

ABSTRACT

A spring mechanism for providing stiffness as well as damping effect is disclosed. The spring mechanism includes a hollow non-magnetic tube, a helical spring, a ferrofluid and a magnetic field. The helical spring is incased in the hollow non-magnetic tube. The ferrofluid is disposed inside the hollow non-magnetic tube and adapted to flow inside the hollow non-magnetic tube. The magnetic field is applied to the ferrofluid. From a distance of free length of the helical spring attractive force between the ferrofluid is minimum, when load is applied to the spring mechanism, the spring mechanism gets compressed and thereby increasing magnetic attraction between the ferrofluid, due to increased magnetic attraction - viscosity of the ferrofluid increases and thereby the spring mechanism provides stiffness as well as damping effect.

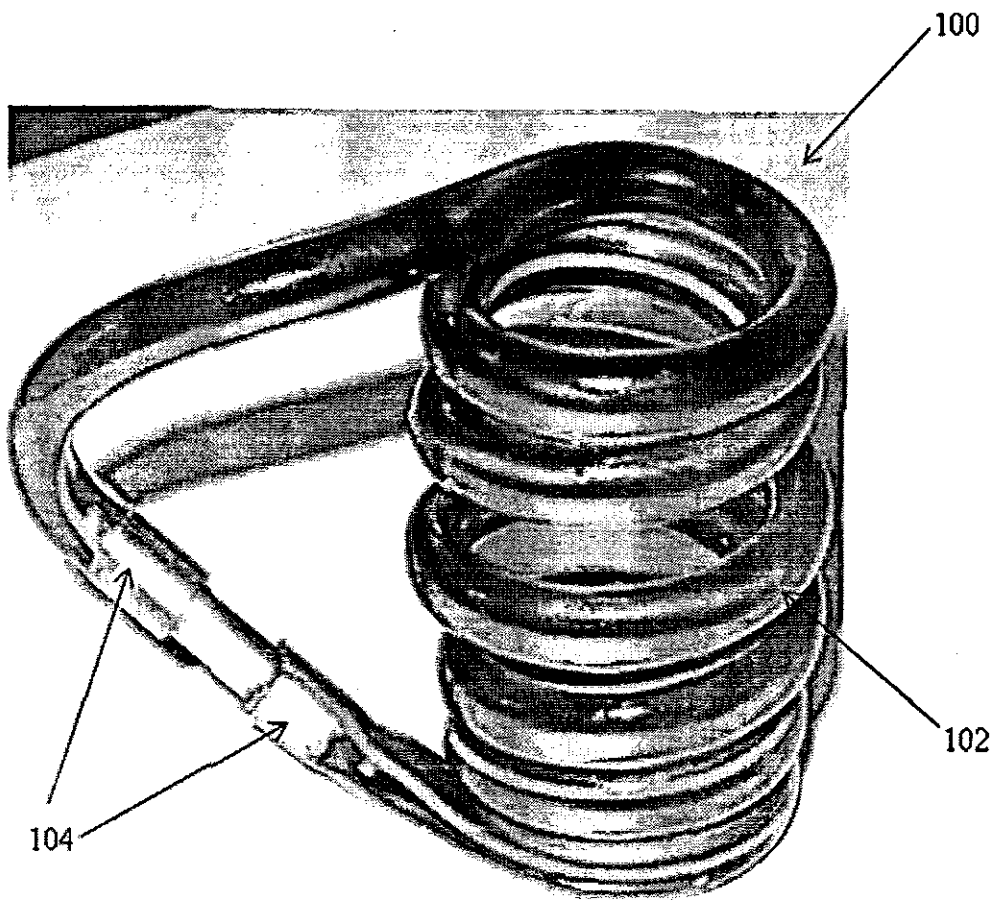


FIGURE 10

I claim:

1. A spring mechanism for providing stiffness as well as damping effect, said spring mechanism comprising:

a hollow non-magnetic tube;

a helical spring incased in said hollow non-magnetic tube,

a ferrofluid disposed inside said hollow non-magnetic tube and adapted to flow inside said hollow non-magnetic tube; and

a magnetic field applied to said ferrofluid,

wherein from a distance of free length of said helical spring attractive force between said ferrofluid is minimum, when load is applied to said spring mechanism, said spring mechanism gets compressed and thereby increasing magnetic attraction between said ferrofluid, due to increased magnetic attraction - viscosity of the ferrofluid increases and thereby said spring mechanism provides stiffness as well as damping effect.

