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Free Vibration Analysis of Differernt Materials under Crack as a Cantilever Beam

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Abstract: ***A simple and unified approach is presented for the vibration analysis of a cantilever beam. Natural frequency and damping ratio are calculated with an experimental process. Estimating damping still remains as one of the biggest challenge in structure made of different materials like brass, stainless steel and aluminium. All materials or structures posses certain amount of internal damping, due to which energy is either dissipated into heat or radiated away from the system. Internal damping includes the 10-15% of the total damping in system. The primary objective of this thesis is the free vibration analysis of different materials under surface cracks to estimate the effect of cracks on damping ratio and natural frequency. The beams of different crack size were pressed up to 30 mm and signals were catches by VIBSCANNER with the help of accelerometer attached at the free end of cantilever. Omnitrend provides Frequency response (FRF) graphs after processing data imported from VIBSCANNER. Damping ratio is determined by half-power bandwidth method. It is observed that damping is increased with increasing crack size for all materials and is minimum in aluminium when compared to brass and stainless steel. The effects of surface cracks and material parameters on the natural frequencies are investigated through this experimental study.***
***Keywords**: Accelerometer sensor, Cantilever Beam, Natural Frequency, Clamp, Damping ratio, Free vibration, Vibscanner, Omnitrend, ANSYS.*

I. INTRODUCTION

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. Vibration analysis is a very important task on designing of a structure or mechanical system. There are lots of things to consider on designing a structure. One of the main things that must worry about is actually making sure the machine runs efficiently. There are lots of things that should be consider includes wear, misalignment and looseness. In rotating machineries, vehicle suspension system and the dynamic behaviour of machine tool structures due to excitation are the important information that design engineer wants to obtain. This data will be helpful to control the excessive amplitude of the vibration. In case of cantilever beams, beam bends due to vertical load and return to its original position after the removal of load. However inertia keeps beam in motion and beam vibrates at its characteristic frequency [1]. Hardeep Singh, Sanpreet Singh, Gurpreet Singh (2014) investigated the vibration damping characteristics of mild steel, brass and aluminium of different lengths under free vibration. The objective of the study is to find out the natural frequency, damping ratio and vibration characteristics with experimental and theoretical method [2]. D.Ravi Prasad (2008) study the dynamic characteristics of structural materials steel, brass, copper and aluminium as a cantilever beam under free vibration to calculate the modal analysis, natural frequency, damping, mode shape and free vibration and the theoretical values are compared with experimental results [3]. Pawar, R.S, Sawant, S.H.(2014) focuses on the study of the vibration analysis of cracked cantilever beam subjected to free and harmonic excitation at the base. The objective of the study is to identify the effect of non-linearity namely material, geometric, and damping on the natural frequency and mode shapes of cracked cantilever beam by theoretical, numerical and experimental methods [4]. Vinay V. Kuppast, Vijay Kumar N. Chalwa, S. N. Kurbet, Aravind M. Yadawad (2014) study the effect of vibration characteristics of aluminium alloys of different compositions. The objective of the study is to find out the natural frequency and mode shapes. The modeling and analysis is carried out using ANSYS software [5]. Shibabrat Naik, Wrik Mallik (2012) estimating the dynamic properties of a cantilever by using aluminium as a cantilever with a experimental test. All these values are then compared with the results obtained from ANSYS [6].Pragnesh K. Chaudhari, Dipal Patel, Vipul Patel investigated the experimental modal analysis and theoretical natural frequency of the test specimens made of different material aluminium and mild steel. FRF graphs are obtained with the help of software named DAQmx [7]. Sadettin Orhan analyzes the free and forced vibrations of a cantilever beam having a V-shaped edge crack are studied. The ANSYS finite element program was used for free and forced vibration of the uncracked and cracked beams [8]. Metin O Kaya uses a semi-analytical technique called the differential transform method, applied to a rotating Timoshenko beam in a simple and accurate way [9]. Simarnjit Singh, Amandeep Singh analysis the behaviour of the cantiilever beam wth the previous data. The purpose of this experiment is to calculate the vibration

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characteristics of Brass, Stainless Steel and Aluminium as a cantilever beam with experimentally and analytical. The effect of cracks on the natural frequency and damping ratio will be observed [10].

A. Beam

A beam is an even or vertical auxiliary component that is equipped for withstanding load basically by opposing twisting. The bowing power impelled into the material of the shaft as an after effect of the external load, own weight, range and external reactions to these loads is known as a bending movement.

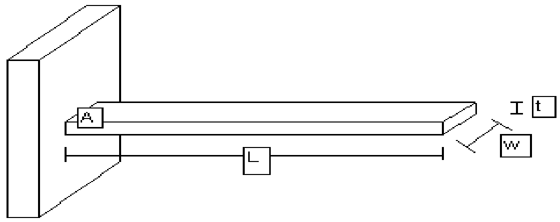

Figure 1 A Cantilever Beam [11]

A cantilever beam is one whose one end is fixed and the other end carries a point or concentrated load.

L-length

W-width

T-thickness

B. Theory of Vibration (Theory of Free Vibration of Cantilever Beams) [12]

For a cantilever beam subjected to free vibration, and the system is considered as continuous system in which the beam mass is considered as distributed along with the stiffness of the shaft, the equation of motion can be written as:-

$$\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2Y(x)}{dx^2}\right\} = \omega_n{}^2 m(x)Y(x)$$

Where,

1) E is the modulus of rigidity of beam material
2) I is the moment of inertia of the beam cross-section
3) $Y(x)$ is displacement in y direction at distance x from fixed end
4) ω_n is the circular natural frequency
5) m is the mass per unit length, $m = \rho A(x)$
6) ρ is the material density
7) x is the distance measured from the fixed end

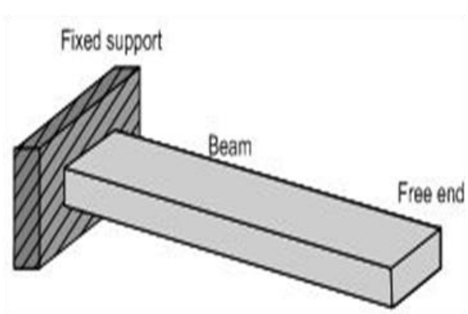

Figure 2 A Cantilever Beam [13]

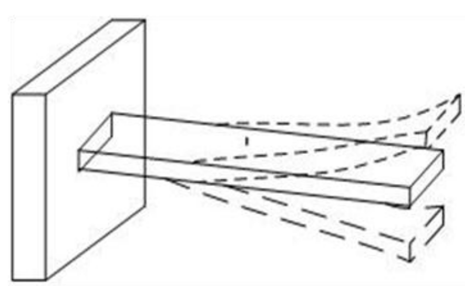

Figure 3 The Beam under free vibrations [13]

Figure 2 shows of a cantilever beam with rectangular cross section, which can be subjected to bending vibration by giving a small initial displacement at the free end and Figure 3 depicts of cantilever beam under the free vibration. The natural frequency is related

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with the circular natural frequency as

$$f_{nf} = \frac{\omega_{nf}}{2\pi} Hz$$

Where *I*, the moment of inertia of the beam cross-section, for a circular cross-section it is given as

$$I = \frac{\pi}{64} d^4$$

Where, *d* is the diameter of cross section and for a rectangular cross section

$$I = \frac{bd^3}{12}$$

Where *b* and *d* are the breadth and width of the beam cross-section as shown in the Figure 4.

