The Causes and Cures of Pumping Unit Reducer Troubles

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GEAR REDUCERS

Although there are many different ways of artificially lifting oil from a well, the old beam type pumping unit is still by far the most popular means and probably the most reliable under all conditions. Most of these units are actuated by a gear reducer which is powered by some kind of prime mover. For years, the internal combustion engine was practically the only source of power. Recently, however, the electric motor is replacing engines to a large degree.

The gear reducer, being the heart of the unit pumper, will be the topic of this paper. These reducers are carefully designed and precisely built so as to give maximum service. With proper care as to loading and maintenance they should deliver many years of useful performance.

To the average individual, gears seem a fairly simple piece of machinery. In their basic concept they are simple. However, the detail operation and actions of gears, as they go through their motions of engaging and disengaging and transmitting power from one to the other, are quite complex and not widely understood. We are not going to go into the technical operations of gears but will consider what can be done by the operator to assure his getting the gear life to which he is entitled.

TYPES OF WEAR

There are numerous kinds of gear wear, each one producing its own characteristic indication. The most common types of wear are: normal wear, initial pitting, progressive pitting, abrasion, galling, advanced galling, spalling, and mechanical damage. We will consider each type individually.

Normal wear is the slight wear observed on a set of gears operating under a load within the design limits of the reducer and with proper lubrication and care. Such wear is usually caused by the very small and unavoidable abrasive particles found in any piece of practical machinery. The indication of normal wear is a very smooth, satiny finish on the surface of the teeth. This is the ideal type of wear but is seldom seen, due to factors such as slight overload, small manufacturing discrepencies, poor lubrication, and less than ideal operating conditions.

Initial Pitting

Initial pitting often occurs when a set of gears is first put into operation. It is caused by high localized stresses resulting from the contact of the microscopically small irregularities on the surface of any commercial gear. As the high spots on the mating teeth come under load, the terrifically high stress at these points causes an early failure of the parts in contact. As the points are worn away, a pitted surface develops and the load on the tooth surface is spread over a larger area, resulting in decreased surface stresses. When the area becomes large enough, and the stress therefore small enough, the pitting stops and normal wear usually follows.

Initial pitting usually appears as small shallow pits along the pitch line of the tooth. As the pitting subsides, the area between the pits takes on a bright, smooth appearance, with the pits themselves showing up as dark spots. This type of pitting usually stops of its own accord. Proper lubrication is very effective and use of the right oil, especially during the initial running of the unit, is very important.

Progressive pitting, as the name implies, is the result of unarrested initial pitting, Fig. 1. It occurs when the area between the pits is not great enough to carry the load. The high unit stresses thus developed cause pitting in originally unpitted areas in exactly the same way as initial pitting.

This type of failure first develops along the pitch line and is identical in appearance to initial pitting. However, the affected area spreads above and below the pitch line and the pits become large and more numerous as failure progresses. A reduction in load on the gear will often stop progressive pitting if it is not too far advanced.

It is well to remember that in pumping unit use, the load is not uniform around the gear. If gear tooth failure is observed to be greatly concentrated in only

