Analysis of wear particles in lubricating oil of worm gearbox using ferrography

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ABSTRACT

Keywords:
Lubricating Oil,
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Wear Particles,
Worm Gearbox

This paper aims to provide the ferrographic analysis of wear particles contained in Extreme pressure gear oil used in worm gearboxes. Working of worm gear box is simulated using an experimental test rig and oil analysis is carried out using Direct Reading (DR) Ferrography. The worm gearbox runs under normal operating conditions of load, speed and duration. DR Ferrography is one among the effective tool to analyze wear particles in lubricating oil. The analyses reveals that the wear particles indicate the performance of device based on wear particle concentration (WPC) and wear severity index (WSI) leading to the earliest advice of component breakdown and prevention of breakdown.

1. Introduction

Wear related problems arising from mechanical components like gears, pumps, motors and bearings etc. are becoming severe in present mechanical industries. Lubricating oils are used to minimize the friction between the material pair. Any deterioration of lubricating oil will lead to the wear and further decreased performance of mechanical components. The deterioration of lubricating oil is decided based on physical, chemical and tribological properties. These properties are based on viscosity, water content, Total Acid Number (TAN), Total Base Number (TBN), insolubles, wear particles etc, Various oil analysis techniques like Viscometers, DR Ferrography and Microscopic analysis are used to determine these properties.[1-3]

Among these techniques Ferrography is introduced in the year 1971 for condition monitoring of mechanical equipments employing lubricating oils. There has been considerable development in techniques required to process oil samples, analyze wear particles and interpretation of the results in Ferrography. Ferrographic analysis of lubricating oils lead to the condition of the machine for safe operation and proper maintenance. This ferrography helps to identify the first symptoms of wear without having to disassemble the complete set.[4-7]

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Lubricating oils used in mechanical components are of different grades which suits the application. There is least reported literature on sliding pair wear analysis. The extreme pressure (EP) lubricating oils are used satisfactorily in most sliding pair applications. In the present study EP lubricating oil is analyzed in an experimental setup for the actual working of worm gear box. The DR Ferrography is used in present study and time interval between two oil samples was set as per standards. Wear Particle Concentration (WPC), and Severity of wear index (SWI) are determined based on large particle Quantum (DL) and small particle Quantum (DS). The Ferrography Analysis technique is explained in next section.

2. Ferrography Analysis

A Ferrography is a technology based on wear particle evaluation instead of oil evaluation. Ferrography has been used effectively inside the monitoring of air craft, gas turbines, gear boxes and transmissions, high speed diesel engines and hydraulic systems. Particles generated by wear and external contaminants in oils used in bearings, gears, bushings etc. can be examined. A Ferrographic analysis involves two stages of evaluation, quantitative or Direct Reading ferrography and qualitative or Ferroscopy. The quantitative evaluation quantifies the debris in the lubricant and the qualitative evaluation or Ferroscopy uses the observation of particles such as shape, size and composition inside the lubricant. Lubricating oil samples are drawn regularly as per standards maintenance. The wear particles in the lubricant are separated using magnetic field in a descending order of size. With this method the degree of severity of wear inside the machine under evaluation is determined.[8-11]

In quantitative or Direct Reading ferrography one ml of oil sample is taken and is mixed thoroughly with solvent. The mixture is siphoned through a precipitator tube. A magnet assembly located beneath the transparent glass tubes precipitates the wear particles according to the size of the particles. Because of varying forces attracting different size of particles, the bigger debris (greater than 5 µm) are deposited at the entry point of the precipitator tube and smaller debris (2-3µm) are deposited a few millimeters downstream of the entry point. Particle size becomes progressively smaller along the path of deposition inside the precipitator tube. During evaluation, light beams of known intensity are projected through the precipitator tube at two places representing D_L and D_S particle concentration. A detector measures the light attenuated by the debris and a digital display gives relative concentration of D_L and D_S. The values of D_L and D_S are calculated by measuring the blockage of light using fiber optics at the locations of large particles and small particles. Trending of the D_L and D_S readings divulge changes in the wear mode of the system. An increase in D_L indicates that the system has entered into an abnormal wear mode; where as an increase in D_S indicates system corrosion. Based on D_L and D_S readings the statistical data like Cumulative Large Particles, Wear Particle Concentration, Severity of wear, Percentage of large particle and Severity of wear index are evaluated.[12-15]

A qualitative evaluation or Ferroscopy uses magnification power microscope. Under magnification of 100x, 500x and 1000x the Ferroscope makes use of both transmitted and reflected light sources together with red, green and polarizing filters to differentiate the size, composition, shape and texture of both metallic and non-metallic wear debris.[16]

3. Experimental Details

The objective of experimental technique is to collect quantitative data for condition monitoring of EP lubricating oil (Servo gear HP 140) used in worm gearbox and to acquire a better insight and understanding of the lifetime and behavior of equipment. Table 1 shows the Oil Properties of HP140.