Figure 4 Cross-section of the Cantilever Beam

C. *Eular Bernoulii Beam Theory [14]*

Euler Bernoulli's Beam Theory also known as engineer's beam theory or classical beam theory is a simplification of the linear theory of elasticity which provides a means of calculating the load carrying and deflection characteristics of beams . It covers the case for small deflections of a beam which is subjected to lateral loads only. It is thus a special case of Timoshenko beam theory. For a cantilever beam subjected to free vibration, and the system is considered as continuous system in which the beam mass is considered as distributed along with the stiffness of the shaft, the equation of motion can be written as:-

$$\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2Y(x)}{dx^2}\right\} = \omega_n{}^2 m(x)Y(x)$$

Following are the boundary conditions for a cantilever beam

$$at\ x = 0, \qquad Y(x) = 0, \qquad \frac{dY(x)}{dx} = 0$$

$$at\ x = l, \qquad \frac{d^2Y(x)}{dx^2} = 0, \qquad \frac{d^3Y(x)}{dx^3} = 0$$

$$\frac{d^4Y(x)}{dx^4} - \beta^4 Y(x) = 0$$

$$\beta^{4=} \frac{\omega_n{}^2 m}{EI}, \beta_n L = \alpha_n$$

$$\omega_{nf} = \alpha_n{}^2 \sqrt{\frac{EI}{mL^4}}$$

D. *Timoshenko Theory of Beams [15]*

The Timoshenko beam theory was suitable for describing the behaviour of short beams, sandwich composite beams or beams subject to high-frequency excitation when the wavelength approaches the thickness of the beam. In static Timoshenko beam theory, for a linear elastic, isotropic, homogeneous beam of constant cross-section these two equations can be combined to give:-

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$$EI\frac{\partial^4\omega}{\partial x^4} + m\frac{\partial^2\omega}{\partial t^2} - \left(\rho I + \frac{EIm}{KAG}\right)\frac{\partial^4\omega}{\partial x^2\partial t^2} + \frac{Jm}{KAG}\frac{\partial^4\omega}{\partial t^4} = q(x,t) + \frac{\rho I}{KAG}\frac{\partial^2 q}{\partial t^2} - \frac{EI}{KAG}\frac{\partial^2 q}{\partial x^2}$$

E. Crack Propagation Analysis [16]

Engineering structures are designed to withstand the loads they are expected to be subject to while in service. Large stress concentrations are avoided, and a reasonable margin of security is taken to ensure that values close to the maximum admissible stress are never attained. However, material imperfections which arise at the time of production or usage of the material are unavoidable, and hence must be taken into account.

II. OBJECTIVE

A. The vibration characteristics of a cantilever beam made with different materials such as Stainless Steel (304), Brass and Aluminum (6063).

B. Natural Frequency of all specimens from FRF graphs.

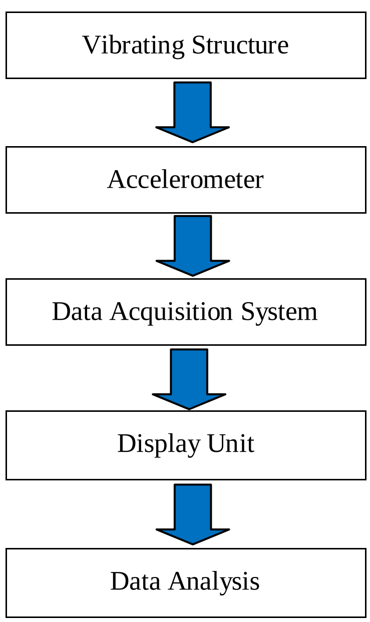
C. To estimate the behavior of damping on varying crack size.

III. EXPERIMENTAL PROGRAM

A. Equipments Used

1) PRUFTECHNIK Condition Monitoring VIBSCANNER (2.9)
2) ACCELEROMETER (VIB 6.142)
3) OMNITREND (2.81.0.25)
4) Specimens: Brass, Stainless Steel and Aluminum bar of dimensions 600 mm X 25.4 mm X 6 mm
5) Display Unit
6) Clamping Device
7) ANSYS R15.0

B. Vibration Measurement Scheme



1) Specimen of Stainless steel, Brass and Aluminium beam of dimensions 600 mm X 25.4mm X 6 mm with no crack, 10 cm, 20 cm and 30 cm crack size was used as a cantilever beam.
2) One end of specimen was fixed on the table with the help of clamping device.
3) The connections of the vibscanner, accelerometer was properly made.

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4) Accelerometer was attached to the free end of the cantilever beam in order to measure the vibration response.
5) The free end of a cantilever beam was pressed up to 30 mm and beam starts vibrating.
6) VIBSCANNER records all the data with the help of accelerometer attached at its free end.
7) The experiments were repeated to check the repeatability of the experimentation (i.e. vibration data).
8) Repeat the whole experiment by changing the specimens.
9) After the completion of experiment, all the data was imported into pc.
10) Then FRF curves obtained by processing the data in Omnitrend software.

C. Experimental Setup

The experiment test rig was built to conduct free vibration analysis on the test specimens to obtain its dynamic characteristics including natural frequencies and damping ratios as shown in Figure 5.

Figure 5 Experimental Setup

D. Frequency Response Function Measurement

Frequency response is the quantitative measure of the output spectrum of a system or device in response to a stimulus, and is used to characterize the dynamics of the system. It is a measure of magnitude and phase of the output as a function of frequency, in comparison to the input. Frequency response or FRF is the graph or spectrums are obtained from the free vibration test. Natural frequency was calculated for each specimen from the spectrum. Then the damping was calculated from the spectrum curves with Half Bandwidth Method.

$$\zeta = \frac{\omega_2 - \omega_1}{2\omega_n}$$

Where ω_2 and ω_1 are the frequencies corresponding to the half power points which are defined at which the response amplitude is 0.707 times the resonant response amplitude and ω_n is the resonant frequency.

