Vibration Analysis of a Rotary System using Viscoelastic Pads

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Abstract - *Viscoelastic materials are utilized to a great extent as a way to give damping to structures, along these lines mitigating thunderous vibration reactions. Vibration causes extensively fast wear of machine parts which results in functional failure of machines along this it reduces the life of machines. Undesirable vibrations may cause slackening of parts from the machine. Inappropriate structure or material dissemination, the wheels of train can leave the track because of inordinate vibration which brings about mishap or overwhelming misfortune. Once in a while due to substantial vibrations appropriate readings of instrument can't be taken. Vibration is seen as productive in mechanical workshops, for example, improving the proficiency of machining, throwing, fashioning and welding strategies. The exchange of noise can likewise be decreased by decoupling the parts so that the commotion way is intruded. This can be accomplished by adding commotion decreasing medications to the structure, for example, versatile components, masses, neighbourhood protecting or damping layers. In the current examination, the utilization of viscoelastic damping layers as a noise and vibration lessening measure in pivoting apparatus is thought of. Here, exploratory arrangement is to be made and engine is to be joined to change speed and quickening are estimated by FFT analyser procedure.*

Keywords: Modal Analysis, FFT, Viscoelastic Material

1. INTRODUCTION

Viscoelasticity is the property of materials that exhibit both viscous and elastic properties along with versatile attributes while experiencing disfigurement. Thick materials, similar to water, oppose shear stream and strain straightly with time when a pressure is applied. Flexible materials strain when extended and quickly come back to their unique state once the pressure is expelled. Viscoelastic materials have components of both of these properties and, in that capacity, display time-subordinate strain. In contrast to simply versatile substances, a viscoelastic substance has a flexible segment and a viscous part. Absolutely flexible materials don't scatter vitality (heat) when a heat is applied. In any case, a viscoelastic substance scatters vitality when a heat is applied, at that point evacuated. Hysteresis is seen in the pressure strain bend, with the region of the circle being equivalent to the vitality lost during the stacking cycle. Modal examination is the investigation of the dynamic properties of frameworks in the frequency area. Models would incorporate estimating the vibration of a vehicle's body when it is connected to a shaker, or noise design in a room when energized by an amplifier. Cutting edge trial modular examination frameworks are made out of sensors, for example, transducers (regularly accelerometers, load cells), or non-contact by means of a Laser vibrometer, or sound system photogrammetric cameras information procurement framework and a simple to-advanced converter front end (to digitize simple instrumentation signs) and have (PC) to see the information and dissect it. Traditionally this was finished with a SIMO (single-input, different yield) approach, that is, one excitation point, and afterward the reaction is estimated at numerous different focuses. In the previous a sledge study, utilizing a fixed accelerometer and a wandering mallet as excitation, gave a MISO (different information, single-yield) investigation, which is numerically indistinguishable from SIMO, because of the standard of correspondence Harmonic examination is a part of arithmetic worried about the portrayal of capacities or signals as the superposition of essential waves, and the investigation of the speculation of many ideas of Fourier arrangement and Fourier changes (for example an all-inclusive type of Fourier examination).

2. LITERATURE REVIEW

Daiki Yano et al. [1] in this paper it presents the vibration of pipes and tube-shaped shells prompting noise and harm is a significant designing issue in plant frameworks and forced air systems, among others. To weaken such vibration, a viscoelastic material is connected to pipes as a damping material. To conquer this issue, this investigation proposes added mass and added damping to address the impacts of vibration of the damping material on the vibration of a channel. To survey the legitimacy of the proposed strategy, numerical outcomes for the vibration of a funnel fitted with silicone got utilizing the proposed technique are contrasted and estimations from a pounding test and numerical outcomes from three-dimensional examination. Funneling frameworks and cylindrical shaped shells are energized by pressure throbs in the liquid inside them and by mechanical burdens. Tso dissect the issue of the twisting vibration of a cylindrical shaped channel with a circle of viscoelastic material appended at one point along its length, we propose an additional mass and an additional damping model. The upside of the proposed strategy is that one-dimensional FEM of the round and hollow channel can be utilized rather than three-dimensional FEM of the tube-shaped funnel and the circle of viscoelastic material, in this manner lessening the calculation time drastically.

Xuyuan Song, et al. [2] In this article it presents an improved bound together methodology of Rayleigh-Ritz strategy to examine the vibration and damping conduct of slim short cylindrical shaped shell with viscoelastic damping materials treatment under self-assertive versatile edges. The detailing of the CLD shell with conventional limit bolsters is determined by the Rayleigh-Ritz technique being bound together with growing a genuine of symmetrical polynomials as the permissible relocation capacities. The accentuation of the current examination of spot on the vibration of the round and hollow shell treated with flexible damping material under versatile limits bolsters as indicated by the Rayleigh-Ritz approach by bringing in a genuine of flexible limit springs and trademark symmetrical polynomials. In view of the technique improved in present writing, a few numerical examinations have been done and some huge and fascinating vibration qualities of the compel layer damping cylindrical shaped shell with subjective limit bolsters have been acquired.

X.Q. Zhou et al. [3] In this paper it presents certain parameters like thickness, damping proportion (the parameters of the VDM), and the cross section consistent of the structure, which sway the frequency attributes of occasionally hardened slight plate, are completely broke down. The SSEM created in this examination guaranteed the exactness and rearranged estimation work. It very well may be utilized in planning aperiodic or semi intermittent slight plate and shell structures for improving the mechanical property. It additionally finished up the flexural vibration qualities of the occasionally solidified plate loaded up with VDM. SE dependent on SEM innovation gave for this exploration. The arrangement technique is disentangled by applying Floquet –Bloch's hypothesis.

