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Experimental Analysis of Faults in Worm Gearbox using Vibration Analysis

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Abstract—**Worm gear are commonly used to reduce the speed and increase the torque. It is used in many application such as conveyor, escalators, and mill. Wear debris analysis, Vibration Analysis, Aquatic Emission and Temperature Analysis are used to detect fault in gearbox. Wear Debris analysis is the main method to detect fault in worm gearbox, after that vibration analysis methods are used to detect faults in worm gearbox. The vibration signal convey the signature of fault in gearbox. This vibration signature is analyzed to identify the fault in worm gearbox. Due to continuous sliding motion the detection of fault in worm gearbox using vibration analysis is challenging. In this paper vibration analysis is used for analysis of seeded defect in worm gearbox. Time domain and Frequency domain analysis are focused for detection of faults. In Time domain analysis values of various indices are calculated for no fault and various fault conditions at two speed with different loading condition. This values of defective condition are compared with values at normal condition. The analysis of vibration signal is done by using MATLAB for calculating values of indices in Time domain analysis. In frequency domain analysis the values of GMF and its sideband values are used for indication of fault. Peak and RMS is found more sensitive for wear fault and Crest factor and Kurtosis found more sensitive to pitting fault condition.**

Keywords — **Worm Gearbox, Fault Detection, Vibration analysis, Indices, MATLAB.**

I. INTRODUCTION

CURRENT trends in industry is to achieve maximum work done with minimum maintenance and operating cost to get maximum profit. Due to Increase in competition, change in technology, Awareness of customer towards quality, reliability, health and safety many companies try at best to improve their performance of their manufacturing techniques and methods. Vibration is the main cause of failure in machinery among all the factor. To increase the life of machinery the vibration must be reduced or kept at minimum level. The cause and source identification producing the vibration in machinery is essential for deciding the appropriate maintenance strategy of a machinery. Gear mechanism is the main part of any machinery so the fault diagnosis of gear mechanism is great concern. If a gear failure occurs it affect either all the gear teeth of a gear or only a few teeth. Several failure modes (e.g. scuffing, pitting, and abrasive wear) are related to tooth surface failures are generally termed distributed gear faults. When a fault develops on a gear, the performance of the gear system depreciates and desired output cannot be achieved.

Worm gears are used for transferring power between two non-parallel, non-intersecting shafts commonly perpendicular to each other. A very high gear ratio up to 200:1 can be achieved using Worm Gearbox. Generally several reduction of conventional gear set is required to achieve same reduction level as that of worm gearbox. They required low space, simpler in construction, self-locking movement, low backlash, high damage tolerance capacity and quitter in operation. This worm gearbox is made with high precision. Worm gearbox is used for increasing Torque and to reduce the speed. It is not possible to reverse direction of power transmission 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, cranes etc.

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. A number of publications are available for fault detection of Spur and Helical gears using vibration analysis. The limited no of publication for fault detection of Worm gearbox are available due to fact that fault detection in spur and helical gear by using vibration analysis is quite simpler as compared to worm gear. 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 due to its continuous sliding motion. Its vibration signal get damped so it get little more difficult to

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analyze fault by using vibration analysis methods. Due to continuous sliding motion the wear of worm and worm wheel is inevitable. To accommodate this fact worm gear are made up of softer material than worm screw. Usually the worm gear is made up of bronze while worm screw is made up of stainless steel material.

The aim of this paper is to find the appropriate features in the failure detection of worm gears and to determine an effective vibration indicator for the analysis and detection of worm gear defects. An experimental test-rig is fabricated which allows testing of seeded defect in the worm gear. The general guide line for vibration measurement is that vibration measurement should be done as near as possible to gear mesh point. The axial direction of worm wheel proved the most sensitive direction for vibration measurement of worm 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 irrespective of the sliding motion of the gears in worm gearbox, detection of faults is possible.

