International Organization of Research & Development (IORD)
ISSN: 2348-0831
Vol 10 Issue 02 | 2023

A Review on Electromagnetic Shock Absorber

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ABSTRACT—

During the everyday usage of an automobile, only 10–16% of the fuel energy is used to drive the car—to overcome the resistance from road friction and air drag. One important loss is the dissipation of vibration energy by shock absorbers in the vehicle suspension under the excitation of road irregularity and vehicle acceleration or deceleration. In this paper we design, characterize and test a retrofit regenerative shock absorber which can efficiently recover the vibration energy in a compact space. Rare-earth permanent magnets and high permeable magnetic loops are used to configure a four-phase linear generator with increased efficiency and reduced weight.

Design of electromechanical shock absorbers for automotive applications relative to commonly used hydraulic shock absorbers ,electromechanical ones are based on the use of linear or rotative electric motors. If electric motor is one of the DC brushless type, the shock absorber can be devised by shunting its electric terminal with a resistive load. The damping force can be modified by acting on the added resistance.

Keywords: Design,Shock Absorber, Permanent Magnet , magnetic field,.vehicle suspension.

I. INTRODUCTION

1.1 Electromagnetic Absorber Shock

With the increasing quantity of possessed automobiles, it has received a great deal of attention from automobile manufacturers and government for the energy energy conservation and environmental protection both at home and abroad. To protect the environment and reduce vehicle emissions and fuel consumption of vehicles, it is necessary to recover the energy wasted by the car, such as the braking energy, engine exhaust emissions energy and vibration energy of suspension, etc. Usually the vibration energy caused by road roughness when car runs has not been paid attention to and it is wasted through conversion to thermal energy. If the vibration energy can be recovered and converted to other form of energy such as electric or hydraulic power so to supply for other devices, then the aim of eco-friendly energy-saving is reached. the vibration energy was converted to electric energy through the innovative electromagnetic absorber shock.

Normally as we know active suspensions like pneumatic suspension with nonlinear rigidity which is well known for its comfort and adaptability and its characteristics such as rigidity and damping ratio can be changed with road roughness. But this kind of suspension is rather complex and need much energy to change its characteristics, moreover it needs complex control algorithm and expensive hydraulic and electric element such as hydraulic pump, ECU, many sensors and control valves. [2]

The vehicle suspension systems is to isolate the vehicle body from road irregularities in order to maximize passenger riding comfort and also to secure continuous road wheel contact, ensuring the vehicle's handling quality. There are three types of suspension system: the first type is a passive suspension system which consists of conventional spring and cylindrical damper or shock absorber. This type has fixed parameters, i.e. stiffness coefficient of the spring and damping coefficient of the damper. The second type is a semi-active suspension which has a mechanical device called an "active damper" which is used in parallel with a conventional spring. The semi-active control device changes the damping of the suspension according to certain criteria. The third type is an active suspension which includes hydraulic actuators that can apply external forces to the vehicle[1]

Suspension system is an assembly used to support weight, absorb and dampen road shock, and help maintain tire contact as well as proper wheel to chassis relationship. A vehicle in motion is more than wheels turning. As the wheel revolves, the suspension system is in a dynamic state of balance, continuously compensating and adjusting for changing driving conditions. Suspension of vehicle need to analyze before be manufacturing .This is because to make sure components in shock absorber system remain in good conditions. In the other hand, shock absorber system need to analyze how shock to see how they going to perform in worst-case scenario.[5]

II. LITERATURE SURVEY

Ammar A.Aldair and et.al , (2011) in their study they reduced the energy consumption resulting for driving the actuators in active suspension, the electromagnetic device has been introduced which is capable of converting most of the vehicle's vibration energy into electrical energy through the rotation of the device and store them in the battery and used to generate appropriate damping forces to improve the riding comfort & road handling. [1]