Gian Luca Ghiringhelli et al. [4], in this paper it presents damping evaluation of exceptionally dissipative materials is a difficult errand that has been tended to by a few scientists specifically. In this examination it likewise presents a blended prescient/exploratory philosophy is created to decide the frequency conduct of the perplexing modulus of such materials. The misfortune factor of sandwich examples, made out of two aluminum layers isolated by the damping material, is controlled by exploratory modular ID. In this examination, notable strategies, for the standard test modular investigation and relationship of limited component models with test information, joined with the Modal Strain Energy technique have been utilized to recognize the frequency subordinate properties of a viscoelastic material. The methodology, which varies from the ASTM rules, was considered with the point of recognizing the shear modulus and damping misfortune factor inside a medium–high frequency scope of 100–2500 Hz appropriate for vibro-acoustic investigations. Two examples, with a solitary viscoelastic layer compelled between two metallic sheets, were utilized. The examples were fabricated with various thicknesses to accomplish diverse twisting solidness, in this way considering a superior fitting of the frequency area.

Wenguang Nan et. al [5] in this paper it proposes a request to evaluate the material damping of distorted adaptable fibres, a straight viscoelastic circle chain model dependent on the discrete component technique is introduced. As to the damping conduct of distorted adaptable filaments, the outcomes propose that the damping coefficient of an individual fiber primarily relies upon the angle proportion of the fiber and the gooey bond damping coefficient. For the most part, to upgrade the worldwide damping of fibres with incredibly huge perspective proportion, the bond moving erosion torque is more viable than the thick bond damping. In any case, its exactness drops drastically with the decline of the viewpoint proportion, and it is suggested for the adaptable fiber with perspective proportion bigger than 6. The impact of the outside power and shear modulus on the fiber damping could be unimportant. Furthermore, the damping coefficient of the entire fiber is direct with the thick bond damping coefficient while demonstrating an exponential abatement with the perspective proportion. The moving rubbing damping is more powerful than the thick bond damping for fibres with huge angle proportion.

3. PROBLEM STATEMENT

In case of any machinery setup there are a large no of parts vibrating with different frequencies and acceleration. If these parts vibrating with the frequency coincides with their natural frequency there is a chance of mechanical failure due to the resonance and also, they can damage the foundation. Also, when the frequency of excitation increases acceleration also increases. So, there is a need to reduce the acceleration. Thus, there is a need to reduce the acceleration of vibration is so that wear and tear can reduce, indirectly we can increase the damping capacity and life of the system.

4. OBJECTIVES

- To study the viscoelastic materials and its application to increase the damping.
- Modelling the system with the help of CATIA V5 R20 software.
- Analyse the natural frequency of the bearing system.
- To perform the harmonic and modal analysis of the bearing system with and without the viscoelastic material and analyse the results accordingly.
- To perform the vibration test for bearing system by using the FFT analyser and impact hammer.
- Manufacturing of whole system having with setup required for testing.

- Experimental testing and correlating results.

5. METHODOLOGY

Step 1:- Initially research paper are studied to find out research gap for project then necessary parameters are studied in detail. After going through these papers, we learnt about viscoelastic material properties on vibration analysis.

Step 2:- Research gap is studied to understand new objectives for project.

Step 3: - After deciding the components, the 3 D Model and drafting will be done with the help of software.

Step 4: - The experimental setup will be manufactured and then assembled together for testing.

Step 5: -The testing will be carried out and then the result and conclusion will be drawn.

6. Design of rotary system:

6.1 CATIA MODEL

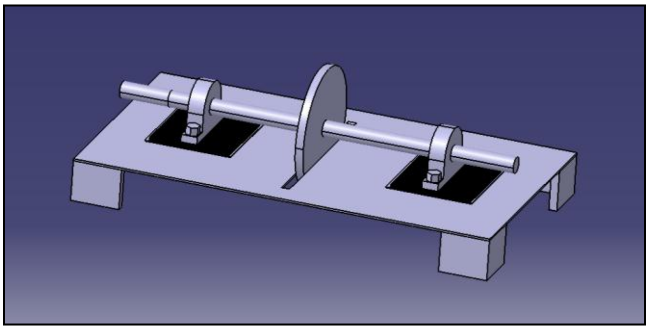


Fig. 1 CAD model of Rotary system in CATIA Software

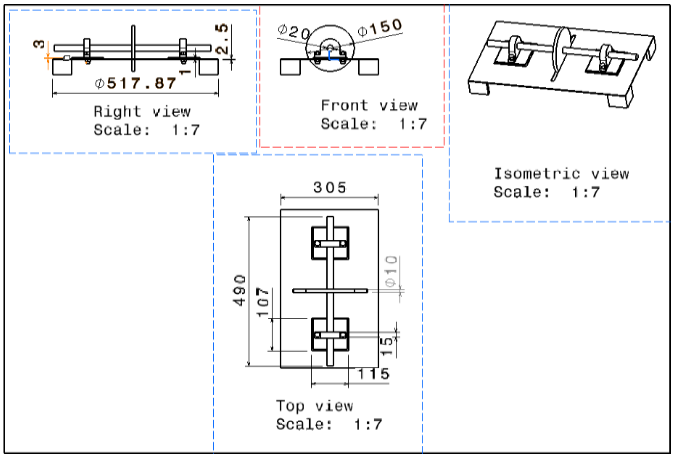
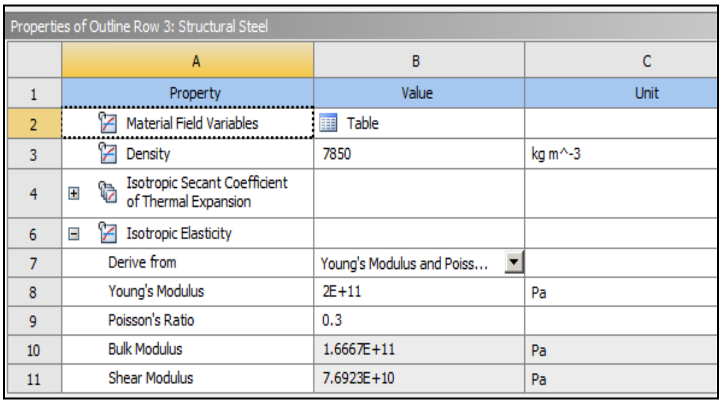


