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Analysis of Eddy current damper for suppression of vibrations using COMSOL software

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A R T I C L E I N F O

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A B S T R A C T

An Eddy current damper uses magnets to suppress vibrations due to external excitations. These dampers also called electromagnetic dampers, have advantages of no mechanical contact, high reliability and stability, but require a relatively large volume and mass to attain a given amount of damping. The magnets respond to an external excitation field. Along with the construction of the damper, COMSOL software is used for analysis of the eddy current damper and got various results like magnetic flux density, eddy current intensity, velocity and acceleration of the moving magnet. For this a standard dimension of an automotive vehicle damper is used so that the prototype could be tested on a damper testing machine. The standard dimension is chosen to increase the adaptability, compatibility and to ease of testing the damper. After this task the response of damper under various loads is observed. Different materials of housing tube are taken to observe the effects of various parameters like flux density, current intensity and, of course, the damping capability of the prototype damper.

1. Introduction

Computer simulation has become an essential part of science and engineering. Digital analysis of components, in particular, is important when developing new products or optimizing designs. A computer simulation environment is simply a translation of real-world physical laws into their virtual form. How much simplification takes place in the translation process helps to determine the accuracy of the resulting model. Various software packages can be used for this. One of the software is COMSOL. COMSOL is a finite element analysis, solver and simulation software/ FEA Software package for various physics and engineering applications, especially coupled phenomena, or multi physics. COMSOL multi physics also offers an extensive interface to MATLAB and its toolboxes for a large variety of programming, preprocessing and post processing possibilities. The packages are cross-platform (Windows, Mac, and Linux). In addition to conventional physics-based user interfaces, COMSOL multi physics also permits for entering coupled systems of partial differential equations

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(PDEs). The PDEs can be entered directly or applying the so-called weak forms (see finite element method for a description of weak formulation). An early version (before 2005) of COMSOL multi physics was called FEMLAB.

Stebner and Hartwig (2012) investigated on transient analysis of Electro-Mechanical Valve Drive (EMVD) in COMSOL. In their work an EMVD is redesigned for combustion engines to reach a fail-safe behaviour when power loss happens. The Magnetic Field interface and the Moving Mesh interface of COMSOL multi physics 4.2 are implemented to build up a transient model. This model also incorporates the calculation of eddy current. The Global ODEs and DAEs interface are applied to use an ordinary differential equation (ODE) which uses Newton's Law to explain the acceleration of the valve plate. Nagaya et al. (1984) studied the eddy current damping force induced on a conducting plate of arbitrary finite size moving with a velocity parallel to the face of a cylindrical magnet. To account for the boundary conditions of the conducting plate, the Fourier expansion collocation method was used, which provides no restrictions on the conductor shape.

Wiederick et al. (1987) proposed a simple theory for the magnetic breaking force induced by eddy currents in a thin rotating conductive disk passing through the poles of an electromagnet. Their model found the damping force to be linearly associated with the velocity, conductivity and air gap, but quadratically dependent on the magnetic flux. The proposed model does not consider the effects of the edges of the conducting plate and while the paper provides an experimental study, Karnopp (1989) introduced the idea that a linear electro dynamic motor consisting of coils of copper wire and permanent magnets could be used as an electromechanical damper for vehicle suspension systems. The study presented the ability to use a moving coil and a moving magnet actuator as the damping mechanism and employed some rough calculations to identify the system performance; however no experiments were performed to validate the calculations.