Peng et al (2003) studied an integrated approach to fault diagnosis of machinery using wear debris analysis and vibration analysis. In practice the vibration and wear analysis is the main condition monitoring techniques for worm gearbox. They found that these techniques individually can detect about 40 % of faults only. When the combination of both this method is done to detect fault it predict better and more reliable information about the fault. Peng et al investigate the correlation between these two techniques. The result shows that vibration analysis and wear debris analysis detect similar wear mechanism which include 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. [1]

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

Faris Elasha et al (2014) studied the pitting detection of worm gearbox with vibration analysis. They have used few statistical measure, special kurtosis and enveloping of vibration signal to detect the faults. They found that Kurtosis showed no difference between three gearboxes. The RMS and FM4 indicate 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 useful to pitting fault diagnosis. Envelope and special kurtosis also shows ability to detect fault in gearbox. They found that Spectral Kurtosis is ideally suited for diagnosis of worm gearbox. The FM4 is effective to detect fault of worm gearbox while Spectral Kurtosis analysis is less susceptible to direction of measurement. [3]

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 including fluid film thickness in lambda ratio parameter. In the analysis 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 on teeth of gear in practice. [4]

Vahaoja et al (2006) studied condition monitoring of worm gearbox. The wear debris analysis and vibration analysis is compared to detect fault in worm gear. The result shows that combination of wear debris analysis and vibration analysis gives best result for indicating faults in worm gearbox. Fault in worm gear is detected by using vibration analysis and Wear debris analysis detect 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 used to indicate fault in worm gearbox with help of acceleration plot. The Kurtosis is the most sensitive factor in frequency range of 3-1000 Hz to detect fault. They found that it is beneficial to measure/ record the signal for 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]

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. 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]

III. EXPERIMENTATION

A. *Experimental Set-up*

It is decided to induce the faults, such as wear, pitting, teeth breakage in the gearbox. The analysis of vibration for every fault is carried out separately. In the worm gearbox worm wheel is made up of BS1400 PB2C bronze alloy. The worm screw is made up of EN34 Steel. The worm gear teeth is machine finished. Firstly vibration signature captured at Healthy condition of worm gearbox. After that on same worm gear the pitting and wear fault is induced for experimental purpose and respective vibration signature are captured. This vibration signature then processed in MATLAB software to obtain the required result.

The gearbox is connected to AC motor. This motor is coupled to gear shaft through belt drive. Output shaft of gearbox is connected to rope brake dynamometer. So that power is transmitted to rope break dynamometer through gearbox from motor. The schematic figure of vibration measurement for fault detection of gearbox shown in figure1.

FIGURE 1. EXPERIMENTAL SETUP

The specification for worm gearbox and electric motor is given in Table I.

TABLE I.
SPECIFICATION OF WORM GEARBOX AND ELECTRIC MOTOR

Sr. No.	Particulars	Specification
1)	Model of the gearbox	Worm gear box with 1:30 reduction.
2)	Worm	Case hardened alloy steel with ground finished teeth
3)	Worm wheel	Centrifugally cast high strength phosphor bronze
4)	Bearings of gearbox	Taper roller bearing (2 × HR 30208)
5)	Capacity of Electric Motor	Single phase 1 H.P.
6)	R.P.M. of Electric Motor	1440

B. Test Procedure

While testing the motor is run at its rated power and speeds. Different load condition such as 0 kg, 10 kg, 16kg etc. applied on worm gearbox using rope break dynamometer. The reading are taken at two input speed as 1440 R.P.M. and 720 R.P.M. of worm gearbox. This speed ratio is achieved by using different size of pulley to get the required speed ratio. The diameter of pulley on output shaft is 125 mm. For vibration measurement magnetic base accelerometer is place on the output shaft bearing casing in axial direction of output shaft of gearbox. By making all above arrangements, readings are taken for healthy gear condition with good lubrication & different fault condition of gears, with different load conditions This data is stored as Vibration spectrums by using FFT analyzer for further analysis. Further analysis is done with help of MATLAB software.

