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Fault Diagnosis in Gears using Vibration Analysis

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Abstract*: In gearboxes, vibration stemming from load fluctuations and gear defects poses significant challenges. However, accessing and mounting vibration transducers in gearboxes can often be difficult. To address this, an experimental approach utilizing FFT analysis is employed to detect various types of gear tooth faults. By analysing vibration patterns, fluctuations in gear load gear faults can be identified effectively. This involves comparing signals from healthy and defective conditions using FFT analysis to trace sidebands of high-frequency vibrations. Validation is achieved by inputting data from an Accelerometer into LabVIEW, This comprehensive approach serves as a valuable tool for monitoring gear health under various operating conditions.*

Keywords: Gearbox, Vibration Analysis, Accelerometer

I. INTRODUCTION

Gears in machinery serve the fundamental purpose of transmitting power or rotary motion between shafts while maintaining the desired angular velocity ratio, ensuring smooth motion transfer and high efficiency. These criteria are typically met unless a gear is defective. When a fault affects one or more gear teeth, it undermines the performance of the gear system, leading to deviations from the intended motion transfer. Gear failure, stemming from various reasons, can impact either a few teeth or the entire gear set. Different failure modes such as scuffing, pitting, abrasive wear, and bending fatigue cracks are associated with tooth surface failures, often caused by excessive stress and inadequate lubrication. Ensuring precision in gear inspection necessitates specialized machinery, often requiring dedicated installation space. In machine shops, there's a need for robust and efficient gear checking arrangements to maintain production efficiency. This gear test rig is such arrangement which simplifies the measurement and saves the labour time and labour cost with greater accuracy. In gear test rig all the gears will be mounted on a structure which will be having rotational motion. To measure the errors or defects sensors will be used to measure vibrations level. It will helps us to find out faults or misalignments in gear-pair. This compact test rig is suitable for shop floor usage, occupying minimal space and offering flexibility for operators to use it as required, thereby optimizing time efficiency.

II. PROBLEM DEFINITION

Advancements in technology have spurred the development of new production methods, enabling the manufacturing of products on a large scale at low costs. with this mass production comes the necessity for precise fitting of component parts, ensuring that any randomly selected part seamlessly integrates with others. Achieving this requires close attention to dimensional tolerances during manufacturing, necessitating thorough inspection at various stages. Traditional gear test rigs have limitations, often requiring different rigs for different types of gears and lacking sufficient accuracy in composite error checking. to address these issues, a new gear test rig design has been proposed. Detecting faults in gearboxes traditionally involves analysing vibration patterns and motor current. vibration analysis relies on changes in frequency spectra caused by faults, identifying specific faults by observing distinctive sideband patterns. However, this method is susceptible to background noise interference. Motor current signature analysis (MCSA) presents an alternative approach, proven effective in monitoring the condition of various machinery such as motor-operated valves, worm gears, induction motors and bearings

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III. METHODOLOGY

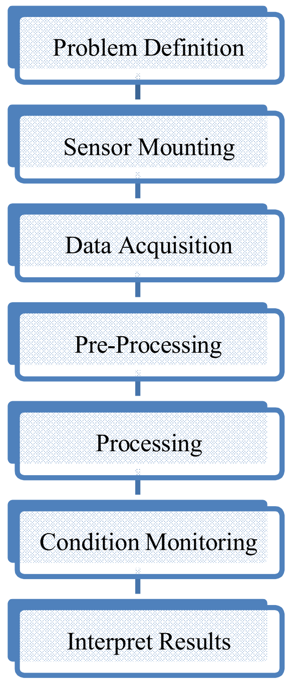

Fig. Methodology

IV. SETUP INFORMATION

Setup consisting of a BLDC motor coupled with a input shaft of the pinion to drive the gear-pair. The primary objective is to facilitate the study of behavior of gear-pair under varying speed. Additionally, a sensor is mounted on the bearing casing to capture vibrations, providing valuable data for condition monitoring and helps to predicting the discontinuities in gear-pair.

Components of the setup include –

BLDC MOTOR : A brushless DC (BLDC) motor is a type of electric motor that operates using direct current (DC) electricity. BLDC motors typically have a rotor with permanent magnets mounted on it. These magnets create a magnetic field that interacts with the stator windings to produce rotational motion. BLDC motors are known for their high efficiency compared to brushed DC motors.

