Design and Development of Novel Semi Active Eddy Current Damper for Aerospace Applications

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Abstract— The structural vibration damping is of utmost priority and critical for electronic and mechanical devices used in aircraft and automobiles. A novel eddy current damper is designed and developed, thereby the damping characteristics were evaluated theoretically and experimentally to obtain an optimum value of damping coefficient to suppress the vibrations in the devices. After performing the various calculations, the desired value for "c" (eddy current damping co-efficient) is found out to be 150.93 Ns/m for a plate thickness of 3 mm, a current value of 3A, number of turns on the electromagnet was 1000. The graph of "c" vs "t" was found out to be a straight line. The nature of the graph obtained between amplitude of vibration vs time was similar to that of logarithmic decrement curve where the ratio of successive amplitudes remains constant. The value of damping coefficient ζ was found out to be in the desired range of the theoretical value.

Index Terms— Eddy current damping; vibrations, aerospace, structural damping

I.INTRODUCTION

The structural vibrations induced in mechanical members and electronic devices are of major concern in aircraft and automobile systems. The variety of innovative technologies have led to development of newer applications like remote sensing, camera devices etc. are mounted in the system [1, 2]. The damping devices are used to isolate and attenuate the vibrations and protect the devices/system from damage. The damping devices designed should possess high reliability, good life and sustainability in operational conditions. Eddy current dampers due to their attractive properties like non-contact and non-leakage, makes it a preferred method to attenuate vibrations of system in aerospace and automobile applications [3]. Extensive research has been carried out in relation damping mechanisms using eddy currents. Schmid et al. [4] designed and developed a vibration attenuation system using eddy current damper to damp the vibrations in high-resolution scanning tunnelling microscope. Sodano et al. [5] proposed a newer type of eddy current damper based on electromagnetic theory and energy method to quickly suppress beam vibration. The results showed generation of sufficient damping force to address the beam structure vibration. Kobayashi et al. [6] developed eddy current damper with two permanent magnets. The results obtained showed that, 2% increase in damping ratio for the Houde damper.

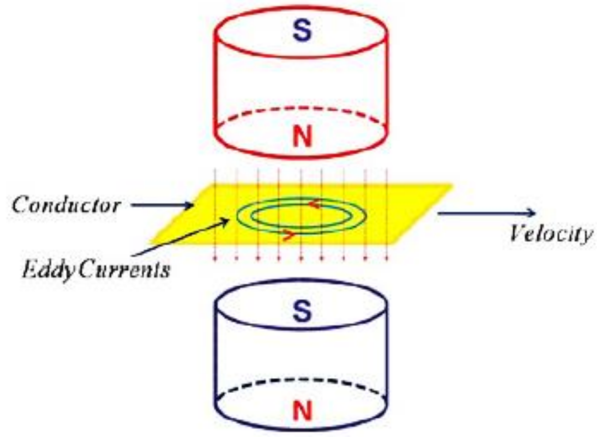

Fig 1. Conductive plate moving perpendicular to the magnetic poling axis

Kienholtz et al. [7] investigated magnetically damped isolation mount for a spacecraft solar array using magnetic tuned mass damper to suppress vibration. The results showed first torsion at 0.153Hz and first out of plane bending of 0.222Hz and increased the damping by 30 and 28dB, respectively, while the higher frequency untargeted modes 0.4–0.8Hz, were damped in the range of 11–16dB. Kwag et al. [8] investigated and developed eddy current shock absorber which used permanent magnet with radial flux being almost perpendicular to tube surface proved to be efficient than Sodano's model. Ebrahimi et al. [9] experimentally verified the analytically obtained damping characteristics of passive eddy current with different configurations of permanent magnets used. Cheah et al. [10] investigated the magnetic bearing using eddy current mechanism and used finite element analysis tool to predict the force with respect to vibration.

In the current investigation, a damper based on eddy current damping mechanism is designed. The damping characteristics of eddy current damper which includes calculations involving magnetic flux density, force experienced by the conductor and eddy current damping coefficient were evaluated.

Revised Version Manuscript Received on 05 August, 2019.

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This was followed by design and development of eddy current damper, which involved structural analysis of the model, calculating parameters like stiffness of spring and the mass required to produce the desired damping. Experiments were conducted after fabrication of experimental setup. Accelerometer and oscilloscope were used to obtain the graph after providing an impulse on the system. Theoretical and experimentally obtained values of damping coefficient (C) were compared to validate the results.

II.MATERIALS AND METHODS

Semi-Active dampers are the kind of the spring mass system where the damping coefficient can be varied easily due to the presence of control system. But in this the control system doesn't have an actuator connected to it. Semi-active suspension system is known to be a good candidate for practical applications because it combines the advantages of both passive and active suspension systems.

