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IMPROVING GEAR BOX DURABILITY

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ABSTRACT
The wear life of a gear box can be greatly extended with a good program of preventive maintenance that consists of periodic inspection of the gear tooth wear, lubricant, bearing endplay and clearances, and operating temperature.

LUBRICATION
The lubrication of the gears and bearings is the most important contributing factor to long life. The functions of the lubricating oil are described below:

1. SEPARATION OF METAL:
To separate the gear teeth and bearing metals from contacting each other, oil provides a very thin film that could be anywhere from several millionths of an inch to perhaps several tenths of one thousandth of an inch. While this appears to be an extremely thin oil film, it is sufficient to keep the metals from touching each other. If the oil film breaks due to heavy loads, water in the oil, or extremely heavy shock loads, the gear teeth or bearings may spot weld to each other then immediately break the spot weld due to continuous motion and result in scoring.

2. LUBRICATION:
Preferably, a gear oil that provides the thickest film for the operating conditions should be selected. A thicker oil film provides more protection from spot welding, scoring, or wear due to abrasive, fine particles of foreign material in the oil. An even greater advantage provided by a thick oil film, is that the forces at the gear teeth and the bearings are transferred from one component to another through an improved hydrostatic load transfer. When the hydrodynamic oil film is two to three times greater than the surface disparities, concentrated loads at high points of disparities are avoided. (Disparities may be caused by small layers of low strength inclusions such as copper, silicon, etc.) The thicker hydrodynamic oil film increases the fatigue life of the steel in gears and bearings.

The preference should always be for the heaviest gear oil so long that the operating temperature is not below the oil pour point in order to avoid channeling. (Oil channeling is defined as exposure to low temperature where the oil becomes grease and no longer flows. When the gears rotate and move, the grease will not flow back between the gear teeth and bearing rollers to provide continuous lubrication. Therefore, even though there is a sufficient amount of oil in the gear box, the gear teeth and bearings could be starved and over heat because oil in the form of grease does not flow.) It should also be considered that at the high temperature end the heavier oils generate more temperature, because the oil film between the gear teeth or bearing rollers provides more resistance to motion. For example, if the gear box continuously operates at temperatures above 200°F, it may be preferable to go to a lighter weight viscosity in order to reduce the operating temperature. In the end, the same oil film thickness would be achieved. A high speed shaft may develop a thicker oil film due to the velocity factor of the hydrodynamic film properties of oil.

During NASA testing it was found that oils with extreme pressure (EP) additives of sulfur phosphorous oxide increase surface durability by a factor of five. For this reason, it is recommended that only oils with EP additives be used. These additives also have the quality of further enhancing the metal to metal separation and in turn increase wear life[1].

A guide to types of oil to be selected for operating temperatures should be used from Figure 2. A guide for oil change intervals for various continuous operating temperature is presented in Figure 1. Figure 4 shows various hydrodynamic oil film thicknesses calculated to develop between gear teeth under heavy loads. This figure is made to illustrate how the oil film thickness varies with temperature and with viscosity.

Some gears and bearings are lubricated with grease, which is adequate for slow operating components. Medium and high speed components cannot be lubricated properly with grease because the centrifugal force would throw the grease away from the gears and bearings. They would soon become dry and then fail.

