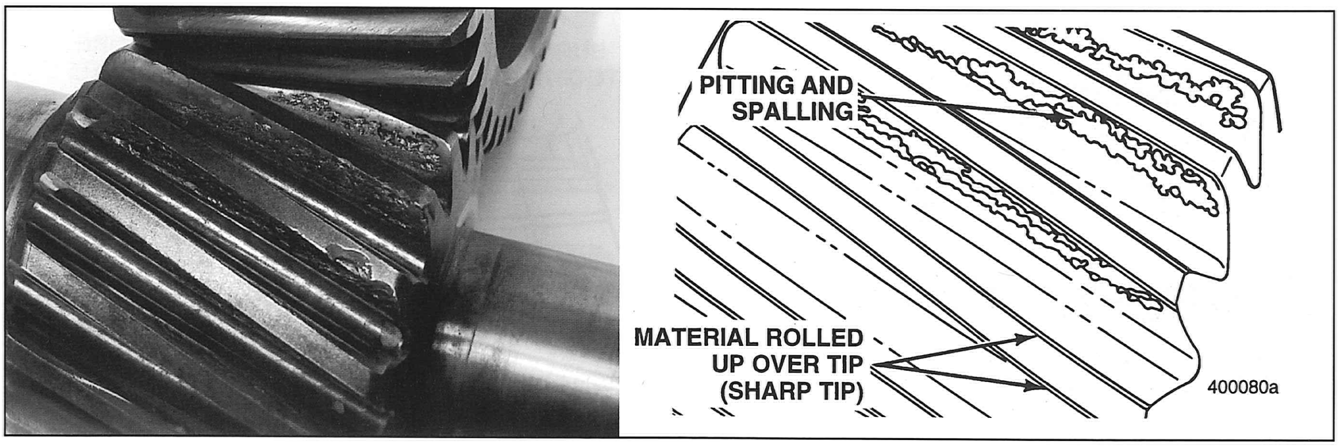

Figure 50

HELICAL GEAR SETS

Shock Load

These photos show gear failure due to shock load. The tooth has broken off completely across the surface. This is a fast fracture shown by the grainy texture and lack of beach or arrest marks.

Other parts may have been damaged by the shock load or due to debris in the oil.

Figure 51 - Shock Load

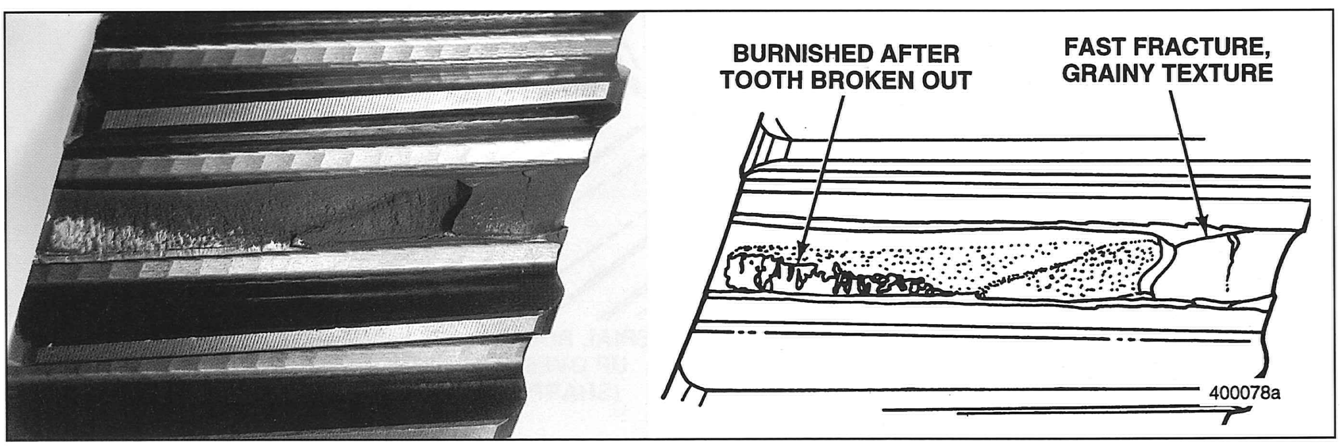

Figure 52

HELICAL GEAR SETS

Bearing Lubrication Failure

This bearing has failed because of lubrication breakdown and/or high load. The inner race is worn and battered. The tapered rollers are pitted and the thrust faces are worn due to skewing. The outer race is pitted in the area of maximum loading.

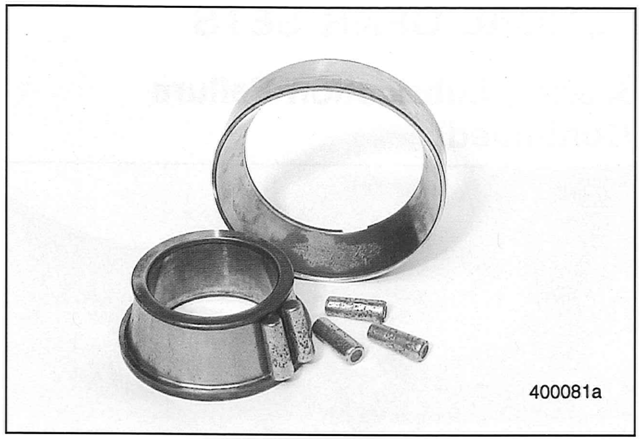

Figure 53 - Bearing Lubrication Failure

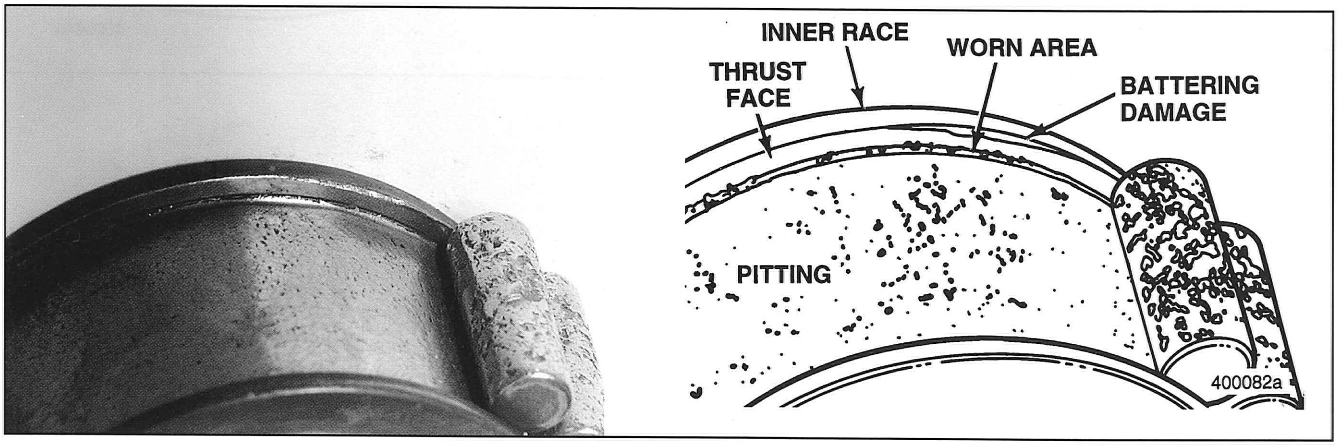

Figure 54

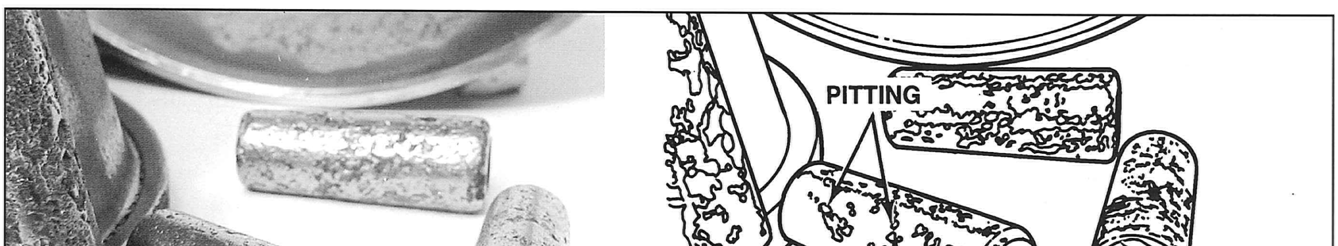

Figure 55

HELICAL GEAR SETS

Bearing Lubrication Failure (Continued)

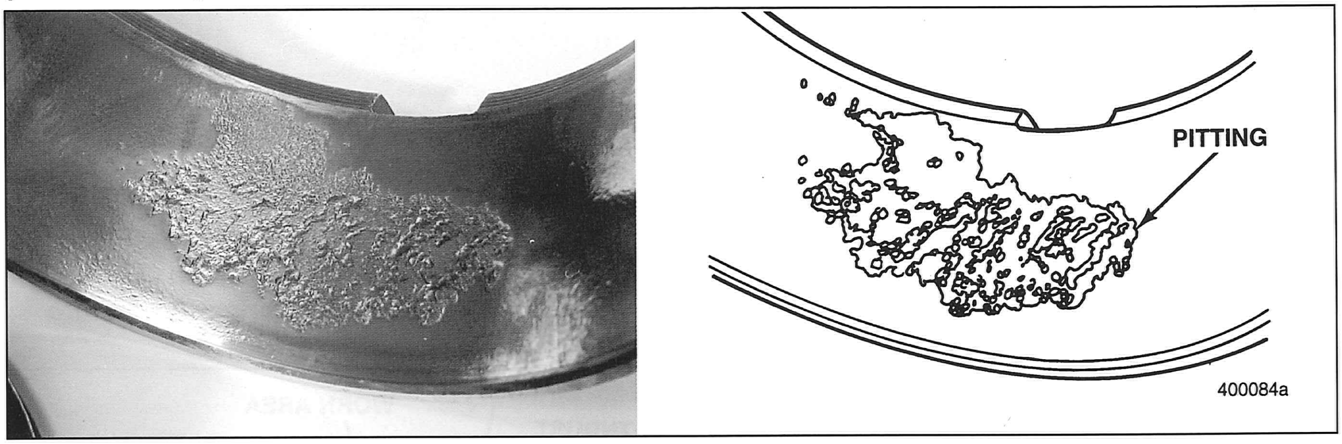

Figure 56

SPIRAL BEVEL GEAR SETS

Low Cycle Fatigue

This gear failure was due to low cycle fatigue. It has a high overstress. Very few beach marks are evident. Notice the large final fast fracture zone.

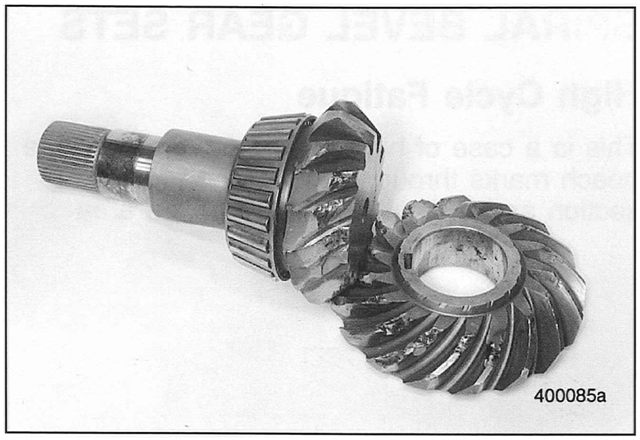

Figure 57 - Low Cycle Fatigue

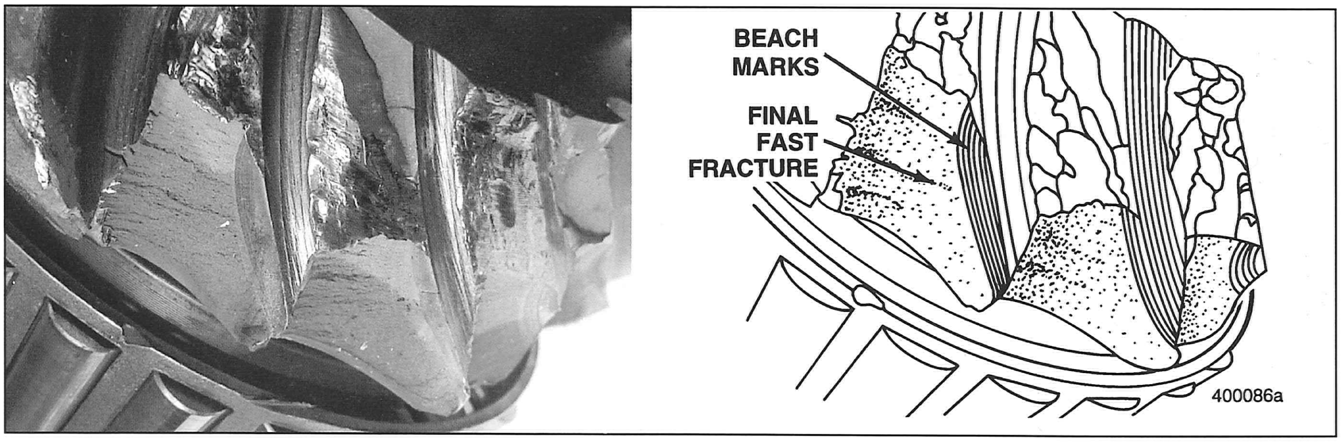

Figure 58

SPIRAL BEVEL GEAR SETS

High Cycle Fatigue

This is a case of high cycle fatigue. There are beach marks through most of the tooth cross section and a small final fast fracture area.

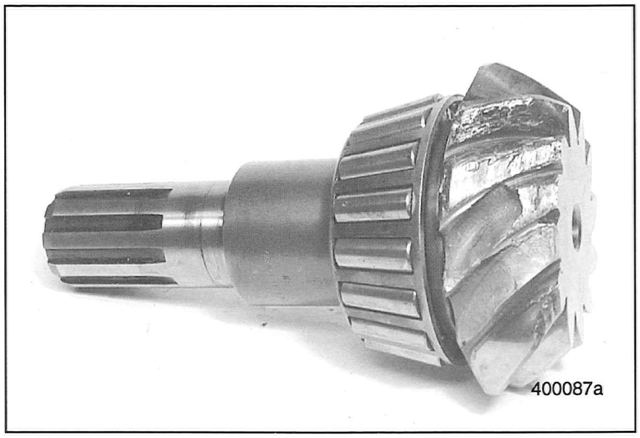

Figure 59 - High Cycle Fatigue

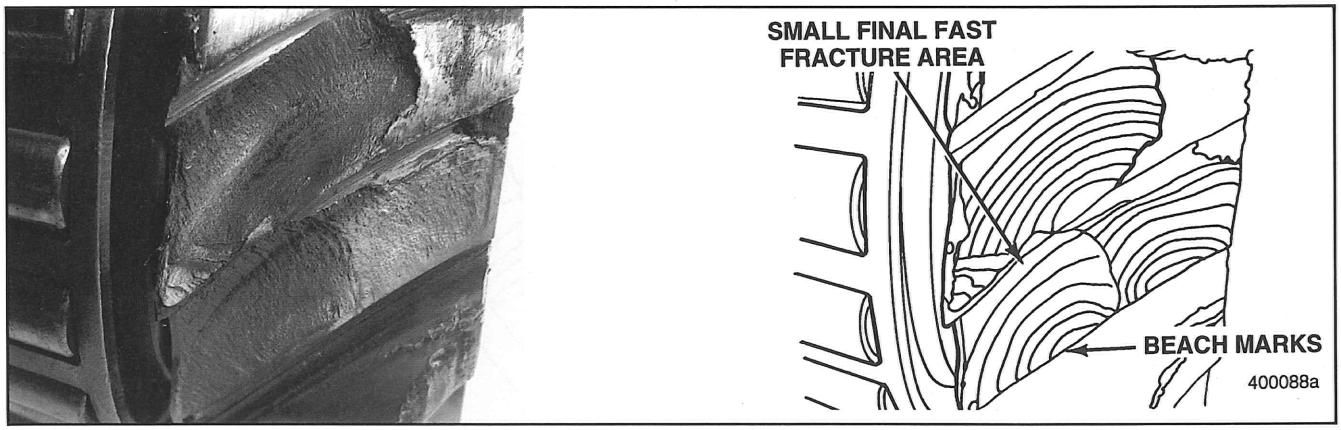

Figure 60

SPIRAL BEVEL GEAR SETS

Surface Fatigue

The cause of failure in this gear was overload. Note the erosion of the tooth surface material. The material is rolled over and the tip is sharp. Pitting and spalling commonly starts at a high stress area and spreads across the tooth contact areas.

