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Optimization of Natural Frequency of Beam by Using Cylindrical Grooves

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Abstract: This is after design method where the natural frequencies of beam alters by creating cylindrical grooves or series of cylindrical groove on beam surface has investigated. There are several method to change the natural frequency of beam like change in support layout, addition of mass like ribs or stiffener but all has design restriction. Proposed method creates only cylindrical grooves to optimize the natural frequency which is one step process. Groove size is very small compare to beam size. Hence total mass of beam doesn't get affected. Grooves affect the local stiffness where they are made on beam. Change in local stiffness changes natural frequency proportionally without changing mass. Effect of groove size and location on natural frequency were studied and presented. To find out the optimal values of groove location and groove size, optimization technique was used. Modal analysis of both non – grooved and grooved beam carried out by both experimentally as well as in simulation. Harmonic analysis were carried out to show the effect of groove on mode shape. FFT analyzer used to extract the natural frequency of beam experimentally.

Keywords: Natural frequency, mode shape, modal analysis, harmonic analysis, cylindrical grooves, FFT analyser.

I. INTRODUCTION

Many mechanical and civil engineering applications like railway bridges, structures & frames, machining supporting parts widely uses beams. Beams are subjected to vertical as well as horizontal unbalance dynamic forces resulting into unwanted large vibration. If the frequency of external excitation force is get tuned up with any one of the natural frequencies cause formation of resonance resulting into vibration with large amplitude. Large amplitude put more stress on the beam. The energy trapped due to deflection is not efficiently dissipated into surrounding may leads to weakening or damage the beam. Thus, improving dynamic characteristics of beam i.e. natural frequency, mode shapes is key necessity for designer in today's design. Keep natural frequency of beam away from the external excitation frequency is the key to avoid the resonance phenomena. The shifting of natural frequency from external frequency to reduced vibration can be done by performing several treatments on beam; by adding masses i.e., ribs or stiffener on locations, by adding supports at desired locations. In this research work, the natural frequency is shifted by creating several cylindrical grooves on beam surface.

In this study, optimization technique for natural frequencies of beam by creating horizontal cylindrical groove is presented. This is after design modification technique to alter the dynamic properties of beam or any components of machine which is not under high stress. Cylindrical groove or series of cylindrical grooves are used to alter the natural frequencies and mode shapes. Area of cylindrical groove is very small as compared to overall area of beam hence there is no any effective change in the mass of beam after being grooved. To change the mass is not a significant method due to design constraint. So, this is advantageous over other structural dynamic modification methods. Cylindrical groove alters the local stiffness of beam which result into change in natural frequency. Without addition of elastic support, masses or stiffener, dynamic modification of beam can be achieved.

Presented study is carried out in ANSYS® Workbench. First, modelling of beam was done and then finite element modal analysis of the grooved beam is performed in ANSYS® Workbench. Results were validated by experimentally.

II. LITRATURE REVIEW

Many researchers have presented their study for shifting of natural frequencies of beams. Nabeel T. Alshabatat (2011) used V – notch stamping method for thin walled beam to optimize natural frequency. Authors used Genetic Algorithm to determine the location & dimension of V-notch. Hai-Ping Lin (2008) presents the method for tuning the natural frequency of beam structures to designated values by using open crack. Wen Nan Cheng, Chih Chun Cheng and Gary H. Koopmann (2007) modified the vibration characteristics of a structure by creating dents, or dimples on its surface. Authors used the impedance method to formulate the dynamic response of beam with several dimples. Chih-Shiung Wang and Lin-Tsang Lee (2011) presents the study of a new sectional flexibility factor to simulate the reduction of the stiffness of a single – edge open cracked beam. Vibration analysis of a cracked beam subjected to a traveling vehicle is presented by Hai-Ping-Lin in 2007 et al. An analytical method was developed to present the forced responses of a cracked simply-supported beam subjected to a traveling vehicle. R. Alebrahim, S.M. Haris, N.A.N. Mohamed and S. Abdullah (2015) investigate vibration analysis of Timoshenko beam with multiple crack and different boundary condition under moving mass. They concluded that, numbers of crack, speed of traveller, location of crack and type of boundary conditions play important roles in the natural frequency and deflection of cracked beam. Mihir Kumar Sutar (2012) presents finite element analysis of a cracked cantilever beam. He analyses the relation between the modal natural frequencies with crack depth, modal natural frequency with crack location. A.V. Deokar, and V.D. Wakchaure (2011) presented the method of crack detection of cantilever beam by experimentally. Author consider first three natural frequency for crack detection. FabrizioVestroni, OlivieroGiannini and Paolo Casini (2014) investigates the specific aspects of a novel methodology for the identification of breathing cracks in beams structures that is able to detect simultaneously the location and the depth of the damage. Zhu Jihong, Zhang Weihong and QiuKepeng presented topology optimization method to maximize the structural natural frequencies by using supports as elastic springs. Wang et al. (2006) presents a good example of designing a beam with an internal support to maximize its natural frequency. Author proposed method to find out minimum stiffness of an intermediate point support to maximize its natural frequency. Theoretical description about experimental modal analysis (EMA) is proposed by Brian J. Schwarz & Mark H. Richardson (1999).

III. METHODOLOGY

The presented study is divided into several steps. First analytical method used to find out the natural frequencies and mode shape of non – grooved beam. Same analysis is also carried out in simulation. Finite Element Method was used for analysis. Considering the higher modal strain area of beam in particular mode shape, cylindrical groove were created on the surface of beam. Parameter correlation optimization method used to find the value of parameters for to achieve optimal natural frequency for particular mode. Harmonic analysis were carried out to study the response of beam under harmonic external excitation. This analysis give better idea about significant of study. Results of simulation finally validated by experimental modal analysis.

Details methodology of work is discussed in following section:

A. Analyaitcal Method

Analytical Modal Analysis (AMA) were used to extract the natural frequencies of beam and corresponding mode shape. Derived the equation of motion by adopting the Euler-Bernoulli beam theory.

B. Finite Element Method

ANSYS Workbench simulation tool used for the Finite Element Modal Analysis (FEMA). This analysis was carried out in several steps.

- Firstly FEMA done on non – grooved beam to extract the natural frequencies and corresponding mode shape of beam. This analysis gives the beam behavior at various modes. Modal strain area is area where the beam deflect with a maximum amplitude. FEMA gives idea about the modal strain area of particular mode shapes.
- Single cylindrical groove was created on beam surface at the mid-point of beam length. FEMA done for single grooved beam. Effect of single groove on natural frequencies were plotted.