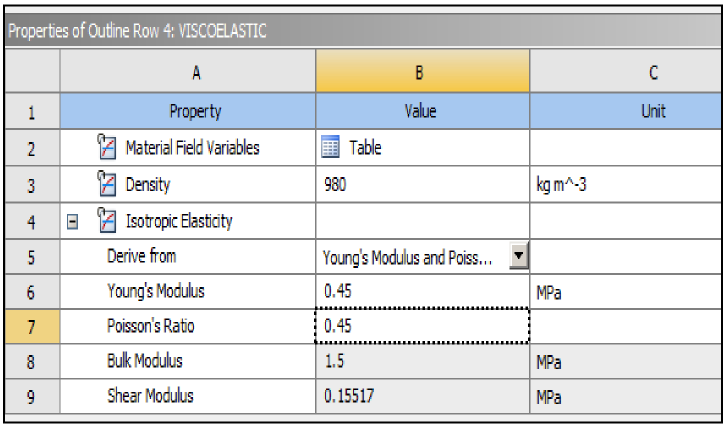
Fig. 2 Drafting of rotary system



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 Modulus and Poiss...	
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

Table 1: Material properties of Steel



Properties of Outline Row 4: VISCOELASTIC

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	980	kg m^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulus and Poiss...	
6	Young's Modulus	0.45	MPa
7	Poisson's Ratio	0.45	
8	Bulk Modulus	1.5	MPa
9	Shear Modulus	0.15517	MPa

Table 2. Material properties of viscoelastic material

6.2 Finite Element Analysis:

The finite element analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics. Problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport & electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. Finite element method formulation of the problem results in a system of algebraic equations. The method yields approximate values of the unknowns at discrete number of points over the domain. To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements. These algebraic equation sets are the element equations. They are linear if the underlying PDE is linear, and vice versa. Algebraic equation sets that arise in the steady state problems are solved using numerical linear algebra methods, while ordinary differential equation sets that arise in the transient problems are solved by numerical integration using standard techniques such as Euler's method.

In order to execute the modal analysis, CAD modelling of rotary system is designed in CATIA software.

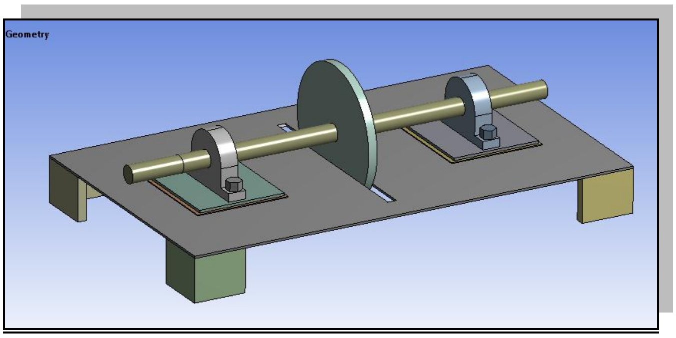


Fig. 3 CATIA Model of rotary system without viscoelastic material imported in ANSYS workbench

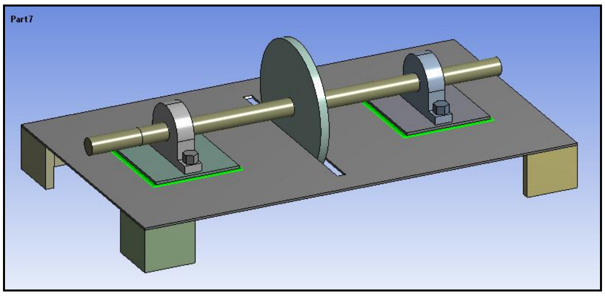


Fig. 4 CATIA model of Rotary system with viscoelastic material imported in ANSYS Workbench

6.3 MESH

In ANSYS meshing is performed as similar to discretization process in FEA procedure in which it breaks whole components in small elements and nodes. So, in analysis boundary condition equation are solved at this elements and nodes. ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Multiphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model.

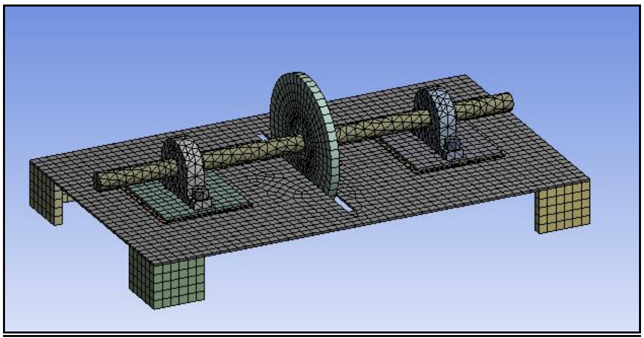


Fig 5. Meshed model of rotary system

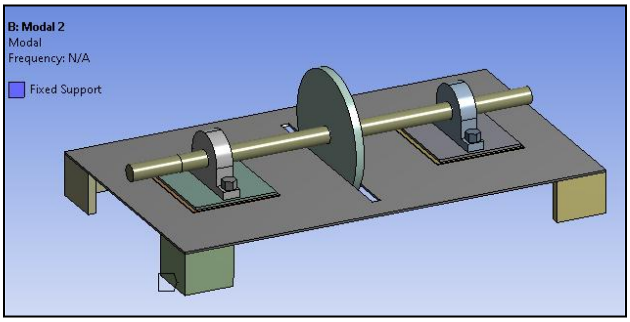


Fig. 6 Boundary conditions for modal analysis

To determine natural frequencies of rotary system along with different mode shapes, fixed support is applied at base of each corner of bracket.

