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MR BASED SEMI-ACTIVE SUSPENSION WITH VARIABLE STIFFNESS AND DAMPING- AN OVERVIEW

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ABSTRACT

In the field of the automotive suspension system, the main aim of all the recent technology and inventions is to provide ace in terms of ride comfort and vehicle handling. Since the semi-active suspension shows intermediate behavior as it provides variable damping using MR damper which is not available in passive suspensions and is less power consuming and cost-efficient than active suspension. For introducing variable stiffness in the semi-active suspensions with MR damper, a lot of new mechanisms were developed and are still developing. In this paper, variable stiffness and variable damping mechanisms for semi-active suspensions with MR dampers are discussed and the conclusion was made that these mechanisms are ace in the performance as compared to conventional passive suspension systems

Keywords: Automotive Suspension, Variable Damping, Variable Stiffness, Ride Comfort, Vehicle Handling.

I. INTRODUCTION

Normally, automotive suspension of automobiles consists of mainly - springs, dampers, and linkages to provide relative motion between the car body and the wheels smoothly. The springs allow the wheel movement in the upward and downward direction to absorb road inputs and reduce jolting while the dampers slow down the spring to get back to its original form. By doing so they provide comfort and better handling characteristics. A good suspension system should be attuned in such a way to provide better handling and ride comfort to the various road inputs. Mainly suspension systems are classified as passive, semi-active, and active suspension systems. Passive suspensions are our conventional suspensions which are tuned to provide moderate damping and stiffness. They have fixed spring and damper characteristics while active suspension systems have an onboard active system (ECU) that provides both variable damping as well as variable stiffness towards the different road inputs. This system detects the inputs from the roads by various sensors. The ECU then control the action of suspension by that data by the help of different control techniques. Add Comment on semi active suspension system. A semi-active suspension is a kind of suspension that utilizes either variable damper or variable dissipater for example twin-tube variable orifice damper. The variable orifice is controlled by the electrically controlled unit which controls the diameter of the orifice. Since the piston moves inside the cylinder which causes the flow of fluid through the orifice. The larger the diameter of the orifice less the dissipative resistance and the smaller the diameter of the orifice more the dissipative resistance.

Table 1: Comparison between different types of suspension systems [11].

Parameters	Passive Suspensions	Semi- Active Suspensions	Active Suspensions
Structure	Simplest	Simple	Complex
Weight/Volume	Lowest	Low	Highest
Cost	Lowest	Low	High
Ride Comfort	Bad	Medium	Best
Handling	Bad	Medium	Best
Reliability	Highest	High	High
Cost	Low	Medium	High

As from the table, semi-active suspension has intermediate behavior i.e., in between passive and active suspension as it provides only variable damping towards the road inputs and cost-efficient and is less power consuming as compared to active suspension.

II. MR DAMPER

Since, the semi-active suspension consists of controllable dampers like servo or solenoid valve damper, magnetorheological (MR), electrorheological (ER) dampers, and electromagnetic dampers. Among these, MR damper is the most commonly used damper nowadays (figure 1). An MR damper or magneto-rheological damper or shock absorbers controls the rheological behaviour of damping fluid by governing the magnetic field. The MR damper consists of a cylinder, accumulator, piston, and MR fluid. MR fluid is comprised of nano or micro ferromagnetic particles, carrier fluid, and additives. A moving piston is used between the accumulator and the chamber holding MR fluid to compensate for the movement of the piston and the gas pressure inside the accumulator. When this fluid passes through the gap from one chamber to another. MR fluids are viscous fluids having some ferromagnetic particles which react to the variation in the applied magnetic field. This smart fluid increases its apparent viscosity when subjected to the magnetic field which is generated by the coil inside the cylinder and it becomes viscoelastic solid and offers dissipative resistance. This property of the fluid is controlled by the amount of electric current given to the MR damper from the source.