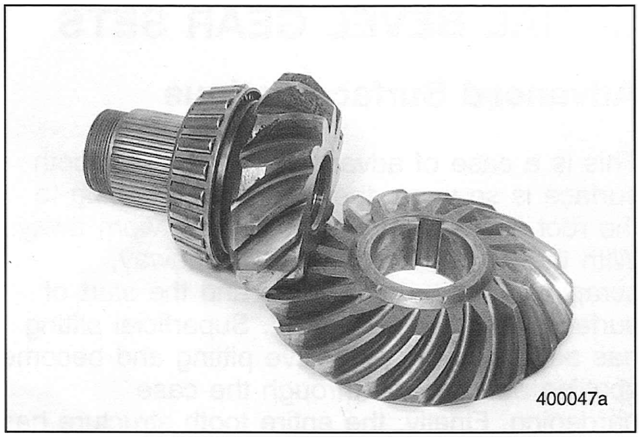

Figure 61 - Surface Fatigue

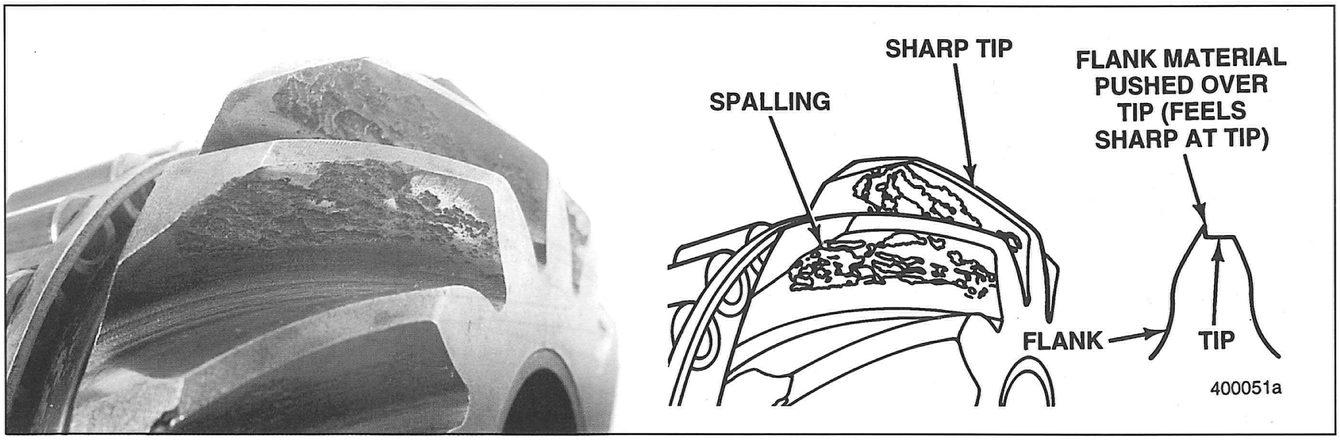

Figure 62

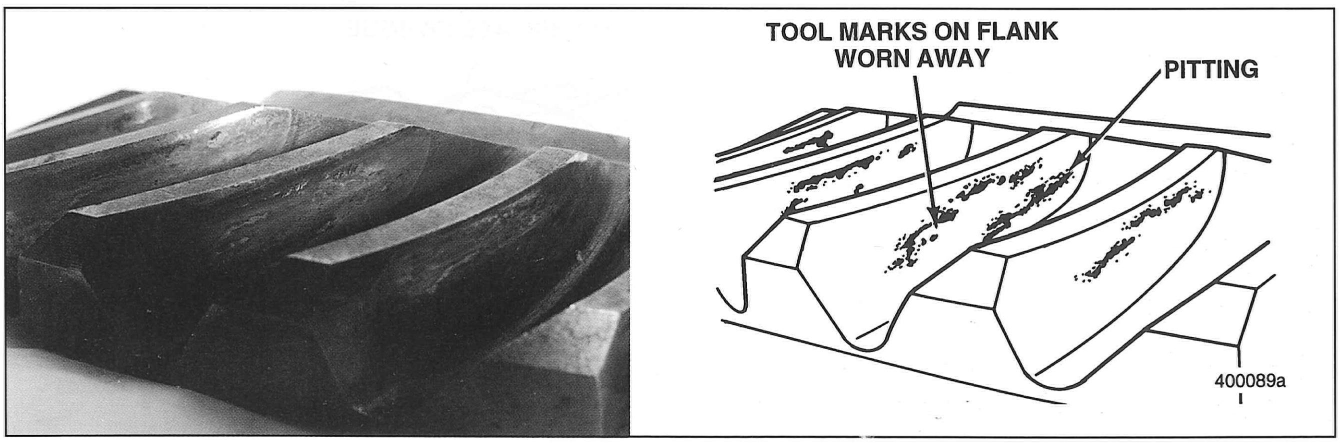

Figure 63

SPIRAL BEVEL GEAR SETS

Advanced Surface Fatigue

This is a case of advancing failure. The tooth surface is so worn, the contact is dropping to the root. Note all tooling marks are worn away. With the active tooth profile worn away, scraping, plastic deformation and the start of surface pitting has occurred. Superficial pitting has advanced to destructive pitting and become spalling as it moved through the case hardening. Finally, the entire tooth structure has begun to fatigue and break down.

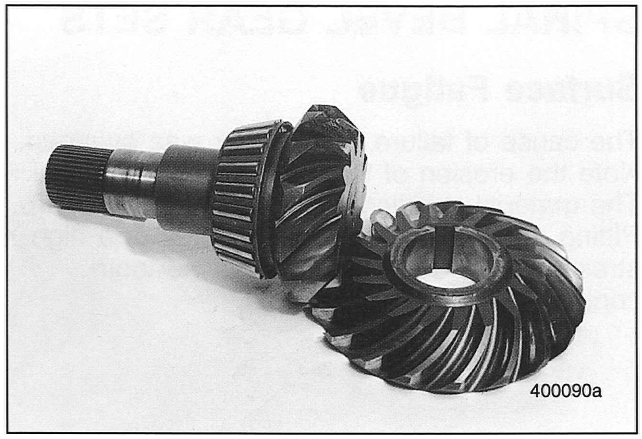

Figure 64 - Advanced Surface Fatigue

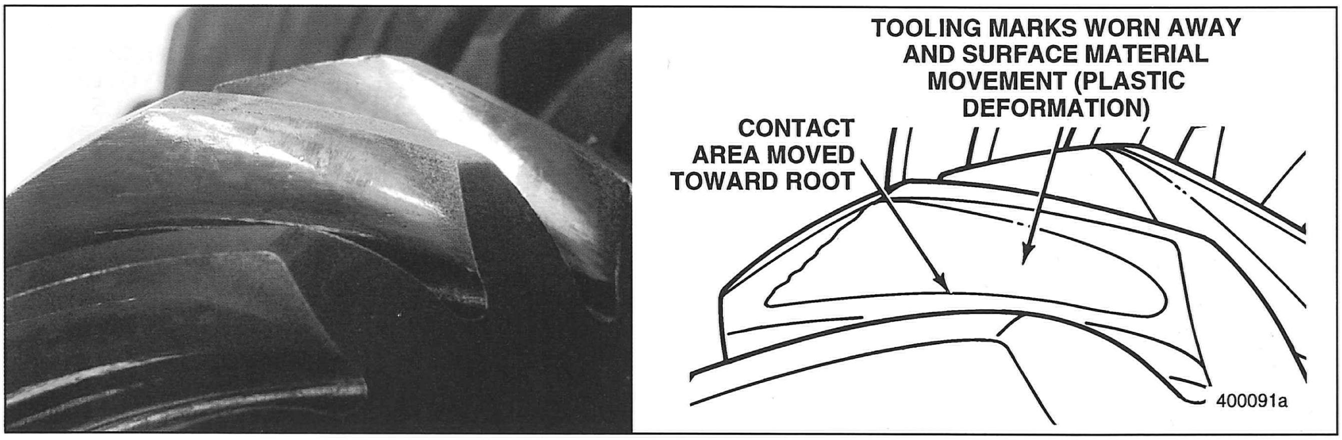

Figure 65

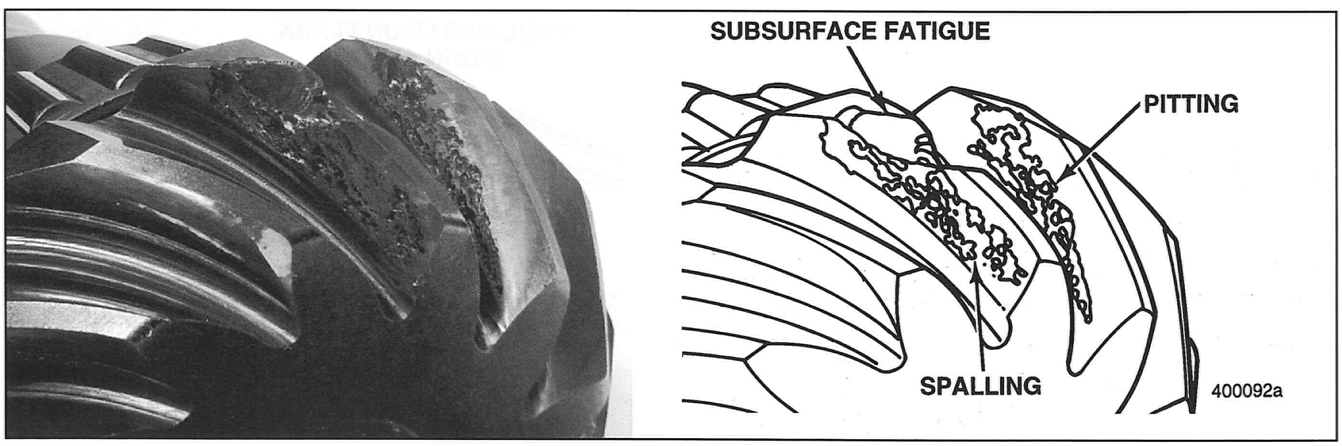

Figure 66

SPIRAL BEVEL GEAR SETS

Power Divider Nut Loosened

The power divider nut has loosened, allowing the pinion to move toward the gear and lose all backlash. The resulting interference caused the tips of the pinion to break down and the central areas of the gear teeth to break out.

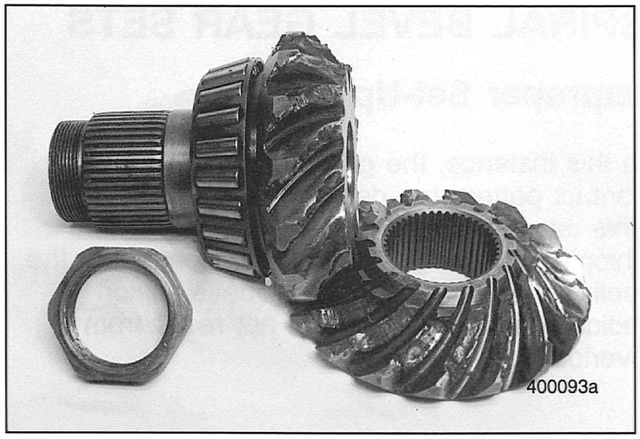

Figure 67 - Power Divider Nut Loosened

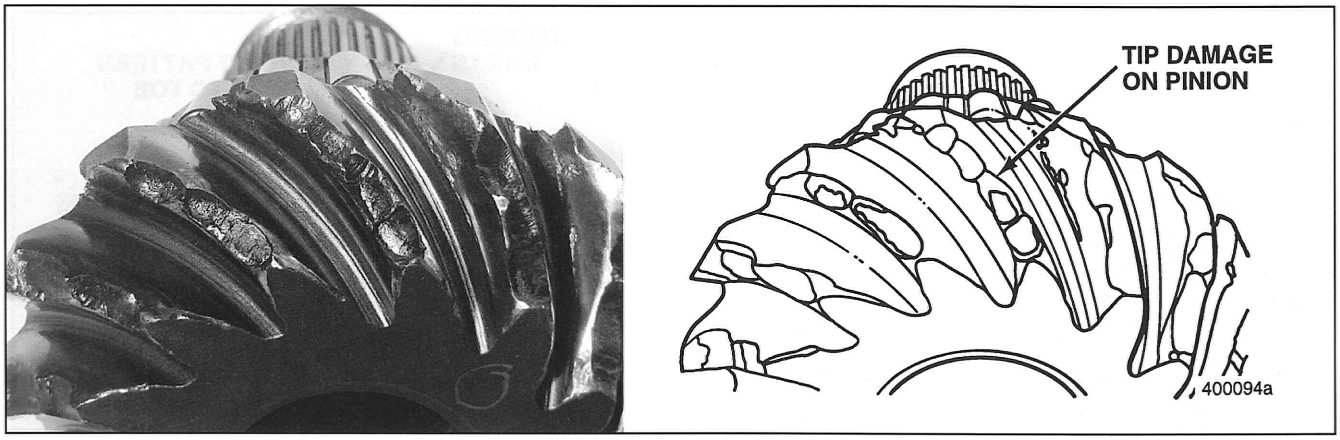

Figure 68

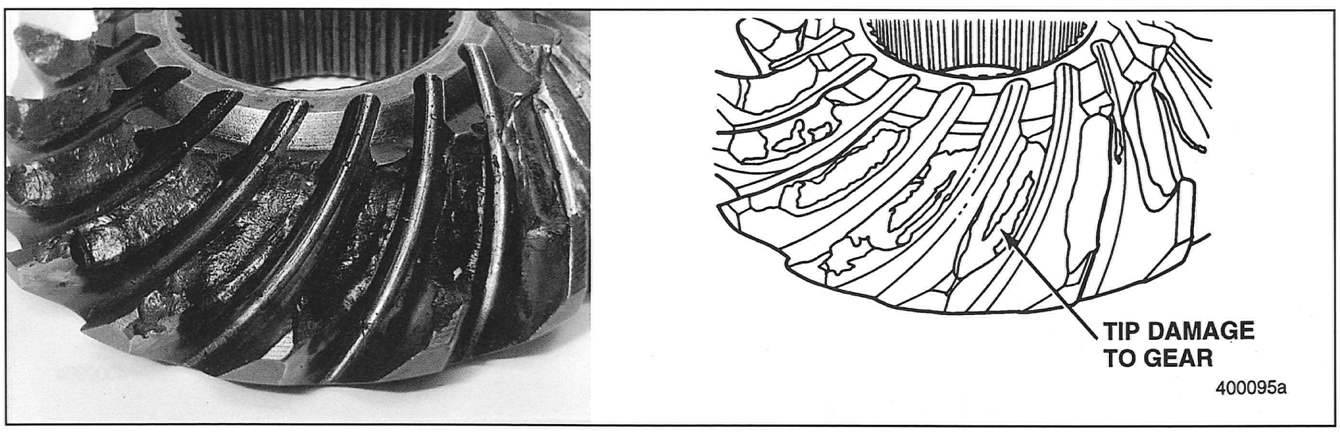

Figure 69

SPIRAL BEVEL GEAR SETS

Improper Set-Up

In this instance, the gear was set up with the contact pattern too deep into the pinion root. This caused pitting on the bevel pinion and chipping on the gear drive tips. Notice that the tooling marks are still on the bevel pinion indicating this condition did not result from overload.

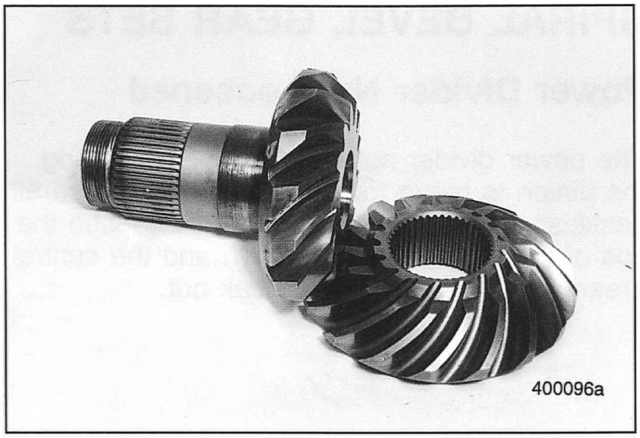

Figure 70 - Improper Set-Up

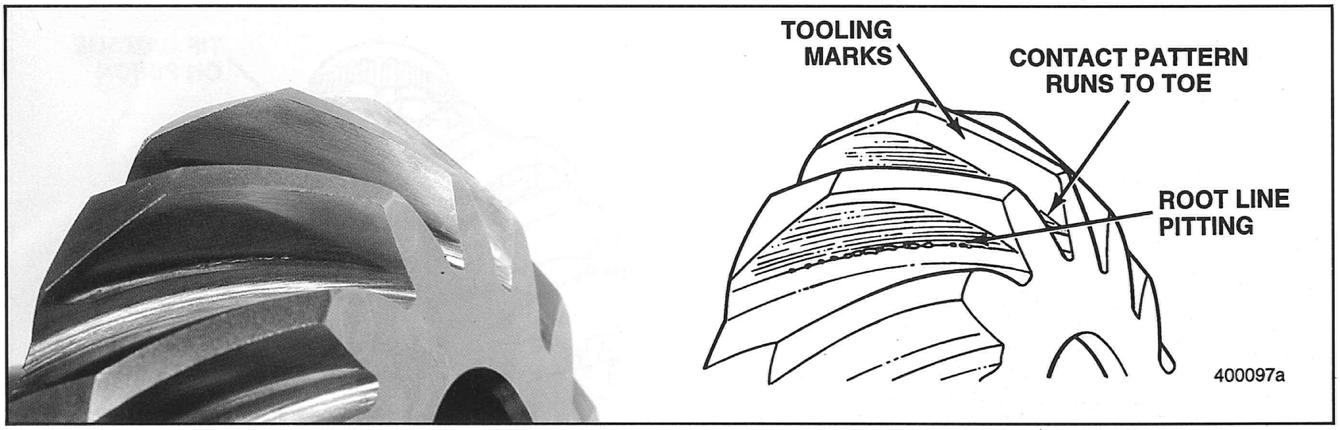

Figure 71

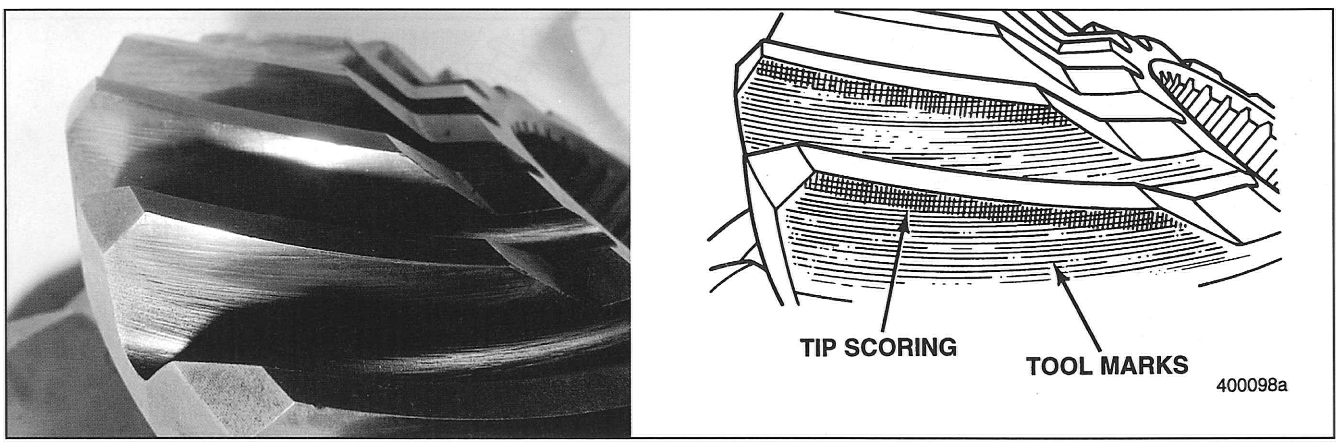

Figure 72

SPIRAL BEVEL GEAR SETS

Improper Set-Up (Continued)