After performing modal analysis of rotary system following mode shapes are obtained at different frequencies.

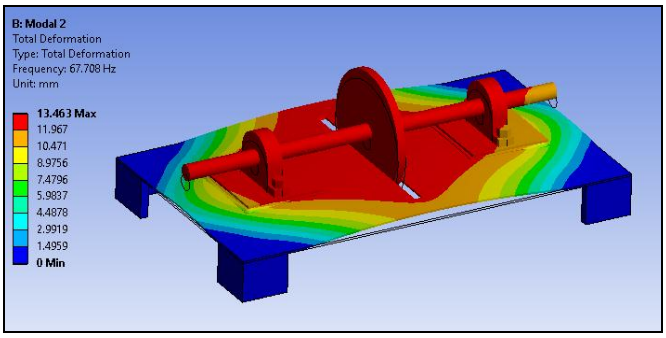


Fig.7 Modes shape 1

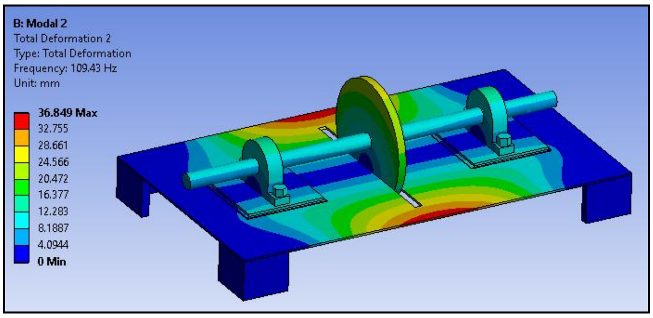


Fig. 8 Mode shape 2

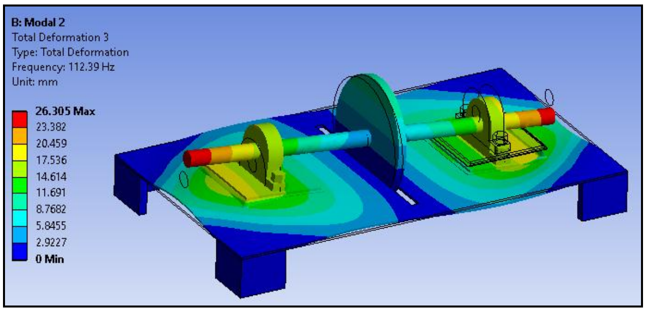


Fig. 9 Mode shape 3

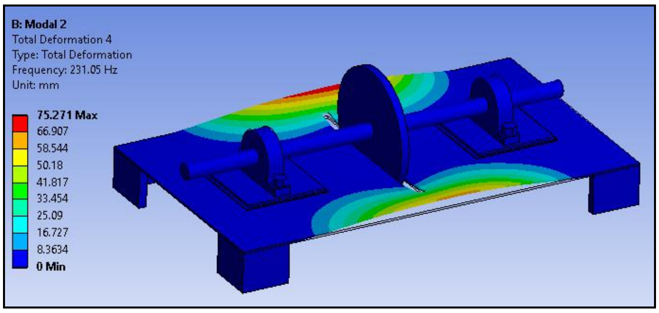


Fig.10 Mode shape 4

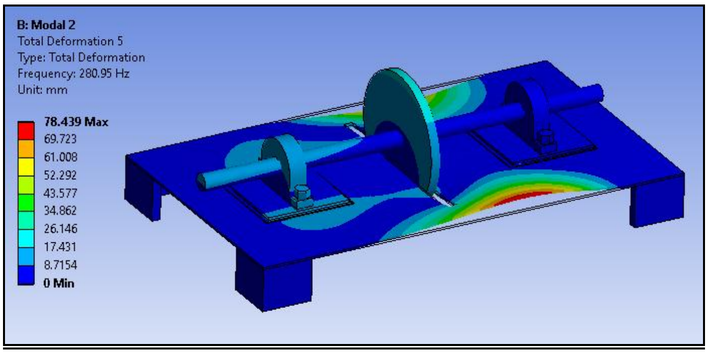


Fig. 11 Modes shape 5

From modal analysis of the rotary system with a viscoelastic material 5 modes are observed and frequency of these 5 modes are 67.708 Hz, 109.43 Hz, 112.39Hz, 231.05 Hz and 280.95 Hz. For these respective modes shapes maximum total deformations are 11.463 mm, 36.849 mm, 26.305 mm, 75.271 mm and 78.439 mm.

HARMONIC ANALYSIS

Harmonic analysis is a technique used to determine steady state response of linear structures subjected to loads that vary sinusoidally (harmonically) with respect to time. Any sustained cyclic load will produce cyclic response (harmonic response) in the structure. Harmonic response analysis provides the ability to predict the dynamic response of structures. From this response it can be determined that will structure overcome the resonance, fatigue and other harmful effects of forced vibration.

