

Experimental studies on semi active suspension systems with various dampers

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Abstract. Some results of an experimental probe on semi Active suspension systems with various Dampers have been studied in the present paper. Dampers with different configurations were studied by using Magneto Rheological gel Damper. A comparison have been done for different configurations of Dampers viz.MR gel Damper with Magnetic field, MR gel Damper without magnetic field, Damper with conventional oil, Natural vibration without damper.

1. Introduction

The experimental setup was fabricated for studying the performance of MR gel under various circumstances. The experimental results on the gel suggest that a significant increase in storage modulus is possible under the influence of magnetic field. This is an important observation in the context of application of the magnetic gel to damp the vibrations produce during ride, as this indicates that it is possible to tune the magnetic composite gels by changing magnetic fields. Also, the significant deformations of the gels and the magnetic shape retaining ability noticed during the conduction of the experiments is a very important aspect in understanding the property of the magneto rheological gel properly. The improvements made in the existing paper i.e., use of variable stiffness springs in suspension system also helps in regulating ride comfort and stability of the vehicle. Both the systems combined together will produce greater ease, flexibility of control and performance. Such, control system is close to active suspension systems and provide large domain to control the ride stability and comfort without compromising according the road conditions. The result obtained from the study proves that, using MR dampers and variable stiffness springs will provide a smoother ride then conventional suspension system.

2. Literature review

Literature provides vibration isolation systems have been studied broadly and in great depth. The vibration control systems can be categorized as passive, active and semi-active systems. Semi-active control systems fill the gap between passive and active control system and they represent a compromise between performance improvement and simplicity of implementation. They only expend a small amount of energy to change system parameters, such as damping and stiffness. The basic idea of variable damping systems has been proposed by many researchers to provide effective vibration control [1-4]. However, there is room for further improvement because variable spring stiffness systems have not been thoroughly investigated in terms of their practical implementation, despite the fact that vibration systems with variable stiffness control



were proposed by a few researchers [5,6]. Kooris proposed a variable stiffness system to suppress buildings response to earthquakes [6]. The aim of Kooris work was to achieve a non-stationary and non-resonant state during earthquakes. Youn and Hack used an air spring in a suspension system to vary the stiffness among three discrete values [5]. In the proposed vehicle suspension system, A Voigt element and a spring in series are used to control the system stiffness. The Voigt element is comprised of a controllable damper and a constant spring. The equivalent stiffness of the whole system is changed by controlling the damper in the Voigt element and the second damper which is parallel with the other elements provides variable damping for the system, a new variable stiffness and variable damping system in which the stiffness and damping can be independently and easily controlled.

3. Experimental set-up

In order to facilitate vibrations with MR gel and to accommodate the Damper, apparatus has been designed and fabricated. This Equipment consists of a Base built up with Mild steel Angles of dimensions 3x1.5 feet. A vertical frame of 2feet height is mounted at one of its ends. A cantilever beam of length 3.6 feet is hinged at a height of 1.5 feet from the base to facilitate the vibrations to occur only in vertical plane. This beam is attached to compression spring, which is fixed to the base. The gap between the spring and beam is compensated by GI rod which is welded to the spring and the beam. The Damper is located adjacent to the spring to show the variations amplitude & damping, a frame is welded to the initial setup. Two metal rods were attached above the frame at a distance from center, perpendicular to the base. PVC pipes with elastic bands wound around them are inserted onto the rods. So that, it supports the drawing sheet & facilitates rolling without slipping. The marker is placed on the bar and pointed towards the sheet to trace the amplitude of vibrations produced. DC motor with a pulley is fixed in a wooden block and it is attached to one of the PVC pipes with connecting belt. This pipes acts as Rollers, such that rotation of one pipe makes the other to rotate and drags the sheet against the marker. When this bar is made to oscillate for a given load, the marker traces the amplitude of vibration & damping effect produced. DC motor is operated by a DC adapter if 12volts and wattage of 12.To produce Magnetic field from AC supply, a step-down transformer with 36 wattage capacity is coupled with AC to DC converter so as to produce a maximum voltage of 12 volts. The output from the converter is connected to MR gel damper. At first the beam, mass and spring assembly is tested to find its natural frequency and