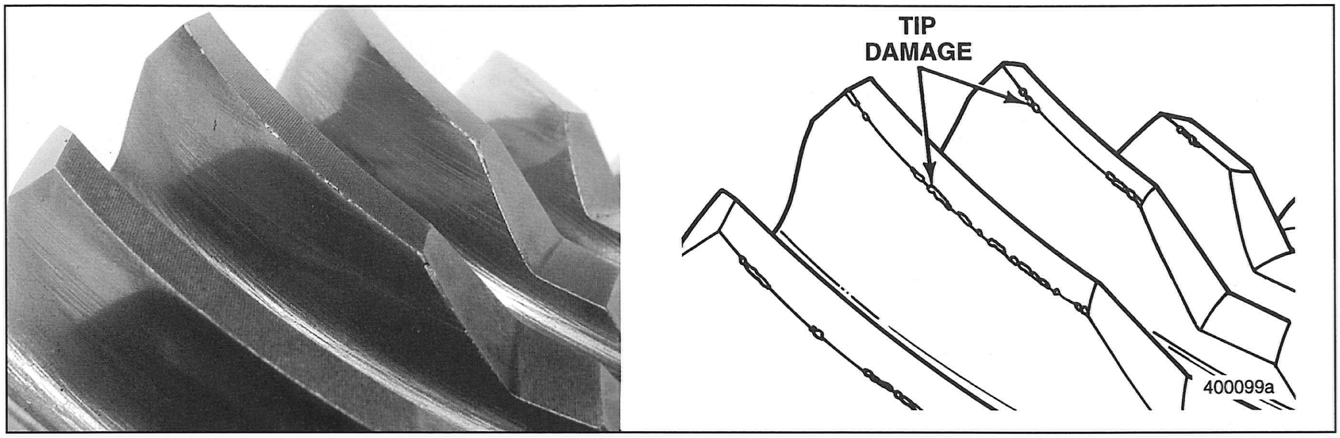

Figure 73

SPIRAL BEVEL GEAR SETS

Lubrication Failure

The EP additive in the lubricant has been depleted and not renewed by changing the lubricant. This resulted in metal-to-metal contact on the gear teeth. The effect is wear and pitting on the gear teeth. Other failures are characterized by pitting starting in localized areas. Lubrication failures are characterized by wear and pitting covering the whole tooth flank. The gear tooth tips are not sharp, due to material movement over the tips, unless overloading has also occurred.

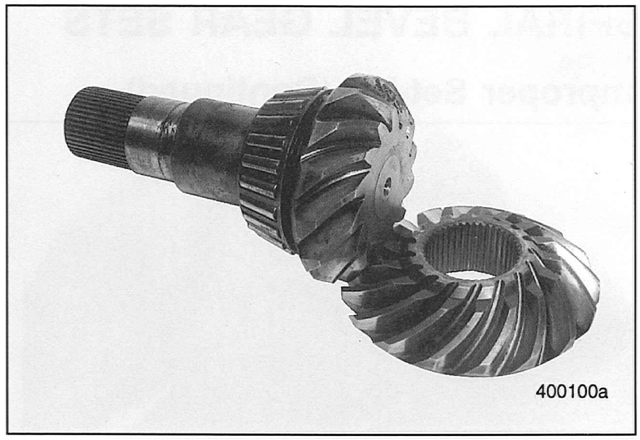

Figure 74 - Lubrication Failure

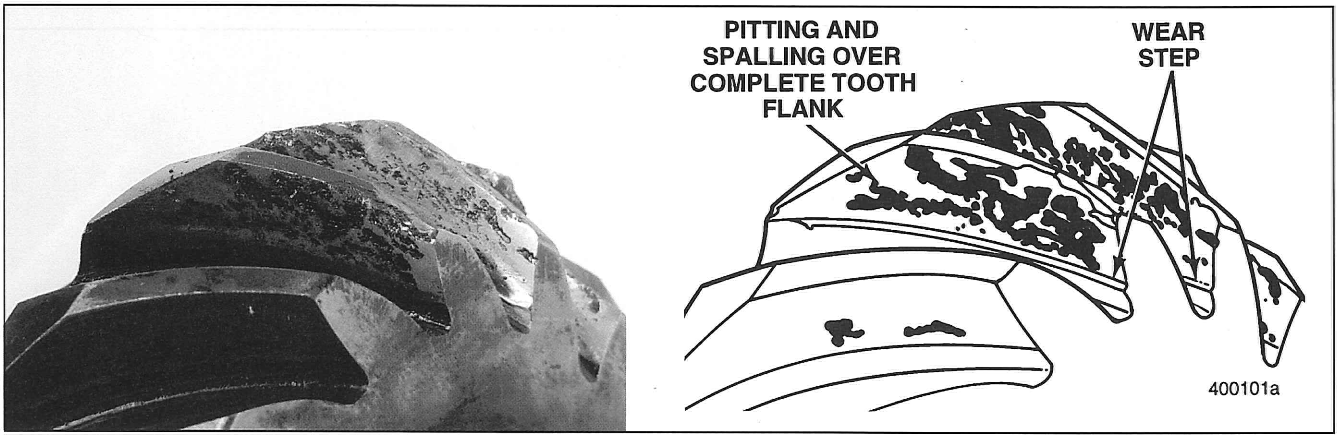

Figure 75

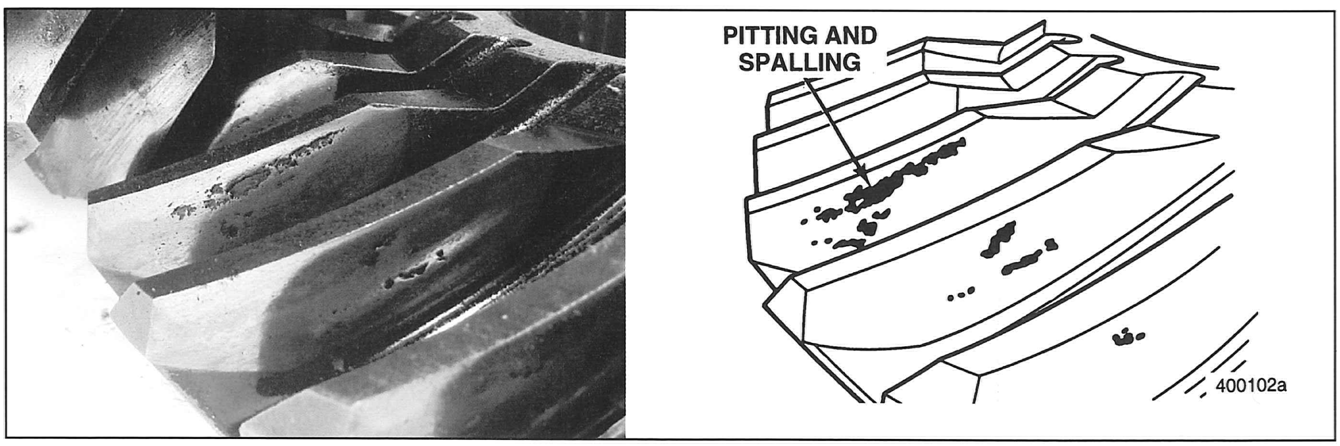

Figure 76

SPIRAL BEVEL GEAR SETS

Lubrication Failure (Continued)

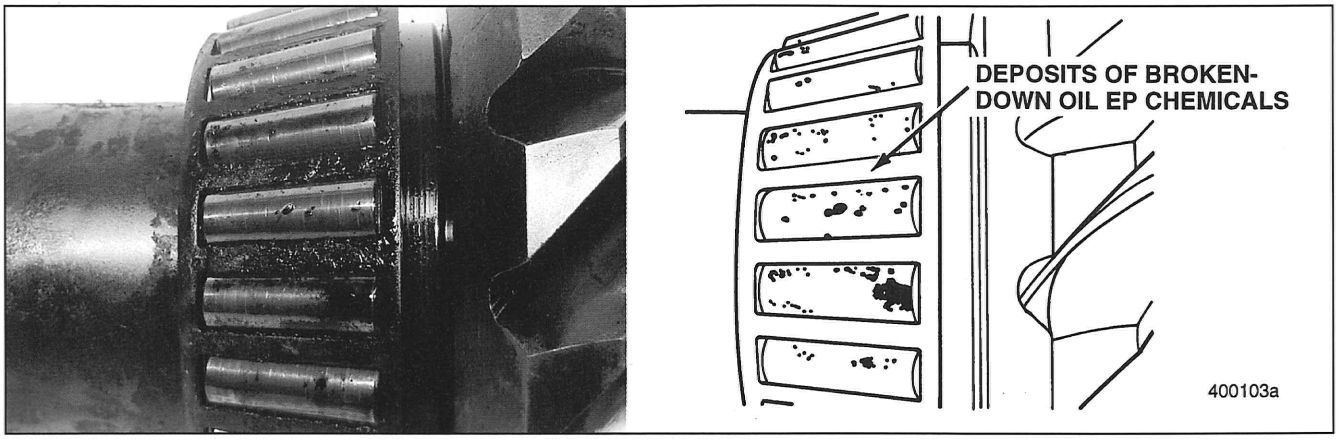

Figure 77

SPIRAL BEVEL GEAR SETS

Lack of Lubrication

This spiral bevel gear set and bearing were damaged by a lack of lubrication. The bearing tapered roller thrust faces as well as the roller bodies show extreme wear. The bevel gear surfaces show extreme scuffing.

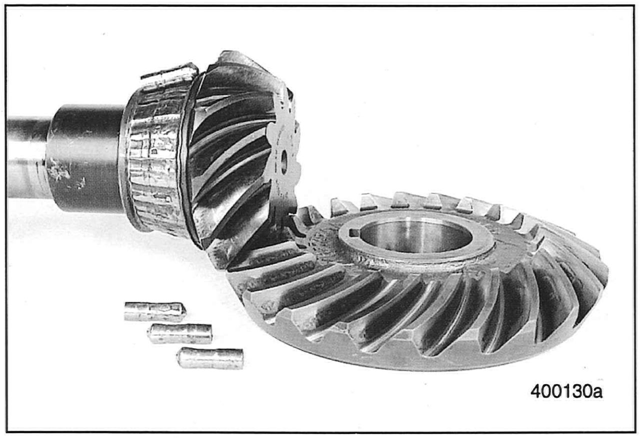

Figure 78 - Lack of Lubrication

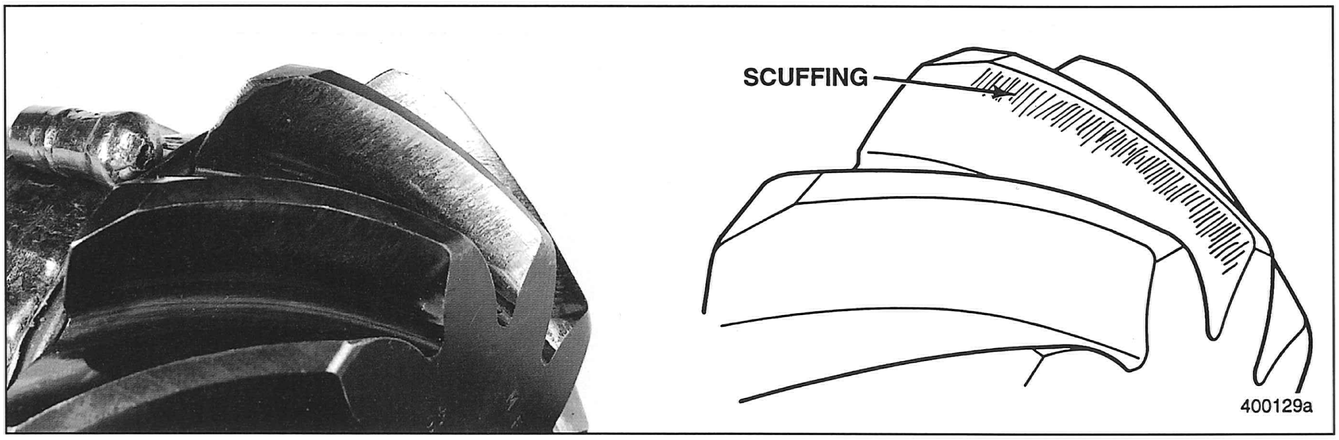

Figure 79

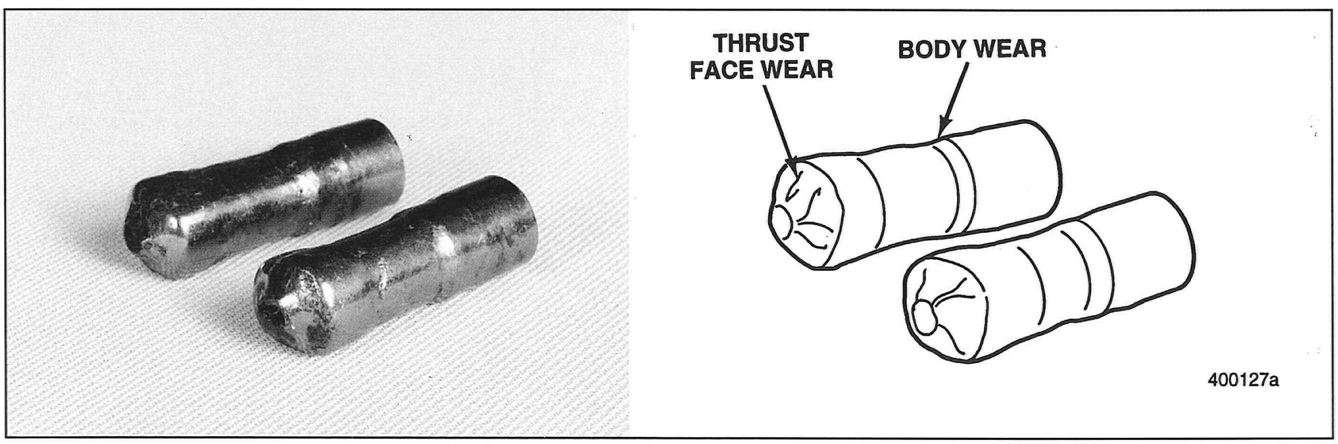

Figure 80

POWER DIVIDER

Wear

Abnormal power divider wear caused by a number of factors.

