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Experimental Study of Vibration Isolation Using Electromagnetic Damping

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1. Introduction

Vibration is a prevalent phenomenon that occurs in various mechanical systems, ranging from large-scale structures to microscopic components. Uncontrolled vibrations can lead to detrimental effects such as decreased performance, structural damage, and increased noise levels. Consequently, mitigating vibration has become a critical area of research across multiple disciplines. A promising approach to tackle vibration-related challenges is varying the stiffness and damping. Many devices, such as electromagnetic damper, magnetic springs, electromagnetic springs, vary the stiffness and damping of the system when attached to the spring mass system. The principles of electromagnetism are used in electromagnetic springs to reduce vibrations in mechanical systems by dissipating energy. The nonlinear force between magnets was used to reduce vibration in the mechanical systems. Magnetorheological fluid damper is used to vary the damping of the system with the help of electromagnetic damper. The use of electromagnets in damping vibrations involves the generation of magnetic field by electrical current, which interacts with the motion of the vibrating structure to produce a retarding force to counteract the oscillatory motion of the system and bring it to a more stable state.

Electromagnets have been increasingly used for damping vibrations in engineering structures due to their flexibility, efficiency and versatility. [1] proposed a variable stiffness semi-active isolation system consisting of leaf springs, electromagnet and permanent magnet connected in parallel. A linearized nonlinear model was used to study the system theoretically with PID controller and proved that the system had fast response and high vibration reduction efficiency. [2] designed an electrodynamic system with simple structure and proposed a PID controller for verifying the system. Also the authors demonstrated the designed effectiveness of the electromagnetic isolator system with PID controller. The natural frequency of the system was tuned by the vibration absorber and vibration suppression upto 61% was achieved using electromagnetic absorber. [3] presented a robust control scheme for a quarter-car suspension system which has selectable damping rates at different velocities and quick changing ability between the two extreme velocities.[4] investigated a permanent passive magnet negative-stiffness device with the use of magnets to reduce the stiffness of the system. [5] used a combined permanent and electromagnet to decrease the amplitude of vibration of the object.

[6] studied the combinational effect on vibration reduction using hybrid magnet and MRF damper and proved that the vibration reduction was better than the passive elements. A dynamic damper developed by [7] with electromagnets produced better vibration reduction than dynamic damper. [8] presented a review of research work carried out by different researchers on electromagnetic damper as a vibration isolation material. Finite element method and MAT lab were used to study the performance electromagnetic damper and one of the researchers proved that slotted type damper was better than the cylindrical type electromagnetic damper. [9] studied vibration suppression of the cantilever beams with permanent magnet and electromagnetic transducer connected to RLC shunt. The influence of magnets with different gaps resulted in large vibration reduction. [10] proposed an electromagnetic damper with resonant shunt to suppress the vibration and the effect on the damping parameters were analysed theoretically and justified experimentally. [11] carried out simulation work on seat suspension with electromagnetic levitation component based on C level road surface.

[12] explored the shift in resonant frequency by implementing adaptive tuned vibration absorbers in a spring mass system and also showed the shift of peak was 23% of its resonant peak. Vibration isolation using two electromagnets in a constrained one fourth model of a car was not yet analysed.

This work aims to study the vibration reduction using two sets of electromagnets of 17 SWG and 19SWG wire at different coil voltages with the help of electrodynamic shaker, Lab VIEW software, DAQ and sensors. The acceleration and displacement of top and base plates were considered for the analysis. The repulsive force between two electromagnets in vibration reduction could be the novel of this work.

