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Failure Indication and Monitoring of Spur Gearbox Using Vibration Analysis and Data Acquisition System

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Abstract: *Gears are a critical element in a variety of industrial applications such as machine tools and gearboxes. An unexpected failure of the gear may cause significant economic losses. For that reason, fault diagnosis in gears has been the subject of intensive research. Vibration analysis has been used as a predictive maintenance procedure and as a support for machinery maintenance decisions. As a general rule, machines do not break down or fail without some form of warning, which is indicated by an increased vibration level. By measuring and analyzing the machine's vibration, it is possible to determine both the nature and severity of the defect, and hence predict the machine's failure. The vibration signal of a gearbox carries the signature of the fault in the gears, and early fault detection of the gearbox is possible by analyzing the vibration signal using different signal processing techniques. This paper presents analysis of vibration in gears using modal analysis and FFT analysis. It also presents analysis of gears with cracks and gear with missing teeth. It also presents the analysis of Natural frequency in steady as well as running condition.*

Keywords: Gears, Gearboxes, Vibration Analysis, FFT Analysis, etc.

I. INTRODUCTION

All machines with moving parts give rise to sound and vibration. Each machine has a specific vibration signature related to the construction and the state of the machine. If the state of the machine changes the vibration signature will also change. A change in the vibration signature can be used to detect incipient defects before they become critical. This is the basics of many condition monitoring methods. Condition monitoring can save money through increased maintenance efficiency and by reducing the risk of serious accidents by preventing breakdowns. The use of vibration analysis as one of the fundamental tools for condition monitoring has been developed extensively over a period of approximately 35 years. Vibration is one of the major limitations in any machining operation, which causes improper surface finish of the work piece. Vibration arises from numerous sources such as misalignment, imbalance, improper tightening, motor, tool chatter, spindle rotation, improper foundation and dynamics of gearbox.

Frequency response analysis of a gearbox is carried out. The external load variation and its response on the vibration characteristics are studied. Studies related to the influence of mesh stiffness in controlling the vibration of spur gears pair is carried out. Although vibration studies have received good attention, the present project focuses in on dynamics of high-speed gearbox where gear meshing frequency, modal analysis and critical speed are analyzed. In order to solve the vibration analysis problems of a flexible and/or rigid shaft carrying flexible or rigid single or multiple disks, mainly lumped parameter-based methods using transfer matrix have been used previously. This way, the problem can be simplified. However, accuracy of the solution is compromised while predicting higher natural frequencies and critical speeds of a shaft-disk system.

In its simplest form, a geared spindle system is modeled as a couple of disk-spindle system connected by a spring representing the gear mesh. The spring connects the disks tangentially. While the disks are considered to be rigid in most of the cases, the shafts are subject to torsional vibration.

Vibration analysis technique is used to identify the status of the gearbox, to distinguish the good and the faulty gear and to indicate the defective components. Examples of widely used techniques for gearbox are such as Waveform analysis, Time-Frequency analysis, Faster Fourier Transform (FFT), Spectral analysis, Order analysis, Time Synchronous Average, and probability density moments. These vibration-based diagnosis techniques have been the most popular monitoring technique because of ease of measurement. Vibration analysis was used former mainly to determine faults and critical operation conditions. Nowadays the demands for condition monitoring and vibration analysis are no more limited trying to minimize the consequences of machine failures, but to utilize existing resources more effectively.

Problem Statement:

We cannot see crack in gears visually. So, to Detect the gear wear the vibration analysis technique is used. this technique it is not necessary to mount the system on gears. We can mount the accelerometer on the gearbox system and detect the faults in gear boxes by observing vibration response of structure.

Objectives:

1. To prepare CAD design of spur Gear box using CATIA V5 software.
2. To study vibration analysis of spur Gear box.
3. To perform modal analysis of spur Gear, with crack, with missing teeth box by using FEA to determine mode shape along with respective natural frequency.
4. To perform experimental study of spur Gear box by using FFT analyzer.
5. To validate FEA and experimental result.

Scope:

Vibrations measured in this paper are based on broken gear teeth. This vibration monitoring technique can be applied to detect Backlash, Scoring, and Pitting of the gear teeth. Vibration monitoring technique can be applied to any rotating machines.