Zhen Longxin and et al (2010) analyzed the structure and principle of regenerative electromagnetic shock absorber in detail. In the innovative generator in principle can generate electric power through the relative reciprocating motion between coil assembly and permanent magnet assembly. At the same time damping can remove discomfort caused by road roughness.[2]

Lei Zuo and et al , (2010) studied the design ,analysis ,and experimental results of a regenerative shock absorber for vibration energy harvesting from vehicle suspension is recover the vibration in compact space[3]

Wang Cheng uo and Qian Lixin , 2008, "Anew Shock Absorber Model with an Application in Vehicle Dynamics Studies" SAE International Truck and Bus Meeting and Exhibition Fort Worth, Nov-10-12, Texas.[4]

M.S. Sani and M.M. Rahman et al (2008) performed the experiment and analysis stiffness and damping of dynamic characteristics of shock absorber the value of stiffness and damping for shock absorber are strongly related to the capacity of shock absorber.[5]

Nicola Amati and et al, (2007) found out the methodology for the design of passive or semi-active electromechanical dampers with segment c-vehicle suspension is effective[6]

III. THEORY

3.1 Implementation

3.1.1 Structure of Regenerative Shock Absorber

The regenerative electromagnetic shock absorber described in this paper mainly consists of four parts: a permanent magnet array, a coil windings array, 2 guide cylinders and a spiral spring., Its structure is shown in Fig. 3.1

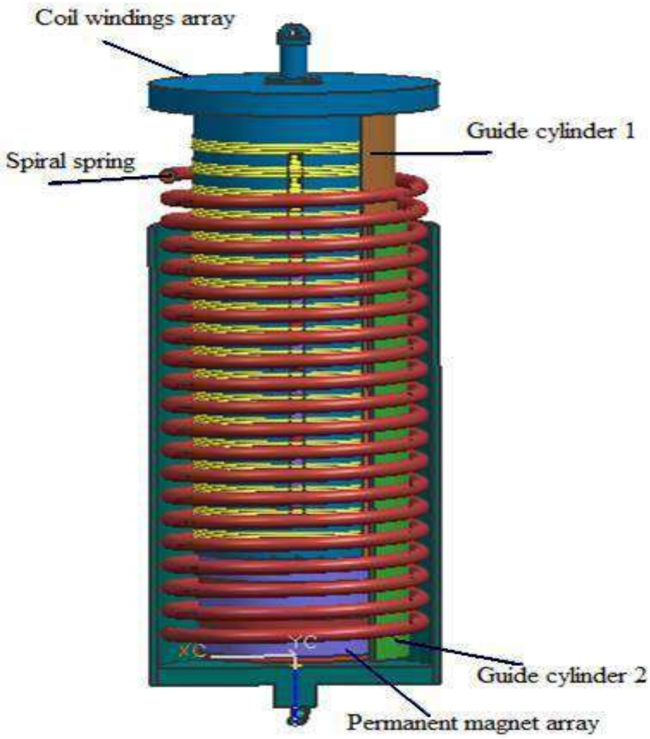

Fig 3.1 Structure of Regenerative Shock Absorber

3.1.2 Permanent Magnet Array

The permanent magnet array includes 2 parts: internal magnet part and external part and both two parts comprise 14 layers of permanent magnet and 15 layers high permeability material and which was permanent magnet repectively. As shown in fig. 3.2,

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ISSN: 2348-0831
Vol 10 Issue 02 | 2023