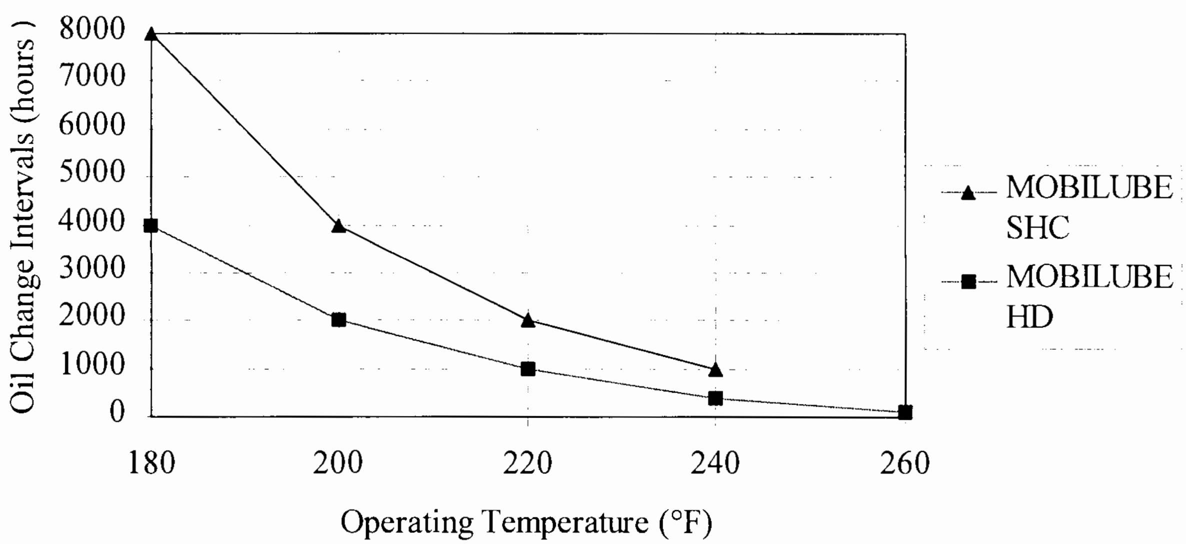

FIGURE 1

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[1]Townsend, D.P., Zaretsky, E. V., and Scibbe, H.W., "Lubricant and Additive Effects on Spur Gear Fatigue Life", ASME Trans. Volume 108 (1986).

