Effect of Abuse and Missapplication On Pumping Unit Gears

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Whenever any piece of equipment is overloaded or abused, some degree of deterioration is inevitable, and this same principle will apply to pumping unit reducers. This paper will outline and illustrate the effects of abuse from the standpoint of seeing a result and then establishing a cause.

REDUCER HOUSING BREAKAGE

All pumping unit gear reducers are made of gray iron castings with proportioning of the casting in the manner required by the particular design and exterior loading of the unit. Fortunately, breakage of the housing is rare; but there have been known a few instances in which the core which makes the interior part of the casting shifts in one direction causing one of the walls or corners to be too thin. This weakened wall surface may crack under high unit loadings, and conditions of impact loading will accentuate this condition.

Also known to have caused breakage of the housing is one other circumstance: after protracted torque overload has caused a pinion or gear tooth to completely break out, this broken tooth can get caught in the mesh and wedge apart the slow speed pinion and slow speed gear shafts and cause the housing to break. But this condition is actually a result rather than a cause.

The reducer manufacturer must take great care that the housing has sufficient rigidity and that this rigidity be in the proper planes. Furthermore the machined housing bores must have correct alignment and tolerances, while the casting design must have a minimum of small radii and sharp corners, either inside or outside. Too the reducer openings should be large enough so the gear teeth and internal parts can be inspected.

BOLT FAILURE

On a reducer, bolts are invariably used in some manner: they either tie together halves or attach the reducer to a sub base. However, in almost all instances the type of failure encountered in bolts will be fatigue, and the cause of failure will be insufficient tightness. Fatigue failure is a progressive type and is illustrated by the clam shell pattern as shown on Figures 1 and 2. The texture of a fatigue break is smooth and satin like, and the fracture will generally be in the first thread inside the nut (Fig. 1), or next to the bolt head (Fig. 2).

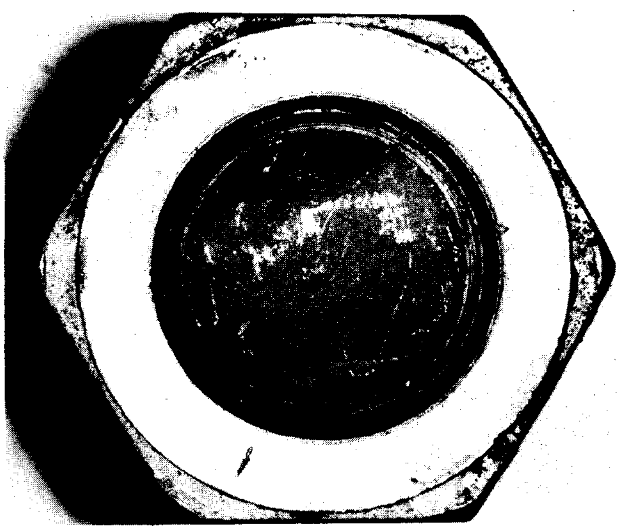

Fig. 1 Bolt failure, fatigue, at first thread of nut.

Fig. 2 Bolt failure, fatigue, at bolt head.

SHAFT BREAKAGE

The type of shaft breakage illustrated in Figure 3 is fatigue, and was caused by variable torsional loads. To be noted is the spiral shape of the fracture and the clam shell progression of the failure.

Figure 4 illustrates a more complicated type of shaft failure in which there was not only excessive torsional load but also reversed bending as well.

Both type of fractures from torsion and reversed bending were caused by excessive loads. Excessive belt tightness, shock loads, and eccentric loading within the reducer will all increase shaft stresses.

The manufacturer must carefully design to eliminate sharp corners which will cause stress concentration: and the material must be properly heat treated and free from flaws.

And another cause of shaft failure is fretting corrosion which will take place beneath a coupling or flange on the shaft. In this instance the surface of the shaft will "powder" away and cause stress concentrations leading to ultimate failure.

The manufacturer must design adequate sized shafts with conservative design stresses.

Fig. 3 Shaft failure, fatigue, from torsional overload.

Fig. 4 Shaft failure, fatigue, from reversed bending and torsional overload.

GASKET LEAKAGE

In some instances oil leakage from reducer covers or bearing carriers can cause unsightly appearance of the equipment. Leakage of the gaskets is generally due to insufficiently tightened cap screws or bolts, and some-