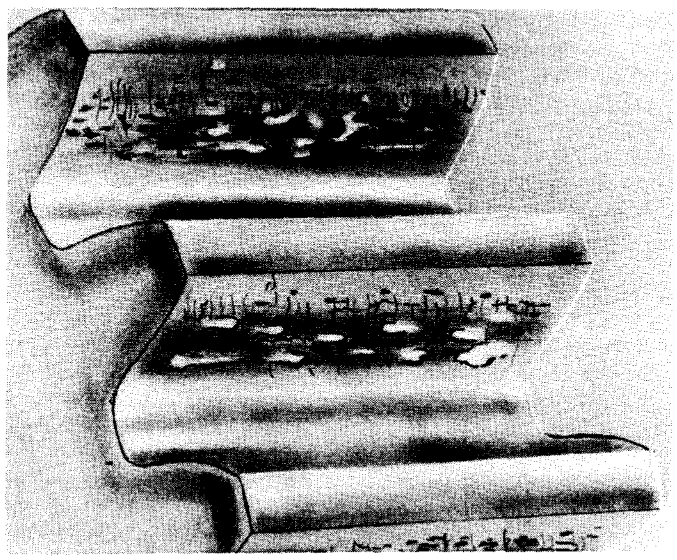

Fig. 1

one or two places around the low speed gear, the well conditions should be investigated for signs of excessive loads at some points in the cycle. The use of a dynamometer in these cases is highly recommended.

In border line cases of progressive pitting, where the appearance of the tooth indicates a very slow deterioration of the surface, a change to a lubricant of heavier body or higher film strength may be all that is necessary. If the pitting cannot be stopped, it will continue at an accelerating rate until the gears destroy themselves and replacement will be necessary.

Abrasive Wear

Abrasive wear is caused by some kind of foreign, gritty material passing through the gear teeth, Fig. 2. It appears in the form of fine scratches, extending in a radial direction from the root to the tip of the teeth on an otherwise smoothly worn surface. It is possible for these scratches to be so fine that it is difficult to differentiate abrasion from normal wear.

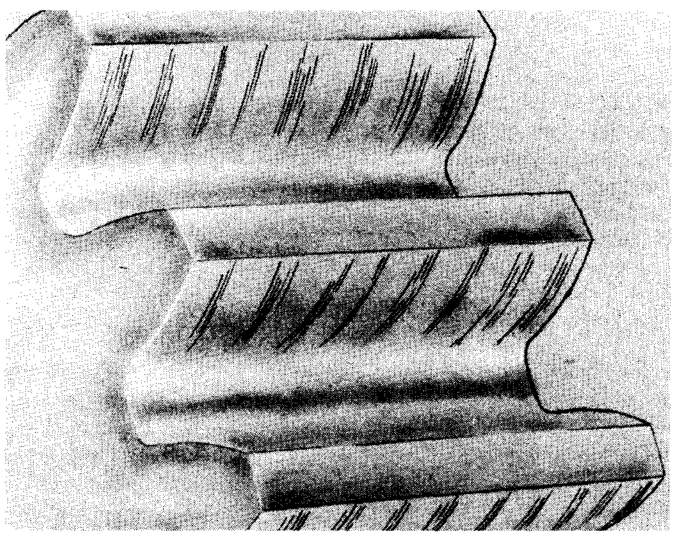

Fig. 2

There are several sources of abrasives in pumping unit gear reducers. Probably the most frequent source is air carried particles such as blowing sand and dust. It is almost impossible to keep this type of material out of reducers in certain areas. The operator should take every precaution to see that his unit is as tight as possible. Particular attention should be paid to filters on air breathers and gaskets on covers and inspection doors. In especially bad locations, the oil should be changed more frequently and this should be accompanied by good flushing of the box, especially in seasons when dust is bad.

The second most common source of abrasives is within the gear box itself. Under certain conditions there can be a chemical reaction between some lubricants and either the metals, paint or water. The result is the formation of particles that are more or less abrasive. One very frequent example is the corrosion caused by the combining of water with some elements of the lubricant to form acids. When this acid attacks the metal in the reducer, iron oxide is formed.

In mild cases the corrosion is not enough to damage the gears directly because the oxide film itself is a protective coating, preventing further oxidation. However, under the movement of the tooth surfaces and the bearings, the oxide is worn off and becomes suspended in the oil. Iron oxide is a very effective abrasive, one of its better known forms being jeweler's rouge. If this material is allowed to remain in the oil, the gears and bearings eventually will be abraded away, the rate and severity of wear being determined by the type and intensity of the corrosion.

