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A Review Paper on Fault Detection of Worm Gearbox

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Abstract: Diagnosis of worm gear defects is challenging and this is reflected in the limited number of publications. However, these gears are commonly used in many applications such as escalators, mills, and conveyors, and are expected to work 24 hours a day in the production system. Any failures with the gearboxes may introduce unwanted downtime, expensive repair, and even human casualties. Therefore it is essential to detect and diagnose faults in the initial stage. This paper aims to give insight on various diagnosis methods to detect the presence of naturally developed faults within worm gearboxes. This was undertaken in an attempt to identify the presence of defects within the worm gearboxes. It is shown that irrespective of the predominantly sliding motion of the gears, diagnosis of faults is feasible as long as the appropriate analysis technique is employed.

Keywords: Worm Gearbox, Fault Detection, Vibration Analysis, Oil Analysis, Condition Monitoring.

I. INTRODUCTION

Worm gears are used for transferring power between two non-parallel, non-intersecting shafts usually perpendicular to each other. A very high gear ratio up to 200:1 can be achieved using Worm Gearbox with little effort. Generally multiple reduction of conventional gear set is required to achieve same reduction level as that of worm gearbox.

They have advantage of taking up low space, simpler in construction, self-locking movement, low backlash, damage tolerance capacity and quitter in operation.This worm gearbox is made with high precision.Worm gearbox is used for increasing Torque or to reduce the speed. It is almost impossible to reverse direction of power by using worm gearbox because of the high friction between the worm and worm wheel.

Hence backstop is not required to add in worm gearbox to avoid power transmission in reverse direction. The worm gearbox has variety of industrial application including Rolling and saw mill, mining machinery, escalators etc.

The efficiency of worm gear pair ranges from 50% to 90% depending on the type of Application. Worm gear generates a lot of heat. To dissipate this heat lubricants, fins to gearbox casing or an extra fan should be provided to keep the operating temperature below 90 ^{0} C. As the movement between the worm and the wheel gear purely sliding there is no rolling movement in between worm and worm wheel.

So that it is relatively difficult to lubricate.The lubricants required are usually very high viscosity (ISO 320 and greater). Bath lubrication can be used for slow speed application (sliding speed less than 4 m/s) of worm gearbox. Splash lubrication is most common in Worm gearbox having sliding speed in the range of 1.5 m/s to 10 m/s. when sliding speed exceed beyond 10 m/s lubrication must be used under pressure.

A. Types of Gear pair used in Worm Gearbox
Combinations of worm and worm wheel that used in the general practice are as follows,
1. Steel worm and Brass worm wheel,
2. Steel worm and steel worm wheel,
3. Brass worm and Brass worm wheel,
4. Plastic on metal.

The most common worm gears are made with a brass wheel and a steel worm because the brass wheel is relatively easier to replace than the worm. When that the two surfaces come into contact, the worm is safe from wear as the wheel is softer so that the wear occurs on the wheel. Oil analysis reports on worm gearbox always show higher level of copper and low level of iron as a result of the sacrificial wheel. [9]

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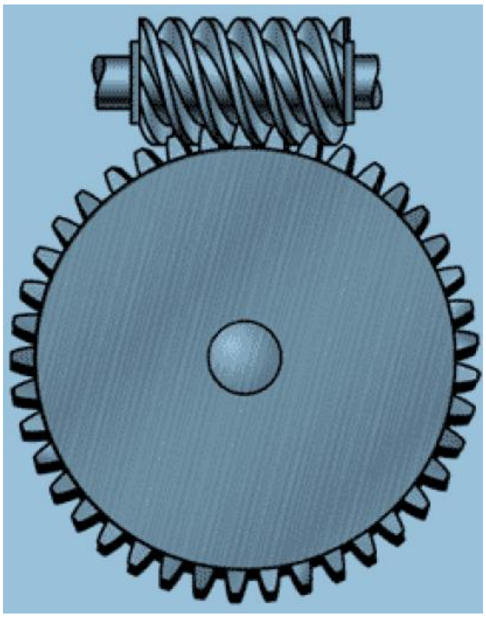

Fig 1. Worm and Worm Wheel

B. Types of Failure in Worm Gearbox

The most common gear failures that occur in worm gearbox are wear, pitting, scoring, fracture and plastic flow.