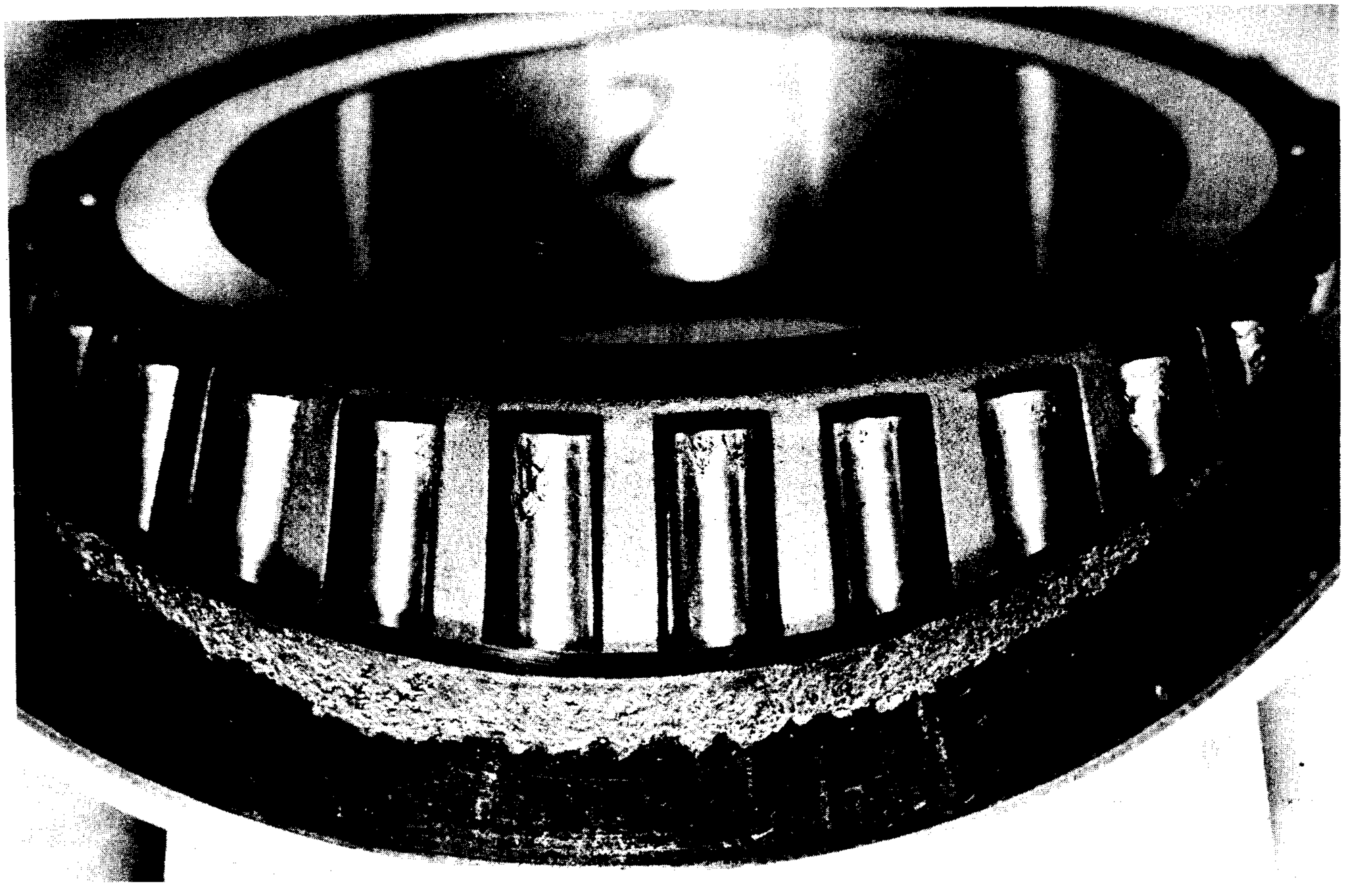

Fig. 5 Bearing failure, spalling and pitting, due to overload from misalignment.

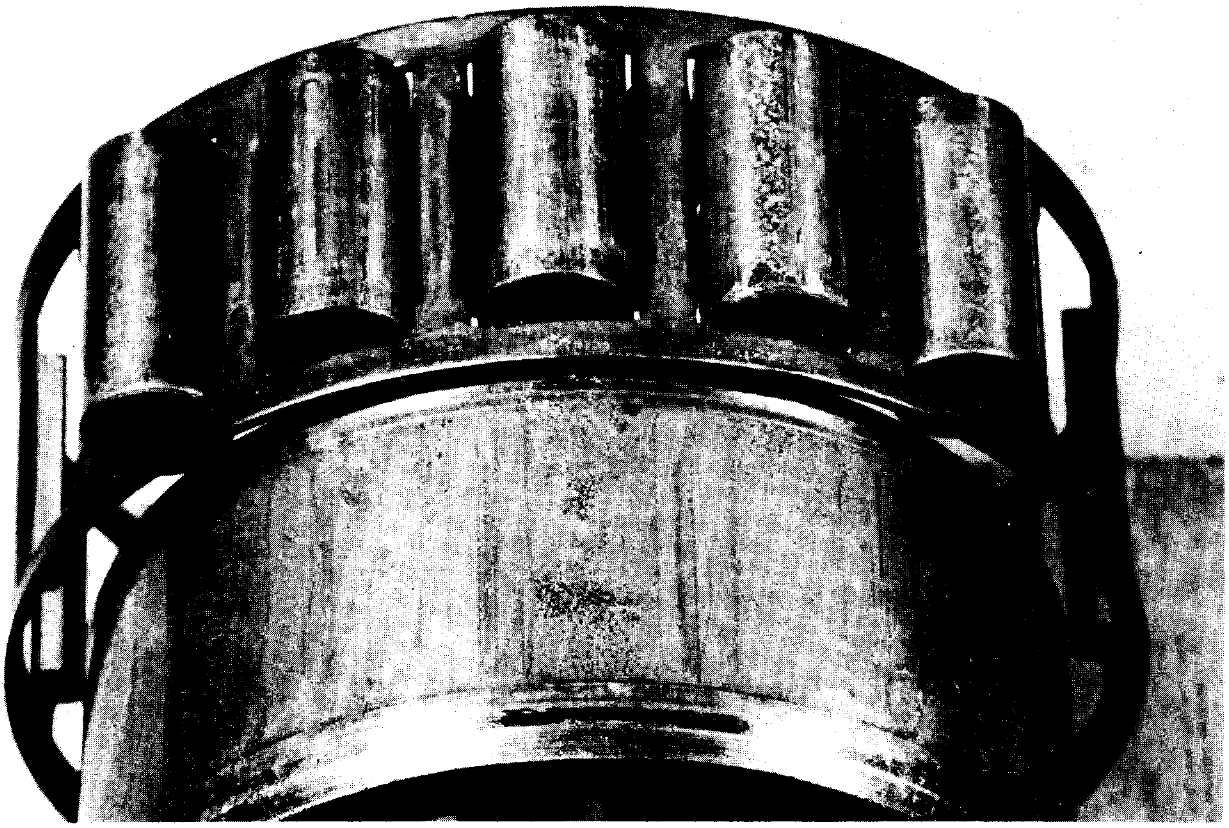

Fig. 6 Bearing failure, corrosion and wear, due to moisture in housing.

times during removal of the cover, to rough handling of the gaskets. The reducer manufacturer must carefully select the proper gasket material and thickness of this material, for each combination of cover - gasket - number and size of cap screws is a design problem unto itself.