2. The spring mechanism as claimed in claim 1, wherein said magnetic field increases its intensity as said load on said spring mechanism increases.

3. The spring mechanism as claimed in claim 1, wherein said hollow non-magnetic tube is endless.

4. The spring mechanism as claimed in claim 1, wherein said hollow non-magnetic tube is made endless by means of a plastic tube.

5. The spring mechanism as claimed in claim 1, wherein said hollow non-magnetic tube has a helical spring shape.

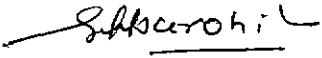
6. The spring mechanism as claimed in claim 1, wherein said helical spring is a compression spring.

7. The spring mechanism as claimed in claim 1, wherein helix angle of said helical spring and said hollow non-magnetic tube is same.

8. The spring mechanism as claimed in claim 1, wherein said magnetic field is generated by an electromagnetic field.

9. The spring mechanism as claimed in claim 1, wherein said magnetic field is generated by a pair of magnets provided in said hollow non-magnetic tube.

APPLICANT


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FIELD OF THE INVENTION

[0001] The present invention relates generally to springs. Particularly, the present invention relates to a spring mechanism.

BACKGROUND OF THE INVENTION

[0002] Spring is an elastic member used to store and dispense mechanical energy as per requirement. More specifically, springs are elastic members that exert forces, or torques, and absorb energy, which is usually stored and later released. Pneumatic springs of various types utilize the elastic compressibility of the air/gases. Hydraulic compact springs are for large forces with small deflections.

[0003] Automotive shock absorbers are most commonly passive hydraulic devices whose characteristics are chosen 'once and for all' so as to achieve an appropriate compromise between ride comfort and other performance criteria such as road holding, handling and control (S.B.Purohit et al.,2011,"*Effect of road profile and curves generated by wheel on the performance of a shock absorber of a motorcycle*", Indian J.Sci.technol.,vol 4, No.5,pp. 534-538). In practice, this leads to a higher value of damping in extension than compression (Vittore Cossalter(2006),Motorcycle Dynamics,2nd Edition).

[0016] Referring to Figure 1, the differential equation of motion for a transient vibration system is expressed in terms of ζ (damping ratio) and ω_n (natural frequency)

$$\ddot{x} + 2 \zeta \omega_n \dot{x} + \omega_n^2 x = 0$$

with initial condition as $x(0) = 0$ and $\dot{x}(0) = F/m$ (D. Hrovat (1997), "Survey of advanced suspension developments and related optimal control applications." Automatica, vol33,No.10,pp1781-1817). F the impulsive force of very short duration and m the mass. With close approximation the peak acceleration becomes:

$$\frac{F}{2m}$$

30 OCT 2013

$$\ddot{x} \approx (4\pi^2 \zeta \sin 2\pi t) / r, 1 \leq r \leq 10$$

[0004] For a shock absorber system the natural frequency is set and therefore during the working conditions changing the value of damping ratio affects the displacement and acceleration (T.P.Waters, Y.Hyun, M.J.Brennan, "The effect of dual rate suspension damping on vehicle response to transient road inputs, *Journal of vibration and Acoustics*," Feb2009, vol131, 011004-1-4). For transient inputs the peak acceleration may be reduced by switching the damper to a lower value during an impulse. The switching of damper to different values should be very quick and must match with the ratio, r , of natural period to impulse duration.

