Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 2, Number 6; April-June, 2015 pp. 481-485

http://www.krishisanskriti.org/jbaer.html

Design of MR Elastomer based Adaptive Tuned Vibration Absorber

Dayanand G. Potdar[1], Sanjaykumar S. Gawade[2] and Samir B. Kumbhar[3]

[1]*Student, M. Tech. (Mech .Design) Mechanical Engineering Department, Rajarambapu Institute of Technology, Sakharale, Dist. Sangli, Maharashtra, India*
[2]*Mechanical Engineering Department, Rajarambapu Institute of Technology, Sakharale, Dist. Sangli, Maharashtra, India*
[3]*Mechanical Engineering Department, Rajarambapu Institute of Technology, Sakharale, Dist. Sangli, Maharashtra, India*
E-mail: [1]dayanand.potdar@ritindia.edu, [2]sanjaykumar.gawade@ ritindia.edu, [3]samir.kumbhar@ritindia.edu

Abstract—*The focus of this paper is to explain the potential of smart materials like MRE in vibration control especially in ATVA. Traditional ATVA has limited application and vibration absorption capacity for its narrow working frequency. MRE's are the kind of smart materials whose stiffness can be changed by application of magnetic field (MRE) which result in change in modulus. This analyzes frequency shift properties of ATVA's with respect to magnetic field and strain for MRE. Model is thus proposed to study variation in Natural frequency to enhance tuning properties. For Vibration analysis both numerical and analytical approaches are taken into consideration. We observed the values of Natural frequencies which are more precise and accurate with numerical approach. However, further refinement in parameters is needed to be done to get wide range of operating frequency range. Mathematical model leads to fixing of specifications of specimen for the optimum vibration attenuation performance and suggesting efficient selection material configurations for matrix material and magnetizable particles from researches carried out till date. Also, significant modifications to be considered from results withdrawn for efficient tuning performance.*

Keywords: *ATVA, MRE, MR Effect, Mathematical model.*

1. PROLOGUE

In most of practical applications of mechanical, civil and construction systems usually encounter with undesirable vibrations problem. At the same time to ensure enhanced system lifetime by avoiding damage, fatigue many research has been done until now. The invention of Dynamic vibration absorber (DVA) by Frahm (1909) found to be an effective solution to suppress unwanted vibrations of machines and structures. Basic elements of traditional DVA include a damping element, a spring element and an oscillator.

However, this passive absorber is theoretically designed to attenuate single excitation frequency, the resonance frequency of the DVA. But for practical systems working conditions may change after time interval and it results the absorber to become inefficient and potentially aggravate the vibrations of primary system. One of the potential solutions to this problem is Adaptive tuned vibration absorber (ATVA) which consists of similar components of DVA but includes an adaptive element to trace and analyze the working conditions. Generally this tracing of working conditions involves varying the natural frequency to track time-varying excitation frequency excitation frequency by changing the stiffness of adaptive spring element. Thus, ATVA can be broadly divided into two major groups one which uses variable geometries and other to use smart materials.

More recently, adaptive TVAs (ATVAs) exploiting the changeable pre-yield properties of MR fluids have been developed. Ginder et.al [1] and Deng et.al [2] designed an ATVA using an MR elastomer. In the TVA was a mass-spring system placed in the air gap of a U-shaped steel base. The mass was connected to the base through an MR elastomer, which behaves as a spring. The stiffness was changed by altering the magnetic field generated by a coil wound around one arm of the steel base. The ATVA showed a variation of the natural frequency of about 22%.The ATVA in had a similar shape to that in, but its relative natural frequency could be changed up to 147%.

2. ROLE OF ADAPTIVE TUNED VIBRATION ABSORBER

It is observed that mistuned vibration absorber leads to increase the vibrations of host structure. Hence, the deviation from tuned condition degrades the performance by variation in either of the variant of the TVA (Brennan, 1997). To avoid this problem, smart or adaptive tunable vibration absorbers (ATVA) have been developed. Such devices are capable of self tuning in real time. Adaptive technology is especially implemented in the machineries and structures since low damping of the spring elements leads the primary system to the dangerous levels of vibrations in mistuned conditions. This mistuning is result of either change in the excitation frequency or change of forcing frequency due to environmental conditions (e.g. temperature change).Hence, traditional TVA to be modified as Adaptive TVA will be of practically use.

An effective means to adjust the tuned frequency in real time is by changing the effective stiffness of the spring element of the ATVA. To maximize vibration attenuation over wide range of frequencies technical challenge is to design an adaptive device such that adjustment must be rapid and with minimum power requirement with wide range of operating frequencies. At the same time device must also be cost effective and easy to manufacture.

