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CONDITION MONITORING & DIAGNOSIS OF GEAR FAULTS USING VIBRATION ANALYSIS

Siddharth Patil*1, Mayur Mohite*2, Akhilesh Wadate*3, Aditya Bhoj*4, Yashashri Nikam*5, Peeyusha Shelake*6, Ganesh Rakate*7

*1,2,3,4,5,6,7Department Of Mechanical Engineering, Annasaheb Dange College Of Engineering And Technology, Ashta. Maharashtra, India.

ABSTRACT

Load variations on the gearbox and gear faults are two significant sources of vibration in gearboxes. Furthermore, due to the inaccessibility of mounting the vibration transducers, measuring vibration in the gearbox can be difficult at times. With the use of an FFT analyzer, experimental data from a single stage gearbox setup is used to detect several types of gear tooth failures. Vibration analysis techniques are utilized for fault identification in gear systems, load fluctuation, and a method for detecting the evolution of gear defects based on time-frequency analysis. Pitting, tooth break, and wear are some of the flaws that can occur on gear teeth.. Through the use of an FFT analyzer, signals from a defective condition are compared to signals from a healthy (normal) condition. Validation is carried out by calculating appropriate statistical parameters for time and frequency domain analysis in a defective state. The defect on the gear can be identified using a variety of vibration metrics such as velocity and acceleration. It's also a useful tool for keeping track of the health of gears in various situations.

Keywords: Vibration Analysis, FFT Analyzer, Time-Frequency Domain, Gear Faults, Pitting, Tooth Break, Wear.

I. INTRODUCTION

In any power transmission system, the gear is the most critical component. In most cases, gears are utilized to transfer power from one shaft to another. A gearbox is a device that transmits power from an engine to the wheels using a series of gears. Spur, helical, bevel, and epicycle gears are among the many types of gears utilized (V. B. Bhandari, 2010). Because gears are power transmission elements, they are prone to developing defects. Tooth damage, wear, pitting, and chipping occur in gears as a result of several factors such as excessive loading, high friction, and fatigue loading, among others. Backlash, eccentricity, run out, and alignment errors are also created during the assembly and manufacturing of gear. During normal operation, the flaws will cause noise and vibrations. Because each fault state produces a different vibration spectrum, these parameters can be utilized to determine the fault condition. As a result, precise vibration analysis techniques are required to determine the failure conditions in the gearbox.

The stud-mounting method was chosen as the best option. The accelerometer was mounted on a smooth, flat surface with a flat magnet to give enough bandwidth for impact and friction detection. On a curved surface, a two-rail magnet would miss multiple occasions where hitting and friction occurred. [1]. Vibrational analysis has been found to be superior to other monitoring techniques. At sub-harmonics and multiples of frequencies, the peaks can be found. The presence of a problem in the Gearbox is the cause of the subharmonics and numerous frequencies[2]. The RMS and FM4 parameters are frequently influenced by system component flaws and are unable to distinguish between them. Unfortunately, all of the pulses and vibrations produced by the system equipment can modify the values of these two parameters. The RMS and FM4 metrics are ineffective in detecting tooth surface pitting on an industrial scale. One of the practical approaches for bridging the monitoring of gear tooth surface imperfection is visual inspection. One of the most effective methods, especially in wide gears like those evaluated in this study, is to pay attention to the area of tooth surface damage[3]. For a double-toothed damaged pinion spinning at 300 rpm (5 Hz), the damaged teeth mesh with the mating gear twice every revolution. Because the pinion rotates at 5 Hz, or 5 revolutions per second, one pinion revolution takes (1/5) second to complete. The considerable impact on the following tooth occurs as the injured tooth meshes. As a result, the peak is seen twice every 0.2 seconds. Graph 3 shows the same thing, but the peak is every 0.1 seconds. It can be extrapolated from this finding that faults such as single and double tooth damage can be recognized simply by observing the time waveform and speed[4]. The accelerometer can provide useful information about a vibrating object as well as the nature of the vibration sources. Students (and professors!) can use the process author to analyze the vibration characteristics of various pieces of equipment, such as speakers, fans, and motors, as well as pumps and even miniature engines. Collecting data at several positions and orientations on the fan, without a fan blade, at varied operating speeds, and with the fan on different surfaces are just a few of the possibilities for research (cushion, rubber mat, floor, etc.). The magnitudes of the accelerations for a single fan could be compared, or the acceleration rates for different fans could be compared(Prior to assessing the subject box fan, the author discovered acceleration rates for a lab room exhaust fan on the order of 5 g's, which are significantly higher than those observed for even the box fan's modified condition)[5]. Waveform generation, Indices (RMS value, Peak Level value, and crest factor) and overall vibration level are time domain techniques for vibration signal analysis that do not provide diagnostic information but may have limited application in fault detection in simple safety critical accessory components. Although statistical moments such as kurtosis can identify fault conditions, the skewness trend has proven no useful fault classification ability in our current gear fault situation[6]. The time-frequency domain average technique (TSA) reliably reduces noise from the signal while capturing the dynamics of one signal period. The Wavelet Transform produces precise results when it comes to identifying and localizing gear tooth fractures of various degrees of severity. Under varying load conditions, time domain approaches for vibration signal analysis such as waveform creation, indices (RMS value, peak level value, and crest factor), and entire vibration level yield no diagnostic evidence[7]. Vibration tests were performed on a healthy and a simulated defective gear in an IC engine's gearbox. The author investigated vibration acceleration values in both the time and frequency domains for both healthy and faulty gear. CWT is utilized for damage detection, and it has been found to be successful in diagnosing gear faults[8]. RMS acceleration increases as the level of pitting progresses from minor to moderate to severe. The most common cause of gear flank degeneration is a pitting flaw. As a result, monitoring the RMS acceleration of the gear can be used to estimate its health (for pitting)[9]. According to the author If we compare the vibration response of a new bad gearbox to the reaction of a known-faulty gearbox, we can figure out what kind of fault this gearbox has without disassembling the entire system. One of the major advantages of this type of system is that it allows us to get to the root of the problem without having to open the entire system. As a result, repairing a malfunctioning system takes less time[10].