- Optimization done for two independent parameters i.e. groove location and groove diameter. Parameter correlation method used for optimization. ANSYS® Workbench tool used for optimization. Some major constrain used for optimization :

1. Certain distance should maintain between the grooves to avoid the overlap.
2. Groove must retain certain distance from both ends.
3. Groove diameter value set up to certain value to ensure that stiffness of beam will not get affected significantly.

Results of optimization were plotted to find out the effect of groove location and groove diameter on the natural frequencies.

- Harmonic analysis was carried out to find the response of grooved beam under the external harmonic excitation. Harmonic remote force of magnitude 100 N was applied on the groove surface to obtain the maximum deflection. Plot were plotted for both frequencies i.e. before groove and after groove.

C. Experimental Modal Analysis.

To validate the simulation results, experimentation modal analysis was done. FFT analyzer used to extract the natural frequency of beam. National instrument's NI 9234 Sound and Vibration module was for experimentation. LabView® signal express FFT analyser used to get the beam response for various natural frequencies. Magnitude vs frequency plot are obtained by Frequency Response Function (FRF).

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D. Results analysis.

Results were analyses of all the analysis to ensure the effect of groove on beam. Also the effect of groove location and groove diameter on natural frequencies are studded to optimize the natural frequency in order to avoid the resonance phenomena.

IV. NATURAL FREQUENCY AND MODE SHAPE EXTRACTION OF NON – GROOVED BEAM

A Structural Steel plate considered as beam for study. The dimensions of beam are, length L = 300 mm, width b = 40 mm, thickness t = 5 mm, young modulus E = 190 Gpa and material density $\rho = 7800$ kg/m^3. Fixed – fixed boundary condition has been taken in consideration during the study. The fixed – fixed boundary condition is fully constrained that does not allowed motion in any direction.

A. Analytical Method

First, the natural frequency and mode shape were extracted by analytical method. Euler – Bernoulli beam theory adopted to derive equation of motion. Solved the differential equation by Eigen value method and natural frequencies and mode shape were extracted. First three mode considered for the dissertation work. MatLab® code used to extract natural frequency and mode shapes. Result of analysis are given in table 1

Mode	**Natural Frequency (Hz)**
1	289.18
2	797.11
3	1562.5

Table 1 Result of Analytical Method

B. Finite Element Modal Analysis (FEMA)

FEMA performed for non – grooved beam. Fine meshing done for analysis. Tetrahedron shape elements were created with fine refinement at boundary condition.

Result of analysis are given in table

Mode	**Natural Frequency (Hz)**
1	292.11
2	803.66

3	1345.3
4	1574.2

Table 2 Result of FEMA

Mode shape of first four natural frequencies were plotted to observe the defection of beam at particular frequency. Figure shows the mode shape of non – grooved beam.

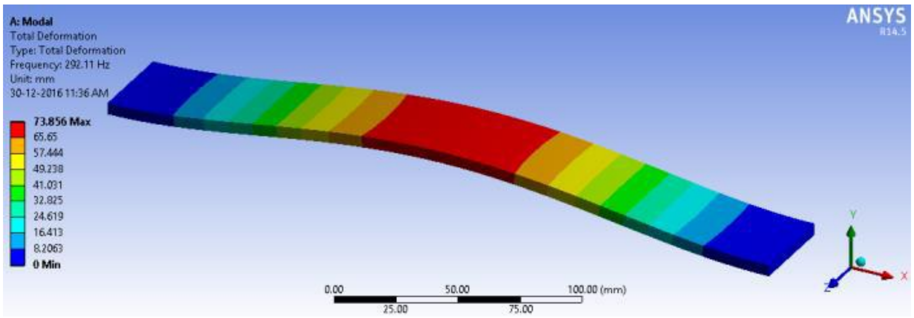


Figure 1Fundamental mode shape of non - grooved beam

Fundamental frequency is the lowest natural frequency responsible for first mode shape of beam vibration. In the first mode shape beam creates single lobe with the maximum deflection at center.

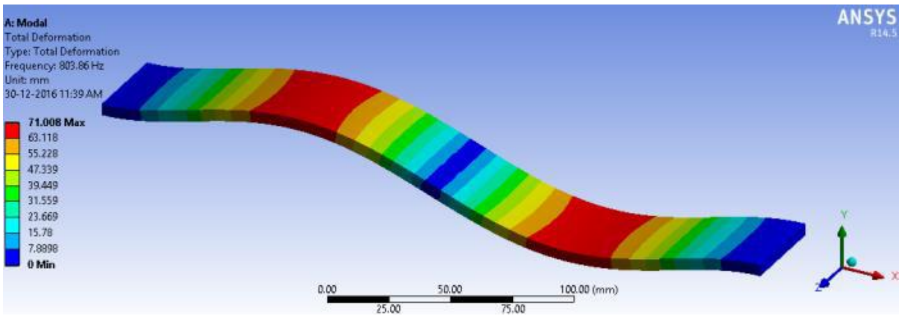


Figure 2 Second mode shape of non - grooved beam

In the second mode shape beam creates two lobe when vibrating where the maximum deflection gets at the center of lobe. The lobe vibrates in opposite phase to each other. Beam has zero deflection at three point, both the boundary condition and at center.

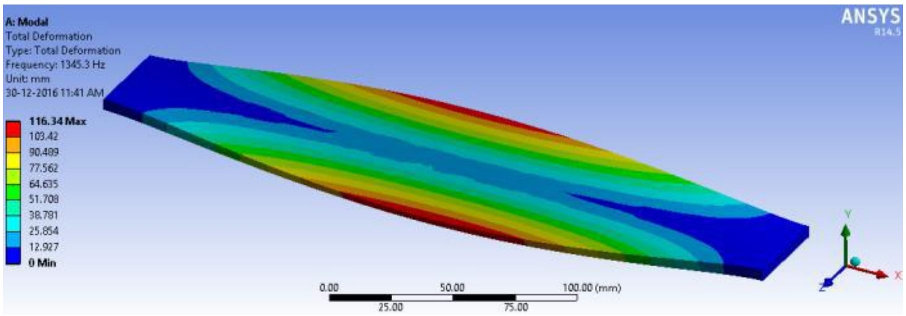


Figure 4 Third mode shape of non - grooved beam

Beam perform twisting motion when vibrate at third natural frequency. This frequency can called as torsional frequency of beam. Beam end has maximum deflection as shown in figure.