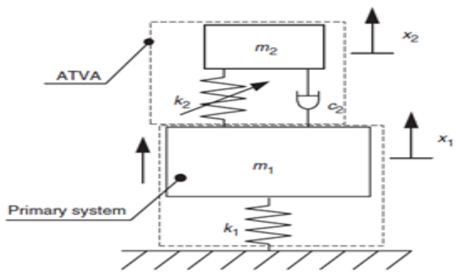

Fig. 2.1: Model of ATVA with primary system

3. OBJECTIVES

This paper aims to design an adaptive tuned vibration absorber which could be self tunable with response of variable excitation frequencies. Since, Vibration absorber can be simplified as a spring- mass system, tuning of natural frequency of the absorber can be done by varying the stiffness of the spring. Here, method of achieving the variable stiffness in ATVA isdone by applying magnetic field over certain region of the smart material sample leads to change the overall effective stiffness of the absorber system.

Due to its variable stiffness capability, absorber is now capable to retune itself with time varying excitations over wide range of frequencies. A practical method of varying stiffness of adaptive element is done by designing a cantilever beam model which made of smart material like MR elastomer acting as spring with movable electromagnet. This tunable vibration absorber will then be mounted on vibratory primary system act as exciter. The design requirement of this project is to design small absorber which can be used in laboratory and capable to track frequency drift ±50 % of its center frequency approximately 25 Hz.

4. PREFERRED COMPOSITIONS OF MRE

MR elastomers consists several kinds of polymers and elastomers have been used as matrix materials. In addition to the actual polymer, additives like cross-linking agents, antioxidants and mixing aids may be used. As a filler material, carbonyl iron has been used in various studies due to its extensive use in MR fluids. The behavior of MR elastomers without the external magnetic field depends basically on the characteristics of the composite material.

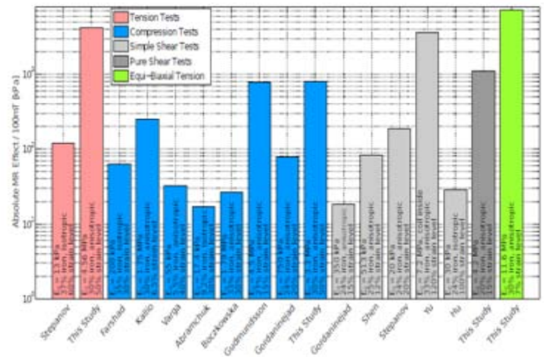

Fig. 4.1: The Absolute MR Effect related to 100mTfor large strain experiment [5]

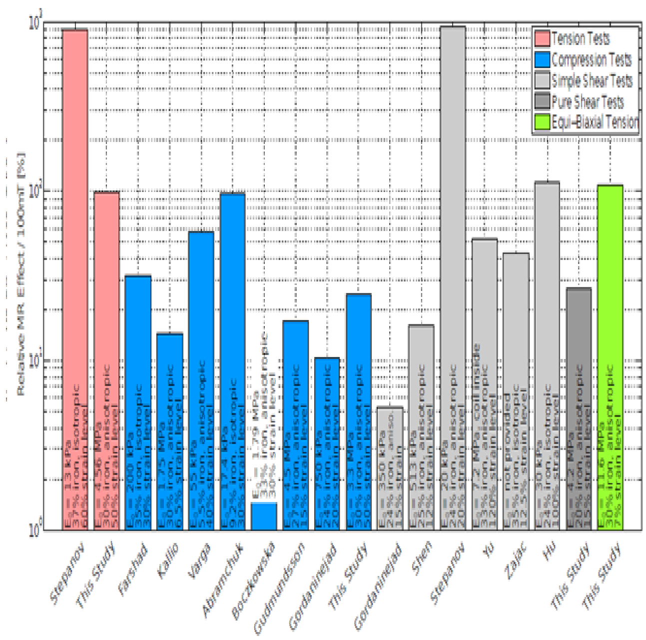

Fig. 4.2: The Relative MR Effect related to 100mTfor large strain experiment [5]

5. OVERALL EFFECT OF IRON PARTICLE EFFECT, OPERATING MODES, TYPE OF MRE ON VIBRATION ATTENUATION PERFORMANCE

To investigate effect of individual parameter on overall performance of MR Elastomer performance, data is combined in single graphical representation. Fig.5.1 shows that zero field modulus is significantly higher for equibiaxial tension mode of anisotropic MRE for 30% iron particle content. Fig.5.2 illustrates that Absolute MR Effect is significantly higher for equibiaxial tension mode of anisotropic MRE for 30% iron particle content.

