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Vibration control of cantilever beam using Eddy Current Damper

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Abstract: - This paper has investigated the ability to use the eddy current generated by magnetic field to suppress the vibration of cantilever beam. Eddy current systems have been employed in many applications such as in braking, transmission or damping system. For damping application the main advantage with respect to other devices is the possibility of working in absence of mechanical contact, eliminating wear problems and reducing the need of high accuracy alignment technique, typically required in mechanical damping system. In this paper finite element analysis (FEA) software was used in developing the model. First we have plotted various mode shapes of cantilever beam and then using a current carrying wire damped the vibration of cantilever beam

Index term: **Eddy current, cantilever beam, damping system, magnetic field.**

I. INTRODUCTION

Eddy currents are generated when a conductor comes under a varying magnetic field. They are generated by the relative motion between conductor and magnetic field. Since the generated eddy current is repulsive in nature in proportion to the relative motion of the field and conductor, hence the moving magnet and conductor behaves like a viscous damper. The application of eddy currents for braking and damping purposes has been investigated for more than two decades and in these years various researchers had suggested and performed different uses of eddy currents in braking and damping system. We can understand this concept more by looking at fig. 1.In conventional fluid damping systems, damper converts the mechanical energy of the vibration into heat energy which is dissipated in the atmosphere. This energy loss in the era of competitive world where the only tip of increasing efficiency is by reducing losses counts much and is very important factor of consideration. Using eddy current damper the kinetic energy of vehicle body vibration can be regenerated as useful electrical energy which can be further utilized for damping purpose. One of the most useful properties of eddy current damper is that it forms a means of removing energy from the system without making any physical contact with the structure. This is beneficial as compared with other damping systems where the system degrades its performance over time due to wear in system. Also the viscous liquid leakage problem is not associated with eddy current dampers as in the case of viscous dampers.

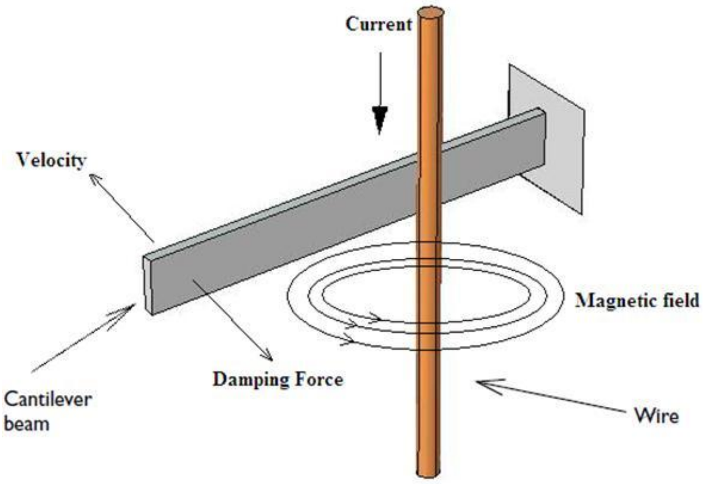
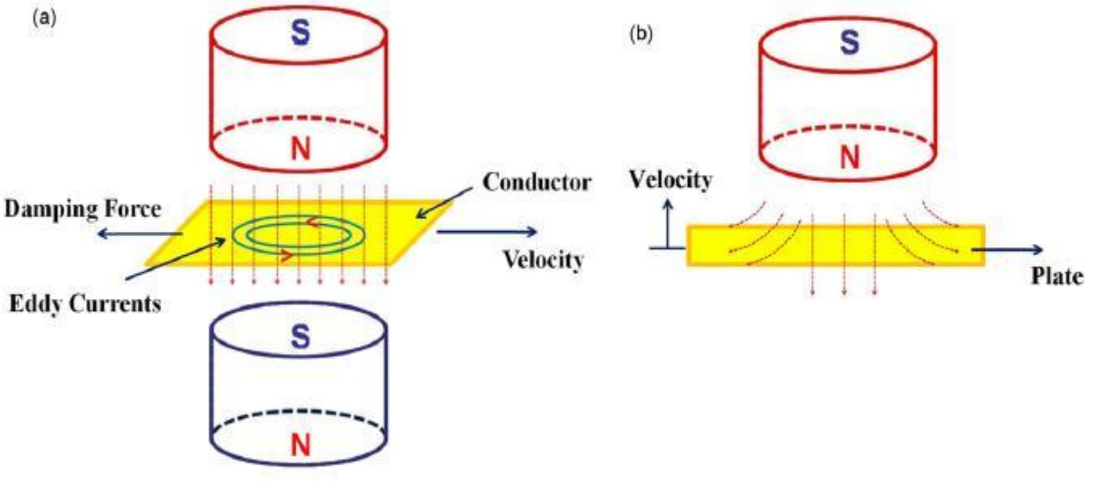