Table 1
Properties of HP140.

Oil Properties	Kinematic Viscosity cSt @ 100°C	Viscosity Index, Min.	Flash point (COC), °C Min.	Pour Point, °C Max.
HP 140	28-34	90	190	0

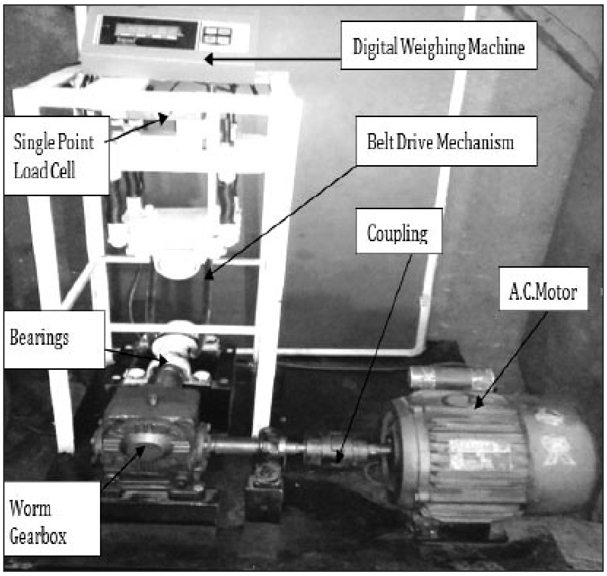

Fig. 1. Experimental setup for oil analysis.

The experimental setup used is as shown in figure 1. The experimental setup uses controlled working parameters set for analysis of gear oil HP 140 which is generally used in worm gearbox.

The oil samples were collected at predetermined running intervals of 100 hours while system is in operation, with known working conditions and from the same place. Speed reduction worm gearbox is intended for constant ratio (1:20) along with right angle between output shaft and input shaft. Input shaft and worm internal part are made up of solid bar stock of EN8 material. Gear wheel is made up of phosphorous bronze alloy PB2 to withstand shock loads and effectively transmit regular load with a lower friction loss. The specifications of worm gearbox and Chemical Composition of Worm and Worm Wheel Material are given Table 2 and 3.

Open V-belt drive type load mechanism is used to load the gearbox. Single point load cell is connected to indicate load. Resisting torque is varied with respect to tension of the v-belt based on speed. Coefficient of friction between pulley and v-belt is assumed to be constant.

A load of 10 kg to 12 kg was applied with an increment of 0.5 kg on gearbox through belt drive due to variation of tension on tight and slack side. Oil sample of 10 ml was collected from experimental setup after every 100 hours of operation for DR Ferrography. One sample of oil has been checked thrice for repeatability. The sample test conditions are as given in the Table 4 below.

4. Results and Discussion

As mentioned in section 3. DR Ferrography is applied to obtain quantitative data of EP lubricating oil inside the worm gearbox. The values of ΣD_L, WPC, SOW, PLP and WSI are plotted against lubricating oil running hours to represent the wear situation. In order to predict the performance of lubricating oil based on observations, the average of three D_L and D_S readings is taken.

It is observed from Figure 4 that there is normal wear situation up to 200 hours. This is because of small duration where wear particle are less and have not mixed in the bulk of lubricating oil. There are very few numbers of wear particles to create wear severity. After 200 hours of oil run rate of D_L increased due to abrasion wear and Oil becomes inefficient to lubricate the gear pair. This is because of D_L creates excess rubbing of internals and lead to the generation of secondary wear in the equipment. Abrasive wear caused by ploughing out or digging of the softer material by the harder material.

Fig. 2. EP gear oil samples (HP140).

Fig. 3. DR ferrography.