ROLLER BEARING FAILURES

The cause and recognition of bearing failures is difficult because so many factors enter into this problem. For instance, the roller bearings may have excessive thrust loading which in turn can be brought on by housing bore misalignments or tapered bores. On the roller bearing themselves may have some out-of-tolerance condition.

The bearing roller surfaces may be deeply pitted or spalled (Fig. 5). This tapered roller bearing was subjected to eccentric loading or misalignment of some type. This condition can originate from an excessive bending load on a relatively small shaft.

If the condition shown in Figure 5 had not progressed so far it would have been known as pitting, and this can actually take place without wear of the race or roller surfaces. As separated pits get larger and join together, the condition known as "spalling" occurs as it did here

The straight roller bearing illustrated in Figure 6 shows a combination of conditions. Corrosion spots are visible on both the rollers and inner race surface. The corrosion can be brought on by exterior moisture leaking into the housing or by condensation, which is in turn aggravated by intermittent reducer operation; but the proper lubricant, changed at regular intervals, will minimize this condition. Further, the inner race shows different surface textures of the race way, for abrasive materials from rust or dirt actually lapped away sections of the race and roll surfaces.

The reducer manufacturer must carefully design to obtain the proper size and type of bearings used in his equipment. The load sources from gear mesh separation, belt loading, and the well load must be considered to establish bearing loading and expected life. Bearing life is very sensitive to load; in fact, it varies as the cube of load, e. g., a bearing subjected to a 100% overload will have its life reduced to 1/8 of normal.

SEAL LEAKAGE

Similar to problems with gaskets, seal leakage causes bad housekeeping around the pumping unit. However, often the oil seal is blamed in leakage when in reality poor installation, tiny scratches on the shaft surfaces, or counterbore rather than the seal proper will cause the leakage. Rust on a rotating shaft can quickly wear away a seal lip until it is no longer effective. Some manufacturers are using a labyrinth type of seal on both the slow speed and high speed reducer shafts, and these seals have proven very satisfactory and are virtually without maintenance problems.

LUBRICANT DIFFICULTIES

The study of lubricant and lubricant difficulties is a tremendous one; however, one authority said: "Look at oil, smell of it, and feel it." A severe darkening or discoloration may take place because of oxidation. An acrid odor may be present and the effects of this odor will be indicated on the entire interior of the box by severe rust because the acid in the lubricant is aggravated by the presence of water. Moisture in the lubricant, either from leakage or condensation in the box, may cause emulsification of the water in the oil and the resulting mixture will be unable to "properly libricate" the teeth and bearings. Some lubricants have foaming properties, and the foam may grow to the extent that it will stop up oil passages and actually cause starvation of bearings for lubricant.

It is always best to follow the recommendations of the manufacturer on the lubrication of his particular reducer. Generally speaking it is desirable to have a very stable lubricant with anti-foam agent and rust and oxidation inhibitors.

It is most important that the producer use the proper type of lubricant, check it occasionally for appearance, smell, and feel, and change it at the recommended intervals.

REDUCER LOADING

In analyzing any kind of failure or difficulty with pumping unit reducers the basis for establishing loading is very important. The exact amount of torque loading on the reducer is the basis for determining the amount of load or overload, and it is essential that an accurate method of making these calculations be used. To determine accurate loadings the torque factor method must be used with a dynamometer card; Sine curve torque calculations are often inaccurate.

TORQUE PEAKS ON SLOW SPEED GEAR

A pumping unit reducer will have two load peaks on the slow speed gear for each cycle of operation. Figure 7 illustrates the points of maximum load, up stroke and down stroke, for clockwise rotation. If one desires to inspect a slow speed gear at these points the reducer must be rotated until the points marked "X" are visible from the inspection opening.

GEARING DESIGN

The theories of involute gearing are fascinating and involved. It is of interest that the maximum relative velocity between the pinion and gear tooth surfaces occurs when the pinion tooth is first making contact with the root of the gear tooth. In pumping unit reducers the size of the teeth must be relatively large to withstand the high bending and shock loads of this application; with larger teeth it is more difficult to obtain quiet operation. Another manufacturing difficulty in pumping unit gearing is that backlash must be kept to a minimum so there will be as little "slap" as possible during reverse torque loads. Pumping unit gear teeth normally have unequal addendums on the pinion and gear so added bending strength is obtained in the pinion teeth. With herringbone gears the slow speed gear set will have about 1.25 teeth in contact in the plane of rotation and about 4 teeth in contact in the axial or transverse direction.

The rating of all pumping unit gearing is established by API in their Standard 11E. The ratings are based on surface durability as the criteria of design, and numerous factors are taken into account.

