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Smart Adaptive Suspension System using MR Fluid

V. Krithika[1*], C. Subramani[2] and A. Geetha[2]

[1]Department of Mechatronics, SRM University, Kattakulathur, Chennai - 603203, Tamil Nadu, India; krithi.sairam@gmail.com

[2]Department of Electrical and Electronics, SRM University, Kattakulathur, Chennai - 603203, Tamil Nadu, India; csmsrm@gmail.com, geeanbu@gmail.com

Abstract

The objective is to develop a smart adaptive suspension system that dynamically varies the damping coefficient to achieve better control and improve the ride quality of an automobile. Adaptive/semi-active systems can only change the viscous damping coefficient of the shock absorber, and do not add energy to the suspension system. Though limited in their intervention, semi-active suspensions are less expensive to design and consume far less power. In recent times, research in semi-active suspensions has continued to advance on their capabilities, narrowing the gap between semi-active and fully active suspension systems. The various ways of achieving semi-active suspension systems are through solenoid/valve actuated, MR fluid and ER fluid mechanisms. Among the ways mentioned above, we chose to realize our objective using MR fluid damper system due to its favourable properties which are discussed later. It consists of an ultrasonic sensor to detect uneven terrain that needs specific hardening/softening of the suspension. The input to the system also includes the speed sensor. Once the central controller calculates the required stiffness of the suspension, it actuates a magnetic circuit that produces a magnetic field around the damper. The damper is filled with Magneto-Rheological fluid (MR Fluid) containing small iron filings. The magnetic field manipulates the non-Newtonian effects of the MR fluid to change the stiffness of the suspension system. This concept can be implemented for vibration control applications from automobiles to railway vehicles and civil structures. This system can be used in modern anti earth quake building base construction.

Keywords: Adaptive Suspension System, IR Sensor, Magneto-Rheological Fluid (MR Fluid), MR Fluid Damper System, Ultrasonic Sensor

1. Introduction

The objective of this study is to create a suspension system that can adapt to any road condition. To achieve this, we plan to use a suspension system driven by MR Fluid. MR fluid is a smart fluid commonly uses any hydraulic oil as a carrier fluid with appropriate stabilizers, surfactants. In the presence of a magnetic field, the viscosity of the fluid increases proportionally thereby becoming a viscoelastic solid. The most significant use of this property of the fluid is that its yield stress can be manipulated precisely by varying the magnetic field intensity as shown below in Figure 1.

In this proposed damper system application, MR fluid is used as the hydraulic oil instead of standard SAE oils. Also, the channel through which the MR fluid flows through inside the damper is surrounded by an electromagnet. After this is incorporated, the result is a Magneto-Rheological Damper.

For the smart adaption[1,2], ultrasonic transceiver is used which consists of an ultrasonic wave generator and receiver. The ultrasonic wave generator generates the sound waves which are transmitted to a particular distance assuming the surface to be flat. The time is taken for the reflected wave to be detected caught in the reference or base time. If there are any irregularities on the surface, the time required for the reflected wave to be detected obviously changes[2,3]. Based on the time difference, we change the stiffness factor of the suspension system.

The sensor readings are in turn used to generate pulse width modulated signals. This signal is given to the base of a Bipolar Junction Transistor (BJT). This PWM signal will in turn modulate the output current from the collector

*Author for correspondence

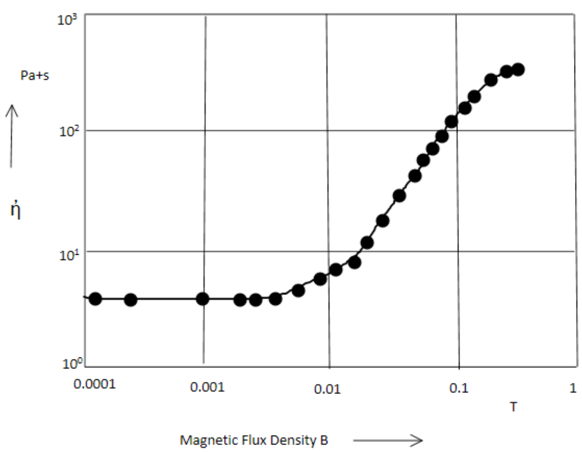

Figure 1. Response of MR fluid.