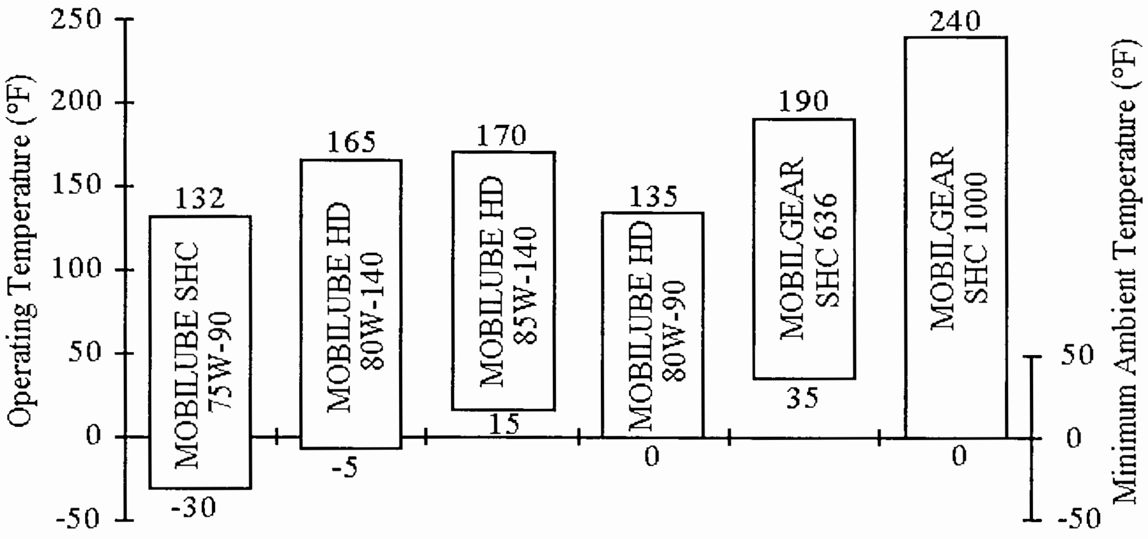

FIGURE 2

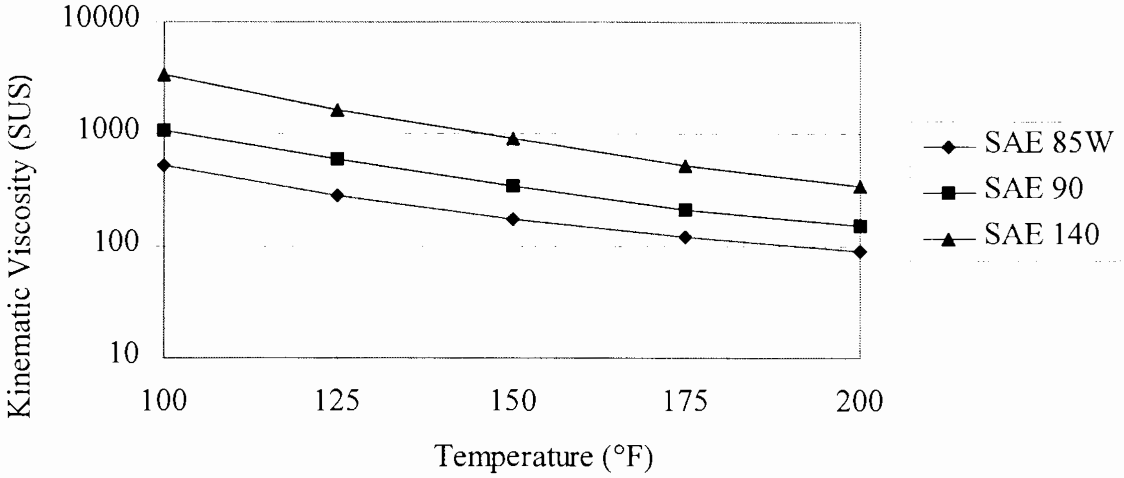

FIGURE 3

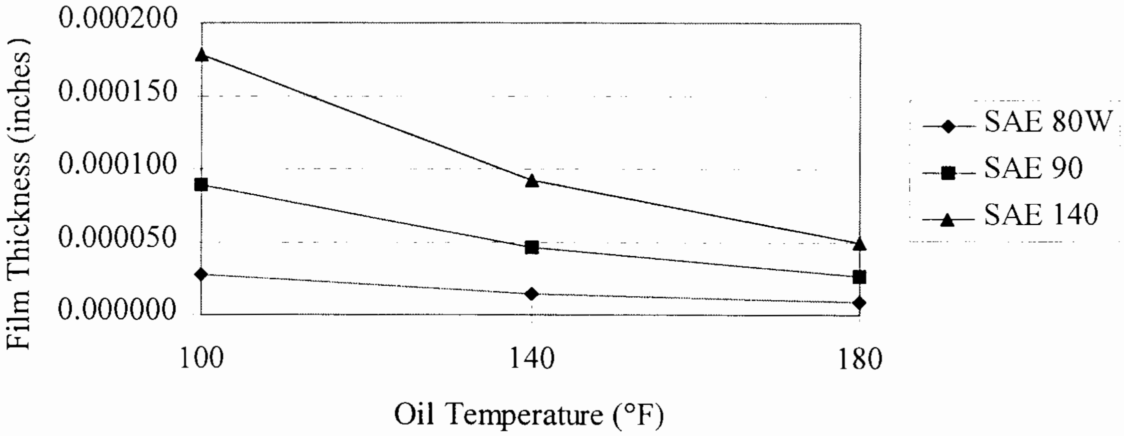

FIGURE 4

3. CARRY AWAY HEAT:
Another function of the lubricant is to carry the heat away from the metal gear teeth and bearings in order to reduce their operating temperatures. When a load is transferred from one gear tooth to another or from one bearing component to another, heat is generated. The heat must be carried away from the generating point in order to reduce the temperature of the metal as much as possible.

Inevitably, even with the best lubrication, the gears and bearings will wear due to sliding -- at the gear teeth, at the bushings, and some amount at the anti-friction bearings due to sliding and skewing. When sliding occurs, metal particles are rubbed off the sliding surfaces and mixed with the oil. The particles that are larger than the oil film thickness may cause depressions on the gear teeth or bearing surfaces when trapped under load. They are further reduced in size under heavy loads until they are about the size of the oil film thickness. Sometimes such large metal particles will make a depression on the gear teeth or bearing surfaces, however, if cracks are not produced the metal fatigue life may not be affected. This example illustrates how good filtration can increase the gear box operating life. A chemical analysis can be done when the oil is inspected to determine whether the suspected metal particles came from gears and bearings or from the case walls. (This is done by determining the amount of a particular alloy such as chrome or nickel.) If some components are subjected to heavy wear, the periodic chemical analysis will alert you when the number of metal particles begins to increase rapidly. At this point, the gear box should be shut down for preventive maintenance and/or repair.

If the gear box is equipped with a magnetic plug that has a check valve to stop the oil from flowing out when the plug is removed, another simple way to inspect for normal wear or imminent failure is by using the procedure that follows.

1. Remove the plug once a week to inspect the metallic deposit on the magnet and to detect wear or damage at its beginning stage to initiate preventive maintenance.

Normal Wear:
Pick up the metallic deposit off the magnet and rub it between your fingers. If it looks like silver paint it is caused by normal wear. Clean the plug. Return it to the gear box and continue to operate the gear box.