Methodology:

In an experimental procedure gearbox is allowed to run at its rated power and speed. For vibration measurements magnetic base accelerometer is placed on the top just below the location of bearing in axial and radial direction of gearbox. By making all above arrangements readings are taken for healthy gear and good lubrication condition. This data is stored in FFT Analyzer for further analysis.

Vibration spectrums are taken for gears having various faults and the data is stored in computer for further Analysis. For different condition of faults & different load conditions data is collected.

Formation of Fault on Gear Tooth:

The one corner defect, two corner defect, one tooth missing, cracked tooth defects are the common faults in gears. The gear tooth fault is generated manually on gear tooth. 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 box.

II. LITERATURE REVIEW

Praveenkumar T, Sabhrish B, Saimurugan M, Ramachandran K I. Pattern Recognition based On-line Vibration Monitoring System for Fault Diagnosis of Automobile Gearbox. (2018), Gearbox is an important equipment in an automobile to transfer power from the engine to the wheels with various speed ratios. The maintenance of the gearbox is a top criterion as it is prone to a number of failures like tooth breakage, bearing cracks, etc. Techniques like vibration monitoring have been implemented for the fault diagnosis of the gearbox over the years. **But** the experiments are usually conducted in lab environment where the actual conditions are simulated using setup consisting of an electric motor, dynamometer, etc. This work reports the feasibility of performing vibrational monitoring in real world conditions**.**

Sanjib Chowdhury, Rama K. Yedavalli, Vibration of high-speed helical geared shaft systems mounted on rigid bearings. (2018), Analytical model for linear vibration analysis of a pair of meshing helical gears mounted on compliant spinning parallel shafts is developed. The gears are modeled as rigid disks while the shafts are modeled as flexible rotating cantilever beams. The rotational speed is high such that the gyroscopic effect is non-negligible. Hamilton's principle is used to obtain the non-dimensional governing equations. Longitudinal and rotational mesh stiffnesses and corresponding elastic energy are incorporated in the total strain energy formulation.

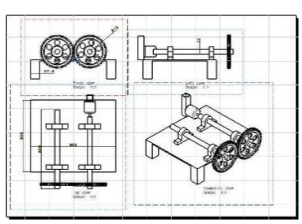
Chao Liu a, Zongde Fang a, Feng Wang, An improved model for dynamic analysis of a double-helical gear reduction unit by hybrid user-defined elements. (2018), Experimental and numerical validation. This paper introduces an improved model generated by hybrid user-defined element method (HUELM) for dynamic analysis of a double-helical gear reduction unit. Based on theories of structural dynamics and system dynamics, the model consists of four developed elements to respectively simulate the gear pair, bearings, flexible shafts and the housing.

Song Xue, Ian Howard, Torsional vibration signal analysis as a diagnostic tool for planetary gear fault detection. (2018), This paper aims to investigate the effectiveness of using the torsional vibration signal as a diagnostic tool for planetary gearbox faults detection. The traditional approach for condition monitoring of the planetary gear uses a stationary transducer mounted on the ring gear casing to measure all the vibration data when the planet gears pass by with the rotation of the carrier arm.

J. Parra, Cristián Molina Vicuña, two methods for modeling vibrations of planetary gearboxes including faults. (2017), Comparison and validation Planetary gearboxes are important components of many industrial applications. Vibration analysis can increase their lifetime and prevent expensive repair and safety concerns. However, an effective analysis is only possible if the vibration features of planetary gearboxes are properly understood. In this paper, models are used to study the frequency content of planetary gearbox vibrations under non-fault and different fault conditions.

III. COMPUTER AIDED DESIGN MODELLING AND ANALYSIS: COMPUTER-AIDED DESIGN (CAD)

CAD is also used for the accurate creation of photo simulations that are often required in the preparation of Environmental Impact Reports, in which computer-aided designs of intended buildings are superimposed into photographs of existing environments to represent what that locale will be like, where the proposed facilities are allowed to be built. Potential blockage of view corridors and shadow studies are also frequently analyzed through the use of CAD.



CATIA model of spur Gear box

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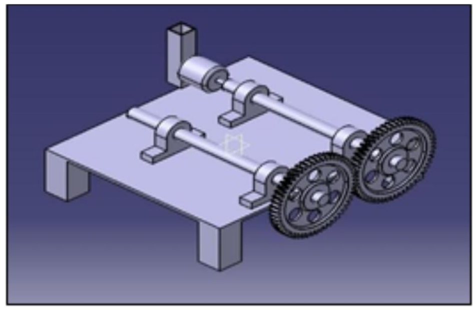

DRAFTING OF SPUR GEAR BOX

According to the 3D design, a prototype was made.