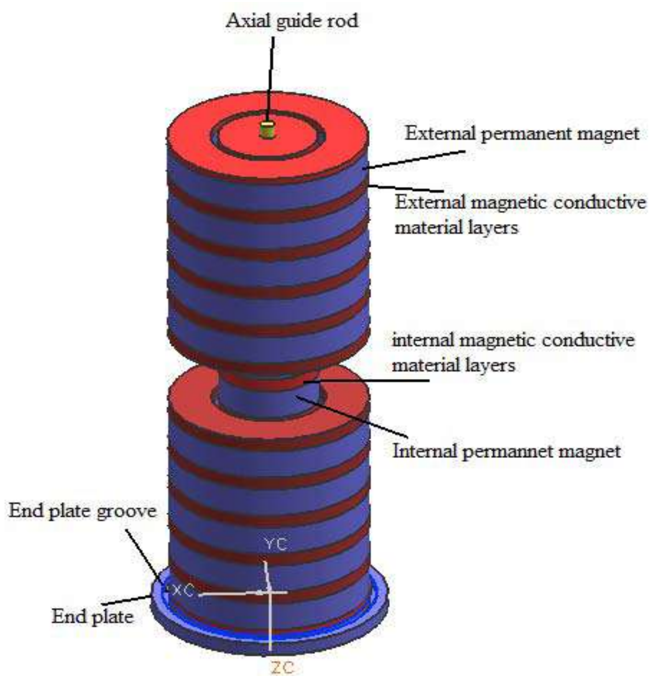


Fig. 3.2 Permanent Magnet Array

A axial guide rod axially penetrates these internal permanent magnets and high magnetic conductive material layers to enhance their strength. In this structure the axially and radially adjacent permanent magnets have opposite polarity. So the magnetic induction line radiated from the adjacent permanent magnet as if it is distorted and forms magnetic vector superposition. At this time the magnetic flux density is about twice that the single one radiates.

Permanent magnets array is fixed to end plate which is fixed on inner side of the shock absorber shell. Permanent magnets are fixed with magnetic conductive layers by mighty bond or mechanical mean. Hard magnetic materials can be chosen as permanent magnet material and in this paper Nd-Fe-B material is chosen. The Nd-Fe-B material has high magnetic energy product (10 times higher than ferrite magnet), high coercive force and high energy density. Soft magnetic materials which usually have high permeability can be chosen as high magnetic conductive material and in this paper 45CrNiMoVA material is chosen.

3.1.3 Coil Windings Array

The coil windings array moves reciprocatingly along the air-gap between the internal part and external part of the permanent magnet array and cuts lines of magnetic force to generate electric power. Both internal and external magnetic conductive guide sleeves are wound by certain number of coil windings groups. In order to enhance the permeability of coils, nickel-like coatings can be applied to outer surface of coils. Various coil windings group can be connected in parallel or in series or in both ways. Its structure is shown in fig. 3.3

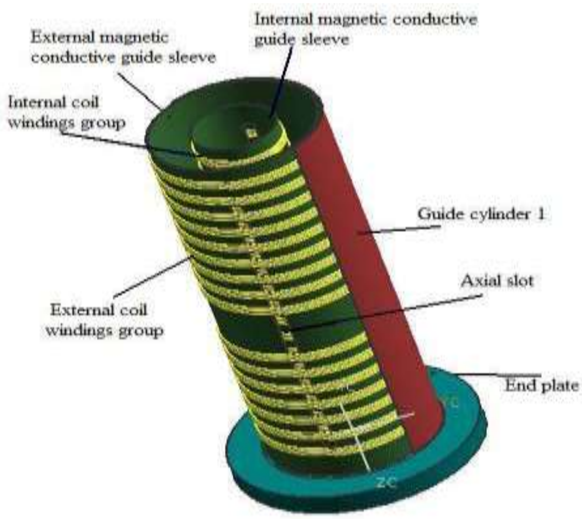


Fig. 3.3. Diagram of Coil Windings Array

Internal coil windings groups wind around the outer surface of the internal magnetic conductive guide sleeve and external coil windings groups wind around the outer surface of the external magnetic conductive guide sleeve. Guide cylinder 1 which forms sliding pair together with guide cylinder 2 shown in figure 1 is attached to outside of the external magnetic conductive guide sleeve to stabilize the coil windings array and to maintain its absolute vertical direction and to avoid friction between it and the permanent magnet array. Thus the coil windings array can move smoothly relatively to the permanent magnet array.