2. Experimental Details

The quarter-car setup of single degree vertically constrained (SDVC) system was fabricated to study the influence of force between electromagnets on damping in the suspension system. A miniature model of 1:25 ratio of one fourth of passenger vehicle (Fig. 1 and Fig. 2) with top plate mass of 4.82 kg and natural frequency of 3.4 Hz. was considered for the experimental work. The size of the electromagnet was decided based on the length of the spring and the gap between the top and base plate of the SDVC setup. The material used for fabrication of the electromagnet core is mild steel as it is ferromagnetic and high magnetic permeability. The full iron core was painted to avoid conductivity of electricity and an insulation was wound on the middle cylindrical portion and side portion of iron core to avoid direct contact with the core.

A cotton tape was wound around the coil to keep the tightness between coils. The 3D view of electromagnet is shown in Fig. 3 and fabricated electromagnet of is shown in Fig. 4. The electromagnets are kept on the top and base plate without the current and the setup was excited at different frequencies from 2 Hz to 20 Hz in the interval of 2 Hz. The quarter car setup was placed on Shaker machine and three accelerometers (Make: PCB piezotronics IEP (Integrated electronic piezo electric) type, PCB J35B33, resolution 0.005 m/s^2 range =1-4000 Hz, sensitivity mV/g) were used to acquire base excitation and top plate response.

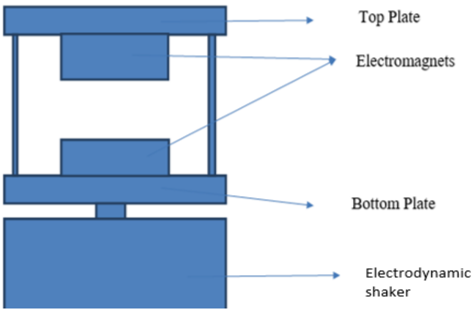

Fig. 1 Schematic diagram of SDVC

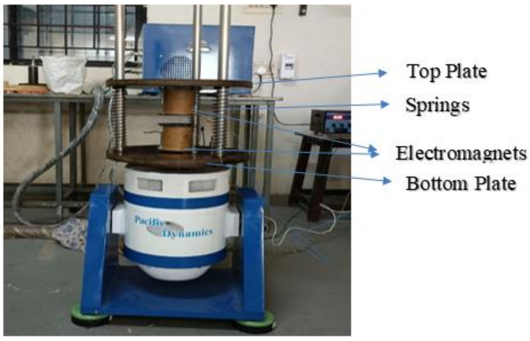

Fig. 2 Experimental setup of SDVC

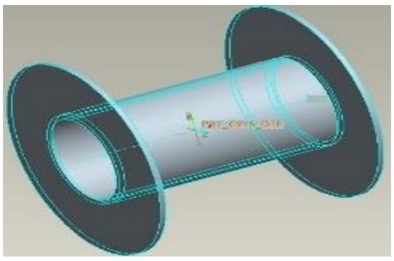

Fig. 3 3D view of electromagnet

Fig. 4 Fabricated model of electromagnet

The output level is proportional to the amplitude of the vibrations. With use of three guide rods, the wooden discs were constrained to move only in the vertical direction. The Coulomb friction in the system between guide rods and discs was reduced by applying oil and grease. The parameters of SDVC setup were listed in Table 1.

Table 1

Parameters of SDVC setup

Sl. No.	Description	Value	unit
1	Spring mass	4.82	kg
2	Spring stiffness	550	N/m
3	Coil diameter	35	mm
4	Spring wire diameter	2.5	mm
5	Pitch	15	mm
6	Total height of the spring	246	mm
7	Number of turns in spring	20	
8	Total weight of the SDOF	10	kg
9	Diameter of the guide rod	25	mm
10	Length of the guide rod	510	mm
11	Outer diameter of the electromagnet	94	mm
12	Inner diameter of the electromagnet	44	mm
13	Thickness of top and base flange	2	mm
14	1127 Gauge wire	340	
15	19 13 Gauge wire	380	