[0005] Fluid dashpot type of viscous dampers are popular in most of the two wheelers in which such desired changes in damping values are not possible. It can be shown with approximation that the damping is given by

$$c = (12\mu A_p^2 L) / (\pi D_m e^3)$$

c = viscous damping coefficient, μ = coefficient of viscosity of the fluid, A_p = area of one flat side of the piston, L = length of the piston, D_m = mean diameter of the piston and the cylinder, e = clearance between the piston and the cylinder. The viscosity of the fluid accounts for the energy dissipation (in the shock absorber) associated with the transport of fluid in the dashpot. Figure.2 illustrates the concept of viscosity and velocity gradient.

[0006] Figure 3 illustrates schematic representation of a fluid within the small gap between two concentric cylinders. A torque is necessary to rotate the inner cylinder at constant rotational speed Ω , while the outer cylinder remains stationary. The resistance to the rotation of the cylinder is due to the viscosity (Merle C Potter, Elain P.Scott, *Thermal Sciences and fluid Mechanics*, Thomson Learning, Brooks/Cole, 2002). The applied torque is related to the resisting torque by the equation:

$$T = (2 \pi R^3 \Omega L \mu) / h$$

L = length of rotating cylinder. The kinematic viscosity,

$$\nu = \mu / \rho$$

ρ = density of fluid. and for the pure viscous conditions

$$\phi \propto \ddot{x}^3$$

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30 OCT 2013

ϕ is the system constant. The differential equation of vibration motion for purely viscous conditions changes to

$$\ddot{x}^3/\phi v + 2\zeta \omega_n \dot{x} + \omega_n^2 x = 0.$$

$$\dot{x}/x = -\omega_n / [(1/\phi v \omega_n) + 2\zeta]$$

[0007] The phase plane plot between the velocity and the displacement is affected by the damping ratio of the fluid and therefore any change in the viscosity affects the damping ratio and any change in the damping affects the energy dissipation and hence the change/ switching of damper to other values. During the earlier developments the orifice of the dashpot was dilated /contracted as per the signals and it resulted in the switching of damping coefficient values as dependent parameter of force function and velocity, as per Figure no.4.

[0008] Dilatants (slurries) become more resistant to motion as the strain rate increases and such fluids e.g. ferrofluids (as per the Bingham model) requires a minimum shear stress to cause motion. Once the minimum value of shear stress is obtained then the switching of damping coefficient from minimum to maximum value is almost instant (H Hirani, course coordinator, QIP short term course on "micro/nano tribology," January 01-05, 2007, IIT Bombay). The variation in damping is due to change in the viscosity of the fluid, as per Figure no.5.

[0009] In dynamic situation the change in viscosity of a fluid is possible by using a ferrofluid in the magnetic field. Ferro fluids (compound of Latin ferrum, meaning iron, and fluid) are colloidal suspensions of fine (~ 0.05-15 nm) dispersions of magnetically soft, multi domain nano particles, such as Fe_3O_4 , coated with surfactants in a carrier liquid (SK Kulkarni, (2007) *Nano technology, principles and practices*, Capital Publishing Company ISBN 81-85589-29-1).

[0010] Although, the conventional springs are useful for various applications, the conventional springs have numerous limitations. For example, the conventional springs are not able to provide stiffness as well as damping effect. Further, the conventional springs are not able

to provide adjustability as per requirement. Furthermore, the conventional springs provide higher value of damping in extension than in compression.

[0011] Accordingly, there exists a need of a spring mechanism that is adapted to provide stiffness as well as damping effect. Further, there exists a need of a spring mechanism that is adapted to provide adjustability as per requirement.

OBJECTS OF THE INVENTION

[0012] An object of the present invention is to provide a spring mechanism that is adapted to provide stiffness as well as damping effect.

[0013] Another object of the present invention is to provide a spring mechanism that is adapted to provide adjustability as per requirement.

[0014] Yet another object of the present invention is to provide a spring mechanism that is cost effective.