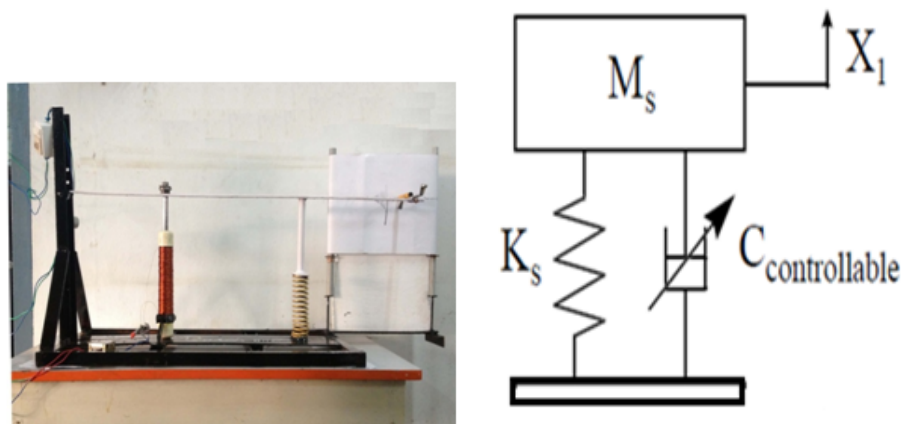


Figure 1. The experimental setup and Schematic diagram.

damping ratio by exciting the end of the beam under different loads and then leaving it for free

vibration. The total mass of the beam and GI rod is 300gms. A known mass is now attached at the end of cantilever beam (without any damper) and excited to produce vibrations which are analyzed to find the natural frequency of vibration. Preliminarily the initial height of the beam is measured using a vernier height gauge placed on flat plate. A weight of 700gms added to the bar, and then the resultant height is measured to determine the deflection produced. Similar process is repeated by varying the loads, incremented one by one and deflection is noted down for loads 1400gram, 2100gram, and 2800gram. Values are noted and average stiffness of the spring is determined. The damper is placed in C-clamps which are welded at the bottom side of the frame. The clamps are holding the damper with the help of nut and bolt system. The piston rod is passed through the holes which are drilled to the beam and nut is used to hold the piston firmly with the beam. The damper and spring are parallel to each other this acts as a shock absorber system. Now the damper is placed in respective position and time period of 5 oscillations is noted down with 2.8 kg mass added to the beam. Beam is excited and the amplitude and decay of vibrations is traced by the system.

3.1. MR Gel preparation procedure

Selecting the appropriate proportions of the gel matrix is the first task in the sample preparation. The plain non-magnetic gel matrix is prepared using the copolymer, White lithium grease like Lubricant, a non-aerosol with mass fractions of the mineral oil as plasticizer. Upon particular proportions of linking agent and plasticizer mass fraction for the gel matrix we get the required softness for the matrix. The MR gel is prepared by interspersing carbonyl iron particles in this matrix. Carbonyl iron powder is used in this study show irregular shape of the particles with sizes ranging from 2 to $10\mu\text{m}$. Isotropic magnetic composite gels are prepared with a proportion of 50% by weight or carbonyl iron particles mixed with a constant ratio 1:12 of copolymer to mineral oil mass fraction. The current scope of preparation is limited to isotropic magnetic gel. The magnetic composite gel is prepared with proportions as follows:

- (i) Mineral Oil 60g / 65.5ml (density 918 kg/m^3)
- (ii) Grease 13g / 10 ml (density 1300 kg/m^3)
- (iii) carbonyl iron particles 92g /25 ml (density 3670 Kg/m^3)

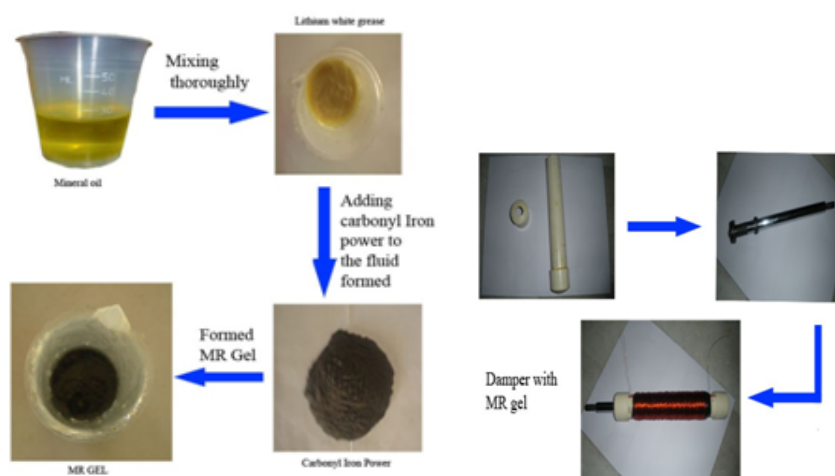


Figure 2. Preparation of MR gel.