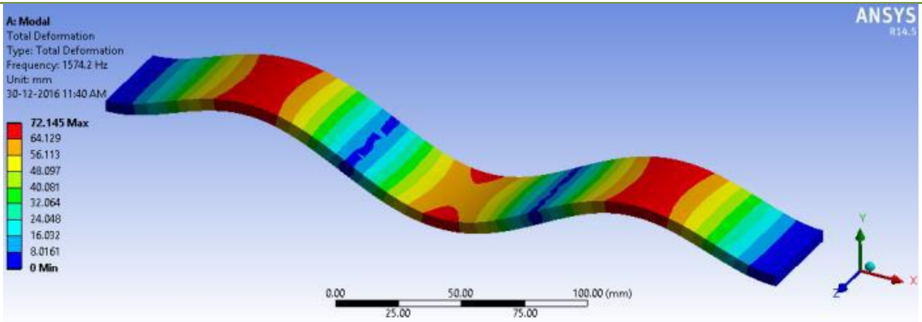


Figure 5 Fourth mode shape of non - grooved beam

Beam creates three lobe when vibrates at fourth natural frequency. One lobe out of three is at center and other two are on either side. The center lobe and other two lobe vibrates in opposite phase.

The modal strain area of beam for particular mode shape where beam deflect maximum. Red colored is the modal strain area for particular mode shape.

V. GROOVED BEAM MODELLING

Effect of groove on the natural frequency

Size of groove is comparatively very small than size of complete beam. While the groove does not change mass of the beam, but it affect the local stiffness of beam where the groove is located on the beam. Here the examples of optimization of first four natural frequencies of beam are presented.

To design the grooved beam, two independent geometrical parameters were considered. Two parameters which were considered in this study, groove diameter (d) and location (x) from left boundary. Groove made on surface was semi cylindrical in shape and its center will lies on top surface of beam. The value of groove diameter (d) was considered 5 mm and the groove were created on the top surface at a distance x from left boundary condition. Model of grooved beam is shown in fig. 1. Beam is thinner at groove and the thickness of beam at groove location is given by

Beam thickness (G) = Beam thickness – Groove diameter (*D*)/2.

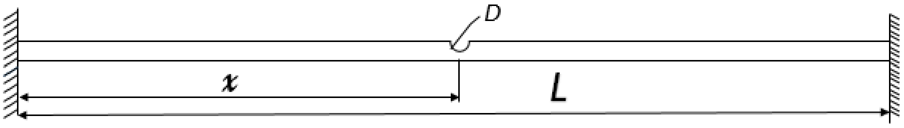


Figure 3 schematic representation of grooved beam

A. Finite Element Modal Analysis (FEMA) of single grooved beam

A single groove of diameter 5 mm at center of beam were created in ANSYS Workbench geometry module. Fine meshing done for better result. Tetrahedron element were created for meshing and refinement was done on groove surface and at boundary conditions. FEMA done for single grooved beam.

Result are shown in table 3

Mode	Natural Frequency (Before) Hz	Natural Frequency (After) Hz	Percentage change in Frequency
1	292.11	279.48	- 5 %
2	802.66	804.82	0 %
3	1345.3	1358.7	+ 0.9 %
4	1574.2	1487.1	- 6 %

Table 3 Comparison in frequencies after creating single groove

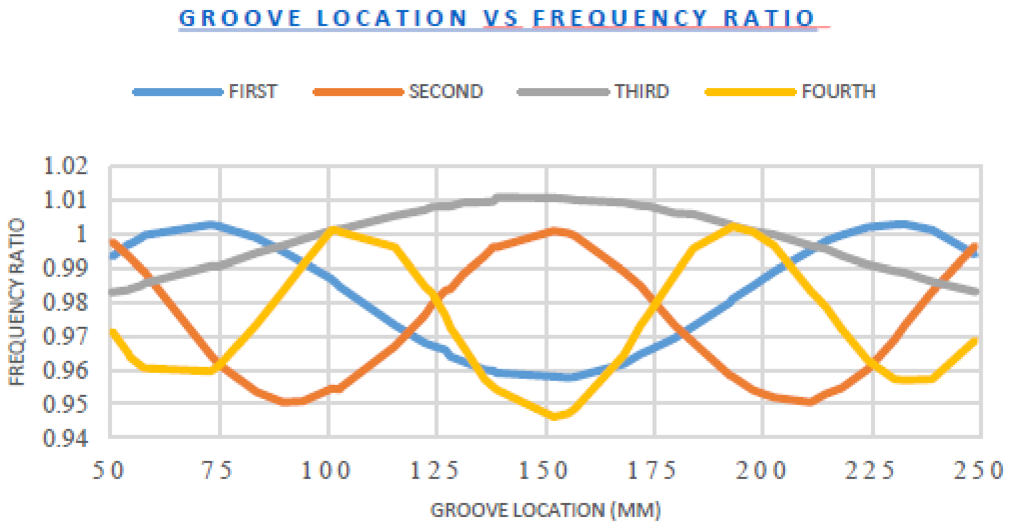
It can be observed that only first and fourth natural frequency has changed and second and third frequency remain unchanged. This results analyzed aligning with mode shape diagram of non – grooved beam. In the first and third mode shape, beam creates the lobe at center which is the higher modal strain area of the particular mode shape and groove also was created at same area. It come to know from analysis that the frequencies are more sensitive with groove if the groove lies at their modal strain area. Optimization technique were used to find out the optimal value of groove location and groove diameter to change frequency up to desired value.

B. Optimisation for optimal values of parameters

Parametric correlation optimization technique were used to get the optimal value of groove location and groove diameter. This technique forms the several combinations of parameters and analyze for each combination.

Three general constrain were considered for optimization. 1) Groove must retains a certain distance from boundary condition. 2) Groove should not overlap on each other. 3) Groove diameter has to be less than certain value to maintain certain stiffness value.