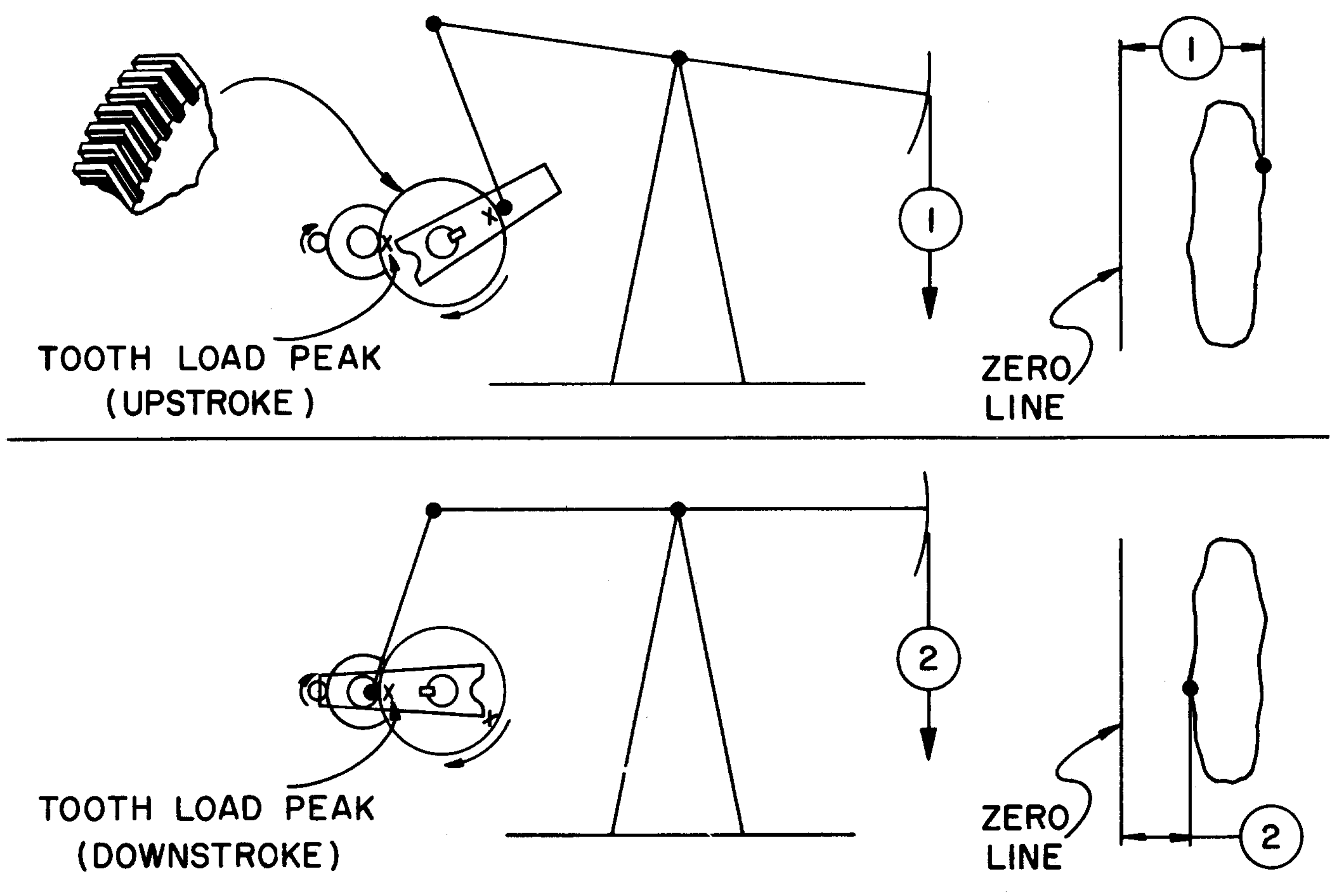

Fig. 7 Slow speed gear torque peaks.

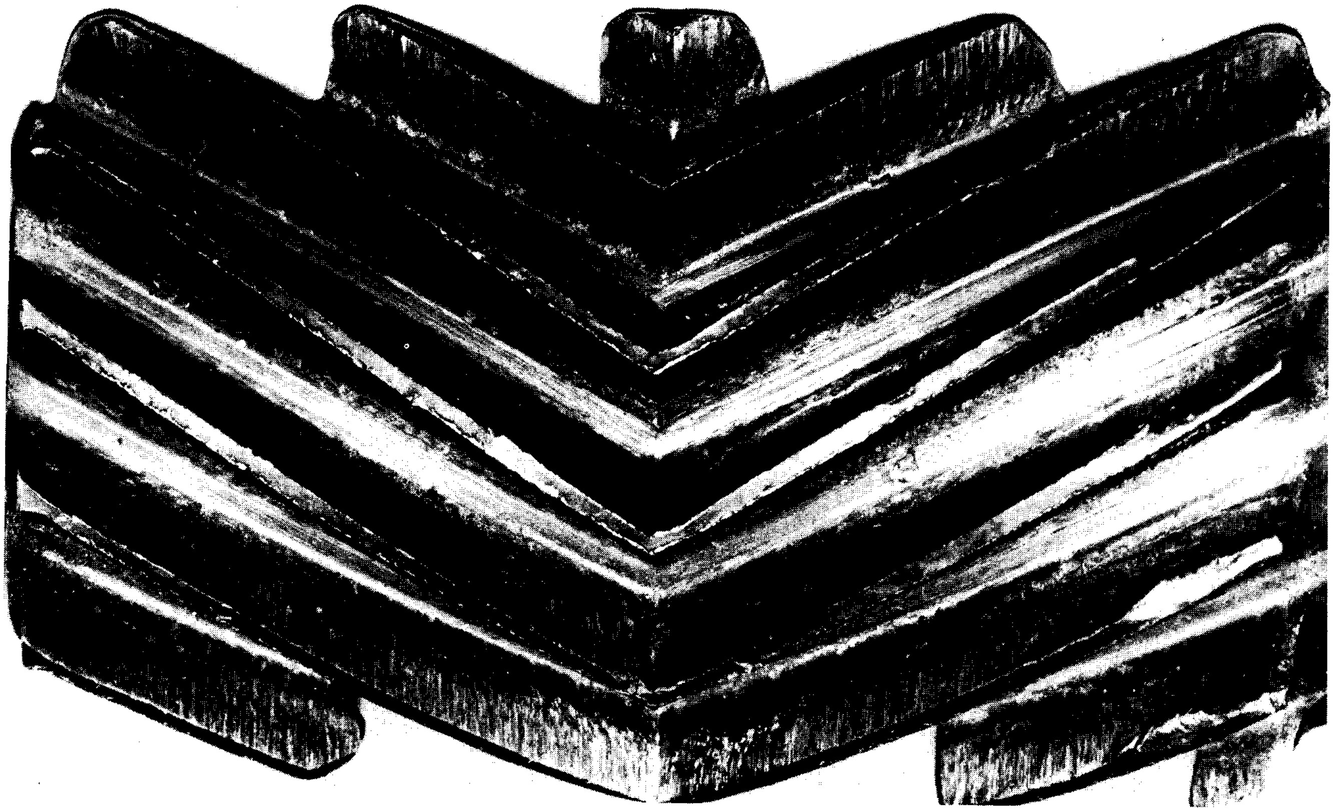

Fig. 8 Pinion teeth scoring from marginal lubrication.

