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Modal Analysis of Intermediate Shaft Used in Automobile Gear Box

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***Abstract*— The paper presents the experimental and FE modal analysis of intermediate shaft used in automobile gear box. For the experimentation FFT analyzer is used to calculate the natural frequencies. The three-dimensional finite element model is constructed in PRO-E. The model is meshed in ANSYS workbench. During analysis the three fundamental bending modes are extracted. The results show that the intermediate shaft is not running in critical speed. The finite element model agrees well with the FFT results and can serve as a baseline model of the intermediate shaft.**

***Keywords: - Finite Element Analysis, FFT analyzer*.**

INTRODUCTION

Intermediate shaft is the most important part in gear box of automobile .on intermediate shaft different gears are mounted to transmit power from input shaft to output shaft with different speed ratio. With refer to the researcher every material system containing individual mass and stiffness distribution is susceptible to vibrate. Free vibration analysis is essential to determine the natural frequencies of material system. These are responsible for resonance phenomenon. When the load frequency is matched with one of the natural frequencies the resonance occurs. It leads to high amplitude of vibration.

Bending vibrations and critical speeds of rotating shafts is perhaps the most common problem that is discussed by a vibration engineer, as it is a vexing day-to-day problem in design and maintenance of the machinery. Some of the rotors weigh as much as 100 tons as in the case of big steam turbines and obviously they deserve utmost attention in this regard. The rotors have always some amount of residual unbalance however well they are balanced, and will get into resonance when they rotate at speeds equal to bending natural frequency. These speeds are called as critical speeds by Rankin as far as possible they should be avoided. Even while taking the rotor through a critical speed to an operational speed, special precaution should be taken. In Fault detection of bearing detection of misalignment and condition monitoring of bearing or gearing system is necessary because the system has to rotate at different speeds. If specific r.p.m. matches with critical speed which is nearer to first bending natural frequency of shaft will generate excessive vibrations due to resonance.

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The experimental modal analysis by impact testing method was explained by C. Azoury in his paper [1].
the analytical and FE modal analysis of a crankshaft was explained by Prof. Dr. S. B. Wadkar in his paper [2].

INTERMEDIATE SHAFT DETAILS

The intermediate shaft of indica car is selected as case study. Fig 1 shows the model of intermediate shaft.

Fig.1 Model of intermediate shaft

The table 1 shows the details of intermediate shaft.

Table 1 intermediate shaft details

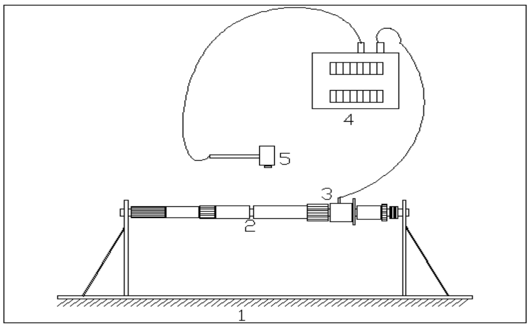
Overall length of shaft	417 mm
Maximum operating speed	5000 rpm
Maximum forcing frequency	83.34 Hz

Experimental Modal Analysis

Experimental modal analysis of a system, deals with determination of natural frequencies, damping ratios, and mode shapes through the vibration testing. In the case of forced vibration, the analysis includes the study of acceleration, velocity and displacement responses of the systems. The basic ideas involve in model analysis are then structure or machine or any system is excited its response exhibits a sharp peak at resonance when the forcing frequency is equal to its natural frequency, if the damping is not present large. The phase of the response changes by 180^0 as the forcing frequency crosses the natural frequency of the structure or machine and the phase will be 90^0 at response.

Experimental Setup

Fig .2 shows the experimental setup for modal analysis.



1- Fixed frame
2- Intermediate shaft
3- Accelerometer
4- Exciter
5- Impact hammer

Fig.2 Experimental Setup

Following are the instruments used for the modal analysis

- FFT Analyzer
- Accelerometer
- Exciter
- Impact hammer

Procedure of Experimentation

1) Connect the accelerometer and Impact hammer to appropriate channels of FFT to cables.
2) Prepare set-up for Modal analysis and In-pulse software.
3) Mount accelerometer on shaft with the help of magnetic base.
4) Excite shaft by giving In-pulse by Impact hammer.
5) Record the response received from accelerometer in frequency domain and time domain.
6) Identify the natural frequencies and corresponding phase in FFT software and record it.
7) Repeat the procedure for different positions of accelerometer to record all vibration modes of shaft.

Experimental Results

The FFT gives result in the form of FRF graph and curser values of frequencies for corresponding mode shape.
The results from FFT are tabulated in the table 2.