IV. ANALYSYS:

In present research for analysis ANSYS (Analysis System) software is used. Basically, its present FEM method to solve any problem. Following are steps in detail.

1. Geometry
2. Discretization (Meshing)
3. Boundary condition
4. Solve (Solution)
5. Interpretation of results

Workbench contain analysis of different types namely static, modal, harmonic, explicit dynamics, CFD, ACP tool post, CFX, topology optimization etc. as per problem defined.

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	⊞ Isotropic Secant Coefficient of Thermal Expansion		
6	⊟ Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

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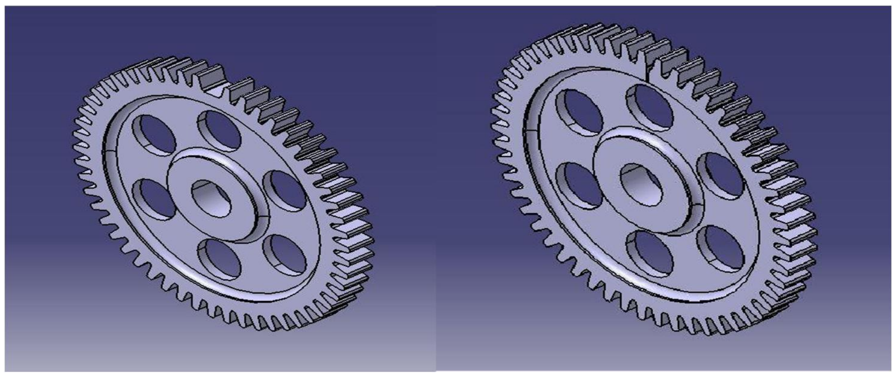
IBRATION ANALYSIS

In spur gear box there are 50 teeth taken length of assembly which is 300*350mm, Radius of gear are 10mm, length of shaft is 330 mm, diameter is 20mm, 1 tooth are missing which is seen, In motor specified 300rpm. We are taking This spur gear box dry condition are present.



A. MISSING TEETH　　B. CRACK OF SPUR GEAR

Geometry:

Figure shows Geometry of spur gear with no faults or healthy in ANSYS software there are 50 teeth

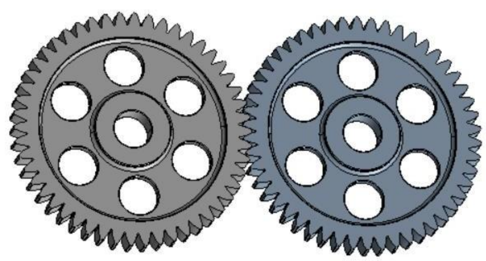


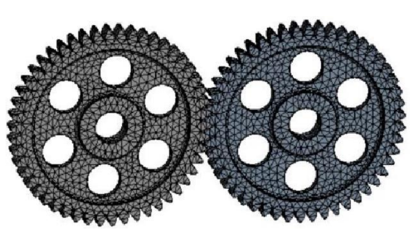
FIGURE 2: GEOMETRY WITH NORMAL OF SPUR GEAR

Contacts:

Figure 2 shows contacts of spur gear which is contact region b and c are showing.

MESH:

The next step is meshing of Gear box which contain Nodes and element shown



Statistics	
Nodes	70117
Elements	38951

FIGURE 3: MESHING OF SPUR GEAR BOX

Boundary Condition

For boundary condition gear are fixed on shaft and motion are given to the gear

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4.1 GEAR WITH NO FAULT

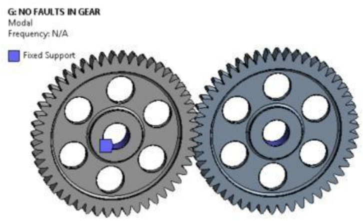

FIGURE 4.1.1: BOUNDARY CONDITION

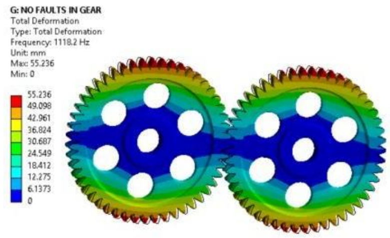

FIGURE 4.1.2: MODE SHAPE 1

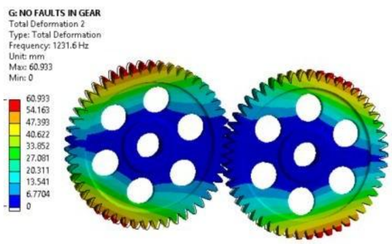

FIGURE 4.1.3: MODE SHAPE 2

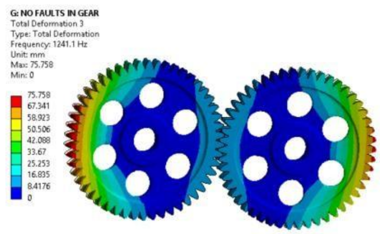

FIGURE 4.1.4: MODE SHAPE 3

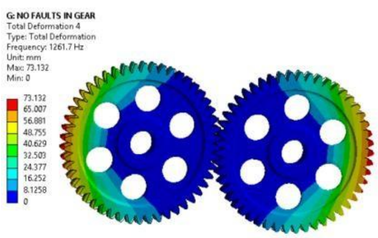

FIGURE 4.1.5: MODE SHAPE 4

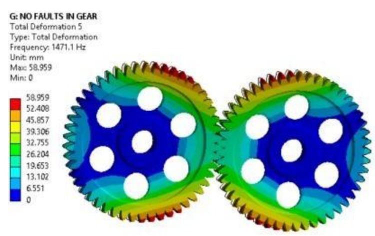

FIGURE 4.1.6: MODE SHAPE 5

Table: Tabular data of natural frequency

Tabular Data

	Mode	Frequency [Hz]
1	1.	1118.2
2	2.	1231.6
3	3.	1241.1
4	4.	1261.7
5	5.	1471.1

4.2 GEAR WITH CRACK

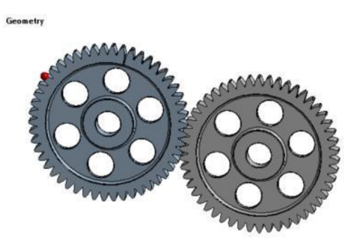

Figure 4.2.1: Boundary condition

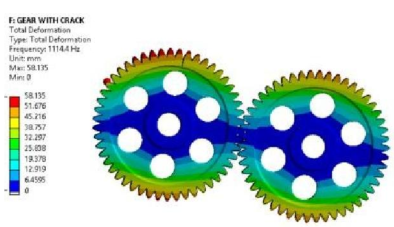

Figure 4.2.2: Mode shape 1

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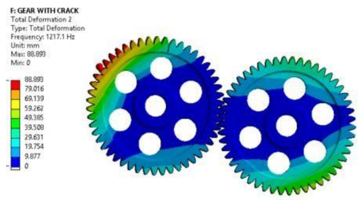

Figure 4.2.3: Mode shape 2

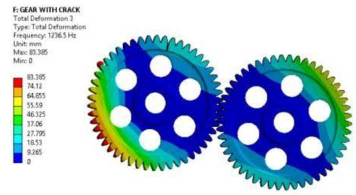

Figure 4.2.4: Mode shape 3

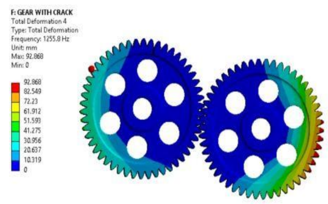

Figure 4.2.5: Mode shape 4

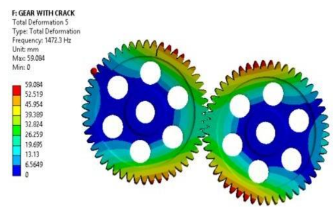

Figure 4.2.6: Mode shape 5

Table: Tabular data of natural frequency

Tabular Data		
	Mode	Frequency [Hz]
1	1.	1114.4
2	2.	1217.1
3	3.	1236.5
4	4.	1255.8
5	5.	1472.3

