Experimental, Analytical and FEM analysis of passive CLD, FLD and patched layer treatment to reduce vibrations with different viscoelastic materials

Pankaj R. Beldar[1], D.V.Kushare[2]

Abstract- **In most of the structures vibrations are not desirable. For better performance we have reduce vibrations by means of active and passive vibration control. As there are many problems with active vibration control, use of passive vibration control comes in picture. There is wide range of viscoelastic materials which can be used as passive constrained layer damping method. In this project ,scope is to find another materials which can be used as passive damping material. For calculating loss factor obrest beam is used with logarithmic decrement and half power bandwidth method.To add damping to the system, viscoelastic materials (VEM) are added to structures, in order to enhance damping effects of the VEM, a constraining layer is attached. Due to the addition of the material on the system the fundamental characteristics of the systems are altered much. vibrations will reduce the life of machine component also effect the reliability and efficiency of machine component. To reduce this types of vibratin and sound proofing we can use materials which possesses the property of energy consumption like viscoelastic materials. Rubber in transition region shows the damping behaviour. In this project aim to find best viscoelastic material for damping purpose by using ross kerwin ugler model in MATLAB.by using FEM analysis damping loss factor is calculated by logarithmic decrement method. For experimentation half power bandwidth method is used. Effect of damping is considerable in machine components and structures.to avoid or eliminate structural vibration passive damping treatment comes in picture. For accounting the damping effects, lots of research and efforts have been done in this field to suppress vibration and to reduce the mechanical failures with different viscoelastic materials. Testing is performed on ni-lab view with analytical modelling in MATLAB.**

keyword- damping treatment, CLD, FLD, Damping factor, loss *factor*

I.INTRODUCTION

Vibrations of structures, moving bodies and sheet metals are responsible for causing many problems such as unbalanced forces in machines, structural fatigue, external excitations. For better performances of machine components it becomes more essential to reduce or eliminate these unwanted vibrations, so that to lifetime of structures will increase. Adding viscoelastic materials to a structure or material system improves the vibration response by reducing the resonant peak response, reducing settling time of the given response and reducing noise transmission.[1] Many polymers exhibit viscoelastic behavior. Viscoelasticity is a material behavior and combination of perfectly elastic and perfectly viscous behavior. An elastic material possesses perfect energy conversion, all the energy stored in a material during loading is recovered when the load is removed. Hence, elastic materials have an in phase stress-strain relationship. Contrary to an elastic material, there exists purely viscous behavior, A viscous material does not recover any of the energy stored during loading after the load is removed (the phase angle between stress and strain is exactly π/2 radians) lost as 'pure damping.' For a viscous material, the stress is related to the strain as well as the strain rate of the material. Viscoelastic materials have behavior which falls between elastic and viscous extremes. The rate at which the material dissipates energy in the form of heat through shear, the primary driving mechanism of damping materials, defines the effectiveness of the viscoelastic material. Because a viscoelastic material falls between elastic and viscous behavior, some of the energy is recovered upon removal of the load, and some is lost or dissipated in the form of thermal energy. The phase shift between the stress and strain maximums, which does not to exceed 90 degrees, is a measure of the materials damping performance. The larger the phase angle between the stress and strain during the same cycle. The more effective a material is at damping out unwanted vibration or acoustical waves. The damped structures are more rigid to give better performance. To attenuate the vibrations and reduce noise level, structures should be properly damped. Lots of research is being carried out in order to reduce the automobile vibrations to increase comfort level of passenger. Mostly the sources of vibrations are engine cabinet, chassis, door panel, front panel, hood of automobile. These high amplitude vibrations cause the increased noise level in automobile. From last few decades the lots of research is carried out in order to find new damping material. Existing materials have low damping capacity. Hence to increase damping performance, new damping materials research is carried out by many engineers. The most common are viscoelastic materials. Viscoelasticity is the combination of viscous and elastic behaviour. They are temperature and frequency dependent. All their properties like young's modulus, tensile modulus, density changes accordingly as frequency changes. To

Pankaj R. Beldar[1] (PG Student) of Mechanical Department Design, NDMVP'SKBTCOE,Nashik,422013India(pankajbell@gmail.com\)
Prof.D.V.Kushare [2] (Asst. professor)Mechanical Department [Design] NDMVP'SKBTCOE,Nashik,422013India (kushare_dv@rediffmail.com)

analyse viscoelastic material the temperature and frequency dependency should be considered. They are the materials which absorbs the energy in the form of heat energy to absorb the vibrations. They shows both behaviour viscous as well as well as elastic. Hence they have ability to absorb the vibrations. For damping purpose they are used in the transition region of polymer state.

