NUST SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING

Modeling, Analysis and implementation of control technique in active suspension system

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Student's Declaration

We hereby declare that the work in this project is our own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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Abstract:

The purpose of this project is to design and simulate a semi-active suspension system for a quarter car models by controlling two input, spring stiffness, k_s, and damper rate, bs. The performance of this system will be compared with the passive suspension system. There are two parameters to be observed in this study namely, the sprung mass acceleration and the suspension distortion. The performance of this system will be determined by performing computer simulations using the MATLAB and SIMULINK toolbox. For the first experiment, the damper rate was set to constant while spring stiffness was set at 373N/m. Increases in damper rate improve the ride quality but slower roll-off will occurred. In the third experiment, the damper rate value was set to maximum while spring stiffness was set constant to achieve optimal performance. The simulation results show that the active system could provide significant improvements in the ride quality and road handling compare with the passive system.

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List of Symbols

M1= mass of the vehicle plate

M2= mass of wheel plate

K1= suspension spring constant

K2= Tire spring constant

b1= suspension damping constant

f= actuator force

w= road disturbance

x1= vehicle plate displacement

x2= wheel plate displacement

CHAPTER 1

Introduction

Suspension systems play a vital role in providing comfortable and safe vehicle ride. The main concern in vehicle design is to develop a system that reduces overall effect of the disturbances that arises not only due to the quality of road, but also due to the driving conditions. Suspensions have been a main concern in the automobile design because of the ever-increasing demand of the customers for comfort, luxury, control and stability within a single vehicle. In past, mechanical designs were altered to cater the needs of the customers. But, as the technology started to advance; new techniques were involved which included variable damper characteristics.

Variable viscosity fluids were used in the dampers which vary in viscosity in accordance to the vibrations produced. With the arrival of computer systems, the automobile industry started focusing on development of quick – responding and intelligent suspension systems. This development put forward the new category of active suspension system that is now one of the most researched areas in automotive industry. Different controllers are being designed and proposed now in this regard to develop new suspension systems with enhanced features.

This project is about the design of controller of quarter car model using suitable suspension system of bikes and practical implementation to obtain desirable results.

1.1 Problem statement

The suspension systems which are commonly used in the vehicles are called passive suspension systems. This system is not capable of giving high performance because its overshoot and settling time are far greater and undesirable. To overcome this problem, active suspension systems are introduced.

1.2 Objectives

- Modeling and Analysis of a suspension system for quarter car model.
- Integration of controller with physical suspension system.
- Testing of manufactured controls system on different road profiles.

1.3 Scope of the project

Due to the high level of competition in automotive industry, demand for safety and comfort is increasing while development time and costs need to be reduced. However, performance is also an important actor next to safety issues. An electronically controlled suspension system can be very helpful to fulfill the requirements of safety, comfort and performance.

CHAPTER 2

Literature review

A literature review has been carried out with reference from different books, journals and thesis. This chapter includes all the information relevant to this project. Active suspension and the problem solving procedures are explained as well.

2.1 Background

A suspension system is a fundamental part of vehicle which acts as a bridge between the tire and the vehicle. The basic function of this bridge is to hold the vehicle above the road and to provide a maximum protection from irregularities of road. The capability of holding the vehicle above the road is called suspension.

If there is no suspension between the vehicle and the tire then vehicle must be directly connected to the tire assembly which will cause severe discomfort to the passengers and the fatigue level to vehicle structure will be very high as well. Essential capacity of suspension system is to disconnect the vehicle body from the tire assembly in order to minimize consequences arising from the irregularities of road. With the advancement of technology, modern age vehicles arouse the need of systems which could provide sufficient road handling. The requirement now is to design a system which could retain energy of the wheel and provide smooth ride without any disturbance.

2.2 Basic tasks of suspension system

The whole function of suspension system is subdivided into two sub-tasks from vehicle dynamics point of view:

- **Ride**: A vehicle’s capacity to ride smoothly on road
- **Handling**: A vehicle’s capacity to securely undergo acceleration, braking and cornering

2.2.1 Road holding

Road handling is the phenomenon of ingesting road shocks from the vehicle’s compartment. This target is achieved by absorbing energy from the wheels and scattering it without creating any imbalance between tires.

2.2.2 Road handling

It is the level to which road administers contact with the road in different scenarios i.e. during braking, acceleration and the shift of vehicle’s weight between front and rear tires. The aim is to keep tires in good contact with grounds. This is achieved by minimizing exchange of weights of on all four sides of the tires, as exchange of weights diminishes the gripping power of tire while it moves.

2.2.3 Cornering

This term refers to the capacity of a vehicle to travel on a bended way. The main objective is to minimize the roll of the body, which happens as diffusive energy pushes outward on a vehicle's gravity center while the vehicle moves around a corner, thus one side of the vehicle is raised up which brings down the other side. This is done by exchanging the weight of the vehicle throughout cornering processing from high side towards low side.

2.3 Vehicle suspension components

A vehicle suspension is made of two parts spring and damper. Their functions and the specifications are described below:

2.3.1 Spring

A sprung mass is the mass of vehicle supported above the suspension. In this case sprung mass is the vehicle's mass. Unsprang mass is the mass between road and the spring. A vehicle having low spring stiffness can easily ingest the shocks and provide smooth rides. Tightly sprung vehicles, for example, sports vehicles, are uncomfortable on uneven streets, however they reduce vehicle movement well, which implies they might be driven forcefully during turning.

In this way, springs without anyone else's input appear as though straightforward apparatuses, planning and actualizing them on a vehicle to adjust to traveler comfort with is a mind boggling task. Furthermore to make matters more troublesome, springs alone cannot furnish a superbly smooth ride. The reason behind is the fact that springs are incredible at retaining energy, however not very great at dispersing it. Different structures, reputed to be dampers, are obliged to do this.

2.3.2 Damper

A vehicle spring will expand and discharge the energy that it retains from a knock at a rate which is uncontrollable. The spring will maintain its oscillations with natural frequency until greater part of the energy initially put into it is utilized. A suspension solely made from springs alone might make for a great degree of bumpy ride and, contingent upon the territory, a vehicle that is uncontrollable. But a damper controls unnecessary spring movement through dampening process. Dampers back off and lessen the size of oscillatory movements by transforming the active energy of suspension development into heat that could be disseminated by the use of hydraulic fluid. A damper is essentially an oil pump set between the vehicle body and wheels. The upper end of the damper is linked with the vehicle body (sprung mass).The lower end of the damper is linked with the axel in close proximity to the wheel (unsprang mass) .

When the vehicle wheel experiences a hindrance and results in the spring to undergo extension and compression, the spring energy is exchanged to the damper through the upper link, piston rod and then it goes in the piston. The piston has an orifice in it and permits fluid to release when piston moves. Since the openings are generally little, just a little measure of fluid, under incredible pressure flows. This eases off the cylinder, which thusly backs off the spring.

Dampening process has two working cycles which are compression and extension cycles. When piston moves in descending direction; it leads to the compression of fluid in the compartment underneath the piston. This cycle is known as compression cycle. When the piston moves in the ascending direction; it leads to the compression of fluid in the compartment which lies above the piston. This cycle is known as extension cycle. An average vehicle will display more safety throughout its extension cycle. On account of that, the movement of the unsprang mass is determined by the compression cycle whereas, movement of the sprung mass is determined by the extension cycle.