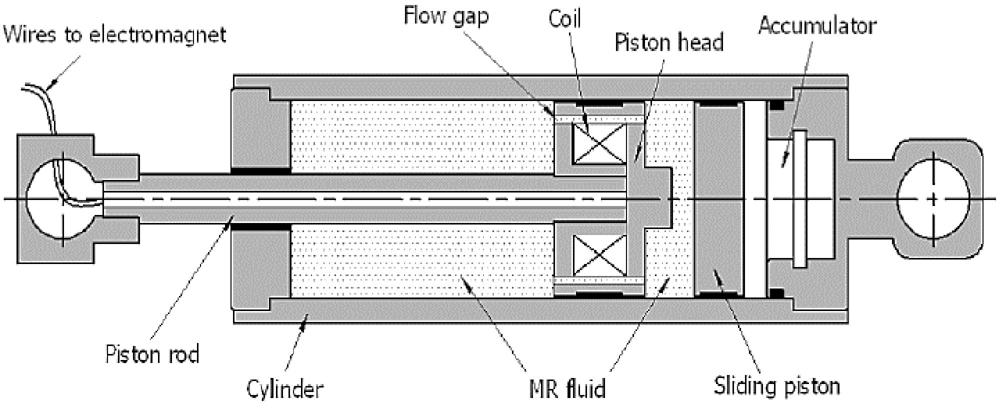


Figure 1: Block Diagram of an MR damper [12].

III. VARIABLE STIFFNESS AND VARIABLE DAMPING (VSVD) MECHANISM

The semi-active suspensions only provide variable damping. There are lots of investigations or experiments going on for providing variable stiffness to the same suspension system. A new configuration using two controllable dampers and two constant springs is proposed by Yanqing Liu et. al [1]. The proposed theoretical as well as experimental analysis of the proposed configuration. The 1-dof model contains 2 springs (k_1 and k_2) as well as 2 MR dampers (c_1 and c_2) to provide variable stiffness and variable stiffness according to the output.

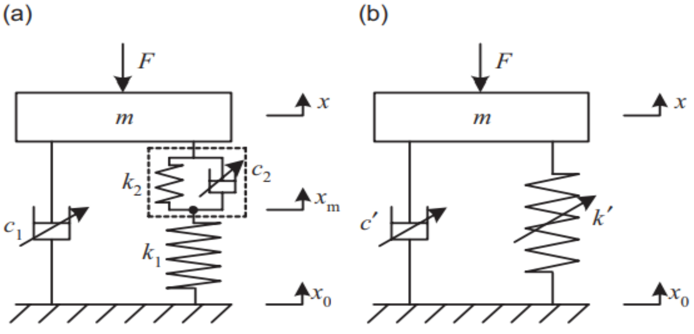


Figure 2: Mathematical model of the proposed system [1]

The system was given the horizontal vibration by an electromagnetic exciter. The damper c_1 was situated in between the mass and midpoint. The damper c_2 and spring k_2 are made in vigot element (figure 2). The equivalent stiffness of the system is altered by governing the damper in the vigot element and the second damper which is parallel with the other element provides variable damping for the system. On the basis of the experiment and results, the conclusion was formed that the projected control system has good performances for the vibration isolation as it has the smallest displacement responses while as compared to soft spring systems the acceleration is slightly greater.

Another research in this field is done by Gongyu Pan et. al [2],. They developed a full car model in AdamsCar with front and rear suspension with variable stiffness and damping. This mechanism had a variable universe fuzzy control system, according to variable universe fuzzy theory and the results were compared to semi-active suspensions having traditional fuzzy control. The co-simulation is done in MATLAB by using inputs of random roads and roof roads. On comparing the co-simulation results of random roads with the passive suspension system the centroid vertical acceleration of the full vehicle with variable stiffness and damping semi-active suspension controlled by the fuzzy system and variable universe fuzzy system were respectively reduced by 24.55% and 29.75%, the pitch angular acceleration of sprung mass were reduced by 15.02% and 10.52%, and the roll angular acceleration was decreased by15.49% and 25.45%. A triangular convex was used for the roof road output at a distance of 2 mm, its dimensions (height and base) were 30mm and 100 mm respectively. On comparing the results of the full car model with passive suspension, the peak values of pitch angular acceleration and vertical acceleration of the full car model with semi-active suspension were remarkably reduced, especially at the first peak value and the vibration response time of the proposed system was shorter as compared to the fuzzy control system.