Abnormal Wear:
If the metallic deposit appears to have steel crumbs when you rub it between your fingers the gear box must be removed from service immediately and inspected for repair. When the gear teeth or bearings disintegrate into crumbs they may break into pieces or pits are formed that will not self heal. The pits will only grow like a pot hole in the road grows. The gear box must be promptly repaired.

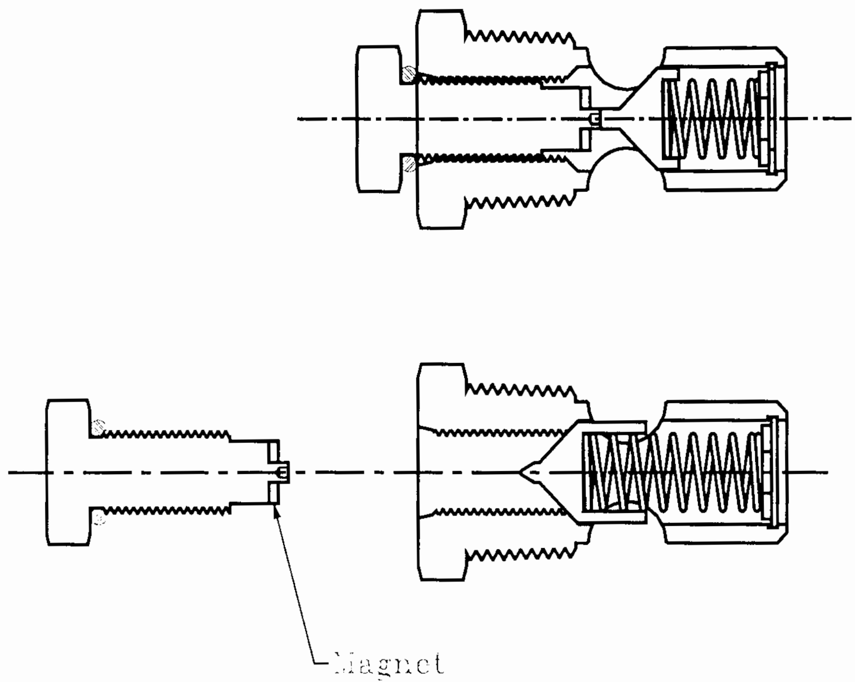

FIGURE 5

2. Check the oil level every time you inspect the magnetic plug. Add or change oil if necessary.

To simplify this inspection, Power Engineering & Manufacturing, Ltd. has designed and currently manufactures a magnetic plug with a check valve, such as the one shown on Figure 5.

BEARINGS

In order for bearings to operate properly they must be correctly installed as well as adequately lubricated. Endplay is defined as axial movement of a shaft. During normal operation the outside walls of the case will be operating at a lower temperature than the gears and shafts. (The reason for this is because the case is exposed to outside air that is cooler than the inside air and also because heat is generated at the gear teeth and at the bearings.) Therefore, the metal of the shaft, bearings, and gears operates at a higher temperature than the case itself. The heat is carried away to the case walls by the oil. For that reason, we expect the shafts to grow in length more than the case walls. If we do not have clearance at the bearings, defined as endplay, or flexible walls, then this shaft growth can impose extremely high loads on the bearings and lead to lower life and failure.

For example, tapered roller bearings operate best with .001 - .005 endplay, unless the gear box manufacturer recommends a different setting or perhaps even no (.000) endplay.

Cylindrical roller bearings must have some endplay as well as radial clearance between the rollers and the outer race. (Figure 7 shows how the bearing roller clearance is checked after installation. This inspection should be made at twelve o'clock on the bearing, or in other words vertically above the centerline where gravity has no effect on the clearance measurement.) This clearance must be at least .002. When it exceeds .010 for a small or medium sized bearing or .015 for a bearing larger than one foot in diameter the bearing should be replaced due to excessive wear.

Spherical bearings should be treated in a similar manner as the straight cylindrical bearing, requiring a minimum of several thousandths endplay and over .002 radial clearance between the roller and the outer race, again when measured directly above the centerline of the shaft (vertically up at twelve o'clock). Refer to Figure 8.

Bushings should have a minimum of .005 clearance with provisions for oil flow so that the oil can circulate through the bearing and carry away the heat generated by the shaft rotation under load.