2.4 Classification of Suspension system

2.4.1 Passive suspension

A passive suspension system is one in which the characteristics of the components (springs and dampers) are fixed. These characteristics are determined by the designer of the suspension, according to the design goals and the intended application. Passive suspension design is a compromise between vehicle handling and ride comfort.

Figure 1 (passive suspension)

2.4.2 Semi active suspension system

In this type of system, the conventional spring element is retained, but the damper is replaced with a controllable damper. Semi active system uses external power only to adjust the damping levels, and operate an embedded controller and a set of sensors. The controller determines the level of damping based on a control strategy, and automatically adjusts the damper to achieve that damping.

2.4.3 Active suspension system

In an active suspension, the passive damper or both the passive damper and spring are replaced with a force actuator. The force actuator is able to both add and dissipate energy from the system, unlike a passive damper, which can only dissipate energy. With an active suspension, the force actuator can apply force independent of the relative displacement or velocity across the suspension.

CHAPTER 3

Modeling

3.1 Mathematical modeling

Quarter vehicle model is regularly utilized for suspension investigation; in light of the fact that it is basic and can catch paramount aspects of full model. The mathematical statement for the model movements are considered by including vertical forces on the vehicle body and wheel.

The spring, damper and control force actuator set between the vehicle body and wheel makes a suspension. From the quarter vehicle model, the configuration might be transformed in full vehicle model.

The fundamental center is to furnish foundation to develop mathematical model of quarter vehicle model. The dynamic model, which can depicts the input and output relationship, empowers ones to comprehend the conduct of the system. The reason for mathematical modeling is to acquire a state space equation of the quarter vehicle model. Modeling of a suspension system is done by considering it a linear suspension system. The state variable might be spoken to as vertical movement of the vehicle body and also of the wheels. The passive components will ensure an insignificant level of execution and wellbeing, while the active component will be intended to further enhance the execution. This mix will furnish some level of reliability. The mathematical model of quarter car suspension system is given in figure 2.2.

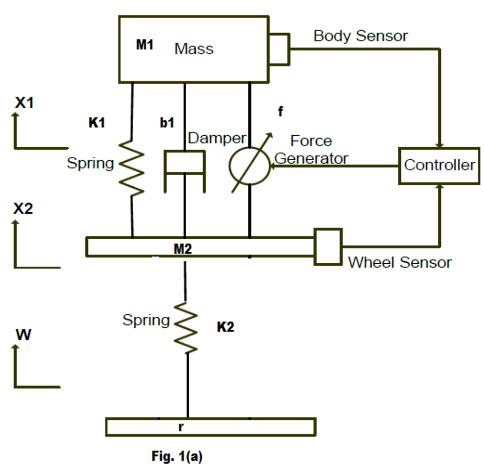


Figure 2(Mathematical model)

Where k1, K2 are spring constants, f is actuating force, x1 and x2 are spring displacements and b1 is damping constant.

3.2 Transfer functions derivation

The two equations obtained from the above mathematical model are:

$$M_1 \ddot{x}_1 = -b_1(\dot{x}_1 - \dot{x}_2) - k_1(x_1 - x_2) + f \qquad 1.1$$

$$M_2 \ddot{x}_2 = b_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_2) + k_2(f - x_2) - f \qquad 1.2$$

The transfer function obtained by solving above mathematical equations is as:

$$G_1(s) = \frac{x_2 - x_1}{f(s)} = \frac{(M_1 + M_2)s^2 + b_1 s + k_2}{\Delta} \qquad 1.3$$

$$G_2(s) = \frac{x_2 - x_1}{w(s)} = \frac{(-M_1 b_1 s^3 - M_1 k_2 s^2)}{\Delta} \qquad 1.4$$

3.3 Modeling in MATLAB/SIMULINK

An exceptional vehicle suspension framework might as well have acceptable road holding capacity, while as of now furnishing comfort when riding over knocks and openings in the street. The point at which the vehicle is encountering any street unsettling influence (i.e. pot gaps, breaks, and rough pavement) the vehicle form ought not to have vibratory motions and the motions might as well disperse rapidly. Since the separation (X1-W) is exceptionally challenging to measure, and the deformity of the tire (X2-W) is insignificant, we will utilize the separation (X1-X2) rather than (X1-W) as the yield in our issue. Remember that this is estimation. The disturbance (W) in road in this issue will be reenacted by a step signal. This step could speak to the vehicle vacating a pothole. Using these limitations, the block diagram can be simplified as:

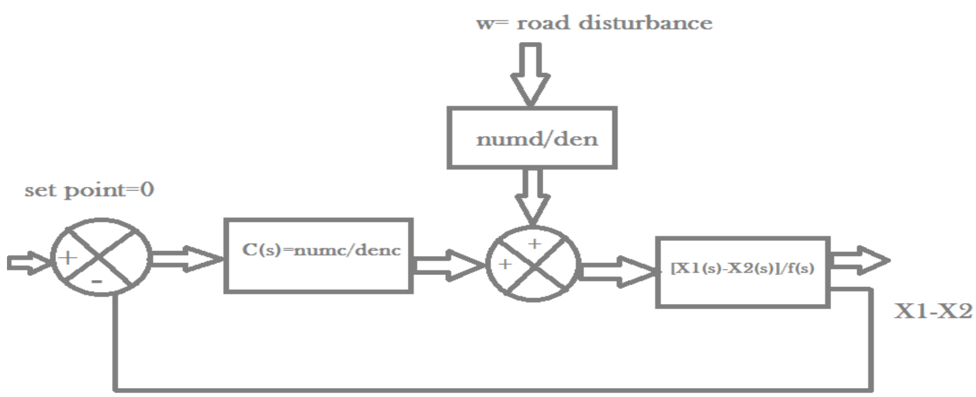


Figure 3 (block diagram)

3.4 Linear Model in MATLAB

A linear model of the system (in state space or transfer function form) can be extracted from a Simulink model into MATLAB. This is done through the use of In1 and Out1 blocks and the MATLAB function linmod. We will extract only the model from the input U to the output X1-X2.

- First, replace the U Step block with an In1 block.
- Also, replace the Scope block with an Out1 block. This defines the input and output of the system for the extraction process.

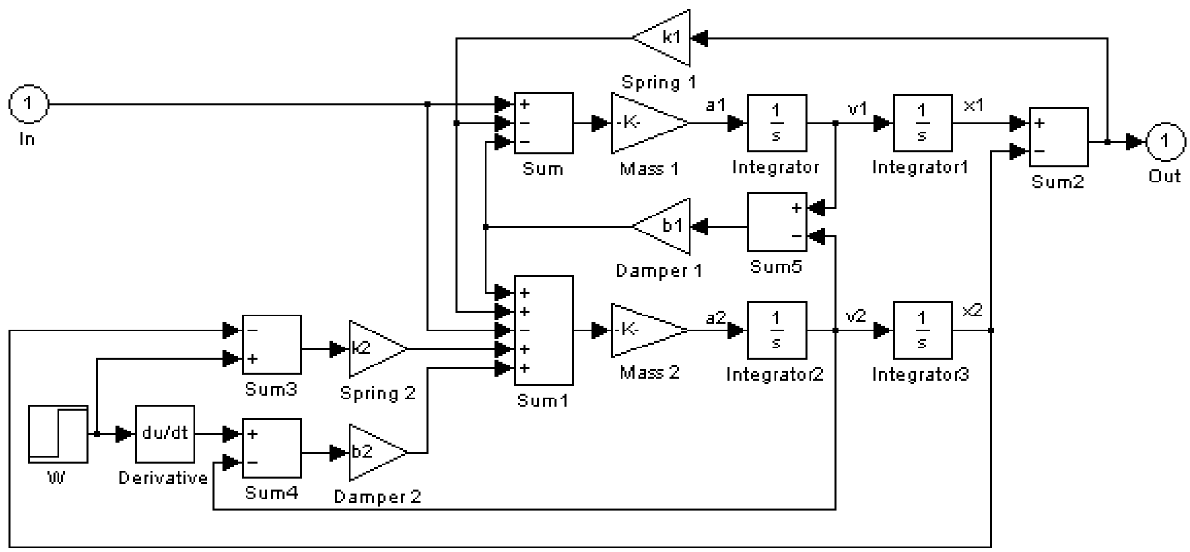


Figure 4 (Linear Matlab model)

To verify the model extraction, we generated an open-loop step response of the extracted transfer function in MATLAB.