Christoph Greiner-Petter et. al [3] presented a semi-active fluid mechanism consists of two MR fluid valves, springs, and three chambers one input and two output chambers having a separate piston in them respectively. The two springs having different stiffness were connected to the output pistons to provide the desired stiffness (figure 3). The three fluid chambers were linked and the mechanism act as a series connection of the two springs, if both valves were open. Closing one of the two valves gives only one stiffness which is of open valve spring. To regulate the MR fluid flow, each valve was embedded in the magnetic circuit.

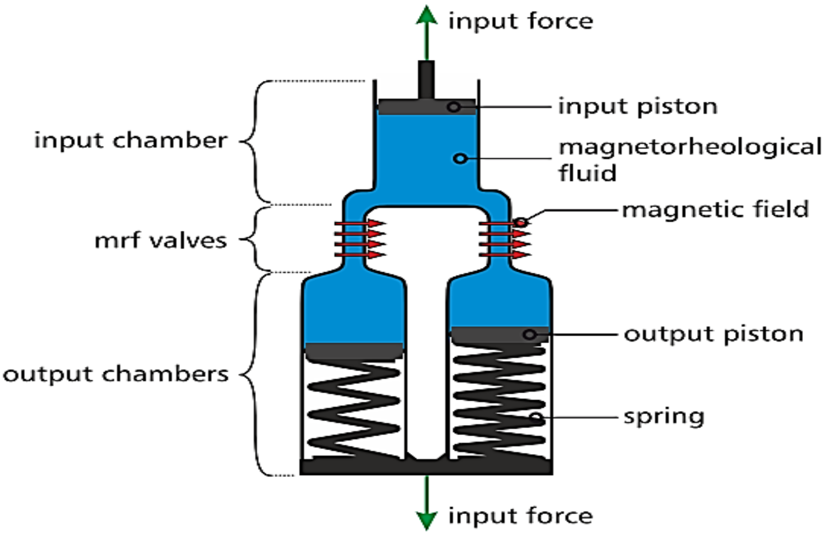


Figure 3: VSVD mechanism [3]

This way the variable stiffness and variable damping were obtained by varying the flow-through chamber and magnetic field strength of both valves. An appropriate test bench was built to examine the behaviour of the system. After testing, the researchers concluded that this setup offers three different values of selectable stiffness with continuously variable damping. The proposed system can be simply expanded to a supplementary selectable stiffness value also.

Tai-Hsun Wu et. al [4] proposed a variable stiffness mechanism for semi-active suspension and compared it to the constant stiffness mechanism. It contains two parallel identical planer springs with the same stiffness value and the variable stiffness was achieved by adjusting their asymmetric rotations. They showed that while increasing pin to pin length (R_0) the stiffness variation increases. They tested their VSM on three different values of $R_{0.}$ For spring rotation range $\Delta\theta_0$ is taken 60^0 because of stiffness variation, adjustment sensitivity, and accommodation space. In the proposed VSM, one end of the springs is connected to the output slider (a,b) and the other ends are connected to the two rollers that slide on their circular spaces(A, B) shown in figure 4.

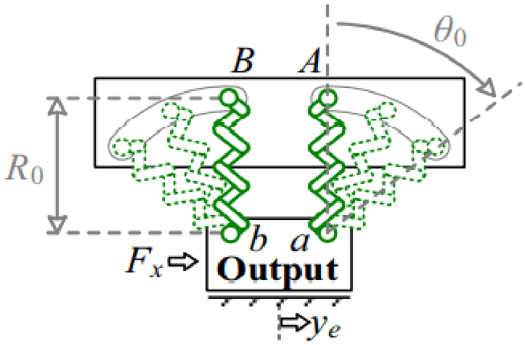


Figure 4: Schematic diagram of the proposed VSM [4]

This stiffness mechanism shows zero to very large stiffness depending on the rotation amount of the springs. They performed the testing and verified the results by using the vibration absorber experiment. Their VSM was proficient in absorbing vibration from an excitation source having a frequency from 8.1 to 17.2 Hz.