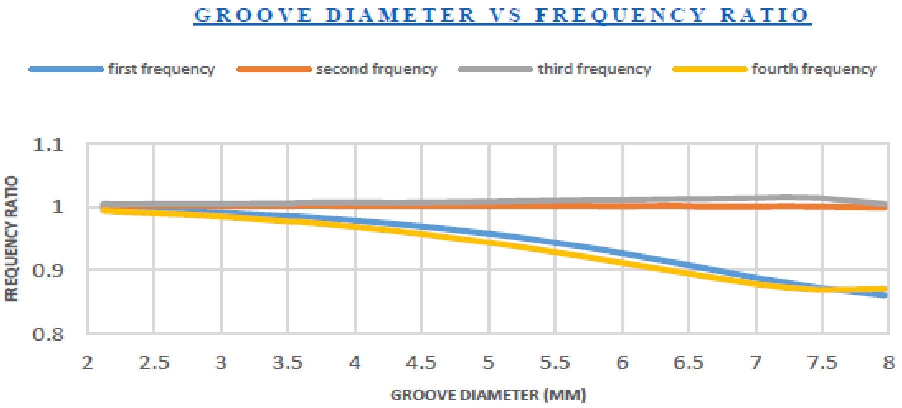
Created a single groove on the top surface of beam at mid-length. Set the range for groove location within constrain. Used parameter correlation optimization technique in Workbench to randomly get the 30 groove location. Considered the range for groove were 50 mm to 250 mm from left boundary. Optimization done for one input i.e. groove location and four output i.e. four natural frequencies. Result of parameter correlation optimization were plotted and seen the effect of single groove locatio on natural frequencies. Graph 1 shows the effect of groove location on frequency ratio (changed frequency to original frequency).



Graph 1 Effect of single groove location on natural frequencies

From graph 1 it can observed that frequencies changes maximum when groove lies on their modal stain area.

To find out the effect of groove diameter on the natural frequencies, groove diameter optimization was done by using parametric correlation. Considered groove diameter in the range of 2 mm to 8 mm. Single groove were created at 150 mm i.e. mid-point. Graph 2 shows the effect of groove diameter on natural frequencies.



Graph 2 Effect of groove diameter on natural frequencies

Graph 2 shows that as we increase the groove diameter, frequencies decreases. Here groove were created at mid-point of beam which is the modal strain area of first and fourth mode shape. Hence only first and fourth natural frequency has been changed. Second and third frequency has not changed.

VI. MODELLING OF GROOVED BEAM FOR OPTIMISATION OF NATURAL FREQUENCIES

A. Modelling of grooved beam for optimisation of fundamental natural frequency.

Fundamental frequency is the lowest natural frequency responsible for first mode shape of beam vibration. For fixed – fixed boundary condition, the fundamental frequency of beam was found to be 292.11 Hz. It can be observed from fig. 1 that the deformation is maximum at half of length of the beam i.e. $x/L \approx 0.5$. Modal strain area for fundamental frequency lies at half of length. So the groove was made at modal strain area. This groove reduces the local stiffness of beam without affecting mass. Fundamental natural frequency is more sensitive when groove lies at mid-point. Here the fundamental frequency is decreased from 292.11 Hz to 279.48 Hz by creating a groove of diameter 5 mm at distance 150 from left boundary.

B. Modelling of grooved beam for optimisation of second natural frequency.

The second natural frequency is found to be 803.66 Hz for non-grooved beam. Beam forms two lobe when vibrating with second natural frequency. The modal stain area for this frequency is lies approx. at L/4 and 3L/4. So the groove was made at this modal strain area.

Optimization done to find out the optimal value of groove location to change second natural frequency. It has been found that the second frequency were recorded lowest valve when the groove created at distance of 91.9 mm and 204.45 mm from left boundary. Change in frequencies after grooving are given in table No 4. It can be observed from table no 2 that only second natural frequency has been changed drastically and the other frequencies are not affected.

Mode	Natural Frequency (Before) Hz	Natural Frequency (After) Hz	Percentage change in Frequency
1	292.11	288.02	- 0.1 %
2	802.66	719.01	- 11 %
3	1345.3	1333.6	- 0.1 %
4	1574.2	1540.6	- 0.2 %

Table 4 Comparison in frequencies after creating two groove

C. Modelling of grooved beam for optimisation of third natural frequency

The third natural frequency is found to be 1345.3 Hz for non-grooved beam. Beam performs torsional vibration i.e. twisting about longitudinal axis, at third natural frequency. Groove was made along with the longitudinal axis throughout the length of beam at center. The diameter of groove was considered 5 mm. After creating longitudinal groove on beam surface, the frequency has been changed up to 1247.4 Hz. Fundamental, second and forth natural frequencies were not affected much. Figure 6 shows the longitudinal grooved beam.

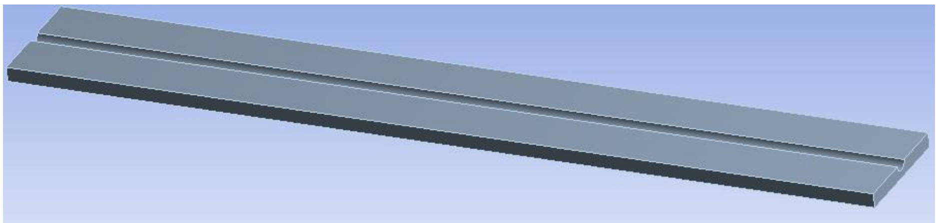
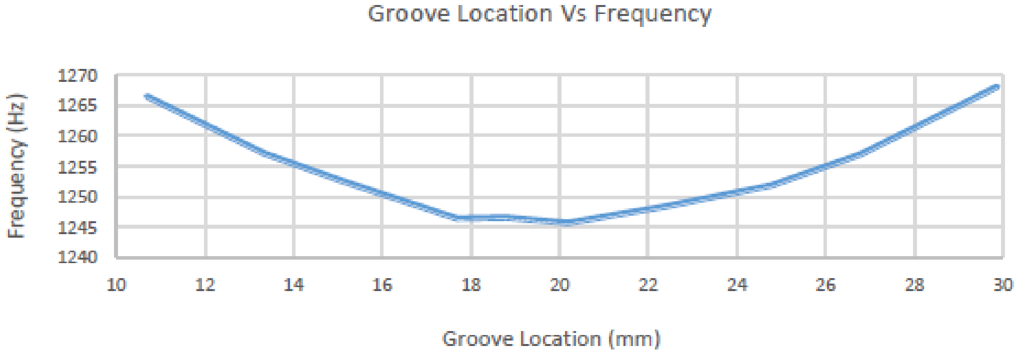


Figure 6 Longitudinal grooved beam to optimize third natural frequency

To find the optimal value of groove location, optimization was done. Graph 3 shows the optimization result i.e. effect of longitudinal groove location on third natural frequency. It can observed from the graph 3 that frequency changes maximum when groove lies at center.



Graph 3 Effect of longitudinal groove location on third natural frequency

Change in frequencies are given in table 5. It can be observed that only third natural frequency has been changed and no any other frequency.