which is given to the electromagnet. So basically the BJT will essentially act as a switch. Its main use is to control the power supplied to the electrical devices (which in our case is an electromagnet). The concept of PWM is based on manipulation of the Duty Cycle. Duty cycle is the ratio between the ON time and the regular interval of time (T_{on} and T_{off}).

Without knowing the velocity of the cycle, it would not be practical to know exactly whether the vehicle has gone past the road disturbance. Therefore, we use a speed sensor which works based on the principle of optical encoding through which, we determine the duration for which a particular damping co-efficient has to be maintained[5]. If the speed of the vehicle is high, the duration is relatively lower, which establishes an inverse relationship between the variables.

2. Hardware

2.1 MR Damper Design

This is a mono-tube MR damper that has only one reservoir for the MR fluid. The entire suspension system had to be designed within a length of 150 mm, since the bracket to bracket length available in the cycle was at the maximum half a foot. Almost a good third part of the stroke length or action of the damper had to be sacrificed for the introduction of magnetic flux in the cylinder. This meant that the stroke length of the damper had to be kept within 25 mm to meet the requirement[6–8]. Therefore, the damper must simultaneously function as an electromagnet too. For incorporating this feature, the piston head had to be redesigned (Figure 2); instead of having a conventional solid piston head, it was designed like a spinning wheel around which the electromagnet's coil had to be wound. Had there not been any more constraints attached to our hydraulic cylinder, it would have been simple to fabricate[6,7].

The purpose to be served by this cylinder was that of a shock absorber, so within a limited inner diameter of the cylinder, multiple through holes in the piston head had to be bored to facilitate the flow of MR fluid (Figure 3) within the cylinder on either side of the piston. Instead of this reason, the plunger rod's diameter had to be limited to 16mm. Giving a clearance of 2mm on one side of

Figure 2. Piston with electromagnet.

Figure 3. MR DAMPER

the plunger rod amounting to 4mm to the diameter of the piston, the four through holes of 5mm diameter each had to be milled. A clearance of 4mm was given surrounding the oil passages to allow the fluid to pass through without wetting the inside of the winding. The diameter worked with until now amounts to 34mm.The cylinder head's width was designed to be 30mm, but a compensation had to be made for the grooves to be made for the placement of oil seals. The top oil seal's sleeve had to be thicker at 4.5mm and the bottom oil seal's sleeve was 3mm thick (the reason behind which is explained later). So the sufficient length to wind the coil in a single layer was eventually 22.5mm.

Using 26-gauge wire which has a wire diameter of 0.43mm, the number of turns in a single layer of winding proved to be approximately 50. In order to achieve 1200 turns, 24 layers consisting of 50 turns each had to be wound, resulting in an efficient coil thickness of 12-13mm, overall piston diameter of 47mm approximately. To accommodate at least 100ml of MR fluid and to prevent any contact of the coil with the walls of the cylinder, the cylinder was designed with an inner diameter of 50 mm. To avoid the loop from getting wet by the MR fluid and interfering with the work of the coil, oil seals are inserted on both edges of the piston. Winding the coil around the core (cylinder) is achievable but drawing the two leads of the coil outside to connect to the external supply like battery proved to be quite challenging. First of all, we had to use a hollow 16mm plunger rod to draw the wires out, then to draw out the first lead (the end that must be drawn out before commencing the actual process of winding), a hole had to be milled through the 34mm diameter part of the piston leading to the hollow of the plunger rod. Drawing out the second end (one after the complete winding is done) required that one end of the sleeve of the top oil seal was deliberately made to be thicker. A portion of that was ground so that after inserting the coil through the hole, the enamel coating does not get damaged due to abrasion with the walls of the cylinder.