[0015] Also, an object of the present invention is to provide a spring mechanism that is adapted to provide more comfort to the rider(s).

SUMMARY OF THE INVENTION

[0016] In accordance with one aspect of the present disclosure, a spring mechanism for providing stiffness as well as damping effect is disclosed. The spring mechanism includes a hollow non-magnetic tube, a helical spring, a ferrofluid and a magnetic field. The helical spring is incased in the hollow non-magnetic tube. The ferrofluid is disposed inside the hollow non-magnetic tube and adapted to flow inside the hollow non-magnetic tube. The magnetic field is applied to the ferrofluid. From a distance of free length of the helical spring

attractive force between the ferrofluid is minimum, when load is applied to the spring mechanism, the spring mechanism gets compressed and thereby increasing magnetic attraction between the ferrofluid, due to increased magnetic attraction - viscosity of the ferrofluid increases and thereby the spring mechanism provides stiffness as well as damping effect.

[0017] In one embodiment, the hollow non-magnetic tube is endless.

[0018] Additionally, in another embodiment, the hollow non-magnetic tube is made endless by means of a plastic tube.

[0019] Typically, the hollow non-magnetic tube has a helical spring shape.

[0020] In one embodiment, the helical spring is a compression spring.

[0021] Typically, helix angle of the helical spring and the hollow non-magnetic tube is same.

[0022] In one embodiment, the magnetic field is generated by an electromagnetic field.

[0023] Alternatively, in another embodiment, the magnetic field is generated by a pair of magnets provided in the hollow non-magnetic tube.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The advantages and features of the present invention will become better understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like elements are identified with like symbols. Further, it is to be understood that drawings are to be used for the purposes of exemplary illustration only and not as a definition of the limits of the invention:

[0025] FIG. 1 illustrates a SDOF model of a motorcycle shock absorber;

[0026] Figure 2 illustrates a schematic representation of a relative movement of two fluid particles in the presence of shear stresses;

[0027] Figure 3 illustrates a schematic representation of a fluid between cylinders with velocity distribution;

[0028] Figure 4 illustrates a schematic representation of a damper with orifice variation;

[0029] Figure 5 illustrates a schematic representation a damper with variable damping coefficient;

[0030] Figures 6a and 6b illustrate schematic representations of a ferrofluid in 'no field' and in 'applied field' configurations;

[0031] Figure 7 illustrates a schematic representation of Ferrofluid as liquid and not so liquid;

[0032] Figure 8 illustrates a schematic representation of damping characteristics of ferrofluid without magnetic field;

[0033] Figure 9 illustrates a schematic representation of damping characteristics of ferrofluid in magnetic field;

[0034] Figure 10 illustrates a perspective view of a spring mechanism, in accordance with one embodiment of the present invention;

[0035] Figure 11 illustrates a schematic representation of Ferrosprings in making and under testing;

[0036] Figure 12 illustrates set up for magnetic levitation and stiffness curves;

[0037] Figure 13 illustrates stiffness curves of ferrospring in accordance with one embodiment of the present invention;

[0038] Figures 14 illustrates set up for measuring stiffness of ferrospring; and

[0039] Figure 15 illustrates stiffness curves of ferrospring, in accordance with one embodiment of the present invention.

[0040] Like reference numerals refer to like parts throughout the description of several views of the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0041] The exemplary embodiments described herein detail for illustrative purposes are subject to many variations in structure and design. It should be emphasized, however, that the present invention is not limited to a particular spring mechanism, as shown and described. It is understood that various omissions and substitutions of equivalents are contemplated as circumstances may suggest or render expedient, but these are intended to cover the application or implementation without departing from the spirit or scope of the present invention.

