Review Paper on Free Vibration Response of Magnetorheological Elastomer-based Sandwich Beam

Eknath L. Manjarekar[1], Suraj H. Kumbhar[2] , Prof. U D Gulhane[3]

[1,2]PG Students
Department of Mechanical Engineering
Finolex academy of management and technology,
Ratnagiri-415639,Maharashtra,india
eknathmanjarekar@gmail.com,surajkumbhar6@gmail.com

[3]Associate Professor,
Department of Mechanical Engineering,
Finolex academy of management and technology,
Ratnagiri-415639,Maharashtra,india
udgulhane@gmail.com

Abstract **- The dynamic analysis of a three-layered symmetric sandwich beam with magneto rheological elastomer (MRE) embedded viscoelastic core and conductive skins subjected to a periodic axial load have been carried out under various boundary conditions by researchers. As the skins of the sandwich beam are conductive, magnetic loads are applied to the skins during vibration. Due to the field-dependent shear modulus of MRE material, the stiffness of the MRE embedded sandwich beam can be changed by the application of magnetic fields. Using extended Hamilton's principle along with generalized Galarkin's method the governing equation of motion has been derived. The free vibration analysis of the system has been carried out and the results are compared with the published experimental and analytical results which are found to be in good agreement. Here, recently developed magneto rheological elastomer based on natural rubber containing iron particles and carbon blacks have been used. The effects of magnetic field, length of MRE patch, core thickness, percentage of iron particles and carbon blacks on the regions of parametric instability for first three modes of vibration have been studied. These results have been compared with the parametric instability regions of the sandwich beam with fully viscoelastic core to show the passive and active vibration reduction of these structures using MRE and magnetic field.**

Index Terms - sandwich beam, magneto rheological elastomer, magnetic field, conductive skin

I. INTRODUCTION

Sandwich beams are in use for many years in structural engineering such as aeroplanes, military aircrafts, space vehicles, bridges, ships, surface transport vehicles and robot arms as a load carrying member with high strength to weight ratio. Traditionally viscoelastic cores are used in these structures for vibration reduction. Recently, magneto rheological elastomer (MRE) is embedded in the viscoelastic core to actively attenuate vibration in sandwich structure by applying suitable magnetic field. Due to the field-dependent shear modulus of MRE, the flexural rigidity of MRE embedded sandwich beams changes rapidly and reversibly with the application of magnetic field. Hence, they are very potential in developing stiffness controllable devices for semi-active vibration control of flexible structures.

Magneto rheological elastomers (MRE) are smart materials whose mechanical properties such as the shear modulus and core loss factor can be reversibly and rapidly controlled by an external magnetic field. Zhang et al proposed a new effective permeability model of MRE with a novel structure, which is designed to improve field-dependent performance. MRE patches are also used in many other applications. Deng and Gong developed a dynamic adaptive tuned vibration absorber (ATVA) which works in shear mode. Watson exploited a variable stiffness suspension bushing using MREs. Ginder et al. constructed tunable automotive mounts and bushings based on MREs.

It has been observed from the available literature that though many works have been reported on the free vibration of sandwich beams with viscoelastic core, very few works have been found on the dynamic analysis of MRE embedded viscoelastic cored sandwich beam. A wide gap has been observed between the theoretical and experimental determination of natural frequencies of MRE embedded sandwich systems. Similarly, many researchers studied the parametric instability regions of sandwich beam with viscoelastic core without taking MRE as the core materials. The present work provides an analysis on how magnetic fields change the dynamic property of the MRE embedded viscoelastic cored sandwich beam with conductive skins. The magnetic field will both change the mechanical property of MRE and generate magnetoelastic loads subjected to the skins. Initially the free vibration of the MRE embedded viscoelastic cored symmetric sandwich beam has been studied. Two types of MREs viz., MRE with and without carbon blacks, have been considered for obtaining the parametric instability regions.