Table 2
Specifications of single speed reduction worm gearbox.

Gearbox component	Description
Gearbox Model	Worm gearbox with 1:20 reduction
Style	WB(worm bottom)
Transmission capacity	0.5 HP
Oil capacity	650 ml
Worm Shaft Material	Steel-EN8
Worm Wheel Material	Phosphorous Bronze-PB2

Table 4
Sample test condition.

Load (kg)	Motor Speed (rpm)	Worm Shaft Speed (rpm)	Oil Running Hours
10	1440	72	100

Table 3
Chemical composition of worm & worm wheel material.

	Composition (%)						
Name of Material	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**
Steel-EN8	0.42	0.20	0.65	0.026	0.015	0.01	0.01
Name of Material	**Cu**	**Sn**	**Zn**	**Ni**	**Pb**	**P**	**Al**
Phosphorous Bronze-PB2	Remainder	11-13	0.3	0.5	0.25	0.15-0.8	0.005

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There is considerable increase in WPC after 200 hours due to adhesion and abrasions as well as

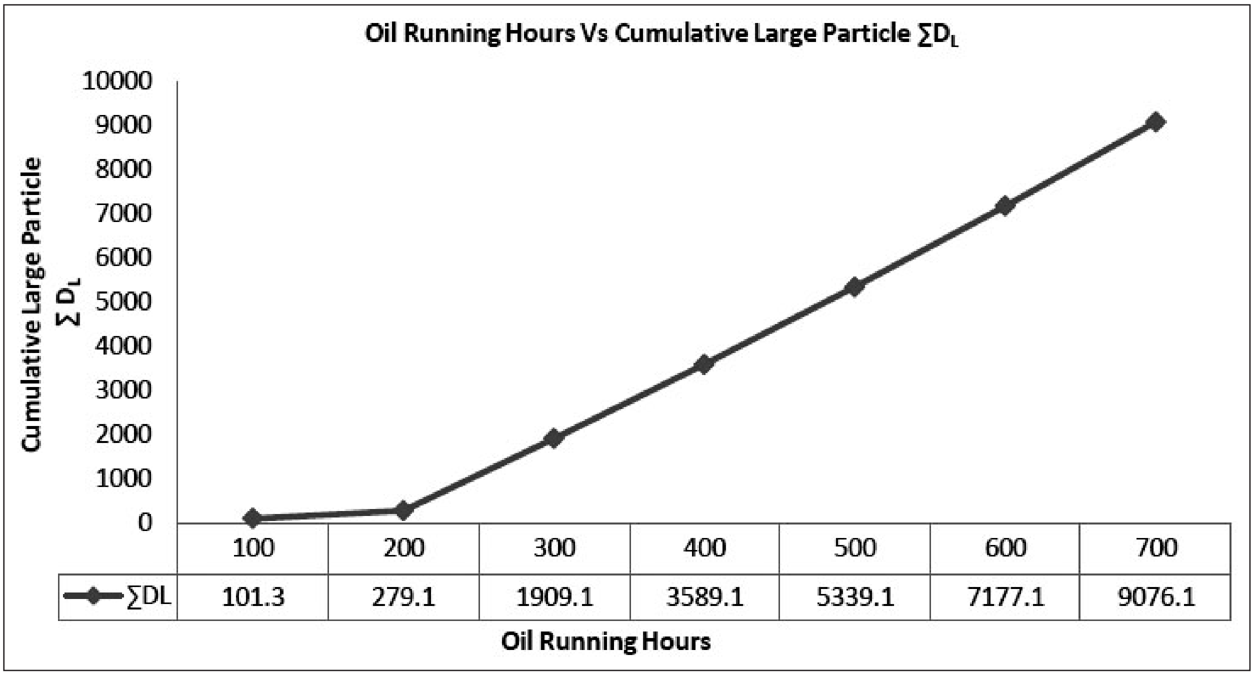

Fig. 4. Oil running hours Vs $\sum D_L$.