Frederick and Darlow (1994) looked at using an eddy current damper to replace the coulomb or squeeze film dampers typically used in rotating machinery, whose damping properties typically change with temperature and cause additional torque loading and wear. The damping system consisted of a horseshoe electromagnet that had a conductive disk rotating between the magnetic poles. The study was purely experimental and showed that the peak to peak response was reduced in the X-direction by 15.6% and in the Y-direction by 27.5%. Cadwell (1996) investigated the breaking force exerted on an aluminum plate as it passes between the poles of a horseshoe electromagnet. A simple model of the system was developed that leaves the length of the eddy currents path as an unknown parameter, which is fit using the experimentally obtained results. Plissi et al. (2004) discussed theoretical and experimental investigations of the use of eddy current damping for multi-stage pendulum suspensions such as those intended for use in Advanced LIGO, the proposed upgrade to LIGO (the US laser interferometric gravitational-wave observatory). The design of these suspensions is based on the triple pendulum suspension design developed for GEO 600, the German/UK inter ferometric gravitational wave detector, currently being commissioned.

Singh and Singh (2011) and Singh et al. (2012) studied the eddy current dampers and the concept of Eddy Current damping in Structures. Eddy Current Damper (ECD) works on the principle of Electromagnetic Induction. According to the theory of electromagnetic induction, a current flows in a conductor whenever a change in magnetic flux is linked with it. Change in magnetic flux takes place when a conductor moves in a stationary or transient magnetic field

Experiments were conducted based on theoretical models proposed in recent literatures on the cantilever beam. It was found that the eddy current damping mechanism adds significant amount of damping to the beam. Singh and Singh (2012) presented analytical expression on eddy current damping caused by electromagnets in a copper tube. In 2008 COMSOL group built a model that illustrates the phenomenon of eddy current. They used a moving conductor in a stationary magnetic field and a simple magnet was used in a stationary magnetic field. With the help of meshing module, mesh was created to locate the critical areas. Areas with high eddy current intensity can be easily identified. From AC/DC module ampere law was applied to the magnet. In this paper using the COSMOL software an eddy current damper is modeled.

In COMSOL multi-physics the modeling process starts with the combination of three physics interfaces. To describe magnetic fields (mf) interface of the AC/DC-Toolbox is used to solve Maxwell's Equations. The moving mesh interface is used to make the mesh deformable. Finally the Global ODEs and DAEs (ge) interface is used to define the deformation inside the moving mesh interface by defining an equation for the acceleration of the valve plate. The geometry is directly drawn in COMSOL multi-physics as parametric definitions are supported. The geometry of the actuator is augmented by additional rectangles which improve the simulation results. In the next section the procedure of modeling is presented and described.

2. Selection of module

According to problem, the particular AC/DC module will be selected which is more suitable than other module, in this module we can perform simulation of capacitors, inductors, power cables, electrical motors, electrical generators, and sensors. Electrostatics, direct current, electro-quasi static excitation and electromagnetic four potentials are included. Combinations with CFD, thermal, acoustic, and structural analysis are common. SPICE circuit import is available for connecting finite element model with circuits. Ordinary (Partial) Global Equations (ODE) module has been selected. The specification of the model is given in the Table 1, where all the parameters are discussed.