Table 2 FFT results

modes	Frequency in Hz
1	709.87
2	2087.04

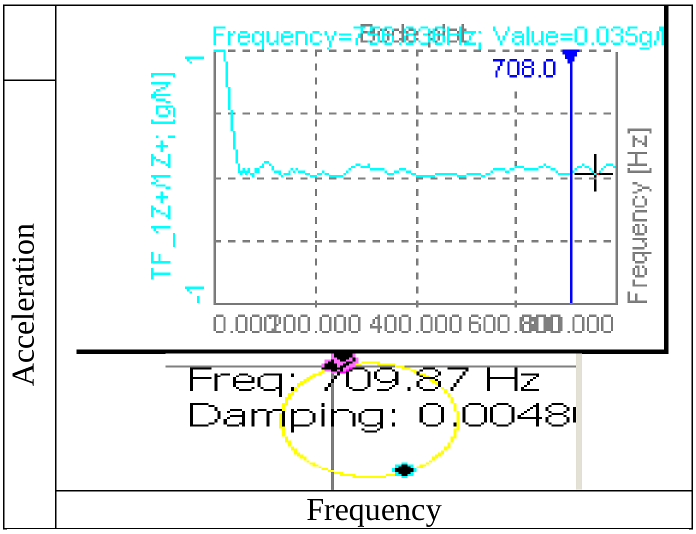


Fig.3 Frequency Response Function (FRF) for first mode

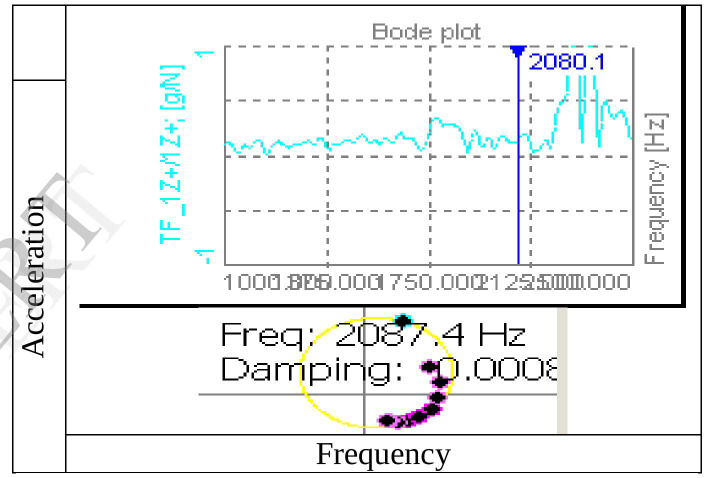


Fig.4 Frequency Response Function (FRF) for second mode

Finite Element Analysis

In this section we discuss the modeling of intermediate shaft, and finite element analysis of intermediate shaft using FEA. Finite Element method (FEM) simulates a physical parts behavior by dividing the geometry into a number of elements of standard shapes, applying constraints. Uses of proper boundary conditions are very important since they strongly affect the results of the finite element analysis. The intermediate shaft is modeled in Pro-E. The step file of model is imported in ANSYS workbench. The main objective of this work is to perform the Finite Element Analysis of intermediate shaft using CAE Tools, so as to determine the natural frequency in the shaft. The material properties are demanded in CAE to perform analysis. The material used for intermediate shaft is steel En19. and material properties are shown in the table 3.

IJERT

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Table 3 Material properties

Density	7800 kg/mm^3
Poisson Ratio	.3
Young's modulus	210000 Mpa

FINITE ELEMENT MODELLING

Definition of FEM is hidden in the world itself. Finite - any continuous object has finite degree of freedom & it's just not possible to solve in this format. Finite Element Method reduces degree of freedom from infinite to finite with the help of discretization. Element - all the calculations are made at limited number of points known as nodes. Entity joining nodes and forming a specific shape such as quadrilateral or triangular etc. is known as Element. To get value of variable at where between the calculation points, interpolation function is used. Method – There are three methods to solve any engineering problem. Finite Element Analysis belongs to numerical method category. Finite element modelling of any solid component consists of geometry generation, applying material properties, meshing the component, defining the boundary constraints, and applying the proper load type.

Geometry of intermediate shaft

the dimensions of intermediate shaft are obtained from selected model of intermediate shaft as case study. By using accurate dimensions the solid model of intermediate shaft is generated by using Pro-E software. The solid model generated of the intermediate shaft is shown in Figure 5.