The governing equations of a single-degree-of-freedom spring - mass system subjected to base excitation and electromagnetic force between the base and top plate is given in Eq. (1)

$$m\ddot{x} + c\dot{x} + kx + F_{electromag} = 0, \quad (1)$$

where c and k are functions of the distance between the magnets and are variable and are given by the equations, m is the mass of the system, $x - x_0$ is the relative displacement of the mass from the equilibrium position, k is the stiffness of the spring, c is the damping coefficient, $F_{electromag}$ is the force of the electro magnets. The force of the electro magnets is modeled using the following Eq. (2)

$$F_{electromag} = k_{electromag} * (x - x_0) / (x - x_0)^3. \quad (2)$$

3. Results and Discussion

Experiments were carried out on SVDC with use of accelerometers placed on top and base plate. In the first phase of experiment the coil voltage was given to the top electromagnet and bottom electromagnet was disconnected from the power supply. The coil voltage of top electromagnet was varied from 2 V to 10 V in the interval of 2 V. The data obtained from accelerometers placed on the base and top plate for 10 seconds are given in Table 2.

3.1. Amplitude of RMS acceleration of top plate for 17-gauge electromagnet

From the data observed for 17-gauge electromagnet at 2 Hz the amplitude of acceleration is very close the value without coil voltage and at other frequencies the amplitude is more (Fig. 5). The first peak of SVDC system (resonant condition) considering spring stiffness without coil voltage was 12 Hz. The amplitude of acceleration for different coil voltages and at all frequencies is more than the amplitude of acceleration without coil voltage.

Table 2

RMS acceleration of top plate of SDVC with 17-gauge electromagnet

Frequency (Hz)	Acceleration (m/s^2)- Top plate electromagnet energized						Both magnets energized		
	without	2 V	4 V	6 V	8 V	10 V	2 V	4 V	6 V
2	0.24	0.30	0.41	0.34	0.33	0.33	0.29	0.39	0.35
4	0.48	0.51	0.61	0.54	0.52	0.35	0.53	0.50	0.58
6	0.75	0.93	0.72	1.03	0.99	0.90	0.98	0.98	0.78
8	0.90	1.58	1.60	1.71	1.98	1.71	1.84	1.43	1.41
10	1.03	1.83	2.03	2.00	2.61	2.40	1.98	1.86	1.93
12	1.74	1.92	2.68	2.58	3.00	3.15	2.02	1.99	2.10
14	0.65	1.94	2.47	2.48	2.82	2.78	2.18	2.05	2.1
16	1.11	2.00	1.95	2.50	2.58	2.33	2.02	1.91	2.03
18	1.32	2.17	2.04	2.63	2.22	2.56	2.12	1.93	1.91
20	1.24	1.6	2.18	2.13	1.76	2.56	2.09	1.88	2.03

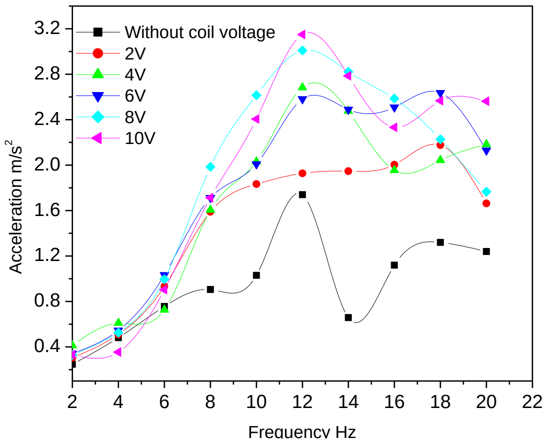

Fig. 5 RMS Acceleration of top plate when only top electromagnet was energized

The shift in peak was noticed at 2 V due to influence of electromagnetic spring stiffness. The peak was shifted to 18 Hz for the coil voltage of 2 V and maintained the same at other coil voltages. The reason could be the gap between the electromagnets and levitation

3.2. Amplitude of RMS acceleration of top plate when both electromagnets are energized

Experiments were carried out by energizing both the electromagnets to study the performance of the SVDC. The gap between two electromagnets were maintained and maximum of 6 V was given to both the electromagnets due to the gap restrictions. The accelerometer data are given in