Fig. 1 Vibration control using current carrying wire in cantilever beam

It is well established that, vibration theory is correlated with the modal parameters, namely frequency, damping, and mode shapes. These physical systems consist of the structure physical properties (mass, stiffness, and damping). These model parameters are the solutions of the homogeneous part of the differential equation of motion of a physical model expressed in terms of its mass, damping, stiffness, acceleration, velocity, and displacement. Consequently, any change in the physical properties of the model is directly proportional changes in the model parameters. In this paper we have studied the effect of physical properties of structure on modal parameters.

II. LITERATURE REVIEW

For more than two decades, the application of eddy currents for damping purposes has been investigated, including magnetic braking systems structural vibration suppression and vibration isolation enhancement in levitation systems. Dean Karnop [1] has reviewed some theoretical concepts used in designing of vibration isolation and discussed the previous work done on active and semi active vibration isolation. Sodano *et al.* [2] have analyzed the suppression of cantilever beam vibrations, where a magnet is fixed so that it is perpendicular to the beam motion, and a conducting sheet is attached to the beam tip. Sodano *et al.* [3] had modified the theoretical model of their ECD, and further developed it by applying an image method to satisfy the boundary condition of the zero eddy current density at the conducting plate's boundaries. Jie liu *et. al.* [4] suggested an electromagnetic vibration absorber (EMVA) whose stiffness can be online adjusted and performed experiments to show EMVA can adjust its frequency as per the tuning conditions. J.-S. Bae *et al.* [5] developed a new modeling technique for the effective eddy current damper and vibration suppression of a beam using the eddy current damper. Tonoli [6] has presented a physical, dynamic model. Ebrahimi *et al.*[7] have developed a novel magnetic spring-damper based on the eddy current damping phenomenon.. Bart L. J. Gysen *et. al.* [8] proposed a new electromagnetic suspension system that uses a tubular permanent magnet actuator (TPMA) whose main advantage is that it is useful for both the eliminating of road disturbances and active roll and pitch control. Ebrahimi *et. al.* [9] have presented a new concept for electromagnetic damper and experimentally tested an active and semi active control strategy. In their experiments they have shown that passive damping can be improved by adding a eddy current damper to a hybrid system. Jae Sung Bae *et.al.* [10] have introduced magnetically tuned-mass-damper (MTMD) to improve the damping performance of a conventional TMD by using an eddy current damping (ECD). As we can see in the fig. 2 [10] it is showing the concept of placing magnets against cantilever beam used by various researchers.



(a)Conductive plate moving perpendicularly to the magnetic poling axis (b)conductive plate oscillating through the magnetic poling axis.

Fig. 2 Concept of eddy current damping [10]

III. MODAL ANALYSIS OF CANTILEVER BEAM

Consider the Rayleigh beam described by

$$\rho A\omega,_{tt} + (EI\omega,_{xx}),_{xx} - (\rho I\omega,_{xtt}),_{x} = 0 \qquad (1)$$

Assuming the modal solution in the form ω (x,t) = W (x) $e^{i\omega t}$, the differential equation of the eigenvalue problem is obtained as

$$-\omega^2[\rho AW - \rho IW''] + EIW'''' = 0 \qquad (2)$$

Substituting in (2) a solution of the form

$$W(x) = Be^{\tilde{\beta}x} \quad (3)$$

Where B and $\tilde{\beta}$ are constants, one can write

$$EI\tilde{\beta}^4 + \omega^2\rho I\tilde{\beta}^2 - \omega^2\rho A = 0 \quad (4)$$

Thus the general solution of (2) is obtained as

$W(x) = B_1\cosh\beta_1 x + B_2\sinh\beta_1 x + B_3\cosh\beta_2 x + B_4\sinh\beta_2 x$ (5)

where B_1, B_2, B_3, B_4 are real constant to be obtained from the boundary conditions.