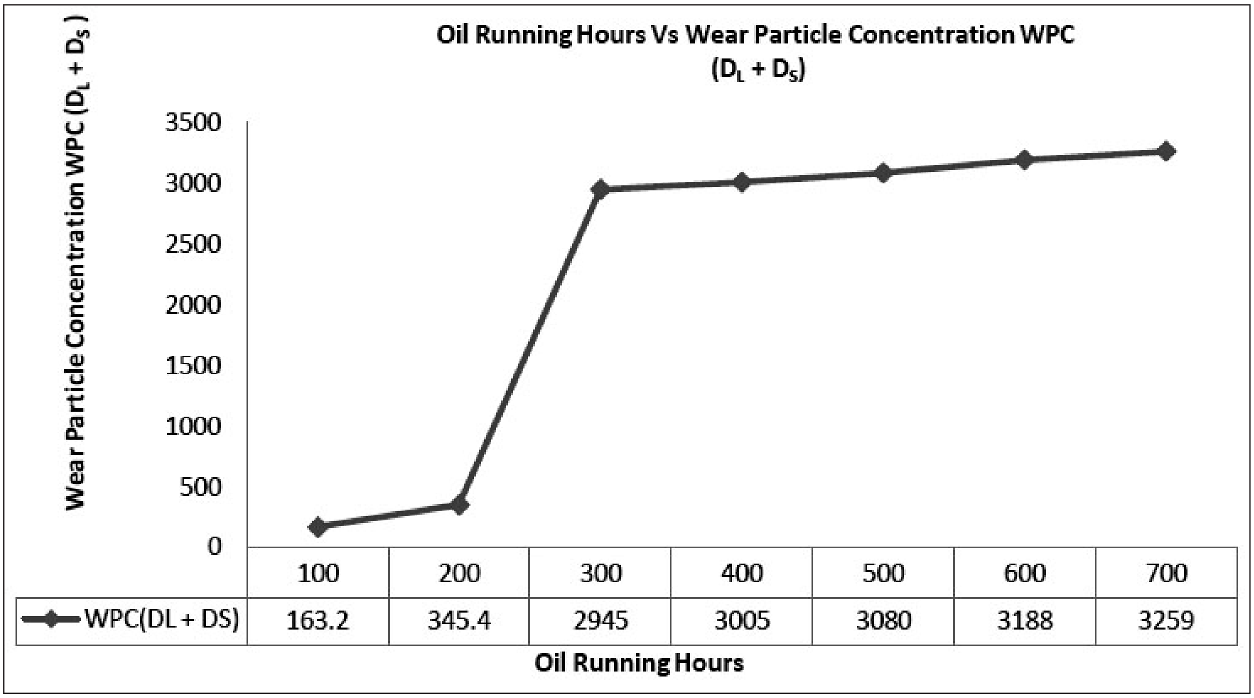

Fig. 5. Oil running hours Vs wear particle concentration (WPC).