The support structure consists of MS plate of 350*200*10mm on the top with four supporting MS cylindrical legs to hold the weight of the structure. The legs are 450mm long and 3mm diameter. The supporting rods also consist of two plates for bolting the electromagnets. The supporting rods are also threaded so as to provide vertical movement of the entire spring mass system. Four parallel MS springs of 5mm diameter are connected to the structure plate on one end and on the other end a 0.2 kg mass is attached which together act as a spring-mass system. The spring has 6 active turns and the mass is of 50*100mm dimension and is made up of aluminium. Two aluminium plates of thickness 3mm and 2mm to cut the flux generated through the electromagnet. The plate dimension is 100mm*100mm. This plate has been attached to the 0.2 kg mass with the help of bolts. Two cast iron rods of 160mm in length and 30 mm diameter is wounded with 500 turns each with 20 SWG (Standard wire gauge) wire. The MS shafts are threaded internally and screwed to the support structure. The electromagnet is designed to withstand current up-to 5A.

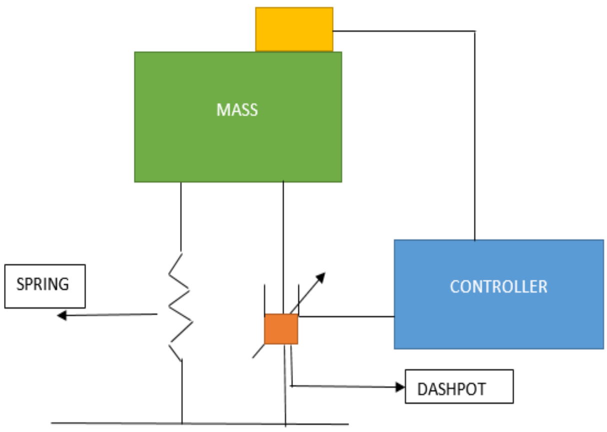

Fig 1. Semi-active dampers

Fig. 1 shows the semi active type eddy current damper. The electromagnet induces a magnetic flux which depends on the current flowing through the conductor. The magnetic flux density between the two electromagnets can be varied by controlling the current flowing through the electromagnet [11].

Force Fc on the conductor is given by Eq. 1,

$$Fc = B * A * Ieddy \quad (1)$$

Where, B is flux density in Gauss or Tesla and A is the area of the conductor plate exposed to magnetic field.

Force acting on the conductor is given by Eq. 2,

$$Fc = B2 * t * A * \sigma * v \quad (2)$$

Where, σ is conductivity of the conductor plate which is the reciprocal of the resistance, R and v the velocity of the conductor plate.

Considering the active area of the conductor in the magnetic field to account the shape of the conductor, a dimensional coefficient, C0 is introduced as shown in Eq. 3.

$$Fc = C0 * B2 * t * A * \sigma * v \quad (3)$$

The magnetic field in the direction of electromagnet is given by Eq. 4,

$$BEM = \frac{\mu N I}{l} \quad (4)$$

Where, μ is permeability of ferromagnetic material = 120*4π*10-7 TA/m, N is number of turns of current carrying conductor, I is the current passing through the conductor, l is the length of the conductor.

Eddy current damping coefficient is computed for the experimental model, that is Eq. 5,

$$c = C0 * B2 * t * A * \sigma \quad (5)$$

Where, the thickness "t" is varied to obtain the desired value of damping coefficient.

Magnetic flux density is computed by Eq. 6,

$$BAir\ Gap = \mu 0\ N.I / l \quad (6)$$

Where, μ0 is the permeability in air equal to 4π*10-7 T/Am, N is the number of turns of coil, I is the current through the coil, l is average length of coil in meters, d is the air gap between the electromagnets.

2.1 Literature Survey

The semi active eddy current damper was CAD modelled using CREO elements software tool to arrive at an optimum sized damper as shown in Fig. 2. The Fig. 2 also shows the fabricated model of the eddy current damper.

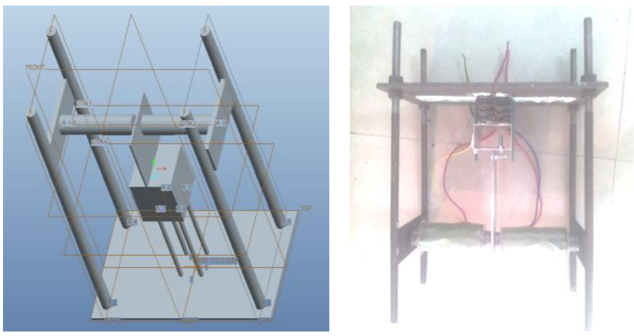

Fig. 2 CAD model and fabricated model of eddy current damper

2.2 Testing of the eddy current damper:

The stiffness of all the springs were calculated by applying a known load and measuring the deflection using Eq. 7.

$$\text{Spring Stiffness (k)} = \text{Applied Load / Deflection} \quad (7)$$

After spring stiffness was calculated the damper was connected with the voltage regulator to obtain a range of current from 0-2A in increments of 0.5A. Accelerometer was attached to the spring mass system and was connected to the oscilloscope. The Fi. 3 shows the block diagram / experimental setup of the eddy current damper. The impulse was provided on the spring mass system, the vibrations were picked up by accelerometer and a graph between amplitude of vibration and time was obtained in the oscilloscope. The nature of graph was found out to be the same as that of logarithmic decrement. The graphs obtained were slightly blurred as the accelerometer was also picking up slight lateral vibrations.