1. **Wear** is a surface phenomenon in which material of gear is removed or worn out from contacting surface of gear teeth. It includes Polishing, Moderate and Excessive Wear, Abrasive Wear and Corrosive Wear. The main reason for wear is inadequate lubrication, rough running etc. To avoid Wear we should use the high viscosity lubricant for worm and worm wheel.
2. **Pitting** is surface fatigue failure which occurs when endurance limit of material is exceeded due to large contact stress and large no of stress cycle. It includes initial pitting, Destructive pitting and Spalling. The main cause of pitting is high contact stress, overload etc. To avoid pitting failure smooth gear surface should be provided, also by keeping the load on contact surface below its Endurance limit and by increasing Hardness of the material pitting failure can be avoided.
3. **Scoring** is rapid wear resulting due to failure of oil film due to overheating of mesh due to which metal to metal contact takes place producing alternative welding and tearing which remove material from teeth surface more rapidly. It include Moderate and destructive scoring which is caused due to inadequate lubrication, excessive operating temperature, excessive surface load and surface speed. To avoid scoring good lubrication system should be provided.
4. **Fracture and Plastic Flow** are very rare in case of worm and worm wheel gearbox. To avoid Plastic failure of a gear good design should be made. To avoid Plastic flow failure contact stress should be reduced with increasing material hardness of surface and sub-surface.[10]

For detecting faults in worm gearbox various techniques are applied such as Oil Analysis, Vibration analysis, Temperature analysis and Acoustic Emission Analysis. Generally Oil analysis is mostly widely used techniques as compared to other condition monitoring techniques for detecting fault in worm gearbox. The impact at gear-mesh frequency and their sideband are used to detect fault in other gear pair, but in case of worm and worm wheel it is quite difficult to implement as continuous sliding motion takes place in worm and worm wheel gearbox. Due to continuous sliding motion the vibration signal get damped so it get little more difficult to analyze that signal by using vibration signal methods to detect faults.

Now let us see various literatures available on fault detection of worm and worm wheel gearbox.

II. LITERATURE REVIEW

The literature on Fault detection/Condition Monitoring of worm gearbox is very rare due to fact that the diagnosis of worm gearbox by using vibration analysis is really challenging due to its continuous sliding motion. However it is shown that irrespective of the predominantly sliding motion of the gears, diagnosis of faults is feasible as long as the appropriate analysis technique is employed.

Peng et al (2003)studied an integrated approach to fault diagnosis of machinery using wear debris analysis and vibration analysis. For their experimentation and validation they fabricated a test set up consisting of worm gearbox driven by electric motor. In practice the vibration and wear analysis is the main condition monitoring techniques for worm gearbox. They found that these techniques individually detect about 40 % of faults only. When the combination of both this method is done to detect fault it predict better and reliable information about the fault. Peng et al investigate the correlation between these two techniques. For investigation the correlation they mainly used three operating condition of worm gearbox as normal lubrication, lack of proper lubrication and with contaminant particle in the lubricant oil. They compare the result obtained from the vibration analysis and wear debris analysis. The result shows that both vibration analysis and ear debris analysis detect similar wear mechanism as detection of rubbing, metal to metal contact and boundary lubrication breakdown. Wear debris analysis further gives insight on wear rate of the gear and mechanism while vibration analysis gives quick and reliable information of bearing condition. By combining these two methods they found that more reliable diagnosis of gearbox can be done.[1]

Mba et al (2012) focus on condition monitoring of worm gear. They have fabricated the test setup to detect the fault in worm gear. For experimentation purpose they have purposefully induced defect in a worm gear and testing is carried out. This is analysed by using acoustic emission with vibration analysis for same defect. The result obtained from the acoustic emission and vibration analysis are compared which shows that Acoustic emission have better capability to detect fault than vibration analysis.[2]

FarisElasha et al (2014) studied the pitting detection of worm gearbox with vibration analysis. The diagnosis of worm gearbox fault by using vibration analysis is relatively challenging due to its continuous sliding motion. They have undertaken few statistical measure, special kurtosis and enveloping of vibration signal to detect the faults. They calculate Kurtosis, R.M.S. value and FM4 factor from statistical parameter with Special Kurtosis and vibration enveloping. For testing purpose they used three operational worm gearboxes of escalators. They found that Kurtosis showed no difference between three gearboxes. The RMS and FM4 shows higher value for gearbox A which is faulty gearbox. As they measured the vibration in all three directions, they found that z direction is more sensitive to pitting fault diagnosis. The z direction is sliding direction of mating tooth. Envelope and special kurtosis also shows ability to detect fault in gearbox. They found that Special Kurtosis is ideally suited for diagnosis of worm gearbox. They found that this technique is more sensitive to direction of measurement as the measurement taken horizontally and parallel to z direction (Wheel shaft axis) are most sensitive in fault detection. The FM4 was deemed effective to detect fault of worm gearbox while Special Kurtosis analysis is less susceptible to direction of measurement.[3]