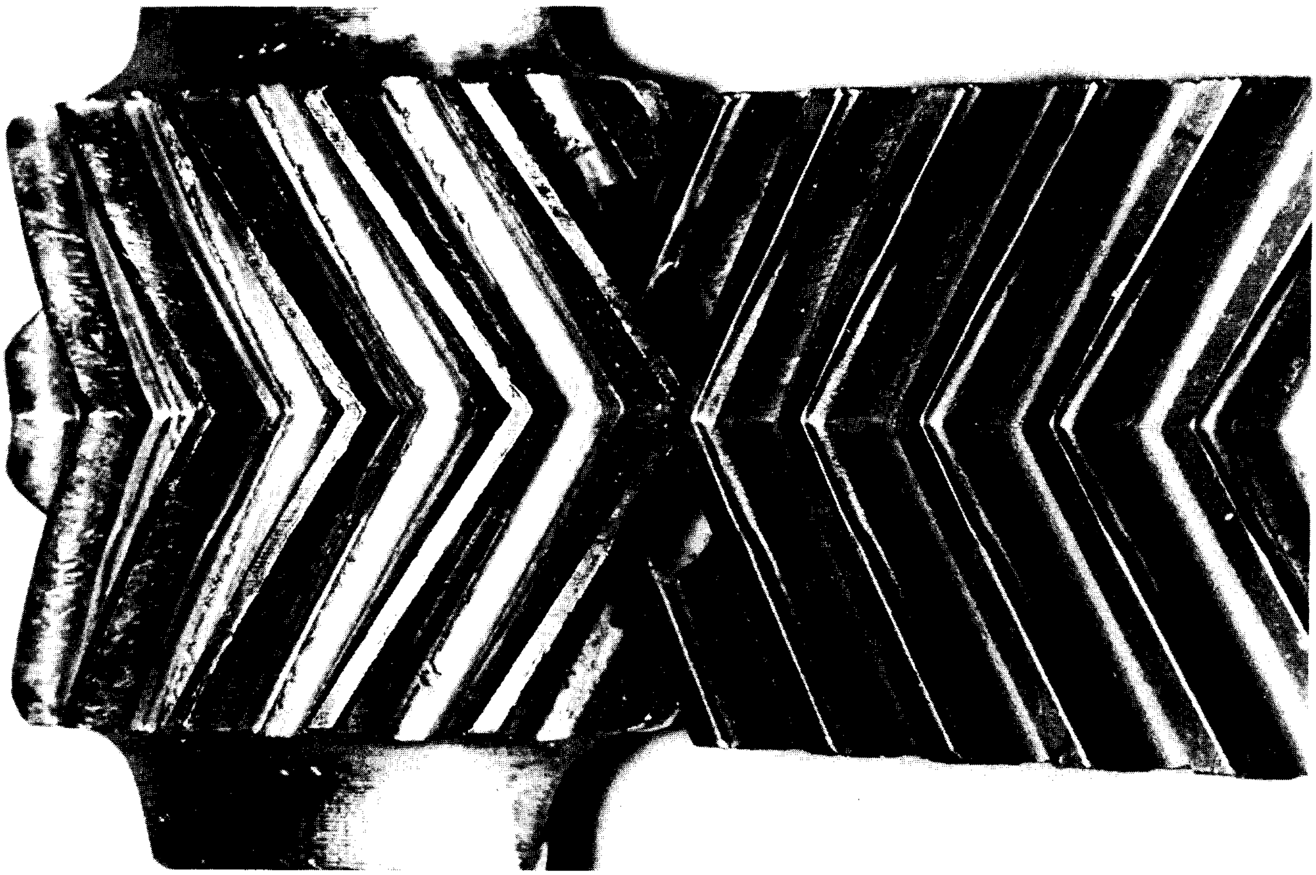

Fig. 9 Pinion and gear tooth scoring, started without oil.

TOOTH DISTRESS AND FAILURE: STEEL

One may have seen, even in a fairly new piece of equipment, tiny flat flakes of material. The exact source of these flakes can be from the tooth surfaces or bearings; but the flaking seems to be more of wearing-in process and causes no difficulty.

Contact surfaces of the gear teeth may show effects of rolling or peening. This condition is not common, though it can happen if the gear material is too soft. Furthermore it is aggravated by torque overload.

Under certain conditions tooth surfaces are subjected to wear, although this is uncommon. But abrasives -- from dirt and the results of corrosion -- in the lubricant can cause wear of the tooth surfaces: overload is often an aggravating factor.

Scoring of the tooth surfaces can happen. Figure 8 shows the pinion of a reducer which is over 10 yr old. In this instance the lubricant lost effectiveness with the resultant scoring shown. The age of the lubricant is unknown; however, it probably went far past the change time recommended by the manufacturer. Figure 9 shows a pinion and gear in which the reducer operated for a short period of time without any oil. After a few days operation oil was placed in the reducer; and there elapsed a total operating time of 30 days before the box was returned to the manufacturer. In this instance the gear material was ductile iron and it had been undercut considerably, although it smoothed out somewhat once lubricant had been added.

By far the majority of steel gear tooth failures are due to pitting which comes directly from torque overload. The involute surfaces develop conical shaped pits or cavities which gradually increase in number until the entire dedendum surface of the involute is badly undercut. And eventually, because of the bending loading on the teeth, some of the pits in the distressed area will initiate fatigue failures in the roots of the teeth. Figures 10 and 11 show the typical pitting, undercutting, and subsequent tooth breakage from metal fatigue. All of these factors are initiated by torque overload. Similarly, Figure 12 shows a pinion with tooth breakage in which the loading was with the "apex leading". The pinion illustrated in Figure 13 was loaded on the inside of the apex, "apex trailing"

Inspection of the fracture surfaces on Figures 10, 11, 12 and 13 shows that the failures are clearly from fatigue. Fatigue failure is a progressive type and takes considerable time from its start as a small crack to ultimate breakage of the part. As mentioned before, the characteristics of fatigue fracture are a satin like finish and a clam shell progression often being visible, while the final portion of the fracture is generally of a brittle nature and has a rough texture. In the illustration, the change from fatigue to brittle fracture can be clearly seen.