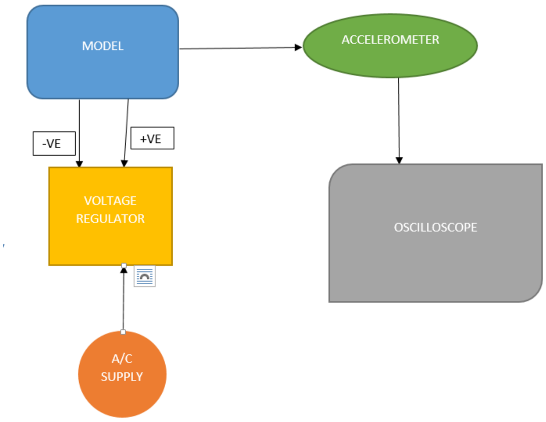

Fig.3 Block diagram/ experimental setup of eddy current damper

III.RESULTS AND DISCUSSIONS

The theoretical values were calculated for a designed and fabricated semi active damper as shown in Table 1 below for a plate thickness of 3mm. The eddy current damping coefficient "c" is evaluated for a varied current "I" Amperes.

Table 1: Depicts the values of current, air gap and damping coefficient for plate thickness 3mm

I (Amps)	3	2.5	2	1.5	1	0.5
B (Air gap)	0.3769	0.314	0.251	0.1884	0.1256	0.0628
c (Ns/m)	150.93	104.82	67.08	37.71	16.76	4.19

Table 2: Depicts the values of current, air gap and damping coefficient for plate thickness 2mm

I (Amps)	3	2.5	2	1.5	1	0.5
B (Air gap)	0.3769	0.314	0.251	0.1884	0.1256	0.0628
c (Ns/m)	100.62	69.88	44.72	25.14	11.17	2.79

Similarly, Table 2 and Table 3 shows values for eddy current damping coefficient "c" is evaluated for a varied current "I" Amperes for a plate thickness of 2mm and 1mm respectively.

Table 3: Depicts the values of current, air gap and damping coefficient for plate thickness 1mm

I(AMP)	3	2.5	2	1.5	1	0.5
B(AIR GAP)	0.3769	0.314	0.251	0.1884	0.1256	0.0628
c (Ns/m)	50.28	34.91	22.30	12.57	5.58	1.39

Table 4 shows the evaluated results of the damping coefficient c, experimentally and theoretically and the values obtained are compared.

Table 4: Depicts the variation of δ and ζ vs current Current

Current (Amps)	No. of cycles	δ	ζ	c (Theoretical)	c (Experimental)
0.5	5	0.088	0.016	4.19	4.52
1	6	0.097	0.080	16.76	22.62
1.5	5	0.130	0.152	37.71	42.97
2	6	0.148	0.190	67.08	53.74

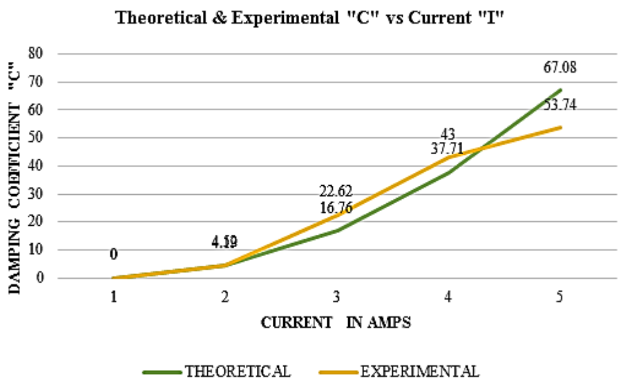

Fig.4 Comparison of theoretical and experimental c values vs current.

Fig. 4 shows that the experimental errors account for slight variation in theoretical and obtained experimental values. As the current increases the difference between theoretical and experimental values also increase.

IV.CONCLUSIONS

After performing the various calculations, the desired value for "c" (eddy current damping co-efficient) is found out to be 150.93 Ns/m for a plate thickness of 3 mm, a current value of 3A, number of turns on the electromagnet was 1000. The graph of "c" vs "t" was found out to be a straight line. The graph obtained from the oscilloscope was slightly blurred because the accelerometer was picking up some lateral vibrations. The nature of the graph obtained between amplitude of vibration vs time was similar to that of logarithmic decrement curve where the ratio of successive amplitudes remain constant. Thus the value of damping coefficient ζ was found out to be in the desired range of the theoretical value

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