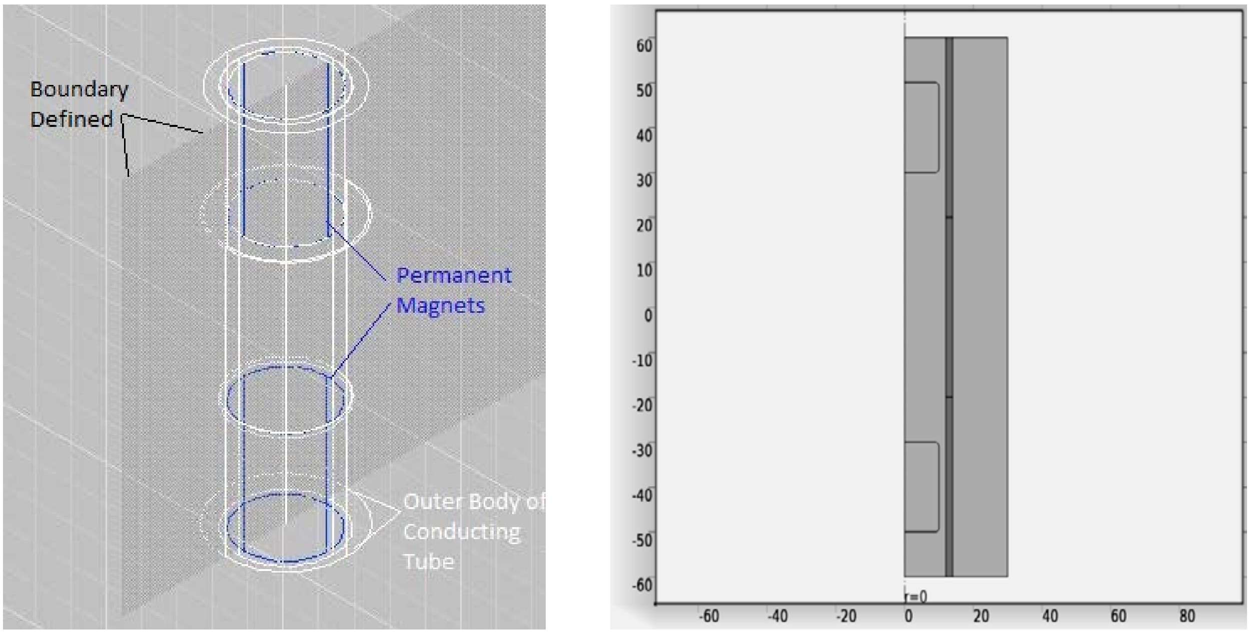
Table 1. Parameters of Model

Name	Expression	Description
mr	10 (mm)	Magnet radius
mh	20 (mm)	Magnet height
ri	12 (mm)	Tube inner radius (copper,brass,aluminium)
ro	14 (mm)	Tube inner radius (copper,brass,aluminium)
dm	10 (g/cm3)	density of magnet
Br	2.5 (T)	Remanent flux density
L	0,10,20,30,40(N)	External load acting on the body
rsi	15(mm)	inner radius of steel tube
rso	16(mm)	outer radius of steel tube

After selection of all parameters, construction of drawing has been accomplished by selecting different parts of drawing assign material from material browser list. Various properties of the material will be assigned automatically with specifications.

2.1 Meshing the geometry

Figs. 1a and 1b show the 3D model and the 2D sketch of the investigated eddy current damper. Now the boundary conditions will be applied. The center line as shown in Fig.1 will be the initial boundary and outer boundary will be the 30 mm beyond the outer radius of steel tube. This Figure shows the one half identical part of eddy current model. The dark vertical line shows steel tube whereas the two smaller cylinders or (rectangles) show the positions of two permanent magnets.



(a) (b)

Fig. 1. (a) three- dimensional model of eddy current damper model and (b) One half the 2D model (dimensions are in mm)

3. Simulation results

The model will be divided into smaller but identical triangular parts for mesh generation and mesh size can be varied as desired or needed, with the help of software (Refer Figs. 2 and 3). Fig. 2 shows the mesh generation in the eddy current damper model in which the concentration of forces is represented by dark areas that is at corners and at the middle or center of the tube. Zoomed view of model is also shown in Fig. 3. The larger size represents less intensity of forces whereas the concentrated ones and the smaller ones represent the high intensity of forces.

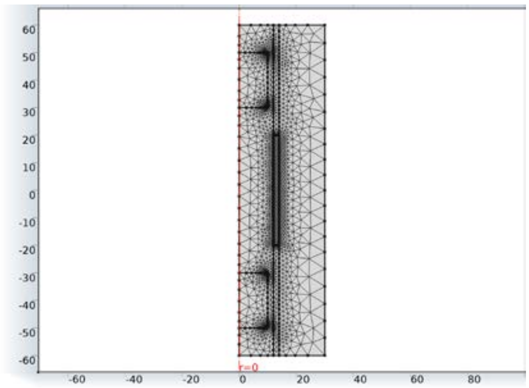


Fig. 2. Generated mesh in the eddy current damper model (dimensions of both axes are in mm)