TOOTH DISTRESS: -- NODULAR IRON
(WITH STEEL PINION)

This new gear material is proving to have remarkable resistance to pitting. The character of pitting on nodular iron is different from pitting on steel. Figure 14 shows a nodular iron slow speed gear which had a torque overload. It is of interest that nodular iron has a "healing" property so that, even when pitting occurs, it does not progress as drastically as it does in steel.

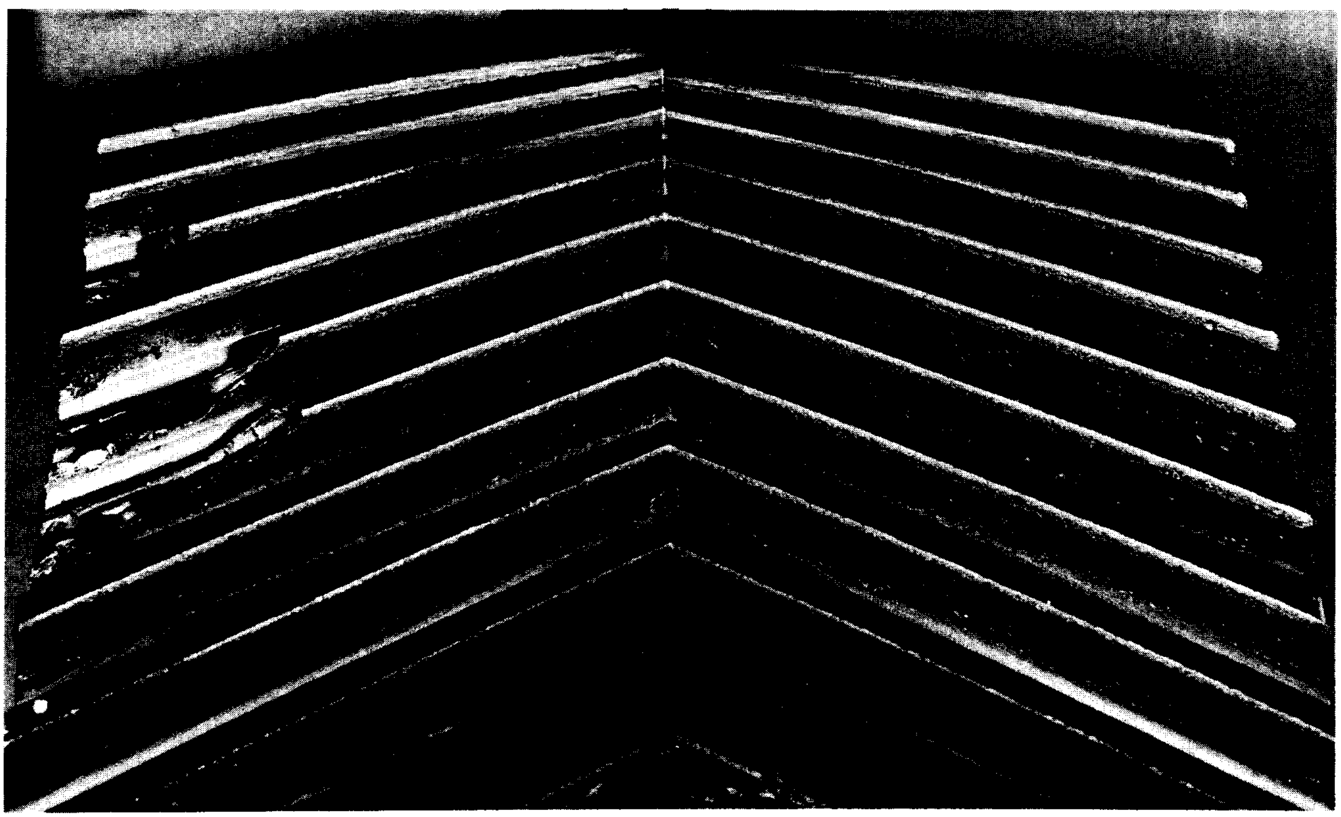

Fig. 10 Gear tooth pitting and breakage from torque overload.

