Performance and ferrography analysis for determining the wear of an external gear pump

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Abstract. The present work employs an experimental and analytical method to investigate the wear of an external gear pump. The first part of experimental method involves, running the gear pump on test rig for set number of working hours and the performance curves are plotted for studying any variation during the course of experiments. In the second part of experimental method the circulated oil was studied for any contamination. Contaminated oil is an indication of wear which is to be detected using ferrography. The gear pump therefore was run for maximum number of hours to study the variation in performance of gear pump due to wear during the running operation. The oil samples were collected after the pump has been run at a set discharge pressure for a certain number of hours. Wear was expected to occur to detect the presence of ferrous particles for checking whether the gear pump components have worn out after the operation. Direct ferrogram reading machine was used to detect small and large particle size concentration and based on this the wear severity index was found out analytically. Also the necessary conclusions using graphical trend are obtained between particle size concentrations and wear severity index with respect to time.

1. Introduction

Wear particle investigation as a non-destructive assessment procedure is a unique technique to decide the lubricating oil conditions inside various lubricated devices to check the wear modes and avoid the probable failures in these devices, such as gear-boxes and engines. Ferrographic examination of lubricating oil could give total data about ferrous debris particle present in the oil sample.

N.K. Myshkin [1] used the standard activity of optical ferro analyzer to found out the contamination of oil for expanding the reliability of tribo-system condition monitoring. The results of various trial of the analyzer were portrayed and an outline of its application for condition monitoring of the system was explained. Szymczyk W. [2] studied the variations in wear particle concentration in lubricating oil. Oluwaseun E. Adedejia [3] adopts a joined CFD-trial approach to improve the execution of some selected erosion models. Likewise, the impacts of target material surface roughness and particle rotation on local wear factors were explored mathematically. Lavern D. Wedeven [4] performed a surface examination of hydraulic gear pumps used in gas turbine power generation and uncovered service life impediments in view of gear wear and scuffing. An adaptable tribology testing capacity was utilized that gave a capacity to simulate oil and failure components. Ashesh Tiwari [5] carried out the analysis of IC engines lubricating oil. Samples of lubricating oil taken in clean bottle and analyzed each sample by ferrography technique and concluded that the wear particle concentration which is actually the number of wear particles increases up to third sample because the particle sizes are bigger in initial sample, there after size of particles was reduced hence number of small size particles were increased. T.H.Wu [6] performed the wear characterization by an on-line ferrograph image. Wear rate and wear mechanism are two fundamental viewpoints in portraying the wear
condition. An online ferrograph image and online visual ferrograph sensor gives an arrangement by which a new wear characterization with measurable examination was researched for online wear revealing. Martijn Woldman [7] used a finite element approach to deal with abrasive wear models. The model gives a premise on which different phenomena for irregularly shaped particles and tedious circumstances can be executed. Volumetric wear was determined by utilizing expulsion of components utilizing a shear damage basis dependent on both fracture strains and identical plastic displacement. P. P. More [8] carried out the wear particle characterization to get the outline of machine condition monitoring as the majority of the failure occurs because of wear debris immersion. The objective of the work was to figure the wear severity index of lubricating oil samples using direct reading ferrography and examine the wear pattern utilizing scientific ferrography. Sayed Y. Akl [9] did condition monitoring of gear box utilizing wear particle investigation procedure. Ferrographic examination of wear particles in lubricating oil gives total data about ferrous and nonferrous solid debris present in the oil sample. K.V. Pagalthivarthi [10] predicts erosion wear in multi-size particulate flow through a rotating channel and objective of the work was to anticipate erosive wear in multi-size thick slurry stream in a rotating channel. The wear models for both sliding wear and impact of wear segments address the particle size reliance.

2. Gear Pump Test Facility
The experimental set up is designed to study the performance of gear pump at particular speed. The performance in terms of head, discharge, pressure and efficiency can be calculated with help of this set up. The setup is complete arrangement of gear pump circuit including the main gear pump, inlet and outlet pressure gauges, pressure regulator valve, energy meter, reservoir and flow measuring oil tank, digital tachometer and heat exchanger with the required valves and piping system. Gear pump apparatus as shown in figure 1 consists of 2.0 HP, 3-phase power unit motor. It is directly connected to the driver gear in the external pump. The gear pump is of the 9.5 cc/rev and 17 LPM rated capacity. The oil used in testing is ‘Mobil DTE ISO VG-32’. Pressure gauges are employed at both inlet and outlet pipes for measuring suction and discharge pressure.