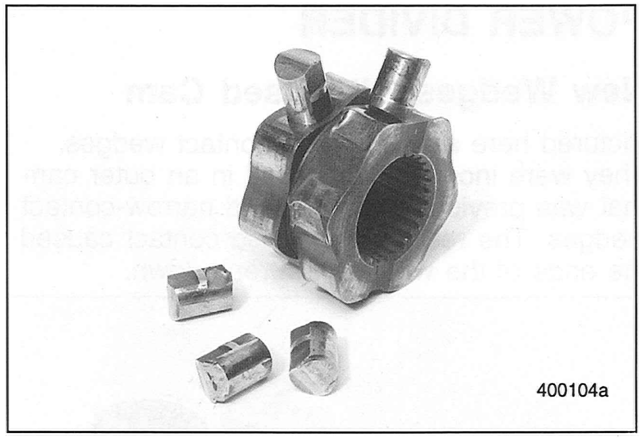

Figure 81 - Wear

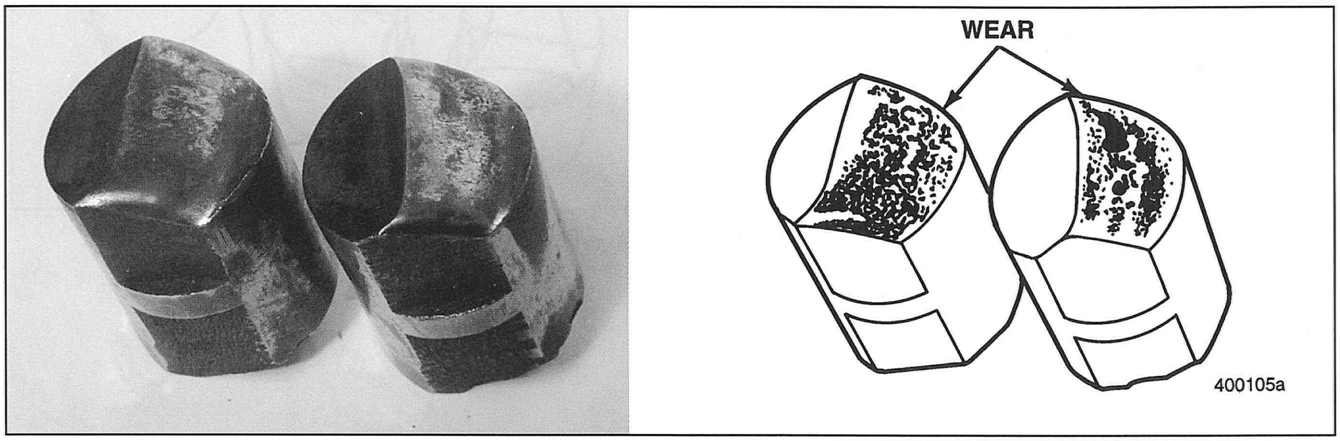

Figure 82

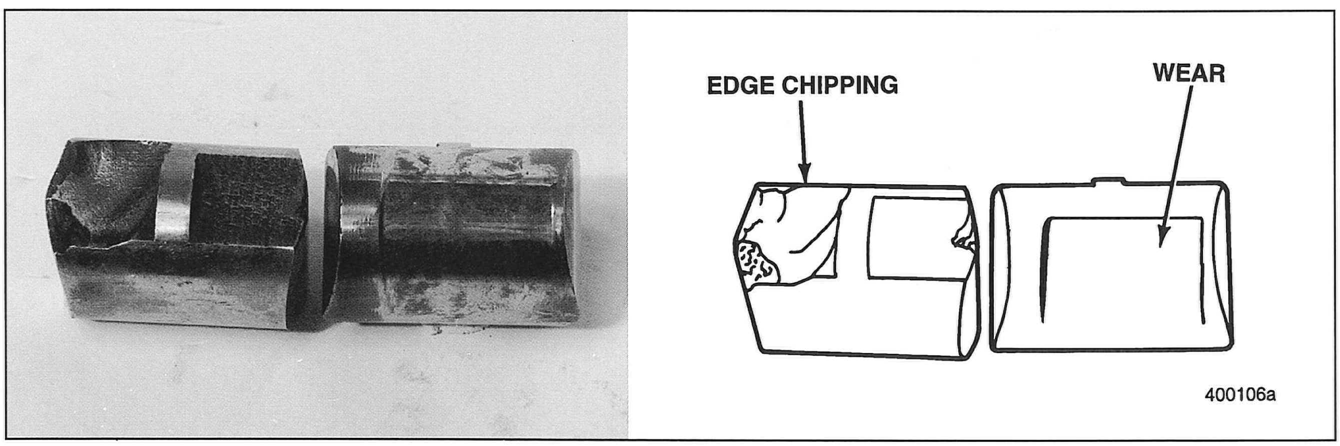

Figure 83

POWER DIVIDER

New Wedges with Used Cam

Pictured here are new wide-contact wedges. They were incorrectly installed in an outer cam that was previously worn by old narrow-contact wedges. The resulting abridged contact caused the ends of the wedges to break down.

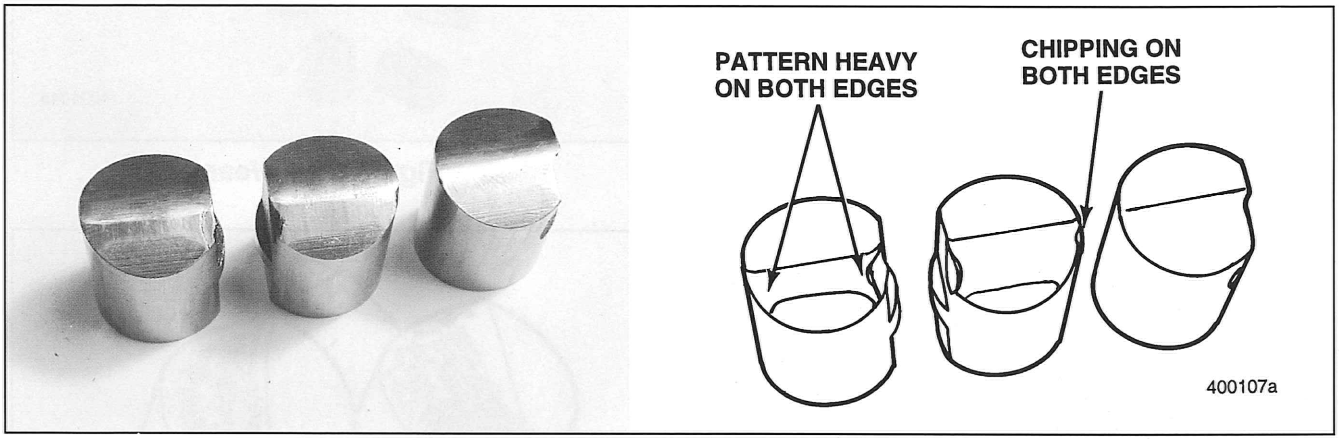

Figure 84 - New Wedges with Used Cam

POWER DIVIDER

Accelerated Wear

Power divider accelerated wear can be due to any of the following or a combination of them.

1. Mismatched carrier ratios.
2. Spinout.
3. Inner cam installed backwards.
4. Mismatched tire sizes.

- When changing dual tires, they must be properly matched. Mismatching the dual tires forces the larger diameter tire into an overloaded condition, causing excessive deflection and overheating. Refer to Mack service manual no. 15-101 (WHEELS, RIMS AND TIRES) for additional information regarding matching of dual tires.

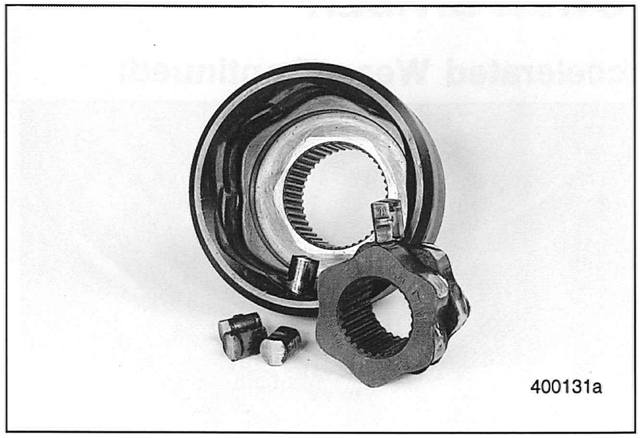

Figure 85 - Accelerated Wear

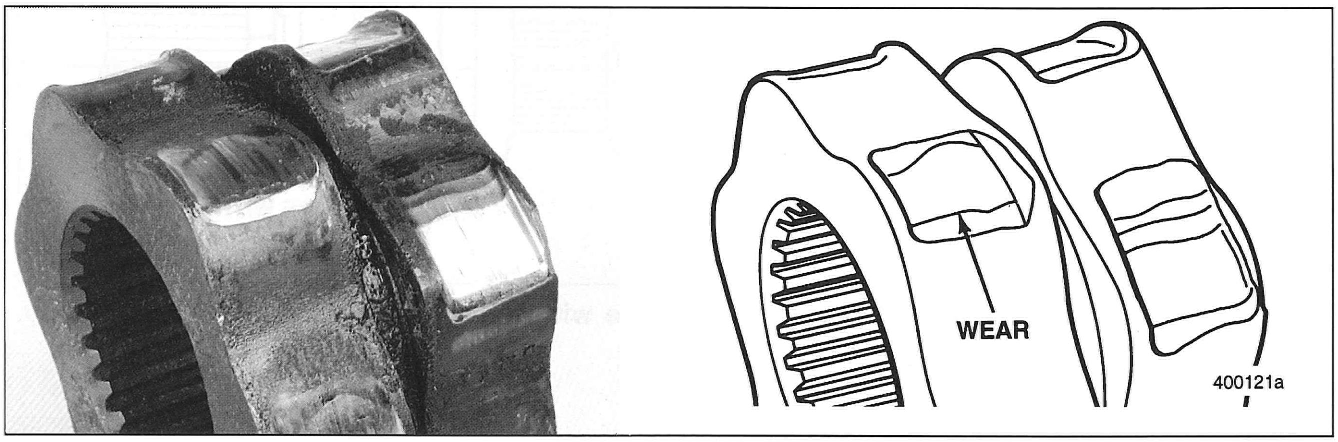

Figure 86

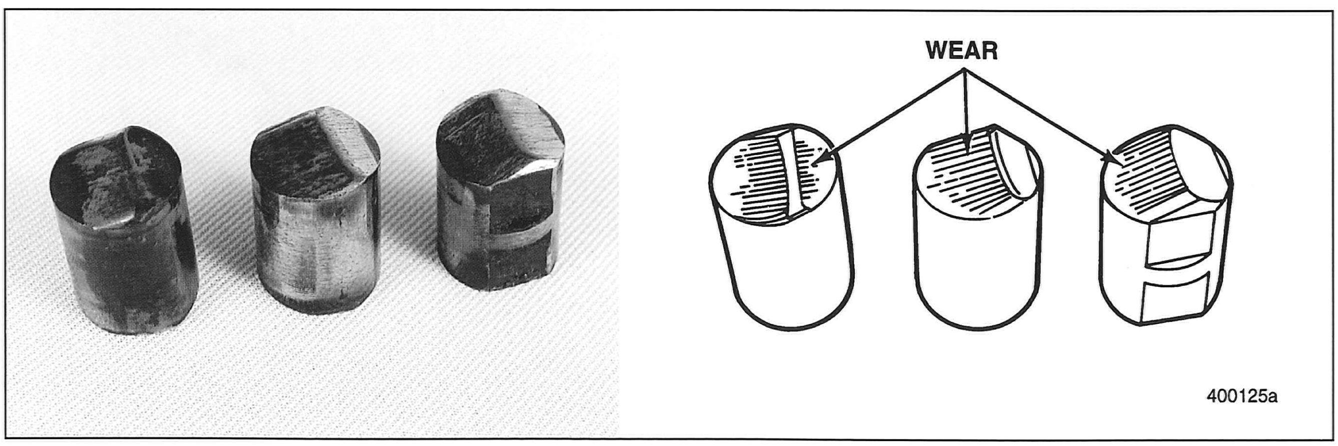

Figure 87

POWER DIVIDER

Accelerated Wear (Continued)

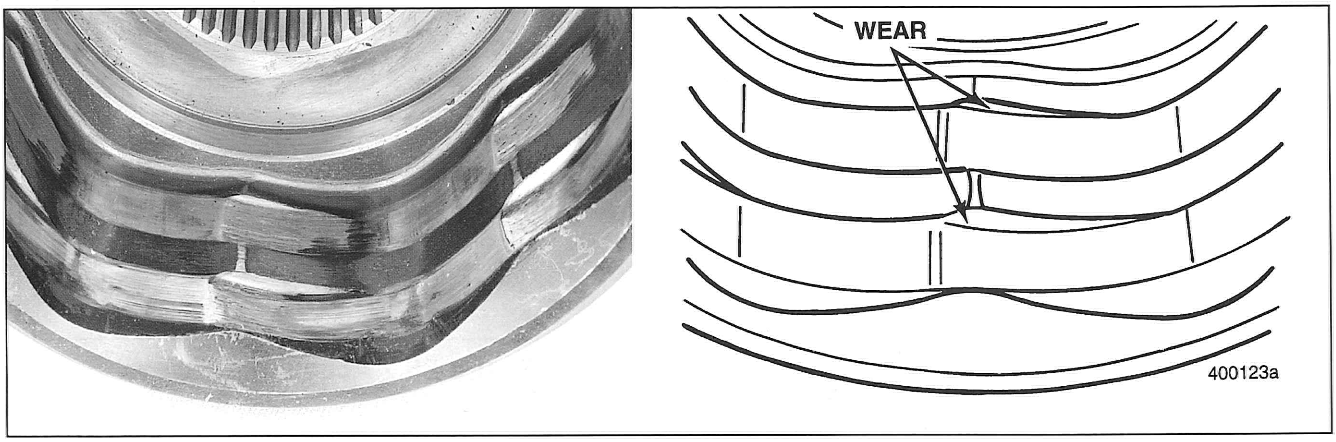

Figure 88

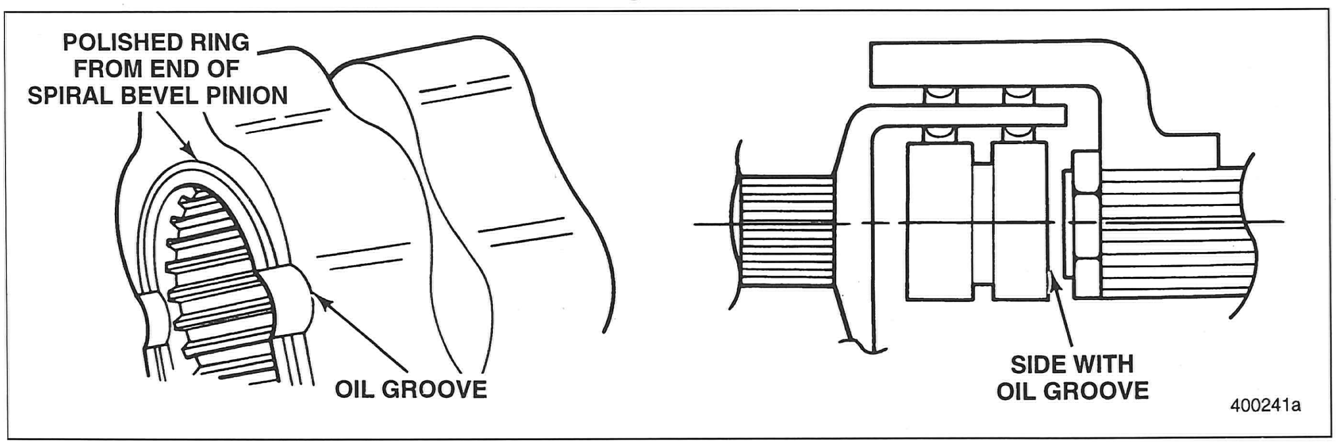

Figure 89 - The polished ring should be on the side with the oil grooves if installed properly.

THROUGH SHAFT

Torsional Fatigue

The through shaft was operated under a torsional overload that caused cracks to start at the spline roots. The cracks progressed inward until failure occurred.

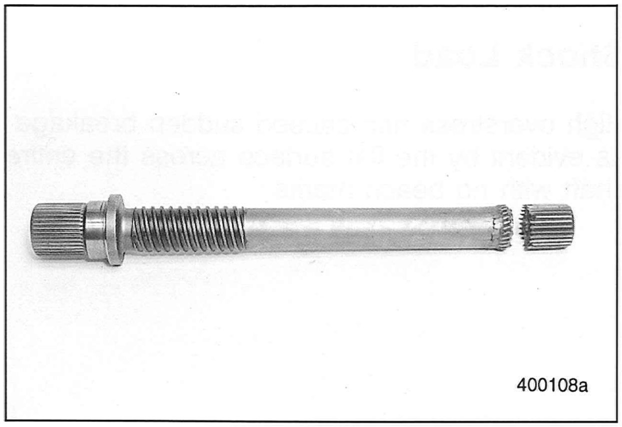

Figure 90 - Torsional Fatigue

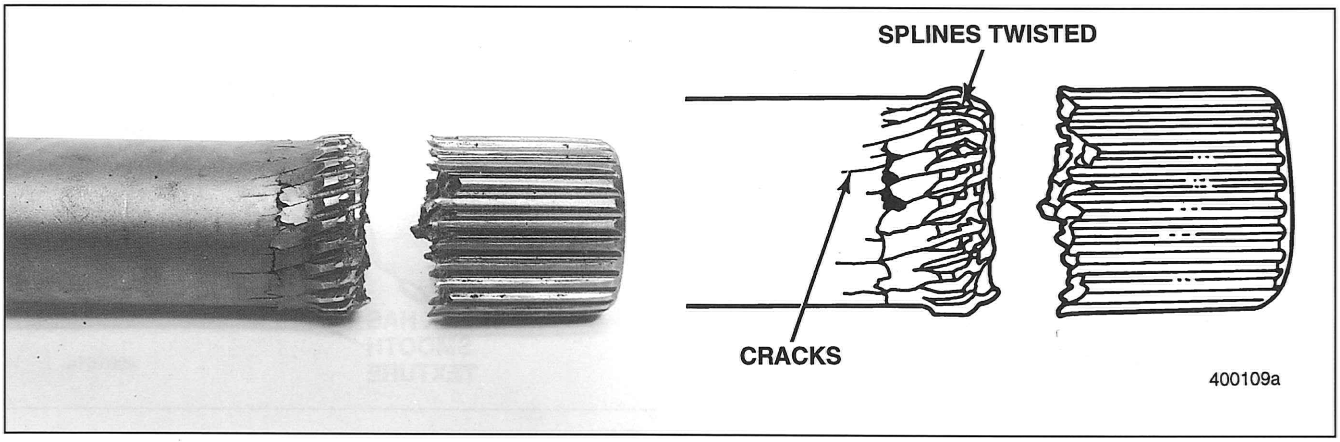

Figure 91

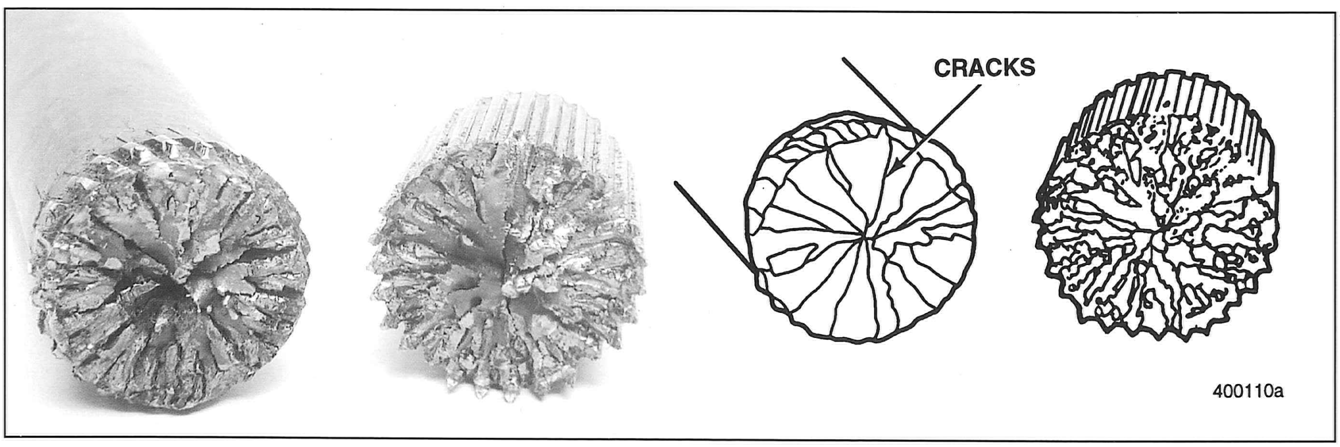

Figure 92

THROUGH SHAFT

Shock Load

High overstress has caused sudden breakage as evident by the flat surface across the entire shaft with no beach marks.