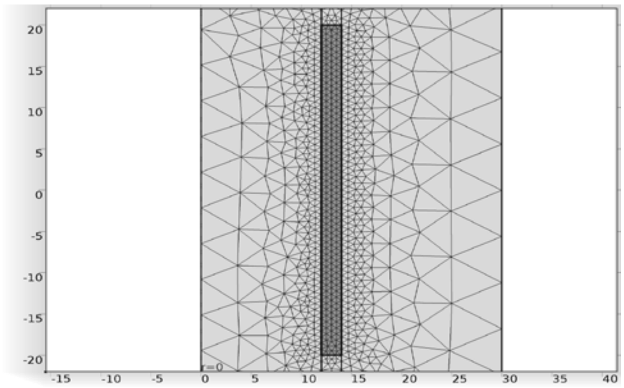


Fig. 3. Magnified view of meshes in the model

4. Results and conclusion

Fig. 4 shows the magnetic flux density at various positions of the arrangement. The linear scale at the right hand side of the figure gives the value of magnetic flux density.

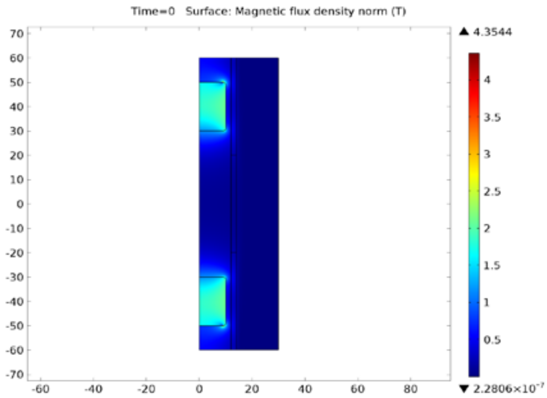


Fig. 4. Results of magnetic flux density

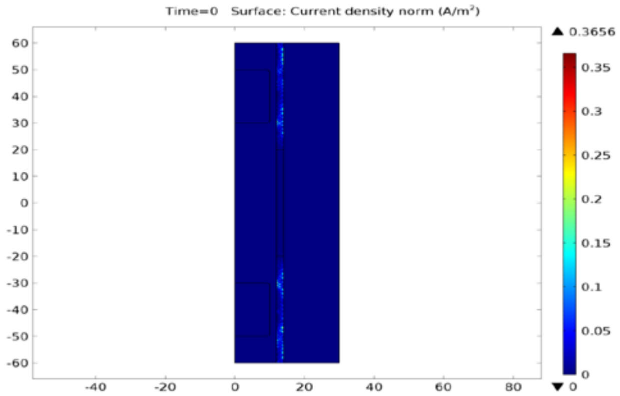
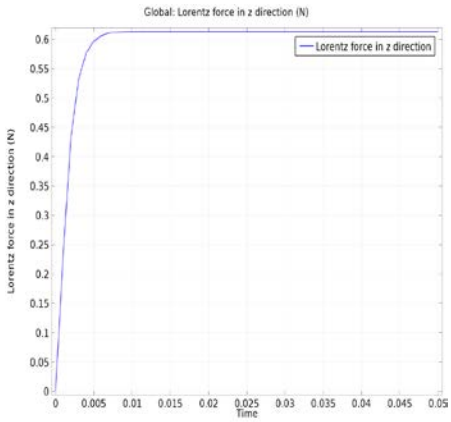


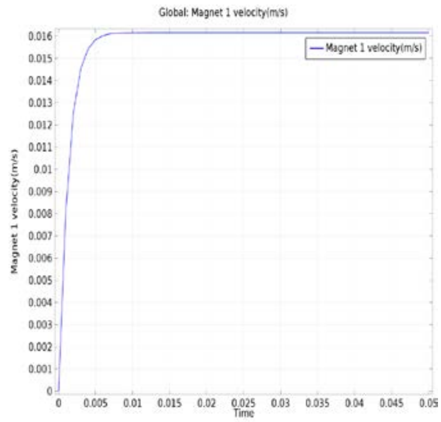
Fig. 5. Results of surface current density

In Fig. 5 current density is shown at various locations. From the figure we can conclude that current is present only in those areas in which magnets and the copper tube are in the vicinity of each other.