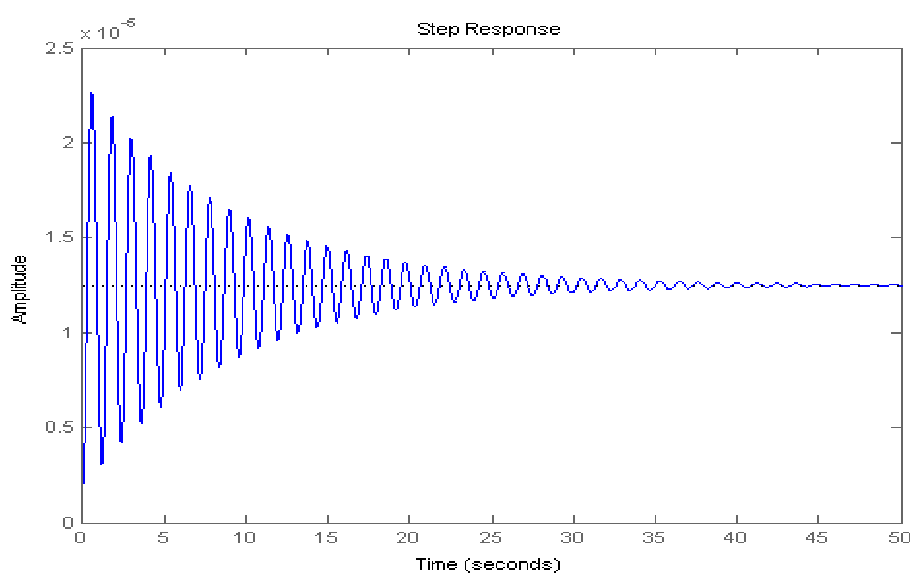


Figure 5 (Open loop response)

3.5 Design Requirements

A good suspension system should have satisfactory road holding ability, while still providing comfort when riding over bumps and holes in the road. When the vehicle is experiencing any road disturbance (i.e. pot holes, cracks, and uneven pavement),the vehicle body should not have large oscillations, and the oscillations should dissipate quickly. Since the distance X1-W is very difficult to measure, and the deformation of the tire (X2-W) is negligible, we will use the distance X1-X2 instead of X1-W as the output in our problem.

The road disturbance (W) in this problem will be simulated by a step input. This step could represent the vehicle coming out of a pothole. We want to design a feedback controller so that the output (X1-X2) has an overshoot less than 5% and a settling time shorter than 5 seconds. For example, when the vehicle runs onto a 10 cm high step, the vehicle body will oscillate within a range of +/- 5 mm and return to a smooth ride within 5 seconds.

CHAPTER 4

CAD Modeling

4.1 SolidWorks model

The CAD model of the suspension system consist of metal plates showing body and tire movement. Four supporting rods are used for balancing of model. One spring and damper is connected between body and tire plates. One spring is connected between tire and base plate showing K2 of tire.

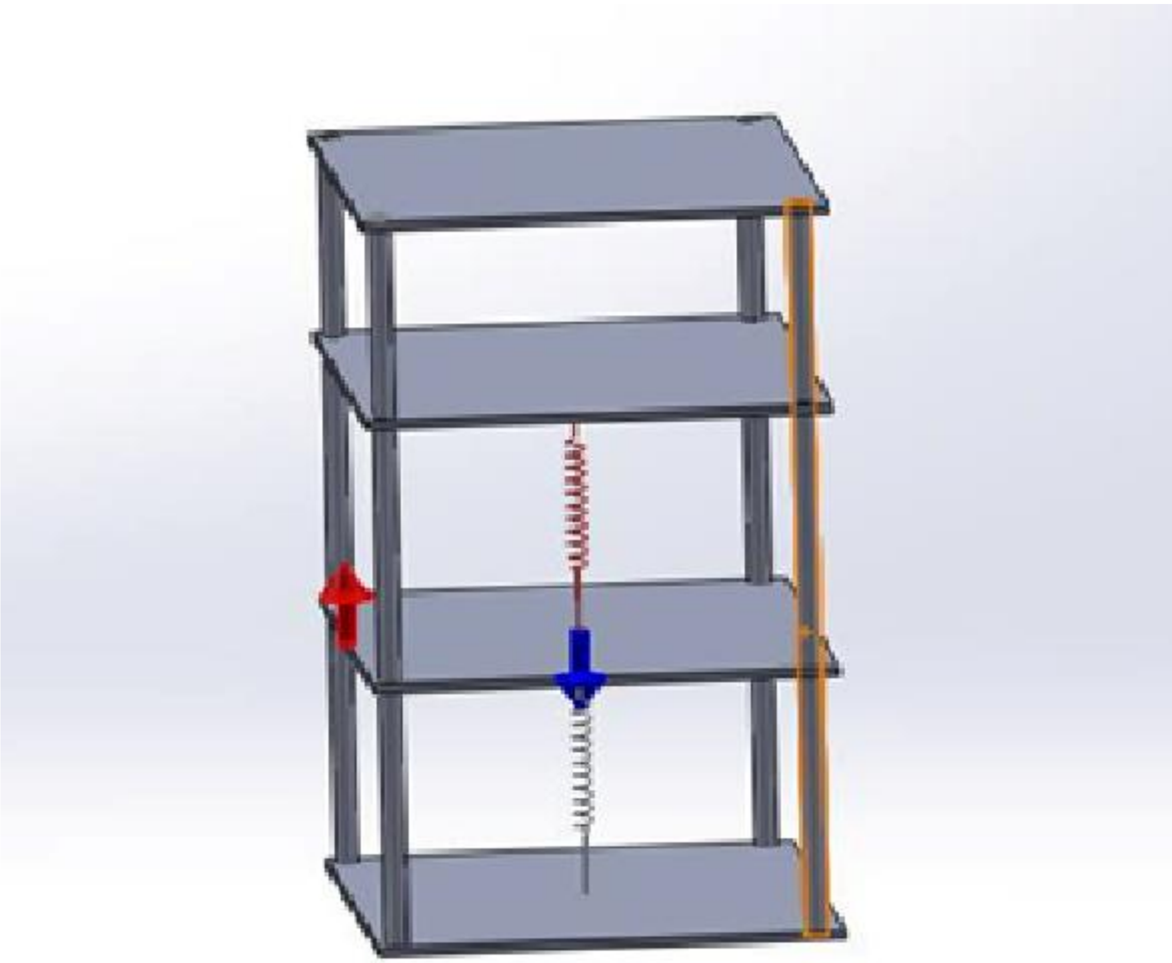


Figure 6 (CAD model)