The effects of magnetic field, length of the MRE patch, core thickness, percentage of iron particles and carbon blacks have been investigated. Also, experiment has been performed to validate the model and the assumption of taking same transverse displacement for the upper and lower skin. Since skins strengthen the bulk flexural rigidities of sandwich beams, this sandwich configuration would lead to applicable semi-active devices by taking the advantage of field-dependent property of MRE.

II. EXPERIMENTATION

The experimental setup is shown in Figure 1. The beam samples are fabricated from commercial grade aluminium sheets as skins and commercial grade rubber sheets as core. The fabricated beam has span, L=500mm; width, b=30mm; the top and bottom skins thickness, 2ht=2hb=2mm and the core thickness, 2hc=6mm [1]. The experimental set-up using the impact hammer kit consisting of a PC driven ACE dynamic signal analyser and two accelerometers are shown in Fig.1. The accelerometers are set one below another at fixed positions on the top and bottom skins of the test specimen. The response signals recorded by the accelerometers attached to test specimen.

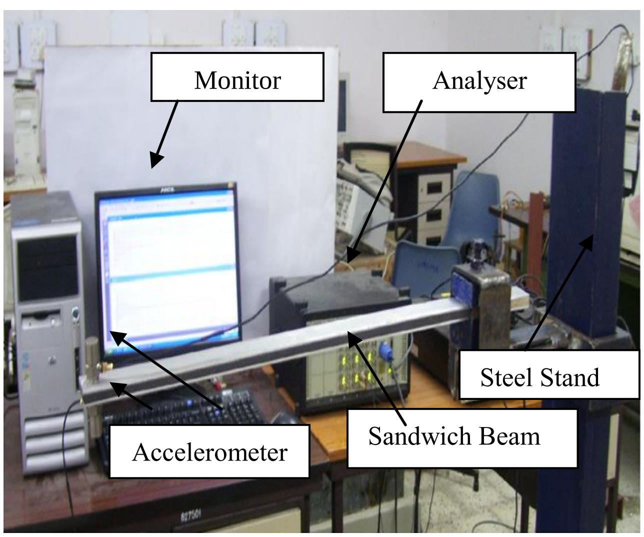

Fig. 1. Experimental setup [B. Nayak et al,2011]

The frequency and time responses are shown in Fig. 2 and 3, respectively, when the accelerometers are placed at the free end of the test specimen. It is found that, the transverse displacements of the top and bottom skins have same amplitude and frequency having some phase difference between them.

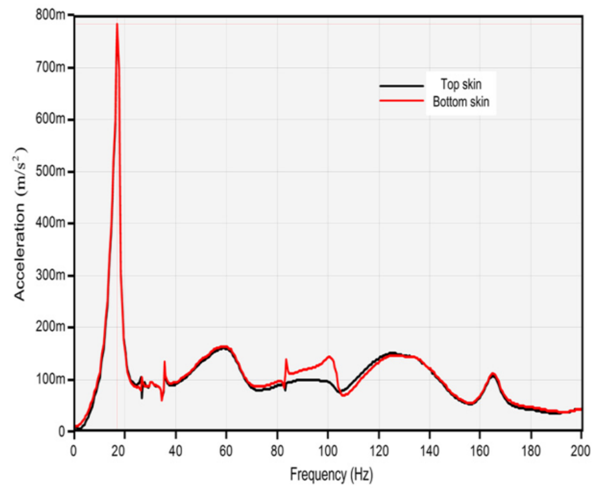

Fig. 2. Frequency response of both the skins sandwich beam subjected to free vibration [B. Nayak et al,2011]

Hence, the assumption of having same transverse displacement in the top and bottom skin in a viscoelastic cored sandwich beam is validated. By taking the Young's modulus and density of aluminium as 69.526 GPa and 2618.025 kg/m3 and for rubber, the shear modulus and density as 1.886 MPa, 1800kg/m3, respectively, the experimental frequency is found to be17Hz [1].