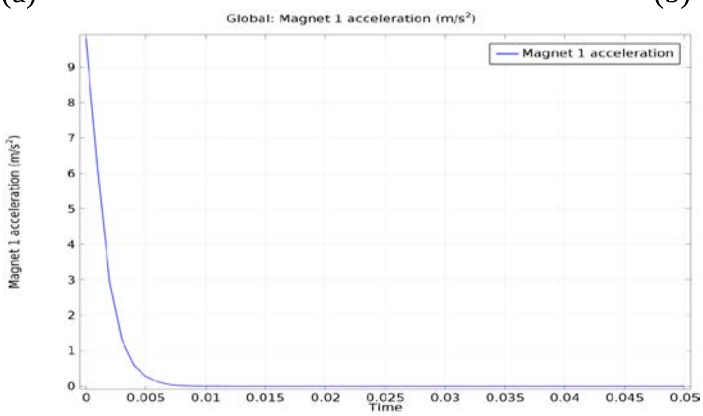
Figs. 6 and Fig. 7 present values of parameters like Lorentz force, magnet velocity and magnet acceleration active at 0 N and 40 N loads, respectively.



(a)

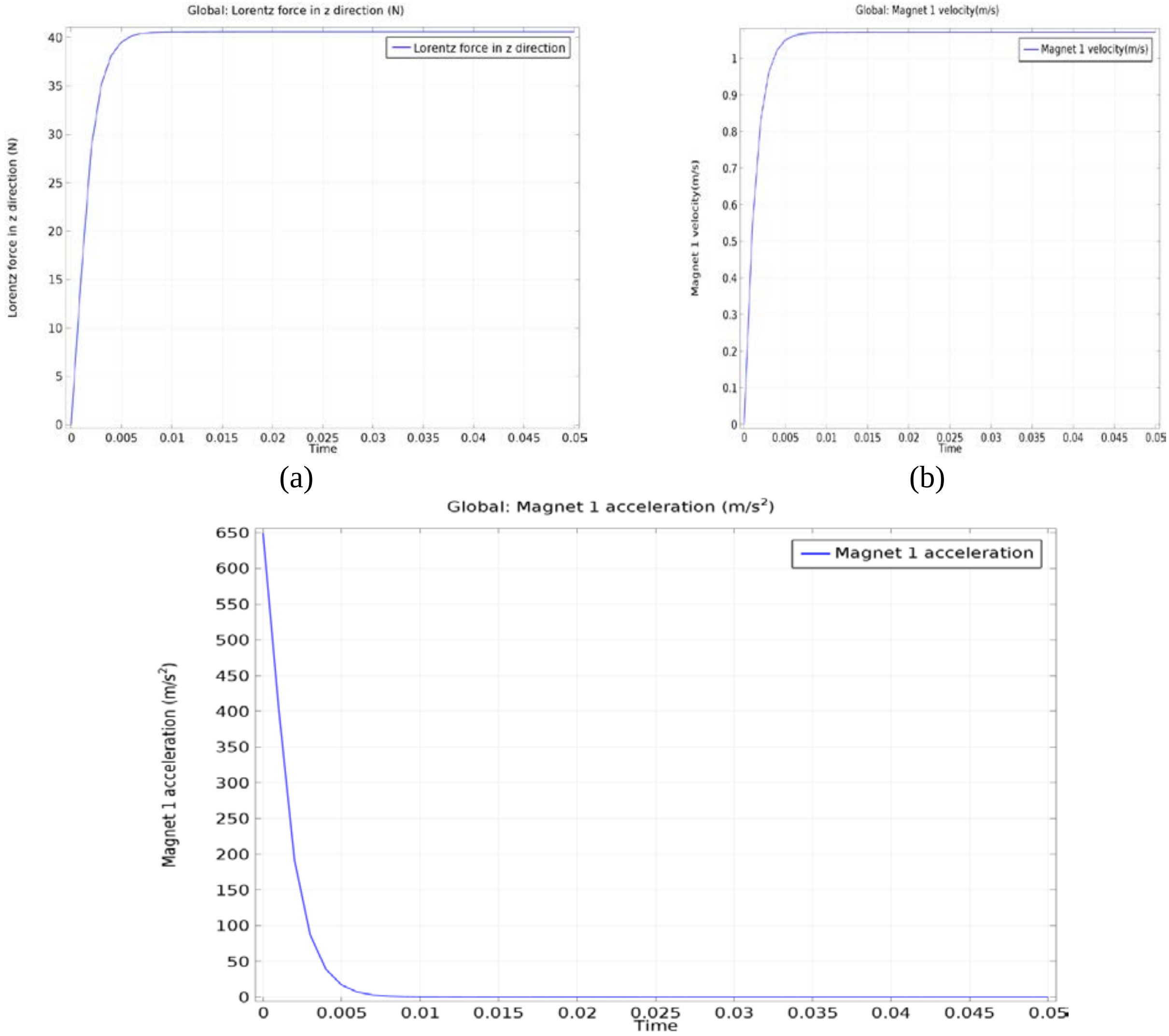


(b)



(c)

Fig. 6. Variations of (a) Lorentz Force, (b) magnet velocity and (c) magnet acceleration with time for the modeled eddy current damper at applied load of 0 N



(c)

Fig. 7. Variations of (a) Lorentz Force, (b) magnet velocity and (c) magnet acceleration with time for the modeled eddy current damper at applied load of 40 N

Table 2. Summary of obtained Results

Sr. no.	PARAMETERS	CALCULATED VALUE	VALUES TAKEN FROM LETRATURE (Crosby & Karnopp 1973; Barak 1992; Furlani 2001; Deo 2007; Biglarbegian et al., 2008)
1	Magnetic flux density	1.2	1.3
2	Surface current density	0.18 A/m^2	0.05-0.15 A/m^2
3	Velocity of magnet at 0 N	0.012 m/s	0.016 m/s
4	Velocity of magnet at 10 N	0.22 m/s	0.28 m/s
5	Velocity of magnet at 20 N	0.48 m/s	0.53 m/s
6	Velocity of magnet at 30 N	0.75 m/s	0.82 m/s
7	Velocity of magnet at 40 N	0.92 m/s	1.1 m/s
8	Acceleration of magnet at 0 N	9.81 m/s^2	9.81 m/s^2
9	Acceleration of magnet at 10 N	41 m/s^2	48 m/s^2
10	Acceleration of magnet at 20 N	92 m/s^2	100 m/s^2
11	Acceleration of magnet at 30 N	164 m/s^2	173 m/s^2
12	Acceleration of magnet at 40 N	318 m/s^2	328 m/s^2
13	Lorentz force at 0 N	0.278 N	0.6 N
14	Lorentz force at 10 N	14.79 N	10.25 N
15	Lorentz force at 20 N	27.12 N	22 N
16	Lorentz force at 30 N	36.98 N	31.50 N
17	Lorentz force at 40 N	49.31 N	42 N

From the above plots it is observed that when the load is applied on the damper model with the help of damping testing machine at 0 N, the Lorentz force produce is in less amount as compared with Lorentz force produced when load applied at 40 N. It is also observed that the response factor of damper at load 40 N is very high and stable. It is observed that magnetic flux density is not affected by presence of steel tube. Moreover steel tube adds to the strength of the equipment .

There is no physical contact between the magnet and conducting tube, which improves the magnetic levitation. As no oil or other fluid is used in the damper there is no threat of leakage and spilling of the oil or fluid. It is of great advantage as it minimizes the use of sealing parts and makes the design simpler and cheaper .

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