Mode	**Natural Frequency (Before) Hz**	**Natural Frequency (After) Hz**	**Percentage change in Frequency**
1	292.11	289.23	- 1 %
2	802.66	795.69	- 1 %
3	1345.3	1247.4	- 7.5 %
4	1574.2	1556.9	- 1 %

Table 5 Comparison in frequencies after creating longitudinal groove

D. Modelling of grooved beam for optimisation of fourth natural frequency.

The forth natural frequency was found to be 1574.2 Hz for non-grooved beam. Beam forms three lobe when vibrating with forth natural frequency. So groove was made at this three modal strain area. Groove diameter was consider as 5 mm and groove were created at 68 mm, 150 mm and 240 mm from left boundary.

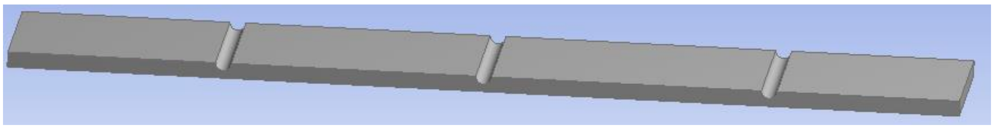


Figure 7 Three grooved beam to optimize fourth natural frequency

To find the optimal value of groove location optimization was done. It has been found that the third natural frequency were recorded lowest value when groove created at distance of 69.9 mm, 146.15 mm, and 231.58 mm from left boundary condition. Table 6 shows the effect of three groove on the natural frequencies.

Mode	**Natural Frequency (Before) Hz**	**Natural Frequency (After) Hz**	**Percentage change in Frequency**
1	292.11	281.26	- 3.5 %
2	802.66	761.3	- 5 %
3	1345.3	1327.4	- 1 %
4	1574.2	1352.6	- 14 %

Table 6 Comparison in frequencies after creating three groov

Out of three lobe, one lobe was formed approximately at L/2 i.e. mid-point, which is the modal strain area of first natural frequency. Modal strain area of first frequency also get affected hence the first natural frequency also changes.

VII. HARMONIC ANALYSIS

Harmonic analysis were carried out to find the beam response in resonance. Harmonic analysis is the tool which gives beam dynamic behavior i.e. deflection under external harmonic excitation within given frequency range. Harmonic remote force of magnitude 100 N were applied on exactly on groove surface to get maximum deflection. For harmonic analysis frequency range of force kept was 0 Hz to 1600 Hz. The location of harmonic force is placed on higher modal strain area of each mode shape at respected natural frequencies. The response of beam under two frequency i.e. non – grooved beam frequency and grooved beam frequency were plotted.

A. Harmonic Analysis for single grooved beam

Groove alter the fundamental frequency to 279.4 Hz from 292.1 Hz. Harmonic analysis were carried out at this two frequencies i.e. frequency before grooved and after grooved. Figure 8 and 9 shows the harmonic analysis response of single grooved beam when external harmonic force has frequency of 292 Hz and 279 Hz respectively.

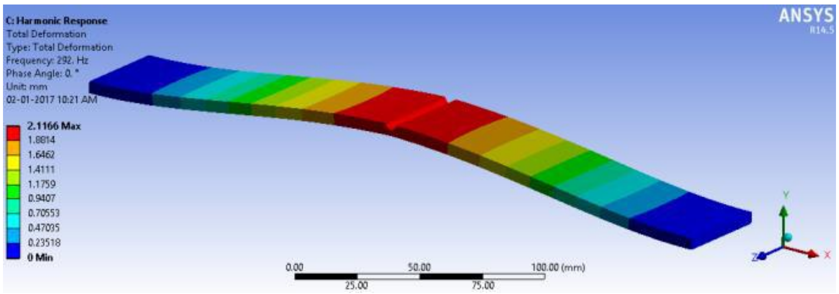


Figure 8 Harmonic response of single grooved beam at 292 Hz

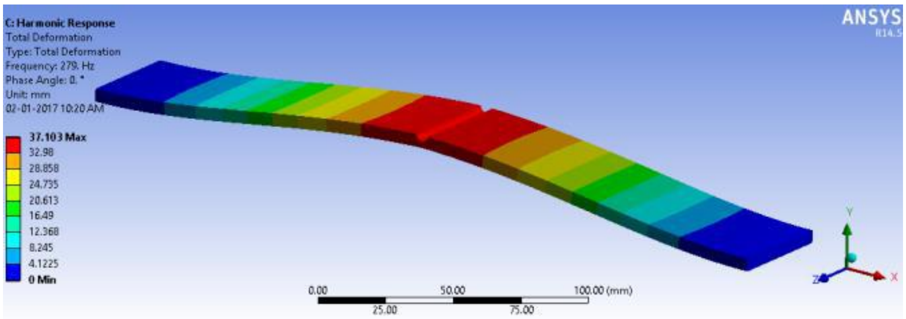


Figure 9 Harmonic response of single grooved beam at 279 Hz

From the figure 8 and 9 it can be observed that the maximum deflection of single grooved beam is 2.11 mm at 292 Hz and 37.1 mm at 279 Hz. It indicates that beam is now vibrating with maximum deflection at 279 Hz than 292 Hz which means resonance of beam has changed on at 279 Hz.

B. Harmonic Analysis for two grooved beam

Two cylindrical groove on beam surface alters the second natural frequency to 719 Hz from 803.3 Hz. Harmonic analysis were carried out to find the response of beam under harmonic force having two frequencies. Harmonic remote force of magnitude 100 N were applied on exactly on groove surface to get maximum deflection. Figure 10 and 11 shows the harmonic analysis response of two grooved beam when external harmonic force applied at frequency of 803 Hz and 719 Hz respectively.