Vahaoja et al (2006) studied condition monitoring of worm gearbox. They used oil analysis and vibration analysis to detect fault in worm gear. They found that combination of wear debris analysis and vibration analysis gives best possible result for indicating faults in worm gearbox. The vibration analysis tells about fault in worm gear and Wear debris analysis tells about wearing machine element. The worm gear failure can be observed in the frequency range of 3-2000 Hz with acceleration. The RMS and X4 value also indicate fault in worm gearbox with help of acceleration plot. The Kurtosis is the most sensitive feature in frequency range of 3-1000 Hz. for cable manufacturing machine gearbox. They have suggested that for wear debris analysis it is sufficient to measure concentration of copper and iron in oil for examining worm gear. They found that it is beneficial to measure/ record the signal foe long period of time. Also the vibration measurement point should be as near as possible to point of contact of worm and worm wheel.[5]

Sharif et al (2016)focus on prediction of wear pattern in worm gearbox under lubricated condition. They considered a wear model based on empirical standard which include fluid film thickness in lambda ratio parameter. The analysis is based on elsto-hydrodynamic lubrication in which distribution of wear on tooth of surface during meshing is calculated to determine wear per cycle. This is repeated in series of wear steps. It help to give information about pattern of wear develop to produce wear scares seen on teeth of gear in practice. [4]

Ismon et al (2013) studied condition monitoring of variable speed worm gearbox lubricated with different viscosity oil. They use vibration analysis as well as temperature monitoring techniques to detect behaviour of worm gear under various type of lubricant's viscosity. They used VG100, VG460, and VG680 in study to aid sliding friction of worm gear at three predetermined speed as 900,1150,1400 rpm. Vibration and temperature monitoring are the most regularly measured condition parameter in rotating machine and it is continuously monitored in important application. From the result they have conclude that lubricant with higher viscosity contribute to less vibration amplitude and higher temperature generation in gearbox. The low viscosity lubricant oil contributes to low temperature stabilization in gearbox. [6]

Vahaoja et al (2010) studied various trends in industrial oil analysis. They studied various literatures on current industrial oil analysis such as wear metal analysis, solid debris analysis, addictive analysis which are categorized as Laboratory (offline) analysis. They made comparison of oil analysis technique with vibration techniques and acoustic emission. Oil analysis gives idea about wearing machine element such as gear, hydraulics and reciprocating engine part. Vibration monitoring can effectively monitor unbalance, misalignment of shaft or gear. The combination of these techniques proves best for fault detection of worm gear. The oil analysis is proved best among all three analysis techniques to detect pitting fault in worm gear.[8]

SagarGhodake et al (2016) gives a brief review on fault diagnosis methods used to detect faults in general gearbox using vibration analysis methods. They gives insight on various vibration analysis methods used to detect fault in gearbox including Empirical Mode decomposition method, Wavelet analysis, various Time domain and Frequency Domain method with some new emerging techniques such as Artificial Neural Network, Fuzzy logic, support vector Machine etc.They conclude that Empirical mode Decomposition system (EMD) use the modal energy associated with deterioration in gear to detect faults. Wavelet Transform shows accurate result in detecting and localizing gear toothfracture with different damage severity. Time domain techniques including waveformgeneration, indices (RMS value, peak level value and crest factor) and complete vibration level do not provide anydiagnostic evidence under varying load condition. In frequency domain, FFT was able to show the whims at faultcharacteristics frequencies and its multiple frequencies but other peaks are also presents due to signal modulationeffect. By this technique identification of fault categories is difficult. Support Vector Machine shows betterclassification ability to detect various faults in the gearbox and it can be used for automatic fault diagnosis. ConvolutionNeural Network could lower cost of maintenance and guarantying a continuous production system, and also it can beused to online diagnosis of process.[7]

III. RESEARCH GAP

From all above literature it is concluded that the fault diagnosis of worm gearbox using vibration analysis is not focused as compared to Oil analysis techniques. As all researcher focus on spur or helical gearbox for application of various vibration techniques to detect faults hence there is a very large research gap for to analyze worm gearbox using vibration analysis techniques. For detection of fault in worm gearbox we can check the feasibility of Empirical Mode Decomposition, Wavelet analysis, Time frequency analysis.

IV. CONCLUSION

Various fault detection techniques for worm gearbox including Wear debris analysis, Vibration Analysis, Acoustic Emission Analysis, and Temperature analysis is studied. Out these techniques more focus is given on Wear Debris Analysis to detect fault in Worm gearbox. Here Combination of vibration analysis techniques and Wear debris Analysis proves best to detect fault in worm gearbox. As currently researcher mainly focus on kurtosis, RMS value of vibration signal so that there is a lot of chance in fault detection of worm gearbox using various vibration analysis techniques including some new approach as Support vector machine, Neural network, Fuzzy logic etc.

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BIOGRAPHIES

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