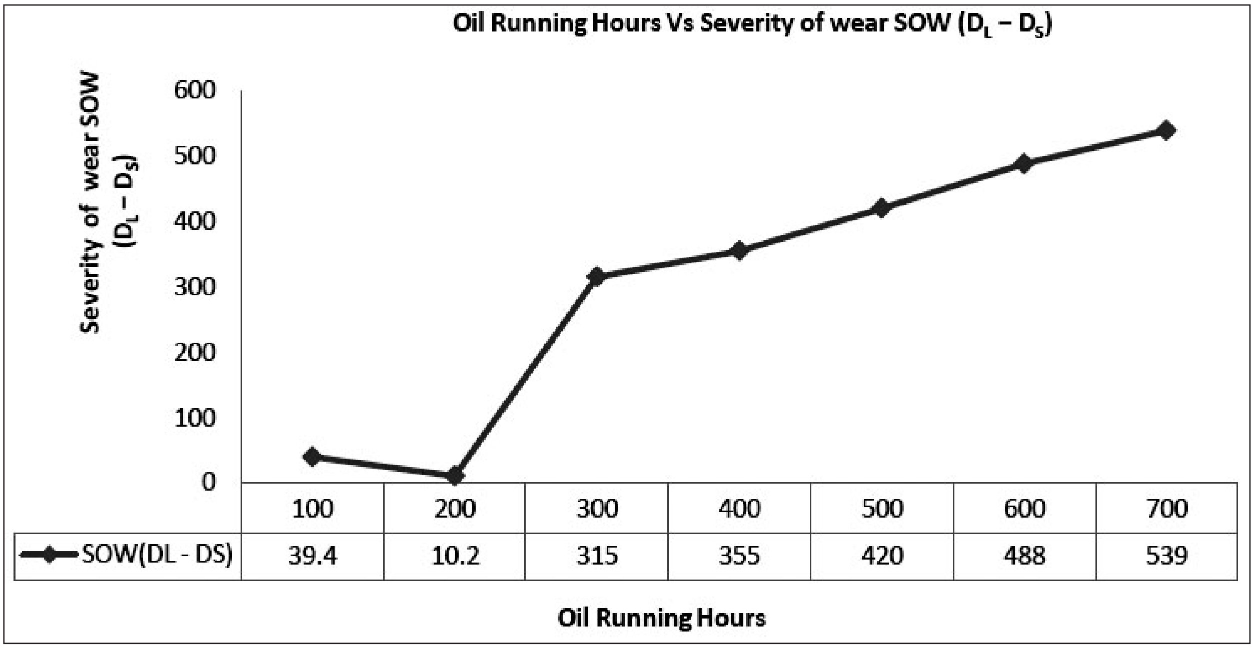

Fig. 6. Oil running hours Vs severity of wear (SOW).

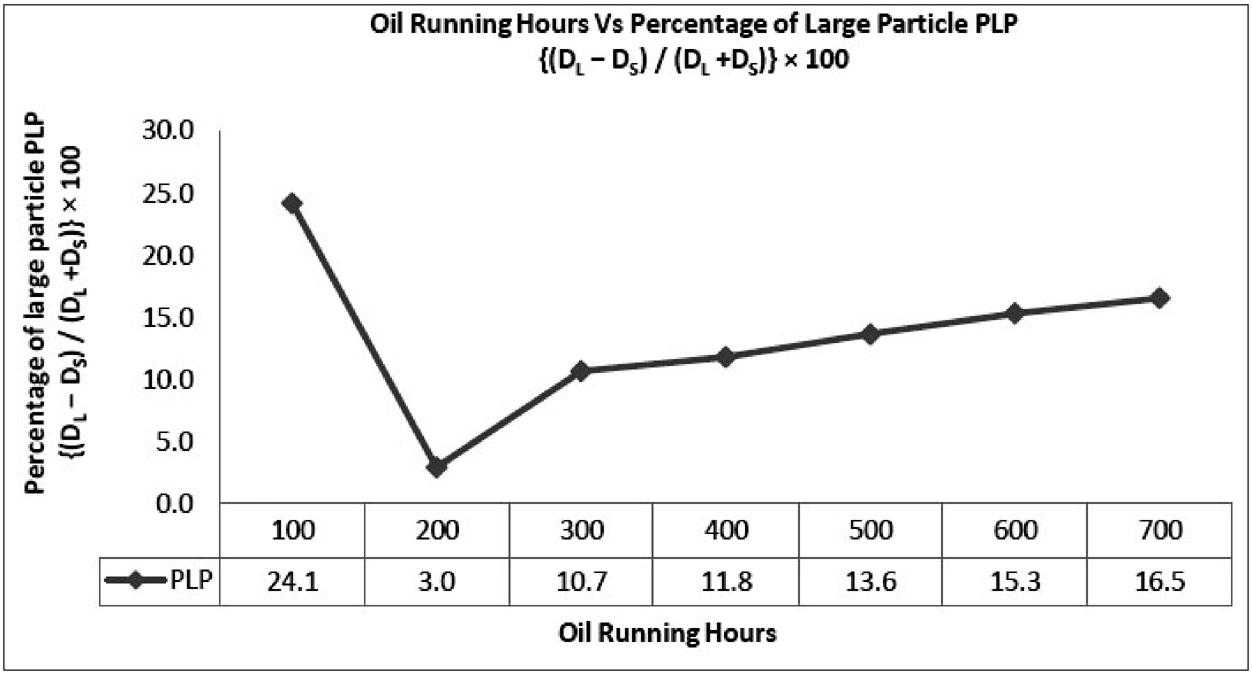

Fig. 7. Oil Running hours Vs percentage of large particles (PLP).

corrosion wear. Abrasion by D_L and adhesion by D_S due to accumulated D_L with approximately same D_S .The corrosion wear is increased due acidic nature of lubricating oil after oxidation. Severity of Wear (SOW) has been increased after 200 hours due to presence of D_L more than D_S indicating abnormal machine conditions and probable breakdown of lubricating film in the gearbox. Percentage of large particles is more in 100 Hours sample compare to 200 Hours because of huge difference between D_L & D_S in first two samples. The PLP is showing increasing trend due to degradation of oil. When both the WPC as well as the PLP increase wear of machine parts is affected. This is because of negligible D_S initially having no corrosion wear. Later as the oxidation of oil takes place the corrosion wear starts. This can be seen from the plot that PLP has maintained almost horizontal trend after 300 hours.

