International Journal of Interdisciplinary Innovative Research &Development (IJIIRD)
ISSN: 2456-236X
Vol. 06 Special Issue 01 | 2021

Effect of added Contaminants in Lubricants by Using Wear Debris and Vibration Analysis Technique

Vikram Yendhe[1], Vishal Lawande[2], Rajendra Belkar[3], Balu Gavhane[4]

[1,2,3] Lecturer, Department of Mechanical Engineering, P.Dr.V.V.P Institute of Technology and Engineering Maharashtra, India
[4] Design Engineer, Allied Industries Pvt. Ltd., Maharashtra, India

ABSTRACT

Condition monitoring of machines is determination of condition of machine and its change with time. Working condition of machines may be analyzed by measuring physical parameters like: vibration, noise, wear debris, temperature, oil contamination etc. Wear debris and vibration condition monitoring have great importance in machinery maintenance and fault diagnosis. This paper deals with effective analysis of both combined vibration condition monitoring and wear debris in machinery maintenance and fault diagnosis. Both techniques have their own merits and demerits associated with monitoring and fault diagnosis of machinery. However, it is seen from the past practical experience that using this techniques independently gives a small portion of machine faults diagnosis. But by combining both the techniques in a machine fault diagnosis it can provides most reliable information. The objective of paper is to analyses the co-relation between both techniques, which is achieved by experimenting worm gear box at different operating conditions, which is driven by electric motor. The worm gear box initially runs with normal conditions of working. A number of tests have performed with different contaminant particles added to various lubricants. Wear debris and Condition monitoring techniques were studied and results obtained are compared.

Keyword : - Wear debris analysis, Vibration analysis, Machine condition monitoring, Contaminant particles, Lubrication.

1. INTRODUCTION

Condition Monitoring sometimes referred to as Condition-Based Predictive Maintenance as its name suggests it is a condition based preventive maintenance program. Due to the high thermal and mechanical stresses worm gearbox lubrication oil is subject to degradation including corrosion, water and particle contamination that affect the efficiency of the worm gearbox and hence the overall performance. Vibration analysis has been widely applied to condition monitoring of rotating machines to identify incipient faults and facilitate root cause failure analysis in order to enhance the life cycle of rotating machinery.

Several papers in the literatures proved that vibration analysis is the best suitable predictive maintenance techniques for industrial machinery. Wang and McFadden investigated the use of vibration analysis as an early detection technique for gear failure Power spectral analysis using FFT which analyses the characteristics of the measured vibration signals .Tan *et al*, investigated the capabilities of the acoustic emission, vibration and spectrometric of lubrication oil for spur gears and how it affects the worm gearbox aging life cycle.. Fischer *et al*, state that lack of proper condition monitoring technique may lead to major failure to the whole system, thus, identifies and corrective actions to the main failure cause as well as a proper maintenance strategy selection will improve reliability of the wind Oil degradation leads to high thermal stress within the worm gearbox of wind turbine that increases bearing temperature and accelerates oil aging. Oil quality can be assessed through the measurements of some parameters such as level of oxidation, acidity, viscosity, water content, temperature and dissolved particles.

1.1 Wear Debris Analysis Vibration Analysis

Wear particle analysis (WPA) is a technology that utilizes microscopic analysis to identify the composition of materials. WPA is a non-invasive examination of the oil-wetted components of machinery. The particle’s size, shape and composition allow a process of elimination in which the abnormal wear of specific components can be identified. Using Ferro graphic techniques, it identifies wear-related failures at an early stage, before collateral damage or failure occurs. Wear particle analysis is used in two ways. A lubricant sample is diluted with a solvent like tetrachloroethylene (TCE) and allowed to flow down a specially prepared low-gradient inclined slide while passing across a bipolar magnetic field. The force that attracts the particles is proportional to their volume, whereas the viscous resistance of the particles to motion is proportional to their surface area.