FIG. BLDC MOTOR

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CONTROLLER : Motor controllers often include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, speeding up or slowing down, and controlling other operational parameters.

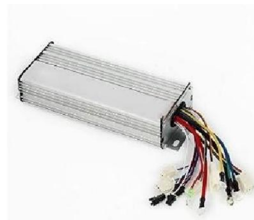

FIG. CONTROLLER

SPUR GEARS : Spur gears are one of the most common types of gears used in machinery and mechanical systems. They consist of cylindrical gears with teeth that are parallel to the axis of rotation. Spur gears have a straightforward design, making them easy to manufacture and maintain. They typically consist of a cylindrical gear with teeth cut straight across the face of the gear. Spur gears are often used in applications where the driving and driven shafts are parallel to each other. They are capable of transmitting motion and power between parallel shafts efficiently.

FIG. SPUR GEARS

2 BOLT FLANGE BEARING : Bearings that are mounted within a flanged housing are used when the bearing mounting surface is perpendicular to a shaft axis. They are commonly available in two, three, or four-hole configurations. Two-bolt flanged ball bearing units have a diamond or winged-shape with 2 holes for mounting.

Fig. Flange Bearing

Specifications :

SR. NO.	COMPONENT	SPECIFICATIONS
1.	800w Dc Motor	Brand : Naks Power : 800w Voltage : 48v Rpm : 1500
2.	Controller	Brand : Xcluma Material: Aluminium Colour : Silver, Rated Power: 800watt Rated Voltage: 48v/64v
3.	Spur Gears	NO. OF TEETH'S – 18, 36, 54 PCD - 72, 144, 216 Module – 4
4.	Accelerometer	Frequency Range – 5-10 Khz Maximum Force – 1000n

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V. EXPERIMENTATION

In an experimental procedure gear-pair is allowed to run at its rated power at different speed. For vibration measurements magnetic base accelerometer is place on bearing casing. By making all above arrangements, readings are taken for healthy gear and good lubrication condition. The data is stored within the fft analyzer for subsequent analysis. Vibration spectrums are taken for gears having various faults & the data is stored in computer for further analysis. For different condition of faults & varying speed conditions data is collected.

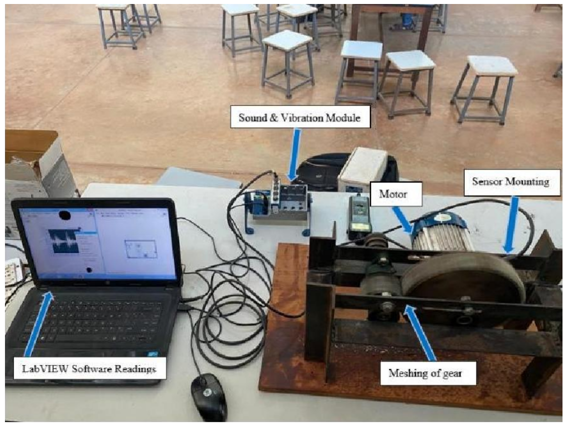

FIG. EXPERIMENTAL SETUP

Sensor Mounting

Mounting the sensor on the bearing casing, it is beneficial to identify potential problems within gear-box like gear teeth wear, discontinuities or misalignment. The casing transmits these vibrations, allowing the sensor to detect issues without needing direct contact with the rotating parts. Bearings are subject to vibrations in both horizontal and vertical directions, often attributed to factors such as shaft misalignment, gear wear, and rotor imbalance. Placing sensors at a vertical angle enables detection of vibrations in both planes concurrently, aiding in diagnosing faults generating combined horizontal and vertical movement. Mounting sensors at an angle can sometimes mitigate noise originating from gearbox housing or external sources. A vertical orientation may strike a better balance between capturing the targeted vibration signal and reducing unwanted background noise.