In order to eliminate this kind of wear, it will be necessary to ascertain the source of abrasion and eliminate it. It may be possible to reduce condensation if that is a contributing factor. An inspection of covers and gaskets may reveal that rain water is leaking in. A change in the type of oil will quite often be the remedy. Whatever the solution, it should always be accompanied with a complete flushing of the box to remove all foreign matter.

Ocassionally the source of abrasives is the oil itself. This happens more frequently where gear reducer oils are filtered and replaced in the unit. There have been cases where foreign matter, such as fuller's earth from the filtering element, has gotten into the oil and therefore into the gear box.

If stopped soon enough, abrasion will not cause permanent damage to the gears. If it escapes undetected, or is rapid, destruction not only of the surface but of the tooth profile will occur. It is possible to completely ruin a set of gears, as well as other parts such as bearings, if this condition is not corrected. The only cure to abrasive wear is the removal of the source of the abrasives followed by replacement of the lubricant with the proper oil after thorough cleaning of the box.

Galling

Galling of gears occurs when, for one reason or another, the metal surfaces of the mating teeth come in contact with each other. This can be caused by any of several things, two of which are the most common. First, the oil film may lack sufficient strength to keep the metal parts apart. Second, the load on the teeth may be so great that the oil film is ruptured, regardless of its quality.

When the gear teeth contact each other under load, without an oil film separating them, terrific heat is generated as these surfaces move in relation to each other. This heat, although it is only on a very thin surface of the metal, is great enough to cause localized welding of one tooth to its mating tooth. As the teeth continue their movement this weld is broken, tearing out chunks of metal.

As this process continues the surface becomes rougher, due to so many irregularly shaped particles being torn from the tooth. This rough surface, being able to penetrate the oil film more easily even than before, allows metal-to-metal contact under higher stresses, which accelerates the galling procedure. Thus, once galling starts, it progresses at an ever increasing rate unless something is done to stop it.

Galling first appears as fine scratches in a radial direction along the teeth, Fig. 3. In its milder or initial stages it is sometimes referred to as scoring. As it progresses, the score lines become deeper and more irregular. Sometimes galled surfaces are excessively worn but smooth. More commonly, however, the surfaces are left rough. In some cases of gear teeth galling, the metal is dragged over the surface and forms a wire or knife edge along the top of the tooth.

As galling continues and the surfaces become extremely rough, a condition then exists which is known

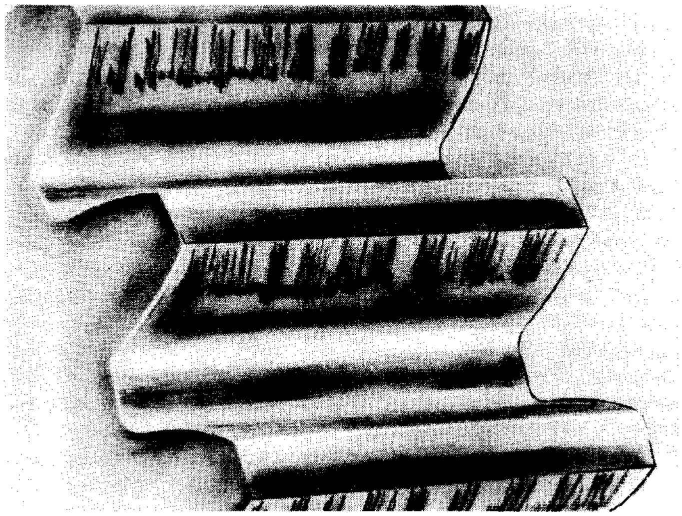

Fig. 3

as advanced galling. When this occurs, all similarity of tooth profile has long since disappeared. During the galling process there is a tendency for the metal to be wiped toward the pitch line on the driven teeth and away from it on the driving teeth. This often results in the development of a ridge along the pitch line of the driven teeth, Fig. 4, and a groove or hollow along the pitch line of the driving teeth, Fig. 5.