The flow rate of the process is such that non-ferrous particles and contaminants are randomly deposited due to gravity down the length of the slide substrate. After this process, a solvent is used to remove the lubricant remaining on the slide This deposition of particles on the slide is called a ferrogram. When the ferrogram has dried, the wear particles and solid contaminants are stuck on the slide surface and are ready for examination under a microscope.[2]

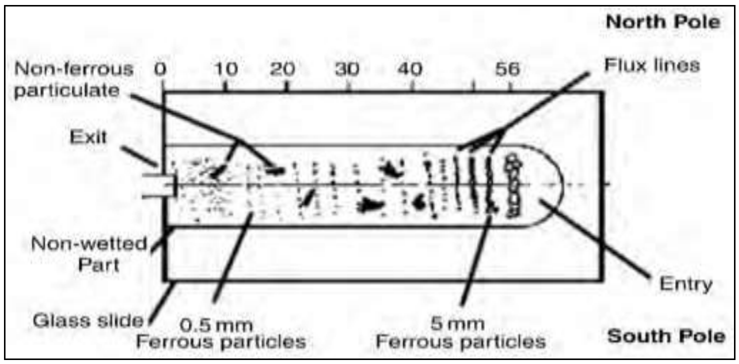

Fig-1 Ferrogram**.**

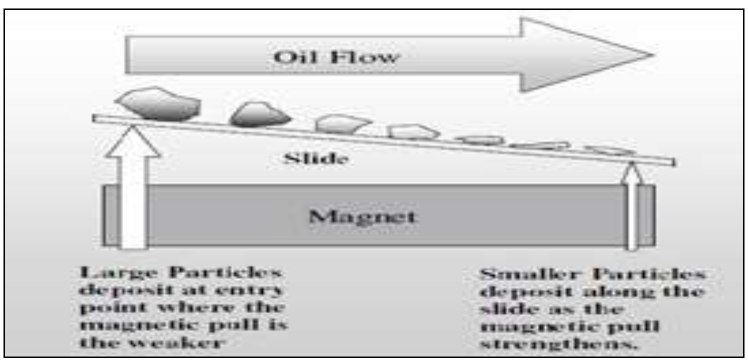

Fig-2 Ferrogram – Schematic diagram

1.2 Vibration Analysis

Vibration measurements are widely used tools that have been around for decades for the monitoring variety of machines and their component. In general machines do not typically fail without some type of advanced warning, which in this case is measured as increased vibrations. Changes in both the speed and load of machinery will have a direct effect on the overall vibration levels of a machine. Most common methods for vibration analysis include measure the overall vibration of the system and spectrum analysis. Overall vibration readings are taken by examining the raw signal data from the transducers and acquiring the peak, peak-to-peak values of the signal. While this approach is simple it tends to be insensitive to considerable amplitude differences in amplitude of particular frequencies, although they make up only a small portion of the overall signal.

Spectrum analysis is a widely used technique in many maintenance management systems due to the recent advancements in computer software. By analyzing time as well as frequency spectrums, and using Fast Fourier signal processing software, the natural frequencies of specific structural components can be identified. Modal parameters are extracted from frequency data domain which is used to produce modal domain data. It also convert time domain to modal domain. While vibration monitoring used for providing quick and cost effective information, it is limited to monitoring the mechanical condition of the equipment, and not other critical parameters. Also, it is often difficult to apply monitoring at low speed machinery (less than 5 rpm).

2.EXPERIMENTAL SETUP

Experimental setup used for the experimentation consisted of electric motor driven worm gearbox and loaded by agitating water within a reservoir tank via a paddle. It is consisting a screw worm which is driving member, that meshes worm wheel which is larger in size.[4] Fig.3 shows experimental set up with assembly motor, worm gearbox, and shaft.

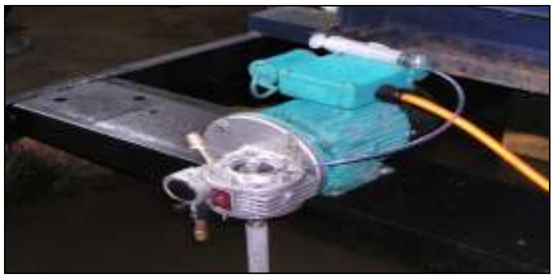

Fig-3: Experimental set up

3.EXPERIMENTAL METHOD

Five tests were conducted. First test relates to normal lubrication that is recommended oil to lubricate worm gearbox with normal working conditions. First test provides good comparison test with proceeding four tests. In Second Test, special operating conditions for worm gearbox have been created relating to the lack of lubrication. Here oil was changed with one forth viscosity that is recommended for test first. Third test introduces the contaminants to worm gearbox with normal operating lubrication conditions. Fourth test is involved in adding contaminants particle to recommended lubricants. In test five MH300.29 iron powder added to worm gearbox working under lack of lubrication [4]