4.2 Spring specifications

Wire diameter	7mm
Coil diameter	48mm
Loaded (normal load) length	128mm
Effective turn	6.2
Spring constant	372.58N/m

Table 1 (spring specifications)

4.3 optimum values

Rod diameter	14 mm
Vehicle plate size	500x500 mm
Vehicle plate thickness	6mm
Vehicle plate weight	4kg
Tire plate thickness	4mm
Tire plate weight	2.5kg
Tire plate size	500x500 mm
Base plate	500x500, 9kg, 13mm

Table 2 (optimum values)

CHAPTER 5

CAD Analysis

5.1 Stress Analysis

Stress analysis was carried out in solidworks using CAD model components. As the weight of both plates is approx. 6kg so the total amount of force exerted on the vehicle plate is 900N including extra weights which are to be applied during testing. Safety factor is 0.3 and the material is mild steel. Once the motion analysis was successfully completed then stress analysis is carried out. The results of stress analysis clearly depict that plates and rods show no deformation under these loading conditions.

5.1.1 Vehicle plate

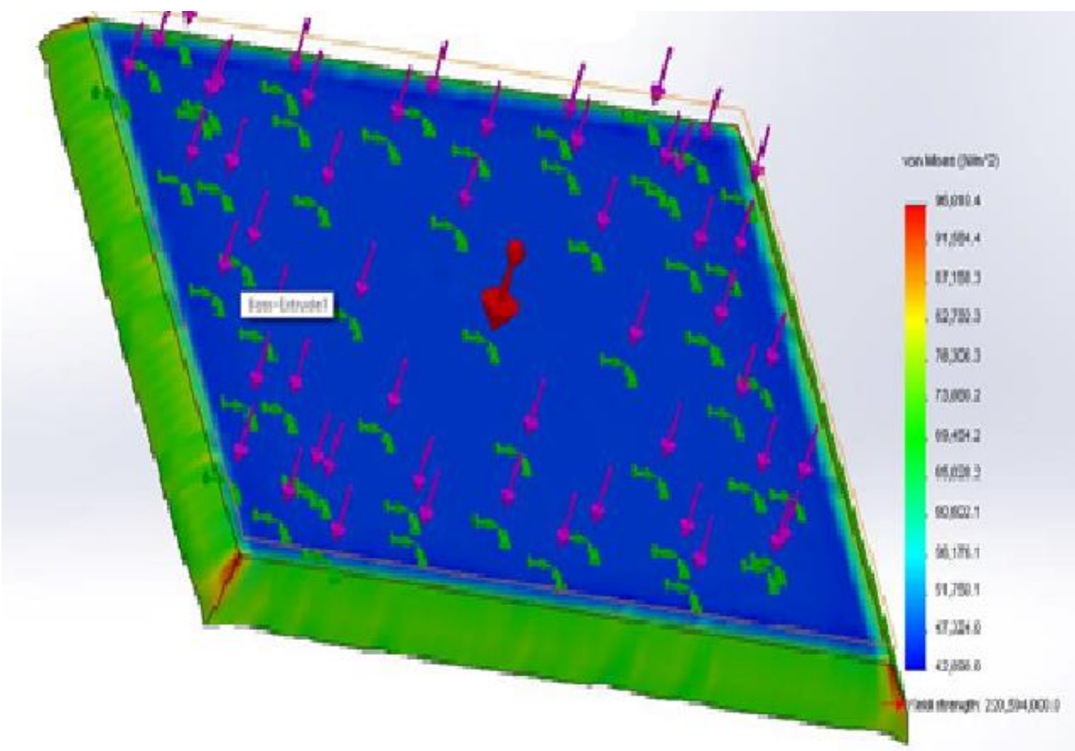


Figure 7 (vehicle plate analysis)

5.1.2 Wheel Plate

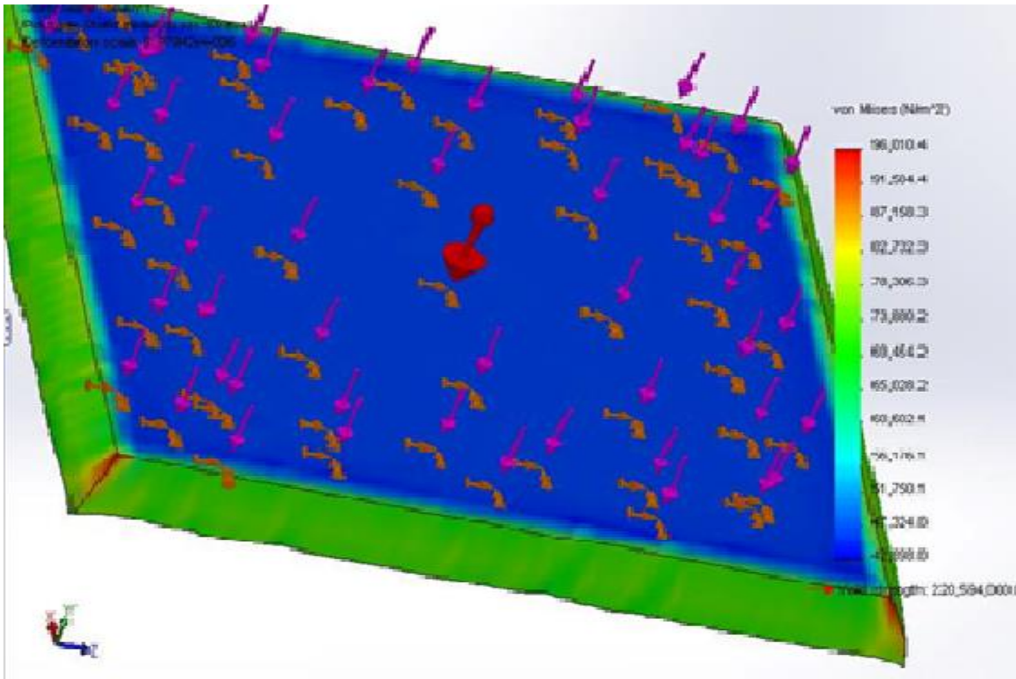


Figure 8 (wheel plate analysis)

5.1.3 Rod

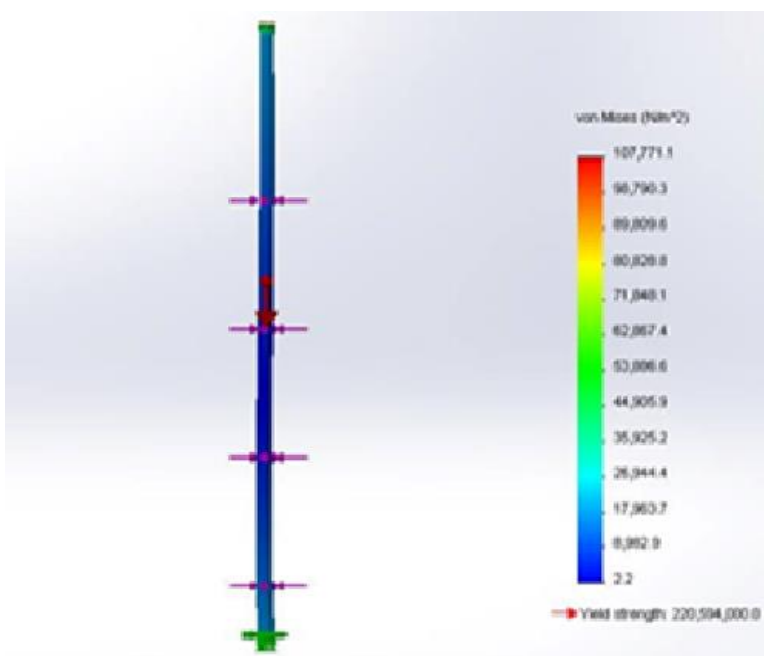


Figure 9 (rod stress analysis)