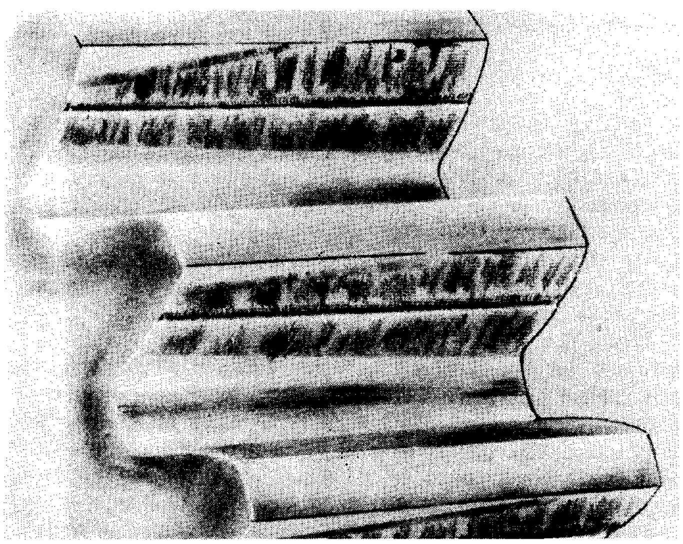

Fig. 4

Very little can be cone about galling in its advanced stages. The tooth involute having been destroyed, the tooth can no longer function properly. If the galling is not too deep, the surface may be restored by recutting the teeth. Of course, this results in a greatly increased backlash between the mating gears. This may be permissible in some gearing but is not recommended for pumping unit gears and is not usually economically feasible.

If galling is recognized in its initial stage, it can usually be arrested before permanent damage is done to the teeth. If it is determined that the lubricant film strength is not sufficient to carry the load, replacement of the oil with a superior quality lubricant is all that is necessary. If, on the other hand, it is found that the load on the teeth is too great, it will be necessary to reduce it to a point where the gears will carry it without galling.

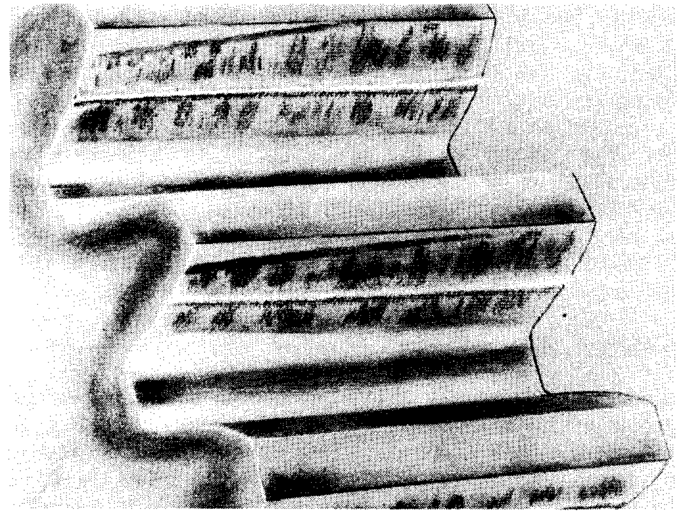

Fig. 5

Remember that here, as mentioned before, it is not necessarily the average gear load around a complete cycle that counts, but the instantaneous load at any one particular point on the gear. If galling is severe, usually the only alternative is to replace the trains. Whatever means is used to stop galling, it should be accompanied by a complete cleaning of the gear box. The small metal particles torn from the tooth surface, if allowed to remain, will further damage the gears and other moving parts.

Spalling

Spalling is caused by abnormal loading of tooth surface resulting in overstresses in the subsurface metal. The metal thus fails in fatigue, due to the repetitive nature of the overstresses. The fatigue cracks progress until small flat flakes break out of the teeth. This leaves a shallow crater on the surface, not greatly different from initial pitting, with which it should not be confused. Earlier it was said that initial pitting was caused by very small manufacturing imperfections on the surface. Spalling may occur on gears that are well broken in and have an excellent surface. It usually starts at the root of the tooth where the work done is concentrated on a smaller area.