A. List of common viscoelastic polymeric materials[13]

1. Acrylic Rubber
2. Butadiene Rubber
3. Butyl Rubber
4. Chloroprene
5. Chlorinated Polyethylene
6. Ethylene-Propylene-Diene
7. Fluorosilicone Rubber
8. Fluorocarbon Rubber
9. Nitrile Rubber
10. Natural Rubber
11. Polyethylene
12. Polystyrene
13. Polyvinyl chloride (PVC)
14. Polymethyl Methacrylate (PMMA)
15. Polybutadiene
16. Polypropylene
17. Polyisobutylene
18. Polyurethane
19. Polyvinyl acetate
20. Polyisoprene
21. Styrene-butadiene (SBR)
22. Silicon Rubber
23. Urethane Rubber

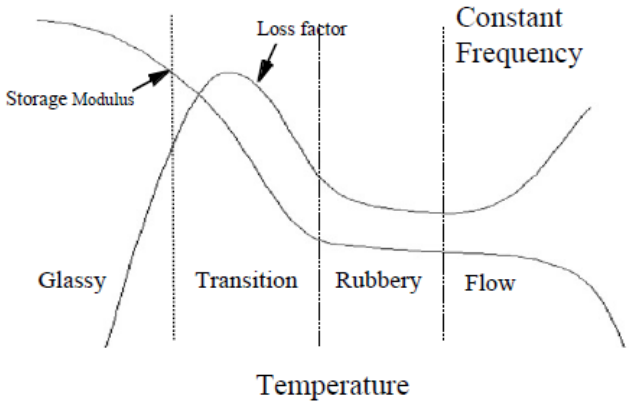

Fig 1: Variation in loss factor with temperature [13]

B. Specimen preparation

The specimen is prepared by standard process ASTM standard E-756(05). Beam size is selected as 400mm X 50mm X 5mm.

Thickness of butyl rubber is considered as 1mm.

Properties of butyl rubber in transition region are given below. Properties are checked by standards on cyclic loading machine to calculate storage modulus and loss modulus.as

Complex modulus= storage modulus (real) +loss modulus (imaginary)

Butyl rubber Properties at 10 hz

Storage modulus= 6.6892Mpa
Shear modulus= 2.2365Mpa
Loss factor= 0.185755

Similarly butyl rubber, buna nitrile, silicon rubber, natural rubber, PVC, SBR core is used for making specimens. After testing whose damping factor is more that material is selected for checking FLD and PATCH layer effect.

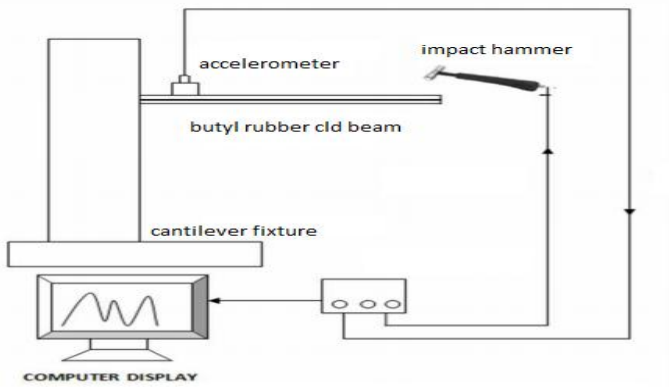

Fig 2: Experimental Set Up

For experimental analysis is done on NILAB view modal analysis model at modern college of enginnering, pune. All the material properties are checked by reputed testing labs in pune, Mumbai and nashik. Experimental results are damping loss factors and natural frequencies. From MATALB coding modal analysis of undamped beam is done. And then another MATLAB code is generated for ross kerwin ugler model of viscoelasticity to calculate damping loss factor. [3]

II.MATHEMATICAL MODELING

In order to approximate system loss factors and hence determine viscoelastic and constraining layer thickness required for maximum damping, an analysis based on the Ross-Kerwin-Ungar (RKU) equations was used .The equations are based on the analysis of a simple sandwich configuration shown in Figure 3.