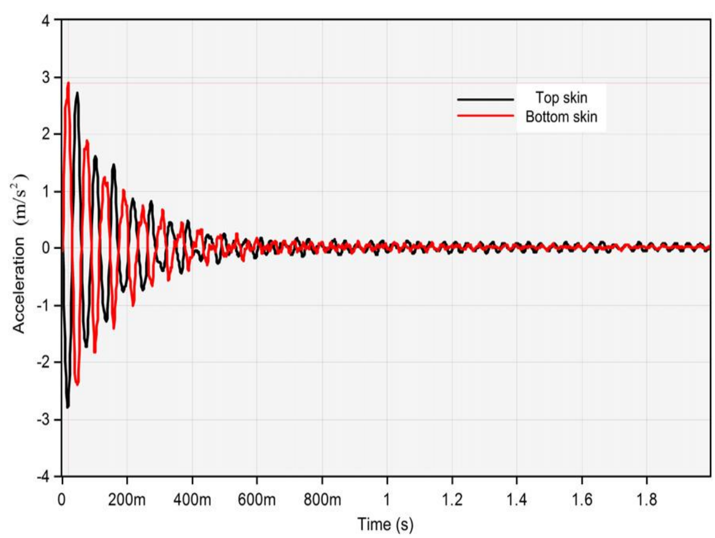

Fig. 3. Time response of both the skins sandwich beam subjected to free vibration. [B. Nayak et al, 2011]

III. FREE VIBRATION RESPONSE OF MRE EMBEDDED SANDWICH BEAM

In this subsection the time response of the MRE embedded sandwich beam with and without magnetic field has been plotted to show the advantage of using magnetic field to reduce the vibration .This has also been compared with a similar sandwich beam without considering MRE patch. Following physical parameters have been taken for the numerical analysis.

The span of the beam, L=230mm; width, b=23mm; the top and bottom skins thickness, 2ht=2hb=4mm and the core thickness, 2hc=8mm.The top and bottom aluminium skins have Young's modulus 72GPa and density 2700kg/m3. The zero fields shear modulus and young's modulus of both MRE and non-MRE parts are same [2,3]. The length of the MRE patch is one third of the length of the core and is symmetrically placed at the middle. MRE containing 80% of iron particles has been considered in this work.

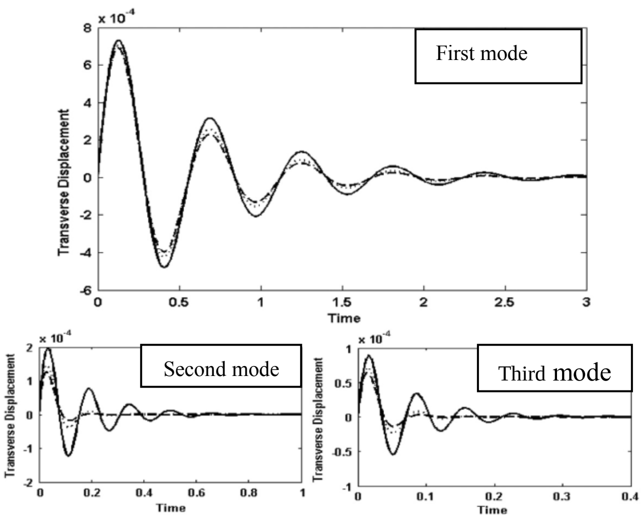

Fig.4. Free vibration response of a simply supported sandwich beam with and without MRE patch in the core . Viscoelastic core ,........... B0=0.2T and - - - -B0=0.6T.[B. Nayak et al,2011]

Fig. 4 shows the first three mode free vibration response of the simply supported sandwich beam without and with MRE patch in the core. The solid line shows the response for the system without MRE patch. For the system with MRE patch ,the dotted line and dashed lines show the response of the system with magnetic fields of 0.2 and 0.6 T, respectively. With the insertion of MRE patch the response peak decreases with the application of magnetic field.