5.1.4 Mesh of CAD model

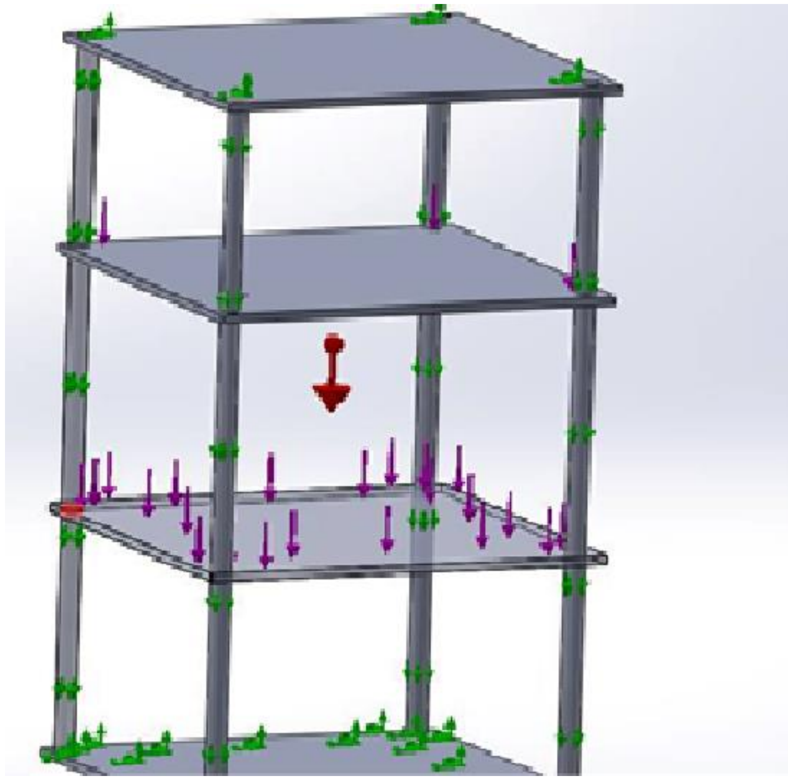


Figure 10 (CAD model mesh)

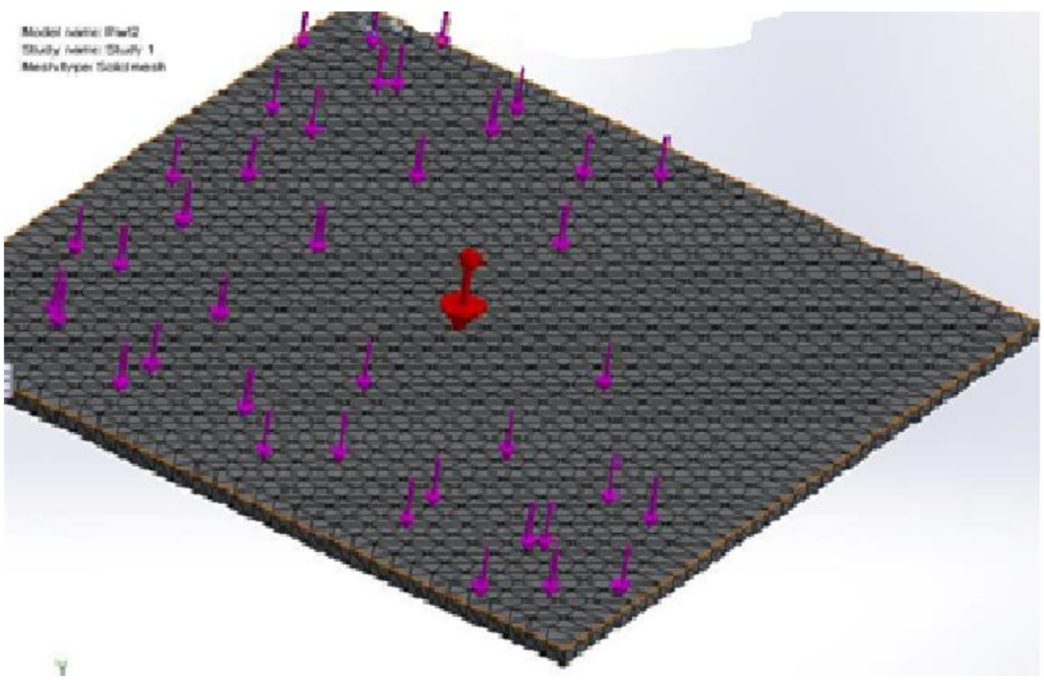


Figure 11 (mesh of plates)

5.2 Motion Analysis

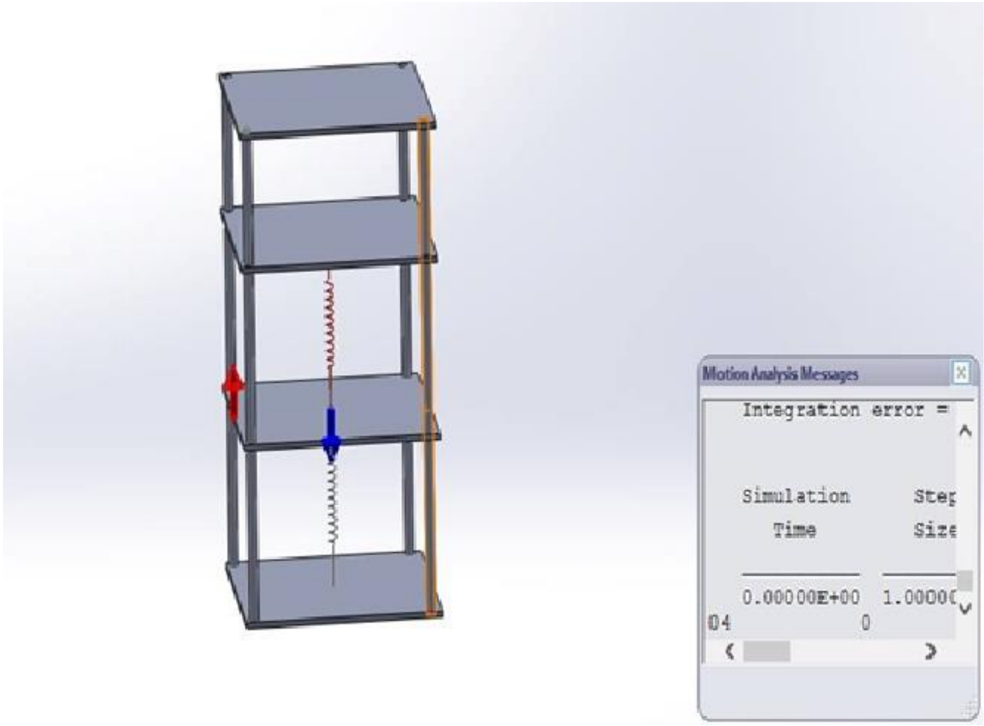


Figure 12 (motion analysis)