For good gear box durability, the bearing endplay and shaft clearances should be checked periodically as deemed necessary for each operation, preferably prior to the start of the season. For bearings, corrective action must be taken whenever necessary because under heavy loads if a bearing fails, gears may fail as well. The resulting failure could lead to an expense many times greater than the cost of replacing a bearing or two.

GEARS

Gears that are in good operating condition must have smooth surfaces with a good involute profile. Although a small amount of wear may be acceptable, heavy wear can cause vibrations or damage to the mating gear. In a speed reducing gear box the gear has many more teeth than the pinion, therefore, the pinion undergoes a larger number of load cycles and will consequently wear and fatigue sooner than the big diameter gear. For this reason, it is often economical to replace a worn or fatigued pinion in order to enable a longer life for the mating gear. For example, in a five to one reduction ratio gear mesh the gear will have a wear and fatigue life five times longer than the pinion. Through adequate maintenance it would be possible to replace the pinion five times before needing to replace the gear. This is more economical than allowing the pinion to operate to failure, resulting in damage or destruction of the gear and possibly other adjacent gears and bearings.

Adequate gear lubrication is very important. Metal fatigue of gear teeth or bearings can be observed if the surfaces have spalling. Spalling is a condition where the metal just flakes away leaving pits that have a rather rough surface. The pits usually grow fast due to the heavy loads that are applied at the periphery of the pit. (These pits grow in a similar manner as a pothole grows in a road under constant traffic.) When spalling is observed the gears should be removed from operation promptly because the metal particles that separate and mix with the oil can damage other components in the gear box.