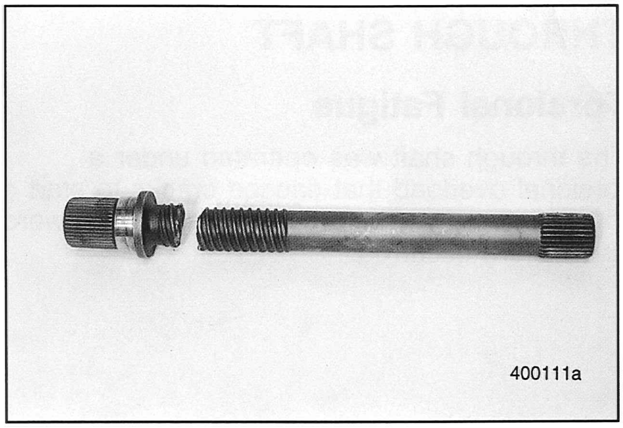

Figure 93 - Shock Load

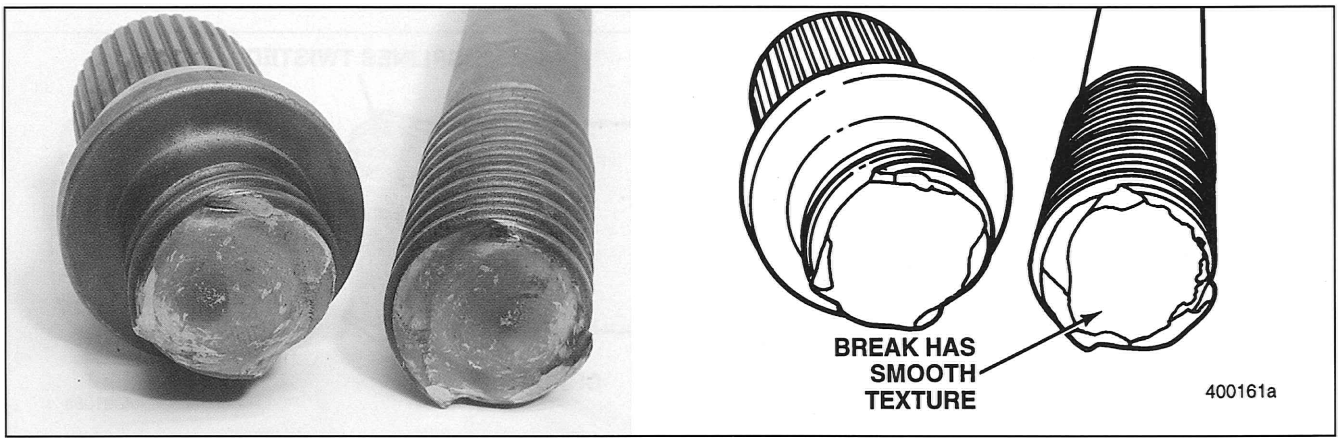

Figure 94

OVERALL FAILURE ANALYSIS

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CRITICAL INSPECTION AREAS DURING DISASSEMBLY

Carrier Overview

Remove the bevel compartment cover. Look for debris and broken or loose fasteners. Verify the carrier ratio by counting the gear teeth or finding the number of spiral bevel pinion rotations for one helical gear rotation.

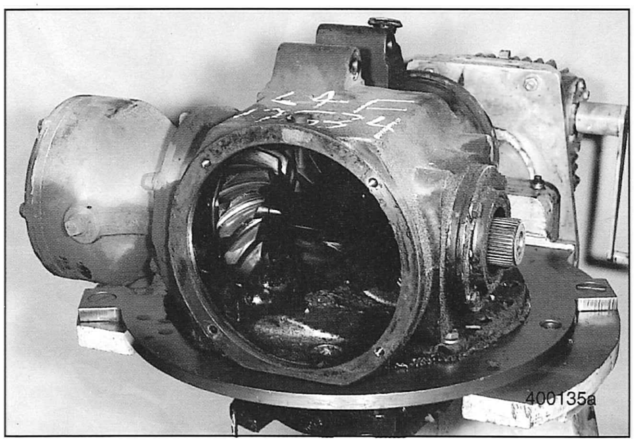

Figure 95 - Bevel Compartment Cover Removed

Look at the condition of seal retainer, internal ball bearing, and input spline for wear or damage. Check the condition of oil seal.

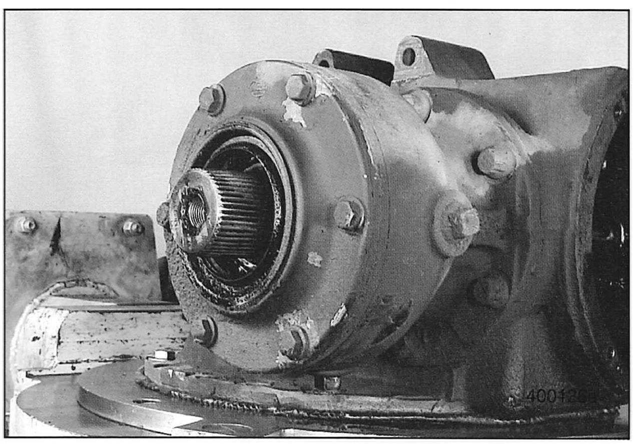

Figure 96 - Input Spline Area

Look at the condition of the breather. Examine the bearing retainer cover for damage or distortion (caused by internal or external impact). Verify carrier identification on stamping pad.

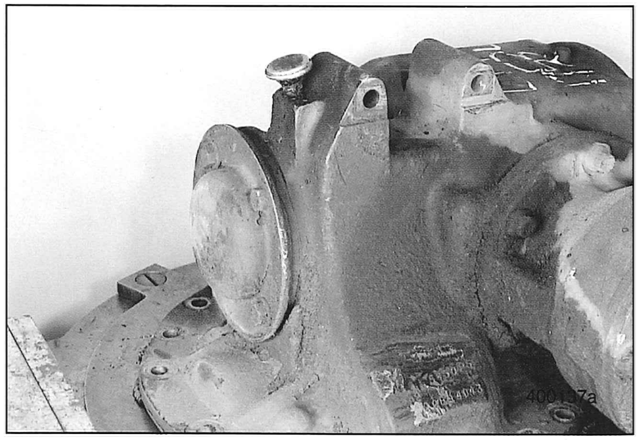

Figure 97 - Bearing Retainer Cover Area

Check the condition of seal retainer, internal ball bearing, and output spline for wear or damage. Check the condition of oil seal. Inspect the drain hole area for damage.

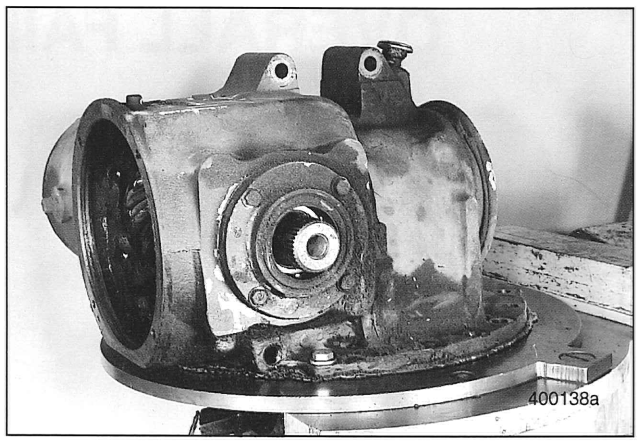

Figure 98 - Output Spline Area

Look at the bevel compartment cover for damage and condition of seal. Examine the oil trough for damage and amount of debris on magnets. Also inspect magnetic filler plug for amount of debris.

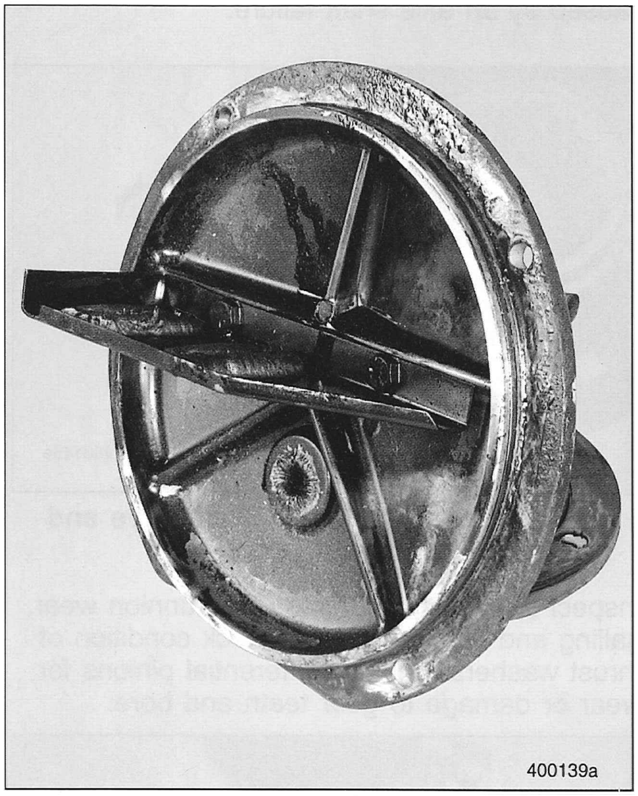

Figure 99 - Bevel Compartment Cover

Look at bearing caps for fretting on abutment faces and any signs of fastener looseness. Check for differential bearing preload and if the pin and cotter pin are properly assembled and not damaged.

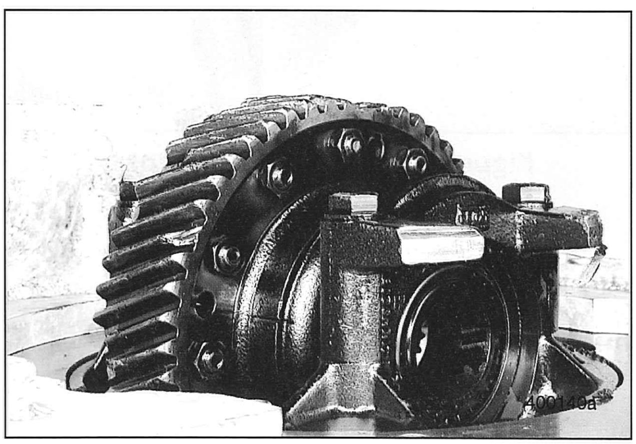

Figure 100 - Differential Assembly Area

Inspect bearing cap surface for fretting and check bore condition. Look at helical gear compartment of the main case for any debris damage.

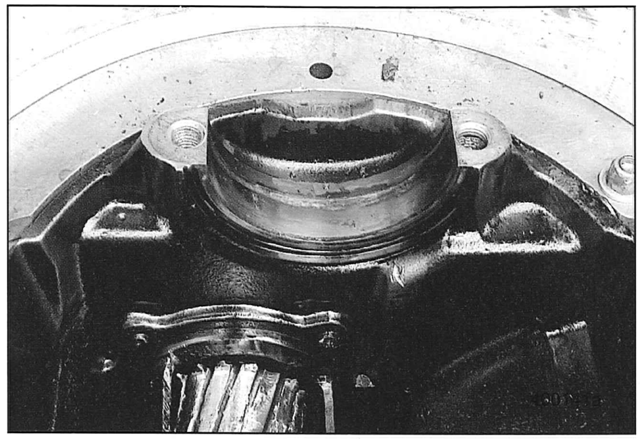

Figure 101 - Helical Gear Compartment

Examine the helical gear for tooth damage. Look at the differential case for damage or rubbing. Check differential case fastener condition and tightness. Check differential bearing condition and tightness on the case trunnion.

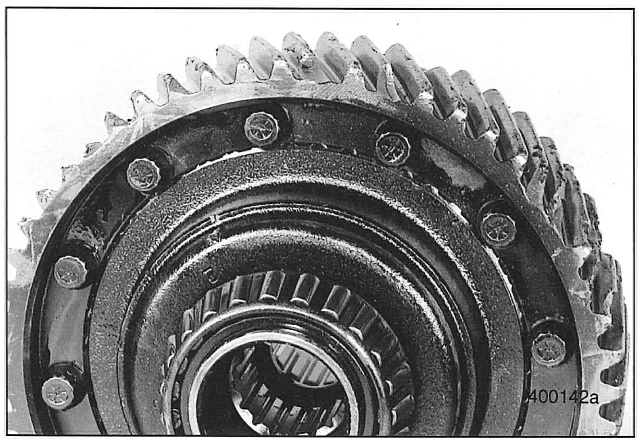

Figure 102 - Differential Case and Helical Gear

Inspect the helical gear for fretting on assembly faces and for any damage or wear on splines. Look for any cracks in the web or gear body.

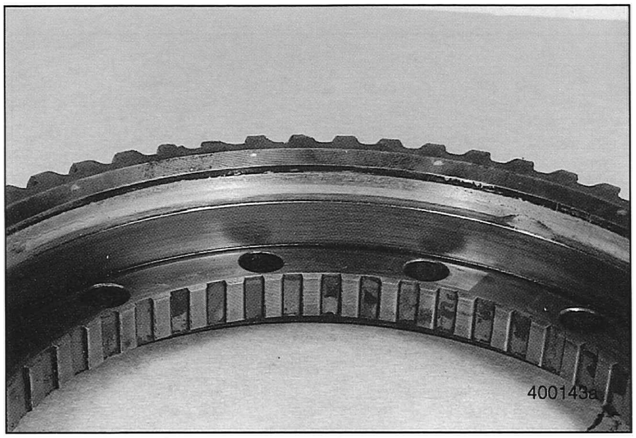

Figure 103 - Helical Gear

Examine the differential case for fretting on the mounting surfaces and check the case for spline damage or wear.

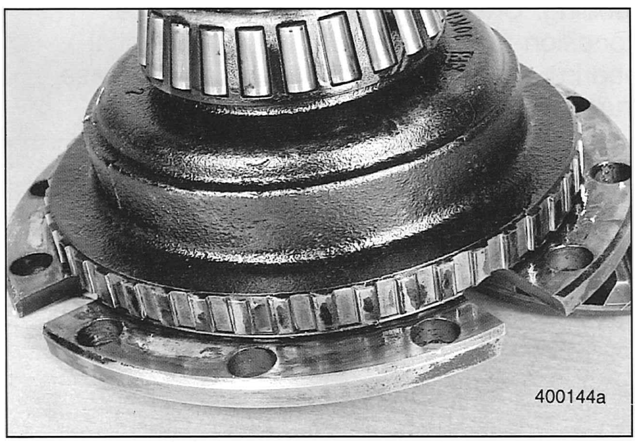

Figure 104 - Differential Case

Examine the differential case for cross-bore condition, fretting on the mounting face and flange cracks at spline undercut. Look for any wear in the case from the thrust washers. Check case and side gear spline for damage caused by an axle shaft failure.

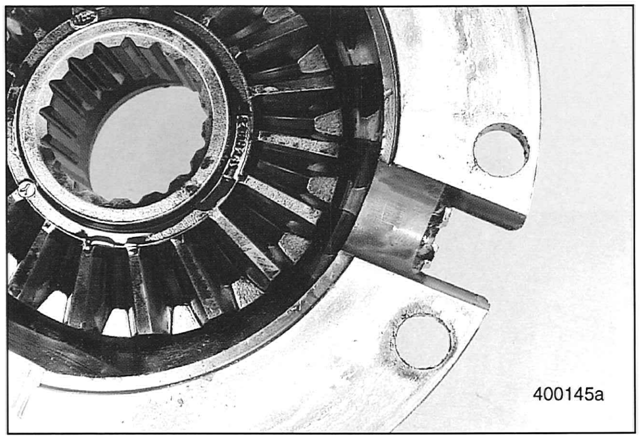

Figure 105 - Differential Case Bore and Mounting Face

Inspect the differential cross for trunnion wear, galling and other damage. Check condition of thrust washers. Look at differential pinions for wear or damage to gear teeth and bore.

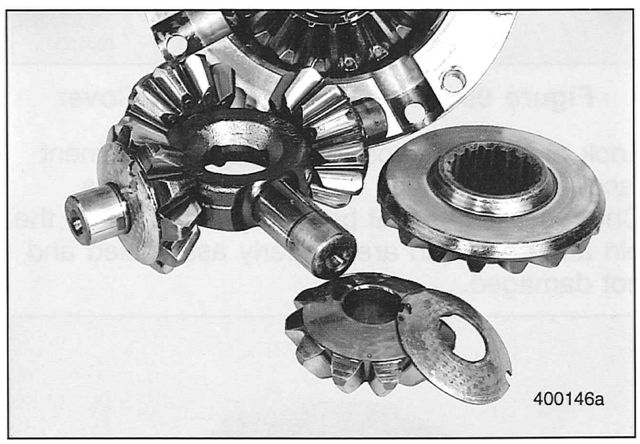

Figure 106 - Differential Cross

Inspect the differential side gear for wear, cracks and damage to the gear teeth or splines.