It has been observed that with the increase in magnetic field to 0.6 T for the MRE embedded viscoelastic core the response peak decreases by 6%, 36% and 28% as compared to the viscoelastic cored sandwich beam for the fast, second and third modes, respectively.

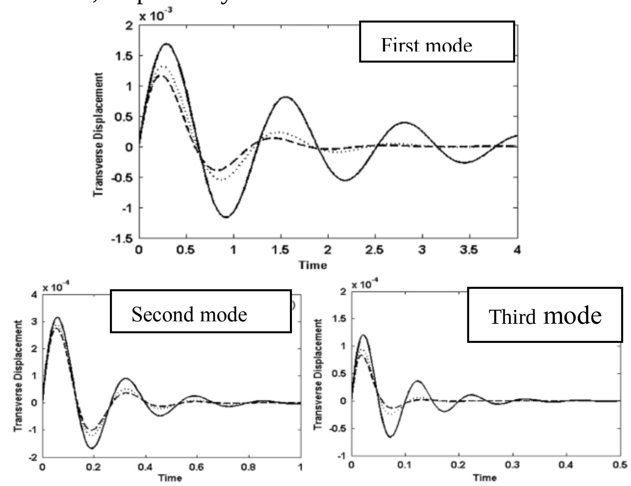

Fig.5. Free vibration response of a clamped–free sandwich beam with and without MRE patch in the core viscoelastic core, ... B0=0.2T and - - - - B0=0.6T. [B. Nayak et al,2011]

Now by considering a clamped–free sandwich beam with MRE embedded viscoelastic core the free vibration responses have been obtained for a magnetic field of 0.2 and 0.6 T (Fig. 5). The physical dimensions and material properties are same as those of the simply supported beam considered before. These responses have been compared with that of a viscoelastic cored cantilevered sandwich beam. It has been observed that with the increase in magnetic field the response amplitude decreases. For example as shown in Fig. 4, with a magnetic field of 0.6 T, for the MRE embedded viscoelastic core the response amplitude decreases by 30.63% for the first mode, 12.7% for the second mode and 30.4% for the third mode in comparison to the viscoelastic cored sandwich beam.

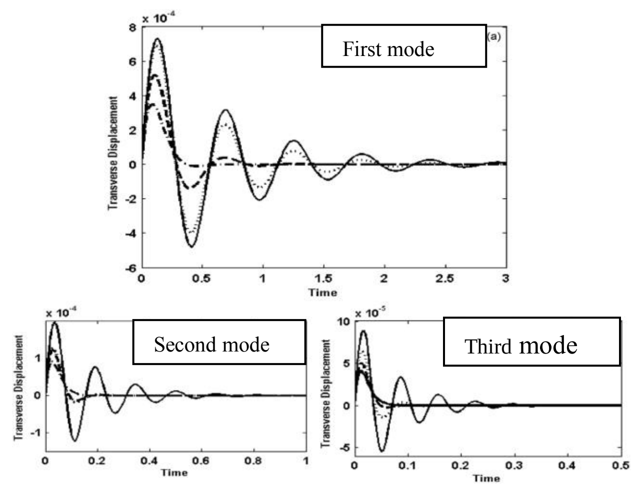

Fig.6. Free vibration response of a simply supported sandwich beam with variation of length of MRE patch viscoelastic core, ... B0=0.2T and - - - - B0=0.6T. [B. Nayak et al,2011]

Fig. 6 shows the first three mode free vibration responses of a simply supported sandwich beam with four different cores, viz., core 1: fully viscoelastic, core2: MRE embedded viscoelastic core with MRE patch length L/3, core3: MRE embedded viscoelastic core with MRE patch length2L/3, and core4: fully MRE core.