IV. FIGURES AND TABLES

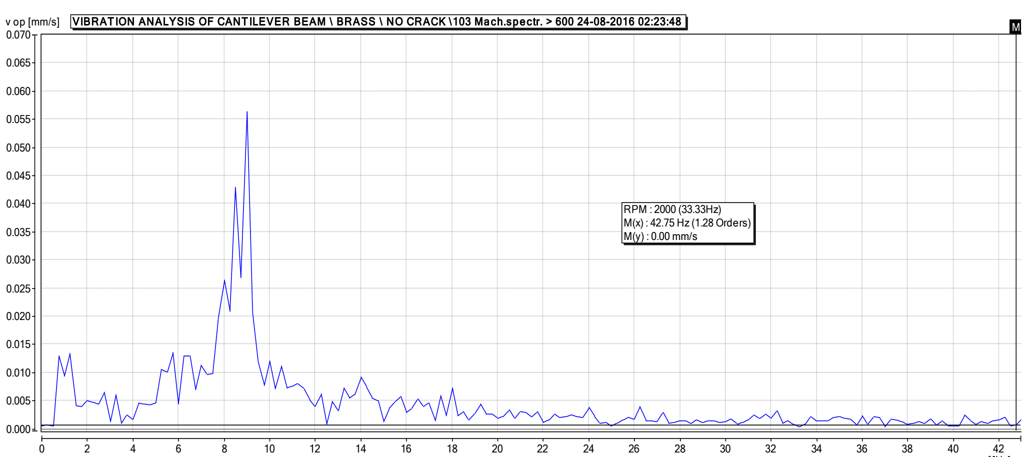

Figure 6 FRF graph of BR1 beam

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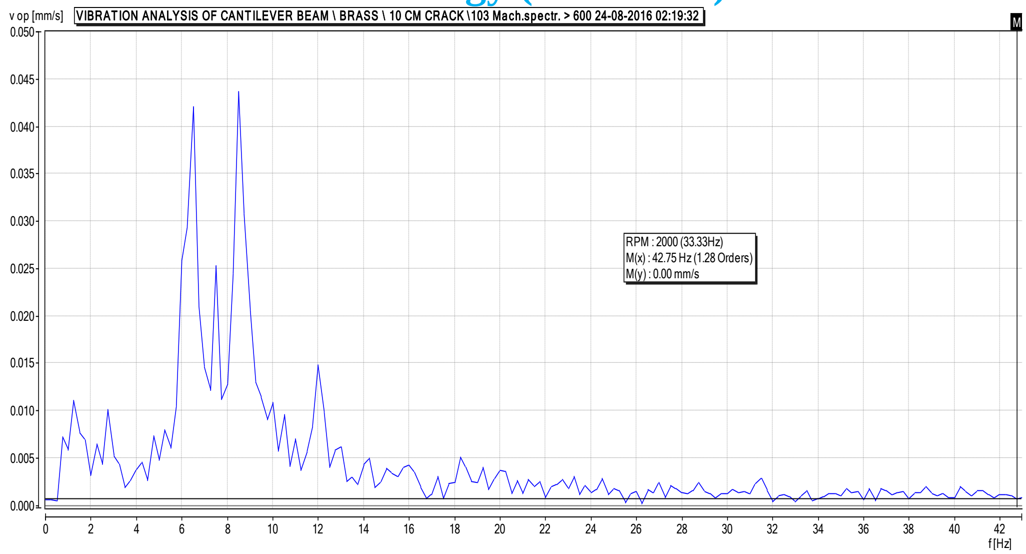