[0042] The terms “first,” “second,” and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another, and the terms “a” and “an” herein do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

[0043] The present invention provides a spring mechanism that is adapted to provide stiffness as well as damping effect. The development is done on a spring of low stiffness. The spring mechanism is typically a compression helical spring incased in a hollow non magnetic endless tube. Inside the tube flows a ferrofluid. From a distance of free length of spring attractive force is less but when the load is applied the spring compresses and the magnetic attraction increases. This alters the viscosity of the ferrofluid inside the spring. Ferrofluid thickens and a typical spring dashpot system acts. The desired viscosity of the ferrofluid can be obtained after the setting the magnetic field. In one embodiment, the magnetic field increases its

intensity as the load on the spring mechanism increases. This is achieved by number of windings. An instant change in damping coefficient of ferro fluid with coupling ($c = 0.8348 \text{ Ns/m}$) and decoupling ($c = 0.2418 \text{ Ns/m}$) with the magnetic field is observed. Also, the spring mechanism of the present invention is adapted to provide adjustability as per requirement. Additionally, the spring mechanism of the present invention is like a self controlled semi active system.

[0044] Referring to Figures 6 to 15, the spring mechanism 100 (shown in Figure 10) of the present invention is disclosed in accordance with one embodiment of the present invention. The spring mechanism 100 of the present invention is used for applications requiring minimum spring mass. The spring mechanism 100 of the present invention has inherent stiffness and dashpot effect both. The development is done on a spring having low stiffness.

[0045] The spring mechanism 100 is essentially a compression helical spring incased in a hollow non magnetic endless tube 102 (instead of spring wire). In one embodiment, the helix angle of the helical spring and the hollow non-magnetic tube 102 is same. Inside the tube 102 flows the ferrofluid 106 (shown in Figure 7). In one embodiment, at each end of the spring mechanism 100 one permanent magnet 104 is attached with the opposite poles attracting each other. From a distance of free length of spring attractive force is less but when the load is applied the spring compresses and the magnetic attraction increases. This alters the viscosity of the ferrofluid inside the spring. Ferrofluid thickens and a typical spring dashpot system acts. One can get the desired viscosity of the ferro fluid after the setting the magnetic field. An instant change in damping coefficient of ferro fluid with coupling ($c = 0.8348 \text{ Ns/m}$) and decoupling ($c = 0.2418 \text{ Ns/m}$) with the magnetic field is observed. The response of the spring gets delayed. This is like a self controlled semi active system.

[0046] Referring to Figure 6a, when there is no magnet nearby, the magnetite particles in ferrofluid act like normal metal particles in suspension. Referring to Figure 6b, in the presence of a magnet, the particles are temporarily magnetized. Ferro fluids respond to an external magnetic field. This enables the fluid's location to be controlled through the application

of a magnetic field. The aligned nano particles due to applied magnetic field resist the motion of the carrier fluid.

[0047] The particles are so small in ferrofluids that they will not settle over time, but remain in place as long as a magnetic field is present. Treatment of particles with surfactants prevents them from clumping up, causing the material to remain stable and act predictably. They form structures within the fluid, causing the ferrofluid to act more like a solid. When the magnetic field is removed, the particles are demagnetized and ferrofluid acts like a liquid again, as shown in Figure 7.

[0048] The apparent viscosity of these fluids can be changed significantly within milliseconds by the application of an external magnetic field. The change in the damping ratios of the ferrofluid is significant. The damping behavior of ferrofluid is observed on vibration fundamental training system (VFT) The figure no.8 shows the VFT results of 'In house made Ferro fluid' as a damping fluid without magnetic field.

[0025] In one embodiment, the natural frequency of the system with Ferro fluid is detected as, $f = 5.88192$ Hz, the circular frequency $\omega_n = 36.9571$ rad /s, the logarithmic decrement $\delta = 0.413$, the damping ratio $\zeta = 0.06559$, the damping frequency, $\omega_d = 36.877$ rad /s, $c_c = 3.6957$ N –sec/m, the damping coefficient, $c = 0.2418$ N –sec/m. Figure 9 shows the VFT results of 'In house made Ferro fluid' as a damping fluid with magnetic field.