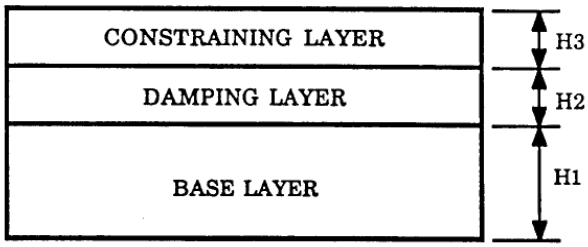

Fig 3: Elements of a Simple Sandwich Damping System.

The first step in determining the composite system loss factor is to determine the system flexural rigidity. The flexure rigidity, El, of the above system can be written

$$EI=\frac{E_1H_1^3}{12}+\frac{E_2H_2^3}{12}+E_1H_1D^2+X-Y$$

$$X=E_2H_2(H_{21}-D)^2+E_3H_3(H_{31}-D)^2$$

$$Y=[\frac{E_2H_2^3}{12}+\frac{E_2H_2^3}{12}(H_{21}-D)+E3H3(H_{31}-D)]\frac{(H31-D)}{1+g}$$

$$D=\frac{E2H2(H21-H31*0.5)+g(E2H2H21+E3H3H31)}{E1H1+E2H2*0.5+G(E1H1+E2H2+E3H3)}$$

$$H_{31}=0.5(H_1+H_3)+H_2$$

$$H_{21}=0.5(H_1+H_2)$$

$$g=\frac{G2}{E3H3H2K^2}$$

E = Young's Modulus
G = Shear Modulus
I = Moment of Inertia
H = Member Thickness

K^2 = Modal Wave Number

$$K^2 = w_n * \frac{1}{\sqrt{\frac{EH^3 g_C}{12(1-v^2)Hp}}}$$

W_n = Natural Frequency

gc = Gravitational Constant

v = Poisson ' s Ratio of Composite Body

p = Density of Composite Body

To introduce damping into the equations, it is necessary to use the complex

following assumptions were made:

(1) Damping of the base structure is small (i.e., eta1 = 0).

(2) Extensional stiffness of damping layer is small compared to rest of composite

(i.e., $E_1 >> E_2$ and E 3> > E_2).

(3) Damping of the constraining layer is small (i.e., eta3= 0).

Under these assumptions the total system loss factor can be calculated using

$$N_{SYS} = \frac{\frac{12}{a^2+b^2}}{EH^3}[A - B - C]_{IM}$$

$$EH^3 = E_1H_1^3 + E^1H_3^3 + \frac{12}{a^2+b^2}[A - B - C]_{RE}$$

$$A = g\, E_1H_1E_3H_{31}^2[a+b*eta2+i(eta2*a)]$$

B=ElH1E2H2H31[a+b*eta2+i(eta2*a)-b)]

C=2gE2H2E3H2lH,l[a-(eta2)^2 a+2b*eta2+i (2a*eta2-b+b* eta2)^2)]

a=E1H1+g(ElHl+E3H3)

b=g*eta2($E_1H_1+E_3H_3$)

i=$(-1)^{0.5}$

eta2 = Viscoelastic Layer Loss Factor

IM = Imaginary Part

RE = Real Part

Nsys = System Loss Factor

Fig 8 shows the modal analysis of Undamped beam. With 6 mode shapes. Modal analysis is carried out to calculate natural frequency of Undamped beam. Fig 10 shows the mode shapes in MATLAB for Undamped beam. Euler bernaullies beam is used for experimental modal analysis.