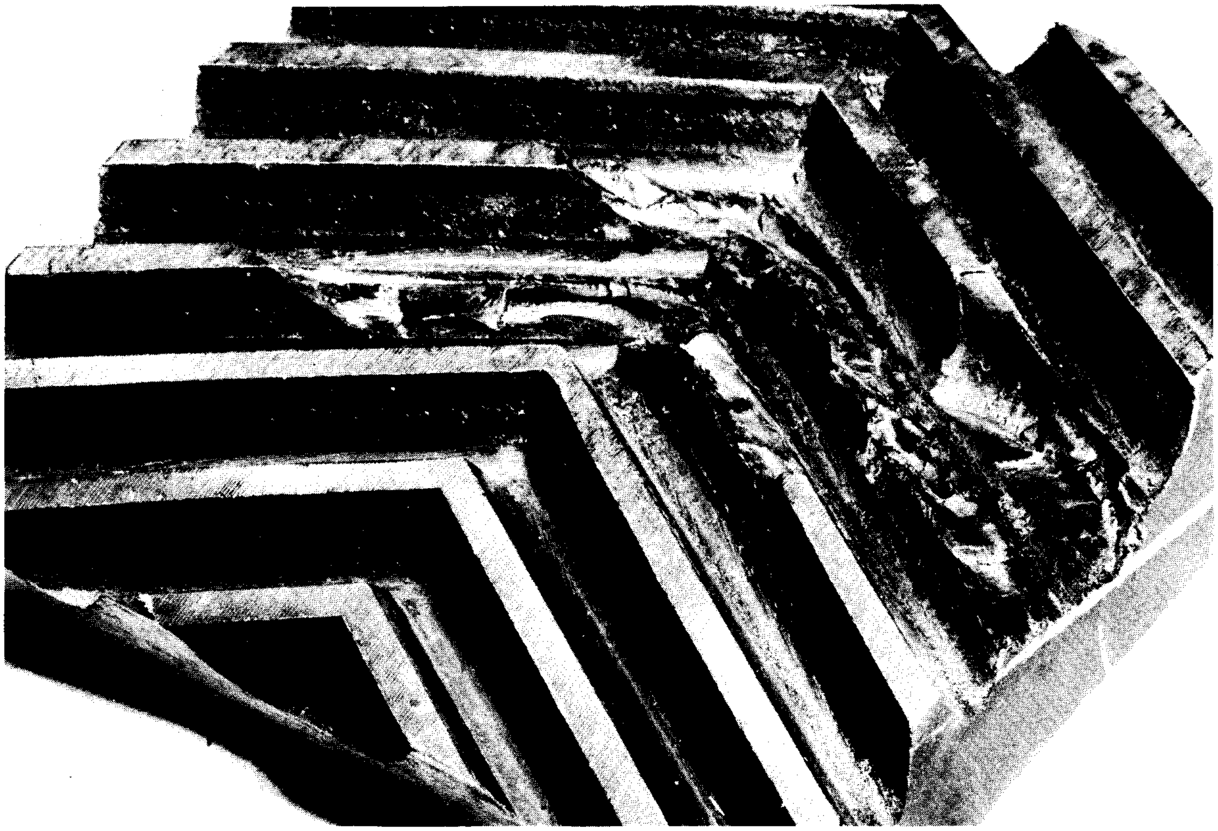

Fig. 11 Gear tooth pitting and breakage from torque overload.

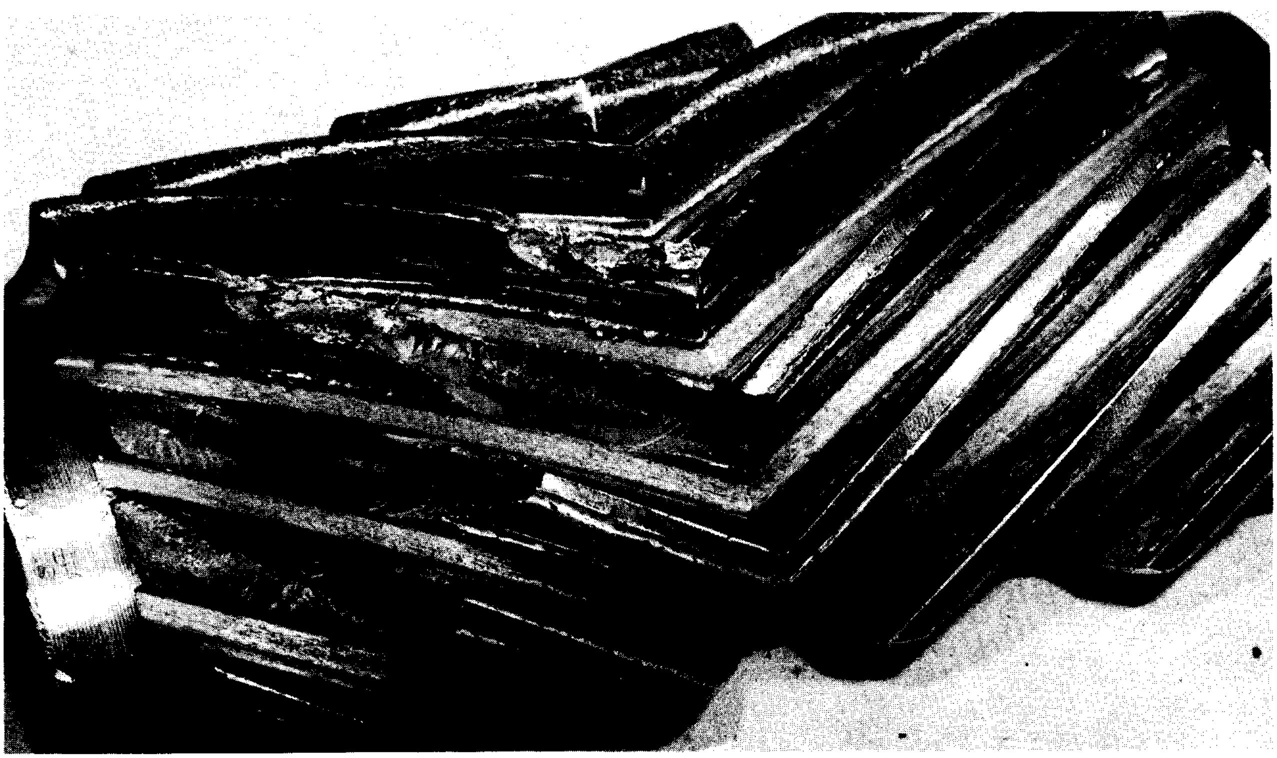

Fig. 12 Pinion tooth pitting and breakage from torque overload applied outside apex.