5.3 Strain Analysis

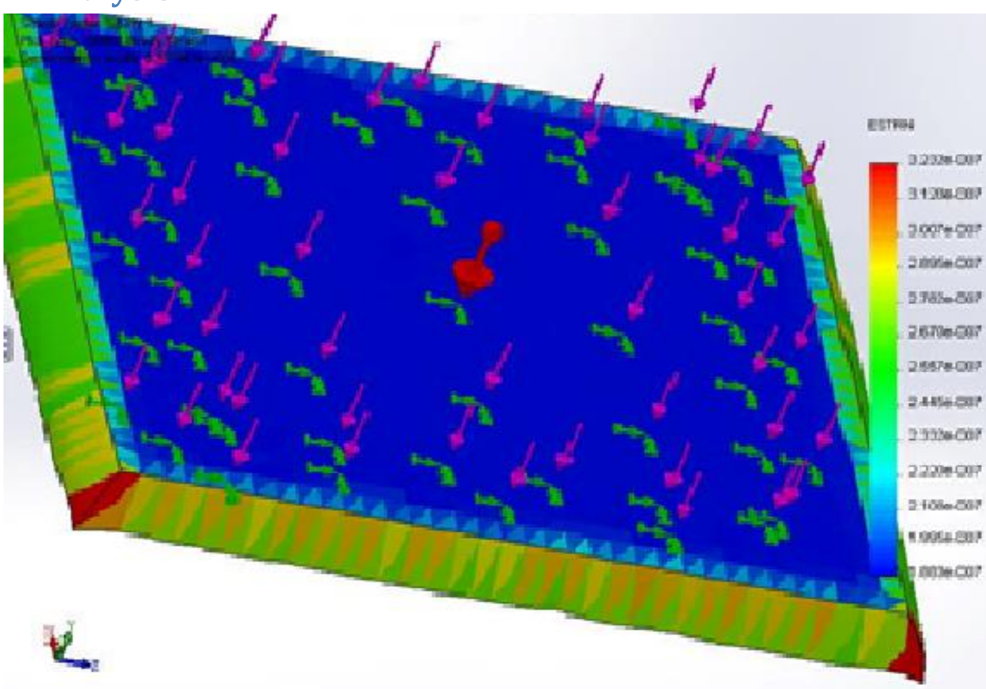


Figure 13 (strain analysis of vehicle plate)

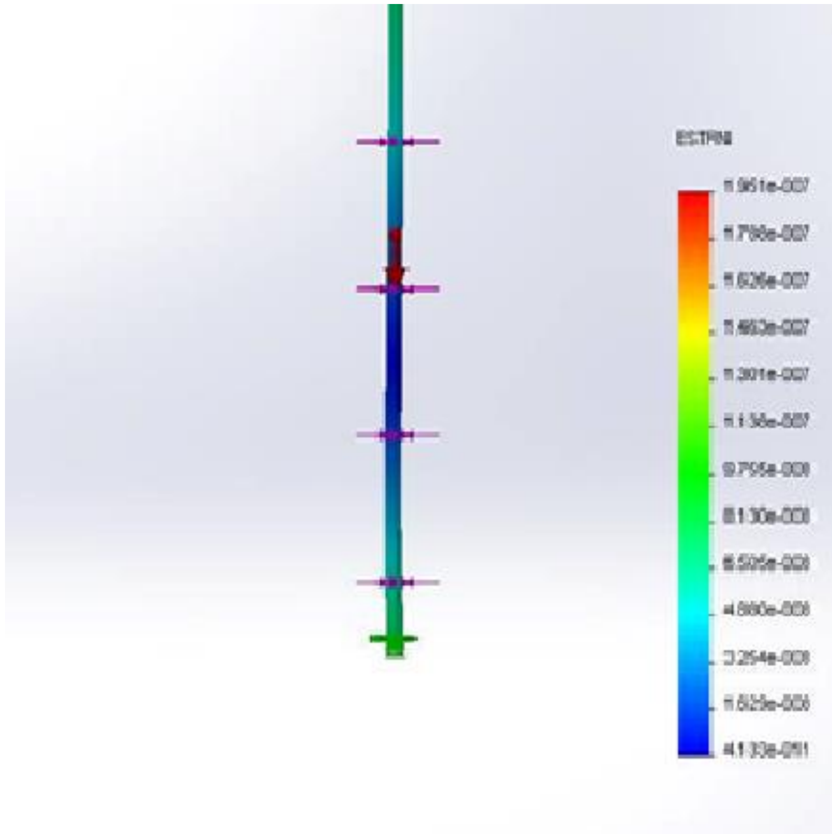


Figure 14 (strain analysis of rod)

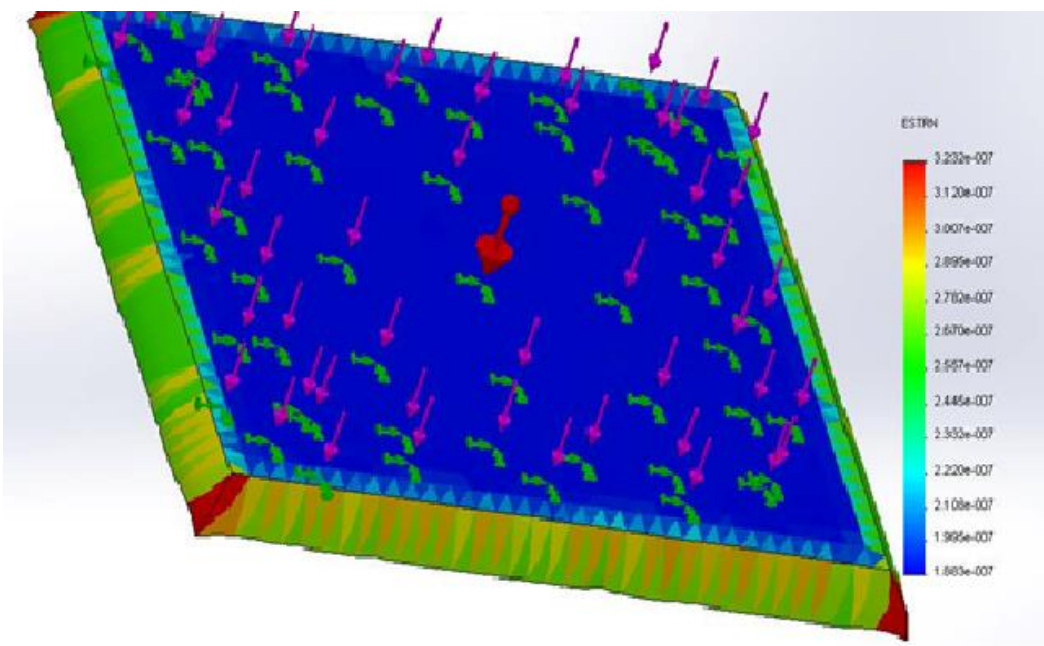


Figure 15 (strain analysis of wheel plate)

5.4 Displacement Analysis

Displacement Analysis results show that maximum deflection in the rod is 1.2005e.008 which is reasonable and does not have much impact on motion of vehicle and tire plates sliding on supporting rods.