[0026] The natural frequency of the system with ferrofluid in magnetic field is detected as, $f = 5.90569$ Hz. The circular frequency $\omega_n = 37.1065$ rad /s, the logarithmic decrement $\delta = 0.225$, the damping ratio $\zeta = 0.03578$, the damping frequency $\omega_d = 37.0827$ rad /s, $c_c = 3.7106$, the damping coefficient $c = 0.8348$ N –sec/m. As the ferrofluid is subjected to the magnetic field, the damping coefficient value changes considerably. The application of such variable viscosity ferrofluid is made in developing a ferrospring. The spring of low stiffness is incased in a flexible pipe. The flexible pipe is made endless. In one embodiment, the hollow non-magnetic tube 102 is made endless by means of a plastic tube. The spring under compression reduces in length but dilates in diameter. The change in geometry of spring allows the ferrofluid

to move inside the annular gap between the spring wire and the pipe. This gives a similarity of fluid flow moving in an annular gap. Faster the impulse force, faster the movement of fluid. When the spring is placed between two magnets then the viscosity changes and this gives resistance to the fluid flow and energy is dissipated in moving the fluid. The spring has its own stiffness and such ferrospring acts like a composite spring with inherent stiffness and damping. The ferrospring is developed having inherent stiffness for energy storage and dashpot effect for energy dissipation, both. The development is done on a spring of low stiffness, as per Figure 11.

[0027] Before taking the experimental observations on the ferrospring, the independent effect of magnetic field and its out come as load deflection curve is recorded. The combination of springs between magnets shows nearly linear graphs but the repulsive levitation force between magnets gives a non linear curve, as per Figure 12.

[0028] The stiffness curve of ferro spring becomes nearly linear. Changing the polarity of magnets gives similar linear stiffness curve with changed values as per Figure 13. Referring to Figure 14, instead of using the permanent magnets, the ferrospring is wound with wire to get the electromagnetic effect and the stiffness is plotted with different combination of windings and the current values.

[0030] The stiffness curves are variable in nature depending upon the changing values of winding and currents. Further, in one embodiment of the present invention, the electromagnets with switchable polarity and multiple outlet windings can also be used.

I claim:

1. A spring mechanism for providing stiffness as well as damping effect, said spring mechanism comprising:

a hollow non-magnetic tube;

a helical spring incased in said hollow non-magnetic tube,

a ferrofluid disposed inside said hollow non-magnetic tube and adapted to flow inside said hollow non-magnetic tube; and

a magnetic field applied to said ferrofluid,

wherein from a distance of free length of said helical spring attractive force between said ferrofluid is minimum, when load is applied to said spring mechanism, said spring mechanism gets compressed and thereby increasing magnetic attraction between said ferrofluid, due to increased magnetic attraction - viscosity of the ferrofluid increases and thereby said spring mechanism provides stiffness as well as damping effect.

2. The spring mechanism as claimed in claim 1, wherein said magnetic field increases its intensity as said load on said spring mechanism increases.

3. The spring mechanism as claimed in claim 1, wherein said hollow non-magnetic tube is endless.

4. The spring mechanism as claimed in claim 1, wherein said hollow non-magnetic tube is made endless by means of a plastic tube.

5. The spring mechanism as claimed in claim 1, wherein said hollow non-magnetic tube has a helical spring shape.

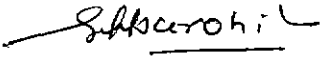
6. The spring mechanism as claimed in claim 1, wherein said helical spring is a compression spring.

7. The spring mechanism as claimed in claim 1, wherein helix angle of said helical spring and said hollow non-magnetic tube is same.

8. The spring mechanism as claimed in claim 1, wherein said magnetic field is generated by an electromagnetic field.

9. The spring mechanism as claimed in claim 1, wherein said magnetic field is generated by a pair of magnets provided in said hollow non-magnetic tube.

APPLICANT


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