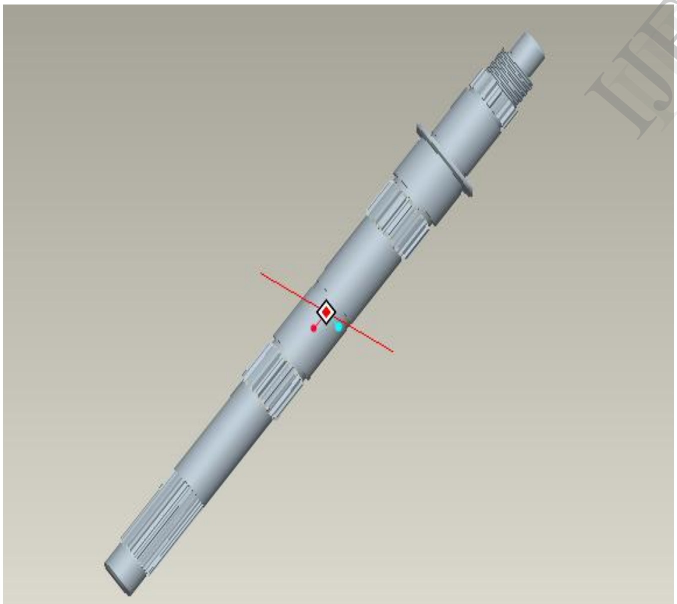

Fig.5 Geometry of intermediate shaft

Mesh Generation

The geometry is meshed in mechanical model window of an ANSYS 14. The hex dominant method is applied for the geometry. This method is used for applying maximum hexahedron elements to complicated geometry. The body sizing is applied for the whole geometry and element size is given as 5 mm. The FE model of the intermediate shaft geometry is meshed with hexahedral elements, with the global element length of 5 mm and local element length of 0.342 mm. The meshed intermediate shaft is shown in Figure 6.

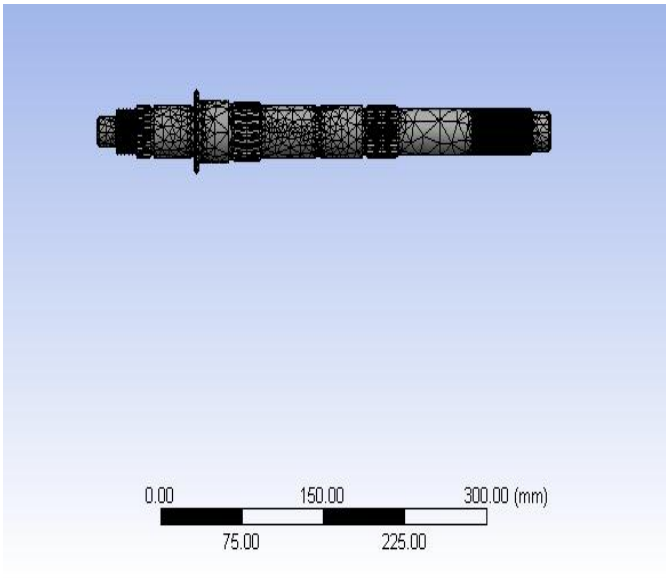

Fig. 6 Meshed Geometry

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FEA SOLUTION

In the analysis of intermediate shaft three modes are extracted. The results are tabulated in the table 4. The following figure 7 to 9 shows the three modes of intermediate shaft.