In this analysis prime importance is given to finding out the response of structure for different frequencies and a graph is plotted displacement vs frequencies. From graphical representation peak values of displacements are identified and stresses at that reference frequency is studied.

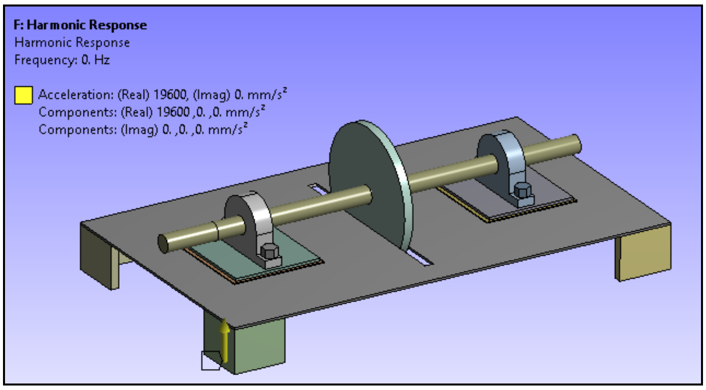


Fig. 12 boundary condition for harmonic analysis

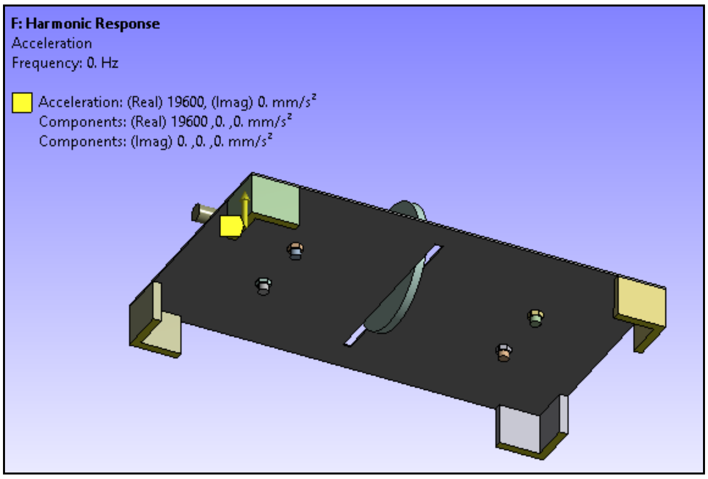


Fig. 13 Boundary condition for harmonic analysis

In harmonic analysis base excitation of 2G is provided at base fixed support to determine acceleration at required surface.

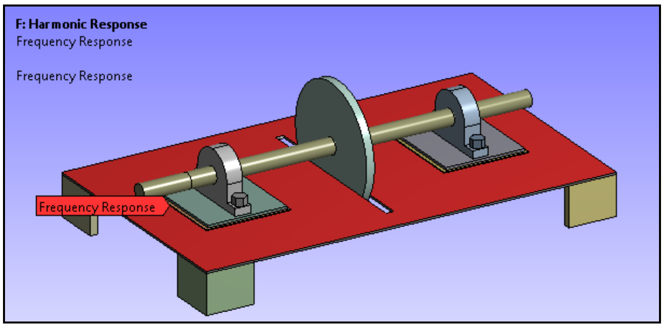


Fig. 14 Frequency response surface

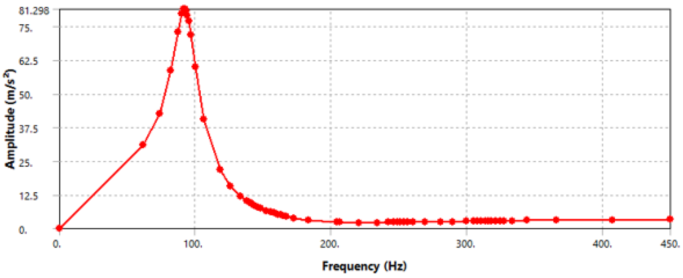


Fig. 15 Frequency response for rotary system without viscoelastic material

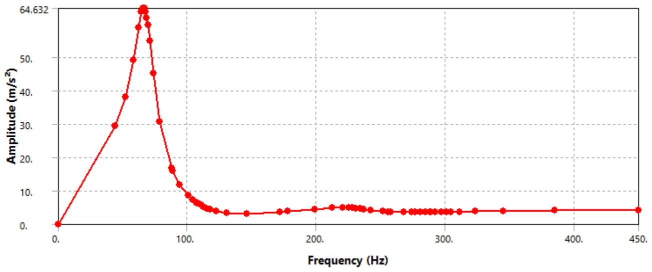


Fig. 16 Frequency response for rotary system with viscoelastic material

In present analysis, natural frequencies of single rotor are calculated in order to investigate the behavior of the rotor which is subjected to external forced vibrations. To investigate the dynamic response of single rotor, CAD model of single rotor is done in ANSYS software. Now fixed support is applied at two end surface this the required boundary condition for analysis. Modal analysis of a single rotor is to be performed and different natural frequencies are identified, these frequencies are validated with FFT analyzer in the subsequent section.