II. ASSEMBLY AND TESTING

In this set up gear pair of healthy pinion and gear are mounted on the shafts. First element is healthy pinion of 18 teeth which is mounted on shaft rigidly by using the key, and a circlip a semi flexible metal ring with open ends is snapped in machined grooves of shaft. A spacer is used fill the gap between gear and circlip. Two Ball bearings are mounted at each ends of shafts to get the friction free motion of shafts. Same procedure is done with second element that is gear with 72 teeth. Then the shafts with assembled gears are supported on the casing. To make the casing fluid tight packing paper i.e. oil paper is used.

To connect the motor shafts with input drive shaft 3 piece L-jaw coupling with rubber spider is used to accommodate the shocks and vibrations. The laser alignment is the instrument that is used to check the alignment of motor shaft and input drive shaft.

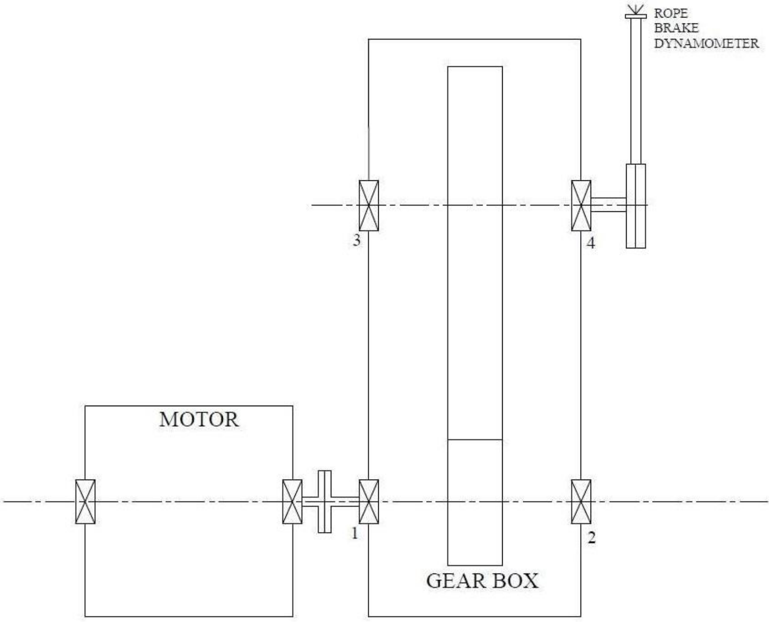

Figure 1: 2D Setup Diagram

Figure 2: Actual Experimental Setup

To apply various loads rope brake dynamometer is used at the output shaft and variable frequency drive is used to vary the RPM of 3 phase induction motor. The same procedure is done for the gears with faults like pitting, tooth breakage and wear.