The internal and external magnetic conductive guide sleeves and guide cylinder 1 all have long axial slots along their outer surface. The purpose is to avoid heat generation and energy loss caused by eddy current.

3.2 Design Principle

The permanent magnet array of regenerative electromagnetic shock absorber is connected to wheel axles of the vehicle and the coil windings array is connected to the framework or body of the vehicle. When the vehicle travels on rough roads, the relative displacement between framework or body and wheel axles causes relative displacement between coil windings array and permanent magnet array. At this point coil groups will be cutting the magnetic induction lines in the air-gap, thus current occurs in the coil and in the mean time damping force occurs correspondingly. The direction of the damping force is relatively opposite to the movement of the coil group.

When the conductor moves perpendicularly to the direction of magnetic induction line Lorentz force can be defined as,

$$\vec{F}_1 = q * \vec{V} * \vec{B}$$

The EMF voltage V (v) generated by a conductor of length l (m) moving in a constant magnetic field $B(t)$, at a constant velocity v (m s^{-1}), is given by

V = Bvl…………………………(1)

The maximum current, I (A), generated by the device with short circuit is given by the equation

$$I = \frac{V}{R} = \sigma B_r v_z A_w \text{……………(2)}$$

3.2.1 Design Parameter of shock absorber

The structure parameters of the shock absorber determined according to vehicle weighing 1.3 ton are shown in table 1.

Table 1

Thickness of radial air-gap	5 mm	Internal radius of internal coil windings group	35.5mm
Thickness of single NdDy	22.5mm	External radius of internal coil windings group	39.5mm
Thickness of magnetic conductive layer	10mm	External radius of external coil windings group	75.5mm
Height of single coil windings group	10mm	External radius of external coil windings group	79.5mm
Height of end plate	5mm	Internal radius of shell of shock absorber	96mm
Height of whole magnet array	495mm	External radius of shell of shock absorber	106mm

Height of whole magnet array	35mm	Diameter of end plate	190mm
Diameter of central guide rod	10mm	Permeability of vacuum	4π×10-7
External radius of external cylindrical magnet	75mm	Conductivity of coil	5×107 S/m
External radius of external cylindrical magnet	40mm	Mean diameter of internal coil windings group	75 mm
Number of internal and external coil windings group	15mm	Mean diameter of external coil windings group	155 mm

The vehicle has 2 wheel axles and 4 suspensions. Each suspension supports 270 kg. The relative magnetic permeability of the air is defined as 1 and the magnetic coercive force of the permanent magnet is defined as 900000 A/m. The relative magnetic permeability of the permanent magnets is defined as ,

$$\mu_r = B_r / (\mu_0 H_c)$$

3.3 Experimental set up

A test set-up was designed to characterize the voltage output and power output of the generator at various road conditions, as shown in fig. 3.4, The magnet assembly of the shock absorber was mounted in the mover of a vibration shaker

A test set-up was designed to characterize the voltage output and power output of the generator at various road conditions, as shown in figure 6. The magnet assembly of the shock absorber was mounted in the mover of a vibration shaker. The coil assembly was mounted to the top plate, which is fixed on the base of the vibration shaker. The position of the coil assembly can be adjusted via a ¼" 20 threaded rod. The shaker drives the relative motion between the magnet and coil assemblies via a 5× power amplifier. Road conditions were simulate with a wavefunction generator. Waves at different frequencies and amplitudes were sent through the power amplifier to the vibration shaker. An oscilloscope was used to measure the output voltage, both peak and RMS values, of the shock absorber. The oscilloscope was also used to view the output waveforms generated from the shock absorber. A multimeter was used to measure current output.

Absorber

A series of experiments were carried out to see the wave shapes, regenerated voltages and powers of the generated voltage at different vibration amplitudes, frequencies and equilibrium positions. The vibration velocity v will depend on the frequency ω and driving voltage. If the inductance of the shaker is negligible, the regenerated voltage (open circuit) under shaker excitation.