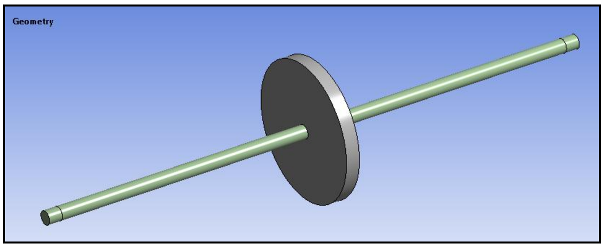


Fig. 17 Single rotor imported in ANSYS

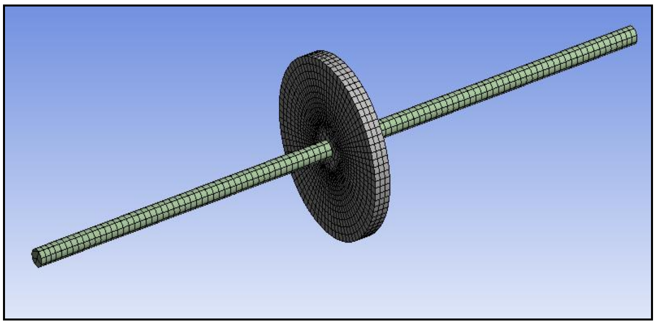
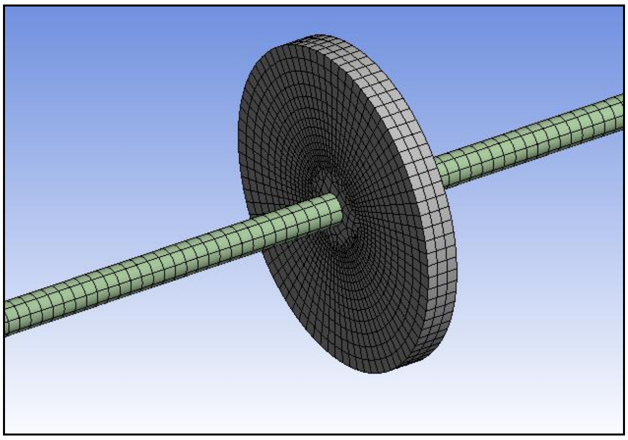
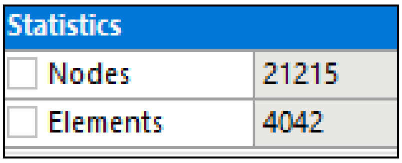


Fig 18. Meshed model of single rotor





Statistics	
☐ Nodes	21215
☐ Elements	4042

Fig. 19 Details of meshing for single rotor

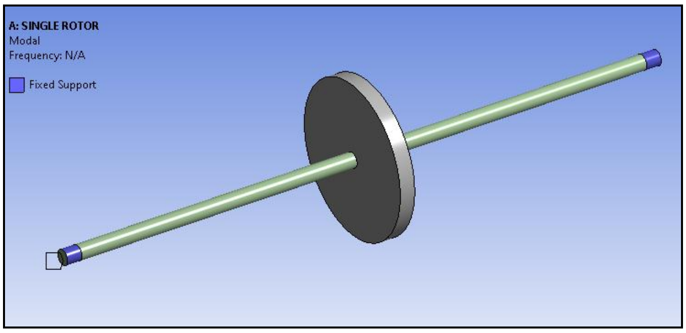


Fig. 20 Boundary condition for single rotor

In present analysis, natural frequencies and different mode shapes of single rotor can be represented as below