Since passive suspensions are tuned for standard input to provide a standard stiffness and damping and are not efficient when the input is less or more than standard input. Lilitkumar Maikulal Jugulkar et al. [5] designed a prototype model which provides variable stiffness and variable damping (VSVD). The system consists of two helical springs and an MR damper (figure 5a).

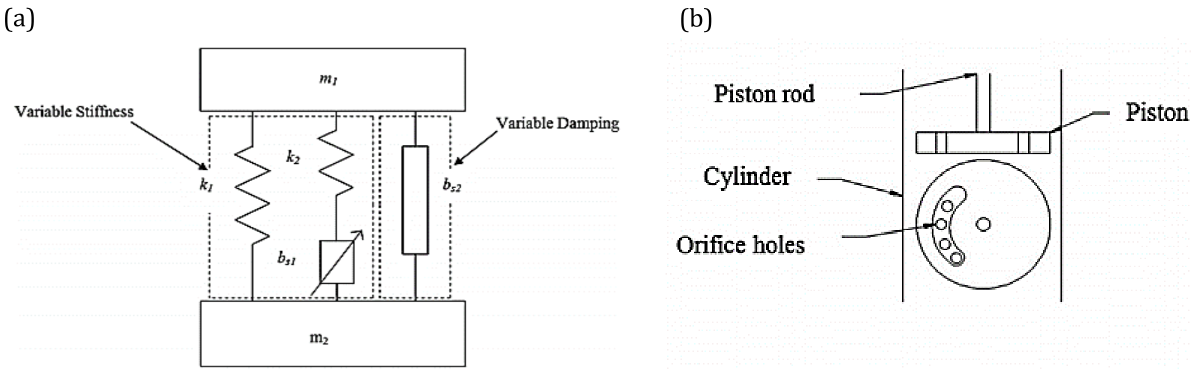


Figure 5: (a) The proposed model. (b) Arrangement to vary holes [5]

By altering the position of the cover piece, the variation in the flow area of the adjustable damper was obtained (figure 5b). The change in the number of active orifice holes causes the change in the damping coefficient of the damper which results in a change in damping characteristics which enables this prototype to provide variable stiffness to the system also. When all the holes were blocked the system acts as two springs connected parrel to each other, then the equivalent stiffness is given by the sum of the stiffness of both springs $(k_1 + k_2)$. However, if the number of active holes increases the damping characteristics decrease result in the equivalent stiffness approaching k_1. MATLAB Sims cape and Simulink were used to perform the numerical simulation on the prototype. The Simulation results show that in comparison to the conventional fluid passive shock absorber, their proposed system will give a 15% improvement in acceleration transmissibility and tire discomfort.

Shuaishuai Sun et al. [6] developed a metrorheological fluid-based damper, which provides the attributes of variable damping and variable stiffness with the help of two MR fluid damping units and a spring. The proposed MRF damper has mainly consisted of springs, a piston rod that runs through two damping cylinders i.e. upper and lower cylinders. Separate electromagnetic coils were used in each cylinder for energizing MR fluid by varying the magnitude of current flowing through the coils.