Initially 60 ml of mineral oil is taken into a Glass beaker and a proper proportion of lithium (white grease) is mixed thoroughly until entire grease and oil form a uniform suspension. Then carbonyl iron particles are introduced into the mixture and stirred so as to form required MR Gel as shown in figure below.

3.2. Damper with the mineral oil

In this system the damper is filled with mineral oil. When weights are added to the beam, the spring starts oscillating with its natural frequency which is damped by the damper. The damping takes place in 5 seconds. With the help of the graph tracing system the damping graph is traced. The amplitude of vibration decreases compared to the graph without damper.

3.3. Damper with MR-GEL and without magnetic field

In system the oil is replaced with the MR GEL. This gel behaves like Newtonian fluid or normal oil when no field is applied. Weights are added to the beam and excited, graph is traced by system.

3.4. Damper with MR-GEL and with magnetic field

Now a Magnetic field is applied to the gel by applying direct current to copper wires which are wound around the damper. The Field is parallel to the direction of applied load and magnetic particles align along the same direction increasing the stiffness. When bar is made to oscillate by giving external force, as stiffness of MR gel is greater than mineral oil. It damp out vibrations very quickly within few seconds (2.2 sec). Graph is traced with the help of graph tracing system. The dynamic response of the system for the given initial excitation depends primarily on the

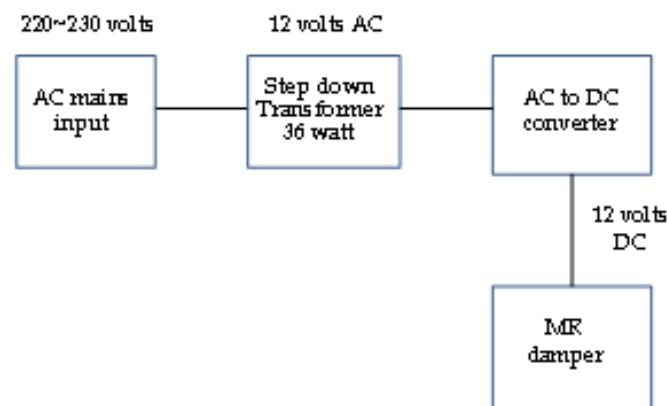


Figure 3. Circuit diagram representing generation of magnetic field.

three dynamic attributes of the system the stiffness of spring elements, the dissipation due to hysteresis damping (internal damping) of the system and the inertia due to mass. The testing system is assumed to be linear. Tests on the system were conducted to validate this assumption. With the mass of the system known, a simple straightforward procedure is adopted to estimate the other two attributes of the system, namely, the storage part, i.e. stiffness of the spring and

the dissipation part, i.e. damping coefficient. Using a free decay test, i.e. by introducing a small initial disturbance excitation to the system, these attributes are then calculated from the measured response data obtained from experimentation. The procedure and the principle used to calculate the above mentioned system attributes are discussed below.

4. Mathematical formulation and solution methodology

Free undamped vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. The mechanical system will then vibrate at one or more of its "natural frequency" and damp down to zero due to hysteresis damping. The fundamentals of vibration analysis can be understood by studying the simple mass-spring-damper model. The force applied to the mass by the spring is proportional to the amount the spring is stretched x (we will assume the spring is already compressed due to the weight of the mass). The proportionality constant, k , is the stiffness of the spring and has units of force/distance (N/m). The negative sign indicates that the force is always opposing the motion of the mass attached to it:

$$F_s = kx. \quad (1)$$

The force generated by the mass is proportional to the acceleration of the mass as given by Newtons second law of motion:

$$\sum F = ma = m\ddot{x} = m \frac{d^2x}{dt^2}. \quad (2)$$

The sum of the forces on the mass then generates this ordinary differential equation:

$$m\ddot{x} + kx = 0. \quad (3)$$

The natural frequency of vibration is given by

Table 1. The experimental data.

S.No	Load mass	Initial height h1cm	Final height h2cm	Deflection H=h1-h2 cm	Stiffness (k)N/m= F/H	Average stiffness of the spring N/m	Natural frequency (f) Hz
1	No load (0.3Kg)	0	0	0	-	2850	15.512
2	0.7	18.62	18.37	0.246	2790	2850	8.496
3	1.4	18.62	18.15	0.469	2920	2850	6.516
4	2.1	18.62	17.91	0.709	2905	2850	5.485
5	2.8	18.62	17.635	0.985	2785	2850	4.825

$$f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}}. \quad (4)$$

Natural frequency of load of mass 2.8 kg (f_n) = 4.825 Hz. Angular velocity (ω_n) = $2\pi f_n$ = 30.31 rad/s. Therefore the stiffness of the spring is 2.88 kN/m Amplitude 5.5 cm, decay period 32 sec The amplitude of vibration traced by the system is shown figure 4.