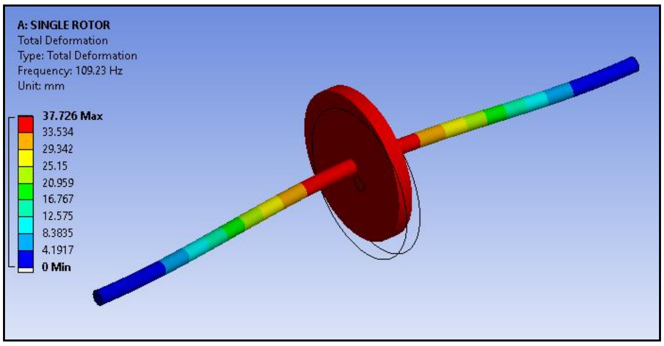


Fig. 21 Mode shape 1 of single rotor

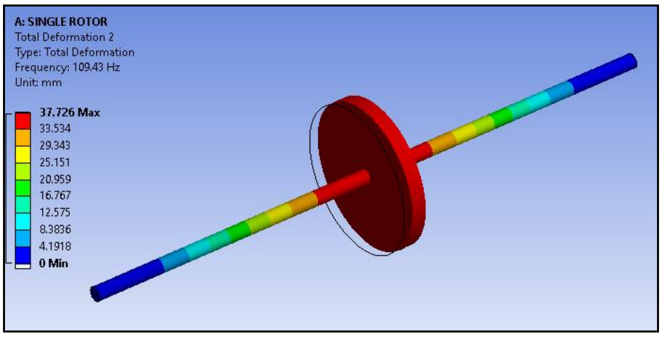


Fig 22. Mode shape 2 of single rotor

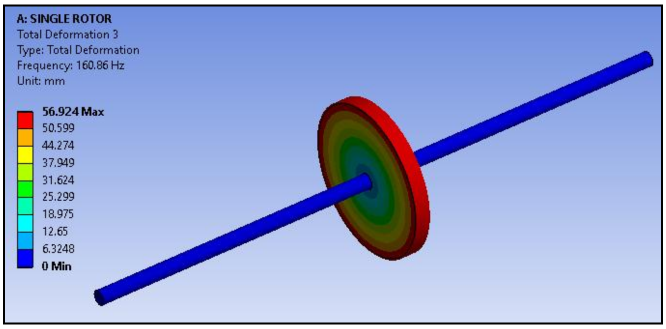


Fig 23. Mode shape 3 of single rotor

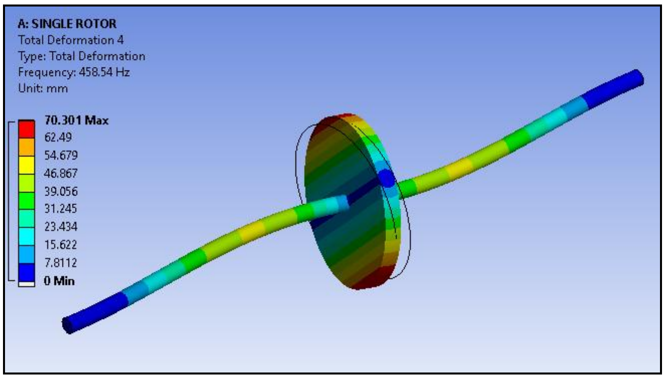


Fig 24. Mode shape 4 of single rotor

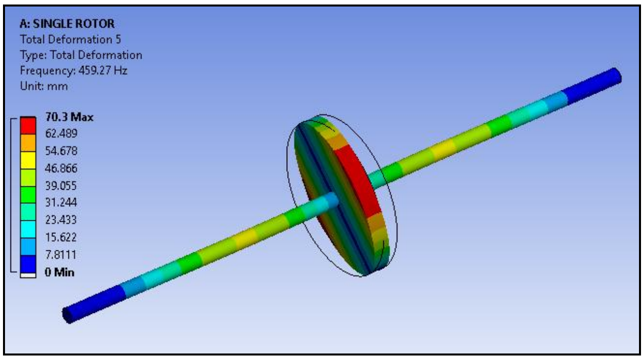
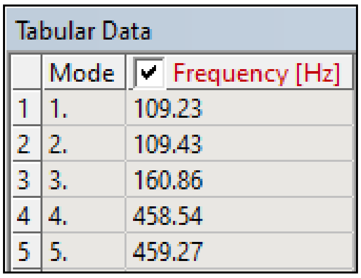


Fig 25. Mode shape 5 of single rotor


Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	109.23
2	2.	109.43
3	3.	160.86
4	4.	458.54
5	5.	459.27

Table. 3 Tabular data of natural frequency with Respective mode shapes

From modal analysis of a single rotor, 5 different modes are observed and frequency at these 5 modes are 109.23 Hz, 109.43 Hz, 160.86 Hz, 458.54 Hz and 459.27 Hz. For these respective modes shapes maximum total deformations are 37.726 mm, 37.726 mm, 56.924 mm, 70.301 mm and 70.3 mm.

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. Furthermore, it is versatile, mobile and produces reliable results. A phenomenon commonly encountered during impact testing is the so called "double hit". The "double hit" applies two impulses to the structure, one initially and one time delayed. Both the temporal and spectral characteristics of the "double hit" input and output are significantly different than a "single hit". The input force spectrum for the "double hit" no longer has the wide band constant type characteristics of a single hit. 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" phenomena 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.

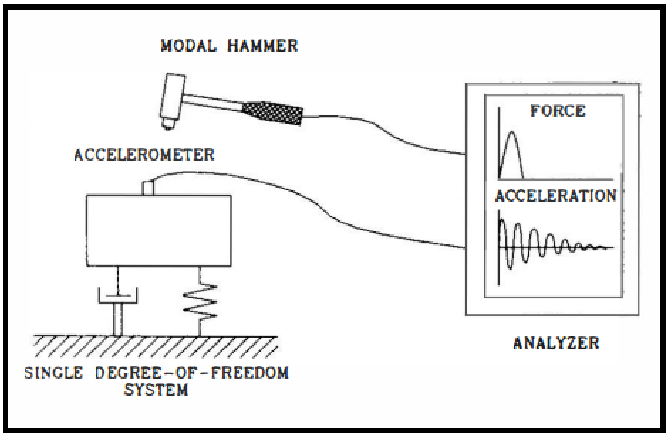


Fig. 26 Block diagram of FFT

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 edge 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 analyzed.

Fig. 27 Experimental setup of the rotary system

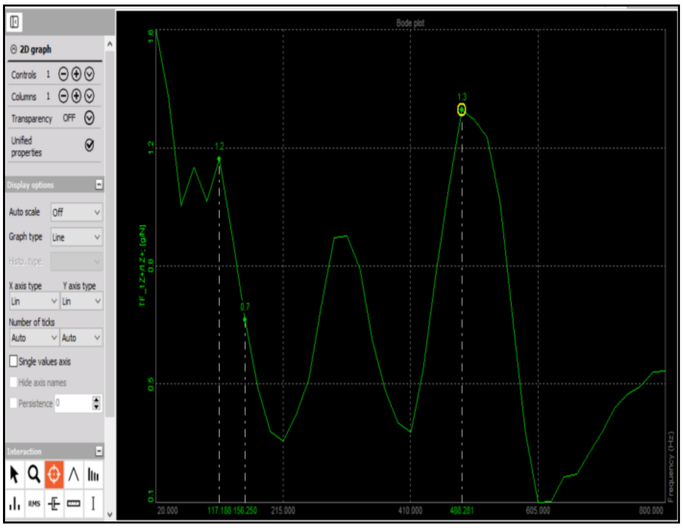
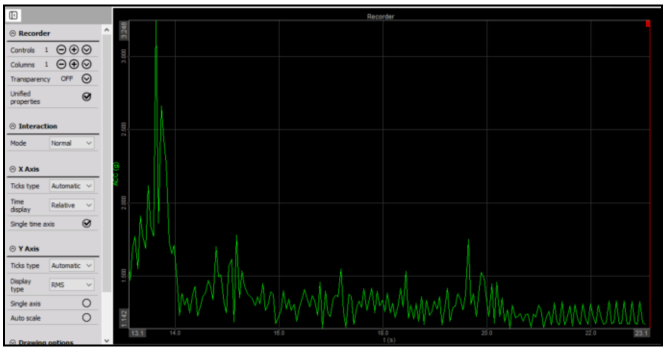

2D graph
Controls 1
Columns 1
Transparency OFF
Unified properties ☑
Display options
Auto scale Off
Graph type Line
X axis type Lin
Y axis type Lin
Number of ticks Auto Auto
☐ Single values axis
☐ Hide axis names
☐ Persistence 0

Fig. 28 FFT plot of single rotor system

MODE SHAPE	FEA	EXPERIMENTAL
1	109.23	117.18
2	109.43	117.18
3	160.86	156.25
4	458.54	488.28
5	459.27	488.28

Table 4. Comparison of Experimental and analytical frequencies

It is observed that experimental and numerical natural frequency are similar in nature and is validated for further experiments.