a) Pitting

(b)Tooth Breakage

(c) Wear

A Fast Fourier Transform (FFT) is a machine vibration analysis device that is used to detect potential defects and assess the machine's condition. The vibration parameters such as natural frequency, amplitude, acceleration velocity etc. The FFT device is also called as Vibration analyzer. Also various types of accelerometers and sensors i.e. piezoelectric sensors used for the experimental analysis which transfers the vibration signals to the FFT device. Microcomputer-based vibration data collectors are available for machine status monitoring and fault diagnosis. They're used in conjunction with vibration sensors to detect vibration, store and transfer data, and do frequency domain analysis.

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III. RESULTS AND DISCUSSION

From the values we have captured by using FFT analyzer we have plotted the graphs for velocity and acceleration. From that we have come to know that the 'Tooth Breakage' has more effect on the velocity and acceleration.

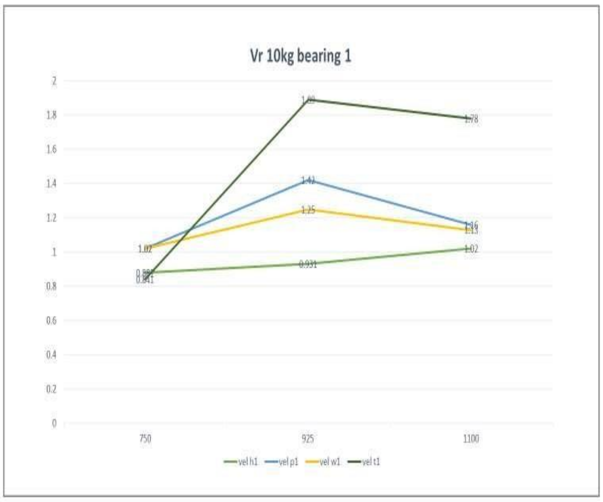

Figure 3: Velocity

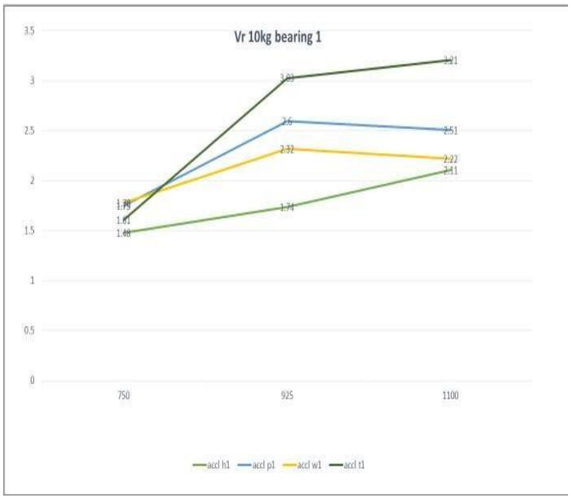

Figure 4: Acceleration

The above graphs are made from the readings captured for 10 Kg load at bearing 1 in vertical direction of accelerometer for velocity and acceleration respectively.