For a uniform Euler – Bernoulli beam, using the solution (3) in the differential equation of the eigen value problem

$$-\omega^2\rho AW + EIW'''' = 0 \quad (6)$$

we obtain

$$-\rho A\omega^2 + EI\tilde{\beta}^4 = 0$$

$$\tilde{\beta}^2 = \sqrt{\frac{\omega^2\rho A}{EI}} \quad (7)$$

Therefore we have the four solutions $\tilde{\beta} = \pm\beta, \pm i\beta$ where

$$\tilde{\beta} = \left(\omega^2\rho A \big/ EI\right)^{1/4} \quad (8)$$

Now one can write the general solution (for w≠0) of the eigenvalue problem (6) as

$W(x) = B_1\cosh\beta x + B_2\sinh\beta x + B3\cosh\beta x + B_4\sinh\beta x$ (9)

where B_1, B_2, B_3, B_4 are real constant which are determined by boundary conditions as discussed below.
For uniform cantilever beam the boundary conditions are given by

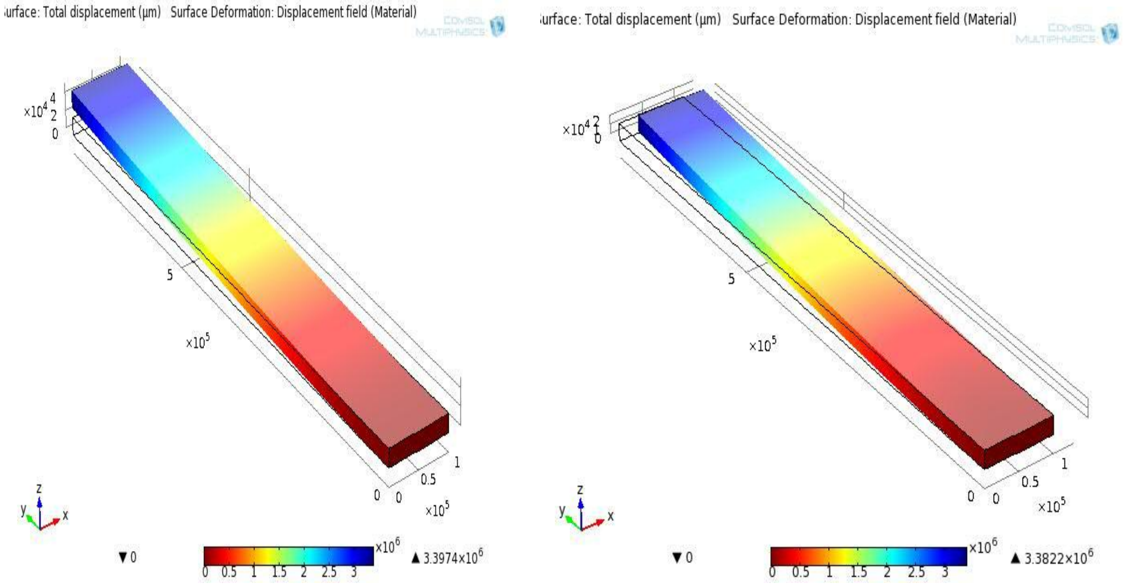
$$W(0) = 0, W'(0) = 0, W''(l) = 0W'''(l) = 0 \quad (10)$$