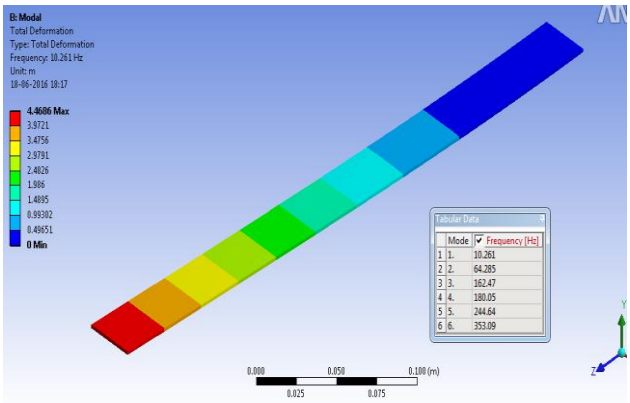

Fig 4: Modal Analysis of undamped beam

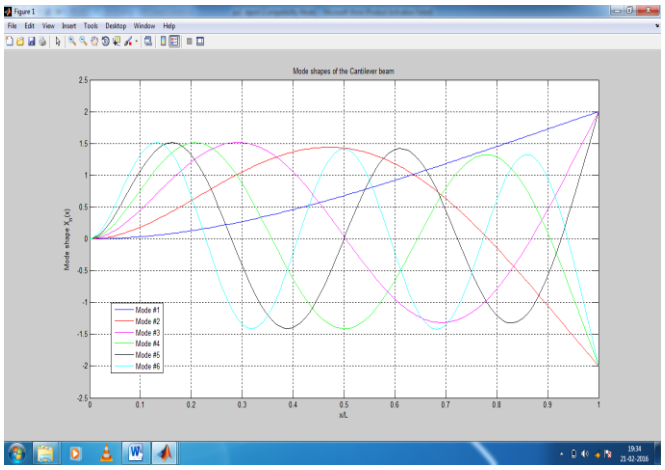

Fig 5: Modal analysis of undamped beam (MATLAB mode shapes)

III. MATLAB PREDICTION

The above analytical model suggested by ross ,kerwin ugler is coded in MATLAB software for calculation of damping loss factor. Following MATLAB graphs shows the variation of loss factor with change in thickness of viscoelastic layer.

Loss factor= storage modulus (A)/ loss modulus(B)