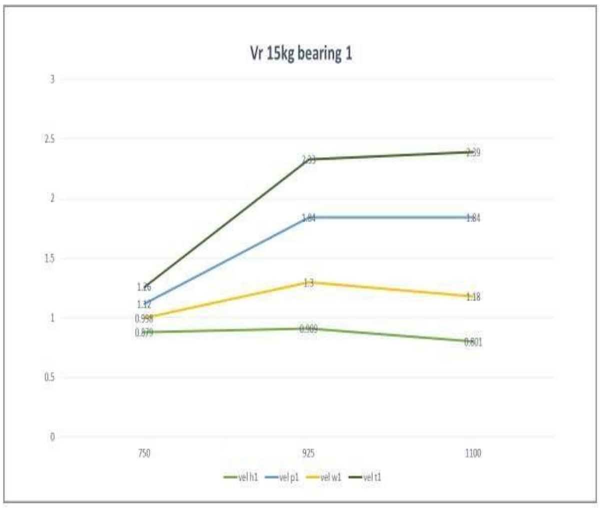

Figure 5: Velocity

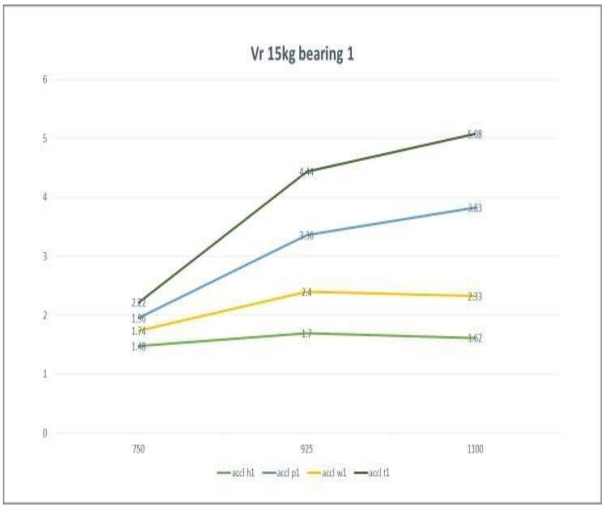

Figure 6: Acceleration

For bearing 1 the maximum velocity is observed in vertical direction. Also, it is observed that as speed and load increases the velocity also increases in vertical and horizontal direction. For axial direction it is observed that the velocity reduces as the speed increases but velocity increases with the increase in load.

The same is observed for bearing 2, bearing 3 and bearing 4. Among these bearings bearing 1 and bearing 3 have more value of velocity compared to bearing 2 and bearing 4.

The maximum acceleration is observed at every bearing in vertical direction. Acceleration increases with speed and load in vertical and horizontal direction. For axial direction it is observed that acceleration reduces as speed increases but acceleration increase as the load increases. Bearing 1 and bearing 3 have higher values of acceleration as compared to bearing 2 and bearing 4.

The peak frequencies we got from the acceleration spectrum are nearly equal to the theoretical frequencies calculated by gear mesh frequency equation for healthy gear pair.

$$GMF = (Z \times RPM)/60$$

For Z = 18 and for RPM 750, 925 and 1100 frequencies are 225Hz, 277.5Hz and 330Hz respectively. And the practical values are nearly equal to these values.

From the values captured for healthy gear pair and faulty gear pair (faults like wear, pitting and tooth break) it is observed that for healthy gear pair the maximum value of velocity and acceleration for 5Kg load is 0.98 mm/sec and 1.85 m/sec respectively at 925 RPM. For 10Kg load at 1100 RPM it is 1.02 mm/sec and 2.11 m/sec and for 15Kg it is 0.909 and 1.7 at 925 RPM.

Figure 7: Velocity and Acceleration for 10Kg load at 1100 RPM

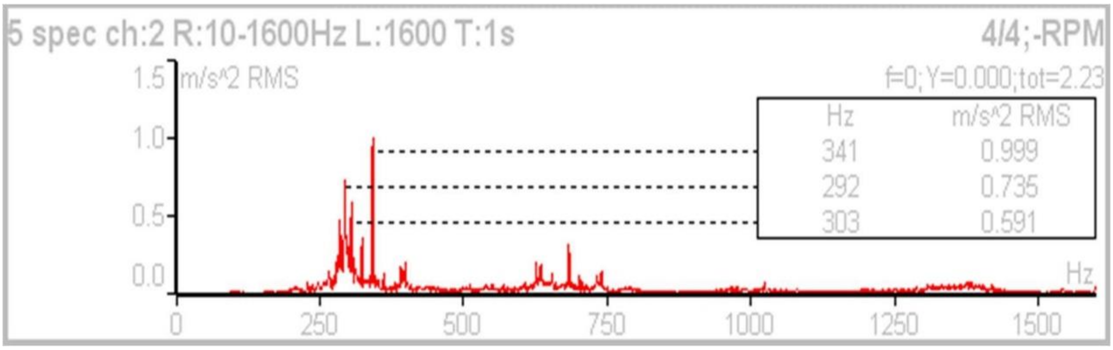

Figure 8: Spectrum at Velocity and Acceleration for 10Kg load at 1100 RPM

For pitting the maximum value of velocity and acceleration for 5Kg load is 0.886 mm/sec and 1.88 m/sec respectively at 1100 RPM. For 10Kg load at 1100 RPM it is 1.16 mm/sec and 2.51 m/sce and for 15Kg it is 1.84$mm/$ sec and 3.83m/sce at 1100 RPM.