The regenerated voltage on one coil of the shock absorber is,

$$V = \int B_r V_z = V_z \int B\, rd_l = V_z(t) B_{ave}(z) L$$

where B_{ave} (z, t) is the average of magnet field intensity Br in the coil segment centered at position z(t). Under harmonic vibration vz (t) = v_{max} sin wt, the coil position z(t) will be shifted from the equilibrium position z_0 :

$$z(t) = z_0 - \left(\frac{V_{max}}{\omega}\right) \cos\omega t$$

The natural frequency ω_n of the shaker is observed to be 13.5 Hz, while the damping ζ is contributed by the shaker's visco-elastic flexure guides, shaker's coil resister and the shock absorber's damping. We observe that the shaker is well damped inherently by the first two factors before we mount the shock absorber.

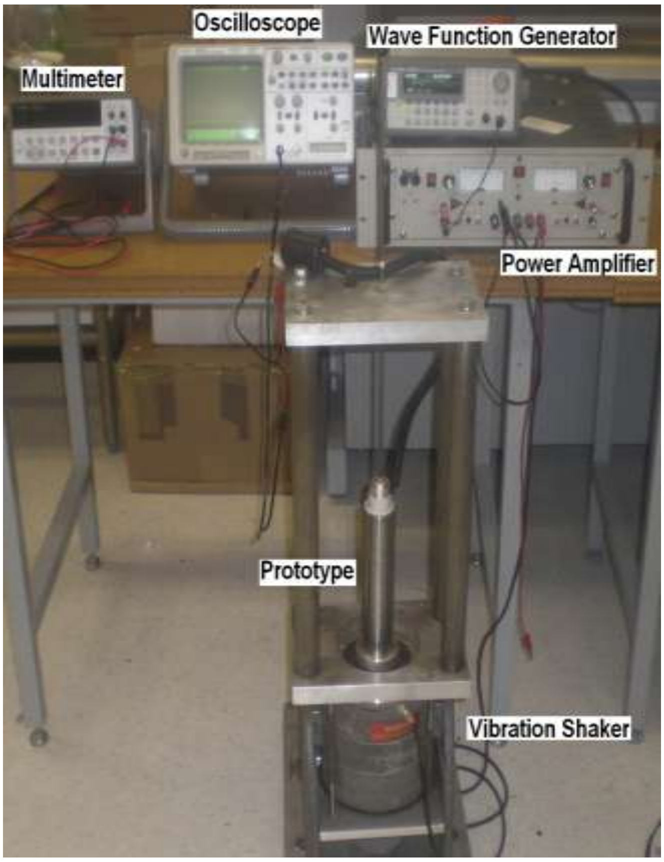
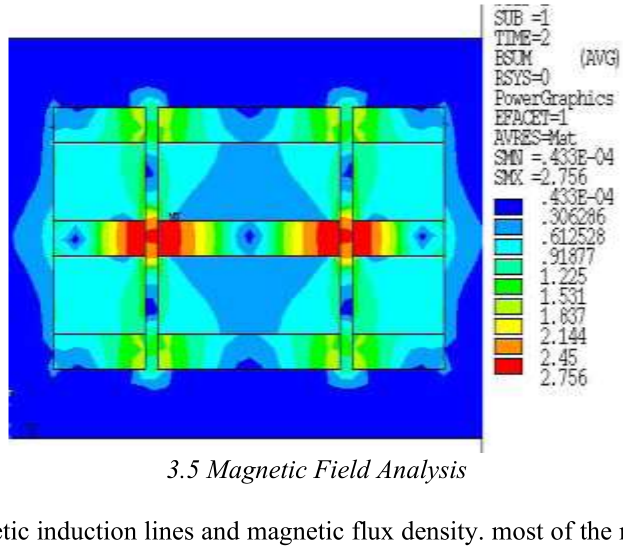


Fig. 3.4 Experiment Set-Up of Magnetic Shock

3.3.1 Magnetic Field Analysis

According to Faraday induction law, the energy recovery efficiency of this shock absorber depends on the magnetic flux density in the air-gap. This paper establishes the model of the permanent magnet array and generates mesh of the model, then analyzes the magnetic flux density in the air-gap with ANSYS software. Due to the symmetry of the permanent magnet array, its model can be simplified to the partial three dimension model and partial two dimension model.