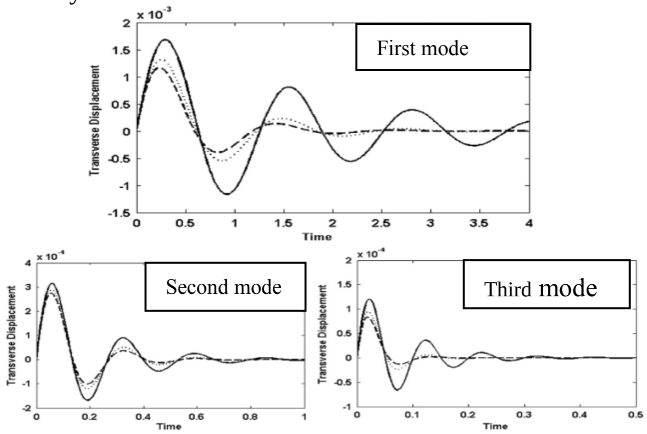

Fig.7. Free vibration response of a clamped–free sandwich beam with variation of length of MRE patch —— viscoelastic core, ... B0=0.2T and - - - - B0=0.6T [B. Nayak et al,2011]

Fig. 7 shows similar plots for a clamped–free sandwich beam. From these two figures one may clearly observe that by increasing the length of the MRE patch, the response amplitude decreases.

Hence, these two examples illustrate that one can control the free vibration of MRE embedded viscoelastic core sandwich beam with the application of magnetic field. For a cantilevered sandwich beam the vibration reduction is found to be more in comparison to that of a simply supported sandwich beam.

IV. APPLICATION OF PRESENT THEORY FOR PASSIVE AND ACTIVE VIBRATION REDUCTION OF SANDWICH BEAM

Clearly by changing the core material, i.e., percentage of iron particles, carbon black in MRE, core thickness, length of MRE and viscoelastic part of the core, one obtains a new sandwich beam which can be used for passive vibration control.

Similarly, by applying magnetic field, which can be applied without altering the basic structure, as the stiffness of the sandwich beam changes actively, using the parametric instability region for various magnetic fields, one can actively suppress the vibration of the sandwich beam.

For example, from Figs. 5-7, one may observe that by applying magnetic field, the free vibration response amplitude and settling time of the MRE embedded beam can be reduced significantly.

V. CONCLUSIONS

In this work, the free vibration analysis of a sandwich beam with MRE embedded viscoelastic core has been carried out using classical sandwich beam theory. Initially taking a viscoelastic cored sandwich beam, experiment has been performed to show that the top and bottom skins have same transverse displacement and hence classical sandwich beam theory can be used for this type of system.

The theoretically obtained fundamental frequency using this theory is found to be in good agreement with the experimentally obtained frequency. It is observed that the free vibration response of the sandwich beam can be passively or actively suppressed by using MRE patch in the viscoelastic core and by applying magnetic field. It has been shown that up to 30% vibration reduction is possible in a cantilevered MRE embedded sandwich beam in comparison to that of a sandwich beam with viscoelastic core. It is expected that by increasing number of MRE patches more vibration reduction can be achieved.

The instability regions of MRE embedded viscoelastic core sandwich beam subjected to periodic axial load have been obtained for five different boundary conditions. It has been observed that in this case the system starts buckling even though the applied load is well below the critical Euler buckling load.

The system becomes unstable when the external frequencies are nearly equal to twice the system natural frequency. It has been shown that by increasing the magnetic field strength, one may alter the instability region. In the considered case a significant attenuation of the vibration has been achieved by incorporating MRE patches in the viscoelastic core. With increase in percentage of iron particles and carbon black, instability region decreases and also the critical value of the amplitude of dynamic loading increases.

The present work will find application in the design of viscoelastic cored sandwich beam and for active and passive attenuation of vibration in the structure using magneto rheological elastomers.

REFERENCES

[1] B. Nayak, S.K. Dwivedy, K.S.R.K. Murty; Dynamic analysis of magnetorheological elastomer-based sandwich beam with conductive skins under various boundary conditions; Journal of Sound and Vibration 330 (2011) 1837–1859.

[2] L.Chen, X.l.Gong, W.Q.Jiang, J.J.Yao, H.X.Deng, W.H.Li, Investigation on magneto rheological elastomers based on natural rubber, Journal of material science 42 (2007)5483–5489.