Controls 1
Columns 1
Transparency OFF
Unified properties ☑
Mode Normal
Ticks type Automatic
Time display Relative
Single time axis ☑
Ticks type Automatic
Display type RMS
Single axis ○
Auto scale ○

Fig. 29 FFT plot of acceleration of without viscoelastic patch

Maximum acceleration is around 3.24 g for bearing system without viscoelastic material attached to the bearing surface.

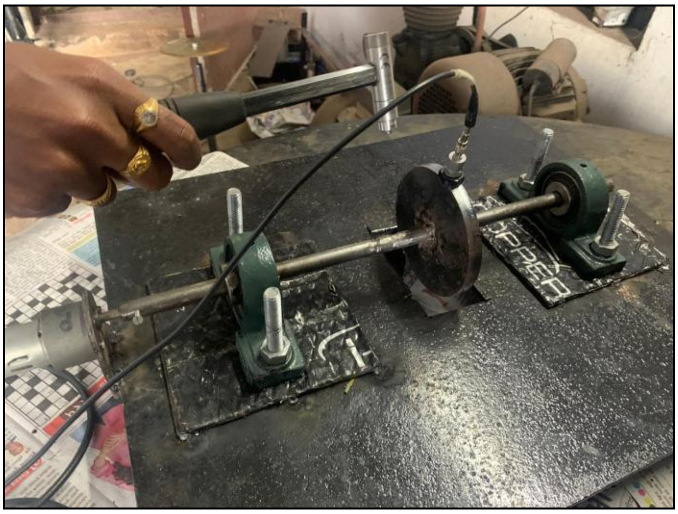
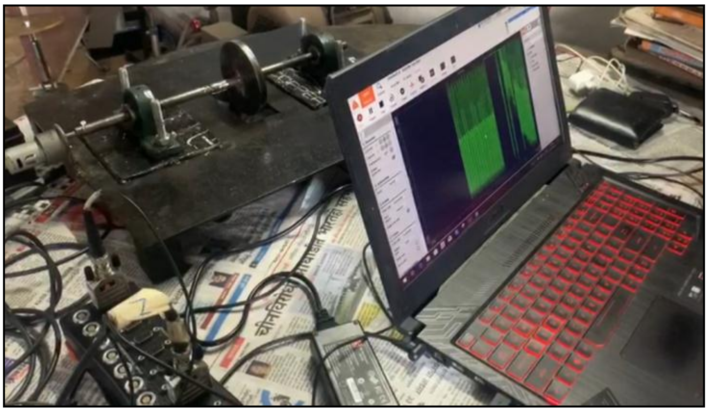
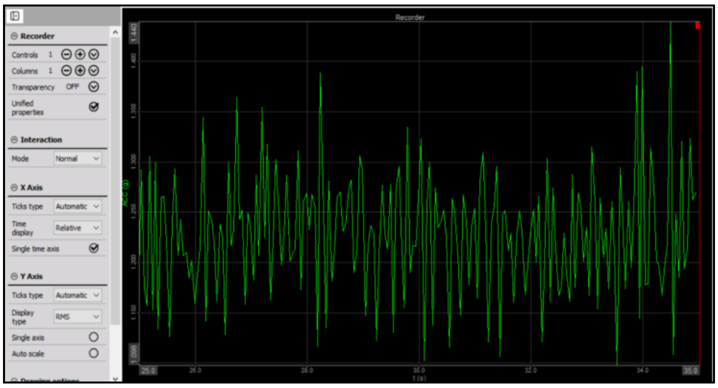


Fig 29 (a)



(b)

Fig. 29 (a), (b) Experimental testing with viscoelastic patch



Controls 1
Columns 1
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Unified properties ☑
Mode Normal
Ticks type Automatic
Time display Relative
Single time axis ☑
Ticks type Automatic
Display type RMS
Single axis ○
Auto scale ○

Fig. 30 FFT plot of acceleration of with viscoelastic patch

Maximum acceleration is around 1.44 g for bearing system with viscoelastic material attached to the bearing surface.

As acceleration have reduced compared to existing design so, viscoelastic material absorbs uneven vibration exerted during rotation of rotor and transmits less vibration to system.

CONCLUSIONS:

- In the present study we have performed the modal analysis for the rotary system with and without the viscoelastic material.
- We concluded that the system with insertion of viscoelastic material has more damping capacity than the conventional system.
- It is observed from harmonic analysis that using viscoelastic material below bearings subjected to vibration have reduced acceleration to a certain limit from frequency response graph.
- In experimental and FEA analysis of single rotor shaft natural frequencies were observed in similar nature of values.
- Acceleration values from FFT during viscoelastic material patch have reduced vibration from 3.4 g to 1.44 g. so, it is beneficial to use viscoelastic patch for mitigating the rotor vibration to a certain limit.

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