The sump is provided with the two flow control valves which are closed in operation to measure the volume of the oil in the cylinder and is opened to let down the oil back to the tank. The outlet discharge pipe is provided with the pressure regulator to control the pressure at the discharge line. The speed is noted down from the digital meter in the apparatus. However, the motor is running at constant rotating speed. For cooling purpose, the cooling coil and the fan are used within the system. When the power is switched ON, the gear pump starts pumping the oil from the tank i.e. suction takes place and pressurizes it to higher pressure to the discharge side where it is measured through the pressure gauges. By regulating the pressure regulator, the outlet pressure is varied. The speed of the gear rotation and the corresponding flow per minute is measured.

3. Performance Analysis
The gear pump was run for 500 hours and the readings of the experimentation have been collected at regular intervals to study the variation in performance of the gear pump as it is being run for long hours. The discharge pressure has been set at fix value and made to run at the same discharge pressure for a set amount of time, and the readings of discharge, suction pressure and time for that discharge were collected all this while. Performance analysis of the gear pump has to do with the head generated, efficiency of gear pump, output power developed and studying these variables that define the gear pump operation. The gear pump was switch on keeping the required outlet pressure reading at 20 kg/cm2. The suction pressure gauge reading and ‘t’ i.e. time required for 10 blinks in the energy meter was noted down. The delivery valve was open and time required for 10 cm rise of the fluid was measured. Delivery valve was closed and repeated the above procedure for incremental values of the outlet pressure. Discharge, output power and the input power are calculated and used for further analysis of various parameters with respect to time.
3.1. Parameter variations with time: Output power is obtained by head developed by the pump using standard formulae while input power is obtained by energy meter. Once output and input power is known, efficiency of the gear pump can be easily found out. The performance of the gear pump varies as the gear pump operation hours increases. The table 1 shows the values of the different variables mentioned at particular instant of time. Using this data the graph has been plotted as shown in figure 2 to understand the behavior of efficiency with respect to working hours. The efficiency of the gear pump after 50 working hours is 88.97% which comes down to 88.48% for 100 hours and subsequently goes down up to 83.59% for 500 working hours.

| Variables | Hours | 50    | 100   | 150   | 200   | 250   | 350   | 400   | 500   |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Efficiency|       | 88.97 | 88.48 | 87.42 | 86.53 | 87.51 | 85.96 | 84.39 | 83.59 |
| Head      |       | 701.13| 700.82| 697.67| 698   | 700.87| 698.87| 701.54| 699.48|
| Discharge |       | 486.04| 488.02| 492.04| 507.5 | 488.82| 480.18| 493.26| 485.25|

Figure 2. Gradual decrease in efficiency of gear pump over time

![Figure 1. Experimental setup](image-url)
The head vs. time graph shown in figure 3 revealed that the head of the gear pump remains slightly constant at all levels of discharge pressure, which indicates that the gear pumps give constant head for a given discharge pressure over the time period. The discharge vs. time graph shown in figure 4 in which the discharge is in liters per hour (LPH). The discharge remains almost constant throughout the gear pump operation. The motor which is connected to the gear pump drive shaft runs at a constant speed of 1400 RPM, hence the flow rate remains constant and it only changes when the discharge is
varied using the flow rate valve. Therefore as the flow rate remains constant throughout with respect
to time there is a linear relation with flow rate and time. The efficiency of the gear pump as shown in
figure 5 slowly decreases in due course of time for individual pressure level. Efficiency of the gear
pump first increases and then decreases which can be seen at 20 kg/cm2 and 100 kg/cm2. From the
above observation and reading it is clear that the performance of the gear pump is deteriorating in due
course of time and this is probably due to wear of the various gear pump parts and the degradation of
working oil.

4. Ferrography
Ferrography is a specific and recent procedure for oil investigation used to contemplate particle wear
on machine segments through examination of impurities in lubricating oil. It may be utilized to foresee
and diagnose errors happening in apparatus. Ferrography works through magnetic separation of
foreign substance particles and its further investigation of these particles. Ferrography can give a set
up and effectively performed investigation technique for deciding the health of a system and giving an
early failure detection strategy. The metallic wear particles are magnetically separated from the
running oil and kept by size on a glass slide, making it feasible for both particle morphology
examination and essential investigation, both on qualitative and quantitative basis.