A 0.68mm drill was used to drill a hole centrally in the grounded portion, such that it too leads to the hollow of the plunger rod. The damper was fabricated such that it looks like a cylinder with one end sealed and the other end would be opened whenever any troubleshooting needs to be performed (lid and cylinder with mating threads), an O-ring was placed at this junction to prevent MR fluid from leaking. Also during the compression and expansion stroke of the damper, MR fluid would leak from the gap between the inner walls of the cylinder's lid and the sides of the plunger rod, so an oil seal (washer type) was strongly bonded to the outside of the lid holding tightly against the sides of the plunger rod. A hole was drilled on one of the sides of the top bracket to allow the leads were coming out from the plunger rod to be able to connect to the power BJT and the external battery.

Now to achieve the damper in spring model, a plate with a peripheral groove big enough to accommodate a compression spring with an ID of 62.5mm was designed to hold the spring's top part against the screw type top bracket attached to the plunger rod. Coming to the design of the spring, a spring with a stiffness of 220 N/mm was to be used, according to the proportionality relating the various parameters that affect the stiffness, whenever the external diameter of the entire spring is increased proportionally the wire diameter of the spring has to be sufficiently increased to compensate to keep the stiffness constant.

So, the wire diameter came out to be 9mm for the given stiffness and an internal diameter of 62.5mm. Further, to fine tune the stiffness offered by the spring dynamically after fabrication, circular threads were created in the bottom half of the outer surface of the damper's body, and mating threads were tapped on the internal surface of a ring with a thickness of 10mm so as to support the bottom part of the spring. In this way, by changing the magnitude of pre-stress applied in the spring, the smoothness in the action of the suspension system is varied.

2.2 Hardware Components

The other components used to realize our concept are as follows:

1. HC-SR04 Ultrasonic Transceiver
2. IR Transceiver Module
3. Arduino Uno Microcontroller
4. 16x2 LCD
5. Power BJT

In the system, Arduino board is used as the primary controller. Since Arduino is relatively inexpensive and compatible with many of the modules, programming with Arduino is easy. The Arduino board in the system is the Arduino Uno.

Infrared sensor module is used as a part of speed measurement (Figure 4). The rotations of the wheel per second are calculated by subjecting the IR light against the wheel reflectors attached to the spokes of the wheel. The range of the IR transceiver is adjusted using a potentiometer. The

IR module has 3 pins – VCC, ground and Digital output. In the system, the Digital output pin is attached to pin2 of the Arduino[5]. The output readings are shown using LCD like the PWM signal values, the speed measurement from the IR sensor and the distance measurement from the Ultrasonic sensor (Figure 5).

The ultrasonic transceiver functions as the road profiler (Figure 6) based on which we vary the damping constant[9,10]. The Module automatically sends eight 40 kHz pulsed signals and detects whether a signal received. Once the signal is received, an echo signal is generated by this module. The pulse width of this signal gives the measured distance.

Measured distance = [high level time*velocity of sound (340M/S)] / 2

PWM signals from the controller are sent to the base of a power BJT. Therefore, this power BJT acts both as an amplifier (magnifying the input current which is in milliamperes to amperes) and as a switch in our circuit and thereby helping us realize the concept of PWM using analog signals[11]. In our case, the analog signal is the current supplied to the electromagnet that is part of the MR damper (Figure 7).

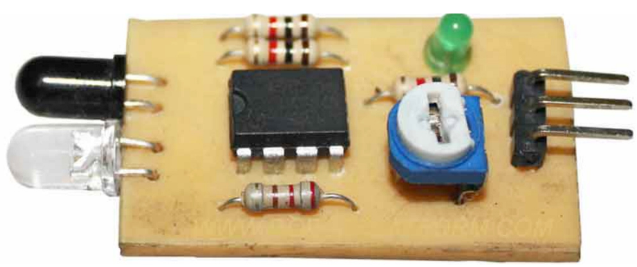

Figure 4. IR Transceiver module.