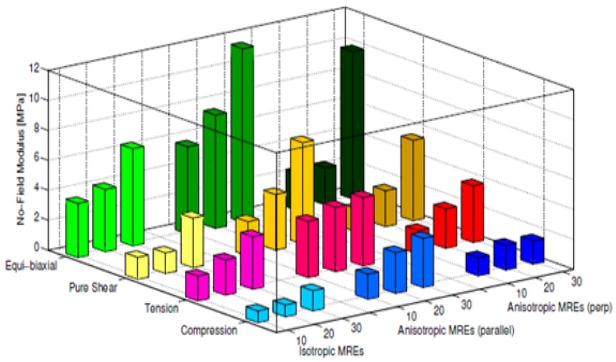

Fig. 5.1: Comparison of the mechanical response for all deformation modes, and all types of MREs with particle concentrations from 10% to 30%.Table illustrates No-Field modulus [5]

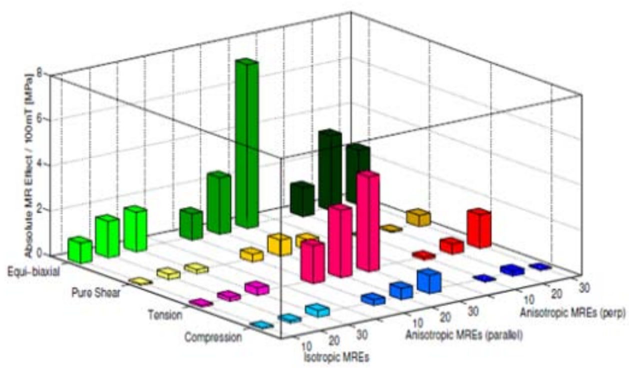

Fig. 5.2: Comparison of the Absolute MR response for all deformation modes, and all types of MREs with particle concentrations from 10% to 30%.Table illustrates Absolute MR Effect [5]

Most of impact of selection of MR Elastomer depends on the enhanced Relative MR effect. Fig 5.3 relative MR effect is highest in biaxial tension mode followed by uniaxial tension test with anisotropic MRE having 30% iron particle content.

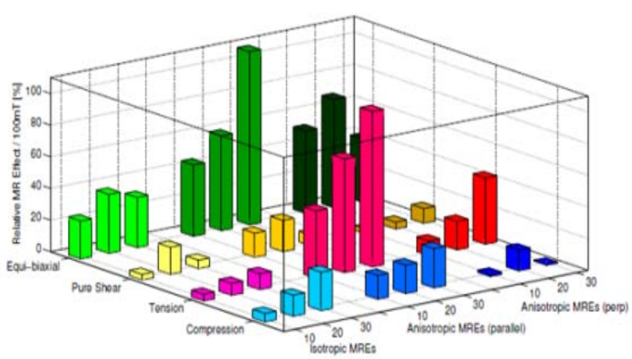

Fig. 5.3: Comparison of the Relative MR response for all deformation modes, and all types of MREs with particle concentrations from 10% to 30%.Table illustrates Relative MR Effect [5]

6. MATHEMATICAL STUDY OF PROPOSED ATVA - [CANTILEVER BEAM MODEL]

Rayleigh's method can be applied to find the fundamental natural frequency of continuous systems. This method is much simpler than exact analysis for systems with varying distributions of mass and stiffness. Although the method is applicable to all continuous systems, we shall apply it only to beams in this section.

The designed model of MR Elastomer based cantilever beam as a Dynamic Vibration Absorber consist of absorber mass (M) and Young's Modulus (E1). It is Actuated by a magnetic field supplied with current I. After application of magnetic field Young's modulus of Elasticity changes to E2.

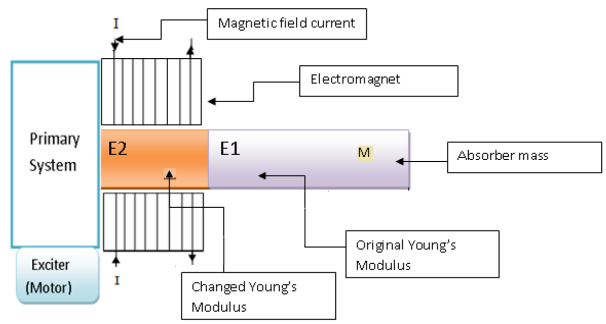

Fig. 6.1: MRE based Cantilever Beam model

Where,
l1 = Position of magnet from fixed end
E1 = Intial Tensile modulus of Beam
(without application of Magnetic field)
E2 = Changed Tensile modulus of Beam
(with application of Magnetic field)
P = Load resulting due to absorber mass
L = LengthOf Beam
B = Width of Beam
H = Height of Beam
d = Length of Electro-magnet
M = Mass of Absorber
ρ = Mass Density Of MR Elastomer