Firstly reading of the heathy condition gearbox is taken. After that fault is induced in the gearbox. Pitting, wear, tooth damage are induced manually for taking vibration signature readings at seeded defect condition. The defective vibration signature reading are captured and process in MATLAB to calculate various parameter in time and frequency domain. This parameter of healthy condition and faulty condition are compared to plot the result.

C. Signal Processing

The processing of signal is carried out by using the MATLAB program in which the input data is taken from different types of fault and load condition in form of .mat and .txt and output data is in the form of time & frequency waveform. This output data is stored and used for extracting the various indices in time domain analysis. The frequency spectrum is analyzed in this paper which shows indication of presence of fault in worm gearbox. Following parameters in time domain are to be calculated including Peak value, Root Mean Square Value, Crest factor, Kurtosis, FM4. M6A, and N4A factors. This factors are calculated for each condition of worm gearbox and compared with healthy condition of worm gearbox.

Out of these peak value, RMS value, Crest factor, kurtosis are presented in this paper. These are defined as follows,

1. Root Mean Square value (RMS):

It is a measure of the energy content in the vibration signature and hence is one of the most relevant statistical parameter.

$$\mathrm{RMS} = \sqrt{\frac{\sum_{n=1}^{N}[A(n)]^2}{N}}$$

Where N is total number of samples, A(n) is amplitude of n th point in time domain signal.

2. Peak (Maximum Value):

The peak value of signal is one of the important features for diagnosis. The value indicates the maximum value without any consideration of the time history of the wave.

Peak = max (A)

3. Crest Factor:

It is also called the ‘peak-to-rms’ ratio and is defined as the ratio of peak value of a waveform to its RMS value.

Crest Factor = (Peak/RMS)

4. Kurtosis:

Kurtosis is obtained from the fourth order central moment (moment about the mean) of amplitude probability distribution and is defined as

$$K = \frac{\sum_{n=1}^{N} [y(n) - \mu]^4}{N\sigma^4}$$

Where N is total no of samples, σ is standard deviation, μ is mean value, and y (n) is data of n point.

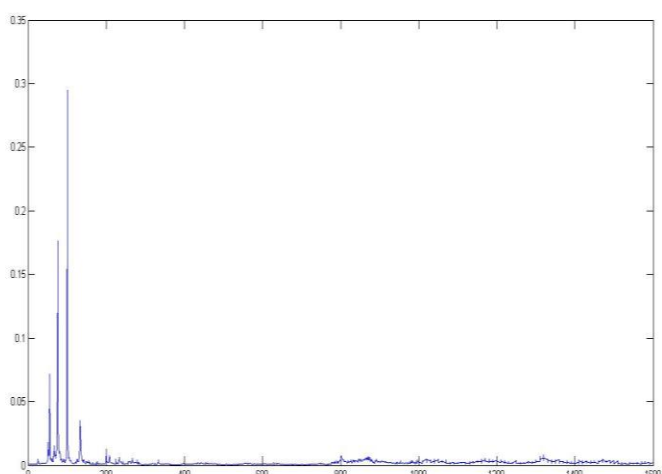
IV. RESULT

Generally, gears contain a gear mesh frequency due to impact of two mating gear. This gear meshing frequency and its harmonics gives information about the failure modes and wear of the gearbox. In case of worm gearbox it operate under a sliding motion instead of rolling motion like spur and helical gear so minimal impact occurs due to sliding nature of gear. So that determination of gear failures for worm gears is little more difficult as no pure impact frequency is present in it.

In this paper healthy, pitting fault and wear fault of gearbox at 1440 rpm with no load condition is discussed.