For the entire test worm gearboxes were run for four weeks. In tests first and Second, worm gearbox was running continuously for full 4-week period, but for tests three to five involving in addition of contaminants in the lubricating oil, the system was running for 48 hours, after that it was flushed and cleaned.[4]

Table-1 Experimental analysis- Test Results

Test No.	Lubricating oil	Contaminant Particles
1	ISO VG 320 cSt	No
2	ISO VG 68 cSt	No
3	ISO VG 320 cSt	SiO_2 abrasive sand particles, Rockwell hardness of~700HRC.
4	ISO VG 320 cSt	NC 100 Iron powder, Rockwell hardness less than 10HRC.
5	ISO VG 68 cSt	MH300.39 Iron powder, Rockwell hardness less than 10HRC

4.RESULTS USING WEAR DEBRIS ANALYSIS

For to detect wear mechanisms and wear modes of the tests in detail particles were examined with standard optical microscope and then a confocal laser scanning microscope (CLSM). Particle type, all surface characteristics and colors were studied by using optical microscope. The CLSM facilitates to acquire sequential images for varying depths. Both boundary and surface definition of particles were obtained with CLSM. Surface roughness (Ra) is a numerical parameter used to describe surface roughness of the particles.

4.1 Wear debris analysis of test 1

The ISO VG 320 cSt oil especially recommended for these applications which were used in test 1 on new worm gearbox. In test first, four slides were made from oil samples collected weekly for 4 weeks. Oil collected throughout test 1was clean and light in color. The Three major types of the wear particles correspond to rubbing, cutting and laminar wear were found in oil sample on first slide. Both crown gear and worm screw gear generates small rubbing and laminar particles. Few particles were found in slide 2 and decrease was because of few cutting particles. This indicate that there was an appropriate lubrication layer existed between two gear surfaces, and wear process was stabilized during the test.

(a) (b)

Fig-4. (a) The new worm screw gear (b) the new crown gear.

4.2 Wear debris analysis of test 2

In test 2, the recommended oil was replaced with a general purpose ISOVG68 cSt oil. To avoid every possible cross contamination and compatibility issues, worm gearbox used in test first was completely cleaned and flushed. The oil samples were again collected on weekly basis for 4 weeks. Careful examination of slides from test second revealed that 5 types of wear particles rubbing, cutting, laminar, sliding, and fatigue particles were present on all slides. The decrease in particle size and number of slides four indicate that the surfaces were becomes smooth. The debris analysis shown in Table 2.

The sliding particles constantly decreasing in the size during test Second, indicates that there is a lubrication problem that caused a significant amount of metal to metal contact. Substantial surface sliding contact broke away particles, and gradually smoothed the surface until the particle size was greatly reduced. Scratches caused from the worm screw gear's contact with the crown were evident. This indicates sliding and abrasion caused by high levels of metal to metal contact due to inadequate lubrication breakdown. Because of machining process, considerable particles on slide 4 have a straight or regular edge. Follows the trend explained above, the particles surfaces becomes rougher from slide 1 to slide 3, and then smoother in slide 4.

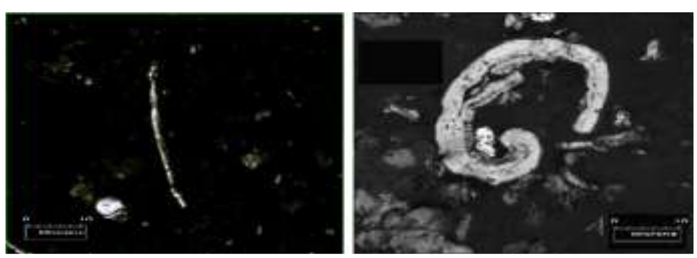

Fig-5. Images of two typical cutting particles from test Second.

(a) (b)

Fig.-6 (a) Worn surface of the worm screw gear after test Second
(b) Worn surface of the crown gear after test Second.

4.3 Wear debris analysis of test 3

In test third, 1 gram of SiO2 abrasive sand particles was added to new worm gearbox with normal lubrication conditions by using ISO VG 320 cSt oil. The new oil and a measured quantity of contaminants particles were then added to worm gearbox. Inspection reveals that the significant wear has been occurred. Scratches along with the direction of contact the screw gear makes with worm crown. It can be linked to sliding and abrasion caused by the high levels of metal to metal contact. It was concluded that large particles were involved in the wear process and were thus broken down into numerous small particles, and larger particles sunk of the bottom of worm gearbox and was not get collected or have any connection with overall wear process. The contaminant particles were observed rather smooth, round and were reflective. Results of wear debris analysis for test three shown in Table 2

(a) (b)

Fig.-7 (a) Worn surface of the worm screw gear after test Third; (b) worn surface of the crown gear after test Third.