For a stepped beam, Equation of Natural Frequency by Rayleigh's method can be more conveniently written as

$$R(w) = w^2 = \frac{\int_o^l E_1 I_1 \left[\frac{\partial^2 w}{\partial x^2}\right]^2 dx + \int_o^l E_2 I_2 \left[\frac{\partial^2 w}{\partial x^2}\right]^2 dx + \cdots}{\rho A_1 \int_0^l w^2 dx + \rho A_2 \int_0^l w^2 dx + \ \ldots}$$

We know,
Deflection Of Cantilever Beam

$$y_1(x) = \frac{1}{E_1 \mathrm{I}}\left\{\frac{-Px^4}{24} + \frac{PL^3}{6}x^2 - \frac{PL^4}{8}\right\}$$

$$y_2(x) = \frac{1}{E_2 \mathrm{I}}\left\{\frac{-Px^4}{24} + \frac{PL^3}{6}x^2 - \frac{PL^4}{8}\right\}$$

Bending Moment of Beam

$$\left\{\frac{d^2y_1}{dx^2}\right\} = \frac{1}{E_1I}\left\{\frac{-Px^2}{2}\right\}$$
$$\left\{\frac{d^2y_2}{dx^2}\right\} = \frac{1}{E_2I}\left\{\frac{-Px^2}{2}\right\}$$

From Rayleigh's Continous beam approach

$$W_n = \sqrt{\frac{E_1\mathrm{I}\int_0^{l1}\left\{\frac{d^2y_1}{dx^2}\right\}^2 dx + E_2\mathrm{I}\int_{l1}^{(l1+d)}\left\{\frac{d^2y_2}{dx^2}\right\}^2 dx + E_1\mathrm{I}\int_{(l1+d)}^{L-(l1+d)}\left\{\frac{d^2y_1}{dx^2}\right\}^2 dx}{\rho A\int_0^{l1} {y_1}^2 dx + \rho A\int_{l1}^{(l1+d)} {y_2}^2 dx + \rho A\int_{(l1+d)}^{L-(l1+d)} {y_1}^2 dx}}$$

To solve this equation Matlab programme is used which yields the value of Natural frequency of beam (Wn) for given value of Magnetic field strength (B) and Location of Electro-magnet (l1).

7. RESULTS AND DISCUSSION

We consider four outputs for smaller strain condition at four given values of magnetic field strength (B). From Matlab code we get values of natural frequency at respective Electro-magnet location (l1).

7.1 Natural Frequencies of model

We get wide range of absorber frequencies as function of magnetic field strength (B) and magnet location (l1). Behavior of the natural frequencies variation is studied carefully to decide best tuning location of magnet. Also, Table 7.1 illustrates frequency shift for particular magnetic field strength (B) over the length of the beam.

Table 7.1: Frequency shift for MRE based cantilever beam model

Magnet position	B (in Tesla)			
	B=0.25	B=0.5	B=0.75	B=1
0	3.183	28.776	9.6399	9.1225
0.02	36.5731	13.5433	13.313	13.776
0.04	14.1682	16.1209	17.514	18.664
0.06	15.2289	19.1913	21.464	23.105
0.08	17.0918	21.6119	24.215	26.081
0.09	17.9872	22.3548	24.922	26.793
SHIFT IN NF (In Hz)	33.3901	15.2327	15.282	17.671
SHIFT IN NF (In %)	1049.01	112.474	158.53	193.71

7.2 Graphical Interpretation

Frequency variation over the length of Cantilever beam for given magnetic field strength can be analyzed through the graphical representation, which shows that better tuning is possible near the fixed end of the beam.