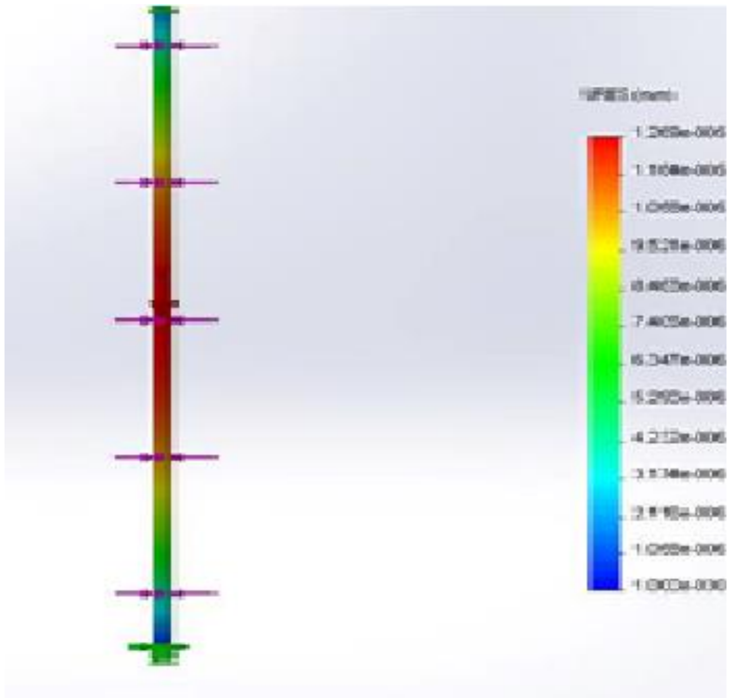


Figure 16 (displacement analysis of rod)

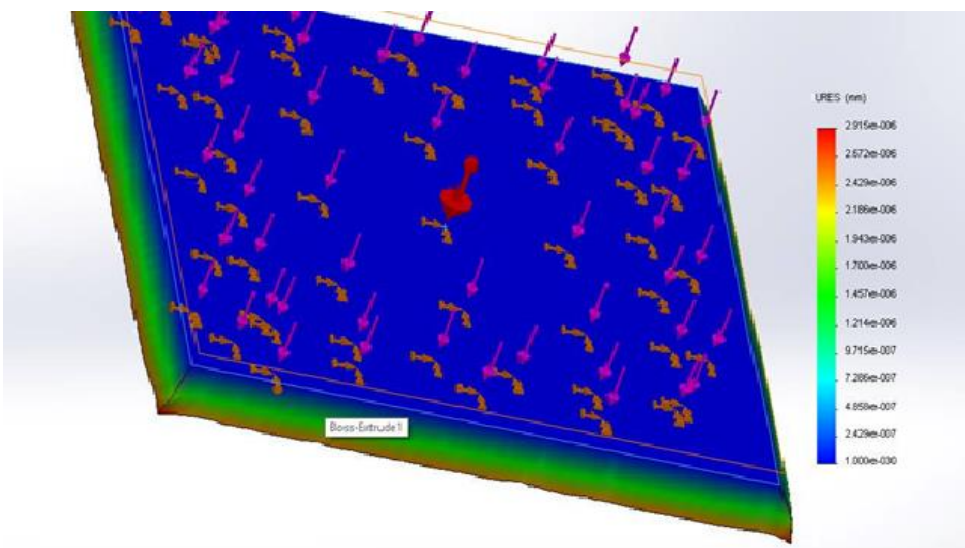


Figure 17 (Displacement analysis of plates)

5.5 Cost Analysis

Weight of base plate	9kg
Weight of vehicle plate	4kg
Weight of tire plate	4kg
Weight of upper supporting plate	2.5kg
Weight of rods	3kg
Total weight	19.5kg
Cost of material	PKR 100/kg

Table 3 (cost analysis)

CHAPTER 6

Implementation of controller

The controller designed in the modeling section can be implemented in numerous ways. For this purpose we have to study the control strategies which can be useful for the implementation of controls system for desired output response

6.1 Controls Strategies

The components used for controls mechanism are:

6.1.1 Hydraulically actuated controls system

In this system, the pressure of oil inside the damper is controlled by using pump which is driven by motor and the motor is actuated by the signals from controller output. It has following components:

- **Actuator (motor)**

The function of motor is to provide power to drive oil pump. It is connected with the controller circuit as shown in block diagram. The output signal from the controller circuit operates the motor to drive the oil pump.

- **Oil pump (centrifugal)**

The oil pump driven by motor provides the pressure which is necessary to increase or decrease the value of the damping force.

- **Mechanism for two way flow of oil through damper:**

The damper used in this project is passive type damper. It will be modified by connecting a mechanism for the flow of oil from inside and outside of it, this mechanism consist of a valve which will be opened when actuator is turned on and it will provide a passage for upward or downward flow of oil.

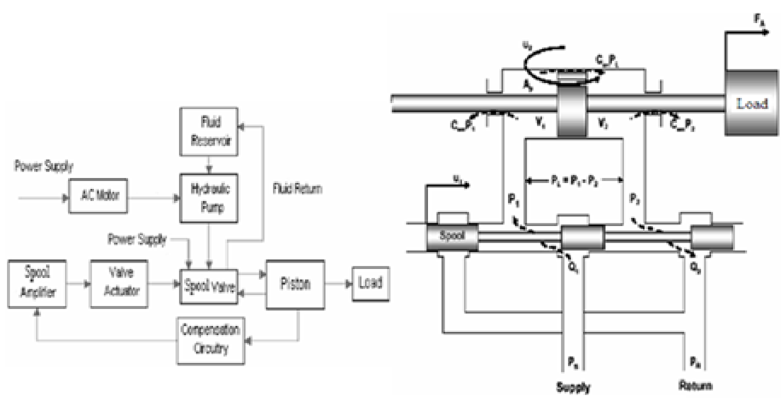


Figure 18 (Spool valve mechanism)

6.1.2 DAQ (Lab View)

In this type of control system, the program for the motor control is designed in MATLAB and the output is controlled directly through Lab View. A data acquisition device is used for the connection of computer program with input of motor.

6.1.3 Controller circuit

The system uses a microcontroller 8051, an encoder motor, an H-bridge circuit, and an SSD board to show the motor's rpm. The H-bridge works to provide 12V, 3A while the microcontroller changes the duty cycle of the motor's revolution. The overall wave frequency being generated by the microcontroller is 200Hz. the microcontroller is mounted on a generic which has LED bar graphs and a oscillating crystal. The code for changing the motor's rpm was written in Kiel and burnt onto the microcontroller using a burner.

These sensors will be connected between the vehicle and suspension support and provide the values of displacements X1 and X2. This output will be used as input for the controller circuit.

6.2 Methodology of implementation

One simple and effective method to control actuator and to monitor feedback is direct interfacing of arduino with sensor using MATLAB/ SIMULINK. Arduino is an open source electronic board which is user friendly and very flexible. It can sense the environment by using inputs from sensor and produce a response according to programme built in SIMULINK. Arduino is made by using microcontroller which is based on arduino programming language. The type of arduino board used in this project is Arduino uno.

6.2.1 Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328.It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

Figure 19 (Arduino Uno)

- **Properties**

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Table 4 (Arduino properties)

- **Power**

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

VIN: The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.

5V: This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.

3V3: A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

GND: Ground pins.

IOREF: This pin on the Arduino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source or enable voltage translators on the outputs for working with the 5V or 3.3V.

- **Input and Output**

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), anddigitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms.