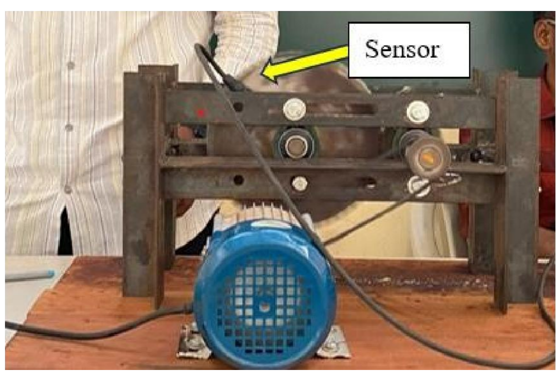

Fig. Sensor Mounting

Data Acquisition

LabVIEW, a graphical programming environment crafted by national instruments (now part of NI), stands as a cornerstone in test, measurement, and control applications across diverse industries like industrial automation, electronics, and aerospace. Its reputation for user-friendliness and adaptability renders it a preferred choice for myriad

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engineering tasks. Through intuitive icon-and-wire connections on the block diagram, LabVIEW empowers users to fabricate virtual instruments and tailored applications. To effectively implement predictive maintenance, proficiency in both LabVIEW and MATLAB is essential, alongside a comprehensive understanding of the monitored equipment or systems.
Version used: LabVIEW 2012 (64-bit).

DATA ACQUISITION FOR LabVIEW BY USING NI-DAQMX

LabVIEW software uses NI-DAQmx to sense the data by using sensor modules. NI-DAQmx short for national instruments data acquisition measurement extension, is a software and hardware platform commonly used in industrial and research applications for data acquisition and control. It's a powerful tool for interfacing with sensors, transducers, and various data acquisition devices. In the context of predictive maintenance, NI-DAQmx plays a crucial role in collecting data from sensors placed on equipment or machinery. These sensors monitor parameters such as temperature, pressure, vibration, and more. DAQmx simplifies the process of acquiring sensor data, often in real-time, and can transmit this data to software tools like MATLab for analysis and predictive modelling. By integrating DAQmx with predictive maintenance software, engineers can continuously monitor the condition of equipment and detect anomalies or patterns that indicate the need for maintenance. This proactive approach helps prevent unexpected failures, reduce downtime, and optimize maintenance schedules, ultimately leading to increased equipment reliability and cost savings in industrial and manufacturing settings.

VI. EXPERIMENTAL TEST RIG

The test was perform on the single gear-pair having different gear ratios (i.e. 1:1, 1:2, 1:3). The specifications of gears are already given in previous slides. The test is performed at different speeds to generate the readings. The gears are tested at approx 450 rpm & 1000 rpm speed. After taking standard gear-pair readings the defects were formed or created on gear tooth profile. The analysis of vibration of fault is carried out separately. For the purpose, gears of same specifications is taken and on each gear separate faults are made. Thus the signals obtained is analyzed which are valuable for the fault diagnosis.

Common Faults On Gear Tooth :

Common gear faults include one-corner defects, two-corner defects, one missing tooth, and cracked tooth defects. For analysis purposes, we focus specifically on the cracked tooth defect, which is manually introduced onto the gear tooth for experimentation. The crack on gear tooth generated by cutting the single tooth using hack saw. After taking reading on of cracked tooth gear then the gear tooth is cut completely and original non defective gear is replaced with this gear.

Testing Samples

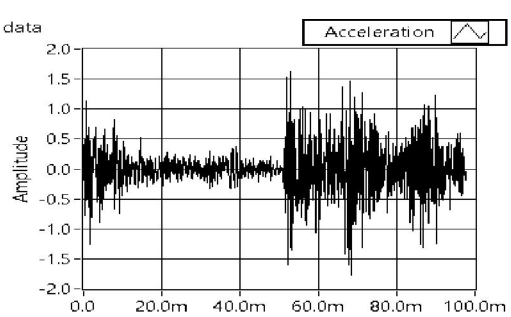

Fig. At 1000 Rpm (Standard)

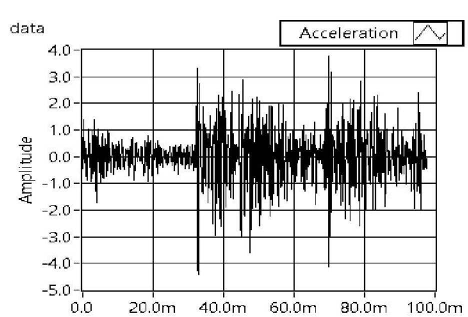

Fig. At 1000 Rpm (Defected)

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VII. RESULT

The basic aim of this project work is to design a test rig and to carry out experimentation to detect different types of faults namely broken tooth and missing tooth in a gear box. In the experimentation, vibration response measured from the gear pair is analyzed to detect different faults. For this analysis gears rotates at loading condition and varying speed of motor. Readings are taken at different speed (i.e. 450 rpm & 1000 rpm). Accelerometer is placed on the bearings in horizontal and vertical positions.