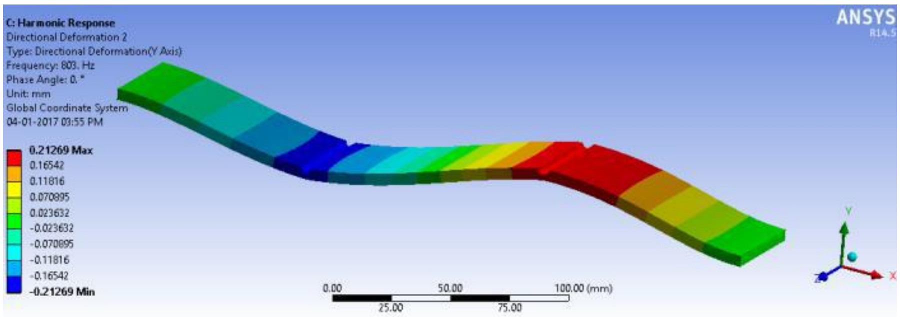


Figure 10 Harmonic response of two grooved beam at 803 Hz

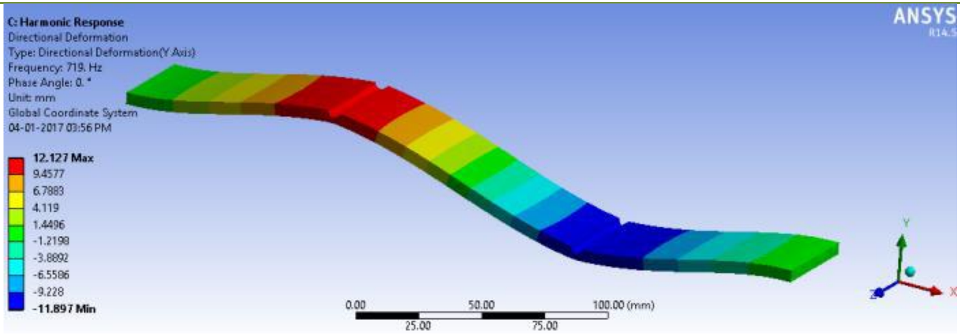


Figure 11 Harmonic response of two grooved beam at 719 Hz

The maximum amplitude of two grooved beam at 803 Hz is 0.21 mm and at 719 Hz is 12.1 mm. It indicates that the beam vibrates with maximum amplitude at 719 Hz than 803 Hz. Resonance of beam is shifted to 719 Hz from 803 Hz.

C. Harmonic Analysis for longitudinal grooved beam

Beam perform twisting motion when vibrates at third natural frequency. Longitudinal groove alters the frequency to 1245 Hz from 1345 Hz. As beam perform twisting motion, a harmonic couple were applied instead of force. The harmonic couple of 1000 N – mm were applied at the center of beam around the longitudinal axis with frequency range 0 Hz to 1600 H

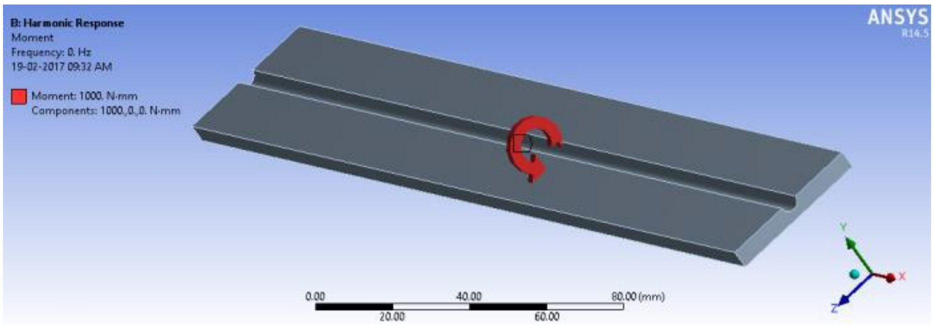


Figure 12 Harmonic couple applied to get maximum twisting motion

Figure 13 and 14 shows the harmonic analysis response of longitudinal grooved beam when external harmonic couple applied at frequency of 1345 Hz and 1245 Hz respectively.

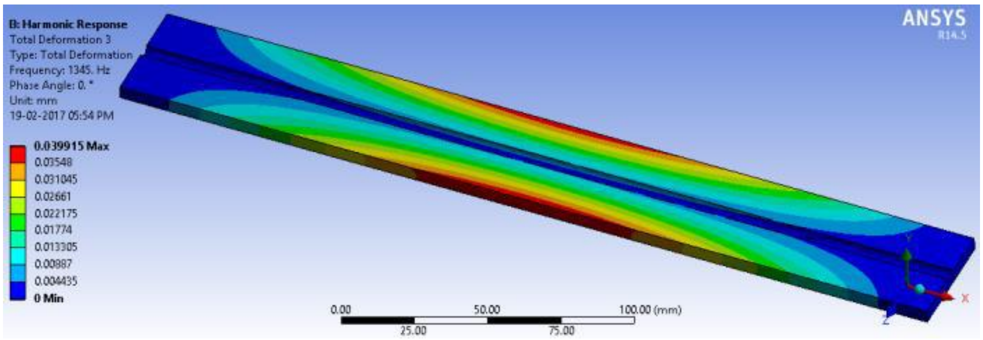


Figure 13 Harmonic response of longitudinal grooved beam at 1345 Hz

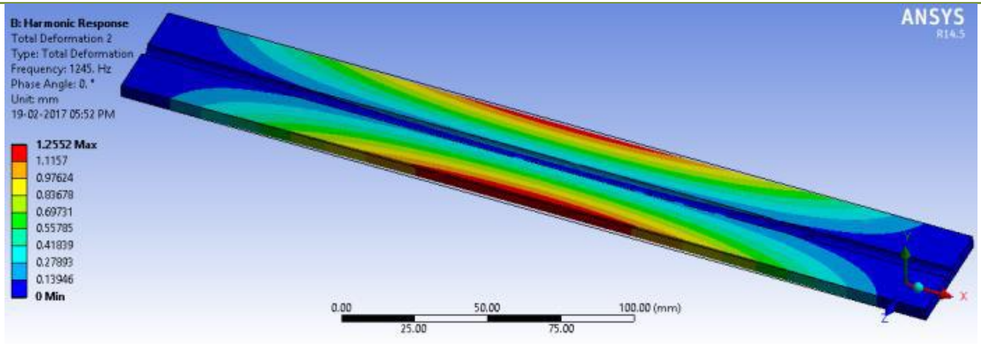


Figure 14 Harmonic response of longitudinal grooved beam at 1245 Hz

Beam vibrates with maximum amplitude of 0.039 mm Hz at 1345 Hz and 1.25 mm at 1245 Hz. Which means resonance occurs at 1245 Hz for grooved beam.