[3] L.Chen, X.L.Gong, W.H.Li, Effect of carbonblack on the mechanical performances of magneto rheological elastomers, Journal of Polymer Testing 27 (2008) 340–345.

[4] R.A.Ditaranto; Theory of the vibratory bending for elastic and viscoelastic layered finite-length beams, Journal of Applied Mechanics 32 (1965)881–886.

[5] D.J. Mead, S. Sivakumaran; The stodola method applied to sandwich beam vibration, Proceedings of the Symposiumon Numerical Methods for Vibration Problems, University of Southampton, UK, 1966.

[6] D.J.Mead, S.Markus, Loss factors and resonant frequencies of encastre damped sandwich beams, Journal of Sound and Vibration 12 (1)(1970)99–112.

[7] N.T. Asnani, B.C. Nakra, Vibration analysis of multilayered beams with alternate elastic and viscoelastic layers, Journal of Institution of Engineers (India)—Mechanical Engineering Division 50 (1970)187–193.

[8] D.K. Rao, Frequency and loss factors of sandwich beams under various boundary conditions, Journal of Mechanical Engineering and Science 20 (1978) 271–282.

[9] W.P. Howson., A. Zare, Exact dynamic stiffness matrix for flexural vibration of three-layered sandwich beams, Journal of Sound and Vibration 282 (2005) 753–767.

[10] J.R. Banerjee, Free vibration of sandwich beams using the dynamic stiffness method, Computers & Structures 81 (2003)1915–1922.

[11] J.R.Banerjee,Freevibrationofsandwichbeamsusingthedynamicstiffnessmethod, Computers &Structures 81 (2003)1915–1922.

[12] J.R.Banerjee, C.W.Cheung, R.Morishima, M.Perera, J.Njuguna, Free vibration of a three-layered sandwich beam using the dynamic stiffness method and experiment, International Journal of Solids and Structures 44 (2007)7543–7563.

[13] Q.Sun.,J.-X.Zhou, L.Zhang, An adaptive beam model and dynamic characteristics of magnetorheological materials, Journal of Sound and Vibration 261 (2003) 465–481.

[14] A.H.Nayfeh, D.T.Mook, Non-linear Oscillations, Wiley Inter science, NewYork, 1979.

[15] R.C.Kar, T.Sujeta, Dynamic stability of a tapered symmetric sandwich beam, Computers & Structures 40 (1991)1441–1449.

[16] K.Ray, R.C.Kar, Parametric instability of a sandwich beam with various boundary conditions, Computers & Structures 55 (1995)857–870.

[17] K.Ray, R.C.Kar, Parametric in stability of multi-layered sandwich beams, Journal of Sound and Vibration 193 (3)(1996)631–644.

[18] H.Boudaoud, E.M.Daya, S.Belouettar, L.Duigou, M.Potier-Ferry, Damping analysis of beams submitted to passive and active control, Journal of Engineering Structure 31 (2009)322–331.

[19] T.Shiga, A.Okada, T.Kurauchi, Magneto viscoelastic behavior of composite gels, Journal of Applied Polymer Science 58 (1995)787–792.

[20] M.R.Jolly, J.D.Carlson, B.C.Munoz, A.Bullions, The magneto viscoelastic response of elastomer composites consisting of ferrous particles embedded in a polymer matrix, Journal of Intelligent material Systems and Structures 7 (1996)613–622.

[21] G.Y.Zhou, Shear property of a magneto rheological elastomer, Journal of Smart Materials and Structures 12 (2003)139–146.

[22] C.Bellan, G.Bossis, Field dependence of viscoelastic properties of magnetorheological elastomers, International Journal of Modern Physics B 16 (2002) 2447–2453.

[23] X.Zhang, W.Li, X.L.Gong, An effective permeability model to predict field-dependent modulus of magnetorheological elastomers, Communications in Non-linear Science and Numerical Simulation 13 (2007)1910–1916.