Result Analysis

Table : Amplitude At Different Speeds (Standard Gears)

SPEED	450 RPM	1000 RPM
GEAR RATIO		
1:1	1.8	3.5
1:2	1.9	4.5
1:3	2.8	7.9

Table : Amplitude At Different Speeds (Defected Gears)

SPEED		
GEAR RATIO	450 RPM	1000 RPM
1:1	1.8	3.5
1:2	1.9	4.5
1:3	2.8	7.9

VIII. DISCUSSION

After visualized these graphs, simply we can see the effect of dynamic vibration by the frequency response and amplitude response. In graphs 1 to graph 8 we can see amplitude response increasing according to gear defect. The 1st condition at which gear has no fault (healthy) amplitude response is minimum. The 2nd condition corresponds to the crack in gear tooth amplitude response is more than that for the healthy gears.

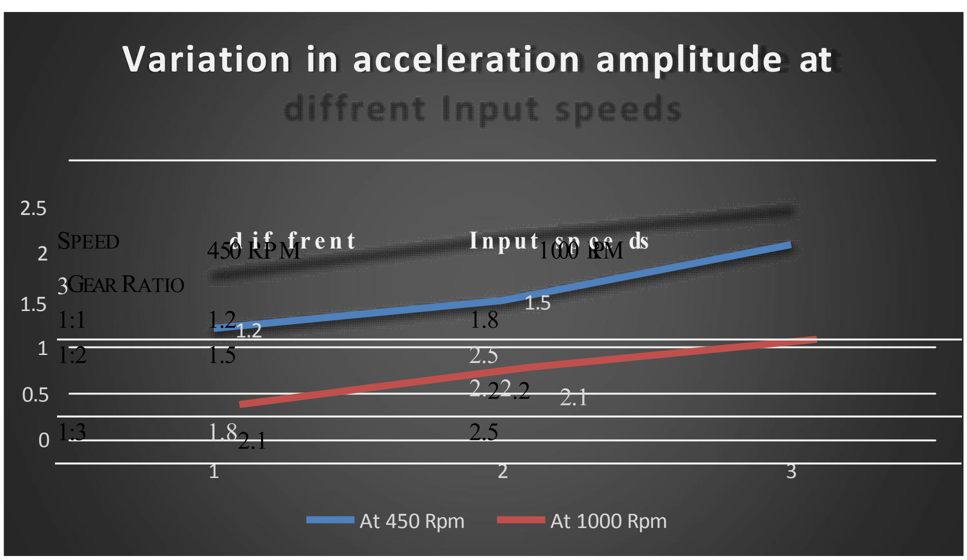

Fig. Amplitude At Different Speeds

Above graphical representation states that as rotational speed increases amplitude of vibrational acceleration increase up to natural frequency of system