Figure 9: Velocity and Acceleration for 15Kg load at 1100 RPM

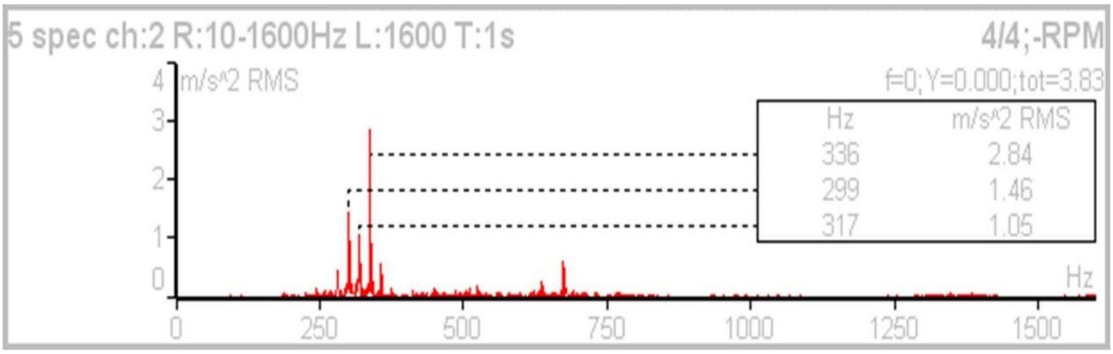

Figure 10: Spectrum at Acceleration for 15Kg load at 1100 RPM

For wear the maximum value of velocity and acceleration for 5Kg load is 1.32 mm/sec and 2.64 m/sec respectively at 1100 RPM. For 10Kg load at 925 RPM it is 1.25 mm/sec and 2.32 m/sce and for 15Kg it is 1.3 $mm/$ sec and 2.4 m/sec at 1100 RPM.

For tooth break the maximum value of velocity and acceleration for 5Kg load is 1.69 mm/sec and 2.12 m/sec respectively at 925 RPM. For 10Kg load at 1100 RPM it is 1.89 mm/sec and 3.03 m/sce and for 15Kg it is 2.39 $mm/$ sec and 5.08 m/sce at 1100 RPM.

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Figure 11: Velocity and Acceleration for 15Kg load at 1100 RPM

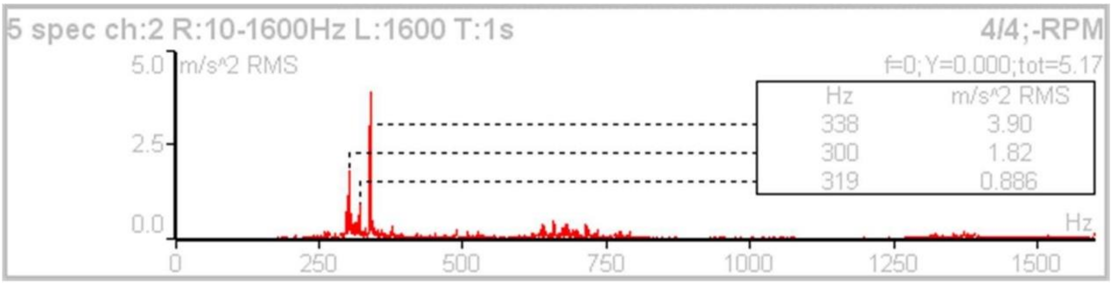

Figure 12: Spectrum at Velocity and Acceleration for 15Kg load at 1100 RPM

These maximum peak values are mostly observed at bearing 1 in vertical direction. For healthy gear acceleration ranges from 1.04 to 2.11 m/sec . For pitting it ranges from 1.62 to 3.83 m/sec . For wear it ranges from 1.49 to 2.64 m/sec . And for tooth break acceleration range is 1.793 to 5.08 m/sec . From this range of acceleration we may know about the faults on the gear that are causing vibrations.

IV. CONCLUSION

- During the vibration analysis the predominant peak of vibration in vertical axis has been observed for bearing no 1 and bearing no 3.
- The values of velocity and acceleration are slightly increased by increasing the load and speed.
- During testing it is observed that the amplitude of vibration for faulty gear also higher than healthy gear. For healthy gear acceleration ranges from 1.04 to 2.11 m/sec . For pitting it ranges from 1.62 to 3.83 m/sec . For wear it ranges from 1.49 to 2.64 m/sec . And for tooth break acceleration range is 1.793 to 5.08 m/sec.

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