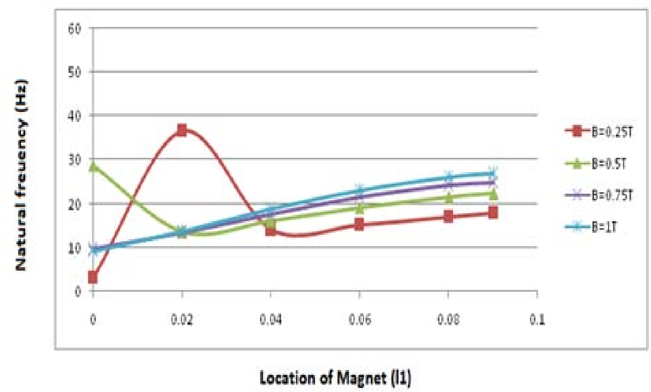

Fig. 7.1: Frequency response of MR Elastomer relative to magnet location

8. CONCLUDING REMARKS

From the results obtained and graphical representation we can conclude that

- Low no-field moduli of the MRE material lead to higher relative MR effects, but not inevitably to large absolute MR effects.
- The MR effect increases with increasing iron content.
- Anisotropic MREs perform better than isotropic MREs. The highest effect were achieved when the magnetic flux density was applied in the loading direction and parallel to the particle alignment
- Better tuning is possible in the region near to the fixed end of the beam.
- Also, with Increase in magnetic field strength, Natural frequency shifts to higher value.
- The MRE material saturates above 700 mT magnetic induction and the MR effects do not increase further when higher levels of magnetic flux are applied.

9. ACKNOWLEDGEMENT

No volume of words is enough to express my gratitude towards **Prof. Dr S. S. Gawade and Prof. S. B. Kumbhar** my guides, philosopher and personality with a Midas touch encouraged me to carry this work with his valuable suggestions and critical examination of work during the progress, I acknowledge with thanks to faculty, teaching and non-teaching staff of the department, Central library and Colleagues. I heartily thank to the institute and my guides for sanctioning all the funds for the dissertation under Research Project scheme (RPS) of AICTE Ref.No.:20/AICTE/RIFD/RPS (POLICY-III)/30/2012-13. Last but not the least; **I am thankful to my parents** for constantly supporting me for this work in all aspects.

REFERENCES

[1] Ginder JM, Schlotter WF, Nichols ME. Magnetorheological elastomers in tunable vibration absorbers. Proc SPIE 2001;4331:103–10.

[2] Deng HX, Gong XL, Wang LH. “Development of an adaptive tuned vibration absorber with magnetorheological elastomer.” Smart Material Structure 2006;15:111–6.

[3] Philip Bonello “Adaptive Tuned Vibration Absorbers:Design Principles, Concepts and Physical Implementation” Vibration Analysis and Control – New Trends and Development .University of Manchester United Kingdom (2011).

[4] Ainatul Mardiah Ibrahim “The design of an adaptive tuned vibration absorber.” University of Malaysia, Nov 2007.

[5] Gerlind Schubert “Manufacture, characterisation and modelling of magneto-rheological elastomers.” University of Glasgow, PhD thesis. (2014)

[6] S.R.Kumbhar, Subhasis Maji, Bimlesh Kumar, (2013), ‘Development and Characterization of Isotropic Magnetorheological Elastomer’, Universal Journal of Mechanical Engineering 1(1), pp 18-21.

[7] Gong XL, Zang XZ, Zhang PQ. Fabrication and characterization of isotropic magnetorheological elastomers Polym Test 2005;24(5):669–76.

[8] Wang YL, Hu Y, Gong XL, Jiang WQ, Zhang PQ, Chen ZY. “Preparation and properties of magnetorheological elastomers based on silicon rubber/polystyrene blend matrix.” J Appl. PolymSci 2007;103 (5):3143–9.

[9] Ting-Kong, C. “Design of an Adaptive Dynamic Vibration Absorber.” The University of Adelaide, South Australia 5005. (1999).

[10] Li and Zhang, (2008), “Research and Applications of MR Elastomers”, Recent Patents on Mechanical Engineering, Vol. 1, No.3, pp 161-166.

[11] S.V. Kankanala, N. Triantafyllidis “Magnetoelastic buckling of a rectangular block in plane strain” Department of Aerospace Engineering, The University of Michigan, Ann Arbor, MI 48109-2140, USA.

[12] Wan-quan Jiang, Jing-jing , Yao , Xing-long Gong, Lin Chen. “Enhancement in MR Effect of Magnetorheological Elastomers by Surface Modification of Iron Particles”. Department of Chemistry, University of Science and Technology of China, Hefei 230026, China.

[13] Marke Kallio, Samu Aalto. “Dynamic Properties of Magnetorheologic Elastomer” Journal of structural Mechanics,Vol. 40, No. 1, 2007, pp. 39-47.

[14] Hu.G, Guo.M, Li. W, Du. H &Alici.G. (2011). “Experimental investigation of the vibration characteristics of a Magnetorheological Elastomer sandwich beam under non-homogeneous small magnetic fields” Smart Materials and Structures, 20 (12), 1-7.