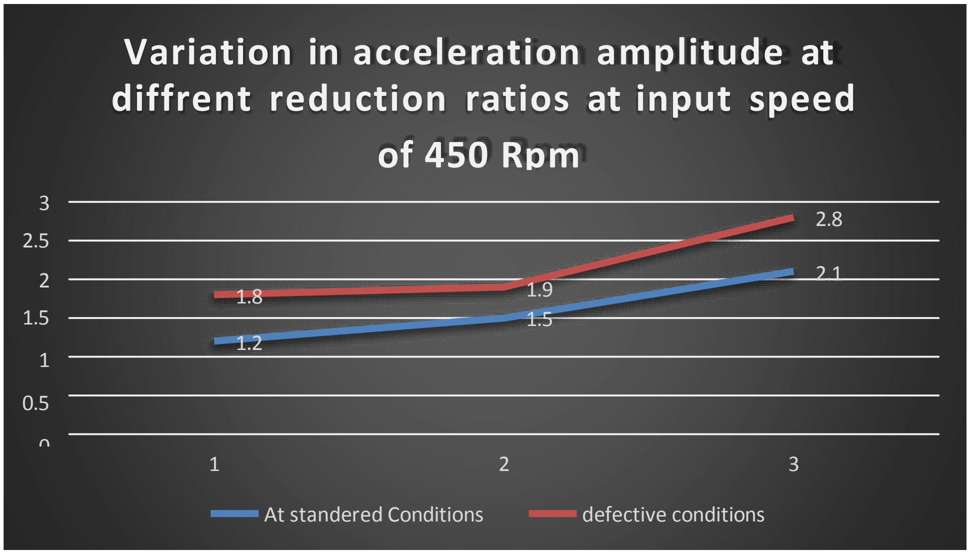

Fig. Amplitude At 450 Rpm At Different Conditions

Above graphical representation shows variation of acceleration amplitude at fixed input speed of 450 rpm. Graph predicts due to small defect in tooth surface amplitude of acceleration increases for same experimental setup.

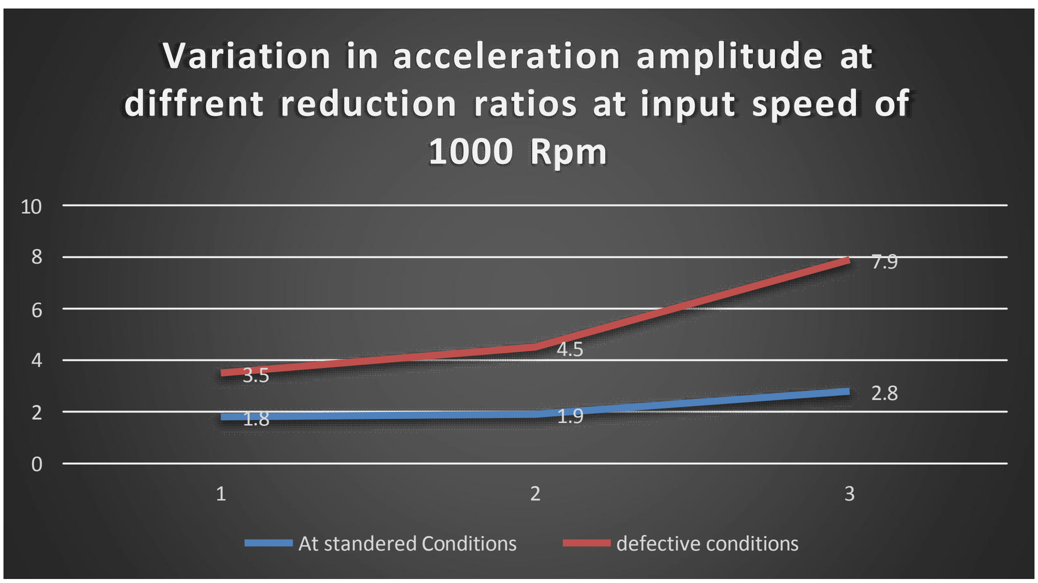

Fig. Amplitude At 1000 Rpm At Different Conditions

Above graphical representation shows variation of acceleration amplitude at fixed input speed of 1000 rpm. Graph predicts due to small defect in tooth surface amplitude of acceleration increases for same experimental setup.

From above discussion it can be concluded that such analysis can be used to predict defects in gear using vibration analysis.

IX. CONCLUSION

After analyzing these all graphs, we got dynamic vibration amplitude values for different faults. So after these result we conclude that this whole system was a modern phenomenon to get defect in a gearbox. Now days this kind of modern system is used by industrial purpose. By comparing the vibration response of a new faulty gearbox to that of a gearbox with a known fault, we can predict the fault or defect without the need for complete disassembly. This approach offers significant advantages, as it allows for direct identification of the fault upon opening the system, streamlining the repair process and reducing overall downtime. So this becomes a less time consuming process to repair a faulty system.

X. FUTURE SCOPE

There is lots of study possible in this field. Because fault can be any kind like misalignment of shaft, crack on tooth or gear, crack in bearing, but here we consider only one kind of fault of a gear. These defects can be incorporated into future studies for further analysis and investigation. So in our opinion these aspects can be taken as future work of this project. Such reading can be taken by defecting more teeth in sequence which will give exact prediction of system.

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