For a non – trivial solution of the (B_1…….B_4) we must have

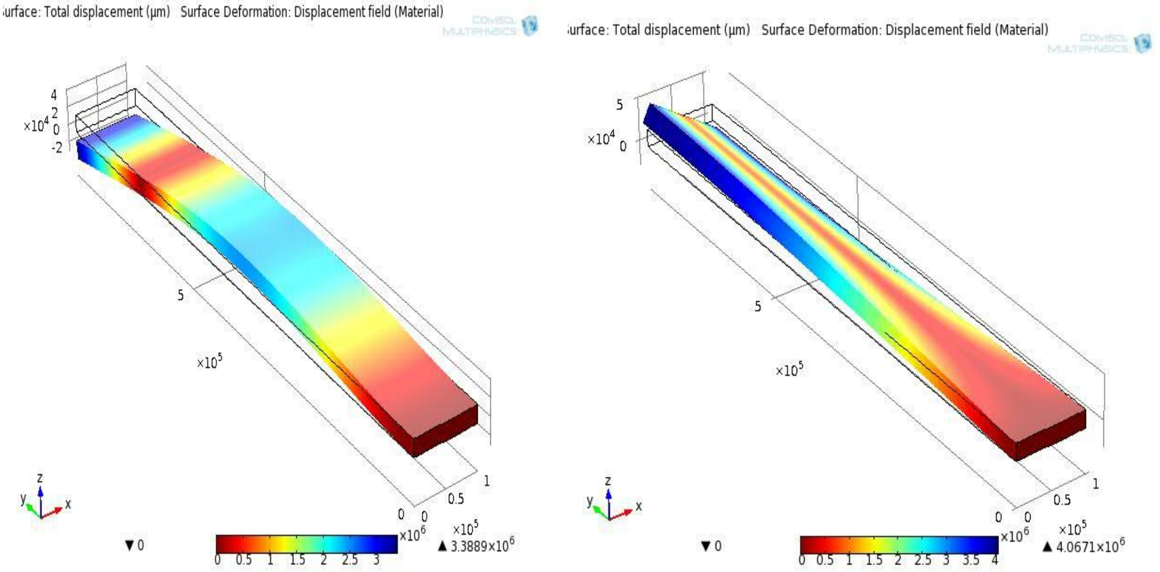
$$\begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ \cosh\beta l & \sinh\beta l & -\cos\beta l & -\sin\beta l \\ \sinh\beta l & \cosh\beta l & \sin\beta l & -\cos\beta l \end{bmatrix} = 0$$

$$\Rightarrow \cos\beta l\cosh\beta l + 1 = 0 \quad (11)$$

which is the characteristic equation of a cantilever Euler – Bernoulli beam.
The modes of vibration corresponding to the first four eigen functions are plotted using Comsol multiphysics software and are shown in Fig. 3 and their respective frequencies are shown in table 1



(a) Mode I (b) Mode II



(c) Mode III (d) Mode IV

Fig. 3 Results of various Mode Shapes for modal analysis of cantilever beam

Table 1 Result of mode shapes w.r.t. its natural frequency

Mode Shape Number	**Natural frequency (Hz)**
1	26
2	128
3	162
4	370

IV. MODELING OF EDDY CURRENT DAMPER

For a solid material experiencing a time-harmonic forced excitation, the displacement field is of the form

$$\mathbf{u}\,(\mathbf{r},\mathbf{t}) = \mathbf{u}(\mathbf{r})\,\sin\,(\omega\mathbf{t}) \qquad (12)$$

Let B = static magnetic field

Then, induced eddy current density is given by

$$J = \sigma(v \times B) \qquad (13)$$

where σ is the material conductivity, $(v \times B)$ term is an electromotive force driving the eddy currents J

The body forces experienced by a current-carrying domain moving through a magnetic field are given by

$$F = \int_{V} J \times B dV \qquad (14)$$

These body forces can be applied to the frequency domain structural mechanics problem and act as a damping on the system.

This model of eddy current damper computes the effect on the magnetic field when a cantilever beam is harmonically excited across a range of frequencies and placed in a strong magnetic field. The approach presented here assumes that the relative magnitude of the structural displacements is small, that the material has isotropic and linear properties, and that the magnetic field is static. It first computes the static magnetic field due to a current-carrying wire which is next to an aluminum beam. In the second solution step, the beam experiences a forced harmonic vibration. The strength of the magnetic field is varied, and the effect of the eddy current damping on the response of the system is observed.

Table 2 Physical property of the beam and electromagnet

Property	**Value**
Material Conductivity of Aluminum	3.774 x 10^{7} [S/m]
Material Conductivity of Copper wire	5.998 x 10^{7} [S/m]
Density of cantilever beam	2700 Kg/m^{3}
Young's modulus of cantilever beam	70 GPa
Applied current on the wire	50 [kA]
Length of beam	0.8 m
Width of beam	0.02 m
Height of beam	0.1 m
Radius of wire	0.06 m

In this model we have assumed that a vibrating beam next to a current carrying wire experiences eddy current damping. To model this problem we are assuming single turn coil carrying current. Material of cantilever beam is Aluminum and of current carrying wire is Copper.