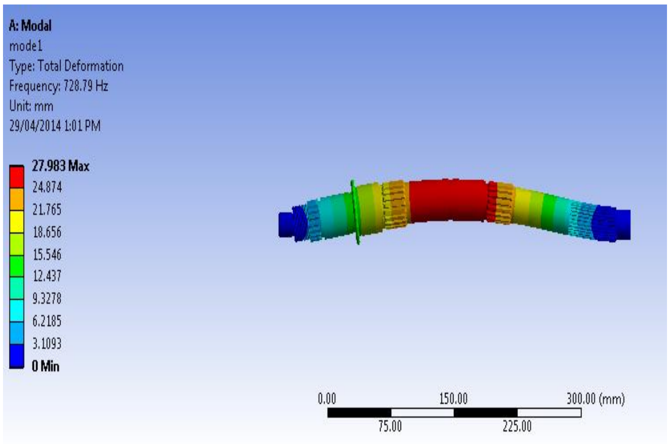

Fig. 7 First vibration mode of intermediate shaft

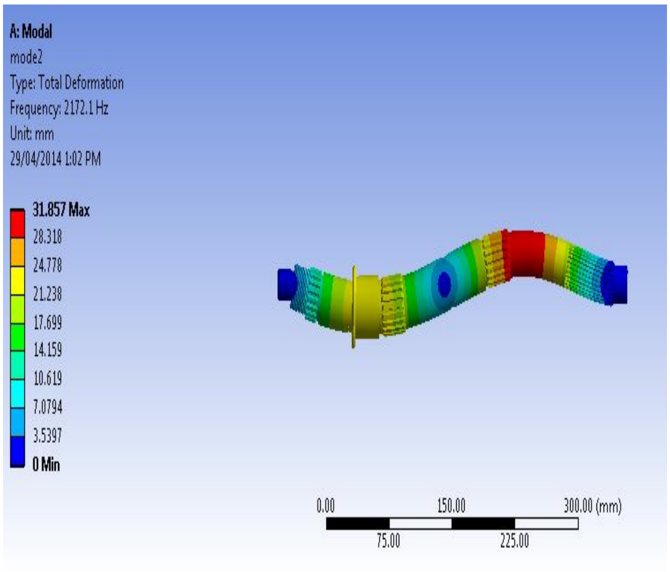

Fig. 8 second vibration mode of intermediate shaft

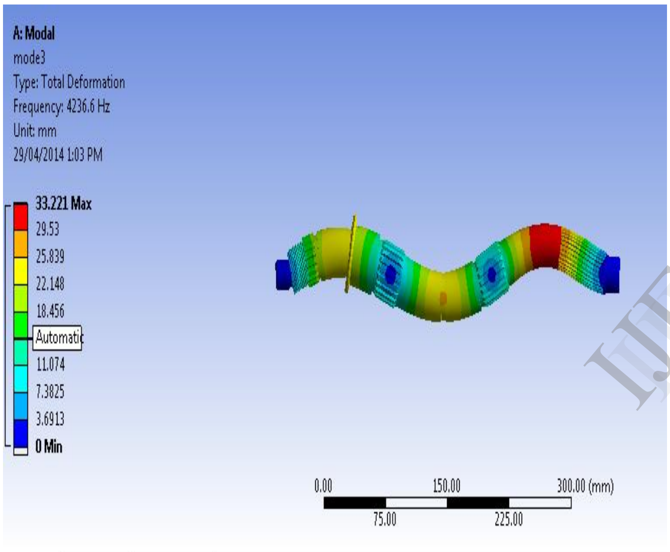

Fig. 9 third vibration mode of intermediate shaft

Table 4 FEA Results

Mode	Frequency in Hz
1	728.79
2	2172.1
3	4236.6

COMPARISON BETWEEN EXPERIMENTAL AND SOFTWARE RESULTS AND DISCUSSION

Table 5 Comparison between Experimental and Software Results

Natural Frequency Hz	Experimental (FFT)	FEM	% Difference
f_1	709.87	728.79	2.6
f_2	2087.04	2172.1	3.91

Above Table 6.3 shows Comparison between Experimental and (FEM) Software Results.
Also fig.10 shows the graph of comparison between FEM or Software Result and Experimental results.

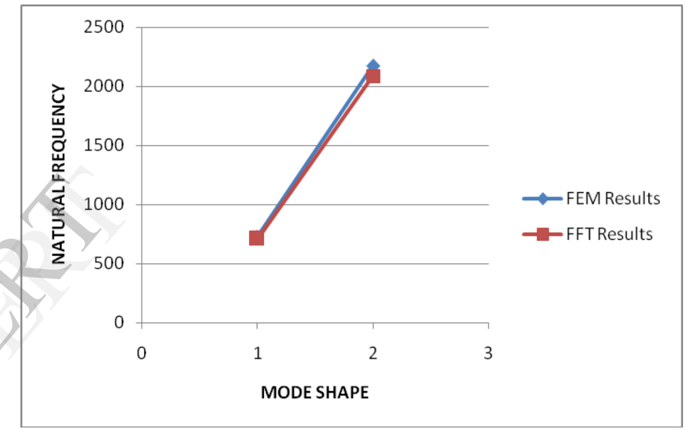

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Fig.10 comparison between FEM or Software Result and Experimental results

The difference between first frequency by FEM and by FFT is about 2.6%.
Intermediate shaft can be vibrated at various orientations. The first mode of vibration is the important mode.
If forcing frequency of any harmonic component is close to the natural frequency of first mode of vibration, resonance occurred. At this condition the component is said to be running at critical speed.

CONCLUSION

In this paper the Experimental and FEM methods for calculation of natural frequencies of intermediate shaft is described. From the experimentation first natural frequency Is determined. This frequency is lowest natural frequency of intermediate shaft.
The intermediate shaft is modelled in PRO-E and analysed in ANSYS for its natural frequency. three modes are extracted during modal analysis. The difference between first frequency by FFT and by ANSYS is about 2.6%.
Forcing frequency of intermediate shaft is 83.34 Hz is very less than natural frequency of intermediate shaft. So, condition of resonance is avoided and intermediate shaft is not running in critical speed.

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