4.4 Wear debris analysis of test 4

In test four, 0.5 gram of NC100 iron powder was added to the new worm gearbox under normal operating lubrication conditions by using the ISO VG 320 cSt oil. As compared to test first, size of the particles in test four is slightly larger. However, As compared to the wear debris analysis results from test three, there is significantly less wear of the worm gearbox by using the iron powder in test four, as compared to by using abrasive wear sand particles in test three. As a result, there is no significant amount of cutting particles have been generated, and both the surfaces of that gears and wear debris have relatively smoother because of that rubbing wear. Posttest inspection of that gear surfaces have confirmed that the outcome of that wear test using the iron particles. The iron particles were observed to be somewhat clear and non-reflective. It was also noticed that the size of iron particles after each of test phase has decreased as that particles were breaking up during the running of the worm gearboxes. The summary of wear debris results for test four is given in Table.

4.5 Wear debris analysis of test 5

In test five, 1 gram of MH300.29 iron powder is added to the new worm gearbox with the lack of lubrication condition by using the ISO VG 68 cSt oil. The similar procedure used in test three for oil sampling, and worm gearbox cleaning and flushing it was repeated for test five. The chunky particles were similar to the fatigue particles, but it is also possessed with variety of features which are more common because of rolling contact between that teeth due to iron particles contaminated. Less wear of worm gear surfaces had been occurred as compared to test two, and there is significant life remains in worm gearbox.

Fig- 8 Representative laminar particle from test five.

Vibration measurement was taken on the DE and NDE both of the worm screw and worm crown gears using a PCB ICP® accelerometer (PCB which is the manufacturer). Integrated circuit piezoelectric (ICP) sensors have built in, signal conditioning electronics which converts entire high-impedance charge signal generated by using piezoelectric sensor into the usable low impedance voltage signal. Hence, the ICP® accelerometer is a very suitable for the use in any dirty field of high temperature environments with the little degradation of signal.

Fig- 9 (a) Worn surface of the worm screw gear after test Fifth; (b) worn surface of the crown gear after test fifth

When manufactured, gears tend to be imperfect in the profiles of those teeth's. During these first few hours of the operation, high amplitudes and evidence of the wear generally subside, as this period is typically is the run-in period. As the gears wear, with the amplitude of the vibrations is observed in the frequency spectrum increases at similar frequencies. These peaks then broaden and develop sidebands. This presence of these sidebands is also provides an indication to the wear of gears.

5.RESULTS USING VIBRATION ANALYSIS

5.1 Vibration analysis of test 1

It was run at normal operating condition. In first test, the worm gearbox was comparatively worn free. Examinations of both time and the frequency domain plots are recorded over the whole duration of test one indicated that the worm gearbox is operating with minimum wear.

5.2 Vibration analysis of test 2

The test conditions used in test second was especially designed to produce an inadequate lubrication conditions. In this frequency region around 270–280 Hz, this increase in energy levels indicates that there may be a bearing defect developing.. The developed bearing defect was consistent with the inadequate lubrication, resulting into the increase in metal to metal contact with the formation of the scratches along with direction of the contact between the worm screw and crown gears.

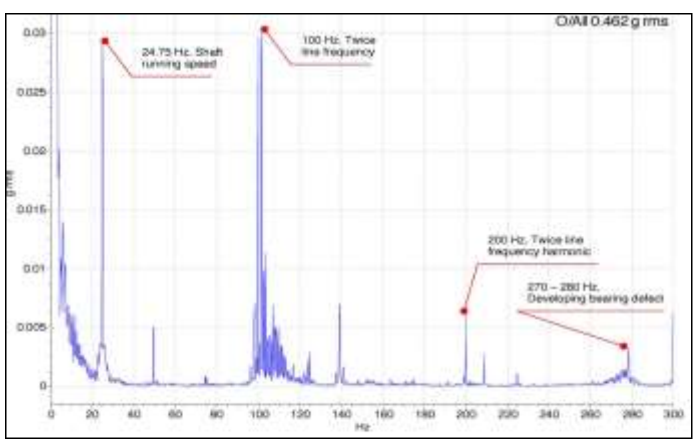

Fig-10 Acceleration–frequency spectrum of the crown drive end Vibration analysis- results of test no. Second