D. Harmonic Analysis for three grooved beam

Three cylindrical groove at optimized locations changes the fourth natural frequency of beam to 1345 Hz from 1574 Hz. Harmonic remote force of magnitude 100 N were applied on groove surface to get maximum deflection. Figure 14 and 15 shows harmonic response of three grooved beam at 1574 Hz and 1345 Hz respectively

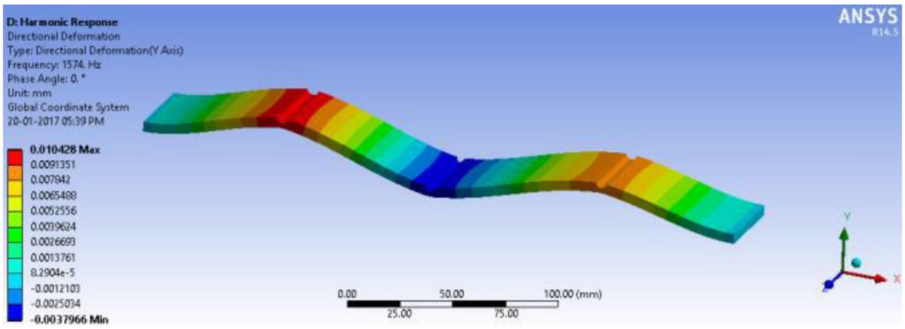


Figure 15 Harmonic response of three grooved beam at 1574 Hz

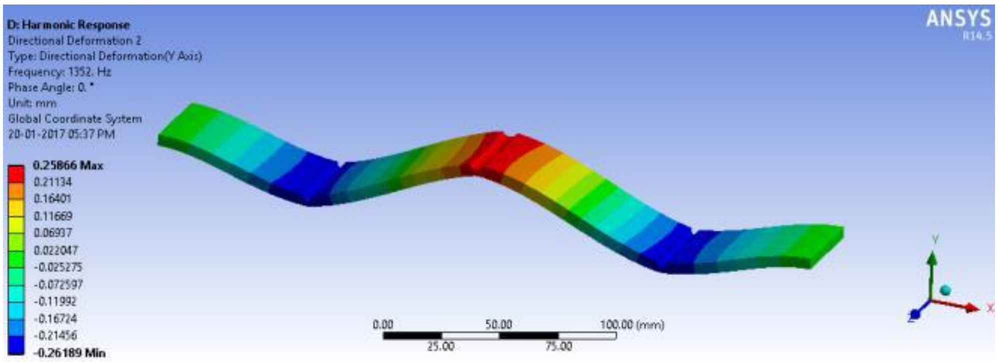


Figure 15 Harmonic response of three grooved beam at 1352 Hz

From the figure 15 and 16 it can be observed that the maximum deflection of three grooved beam is 0.010 mm at 1574 Hz and 0.25 mm at 1345 Hz. It indicates that beam is now vibrating with maximum deflection at 1345 Hz than 1574 Hz which means resonance of beam has changed on at 1345 Hz.

From the harmonic analysis it can be observed that after creation of cylindrical groove or series of cylindrical grooves alters the resonance frequency of beam and at new frequency beam vibrates with maximum amplitude.

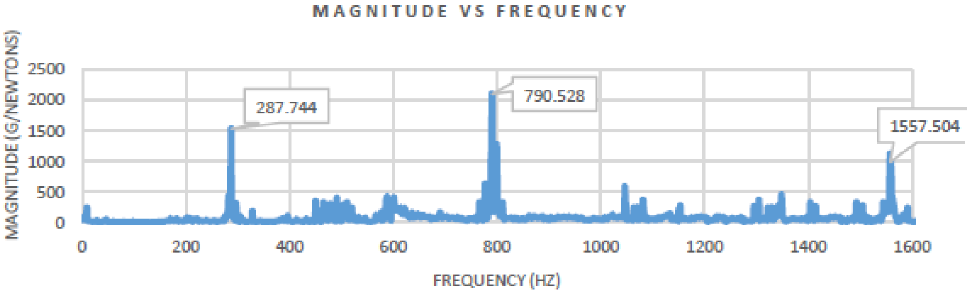
VIII. EXPERIMENTAL MODAL ANALYSIS (EMA)

Experimentation was conducted to validate the results. Sample were prepared on the basis of FEMA and optimization results. The parameter value which has changed the frequencies maximum were considered for analysis. Five cases were considered for study i.e. non – grooved, single grooved, two grooved, longitudinal grooved and three grooved beam. Vertical milling machine used to create groove on beam surface. A heavy fixture made to provide fixed – fixed boundary condition. Frequency Response Function (FRF) were used to extract natural frequencies.

Figure 17 Work piece sample

A. Experimentation modal analysis for non grooved beam

Frequency range set for experimentation was 0 Hz to 1600 Hz. Result of experimentation are shown in graph 4.



Graph 4 Frequency response of non-grooved beam

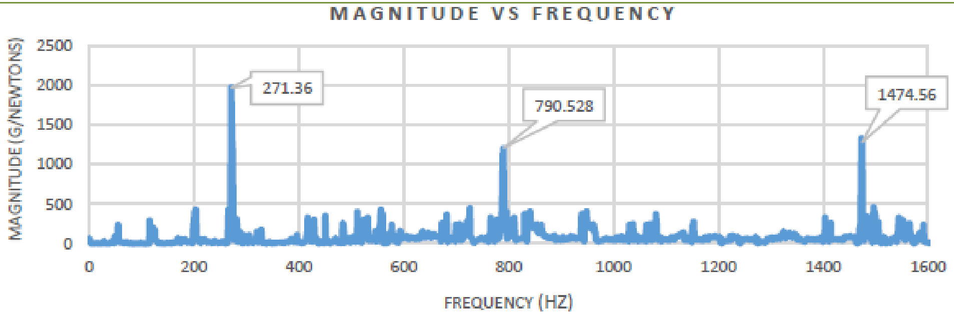
The comparison between Analytical method, FEMA and EMA are given in table 7. Third natural frequency was not appeared in analytical as well as in the experimental modal analysis. Table 7 gives the value of natural frequencies of non – grooved beam obtained by all three analysis.

Mode	Analytical method Natural Frequency (Hz)	FEMA Natural Frequency (Hz)	EMA Natural Frequency (Hz)
1	289.18	292.11	287.74
2	797.11	802.66	790.52
3	-	1345.3	-
4	1562.5	1574.2	1557.5

Table 7 Comparison between analyses

B. Experimentation modal analysis for single grooved beam

Single groove of diameter 5 mm were created at the center of beam to optimize the first natural frequency. This groove location alters fundamental frequency. Results of experimentation are shown in graph 5.