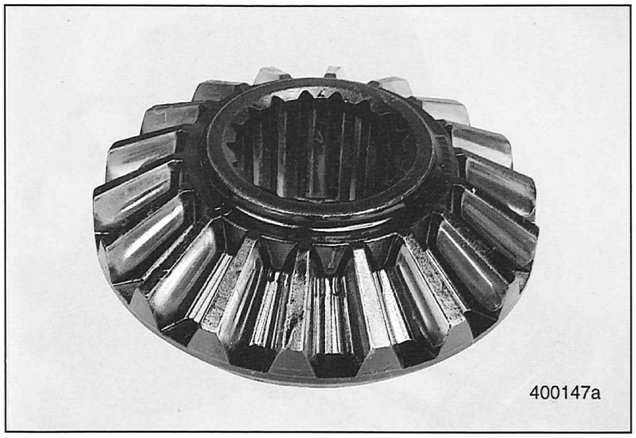

Figure 107 - Differential Side Gear

Check the through shaft retainer for debris that could cause an oil restriction. Check tube for damage from bevel pinion bore interference or impact from debris. Check the through shaft for damage or spline wear.

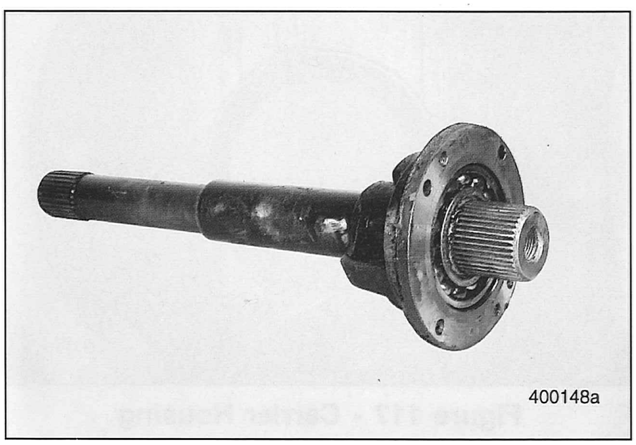

Figure 108 - Through Shaft

Inspect the power divider components for excessive wear or damage.

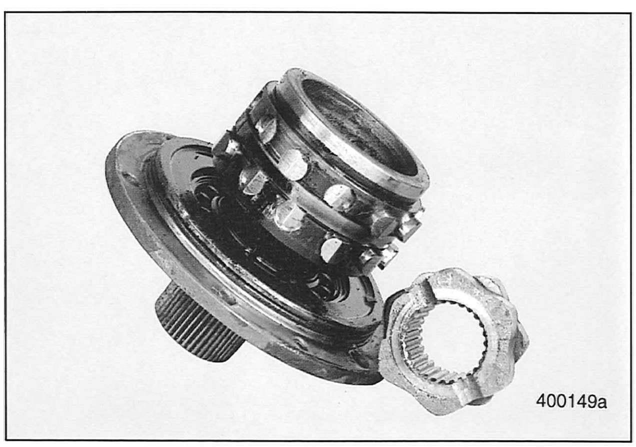

Figure 109 - Power Divider

Check power divider nut for tightness.

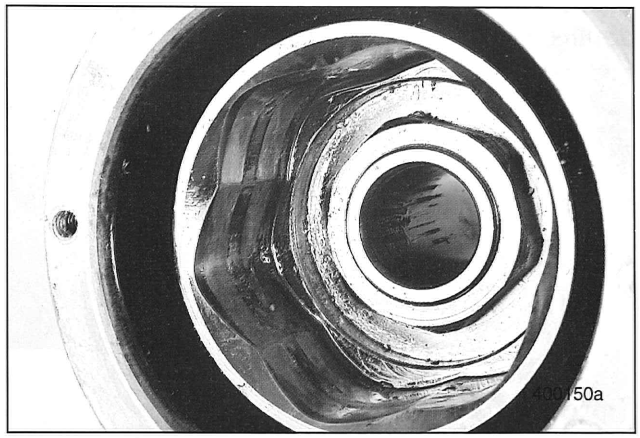

Figure 110 - Power Divider Nut

Check spiral bevel gear set for backlash, contact pattern and tooth deterioration. Check pinion bearing for any damage.

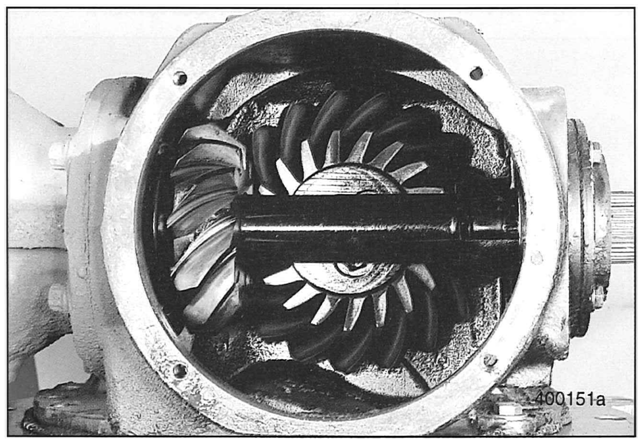

Figure 111 - Spiral Bevel Gear Set

Check spiral bevel tooth condition after through shaft tube removal. Check gear clamp plate fasteners for tightness.

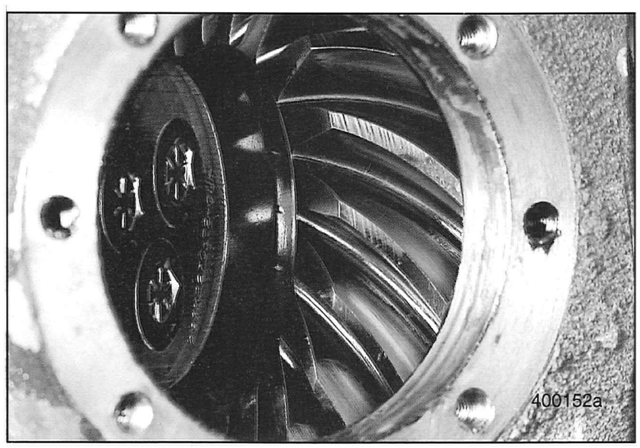

Figure 112 - Spiral Bevel Gear

Check back face of spiral bevel gear teeth, on pinion and gear, for matching gear set identification.

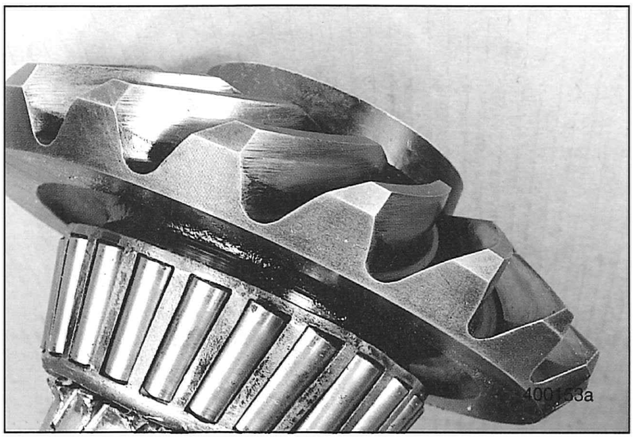

Figure 113 - Spiral Bevel Gear

Check helical pinion shaft bearing retainer for damage, wear and retaining pin condition.

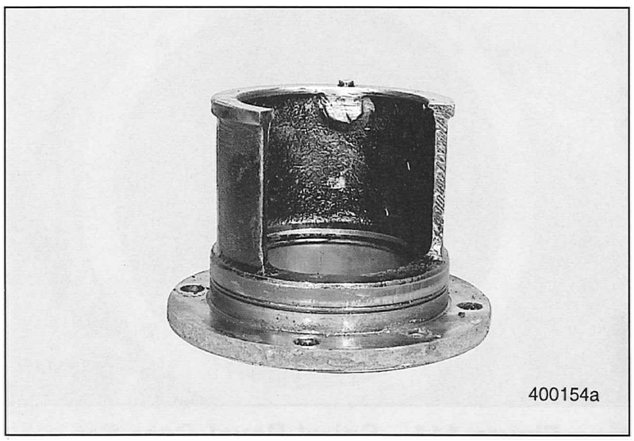

Figure 114 - Helical Pinion Shaft Bearing Retainer

Check tightness of clamp plate fasteners. Inspect bearing condition.

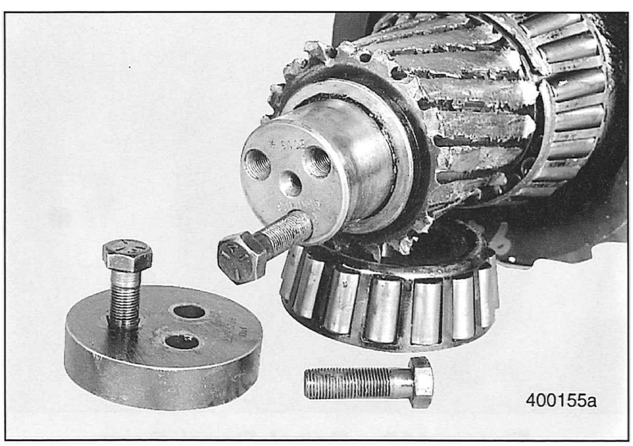

Figure 115 - Helical Pinion Shaft

Check helical pinion for gear tooth damage or wear. Check inboard bearing for wear or debris.

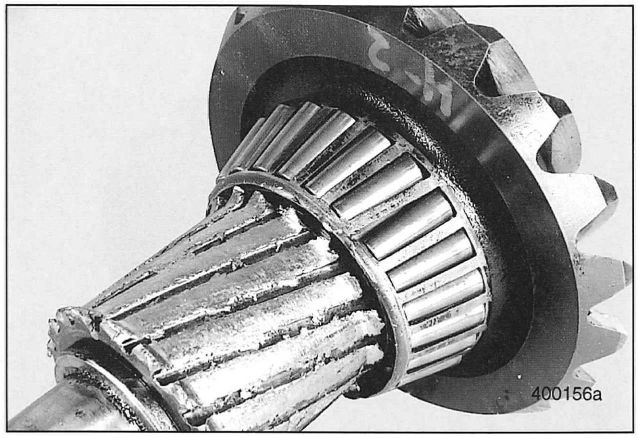

Figure 116 - Helical Pinion

Check carrier housing for internal damage, bearing cup and bore condition and housing cracks.

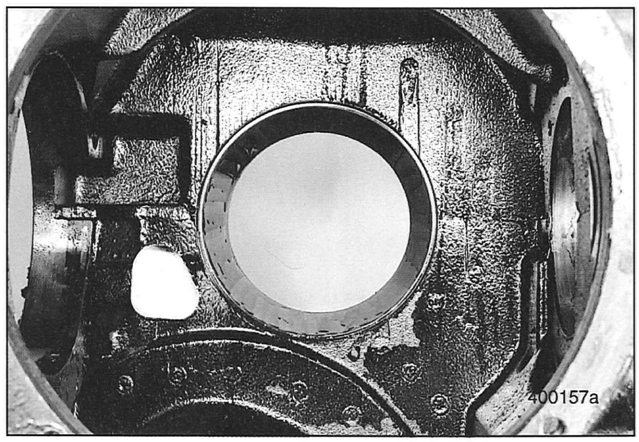

Figure 117 - Carrier Housing

Inspect condition of housing tapped holes. Check oil passages for accumulated debris. Remove any external dirt that may affect rebuild.

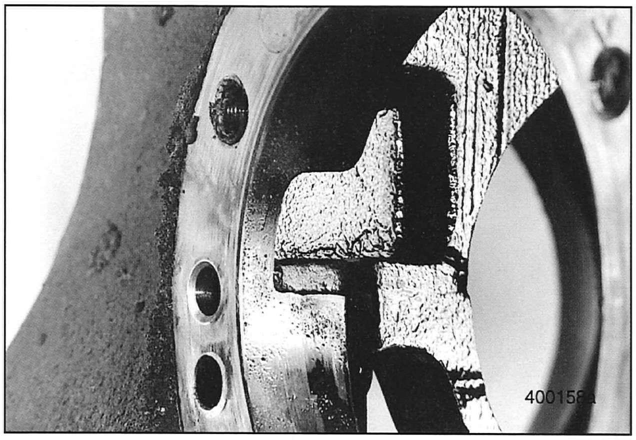

Figure 118 - Carrier Housing

Check carrier housing mounting flange for cracks, fretting or witness marks from axle housing cracks.

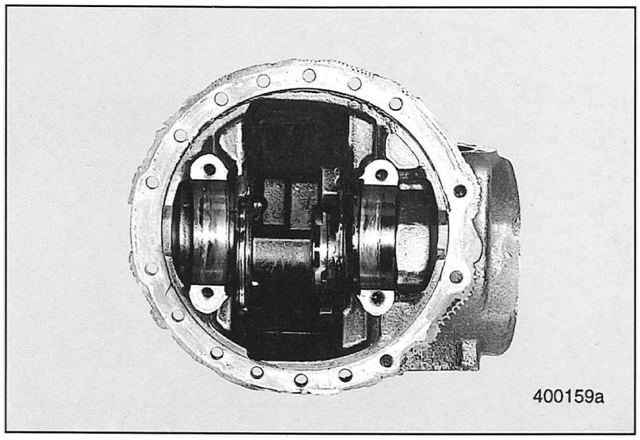

Figure 119 - Carrier Housing

NOTES

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CARRIER GEAR
FAILURE ANALYSIS
21-201

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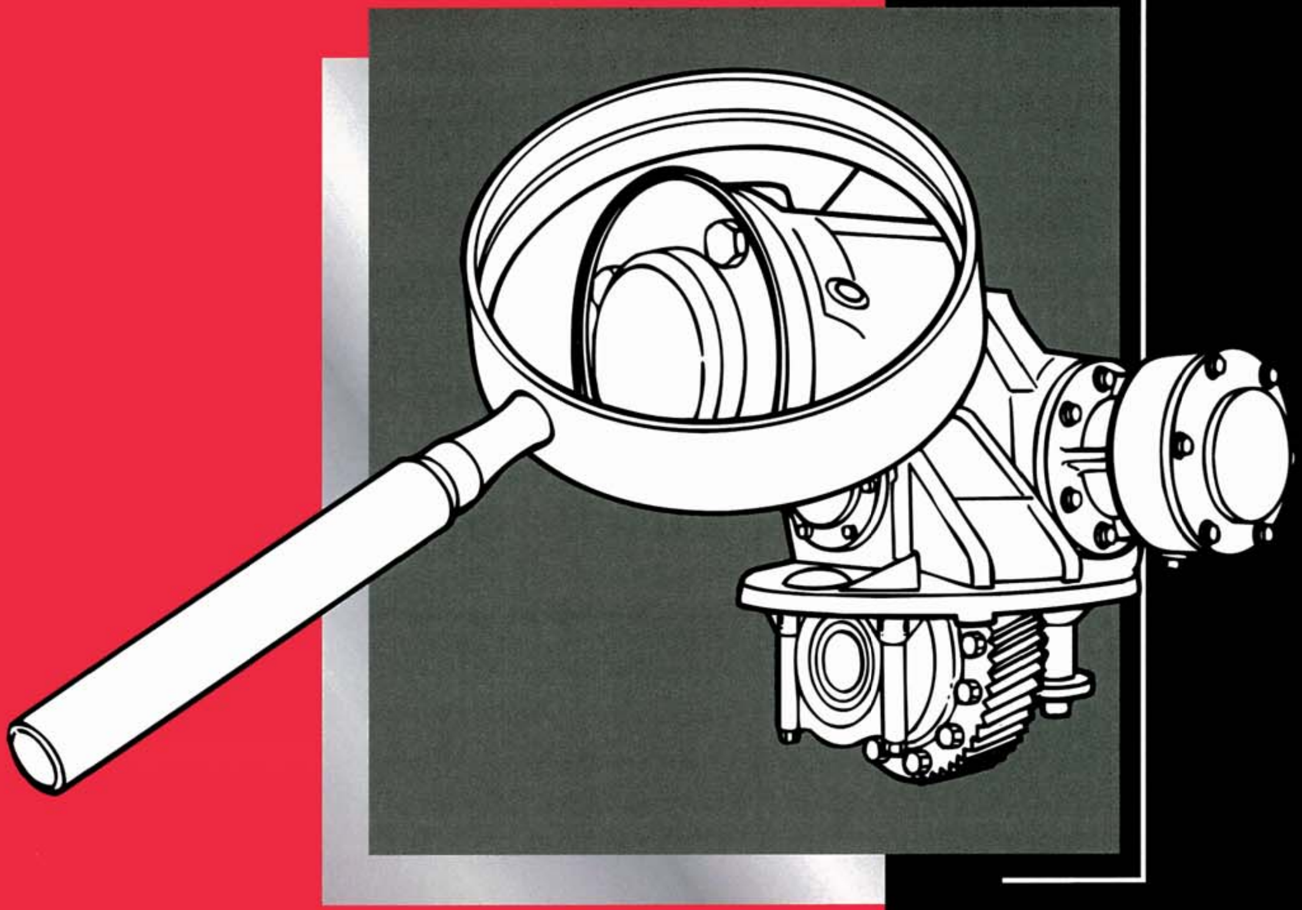


MACK CRD 92/93 SERIES CARRIER

BEVEL GEAR SET FAILURE ANALYSIS SUPPLEMENT

FAILURE ANALYSIS

21-201

IMPROPER SET-UP

Heel Loaded
(Most Common Situation)

Contact witness marks, pitting or spalling on the bevel pinion drive are not distributed, but isolated to the heel only, the failure is typically warrantable.