3.5 Magnetic Field Analysis

The distribution of magnetic induction lines and magnetic flux density. most of the magnetic induction lines at the air-gap distribute radially and they go as if they were bent because both radially and vertically adjacent permanent magnets have opposite polarity. Thus magnetic induction lines of adjacent magnets superpose mutually in the air-gap to magnify magnetic flux density and increase energy production efficiency. As is shown in Fig.3.5 the maximal magnetic flux density reaches as high as 2.7T and the average value is about 2.3T. So result of magnetic field analysis is satisfactory.

3.4 Experiment Result

Regenerated voltage and excitation frequency. The second experiment was conducted to check the RMS value of the regenerated voltage at different excitation frequencies from 0 to 60 Hz. Coils at the phases 0◦ and 180◦ were recorded together, and coils of 90◦ and 270◦ phase were also recorded. The shaker excitation voltages are set as 0.25, 0.6, 1, 1.2 and 1.7 V, which correspond to the vibration amplitude (peak-to- peak) around 0.14H , 0.36H , 0.61H , 0.72H and 1H (H = 11.35 mm) at low frequency. Figures 09 and 10 show the experimental results obtained from 0◦ /180◦ and 90◦ /270◦ phases of the prototype. The frequencies at which peak voltage occurs on the 0/180◦ and 90/270◦ are not the same.

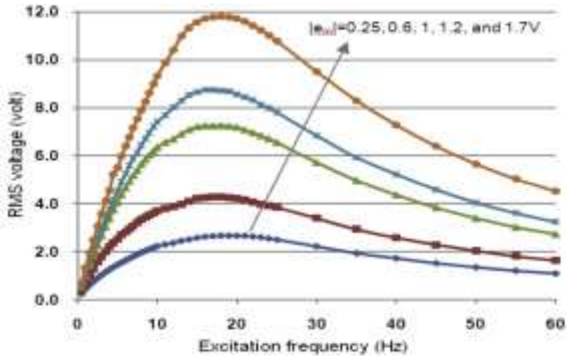


Fig 3.6 RMS Voltage Output Versus Input Frequency For 0◦ Phase Coil Set (Eight Coils) At Different Shaker Excitation Voltages

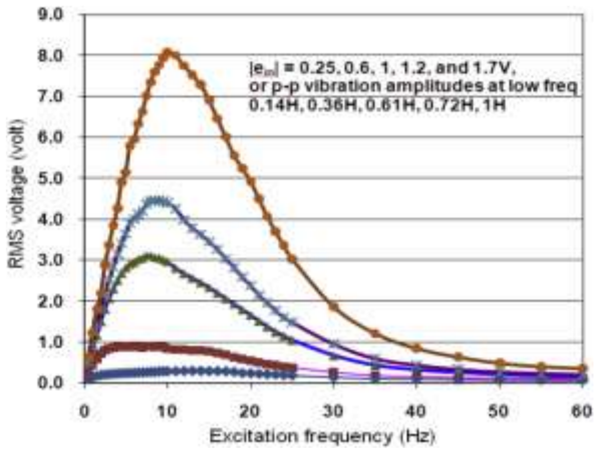


Fig 3.7 RMS Voltage Output Versus Input Frequency For 90◦ Phase Coil Set (Eight Coils) At Different Shaker Excitation Voltages.