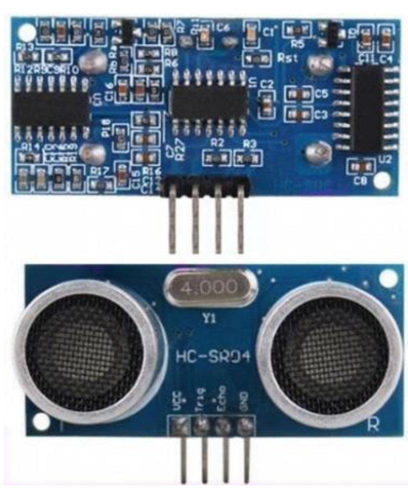

Figure 5. Ultrasonic transceiver.

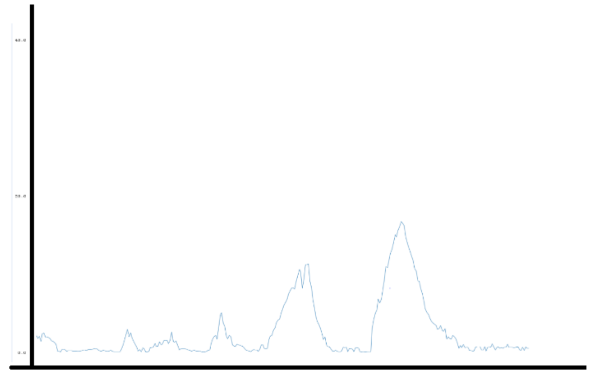

Figure 6. Sample road profile.

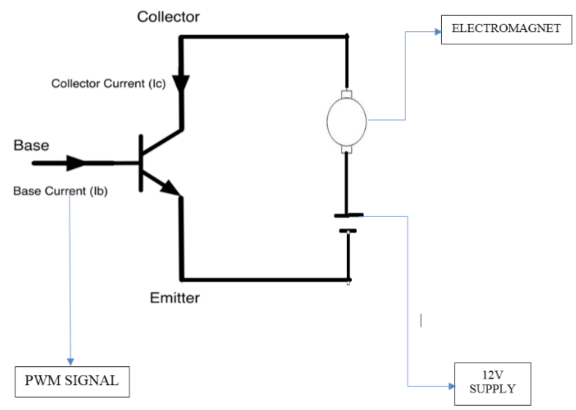

Figure 7. Incorporation of power BJT in the circuit.

3. Algorithm

Initially, the pins and variables used are declared. For instance, 'i' is a variable used during run time which helps in identifying the maxima of a road disturbance. This is done by using a simple bubble sort technique[12,13]. This is an easy and efficient way as no memory storage is required during the process even though this deals with the previous readings. Also, only the magnitude of road disturbance is considered as the initial variable 'distance' is modified to 'distance2' by taking the absolute value. So, it does not matter whether the disturbance is a ditch or a bump. Simultaneously, the IR transceiver is also active, which not only computes the instantaneous speed of the vehicle but also aids in the calculation of the time 't' which is given by the DELAY sub-routine(Figure.8). The variable 'i' is reset to zero once a flat surface is detected. But this is not reset immediately because 't' is to be given as the delay time so that the entire cycle crosses the road disturbance. The distance being constant, as the speed is higher, the magnitude of 't' is lesser and vice-versa. The ultrasonic sensor's range is between 2 and 450 cm, which is then scaled and rounded off between 0 and 255 which is the PWM output range. Based on the value of variable 'i', a PWM output is given which ranges between 0 and 255. The value 255 is assigned when the road disturbance is less than a centimeter in magnitude, and the value is reduced depending on the increase in the magnitude of the road disturbance to soften the suspension.