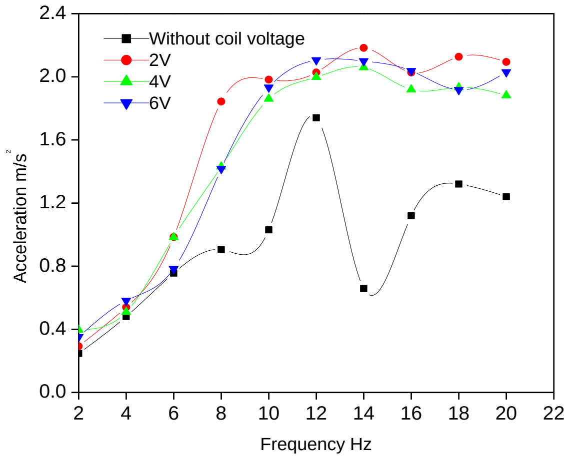

Fig. 6 RMS Acceleration of top plate when both the 17-gauge electromagnets were energized

Table 3

RMS acceleration of top plate of SDVC with 19-gauge electromagnet

Frequency (Hz)	Acceleration (m/s^2)				
	without	2 V	2.5 V	3 V	3.5 V
2	0.03	0.03	0.03	0.03	0.04
4	0.07	0.05	0.06	0.06	0.07
6	0.10	0.11	0.16	0.09	0.17
8	0.18	0.30	0.43	0.25	0.32
10	0.25	0.25	0.36	0.29	0.35
12	0.75	0.74	0.66	0.60	0.59
14	0.92	1.22	1.28	1.18	1.19
16	0.80	1.15	1.07	0.86	0.88
18	0.64	0.74	0.89	1.08	0.59
20	0.48	0.62	0.55	0.76	0.60

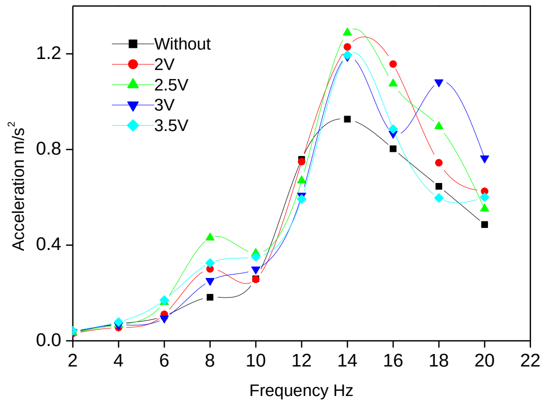

Fig. 7 RMS Acceleration of top plate when the 19-gauge electromagnet was energized

the Table 1. From the Fig. 6, it was observed that the amplitude of acceleration of top plate at different base excitation frequencies and coil voltages is more than the amplitude of acceleration of the system without coil voltage. At lower frequencies, up to 6 Hz the amplitude of RMS acceleration was same at higher frequencies, above 10Hz, all 2 V, 4 V and 6 V of energized electromagnets in the SDVC system negligible variation in the RMS amplitude of acceleration was observed. But the amplitude of acceleration of top plate without energizing the magnet at higher frequencies varies almost in a sine pattern. Levitation of the top plate due to electromagnets could be the reason for uniform pattern in energized electromagnets.