A. Butyl rubber

loss factor=0.074>>

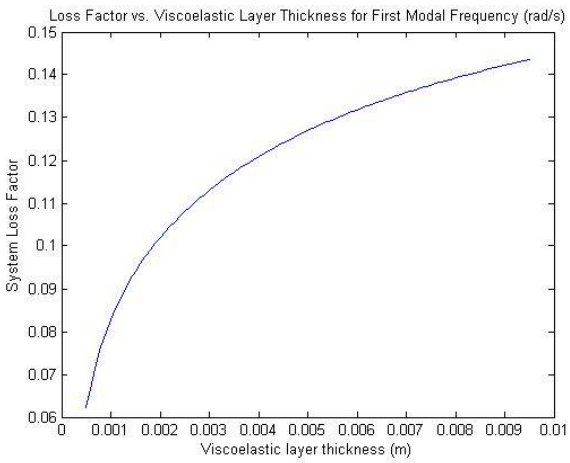

Fig 6: MATLAB results- loss factor vs thickness Butyl rubber

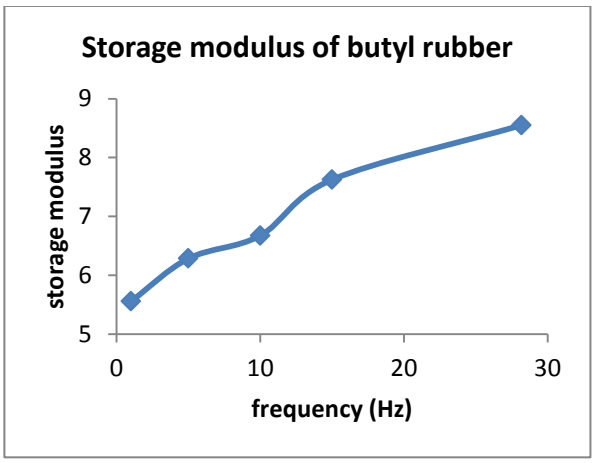

Fig 7: Storage modulus of butyl rubber

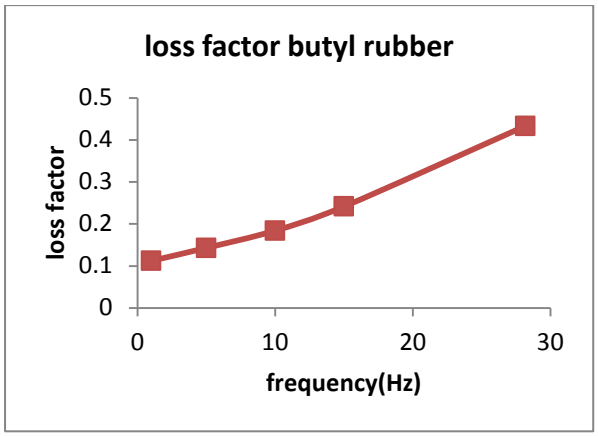

Fig 8: Storage modulus of butyl rubber

IV. EXPERIMENTATION

Fig 9: Experimental Setup

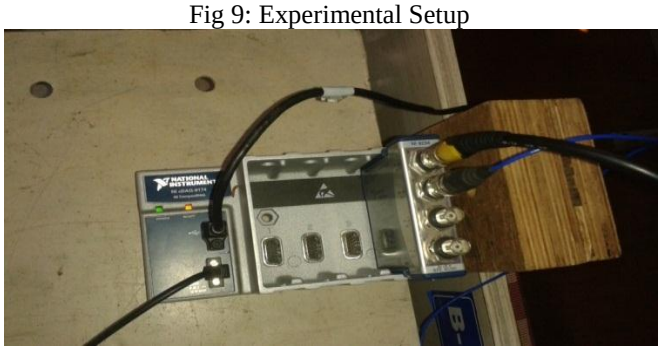

Fig 10: DAQ system

Experimentation is done with NI-LAB view testing module of modal analysis at modern college of engineering, pune with 8 specimens. Impact hammer testing is performed on CLD and FLD beams. Firstly experimentation is done with 6 materials and 6 specimens. Afterward depending upon results FLD and Patched layer beam were tested.

NI-LAB view provides modal analysis module. DAQ system is used for interfacing the actual model and FFT

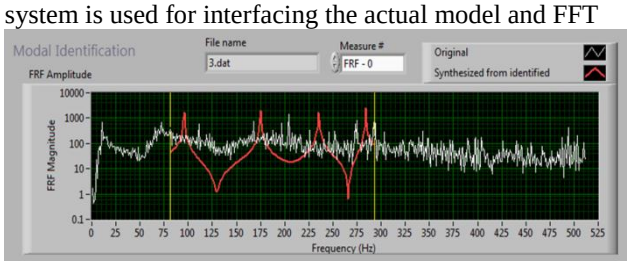

Fig 11: FRF Spectrum of butyl rubber CLD beam

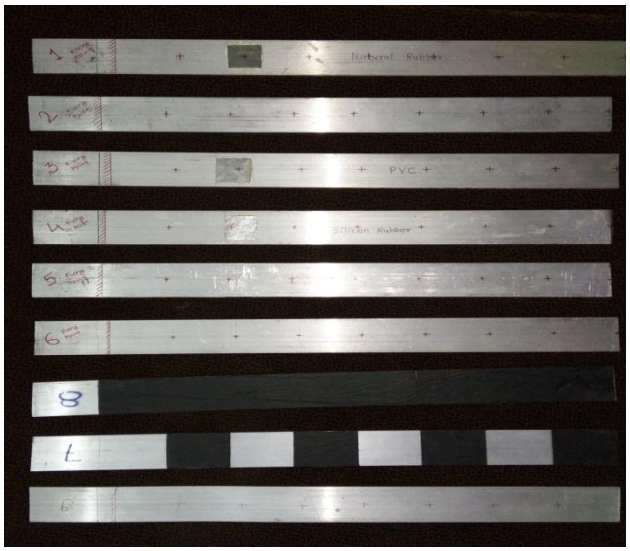

Fig 12: specimens

V. FEM RESULTS

FEM analysis of viscoelastic material is most challenging thing this project. VISCO88- VISCO89 elements can be used for viscoelastic analysis in ANSYS. Use of prony series, shift function helps to model viscoelastic material in ANSYS. BEAM23 element is used modal analysis of Undamped beam. SHELL188 element is used for formation composite layers. FEM analysis is performed on ANSYS-15.Transient, modal analysis is performed to calculate natural frequencies and damping loss factor. Obtained data is converted into excel sheet for ease of calculation. MATLAB program is used to calculate the damping loss factor with the help of excel data.