Spalling is the result of overloaded teeth and is not related to lubrication. The only remedy is to reduce the load. If this is not done, spalling will spread, due to the load being carried on ever diminishing areas, until the tooth is destroyed. At this point, again, the gear trains must be replaced.

Mechanical Damage

Mechanical damage to gear teeth is caused by some foreign object passing through the gears. This object can vary in size from a grain of sand to a nut, bolt or bearing roller. The extent of damage is determined by the number, the size and the length of time of action of these objects. Small particles will cause scratches or indentations which may seem like abrasive wear, which, in fact, it is on a greater scale. Larger objects will make severe marks on the teeth and will occasionally deform or break them off completely.

This type of damage is quite readily recognized, especially if the object is of any size at all. It is characterized by a somewhat local nature and repetitive pattern. As the object passes through the meshing gears it makes an indentation on the surface of the teeth. There is an accompanying upsetting or raising of the surface around the indentation. As one of these points mates with another tooth, the surface of the new tooth will be marked in a similar pattern to the original mark. As this new mark engages another tooth and as the original mark continues to come in contact with other teeth, this mark is finally transferred from tooth to tooth until all the teeth possible will be marked.

Whether all the teeth in the train or only every second or third tooth is affected depends on the relative numbers of teeth on the two mating gears. If the train was designed with perfect hunting tooth action, that is if every tooth on the driver gear comes in contact with every tooth on the driving gear, the pattern of marking will appear on every tooth of both gears. The marks will be in the same relative location on all teeth.

Mechanical damage usually does not cause complete or permanent damage to the gears, especially if the tooth is not deformed and the action is not widespread enough to cause appreciable reduction in area of the mating surfaces. The damage often cures itself but, at its worst, it may be necessary to file or hone the bad places on the teeth. The source of the foreign object should be ascertained and steps taken to see that the same or similar objects cannot again become free in the gear box. Screws often can be wired or lock washers installed to prevent them loosening.

WEAR ON BEARINGS

Bearings are often the forgotten part of a pumping unit reducer. Although possibly less glamorous, they are just as important for the proper functioning of the unit as the gears. In fact, many a set of gears has been completely ruined because of bad bearings.

When a bearing becomes severly worn and excessive radial clearance develops, it is impossible for the gears to mesh properly. The increased clearance alters the actual center distances from that for which the gears were designed. As the loads vary, the gears will move with relation to each other with a sliding motion between the mating teeth. This is conducive to rapid tooth wear and the profile is soon destroyed. Bearing wear is similar to gear tooth wear, in that bearings are subject to spalling, mechanical damage, galling, improper lubrication and abrasions.

A roller bearing, operated properly, will eventually fail by spalling, usually on one of the races. This should happen only after many years of service. However, if the bearing is greatly overloaded, it will fail in a much shorter period of time. Roller bearings have a peculiar characteristic in that the life expectancy is inversely proportional to the cube of the load. This means that if the operating load on a bearing is twice its design load, the bearing will have a life expectancy of one eighth its design life. Or, if the load on a bearing is increased only 26%, the life of the bearing will be cut in half ($1.26^3 \doteq 2$).

A bearing which has become spalled or pitted will be quite noisy. Sometimes this noise is interpreted as gear growl. Examination of the bearing will ascertain if it is damaged and should be replaced.

As in the case of gears, mechanical damage to bearings is caused by some foreign object passing through the rollers. Pits or indentations result but are usually not nearly so severe as on gear teeth, due to the greater hardness of the bearings. Also, the smaller openings between the rollers protect the bearing and make it impossible for large objects to get in. Unless marking is great, the bearings are not usually permanently damaged.

Galling occurs when severely spalled bearings are kept in operation or when the bearing is run without lubrication. When this happens, the operator is lucky if the bearing is the only thing that requires replacement.