4.3 GEAR WITH MISSING TEETH

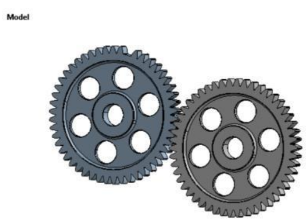

Figure 4.3.1: Boundary condition

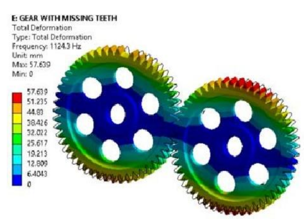

Figure 4.3.2: Mode shape 1

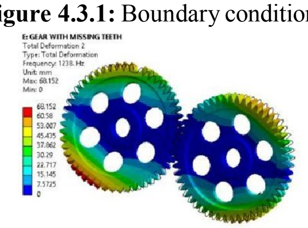

Figure 4.3.3: Mode shape 2

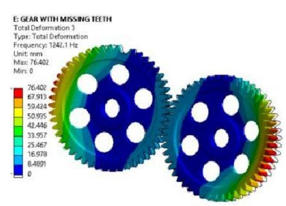

Figure 4.3.4: Mode shape 3

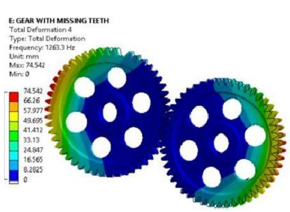

Figure 4.3.5: Mode shape 4

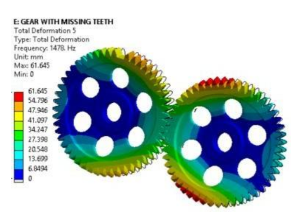

Figure 4.3.6: Mode shape 5

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Table: Tabular data of natural frequency

Tabular Data

	Mode	Frequency [Hz]
1	1.	1124.3
2	2.	1238.
3	3.	1242.1
4	4.	1263.3
5	5.	1478.

V. EXPERIMENTAL TESTING

Fast Fourier Transform

The experimental validation is done by using FFT (Fast Fourier Transform) analyzer. The FFT spectrum analyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays the spectrum of these measured frequency components. The advantage of this technique is its speed. Because FFT spectrum analyzers measure all frequency components at the same time, the technique offers the possibility of being hundreds of times faster than traditional analog spectrum analyzers.

Impact Hammer Test

Impact excitation is one of the most common methods used for experimental modal testing. Hammer impacts produce a broad banded excitation signal ideal for modal testing with a minimal amount of equipment and set up. The characteristics of the impact testing procedure are examined with analytical time and spectral functions developed for an idealized test: a single degree of-freedom system excited by a half sine impact force. Once an understanding of the fundamental characteristics is developed it is applied to examine the specific situations encountered in structural impact testing. The relationship of the system's parameters with respect to data capture requirements is evaluated. The effects of exponential windowing are developed to examine the effects on the estimated spectra and modal parameters. Finally, the "double hit" phenomenon is examined by combining the results from the single degree-of-freedom system excited by two impulses, one of which is time delayed. The results from these related studies are combined to provide insight into data acquisition guidelines for structural impact testing.

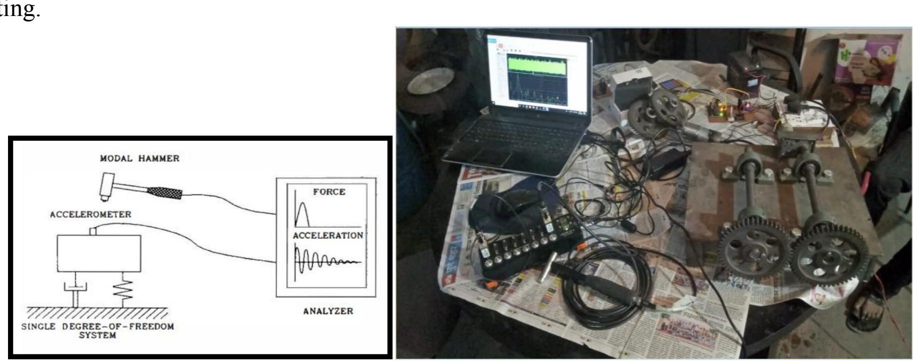

Figure: FFT construction FFT analysis Setup for gearbox

VI. EXPERMENTAL PROCEDURE

- Initially fixture is designed according to existing boundary condition as per FEA results.
- FFT consists of impact hammer, accelerometer, data acquisition system in which each supply is applied to DAS and laptop with DEWSOFT software to view FFT plot.
- Accelerometer is mounted at surface as per high deformation observed in FEA results along with initial impact of hammer is placed for certain excitation to determine frequency of respective mode shapes.
- After impact FFT plot are observed on laptop and comparison of FEA and experimental results are analysed.