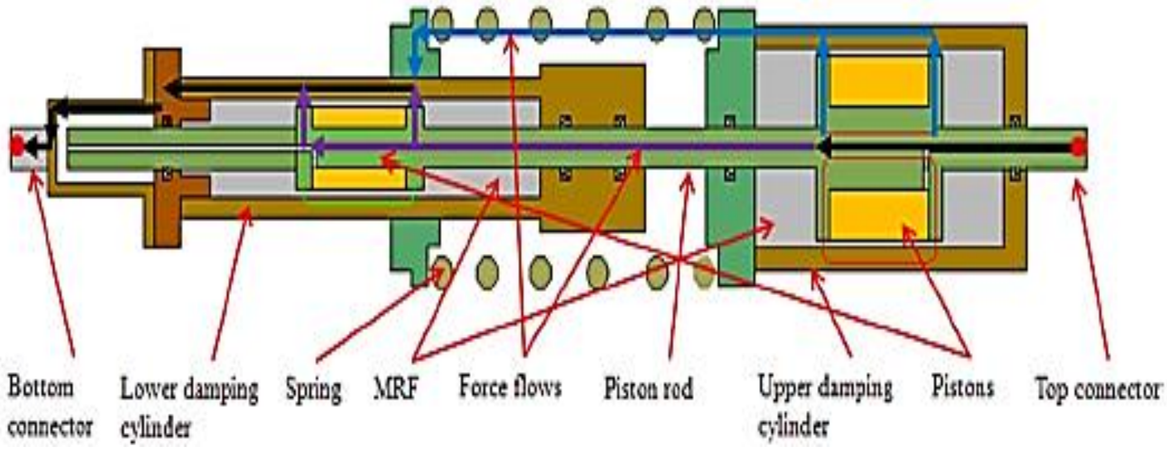


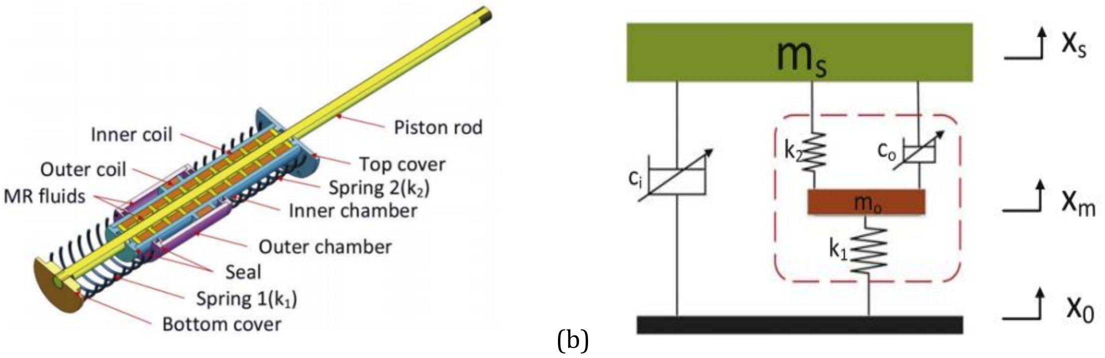
Figure 6: Schematic design, drawing, and prototype of the MRF damper [6]

In the proposed system, the variable damping was obtained by varying the magnitude of current in the lower cylinder while the variable stiffness was obtained by controlling the MR fluid in the upper cylinder which was connected to the spring. An MTS hydraulic testing machine was used to evaluate the damper's behaviour i.e., variability of damping and stiffness. After the testing, test results verified that both the damping and the stiffness properties of the damper can be controlled. It was observed that the stiffness of the proposed damper varied from 11.3 kN m^{-1} to 3 kN m^{-1}, when the current applied to the upper damping cylinder, was amplified from 0A to 1A. The equivalent damping coefficient can be varied from 21.55 kN $(m\ s^{-1})^{-1}$ to 51.21 kN $(m\ s^{-1})^{-1}$. Shuaishuai Sun et al. [7] moved one step further in their innovative work by designing, fabricating, and testing that innovative model and verified. Then a quarter car model was set up which uses this damping system to evaluate its performance.

Figure 7: The testing system with the proposed MRF damper [6]

The simulation of the quarter car model showed that the system with the proposed variable stiffness and variable damping setup has better vibrational control than other conventional dampers. For simulation, random road and bump excitation were used as input to the setup to evaluate its behaviour.

Huaxia Deng et al. [8] presented a variable stiffness and variable damping mechanism to enhance ride comfort. Since this suspension is built only to provide ride comfort so it was directly attached to the seat of the vehicle while testing. The proposed suspension system comprised of springs in series and damping unit which consists of two chambers inner chamber damping unit which was connected to the seat and outer chamber damping unit connected to the springs of different stiffness. in this, the seat model was simplified as 2 -dof vibration attenuation system.