International Journal of Interdisciplinary Innovative Research &Development (IJIIRD)
ISSN: 2456-236X
Vol. 06 Special Issue 01 | 2021

Table-2 Wear debris analysis- Test Results [4]
Result Using Vibration Analysis [4]

Wear debris analysis	Test 1	Test 2	Test 3	Test 4	Test 5
Particle number	low	high	Very high	Very high	Very high
Particle size (μm)	Several microns ~50	Several microns ~100	Several microns ~20	Several microns ~50	Several microns ~30
Particle types	Rubbing, cutting and laminar	Rubbing, cutting, laminar and sliding	Rubbing, cutting	Rubbing, laminar	Laminar Rubbing and other small particles
Surface characteristics	Smooth surface 0.06	Rough surface 0.26	Smooth surface 0.48	Smooth surface 0.13	Smooth surface 0.18
Overall observation	90-95% ferrous, 5-10% bronze particles	20% ferrous, 80% bronze	30-35% ferrous particles, 65-70% bronze particles	30-35% ferrous particles, 65-70% bronze particles	30-35% ferrous particles, 65-70% bronze particles

5.3 Vibration analysis of test 3

The acceleration frequency spectrum is obtained at crown DE at completion of the testing. The frequencies which are present include the shaft speed peak, line frequency and twice the line frequency along with the harmonics, and outer race bearing frequency. This is the fact that the outer race bearing frequency which is present indicates a developing bearing problem. This is as expected as abrasive sand particles that were added to the system, and this will have great impact on bearings. In addition to that, the region of increasing energy content and broadband noise in the frequency range of 220 to 340 Hz indicates that both have increased the wear and a\the bearing defect

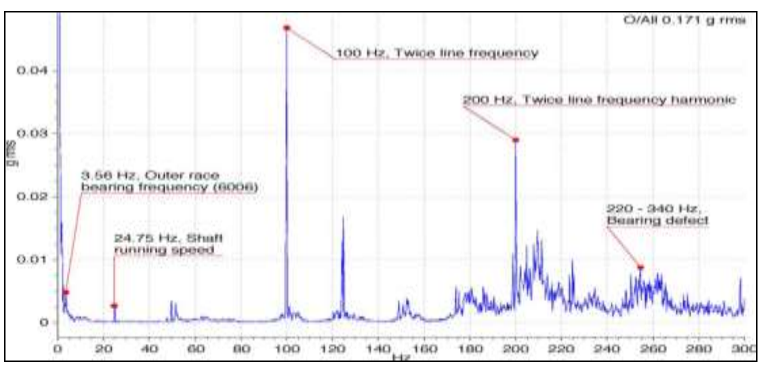

Fig-11 Acceleration–frequency spectrum of the crown drive end. Vibration analysis- results of test no. Third

5.4 Vibration analysis of test 4

During test four, vibration amplitudes were shown aa slight increase in shaft running speed, which indicating an increase in wear rate. The harmonics of shaft running are also present. Fig. shows that narrowband region of the increasing energy content around 260 to 280 Hz with the energy levels which are not significant or raised from baseline compared to test third. This region represents that the bearing defect and mound of energy indicates the increased wear. Narrowband region of the increasing energy content which is around 260 to 280 Hz, though the energy levels are not that much significant or raised from the baseline as compared to the test 3. Shafts running speed are also rises.

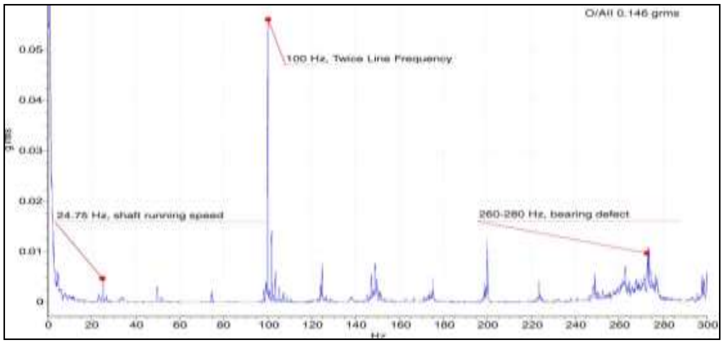

Fig- 12 Acceleration–frequency spectrum of the crown drive end.
Vibration analysis results of test no. Fourth

5.5 Vibration analysis of test 5

The acceleration frequency spectrum obtained at the worm crown DE at completion of test fifth. The specific frequencies which are present include the shaft speed peak and the line frequency, and twice the line frequency along with the harmonics. Now line frequency and its harmonics have observed due to the fact that the drive end of the worm gearbox which is directly fastened to the motor causing all vibrations that are directly transmitted through the shaft and housing.