4.1. Working Principle: The adjacent figure 6 is that of direct reading ferrograph for explaining the
working principle. The oil that is to be tested for any ferrous contamination is first diluted for
improved particle precipitation and adhesion. The diluted sample is made to flow down a precipitator
tube as shown in the figure. A magnet is placed below an inclined tube (shown horizontal in photo for
illustrative purpose) which creates a magnetic field that attracts the ferrous particles in the oil. A lamp
throws light on the tube and a photo sensor above senses this light and encodes the data regarding the
intensity of light using a microprocessor. When the contaminated oil enters the tube the ferrous
particles if any are deposited and there is interference in the light that is being sensed by the sensor.
The sensor is very sensitive to the change in intensity of light, which is then processed by the
microprocessor as presence of contamination in oil.

4.2. Testing procedure: The experimentation was done on new gear pump and afterward oil sample
was drawn at standard time span of working hours. The lubricant is a useful source of data on machine
condition. At the point when the oil deteriorates, at that point so too does the machine condition. The
oil examination for the most part dependent on two viewpoints i.e. quantitative and qualitative
analysis. Quantitative investigation of oil sample was done utilizing direct reading ferrography (DR-5)
with details as demonstrated in figure 7.

![Figure 6. Working Principle of Ferrography](image-url)
4.3. **Observations:** After frequent running of gear pump oil samples were taken and analyzed in the direct reading ferrography machine. Figure 8 shows the large size particle count and the small size particle count obtained. The Dual Slide Ferro Maker requires the large size particle count to be greater than 90. As the large size particle count is less than 90, preparing the slide for studying the morphology of these particles is insensible. As the total particle count is very less, it can be inferred that wear in gear pump set-up is negligible for chosen running time. Figure 9 and 10 shows photographic image of the readings of small and large particle size count given by direct ferrography machine for oil samples taken after 250 and 500 working hours respectively of gear pump. Photographic images are to be taken carefully to get the clear readings of the particle counts otherwise it will be blurring since these are the readings taken for the ongoing process.
Figure 10. DR Ferrography reading of lubricating oil after 500 hours of operation

4.4. Quantitative Wear Analysis: Quantitative examination of wear particles was done by utilizing direct reading ferrography. Direct reading ferrography gives the concentration of large and small size particles. Wear severity index and percentage of large size particles are determined by equation 1 and 2 as given underneath. Particle size more noteworthy than 5 micron is considered as large size particle and less than 5 micron is considered as small size particle.

Wear Severity Index (WI) = (dl + ds) (dl - ds) = (dl2 - ds2) 

Percentage of Large Particles in % (PLP) = (dl - ds)/(dl + ds)*100 

Here, dl: Wear particle count (large size), ds: Wear particle count (small size)

Large size and small size particle concentration as well as wear severity index and percentage of large particles for gathered samples are recorded in table 2.

Table 2. Wear Severity Index

| Machine Running Hours | Start | 250 | 500 |
|-----------------------|-------|-----|-----|
| Large Size Particles count | 2.8 | 26.3 | 52.8 |
| Small Size Particles count | 1.4 | 10.6 | 23 |
| Wear Severity Index | 5.88 | 579.33 | 2258.84 |
| Percentage of Large Particles | 33.33 | 42.54 | 35.31 |

Figure 11. (a) Particle concentration
Graphs in figure 11 (a) and (b) shows the particle concentration and wear severity index versus machine running hours. The concentration of large and small size particle increment regarding time which demonstrates that the wear severity increases.

5. Conclusion
Experimental performance of the new gear pump was checked by running it for set working hours. Various parameters like head, discharge and efficiency of the pump were plotted against working hours and they were found deteriorating as expected. Simultaneously study was performed on the wear particles from lubricating oil of gear pump test rig. Three lubricating oil samples were gathered from the gear pump for wear test and ferrographic investigation. It is seen that wear severity index increases with time because of increase in wear of gear pump parts. The wear quantitative examination showed that there is no need to change lubricating oil with new oil since the small and large size particle count is less than standard particles count. Since small and large particles are less in numbers the gear pump is to be run for more working hours to get the larger count for further analysis using ferrogram slide maker and microscopic observation. This study can be used to diagnose the probable failure in gear pump and decide oil changing or other maintenance policy.

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