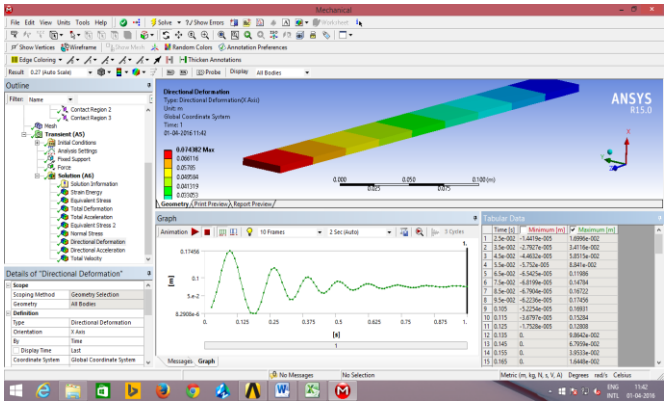

Fig 13: Transient Directional Deformation of butyl rubber

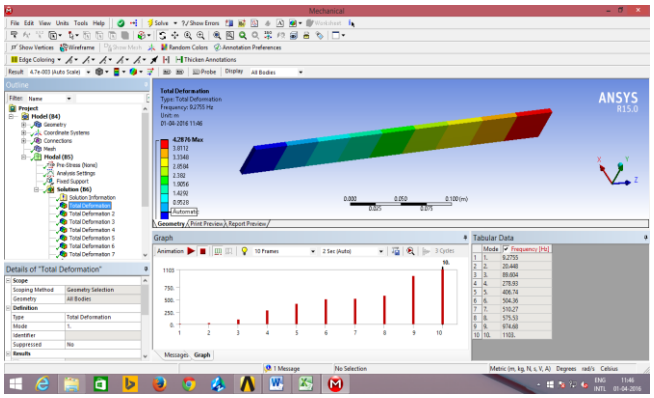

Fig 14: Modal Analysis of butyl rubber

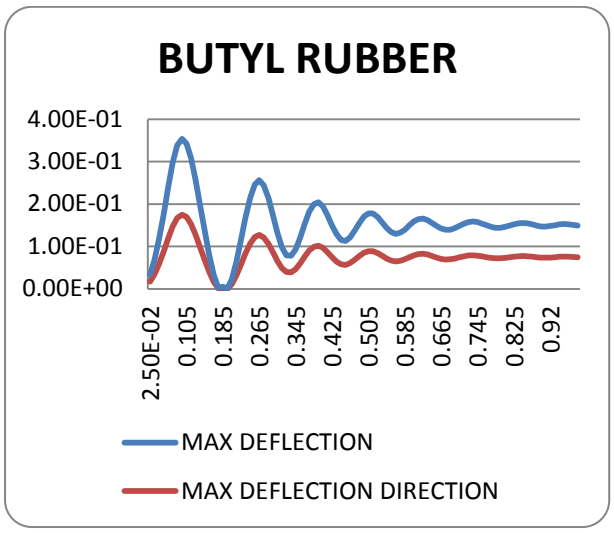

Fig 15: Logarithmic Decrement of butyl rubber

For patched layer testing 10 specimens with different patch size were selected, which are tabulated in the following table. Same procedure is repeated to analyze the damping behavior of patch layer treatment.