Figure 7 FRF graph of BR2 beam

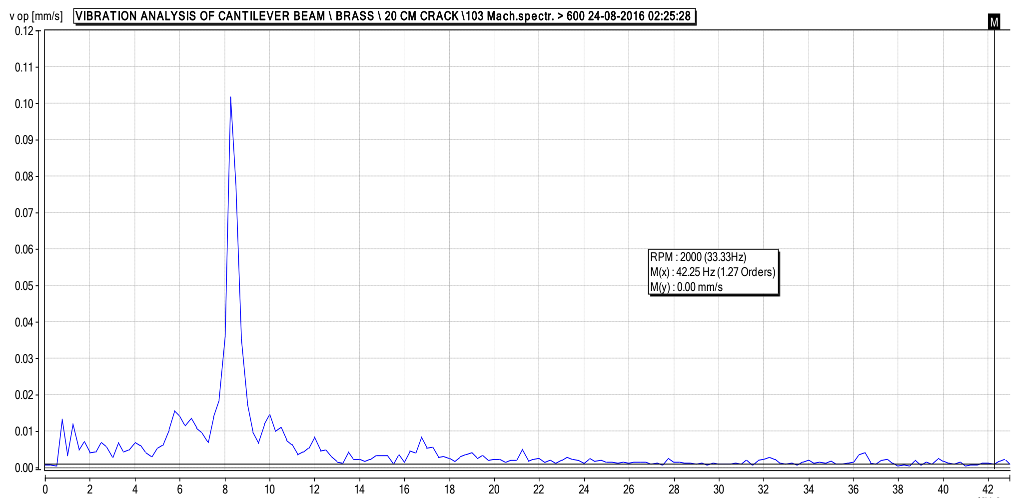

Figure 8 FRF graph of BR3 beam

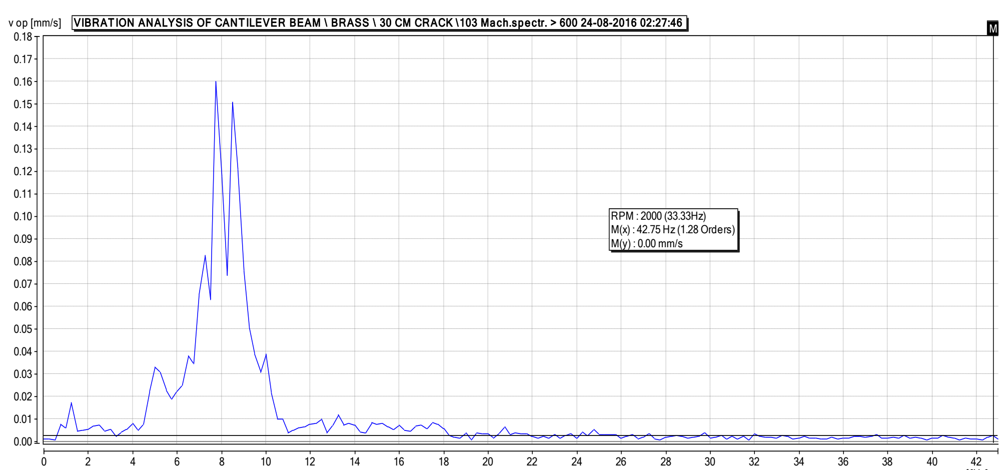

Figure 9 FRF graph of BR4 beam

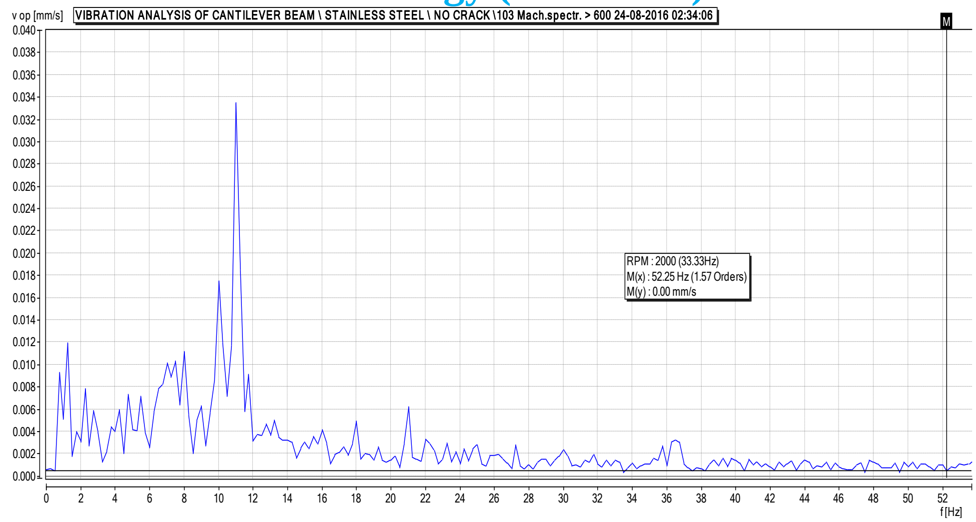

Figure 10 FRF graph of SS1 beam

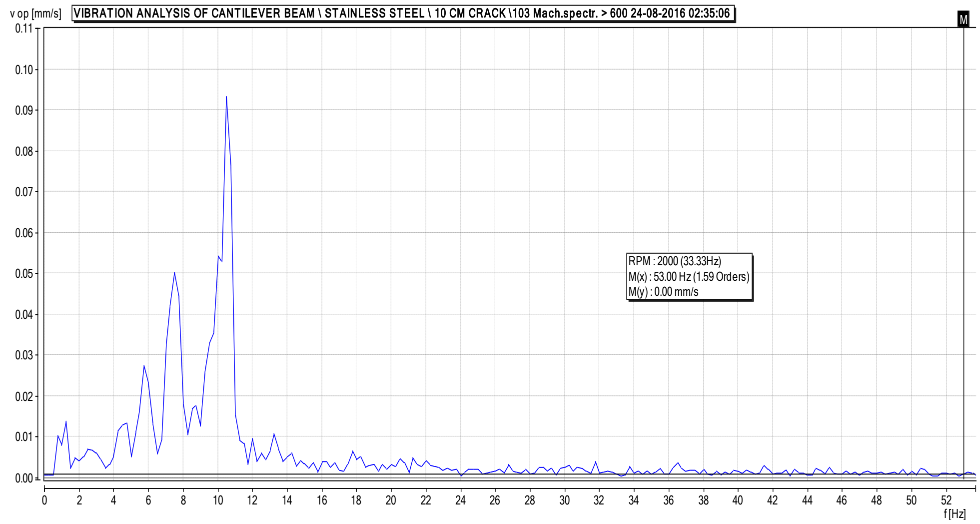

Figure 11 FRF graph of SS2 beam

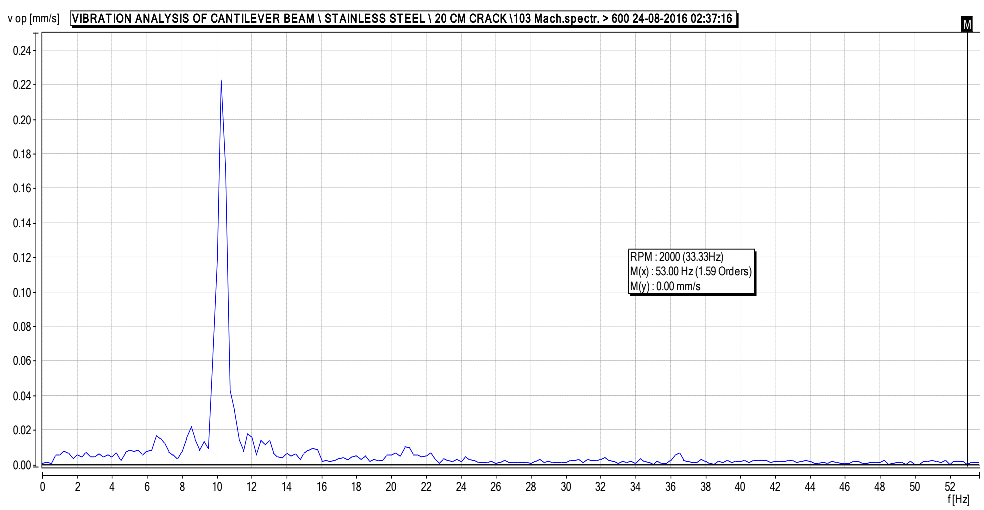

Figure 12 FRF graph of SS3 beam

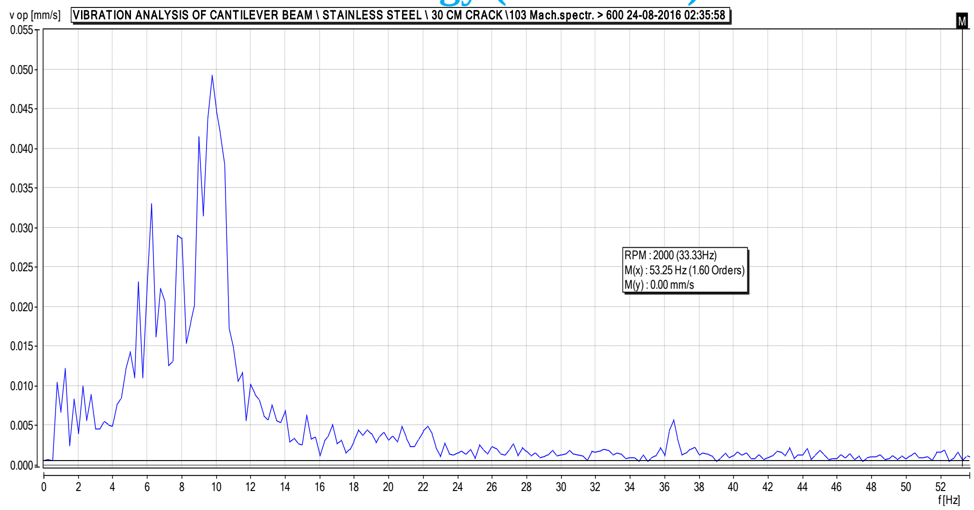

Figure 13 FRF graph of SS4 beam

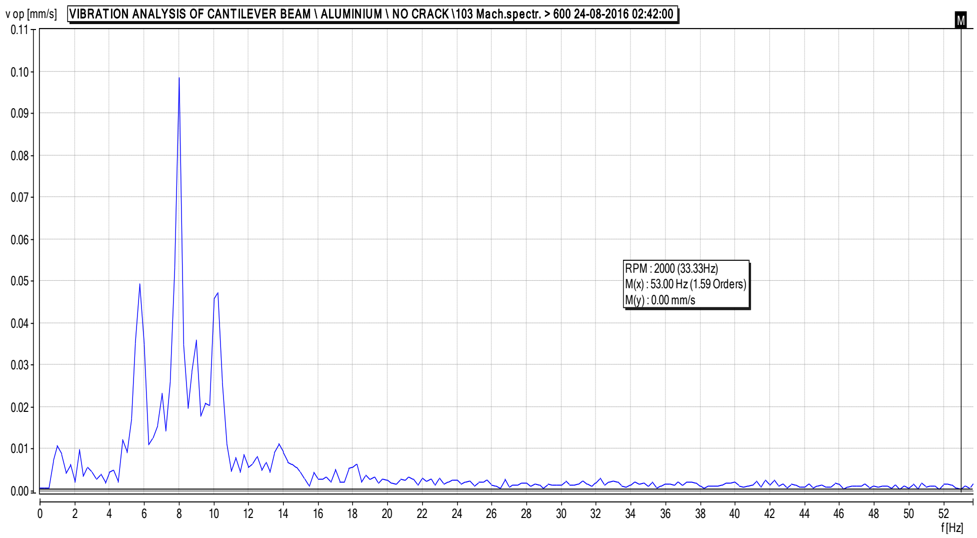

Figure 14 FRF graph of AL1 beam

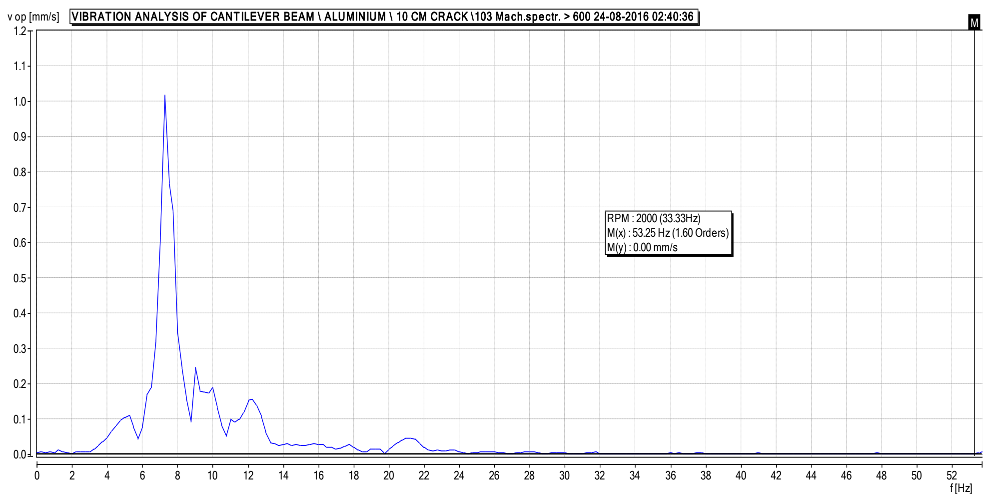

Figure 15 FRF graph of AL2 beam

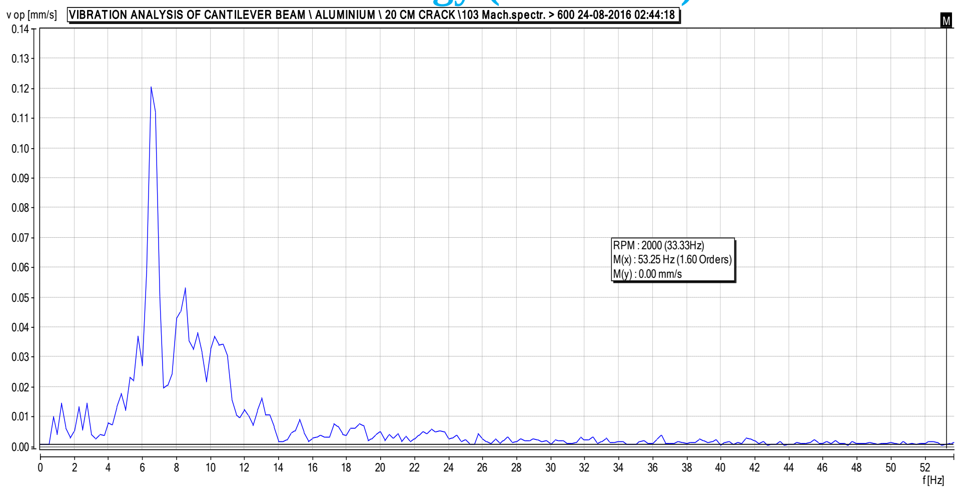