A. Frequency Domain Analysis

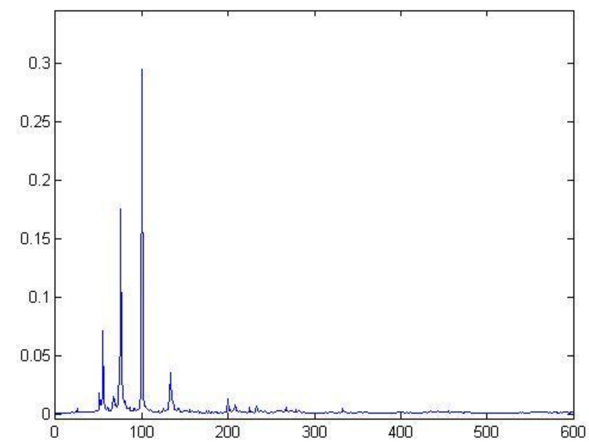
In frequency domain analysis the following graph shows frequency response at healthy condition of worm gearbox at frequency range of 0 Hz to 1600Hz.



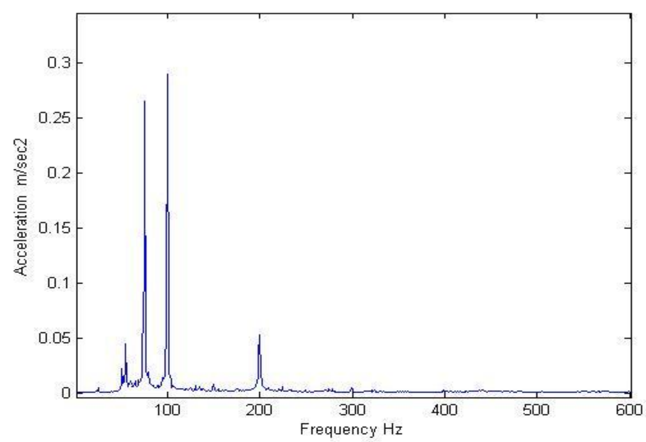
Graph 1. Frequency Response at healthy condition

In all frequency spectrum we can see the offset of acceleration from base (zero) line. This is due to sliding and rubbing in between worm and worm wheel the vibration amplitude is increased. The gear meshing frequency of this worm gearbox is 24 Hz. A peak at Gear Meshing Frequency is indicated.

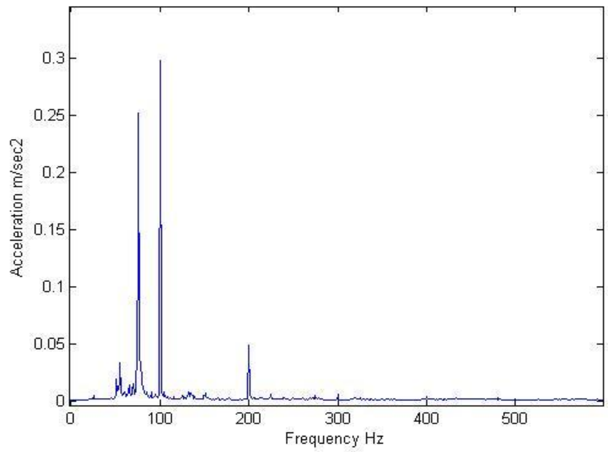
In Graph 1. peak at frequency of 100 Hz is shown. This peak present in all frequency domain graphs which indicate the fault in driving electric motor. This fault may be uneven air gap in between stator and rotor of the motor or misalignment of two mating gear. Its harmonic are also detected in the graphs at 200 Hz, 300 Hz frequency.



Graph 2. Frequency Response at healthy condition in frequency range 0-600 Hz



Graph 3. Frequency Response at pitting condition in frequency range 0-600 Hz



Graph 4. Frequency Response at wear condition in frequency range 0-600 Hz

Graph 2, Graph 3, and Graph 4 shows the closer view of frequency spectrum from 0 Hz to 600 Hz frequency for healthy condition, pitting condition and wear condition of gearbox at 1440 rpm respectively. The test represented in this study are representative for all test taken.

B. Time Domain Analysis

Time domain Analysis is calculation of various parameter with respect to time. Indices of the vibration signature including peak value, RMS value, crest factor, and kurtosis etc. are calculated from time domain vibration signal with help of matlab.