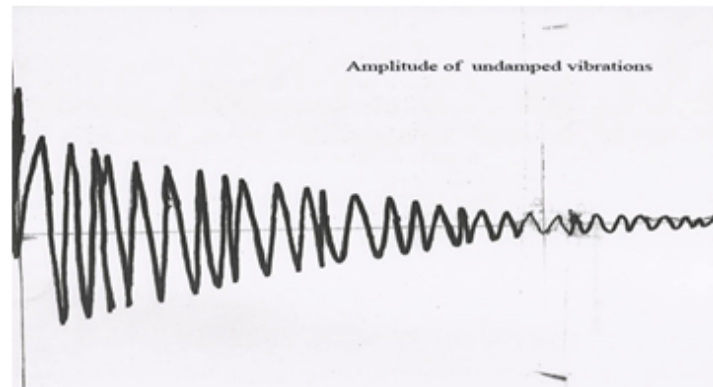


Figure 4. Pattern of vibration occurred and traced for natural vibration of the beam.

4.1. Free vibration with damping

We now add a "viscous" damper to the model that outputs a force that is proportional to the velocity of the mass. The damping is called viscous because it models the effects of an object within a fluid. The proportionality constant C is called the damping coefficient and has units of Force over velocity (N s/m).

$$F_d = -cv = -c\dot{x} = -c\frac{dx}{dt}. \quad (5)$$

By summing the forces on the mass we get the following ordinary differential equation:

$$m\ddot{x} + c\dot{x} + kx = 0. \quad (6)$$

The solution to this equation depends on the amount of damping. If the damping is small enough the system will still vibrate, but eventually, over time, will stop vibrating. This case is called under damping this case is of most interest in vibration analysis. If we increase the damping just to the point where the system no longer oscillates it reaches the point of critical damping (if the damping is increased past critical damping the system is called over damped). The value that the damping coefficient needs to reach for critical damping in the mass spring damper model is:

$$C_c = 2\sqrt{km}. \quad (7)$$

To characterize the amount of damping in a system a ratio called the damping ratio (also known as damping factor and critical damping) is used. This damping ratio is just a ratio of the actual damping over the amount of damping required to reach critical damping. The formula for the damping ratio ζ the mass spring damper model is:

$$\zeta = \frac{C}{2\sqrt{km}}. \quad (8)$$

Metal structures (e.g. airplane fuselage, engine crankshaft) will have damping factors less than 0.05 while automotive suspensions in the range of 0.2–0.3. The solution to the under damped system for the mass spring damper model is the following:

$$x(t) = Xe^{-\zeta\omega_n t} \cos(\sqrt{1 - \zeta^2}\omega_n t - \phi), \quad (9)$$

$$\omega_n = 2\pi f_n. \quad (10)$$

The value of X , the initial magnitude, and ϕ the phase shifts, are determined by the amount the spring is stretched. The formulas for these values can be found in the references.

4.2. Damped vibration with MR gel without Magnetic field.

From the table the damped frequency of spring mass and MR damper without Magnetic Field is given by Then $\zeta = 0.90$, Damping coefficient = 169.19 (N. sec/m) ,Amplitudes 5.5cm , decay 5 sec The amplitude of vibration traced by the system is given by figure

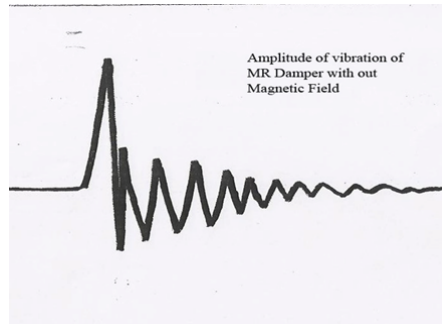


Figure 5. Pattern of vibration occurred and traced far damped vibrations with damper of MR Gel without Magnetic Field.