Figure 16 FRF graph of AL3 beam

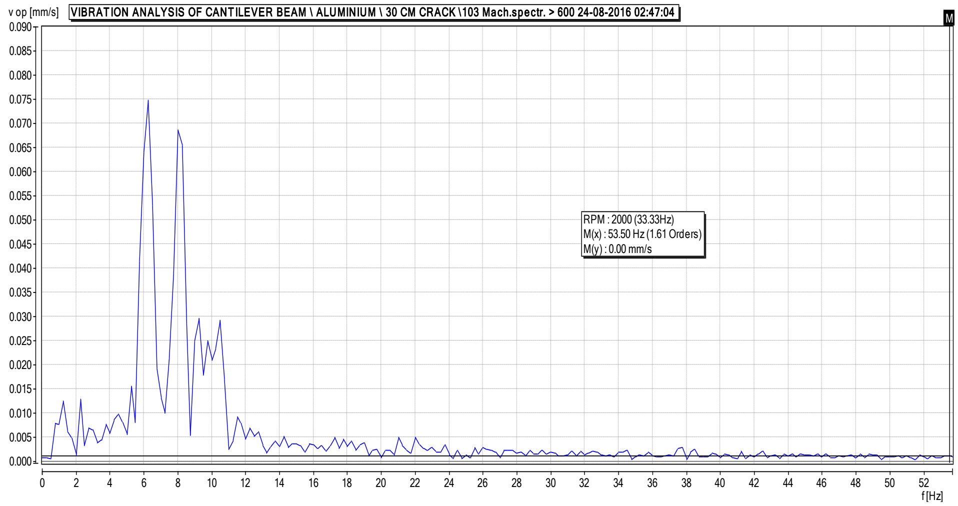

Figure 17 FRF graph of AL4 beam

ANSYS is engineering simulation software based on the finite element method and is capable of performing static (stress) analysis, thermal analysis, modal analysis, frequency response analysis, transient simulation and also coupled field analysis. The ANSYS metaphysics can couple various physical domains such as structural, thermal and electromagnetic. The harmonic analysis is performed in ANSYS to find the natural frequency of first mode and to plot the graph between frequency and displacement. The graphs so obtained are as