Table 4
RMS Displacement of top plate of SDVC with 17-gauge electromagnet

Frequency (Hz)	Displacement of top plate in mm –top plate eletromagnet was energized						Both electromagnets were energized		
	without	2v	4v	6v	8v	10v	2v	4v	6v
2	0.55	4.55	6.74	4.19	3.67	3.84	5.25	4.22	4.85
4	0.60	5.75	5.85	5.75	6.00	5.49	5.96	5.20	5.73
6	0.40	6.27	5.84	6.56	6.53	5.75	6.27	6.20	6.10
8	0.32	6.20	5.04	5.91	5.37	7.31	6.04	5.66	7.14
10	0.25	5.45	2.97	4.49	4.24	4.52	4.89	5.46	8.47
12	0.15	3.47	1.82	3.04	3.03	3.2	4.21	3.66	3.12
14	0.10	1.82	1.27	1.98	2.22	2.07	2.55	2.49	3.0
16	0.11	1.97	1.27	1.39	1.62	1.88	1.71	2.10	1.94
18	0.08	1.51	1.55	1.25	1.68	1.42	1.61	1.85	1.61
20	0.07	1.21	1.62	1.46	1.20	1.19	1.741	1.71	1.38

Amplitude of RMS acceleration of top plate of 19-gauge electromagnet was energized. The maximum voltage of 3.5 V was given to 19 gauge as the resistance of 19-gauge SWG wire was less when compared to 17-gauge SWG wire electromagnet from 2 V in the interval of 0.5 V. The accelerometer data from the top plate for different voltages are given in Table 3. Fig. 7 shows the variation of RMS acceleration of top plate with different base excitation frequencies. Multiple peaks were observed. The reason could be the influence of nonlinear spring stiffness of electromagnetic spring with normal suspension springs.

3.3. RMS displacement of top plate of 17-gauge electromagnet

The RMS displacement of top plate was obtained from accelerometer data and given in the Table 4. Fig. 8 shows the variation of RMS displacement with different base excitation frequencies.

The variation of displacement was non linear and for all coil voltages the peak was at 6 Hz except for 10 V coil voltage of electromagnet. At higher frequencies the differece between amplitude of displacement with and without voltage was less when compared to lower frequencies. This could be due to more levitation at lower frequenciess than at higher frequencies. The trend was similar when both the electromagnets were energized as shown in Fig. 9.

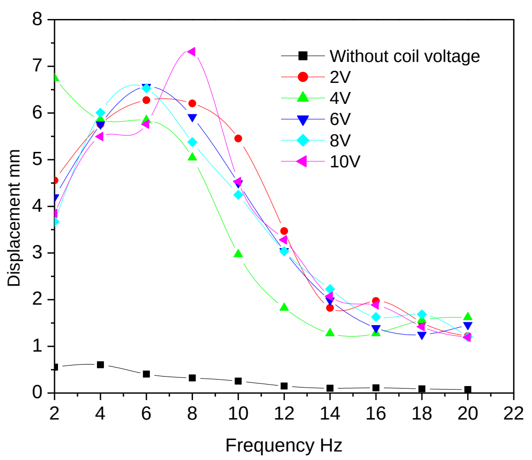

Fig. 8 RMS Displacement of top plate when the 17-gauge electromagnet was energized

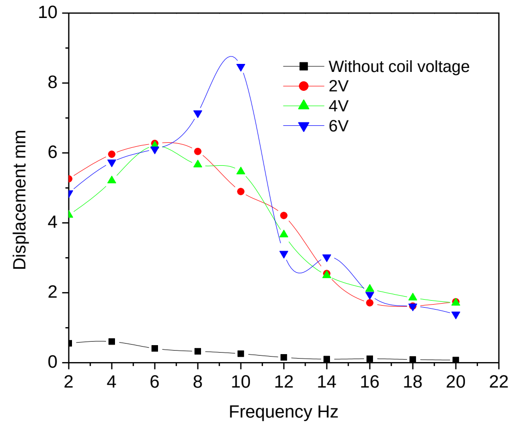

Fig. 9 RMS displacement of top plate of when both 17-gauge electromagnets were energized