The flowchart of the Arduino code used to realize our concept of dynamically varying the damping coefficient is shown in Figure 8.

4. Conclusion and Future Enhancements

This semi active suspension system was aimed at reducing the vibrations felt by the passenger due to the irregularities in the terrains to be traversed. After referring to various papers and journals, researching about various possible and concepts that are suitable for being implemented at an undergraduate level, the initial phase of our project was commenced, wherein the several components pertaining to the final system realization was procured. This had to be done keeping in mind several constraints like complexity in implementation, cost, compatibility with a controller and the knowledge base surrounding the particular components.

Next, the concepts involved behind the working of the suspension system was logically realized in the form of Arduino coding. Then the integrated working of all the electronic components like the sensors, switching devices and realization of various concepts like PWM, optical encoding (used for speed sensing) was tested, troubleshot and improved upon. After the damper was designed and fabricated, with the MR fluid filled and functioning as the hydraulic oil, the hardware, and software integrated working was tested, results were worked upon and perfected.

This project as explained above due to various constraints turned out to be a fruitful and proper working prototype which can be worked upon in the future, improved and developed for greater purposes.

Due to the high pricing of MR fluid damper, we had to compensate that with a relatively lower cost vehicle model. The bicycle was thus chosen as the vehicle design (Figure 9). Considering all possible means of detection, we preferred to go with the ultrasonic sensor because we are a little more comfortable and familiar with ultrasonic sensor than other alternatives which might be more efficient. The Controller used is Arduino UNO Controller, which is compatible with most of the interface modules

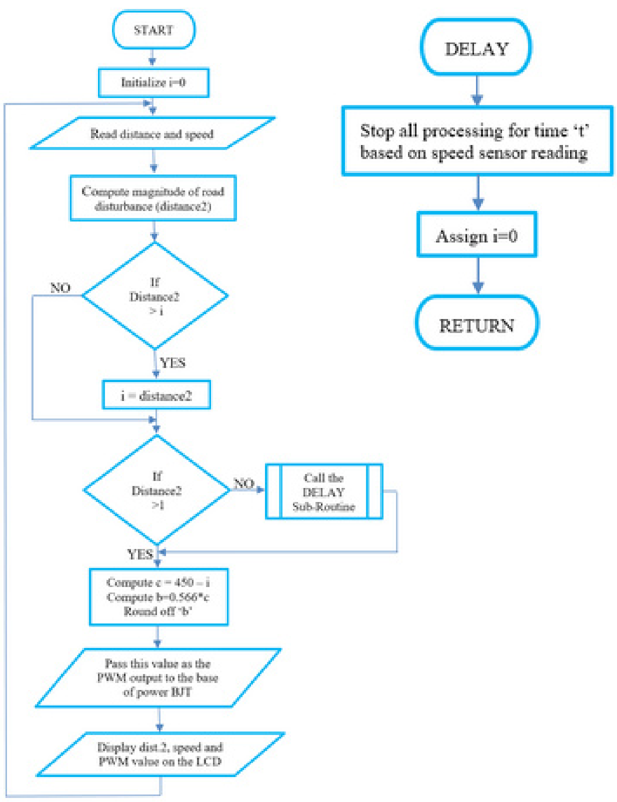

Figure 8. Flowchart.

Figure 9. Final setup of the system.

and is relatively easier to program compared to other Microcontrollers. The Ultrasonic sensor had to measure the distance from the disturbance in advance so that the MR Damper could react in response to the measured distance. So it had to be attached to a rod and placed vertically so that the computation is easier, as we get the depth of the road disturbances directly. The system only compensates for the road disturbances. Therefore, this can be enhanced by also compensating for various payloads too. This prototype can be extended to bigger and faster moving vehicles like cars by utilizing sensors with greater accuracy, resolution and precision and control algorithms can be incorporated into the HCU's which have higher processing speeds.

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