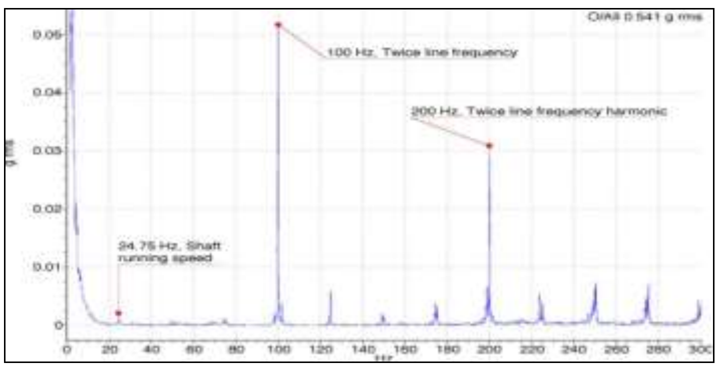

Fig-13 Acceleration–frequency spectrum of the crown drive end. Vibration analysis- results of test no. Fifth

Fig.13 also shows that numerous smaller harmonics of the running speed, which are attributed to the mechanical looseness within the worm gearbox. Even under the lack of lubrication conditions, there is no any noticeable bearing fault that is developing from the vibration spectra that is attributed to anti wear properties of MH300.29 iron powder. Now the vibrations data have consistent with both wear debris analysis and posttest visual inspections.

6. CONCLUSION

- Both the wear debris and vibration analysis techniques were used to assess the condition of the worm gearbox and diagnose if any problems.
- Wear particle analysis provides most conclusive results Presence of these sliding particles due to metal to metal sliding is better indicator of the lubrication breakdown.
- The inclusion of the abrasive sand particles greatly accelerated the gear wear rate.
- Vibration analysis concluded that there is considerable damage of bearings due to motor problems.
- Three-body abrasive cutting is major contributor for abnormal wear results into catastrophic failure..
- Vibration and oil analysis are most effective techniques for monitoring of machinery.
- Wear debris include the calculation of wear rate, metal in contact, and lubrication breakdown at boundary.
- Both the techniques are used to monitor the performance of worm gear under different working conditions.
- Both the techniques are used to monitor the performance of worm gear shows similar results.
- After comparison of results of both techniques, most appropriate analysis of condition of the experimental setup can be possible.

7. REFERENCES

[1] Heidarbeigi Kobra, Hojat Ahmadi, M. Omid, Adaptive Vibration Condition Monitoring Techniques for Local Tooth Damage in Worm gearbox, Modern Applied Science, July 2010, 4(7), pp. 104-110.
[2] Govindarajan N. and R. Gnanamoorthy, Ferrography-A procedure for measuring wear rate, Indian journal of engineering and material sciences, October 2008, 15, pp. 377-381.
[3] Ebersbach S., Z. Peng, N. J. Kessissoglou, The investigation of the condition and faults of a spur worm gearbox using vibration and wear debris analysis techniques, Elsevier Science direct, Wear 260 (2006), pp.16–24.
[4] Peng Z., N. J. Kessissoglou, M. Cox, A study of the effect of contaminant particles in lubricants using wear debris and vibration condition monitoring techniques, Elsevier Science direct, Wear 258 (2005), pp.1651–1662.
[5] Sondhiya Om Prakash and Amit Kumar Gupta, Wear debris analysis of automotive engine lubricating oil using by Ferrography, International journal of engineering and innovative technology (IJEIT), November 2012, 2 (5), pp. 46-54.
[6] Yarrow A.S., An overview of mechanical condition monitoring by wear debris analysis, Proceedings of Australian society of sugar cane technologists, 1993, pp. 83-88.
[7] Girdhar P., Practical machinery vibration analysis and predictive maintenance, an imprint of Elsevier, 2004, pp. 88-224.
[8] Singh S. K., Acoustics Based Condition Monitoring, IIT Guwahati.