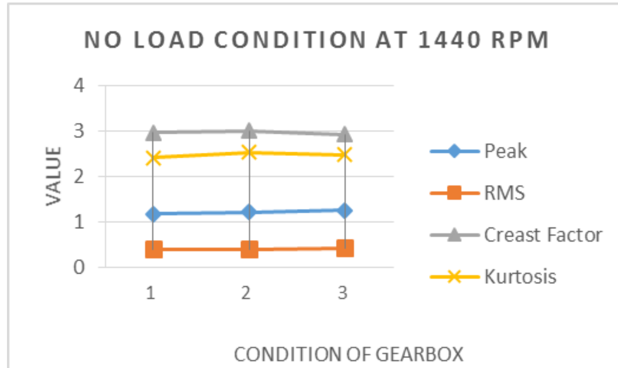
The following tables shows the values of time domain parameter at no load applied on the gearbox.

The table 2 gives value of various parameter at no load condition of gearbox. From this table we can note that the Peak and RMS value of vibration signal is increasing from healthy condition to wear condition. Hence it is found effective for determining the condition of gearbox. The value of crest factor and Kurtosis factor has highest value at pitting fault hence it can be used effectively to found the pitting fault condition.

Table 2. No Load Condition at 1440 RPM

Factor	Healthy Condition	Pitting Condition	Wear Condition
Peak	1.1764	1.2199	1.2541
RMS	0.397	0.4067	0.4279
Crest Factor	2.9635	2.9997	2.9308
Kurtosis	2.4118	2.5296	2.48

The graphical representation of above table is shown in graph 5.

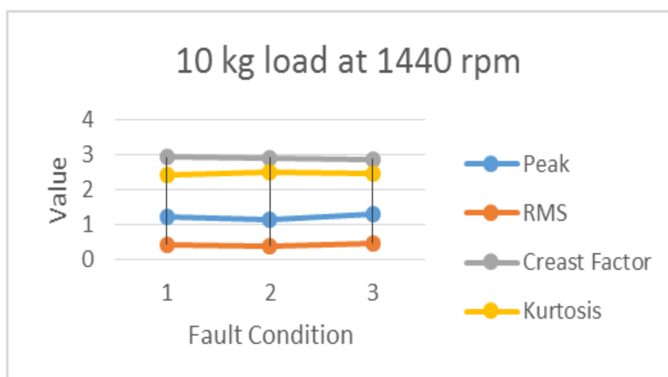


Graph 5. No load condition at 1440 RPM

The table 3 gives value of various parameter at 10 kg load applied to gearbox. From this table we can note that the Peak and RMS value of vibration signal highest value at wear condition. While the value of crest factor and Kurtosis factor has highest value at pitting fault hence it can be used effectively to found the Wear and pitting fault condition respectively.

Table 3. 10 kg load applied at 1440 RPM

Factor	Healthy Condition	Pitting Condition	Wear Condition
Peak	1.1885	1.1066	1.2929
RMS	0.406	0.3824	0.452
Crest Factor	2.927	2.8938	2.8607
Kurtosis	2.4036	2.5036	2.4585



Graph 6. 10 kg load applied at 1440 rpm

V. CONCLUSION

In this study frequency domain analysis and time domain analysis is used to detect the faults in worm gearbox. Due to continuous sliding motion of worm and worm wheel, wear in worm and worm wheel takes place which is indicated by the offset of frequency from the base line in frequency domain analysis. Time domain analysis shows that Peak and RMS value are sensitive to the wear fault condition while Kurtosis and Crest Factor are sensitive to indicate the pitting fault condition of the worm gearbox.

VI. FUTURE WORK

Future work includes the processing of the captured vibration signal in time domain analysis and empirical mode decomposition method. In time domain analysis values of indices including FM4 Factor, M6A Factor, N4A Factor by using MATLAB program. In Empirical Mode Decomposition the vibration signal is decomposed into Intrinsic Mode Function. The energy content in this Intrinsic Mode Function is used to indicate faults in worm gearbox.

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