Abrasive wear of bearings can be quite rapid. It is usually caused by grit in the oil. This could be from any one of several sources, as mentioned earlier. Blowing dust and the products of corrosion are probably the most prevalent sources. A bearing worn by abrasion is often hard to detect by examination of the rollers and races. The surface is frequently not much rougher than a new bearing. However, a quick check of the diametral clearance will give the answer. If the clearance is more than a few thousandths of an inch, the bearing should be either readjusted, if possible, or replaced. Of course, the box should be thoroughly cleaned and or replaced. Of course, the box should be thoroughly cleaned and the oil replaced after the source of the abrasion is eliminated.

Proper Lubrication

Proper lubrication is as important as the original engineering design, proper material and precise manufacture of the gear reducer. The primary function of a lubricant is to keep the metallic surface of the gears separated during their engaging period. If for any reason, whether it be poor film strength, excessive loads, or uneven surfaces, the surfaces actually contact each other, damage will result.

Different oils have different film strength. For lightly loaded teeth almost any oil will serve. However, for heavy duty work such as occurs in reducer gears, it is necessary that oil with a high film strength be used. Usually the heavier and more viscous the oil, the higher the film strength.

In order to improve the lubricating qualities of oils, chemicals of certain characteristics may be added. These oils then become known as "extreme pressure" or "EP" lubricants. The chemicals in EP oils have a peculiar action. Under the normal operating conditions, these additives have very little effect. However, at greatly elevated temperatures, the chemicals actually attack the metal of the gears.

Earlier, the cause of initial pitting was shown to be unavoidable surface irregularities, which break through the oil film and cause metal-to-metal contact. At these points, the metal temperature is greatly increased. The additives attack the very hot metal and gradually remove the protrusion that is causing the heat, forming lead oxides. Thus, by a system of selective corrosion, due to the additives being active only at the very high temperature points, the surface of the gear tooth is greatly improved. This is the reason many gear manufacturers recommend the use of such lubricants, especially during the critical breakin period of a new gear train. EP lubricants may also be used to advantage to correct gears that are slightly damaged for some previsouly mentioned reason.

There are a number of EP lubricants. All of them have similar characteristics under normal conditions.

However, there are some which become corrosive when moisture is present. It is almost impossible to keep condensation out of pumping unit gear reducers, so it is only sensible to use a lubricant that is compatible with water. There are kinds of EP lubricants which are specified as non-corrosive and are entirely stable in the presence of water.

Some suppliers will state that their lubricants are noncorrosive, which they are while being tested in the laboratory. When water is added, it is quite a different story. To be safe, the oil should be specified as noncorrosive when mixed with water. For years the lead naphthenate type of additive has been accepted as very stable and effective. Lately there have been other materials used which are supposed to be just as reliable.

Many operators make a practice of filtering and reusing reducer oil. This procedure may be permissible if only solids are present. If, however, removal of certain liquid elements such as acids is necessary, an extensive reconditioning process will be required. This almost becomes re-refining, in which case all of the foreign materials, the desirable and expensive additives as well as the harmful ones, are removed. All of the EP qualities of a lubricant will be lost when oil is reconditioned. The oil is then no better than a straight mineral oil.

CONCLUSION

Good lubrication is of primary importance in the proper performance of gear reducers. Certainly it is poor economy to jeopardize the long and useful life of an expensive set of gears to save a few dollars on oil. A good, practical lubrication program should be set up, with local conditions influencing the frequency of oil change. The equipment manufacturer or the lubricating engineer of your oil supplier will be glad to make recommendations. The box should be thoroughly cleaned and flushed before refilling with good, new oil.

A person wouldn't think of putting an inferior oil in his automobile and running it for a year without changing it. Why not use the same logic with a pumping unit, which usually costs considerably more and is expected to last many times as long? Only one year additional life of a unit would probably more than pay the extra cost of good lubrication practice.