Graph 5 Frequency response of single grooved beam

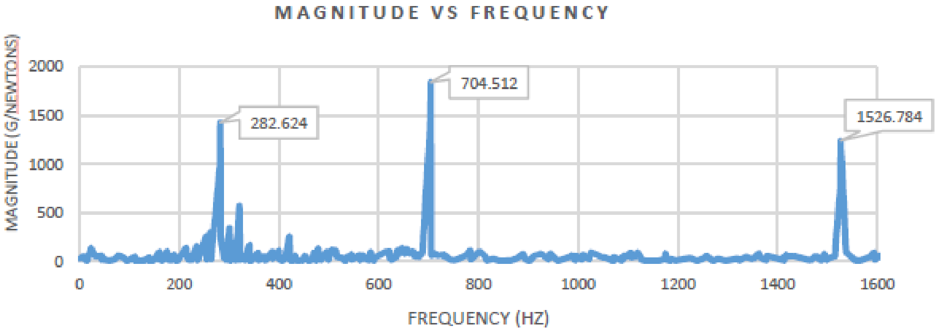
Table 8 shows the natural frequencies of single grooved beam in comparison with FEMA results.

Mode	**FEMA**		**EMA**	
	Non grooved (Hz)	**Single grooved (Hz)**	**Non grooved (Hz)**	**Single grooved (Hz)**
1	292.11	279.48	287.74	271.36
2	802.66	804.82	790.52	790.42
3	1345.3	1358.7	-	-
4	1574.2	1487.1	1557.5	1474.56

Table 8 Comparison between analysis results of single grooved beam

C. Experimentation modal analysis for two grooved beam

Two groove of diameter 5 mm were created on work piece at locations which were given by FEMA optimization. Groove were created at distance of 91.9 mm and 204.45 mm from left boundary. This groove location alters the second natural frequency. Graph 6 shows the results of experimentation.



Graph 6 Frequency response of two grooved beam

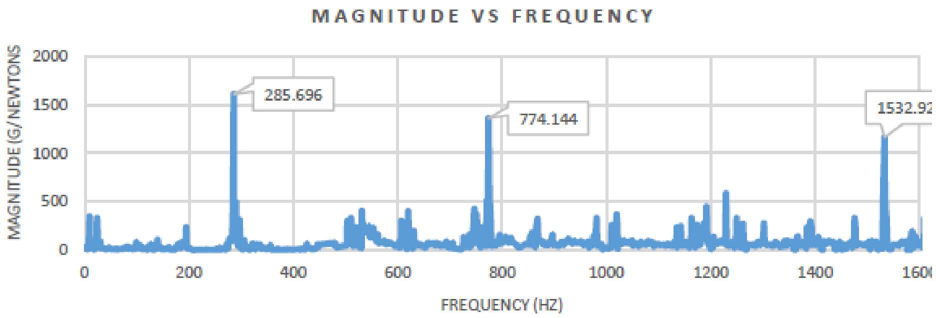
Table 9 shows the natural frequencies of two grooved beam in comparison with FEMA results.

Mode	**FEMA**		**EMA**	
	Non grooved (Hz)	**Two grooved (Hz)**	**Non grooved (Hz)**	**Two grooved (Hz)**
1	292.11	288.02	287.74	282.62
2	802.66	719.01	790.52	704.51
3	1345.3	1333.6	-	-
4	1574.2	1540.6	1557.5	1526.78

Table 9 Comparison between analysis results of two grooved beam

D. Experimentation modal analysis for longitudinal grooved beam

A longitudinal groove of diameter 5 mm thought the beam length was created to optimize the third i.e. twisting natural frequency. Results of experimentation are shown in graph 7.



Graph 7 Frequency response of longitudinal grooved beam

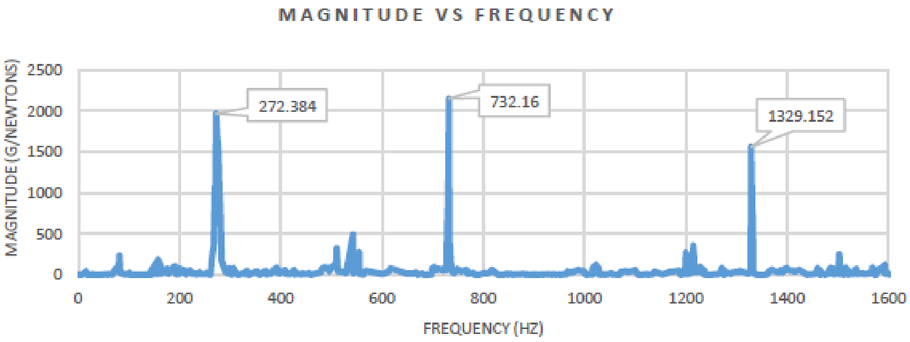
Table 10 shows the natural frequencies of longitudinal grooved beam in comparison with FEMA results.

Mode	**FEMA**		**EMA**	
	Non grooved (Hz)	**Long. grooved (Hz)**	**Non grooved (Hz)**	**Long. grooved (Hz)**
1	292.11	289.23	287.74	285.26
2	802.66	795.61	790.52	774.63
3	1345.3	1245.4	-	-
4	1574.2	1556.9	1557.5	1532.11

Table 10 Comparison between analysis results of longitudinal grooved beam

E. Experimentation modal analysis for three grooved beam

The optimal values of three groove location obtain from optimization were considered for preparation work piece. Groove were created on beam at 69.9 mm, 146.15 mm, and 231.58 mm from left boundary condition. This groove location gives the minimum value of fourth natural frequency. Graph 6 shows the results of experimentation.



Graph 8 Frequency response of three grooved beam

Table 11 shows the natural frequencies of three grooved beam in comparison with FEMA results.

Mode	**FEMA**		**EMA**	
	Non grooved (Hz)	**Three grooved (Hz)**	**Non grooved (Hz)**	**Three grooved (Hz)**
1	292.11	281.26	287.74	272.38
2	802.66	761.3	790.52	732.16
3	1345.3	1327.4	-	-
4	1574.2	1355.8	1557.5	1329.15

Table 11 Comparison between analysis results of three grooved beam

IX. CONCLUSION

To avoid the resonance of existing structure has certain limitations like to change geometry of structure, mass of beam or support layout. This is after design method in which the frequency of beam is changed without changing mass or disturbing support system. Producing the groove on desired locations with desired dimension makes large difference in natural frequency. Natural frequencies are very sensitive with groove locations hence it can be changed to particular value by creating the groove at higher modal strain area of that mode shape. In this study frequency has been changed up to 14 % by creating series of grooves at modal strain area. Harmonic analysis results shows that resonance shifts after creating groove or series of grooves. The disadvantage of this method is that groove makes the structure weaker at particular location hence this method cannot be used for those structure which are under high stress.

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