4.3. Damped vibration with MR Gel Magnetic field.

The magnetic fields generated by currents and calculated from Ampere's Law or the Biot-Savarts Law are characterized by the magnetic field B measured in Tesla. Using Ampere's law, one can determine the magnetic field associated with a given current or current associated with a given magnetic field, providing there is no time changing electric field present. Ampere's law is a mathematical statement of the relationship between currents and the magnetic fields they generate. Field at Centers of Current Loop, The form of the Magnetic field from a current element in the loop is given by

$$dB = \frac{\mu_0 IdL \times \vec{r}}{4\pi R^2} = \frac{\mu_0 IdL \sin\theta}{4\pi R^2}. \quad (11)$$

Which in this case simplifies greatly because the angle 90 degrees for all points along the path and the distance to the field point is constant. The integral becomes

$$B = \mu_0 \frac{I}{4\pi R^2} \oint dL = \frac{\mu_0 I}{4\pi R^2} 2\pi R = \frac{\mu_0 I}{2R}. \quad (12)$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T.m/A}.$$

Now the current in the copper coil is determined by determining the resistance as voltage is constant. The resistance of a wire is given by

$$R = \rho \frac{L}{A}. \quad (13)$$

Resistance = resistivity $\times \frac{\text{length}}{\text{area}}$. For a wire of length $L = 2\pi R_p \times \text{no of turns}$. R_p =outer radius of CPVC pipe=.0225m. $R_p=2\pi \times 0.0225 \times 1450 = 205$ meters.

$$\text{Area}(A) = 3.142 \times 10^{-6} m^2,$$

resistance $R = 4.38 \Omega$. Current $I = \text{voltage} / \text{resistance} = 12 / 4.38 = 2.74$ Amperes. Therefore the magnetic field produced is given by $B = 0.11$ Tesla. The amplitude of vibration traced by the system is given by figure. From table 5 the damped frequency of spring made and MR damper is given by $\zeta = 0.92$. Damping coefficient $= 172.96$ (N. sec/m). Amplitude 5.5cm, decay period 3sec.

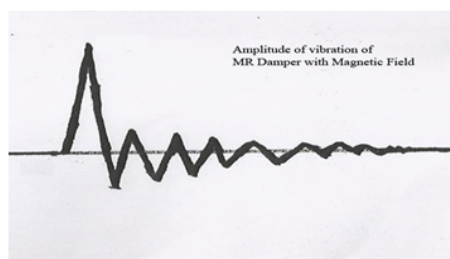


Figure 6. Pattern of vibration occurred and traced for damped vibrations with damper of MR Gel with applied Magnetic Field.

Table 2. The experimental data of various configurations with dampers.

S.No	Load (W)	Time for 5 oscillations (sec)	Average time sec	Time for 1 oscillation(t) sec	Damped frequency(f) Hz F_d	Damped Angular velocity (rad/s) ω_d
1. Damper With Oil	2.8	4.42	4.4	.44	2.27	14.26
	Or	4.62				
	27.45	4.23				
	N	4.33				
2. Damper with MR Gel & No Magnetic Field	2.8	2.39	2.44	0.487	2.05	12.88
	Or	2.57				
	27.45	2.36				
	N	2.42				
3. Damper with MR Gel	2.8	2.55	2.61	.522	1.91	12
	Or	2.69				
	27.45	2.61				
	N	2.58				

5. Results and discussion

Comparing various systems with respect to amplitude of vibration and decay period is shown in below figure. This clearly shows the effect of damping produced by MR gel damper with

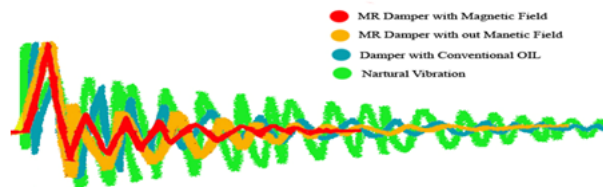


Figure 7. Pattern of vibrations

Magnetic Field is more effective than the other systems. So this provides added flexibility to control damping according to the road conditions and The effect of variation of current on the magnetic field generation is linear. The observations made during the experimentation of various systems and comparing of various systems with respect to amplitude of vibration, by un damped system are as follows, the damped system with mineral oil is 47% (decrease of 53 %), the damped system with MR gel and without magnetic field is 42% (decrease of 58%) and the damped system with MR gel and with magnetic field is 39% (decrease of 61%). The improvements made in the existing work i.e., use of variable stiffness springs in suspension system also helps in regulating ride comfort and stability of the vehicle. Both the systems combined together will produce greater ease, flexibility of control and performance. Such, control system is close to active suspension systems and provide large domain to control the ride stability and comfort without compromising according the road conditions. The results obtained from the study prove that, using MR dampers will provide a smoother ride then conventional suspension system.

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