Table 5
RMS Displacement of top plate of SDVC with 19-gauge electromagnet

Frequency, Hz	Displacement, mm				
	without	2v	2.5v	3v	3.5v
2	0.06	0.05	0.05	0.06	0.02
4	0.05	0.06	0.07	0.08	0.07
6	0.07	0.07	0.07	0.06	0.07
8	0.08	0.08	0.03	0.08	0.07
10	0.07	0.06	0.07	0.07	0.06
12	0.12	0.09	0.09	0.08	0.08
14	0.11	0.14	0.15	0.14	0.13
16	0.09	0.12	0.12	0.06	0.08
18	0.05	0.06	0.06	0.10	0.06
20	0.03	0.05	0.05	0.06	0.04

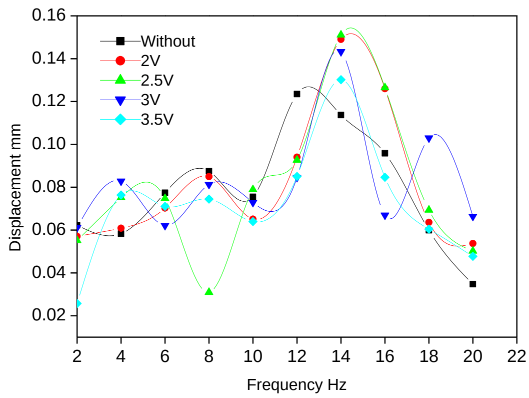

Fig. 10 RMS displacement of top plate of when both 19-gauge electromagnets were energized

3.4. RMS displacement of top plate of 19-gauge electromagnet

In 19-gauge electromagnet the variation trend of RMS displacement of top plate was different when compared to 17-gauge electromagnet (Fig. 10). The shift in peak was observed in all the coil voltages and also the reduction in amplitude of displacement was observed at 6 Hz, 8 Hz, 12 Hz and 16 Hz. The non-uniform pattern of variation of RMS displacement was observed. This could be due to nonlinearity of electromagnetic spring stiffness (Table 5).

4. Conclusions

An experimental study was carried out on a SDVC system with two electromagnets of 17gauge and 19gauge SWG. The accelerometer data of top plate at different base excitation frequencies and coil voltages were obtained and analysed. From the observed data it was found that the influence of electromagnetic spring on the amplitude of acceleration of top plate was more at all frequencies of base excitation. The reason could be the levitation of top plate due to electromagnetic force and also the shift in peak was observed in both acceleration and displacement plot. The gap between the electromagnets and the mass were kept constant and detailed study has to be carried out on elec–tromagnetic vibration reduction by varying the load on the single degree of freedom system and also if a proper controller is designed to change the voltage of electromagnetic coil then the system will become an active vibration isolation system which can be further used for the next generation vehicles.

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EXPERIMENTAL STUDY OF VIBRATION ISOLATION USING ELECTROMAGNETIC DAMPING

S u m m a r y

This study presents an experimental investigation focused on the reduction of vibrations using electromagnetic damping techniques. The objective is to explore the effectiveness of electromagnetic damping in mitigating undesirable vibrations and enhancing system stability. A single-degree vertically constrained spring-mass system, two pairs of electromagnets, Lab VIEW software, an accelerometer, DAQ card were used for the experimentation. SWG 17 and SWG19 coil electromagnets were used in different conditions of energization to evaluate the effectiveness of the electromagnetic damping system. The parameters such as excitation frequency, vibration amplitude, and electromagnetic damping force are systematically varied and their effects on vibration isolation are analysed. The results demonstrate that the electromagnetic damping system effectively isolates base induced vibrations across a range of frequencies and amplitudes. The experimental data reveal that at lower frequencies, up to 6Hz the amplitude of RMS acceleration was same as that of the system without energizing the electromagnet and at higher frequencies, above 10 Hz, all 2V,4V and 6V of energized electromagnets in the SDVC system showed negligible variation in the RMS amplitude of acceleration. A substantial isolation of top plate was observed at higher frequencies of base excitation.

Keywords: electromagnets, vibration isolation, nonlinear force, levitation, repulsive force.

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