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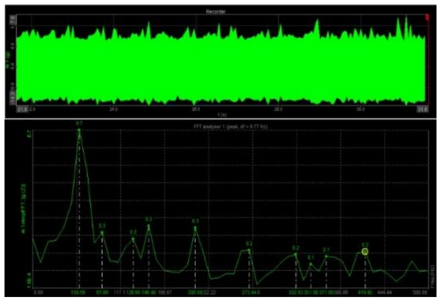

Figure 6.1: FFT plot of original gear with no faults

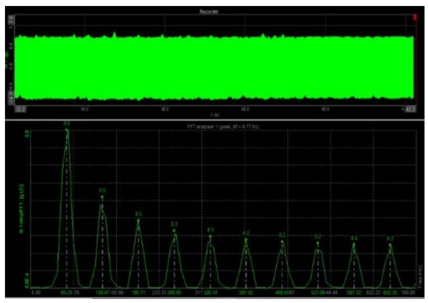

Figure 6.2: FFT plot of original gear with crack

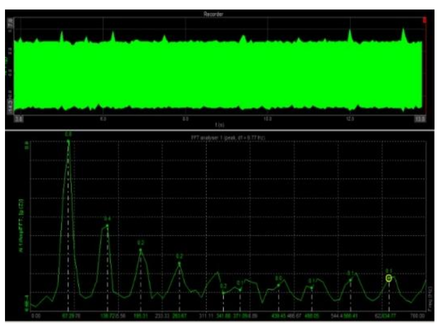

Figure 6.3: FFT plot of original gear with missing teeth

Table: Tabular data of natural frequency in running condition

FFT Reading	No faults	Gear with crack	Gear with missing teeth
1	58.59	65.25	67.29
2	87.89	130.47	136.72
3	126.95	195.71	195.31
4	146.48	260.95	263.67
5	205.08	326.11	341.80
6	273.44	391.42	371.09
7	332.03	456.65	439.45
8	351.09	521.89	498.05
9	371.09	557.12	566.41
10	419.91	652.35	634.77

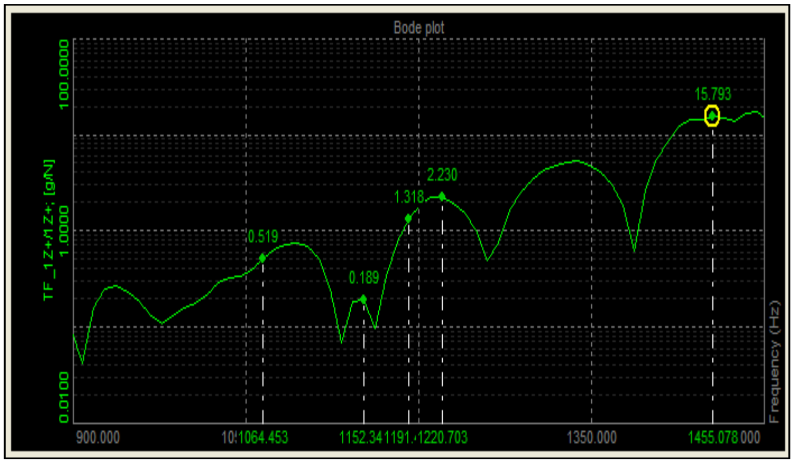

Figure 6.4: FFT plot of experimental setup gear pairs

Table: Comparison of FEA and FFT results

MODE SHAPE	NO FAULTS	GEAR WITH CRACK	GEAR WITH MISSING TEETH	EXPERIMENTAL
1	1118.2	1114.4	1124.3	1064.45
2	1231.6	1217.1	1238	1152.34
3	1241.1	1236.5	1242.1	1191
4	1261.7	1255.8	1263.3	1220.7
5	1471.1	1472.3	1478	1455.07

VII. CONCLUSION

- In present research modal analysis have been performed to determine natural frequency with respective mode shape for gear with no faults, gear with crack and gear with missing teeth.
- Experimental testing using FFT is used to determine natural frequency in steady and running condition.
- FEA result is in good relationship with testing result in terms of Natural Frequency.
- The monitoring of health of gearbox is easy due to variations in natural frequencies at mid and higher frequencies.

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