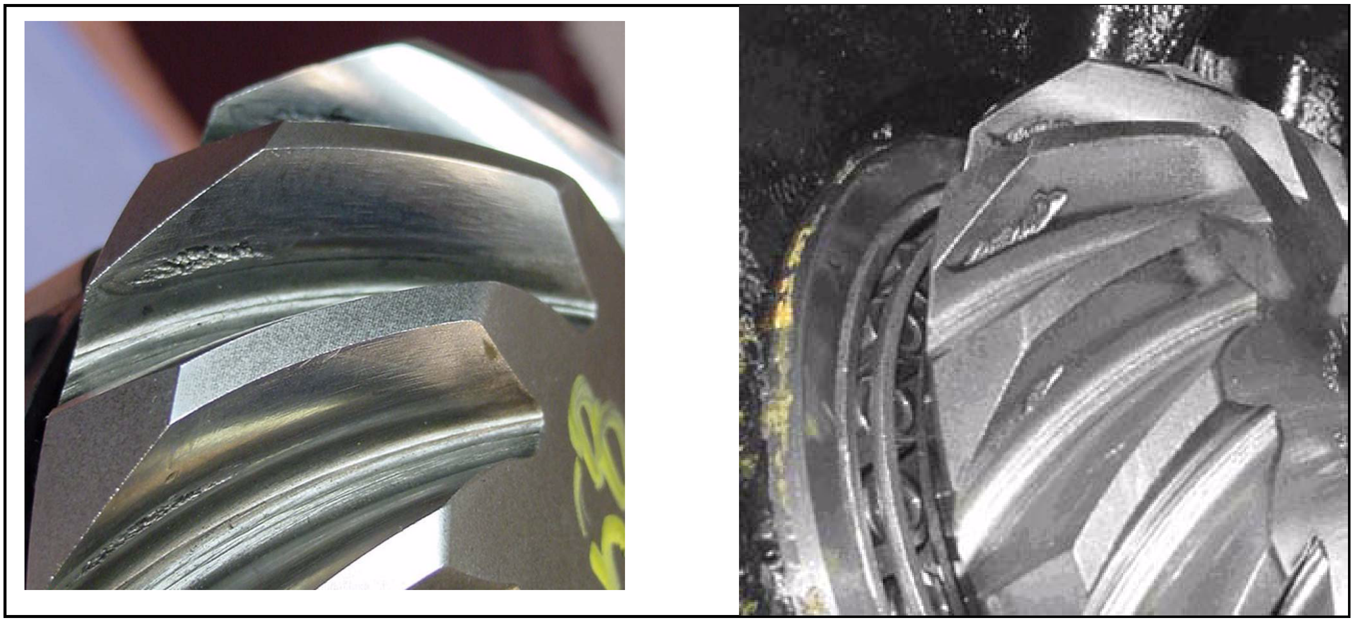


Figure 1 — Spiral Bevel Pinions

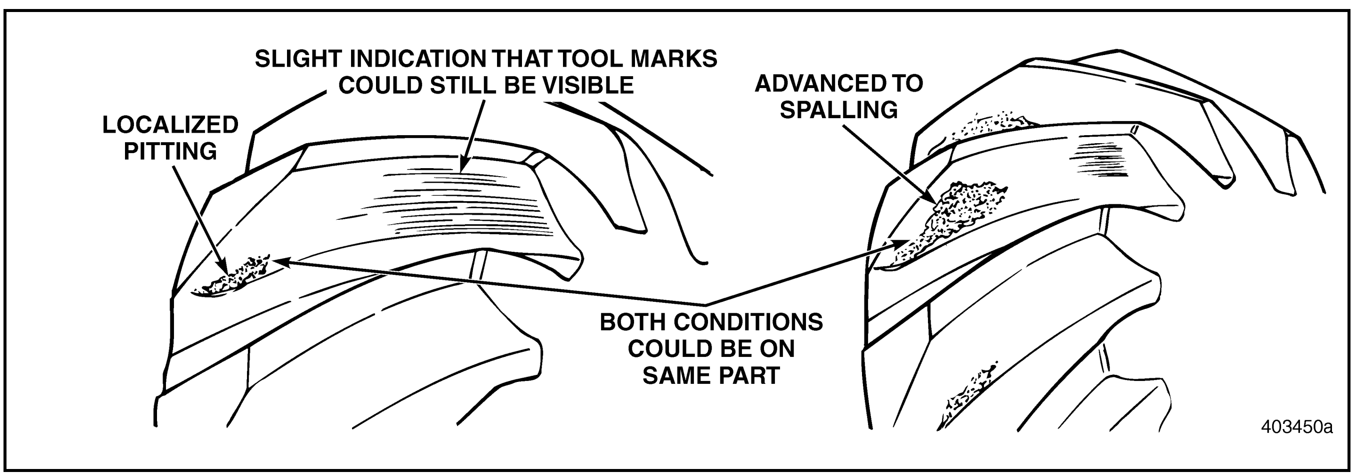


Figure 2 — Heel Loaded

IMPROPER SET-UP

Root Line Pitting

This gear set was set up with the contact pattern too deep into the pinion root. This caused pitting on the bevel pinion and chipping on the gear drive tips. Tooling marks are still on the bevel pinion and no flank material pushed over tip (sharp) indicates that this condition did not result from overload.

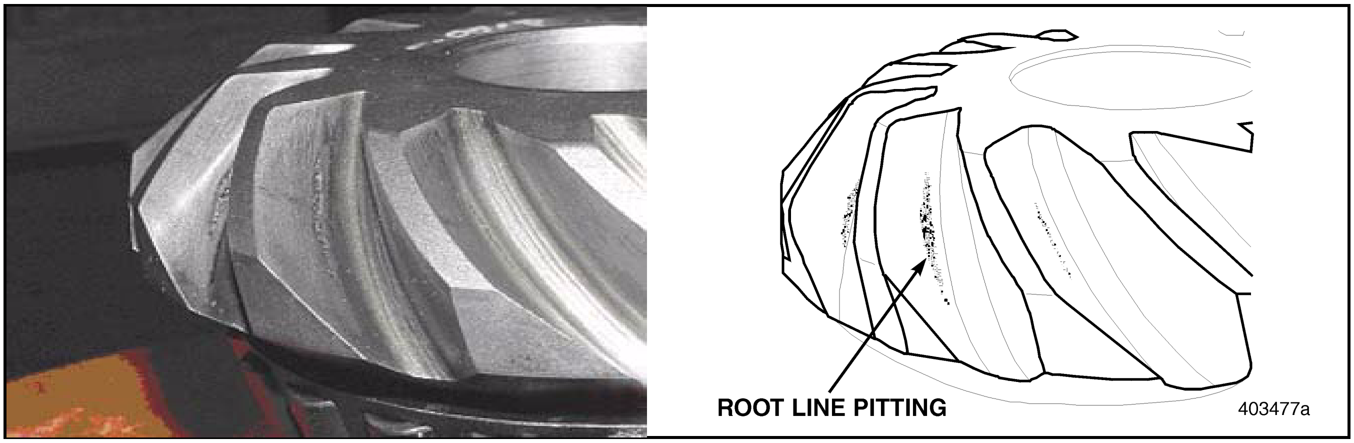


Figure 3 — Spiral Bevel Pinion

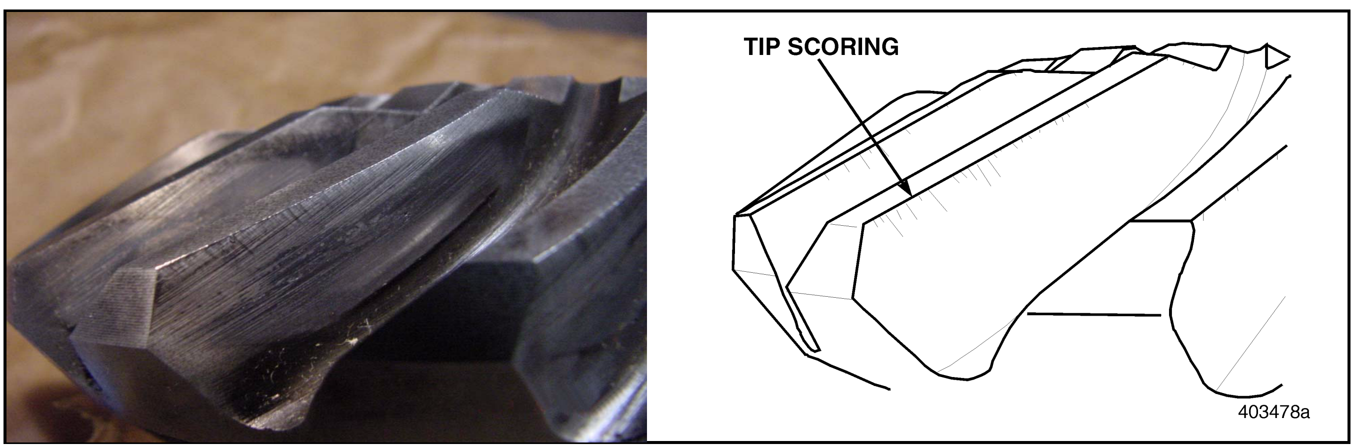


Figure 4 — Spiral Bevel Gear

IMPROPER SET-UP

Toe Loaded

Contact witness marks, pitting or spalling on the bevel pinion drive are not distributed, but isolated to the toe only, the failure is typically warrantable.

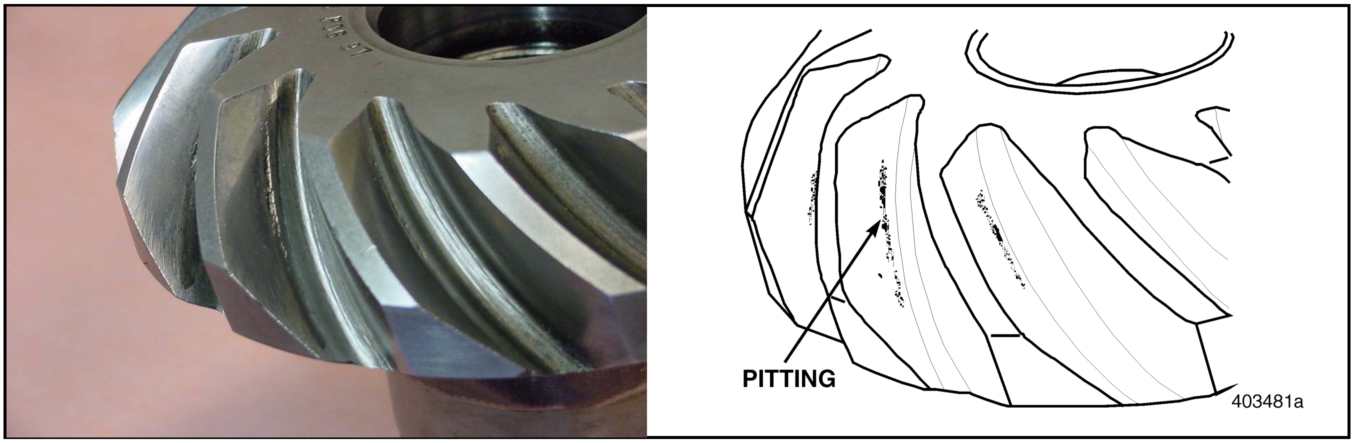


Figure 5 — Spiral Bevel Pinion

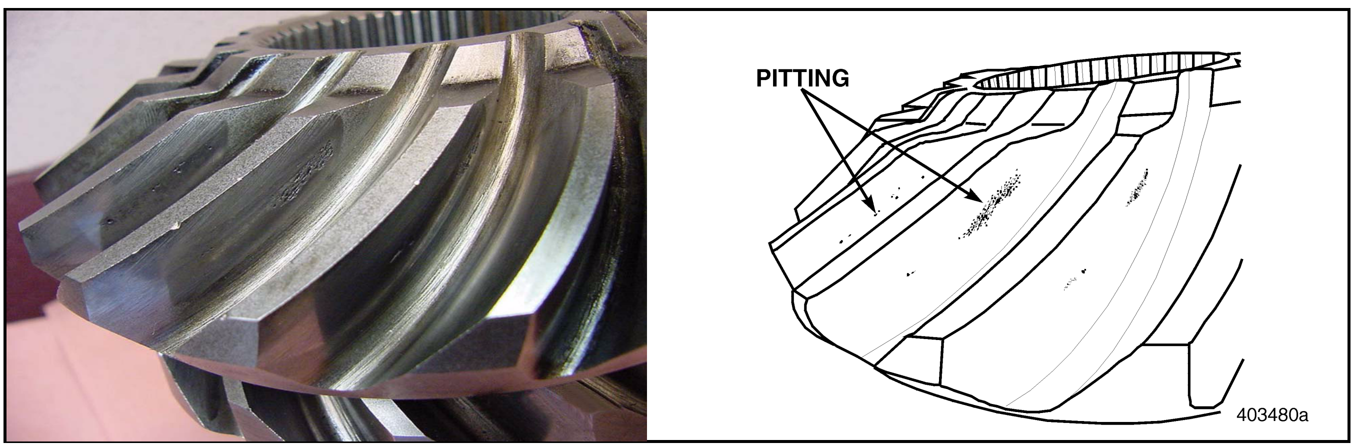


Figure 6 — Spiral Bevel Gear

LOOSE POWER DIVIDER NUT

Situation Indicating Power Divider Nut Was Loose

The power divider nut has loosened, allowing the pinion to move toward the gear and lose all backlash. The resulting interface caused the tips of the pinion to break down and the central areas of the gear teeth to break out.

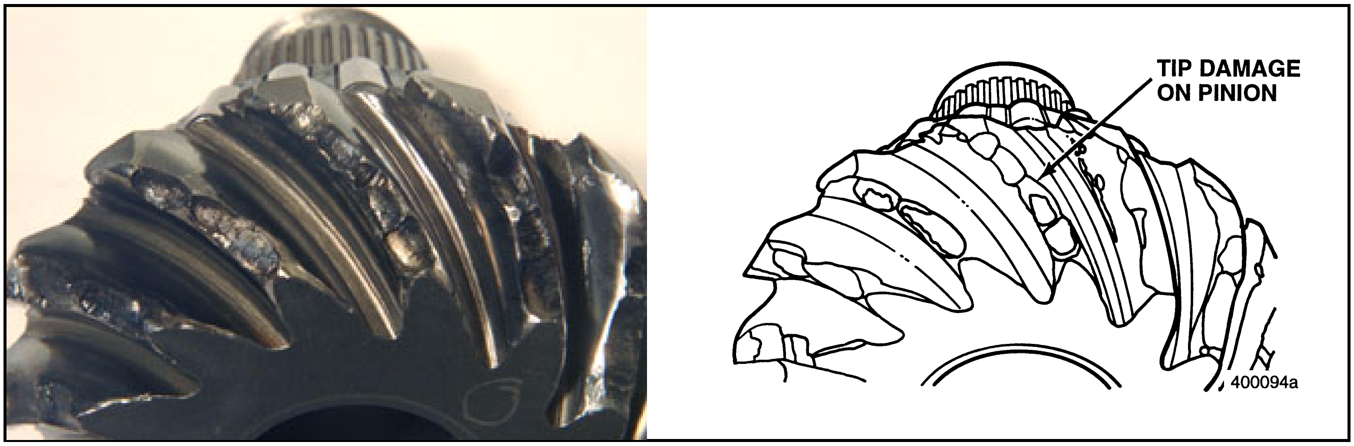


Figure 7 — Damage Caused by Loose Power Divider Nut

DEFINITION OF OVERLOAD

Overload is the result of truck usage beyond the limits set forth by the vehicle and carrier application categories for which the truck was registered at the time of sale.

Overload condition is created over time when one or a combination of any of the following limits are exceeded:

- Operating on grades exceeding maximum allowed.
- Operating on road conditions more severe than those allowed.
- Operating on specified grades or road conditions in excess of percentage allowed.
- Exceeding GCW limits.

OVERLOAD

Low Cycle Fatigue

This failure was due to low cycle fatigue. It was highly overstressed with very few beach marks. Notice the large final fracture.

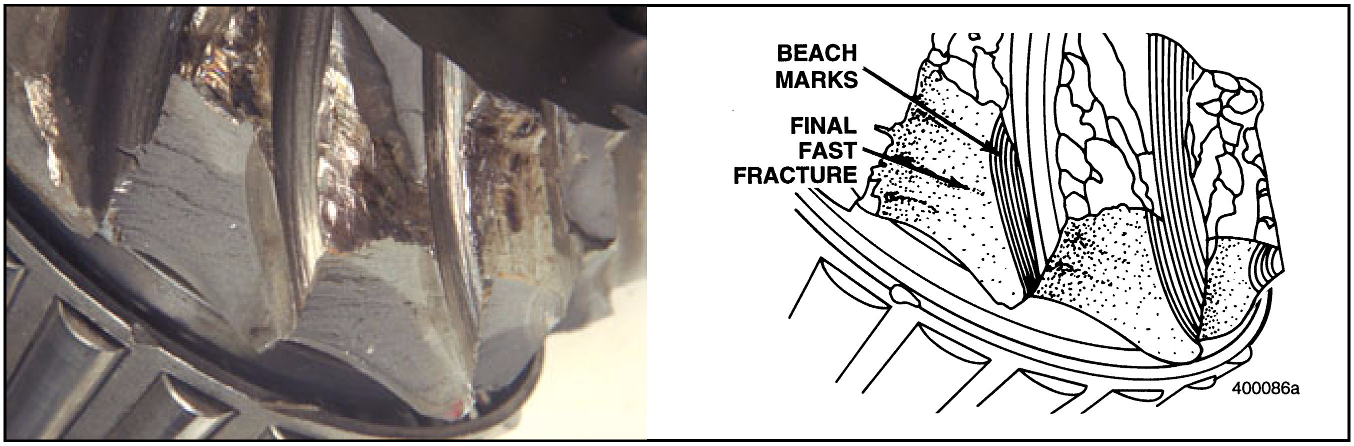
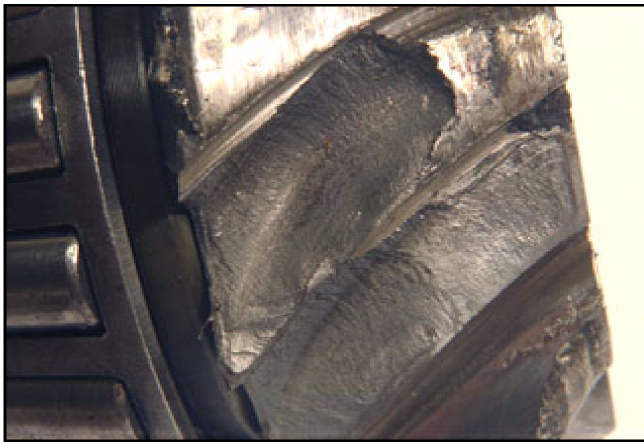


Figure 8 — Low Cycle Fatigue

OVERLOAD

High Cycle Fatigue

This failure was due to high cycle fatigue. It was overstressed with beach marks through most of the tooth cross-section and a small fast fracture area. Unbroken teeth should have signs of overload.