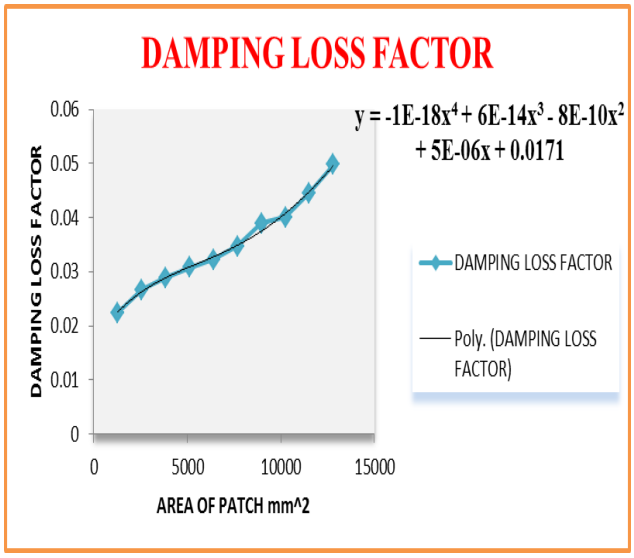

Fig 16: Damping Loss Factor Vs Area of Patch

After performing regression analysis ;

We have following equation which shows the relation between patch area and damping capacity.

$$y = -1E\text{-}18x^4 + 6E\text{-}14x^3 - 8E\text{-}10x^2 + 5E\text{-}06x + 0.0171$$

where, y= damping loss factor

x= patch area (mm^2)

Table 1: Patched Layer Result Table

Sr no	Width of patch	Length of patch	Area of patch	Damping loss factor	Vibration amplitude db
1	32	400	12800	0.0498	4.5
2	32	360	11520	0.0445	5.3
3	32	320	10240	0.0401	5.9
4	32	280	8960	0.0389	6.4
5	32	240	7680	0.0347	6.8
6	32	200	6400	0.0322	7.6
7	32	160	5120	0.0308	8.1
8	32	120	3840	0.0289	8.7
9	32	80	2560	0.0267	9.5
10	32	40	1280	0.0224	10.3

VI. . RESULTS

In this project basic aim to find damping loss factor with constrained layer, free layer, patched layer. Results are compared with analytical , experimental and FEM analysis. In FEM analysis directional deformation vs time graphs are plotted to calculate logarithmic decrement. From logarithmic decrement damping and loss factor is determined by using MATLAB code.

Table 2: Result Table

Material	Loss Factor		
	Experimental Results	ANSYS Results	MATLAB Results
Butyl Rubber	0.070	0.06913	0.07413
Sbr	0.036	0.03958	0.03676
Pvc	0.066	0.06189	0.06665
Buna Nitrile	0.034	0.03869	0.03622
Natural Rubber	0.014	0.01787	0.01595
Silicon Rubber	0.024	0.02271	0.02577
Undamped Beam	0.0030	0.0033	0.0038

Table 3: Result Table

Damping treatment	Loss factor by experiment	Loss factor by FEM	Loss factor by MATLAB
Undamped	0.0033	0.0038	-
CLD damped	0.0749	0.0709	0.07
Free layer	0.0568	0.0498	-
Patched layer	0.0345	0.0328	-

VII. FUTURE SCOPE

In future scope, effect of different thickness on damping can be tested, effect of temperature and frequency can be considered. Nonlinear analysis can be studied with the help of regression in damping energy. finding another materials which may be composites for damping purpose.

VIII. CONCLUSION

In this project, different types of viscoelastic materials are tested for damping purpose with constant thickness of 1mm. hence from results we can conclude that butyl rubber has better damping property as compared to other materials.

Then PVC, SBR, Buna Ntrile, silicon rubber and natural rubber have better performances respectively. By observing effect on natural frequency butyl rubber material is selected for testing of free layer and patch layer damping. For patch layer damping size of patch is selected as 50mm*50mm*1mm. FLD and patch layer damping have less damping capacity than CLD. Patched having maximum area shows the maximum damping capacity.

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Pankaj R. Beldar,
M.E.Pursuing,
PG Student,
NDMVP'SKBTCOE,nashik
B.E. (DYPCOE, Akurdi)
Total publications- 03
Email.-
pankajbell@gmail.com
Contact no- 8793725713

Prof. D.V.Kushare
M.E.(Mechanical Design)
Assistant professor
NDMVPSKBTCOE, nashik
Teaching experience-12 years
Total publications-04
Email-
Kushare_dv@rediffmail.com
Contact no-9850143608