(a) (b)

Figure 8: (a)Structure of proposed MR damper (b) Mathematical model of proposed suspension system [8]

The vigot element was formed by the outer chamber damping unit and spring 2. The vigot element and spring 1 were connected in series as shown in figure 8. The variable stiffness is obtained by controlling the outer unit damping coefficient (c_0) as if c_0 is smaller than the equivalent stiffness of the system approaches the series stiffness of both springs similarly if the c_0 is large enough the equivalent stiffness approaches 1. This system was first evaluated theoretically for vibration isolation and then was manufactured and tested for random excitation. It was concluded that the RMS value of the seat acceleration with this proposed system decreased by 22.1 % than that of excitation acceleration and the experimental results show that the seat suspension with variable stiffness and variable damping control gives the lowest seat acceleration and has the most operative vibration isolation performance when compared to passive and variable damping control.

Some researchers investigate the effect of VSVD by using rotatory MR dampers since compare to linear MR dampers the rotatory MR dampers have advantages like less requirement of MRF, less sealing required, and are cost-efficient. Xiaomin Dong et al. [9] proposed a 1 -dof variable damping and stiffness system comprise of two controllable damper and two springs. Damper c_2 and spring k_{s2} formed the vigot element and this vigot element was connected to spring k_{s1} in series (figure 8). In this arrangement linear springs were used to accomplish the rotary stiffness. By controlling the magnitude of the current in the damper c_2 the variable equivalent stiffness of the system was obtained whereas damper c_1 controls the damping of the system.

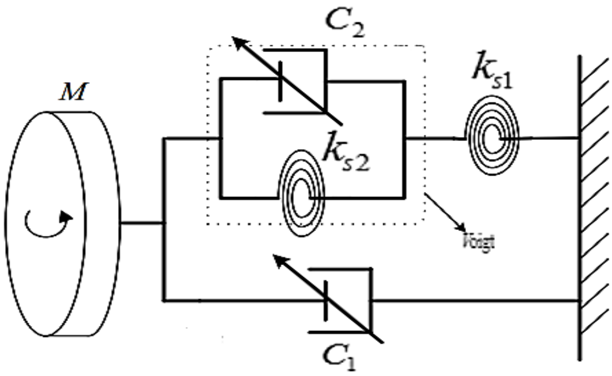
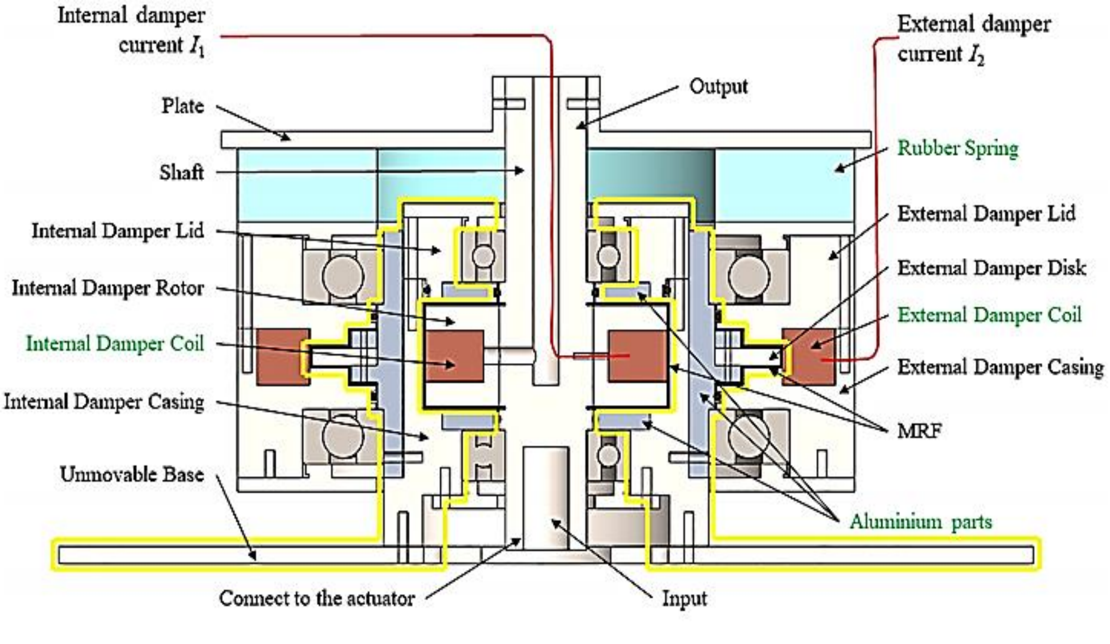