V. RESULTS AND DISCUSSION

Once the beam starts vibrating the beam experiences a damping due to generation of eddy currents through current carrying wire at the surface of cantilever beam various results obtained are shown in the fig 4 – 7. Fig 4 shows the magnetic field around a current carrying wire. As we can see in the figure the magnetic field decreases as the distance from wire increases. In fig 5 we can see the von Mises stresses generated to damp the cantilever beam, in fig 6 we can observe by the arrows body forces on the beam due to the induced currents which are responsible in damping the cantilever beam and in the last fig 7 we have plotted the tip displacement of beam with respect to various range of frequency with or without the eddy current damping.

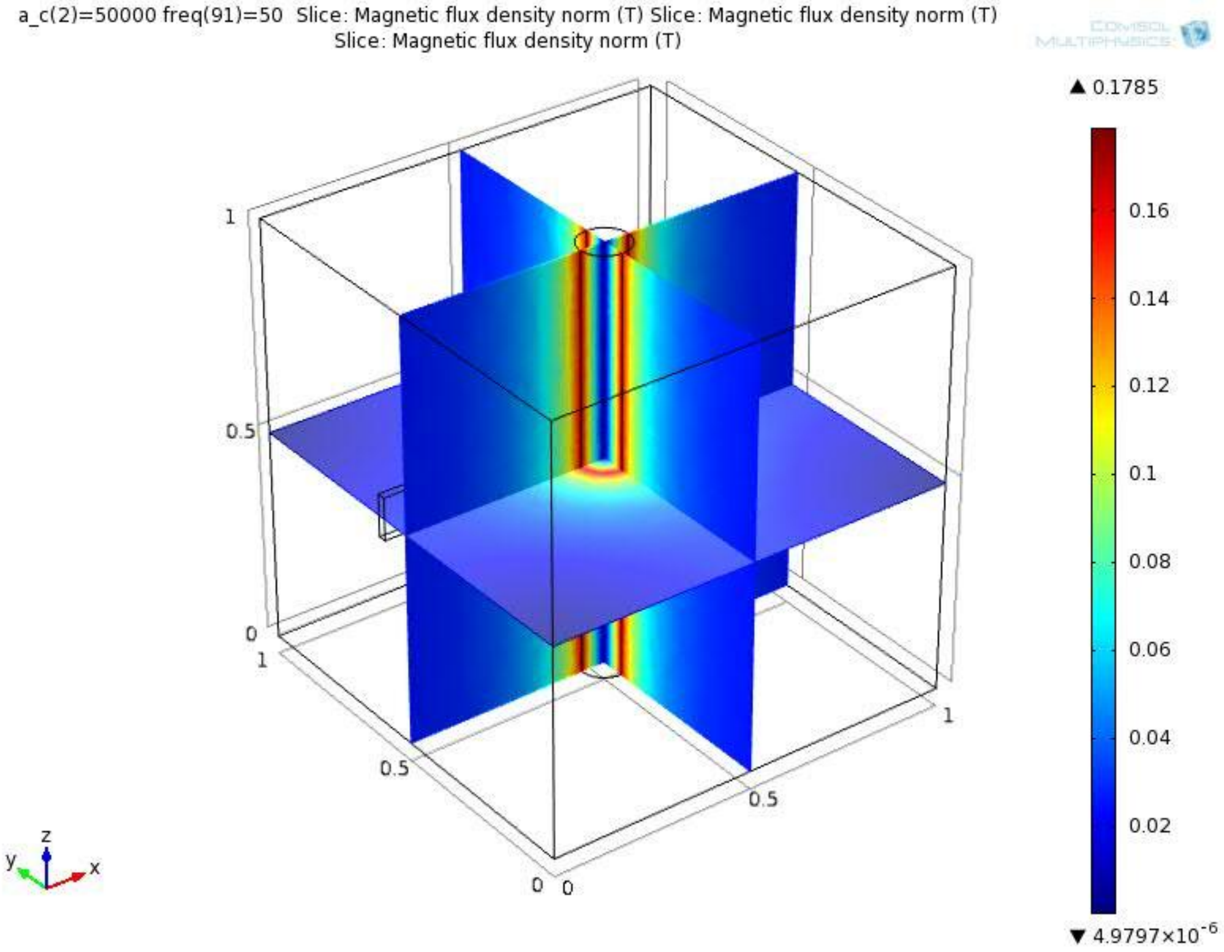


Fig. 4 Magnetic fields around a current carrying wire

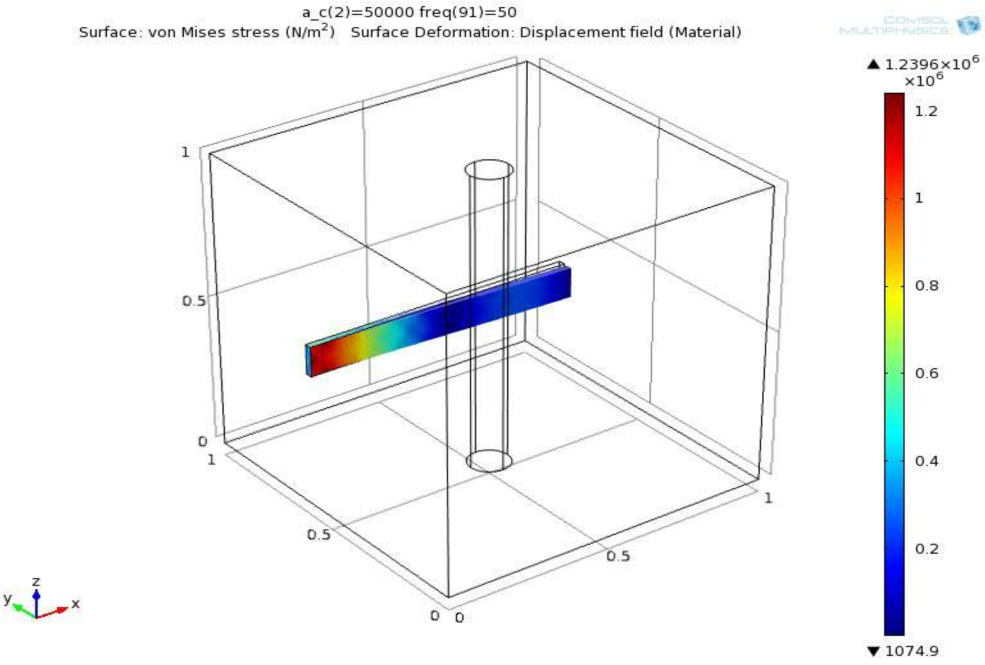


Fig. 5 Von Mises stresses developed in the cantilever beam

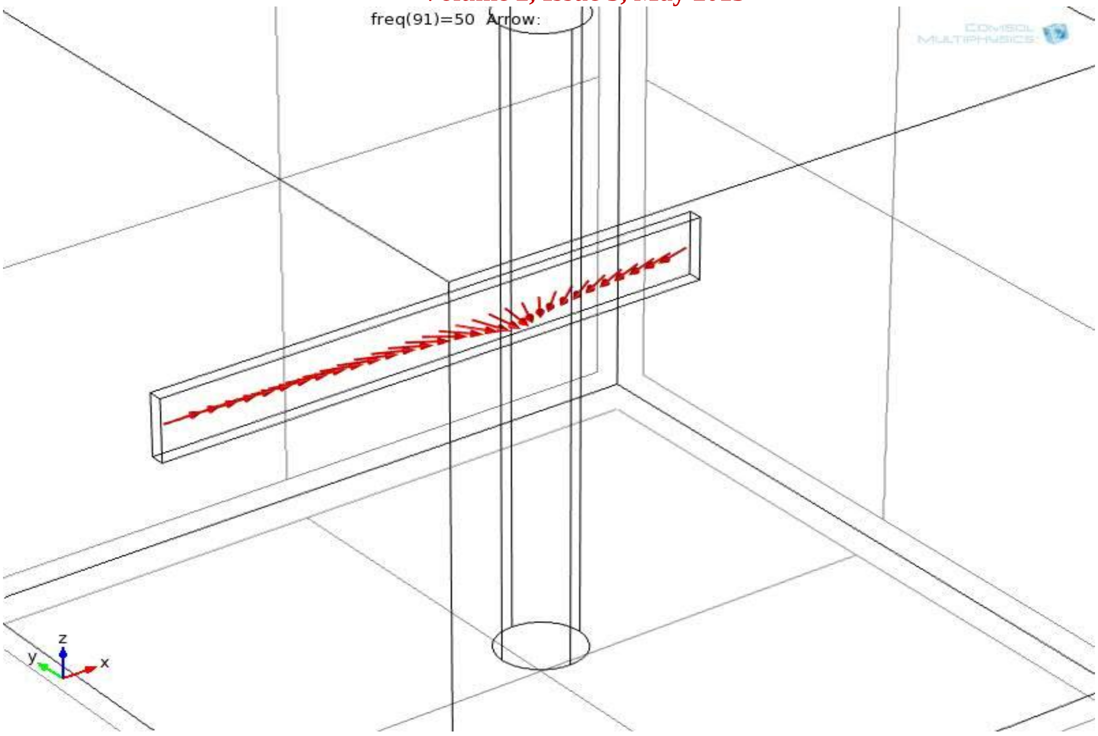


Fig. 6 Body forces developed on the beam due to the induced currents

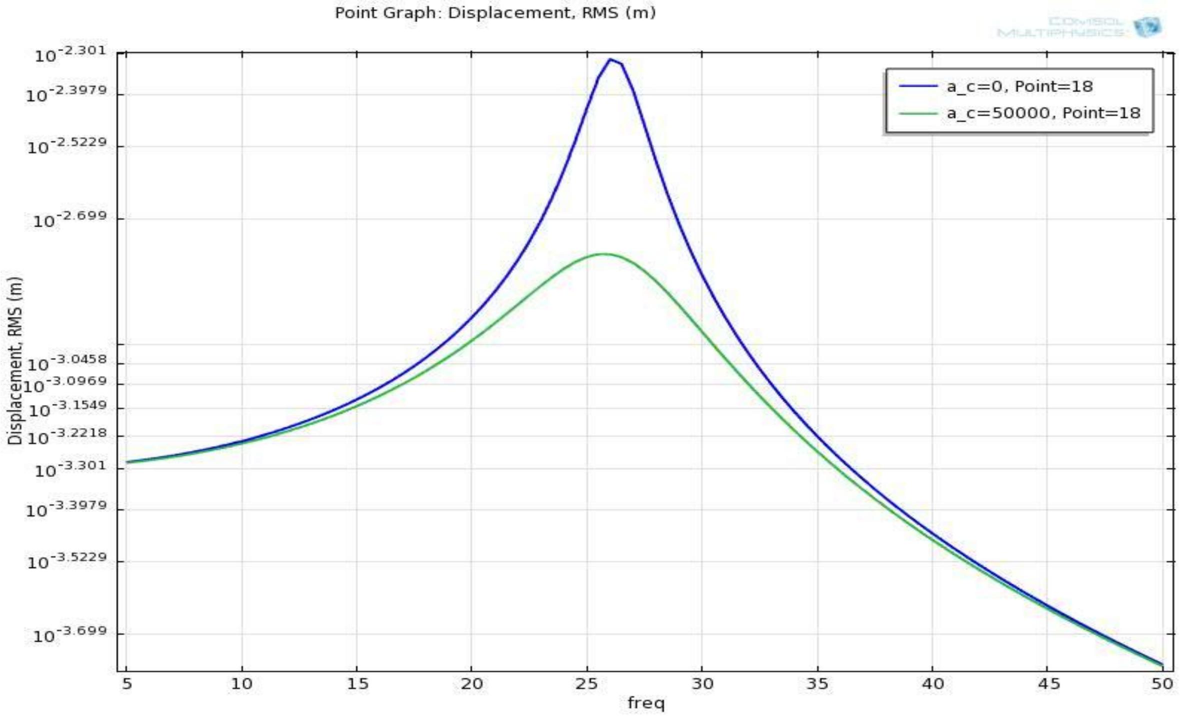


Fig. 7 Tip displacement of cantilever beam for a range of frequency

VI. CONCLUSION

For a optimal performance of a beam structure it requires that vibration of system must be suppressed quickly which can be achieved by using eddy current damper. Also in the case of eddy current damper the dampers do not contact the structure, thus allowing them to add damping to the system thereby eliminating the possibilities of the localized damage, altered dynamics of structure and problem like deterioration of seals, leaking liquid etc. as in the case of other traditional damping mechanism. This paper has investigated vibration control mechanism that function through the eddy current generated in a conductive material that is subjected to time varying magnetic flux. Eddy current damper has been designed and modeled showing that it can apply significant damping to a vibrating structure. Additionally we have also studied the basics of vibration theory of cantilever beam and plotted various mode shapes at various natural frequencies.

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