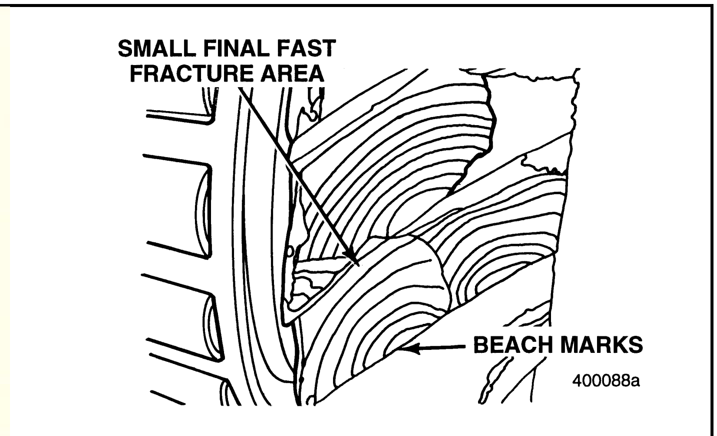


Figure 9 — High Cycle Fatigue

OVERLOAD

Surface Fatigue

In this overload situation note the erosion of the tooth surface material. On the pinion teeth the material is rolled over and the tip is sharp. Pitting and spalling commonly starts at high stress areas and spreads across the tooth contact areas.

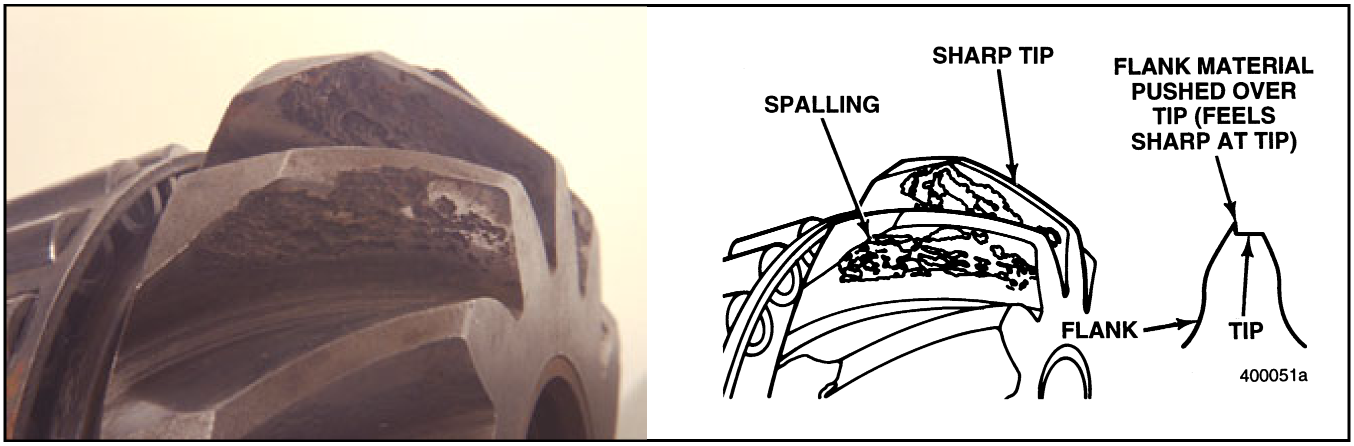


Figure 10 — Spiral Bevel Pinion

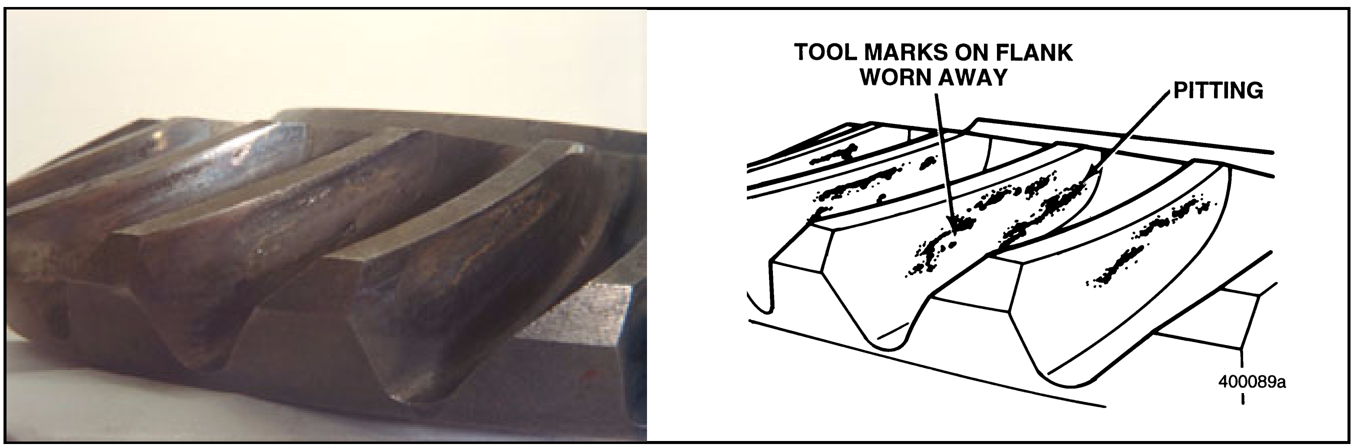


Figure 11 — Spiral Bevel Gear

...continued

OVERLOAD

Advanced Surface Fatigue

In this case of advanced failure, the pinion tooth surface is so worn, the contact is dropping to the root. Note all tooling marks are worn away. With the active tooth profile worn away, scraping, plastic deformation and the start of surface pitting has occurred. Superficial pitting has advanced to destructive pitting and becomes spalling as it moves through the case hardening. Finally, the entire tooth structure has begun to fatigue and break down.

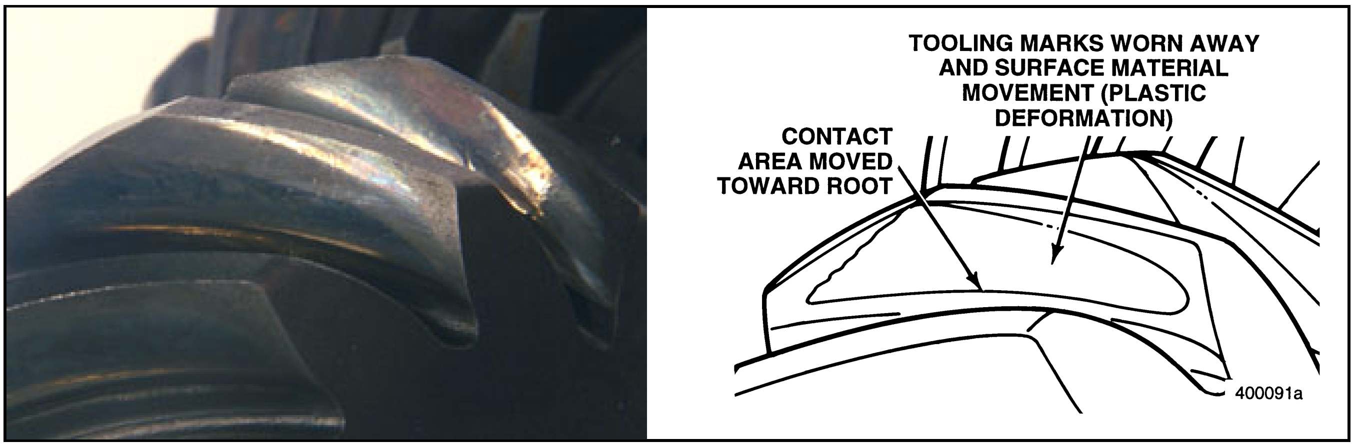


Figure 12 — Advancing Failure

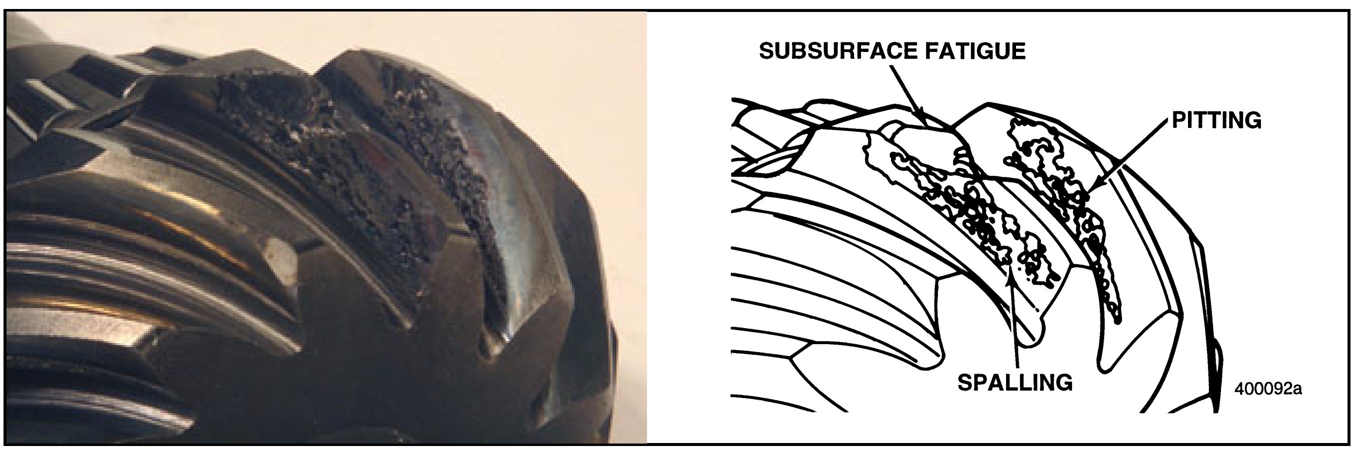


Figure 13 — Advanced Surface Fatigue

LUBRICATION FAILURE

Loss of Oil EP Additive Due to Lack of Maintenance

The EP additive in the lubricant has been depleted and not renewed by changing the lubricant, resulting in metal-to-metal contact on the mating teeth. The effect is wear and pitting on the teeth. Warrantable failures can be characterized by pitting in localized areas. Lubrication failures are characterized by wear and pitting covering the whole tooth flank. The gear teeth are not sharp due to material movement over the tips, unless overloading has also occurred.

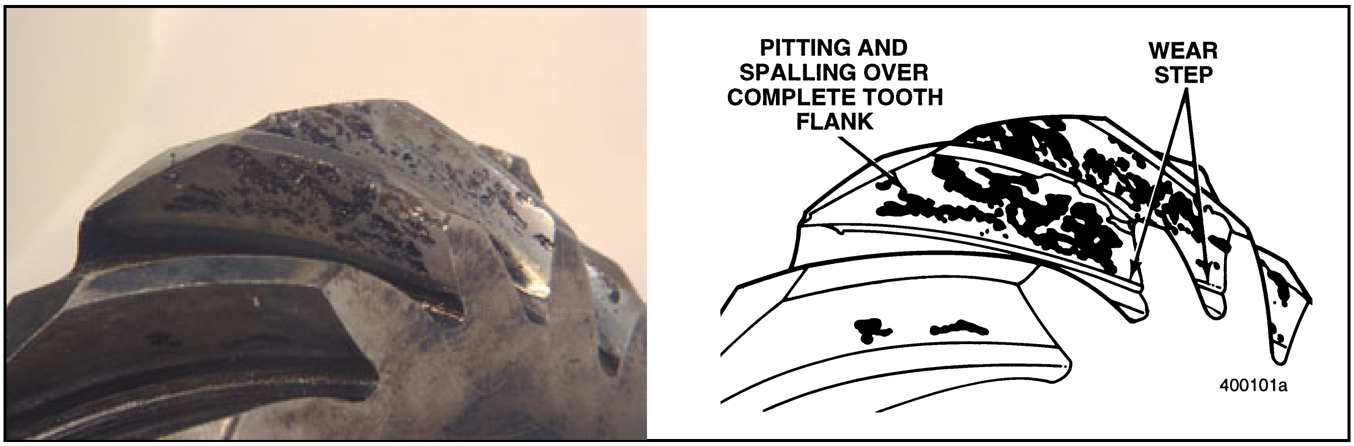


Figure 14 — Spiral Bevel Pinion

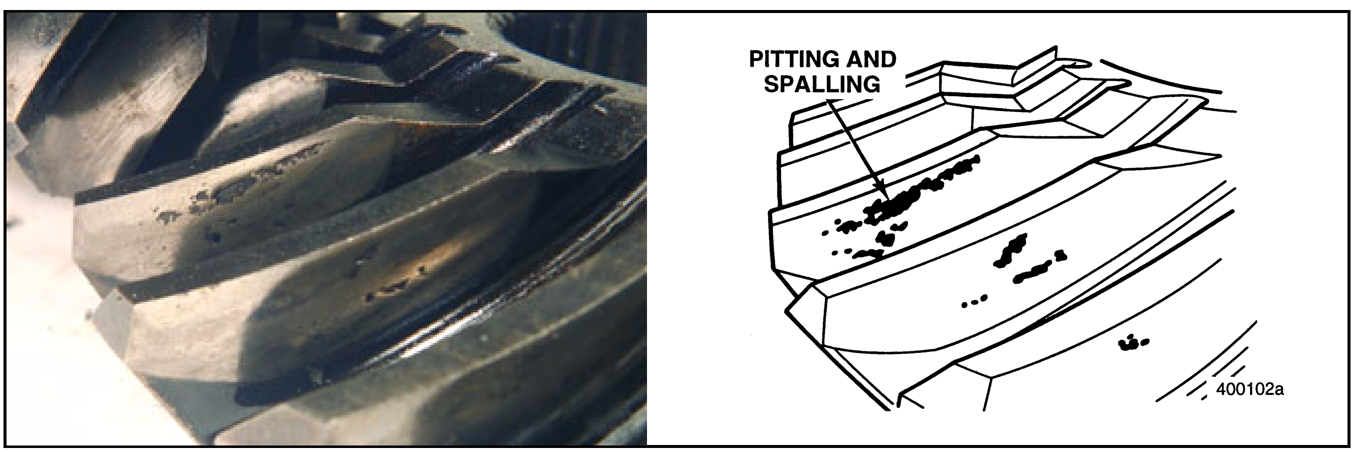


Figure 15 — Spiral Bevel Gear

LUBRICATION FAILURE

Lack of Oil

This bevel pinion was damaged by lack of lubrication. Note the extreme scuffing.

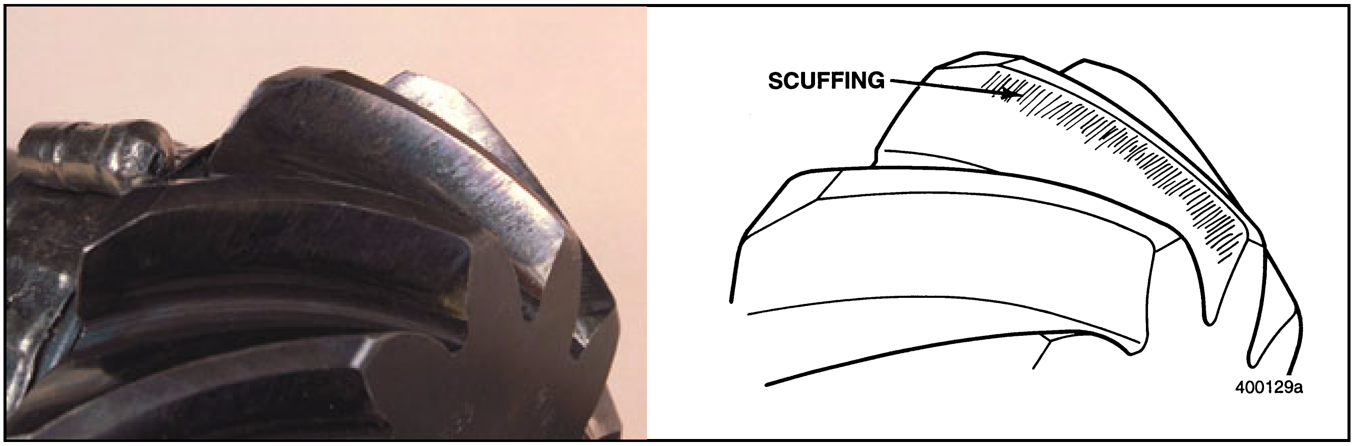


Figure 16 — Bevel Pinion

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BEVEL GEAR SET FAILURE ANALYSIS SUPPLEMENT