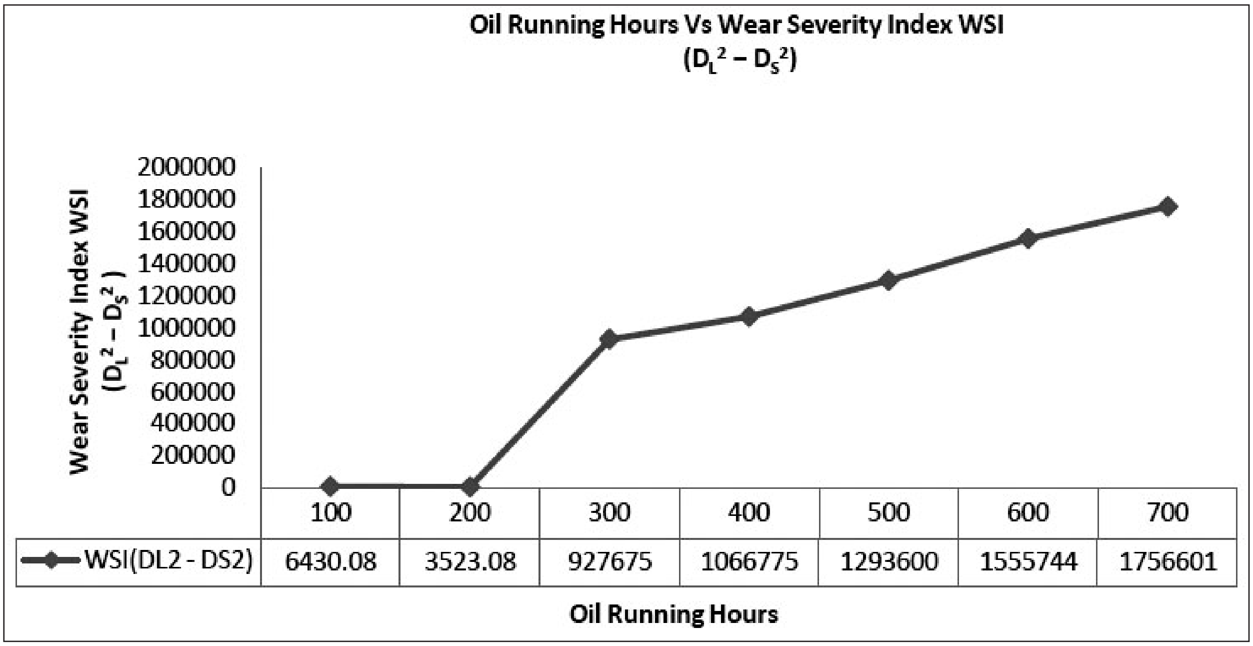

Fig. 8. Oil running hours Vs wear severity index (WSI).

The oil has degraded after 200 hours because of abrasion, corrosion and adhesiveness of oil. Sliding contact wear takes place mainly by adhesion and abrasion. It is found that dust and dirt along with wear particles in the oil during the sample collection.

The results obtained show that there is deviation of 1 % in DL & DS. The Uncertainty in WPC, SOW is ± 2 %, PLP ± 1 % and WSI ± 0.2 %.

5. CONCLUSIONS

Following conclusions can be drawn based on present analysis of wear particles in lubricating oil of worm gearbox using Ferrography:

- The existence of abnormal wear particles will cause the lubrication system not to work effectively and at the same time damage metallic components.
- Preventive maintenance can be done to avoid failure of worm gearbox of an industrial application using DR Ferrography.
- Ferrography helps to identify the first symptoms of wear without having to disassemble the complete set.
- DR Ferrographic analysis provides the earliest advice of component breakdown.
- Inspection of internals can be planned at the earliest for possible maintenance schedule for severe wear.
- Analytical or Qualitative Ferrography may lead to further understanding of wear pattern.

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