Figure 9: Mathematical model of proposed system [8]

The Bingham model was made and the system was analytically derived. The FEM was employed to find out the magnetic field intensity of the dampers. It was verified that stiffness and damping properties can be controlled by the test and analysis. Experimental results showed that equivalent stiffness could change from 5.15 Nm/rad to 12.28 Nm/rad and the equivalent damping coefficient could be varied from 0.83 kN.s/m to 3.6 kN.s/m.

Another admirable work in this of variable stiffness and variable damping field is carried out by Lei Deng et al. [10]. Their system possessed variability in stiffness and damping by assembling a set of two MR damper i.e., inner damper and outer damper.



* Yellow block parts: fixed; other parts: rotatable
* Green words parts: non-ferromagnetic; other parts: ferromagnetic

Figure 10: Structure of VSVD rotary MR shock absorber [9]

A silicone rubber (M4601A/B, Barnes crop.) was used to make a cylindrical rubber spring placed between the plate and the external damper casing. The internal damper coil was situated inside the rotor whereas the external dampers coil mounted to the external casing. Since these coils can generate magnetic flux so yield stress of the MR fluid can be controlled. The proposed system was simulated using COMSOL Multiphysics with a two-dimensional (2D) axisymmetric study and an experimental setup was made up for testing the feasibility of the system. By supplying current to the inner damper coil, the relative movement between the internal damper rotor and the casing is controlled by the semi-solid MRF between them this helps in achieving the variable damping. If even a small current was given to the external damper coil, the external damper casing no longer be capable of rotating without restriction from the external damper disc because of the braking torque induced with the aid of using the MR fluid. However, the plate was capable of constantly moving concurrently with the shaft. As a result, the rubber spring stretched, which in large part will increase the stiffness of the whole device. The experimental test was conducted to evaluate its performance, and the test results showed that the damping amplified 141.6% from 13.98 Nm.s/rad to 33.78 Nm.s/rad as the current increased from 0 to 1.0 A with a 10° amplitude and, a maximum of 618.1% increase in effective stiffness from 31.51 Nm/rad to 226.26 Nm/rad was acquired with the change in current from 0 to 2 A at the amplitude of 10°. The test results and the simulated model confirm the possibility of the shock absorber with the capability to vary damping and stiffness simultaneously.

IV. SUMMARY

In this paper, various types of variable stiffness and variable damping techniques for semi-active suspensions are discussed to make it a wholesome suspension that provides better ride comfort and vehicle handling both in a single mechanism. To provide variable damping, an MR damper is used and for achieving variable stiffness, the assembly of springs either in series or parallel or with the help of an MR damper is discussed. The variation of current is used to controlling the MR fluid property. In some of the cases there were significant amount of betterment in the performance [2,5,8,9] of the suspension system with MR damper as compared to passive suspension system.

In some cases, MR damper and spring configuration shows the significant betterment in suspension behaviors like amplification in damping [10], change in equivalent stiffness [9] and acceleration of sprung mass [5,4].

V. CONCLUSION

The review study shows that the semi-active suspension system having VSVD has advantages over the conventional passive suspension systems. These techniques will surely bring change in the field of automotive suspension systems as it can be controlled by various control strategies for enhancement in specific behavior also.

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