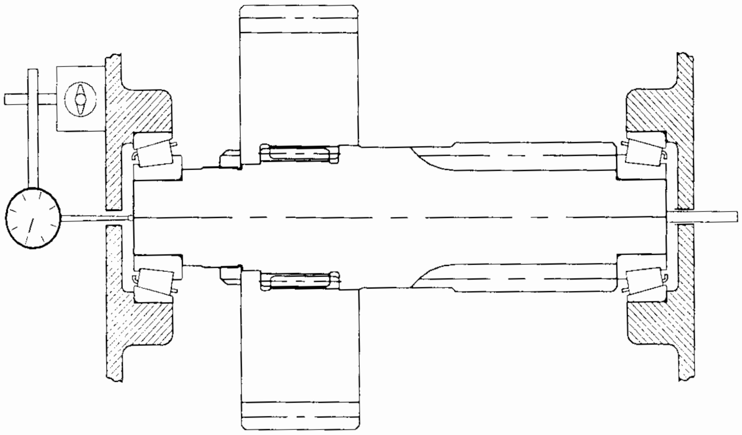

FIGURE 6

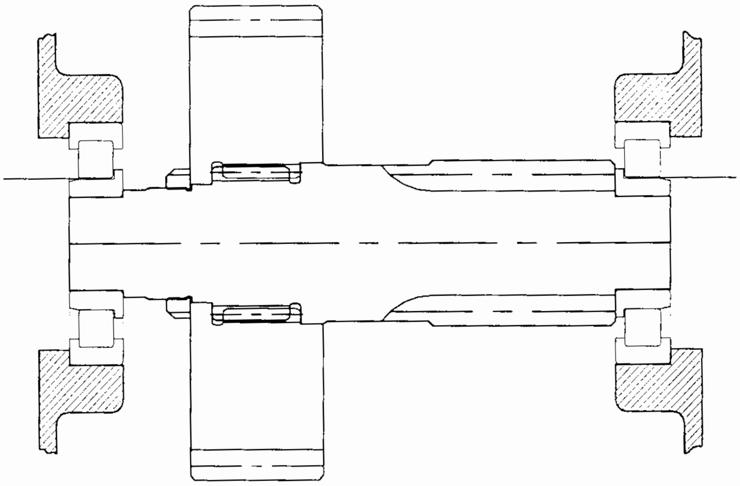

FIGURE 7

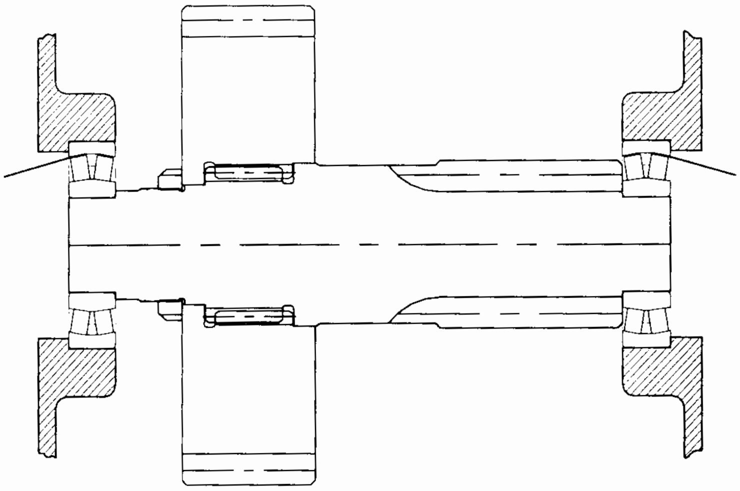

FIGURE 8

SHAFT AND GEAR ALIGNMENT

In order to have good, even load distribution over the entire width of the gear teeth and the entire length of the bearing roller, the shafts must operate parallel to each other. If the shafts are not parallel and the gears do not have good load distribution, end loading develops as shown on Figure 9. In extreme conditions it is possible that only half (or even less) of the gear tooth face may carry the load. This condition is the same as having a gear that is half as wide. Note that gears and bearings behave in a similar manner. The life to load relationship is such that when the load is doubled the life is reduced by a factor of ten. The following equation governs the life load relationship for bearings as well as gears.

$$(\text{LIFE A}) * (\text{LOAD A}/\text{LOAD B})^{3.333} = \text{LIFE B}$$
$$\text{LIFE A} * (1/2)^{3.333} = 0.1 \text{ LIFE B}$$

When gear box maintenance is performed on parallel shaft gear boxes, a load pattern inspection is recommended using a spray powder penetrant and developer (such as Magnaflux® SpotCheck®). Under extreme conditions where heavy loads are applied, the gear box case could permanently distort. When this happens, one side of the gear case may distort more than the other side leading to permanently positioning the shafts in a non-parallel condition of operation. In order to maintain good load distribution at the gear teeth, shaft and gear misalignment must be avoided at all costs.

The bearing pockets must be square with the shafts in order to have good load distribution for the full length of the rollers and so the bearings attain their full designed life. If, by the load pattern test, a parallel shaft gear box is found to have uneven load distribution at the gear teeth the situation may be improved by raising one corner of the gear box with shims in order to physically bring the walls into a squarer position and again enable the shafts to operate parallel to each other. Once the raised position is found that will provide better load distribution, all of the bolts that fasten the gear case to the foundation should be shimmed so that no distortion is imposed by the retaining bolts.

Figures 10 and 11 show a planetary type gear box. This gear box does not need re-alignment at installation time because the internal components are such that either the sun pinion, the planetary carrier, or both are floating in order to provide equal load distribution between the three planet gears, the sun, and the ring gear. This type of gear box will always maintain good load distribution by its inherent design.[2] In addition, such a gear box has a high power density and is smaller in size than a parallel gear box due to the advantage of having three gears and the planet carrier carrying the load simultaneously as compared to only one gear in a parallel reducer or two gears in a herringbone arrangement. Planetary gear boxes will become more popular because of their power density, smaller space requirement, and consequently lower cost -- particularly in sugar mills where space availability becomes a problem when converting a double roll drive to a single roll drive to transfer more power to each roll.

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[2]Herscovici, Saul (Power Engineering & Manufacturing, Ltd.), "High Horsepower Planetary Gear Boxes for Reduced Cost and Improved Efficiency in Sugar Cane Mill Applications", American Society of Sugar Cane Technologists Annual Meeting of the Louisiana Division (1995).