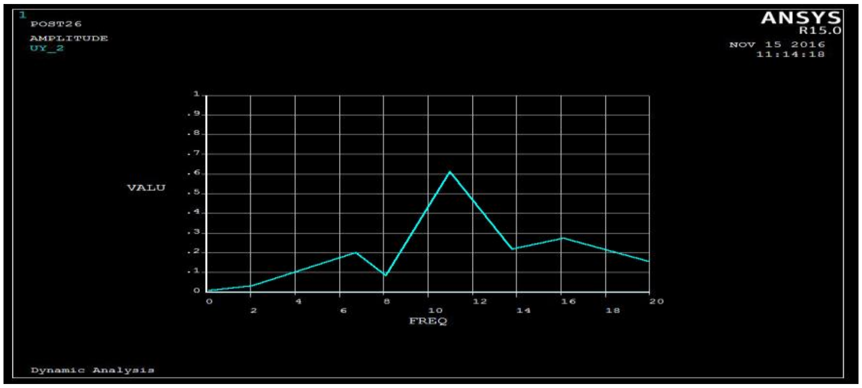

Figure 18 FRF graph of BR1 beam

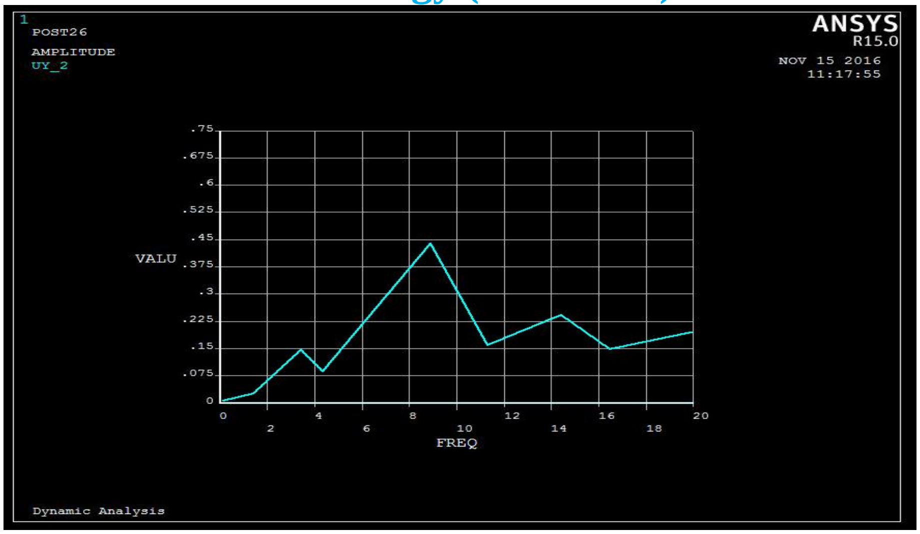

Figure 19 FRF graph of BR2 beam

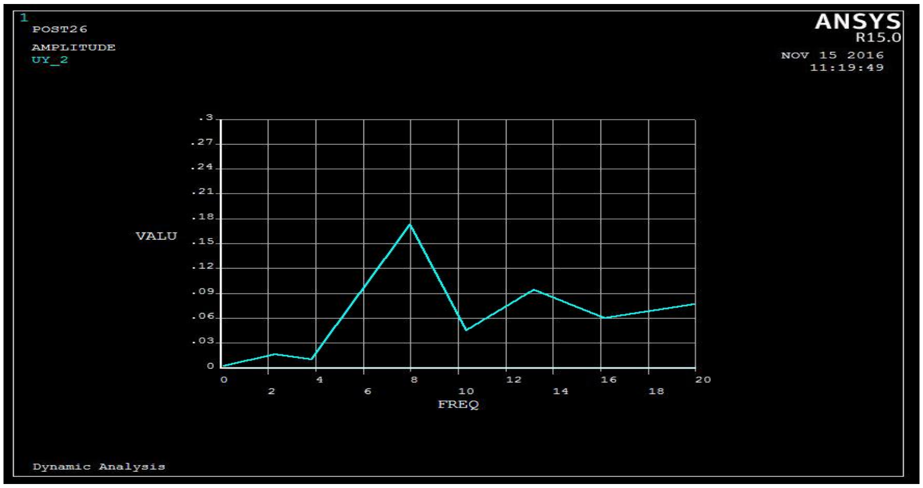

Figure 20 FRF graph of BR3 beam

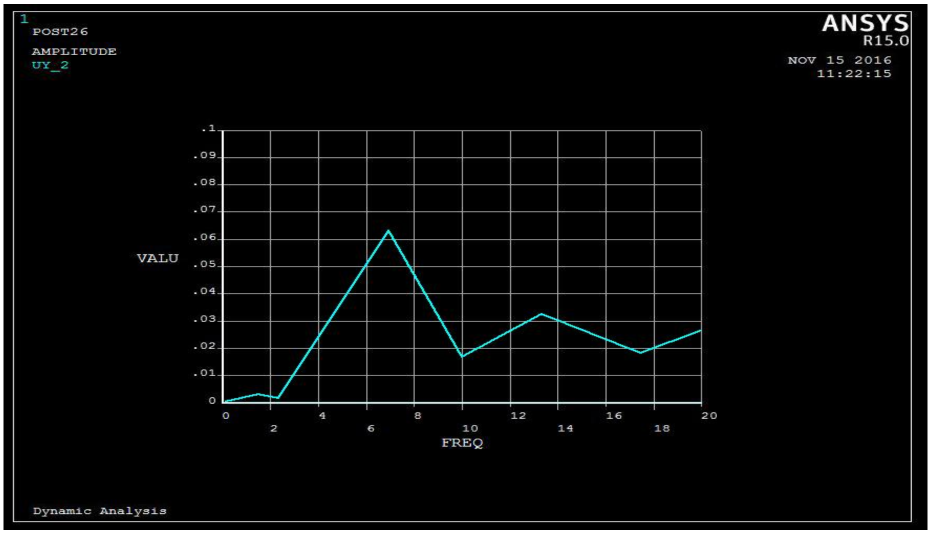

Figure 21 FRF graph of BR4 beam

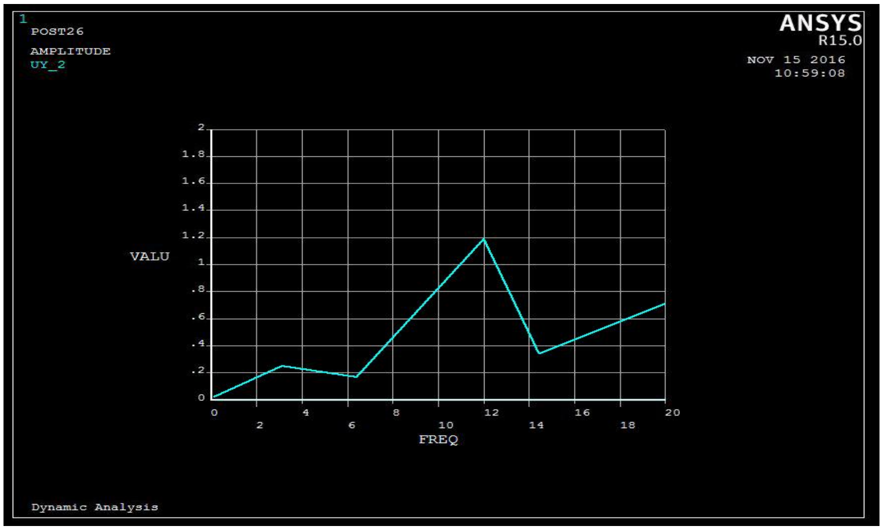

Figure 22 FRF graph of SS1 beam

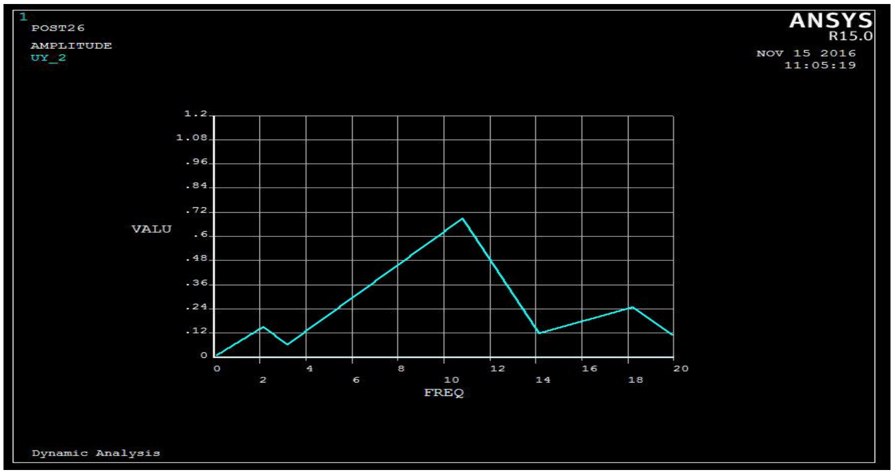

Figure 23 FRF graph of SS2 beam

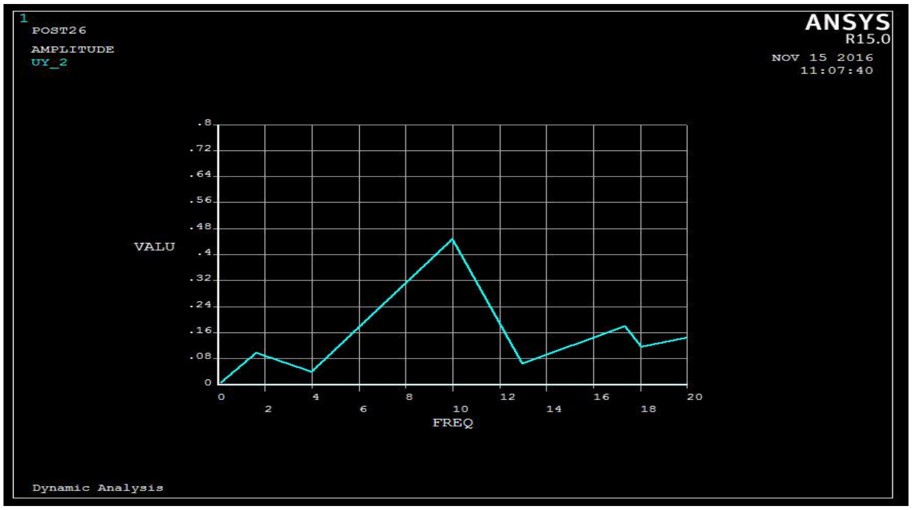

Figure 24 FRF graph of SS3 beam

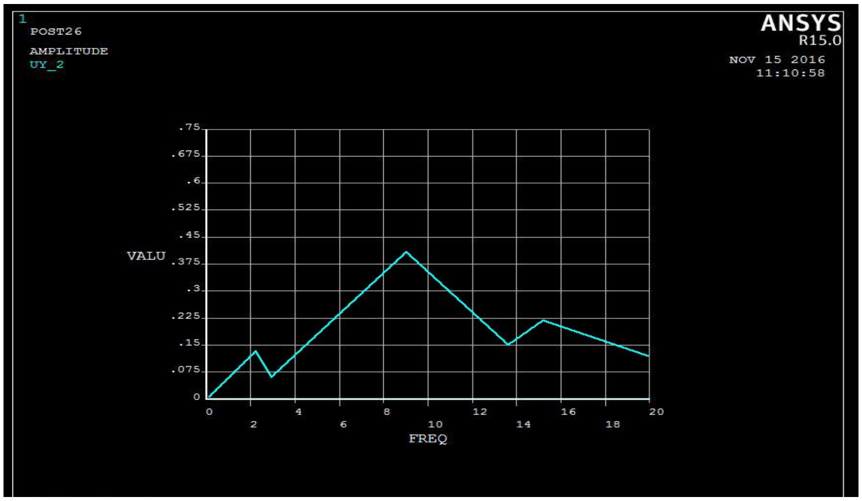

Figure 25 FRF graph of SS4 beam

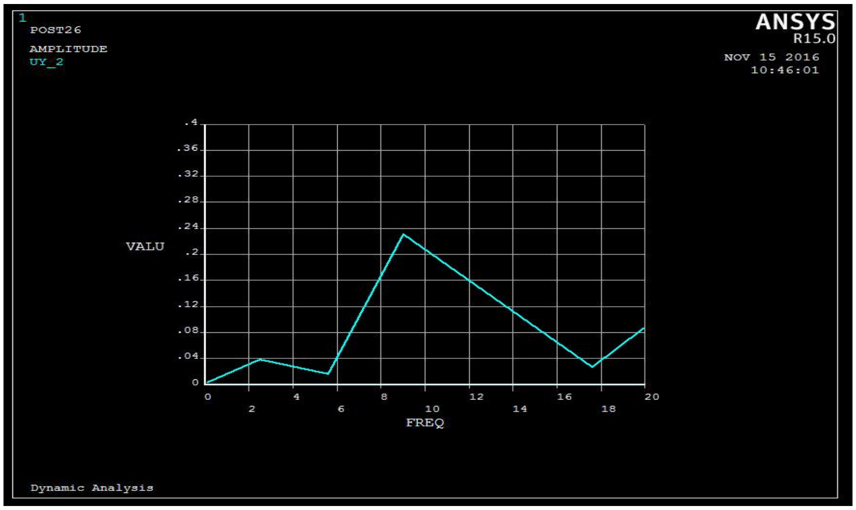

Figure 26 FRF graph of AL1 beam

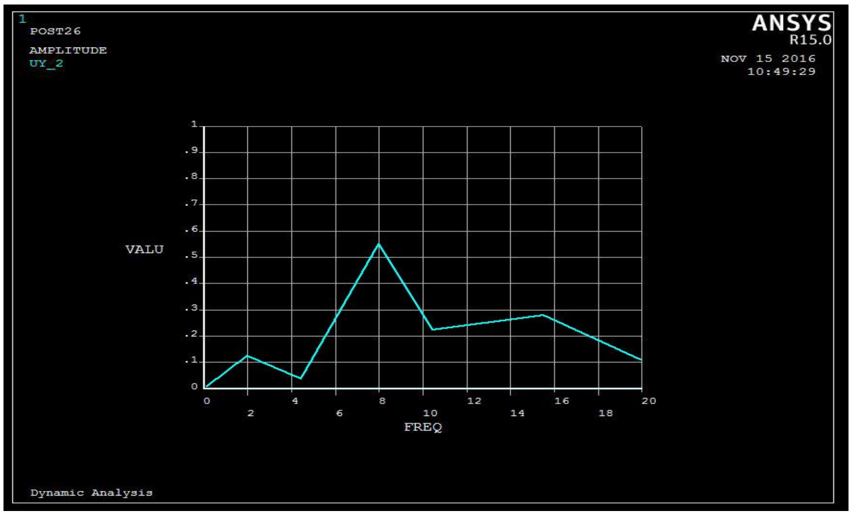

Figure 27 FRF graph of AL2 beam

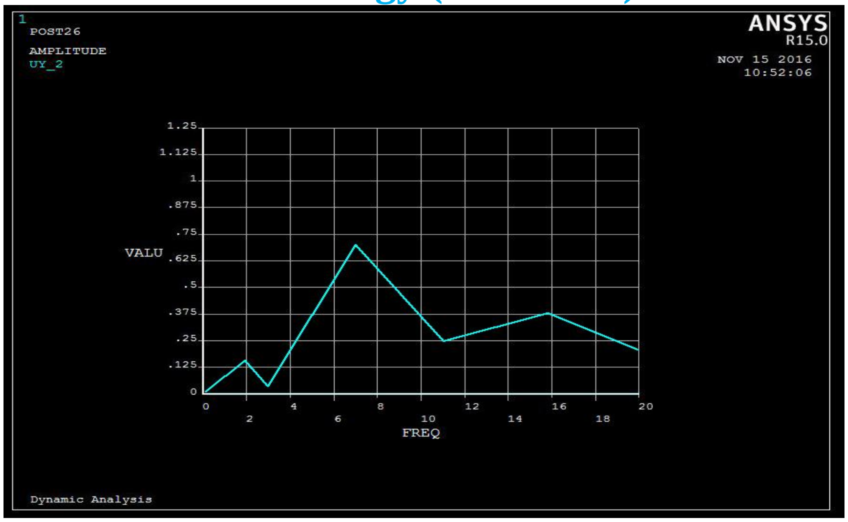

Figure 28 FRF graph of AL3 beam

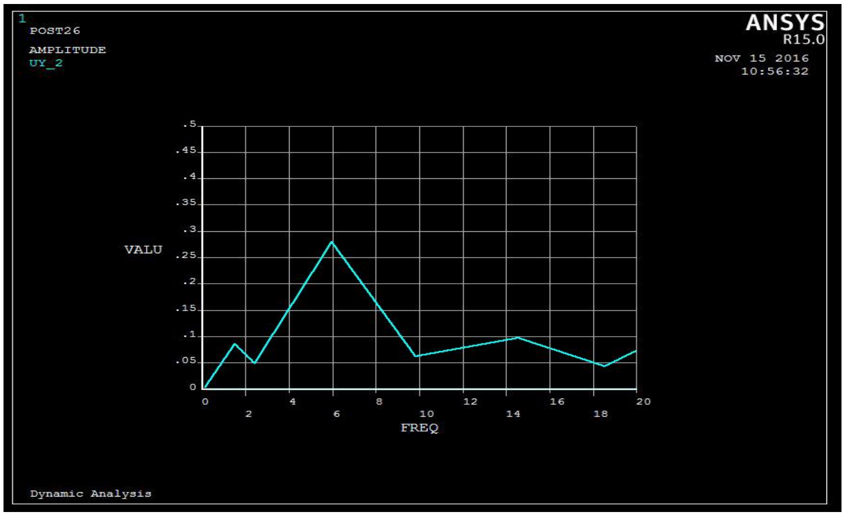

Figure 29 FRF graph of AL4 beam

Table 1 Notation Used

Crack Size	**Brass Specimens**	**Stainless Steel Specimens**	**Aluminium Specimens**