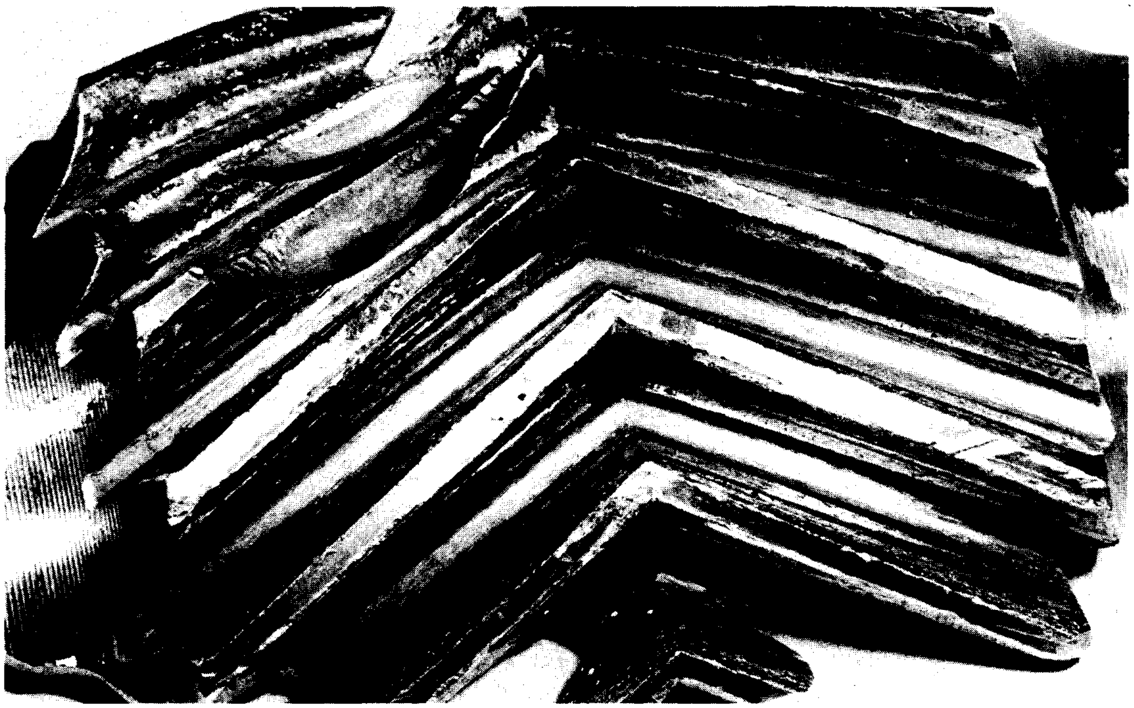

Fig. 13 Pinion tooth pitting and breakage from torque overload applied inside apex.

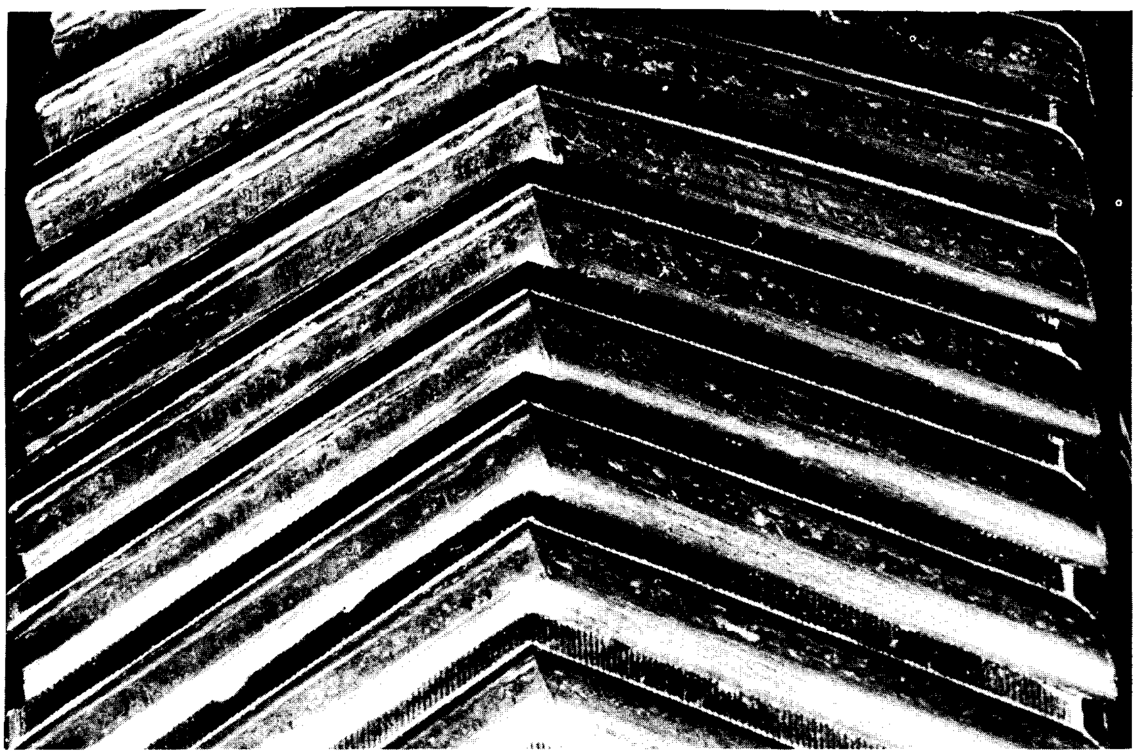

Fig. 14 Gear tooth pitting, nodular iron, from torque overload.

CONCLUSION

(1) Rating: the single most important item in pumping unit reducer care is to keep the loading within the manufacturer's rating.
(2) Counterbalance: to obtain optimum use of the equipment with no torque overload, the reducer should be carefully counterbalanced.
(3) Fluid Pound: this down hole condition causes severe shock loading on the entire pumping unit as well as on the reducer.
(4) Belt tightness: when belts are excessively tightened the shaft stresses can be very high. Reasonable belt tightness will reduce the possibility of shaft failure and add to belt life.

(5) Lubricant: the incorrect lubricant can cause difficulties in the bearings and tooth surfaces. The recommendations of the manufacturer should be followed.
(6) Gear Material: different gear materials respond in different ways to torque overload. Nodular iron shows great promise to resist pitting and withstand torque overload.
(7) Rotation: if an electric motor prime mover is being used, the producer would do well to alternate periodically the direction of unit rotation; so opposite tooth surfaces would be exposed to contact loading. The time intervals between reversals would depend on the degree of torque loading.
(8) Loading: to protect pumping unit reducers it is always best for the operator to know the actual loading on his equipment and not to operate at an overload.

BIBLIOGRAPHY

(1) "Nomenclature of Gear - Tooth Wear and Failure," AGMA. 110.03.
(2) TORRINGTON. "Spherical Roller Bearing Service Damage and Causes."
(3) "API Specification for Pumping Units," API STANDARD 11E
(4) R. Q. SHARPE "Why and When to Drain Hydraulic Oil," (Mobil)