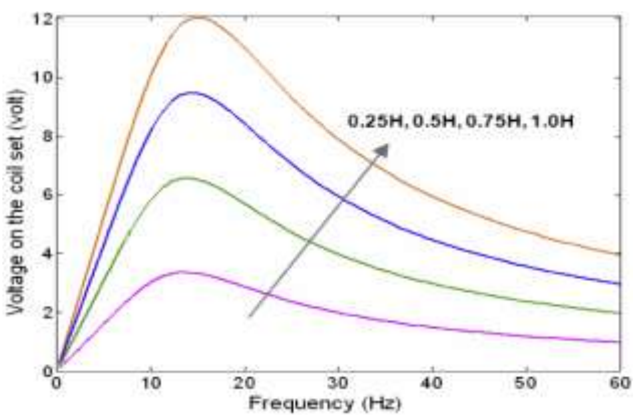


Fig 3.8 Theoretical Prediction: RMS Voltages Of 0◦ /180◦ Phase Coil At Different Shaker Excitation Voltage Levels, Which Correspond To Peak-To-Peak Amplitudes 0.25H , 0.5H , 0.75H , 1.0H And 1.0H

Fig.3.8 and 3.9 show the predicted relation of the RMS voltages and frequency of the 0◦ /180◦ and 90◦ /270◦ phases at DC vibration amplitudes of 0.05H , 0.25H , 0.4H , 0.6H , 0.75H and 1.0H . The trends closely agree with the experimental results.

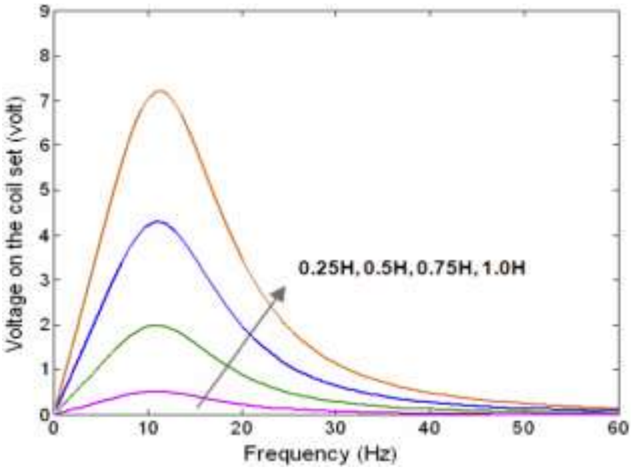


Fig 3.9 Theoretical Prediction: RMS Voltage 90◦ Phase Coil At Different Shaker Excitation Voltage Levels, Which Correspond To Peak-To-Peak Amplitudes 0.25H , 0.5H , 0.75H , 1.0H And 1.0H .

IV. CONCLUSION

The design, optimization, analysis and experimental results of a retrofit regenerative shock absorber for vibration energy harvesting from vehicle suspensions. Theoretical predictions and experimental results agree very well. A prototype of a four-phase linear generator was developed and characterized both experimentally and analytically. The half-scale prototype was able to harvest 2– 8 W of energy at 0.25–0.5 m s^{-1} RMS suspension velocity. It was also found that the frequency of the regenerated voltage does not necessarily have the same frequency as the excitation. Instead, the wave shapes of the regenerated voltage will depend on excitation frequency, amplitude and equilibrium position. The regenerated power will be the largest at a frequency around the resonance of the vibration system. Though the voltage waveform of the individual coil depends on the equilibrium position, the total power of the four phases does not depend on it. The overall conclusion of this research work is that it is possible to harvest energy from vehicle vibrations travelling on a bumpy road.

ACKNOWLEDGMENT

I take this opportunity to express our gratitude towards Honorable Principal **Dr. Bimlesh Kumar**, who has been a constant source of inspiration to me. I also express my thanks to our P.G. Coordinator **Prof. M.M.Patil** and my guide **Prof.K.K.Chaudhari** for the constant encouragement and guidance. He was constant source of motivation and inspiration. Without his efforts this work could not have taken the final shape.

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