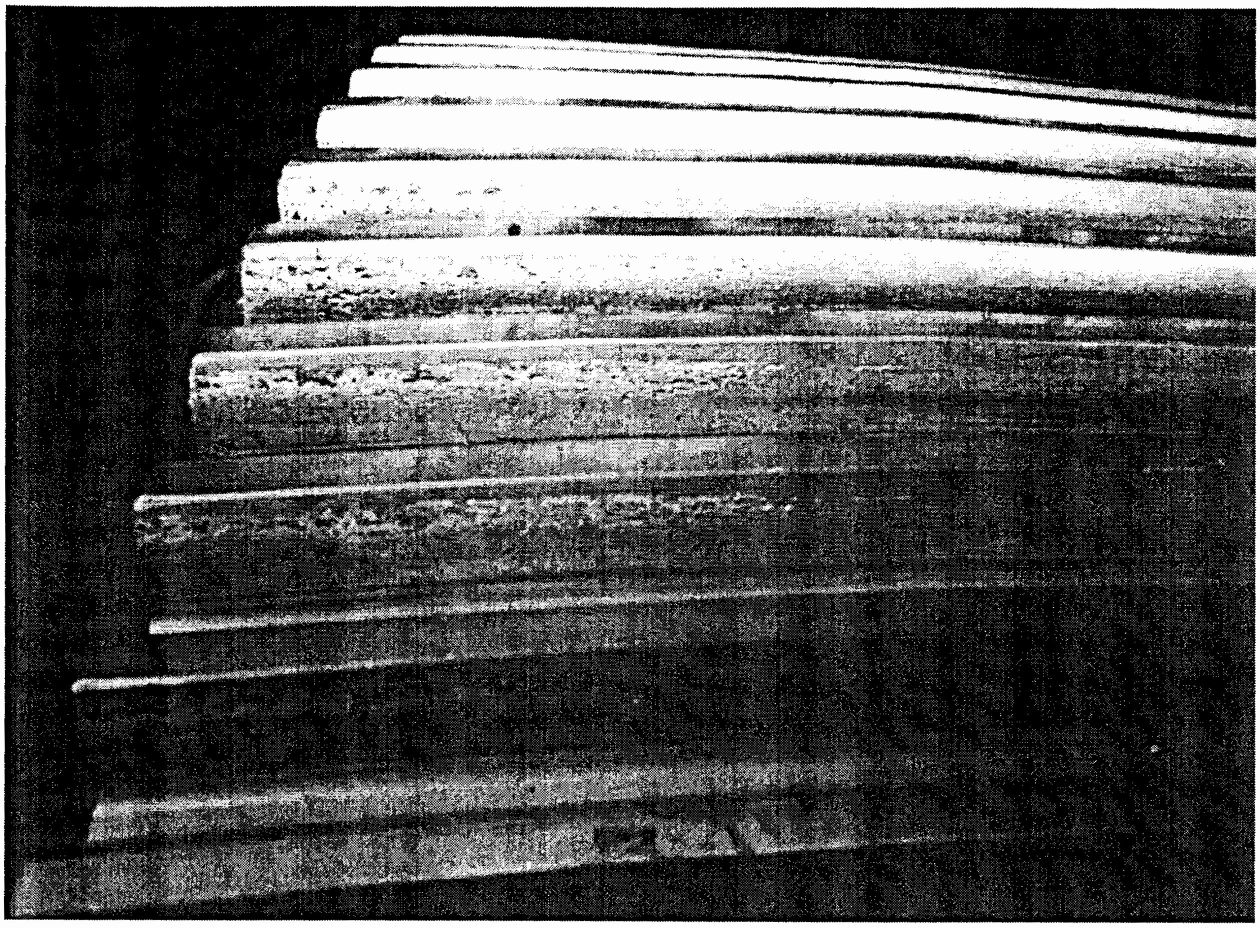

FIGURE 9

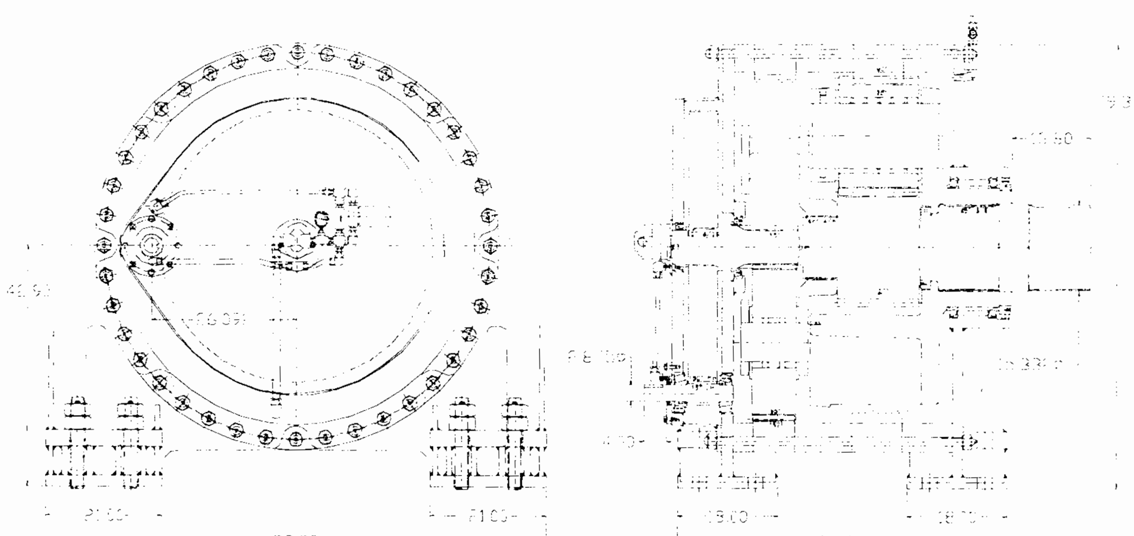

FIGURE 10

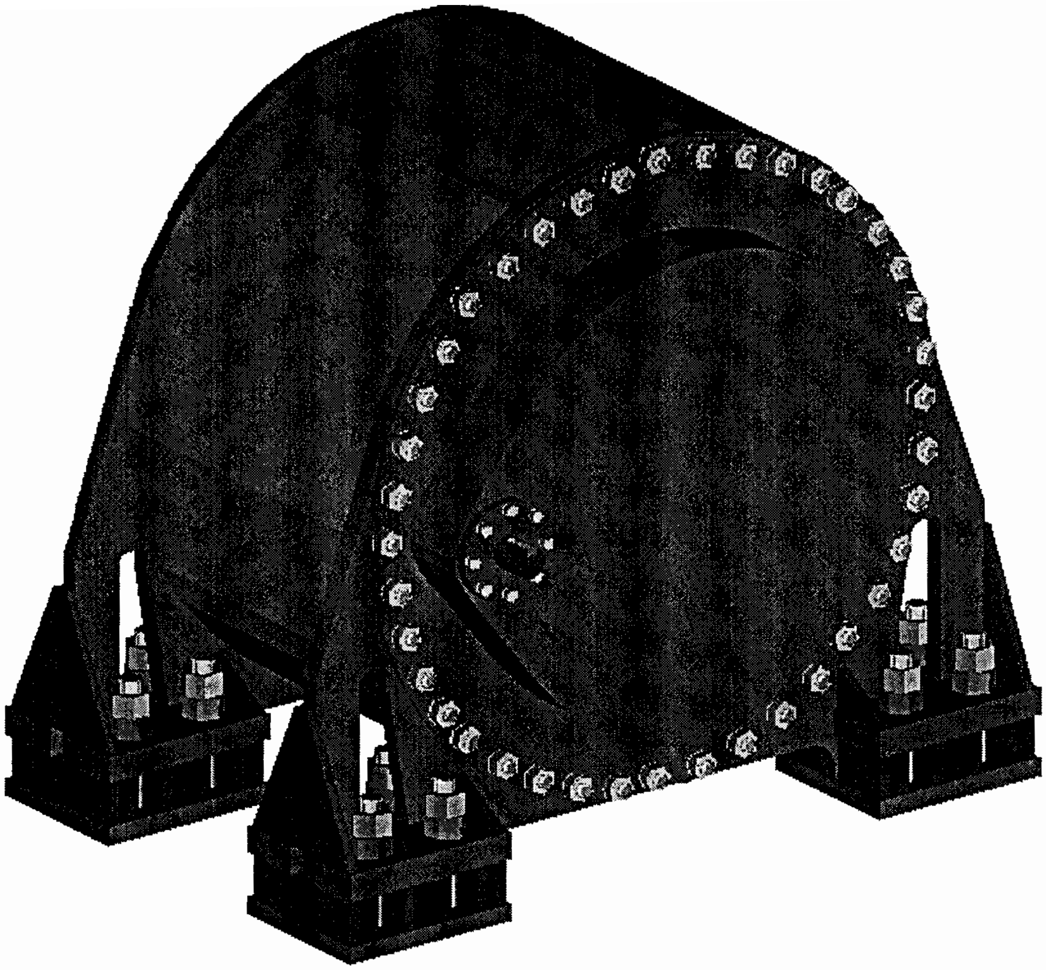

FIGURE 11

CONCLUSION

In conclusion, the gear box wear life can be increased by a factor of 100% to as much as 500% with proper and complete preventive maintenance. Whenever a problem exists with gears or bearings in a gear box, contact the author of this paper for free consultation.

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