No Crack	BR1	SS1	AL1
10 cm	BR2	SS2	AL2
20 cm	BR3	SS3	AL3
30 cm	BR4	SS4	AL4

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V. CALCULATIONS

Table 2 Natural Frequency

S. No.	Specimens	Experimental Frequency (ω_n) Hz	ANSYS Frequency (ω_n) Hz	% of error
1	BRI	9	11	18.18
2	BR2	8.5	9	5.55
3	BR3	8.25	8	3.03
4	BR4	7.75	7	9.67
5	SS1	11	12	8.33
6	SS2	10.50	11	4.54
7	SS3	10.25	10	2.43
8	SS4	9.75	9	7.69
9	AL1	8	9	10.00
10	AL2	7.25	8	9.37
11	AL3	6.50	7	7.14
12	AL4	6.25	6	4.00

Table 3 Damping Ratio

S. No.	Specimens	ζ (Half Power Bandwidth)
1	BRI	0.0111
2	BR2	0.0176
3	BR3	0.0242
4	BR4	0.0323
5	SS1	0.0136
6	SS2	0.0238
7	SS3	0.0292
8	SS4	0.0359
9	AL1	0.0063
10	AL2	0.0138
11	AL3	0.0230
12	AL4	0.0319

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VI. CONCLUSION

The primary objective of this thesis work is to calculate the natural frequency and damping ratio of different materials (Brass, Stainless Steel and Aluminium) under different crack size. The data has been collected with the help of VIBSCANNER instrument, which gives results in the form of frequency spectrums. Then these spectrums are used to calculate the damping ratio with the help of Half Bandwidth method. Thus the values of natural frequency and damping ratio are obtained from this experiment. Then the same results are obtained after anlysing on ANSYS software and compare it with experimental result.
On the basis of this experimental study, it is concluded that

A. The natural frequency decreases with increase the crack size in each specimen.
B. The value of damping is increases with increase the crack size.
C. The damping ratio of Aluminium specimens is found to be lowest than Brass and Stainless Steel.
D. The increase in material damping could be correlated to the stiffness of materials.
E. All the values constantly increases or decreases on in increasing crack size in all materials.

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