In addition, some pins have specialized functions:

Serial 0 (RX) and 1 (TX): Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.

External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

PWM 3, 5, 6, 9, 10, and 11: Provide 8-bit PWM output with the analogWrite() function.

SPI 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK): These pins support SPI communication using the SPI library.

LED 13: There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

TWI: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.

There are a couple of other pins on the board:

AREF: Reference voltage for the analog inputs. Used with analogReference().

- **Communication**

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. For SPI communication, use the SPI library.

6.2.2 MATLAB library (Arduino I/O)

Arduino board is directly interfaced with MATLAB using Arduino I/O library. This library helps in reading real time data from the system and this data is then processed in SIMULINK and commands are transmitted according to programme. This technique is very simple, effective and economic. Using this technique, cost of implementation is reduced upto 70%.

This approach helps to:

- Start programming right away without any additional toolboxes.
- Work in the MATLAB or Simulink environment for interactive development and debugging.
- Interactively develop programs to acquire analog and digital data, and to control DC, servo, and stepper motors.
- Run control loops at up to 25 Hz.

6.2.3 H-Bridge (L298)

This dual bidirectional motor driver, from Cana Kit, is based on the very popular L298 Dual H-Bridge Motor Driver Integrated Circuit. The circuit will allow to easy and independent control of two motors with current ratings up to 2A each in both directions.It is ideal for robotic applications and well suited for connection to a microcontroller requiring just a couple of control lines per motor. It can also be interfaced with simple manual switches, TTL logic gates, relays, etc. The circuit incorporates 4 direction LEDs (2 per motor), a heat sink, screw-terminals, as well as eight Schottky EMF-protection diodes. Two high-power current sense resistors are also incorporated which allow monitoring of the current drawn on each motor through your microcontroller.

An on-board user-accessible 5V regulator is also incorporated which can also be used to supply any additional circuits requiring a regulated 5V DC supply of up to about 1A.The circuit also offers a bridged mode of operation allowing bidirectional control of a single motor of up to about 4A.

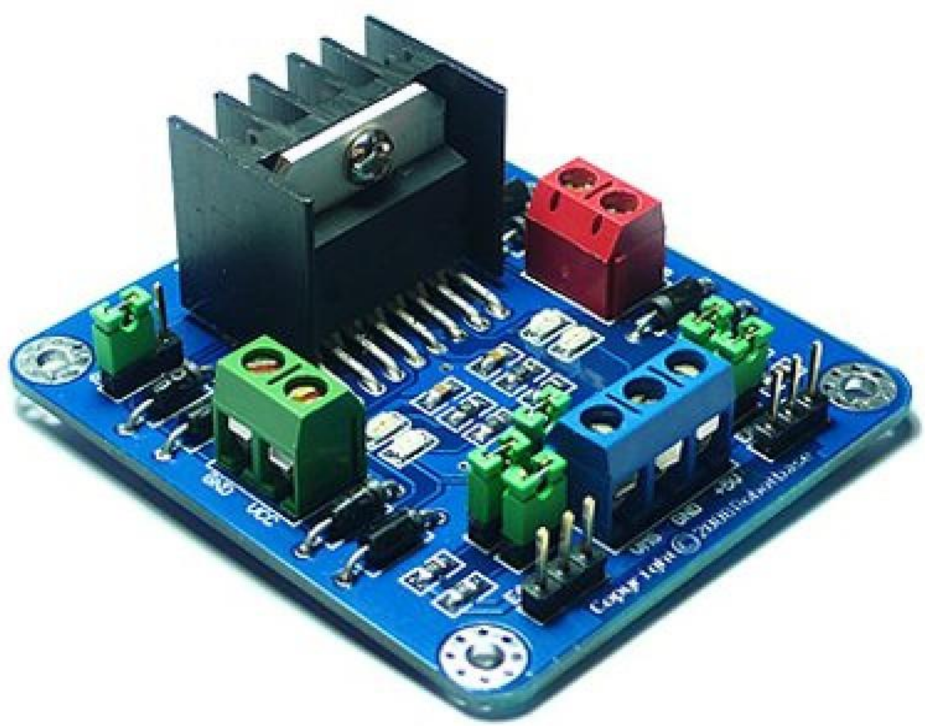


Figure 20 (H-Bridge)

- **Properties**

Motor supply	6 to 35 VDC
Control Logic	Standard TTL Logic Level
Output Power	Up to 2 A each
Current Sense Outputs	✓
Onboard Power Resistors Provided for Current Limit	✓
Enable and Direction Control Pins	✓
External Diode Bridge Provided for Output	✓
Heatsink for IC	✓
Power-On LED indicator	✓
4 Direction LED indicators	✓

Table 5 (H-Bridge Properties)

- **Wiring Diagram**

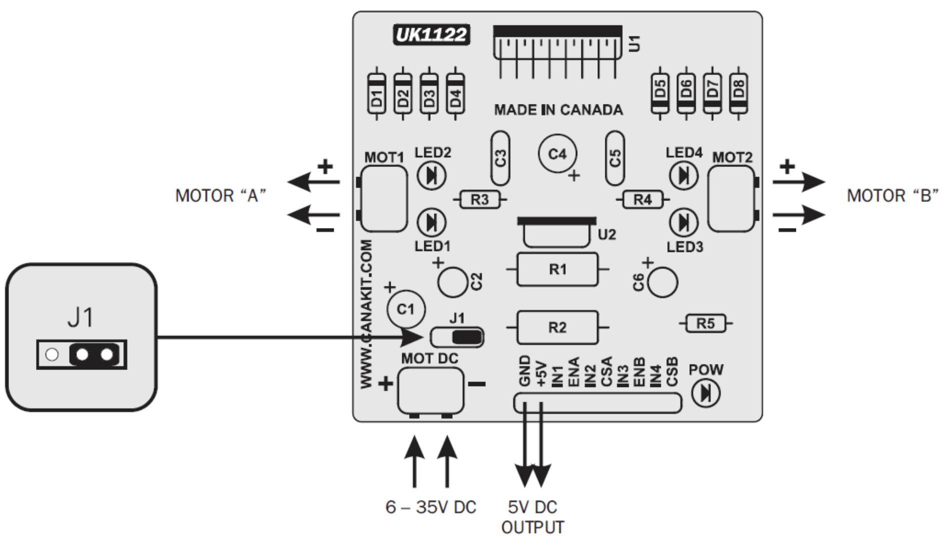


Figure 21 (Wiring Diagram of H-Bridge)

6.2.4 Linear Potentiometer:

A simple slider potentiometer is connected between the vehicle and the wheel plates. Variation in voltage is used as a feedback for the system which is fed to controller and commands are processed accordingly to minimize error. The model used for this purpose is SLV60B10k.

- **Properties**

Resistance Tolerance	± 20%
SVHC	No SVHC
Temperature Coefficient	-
Track Resistance	10kohm
Track Taper	Log (Audio)
Voltage Rating	200V
Adjustment Type	Slider
External Width	16mm
Fixing Centers	80mm
Operating Temperature Max	60°C
Operating Temperature Min	-10°C
Operating Temperature Range	-10°C to +60°C
Series	RS
Termination Type	Solder
Travel	60mm

Table 6 (Sensor Properties)

6.3 SIMULINK Block diagram

- The voltage received from sensor is filtered to put a limit of -24 to 24 v
- The voltage is then compared with zero to check polarity of sensor
- The voltage value is converted to absolute value.

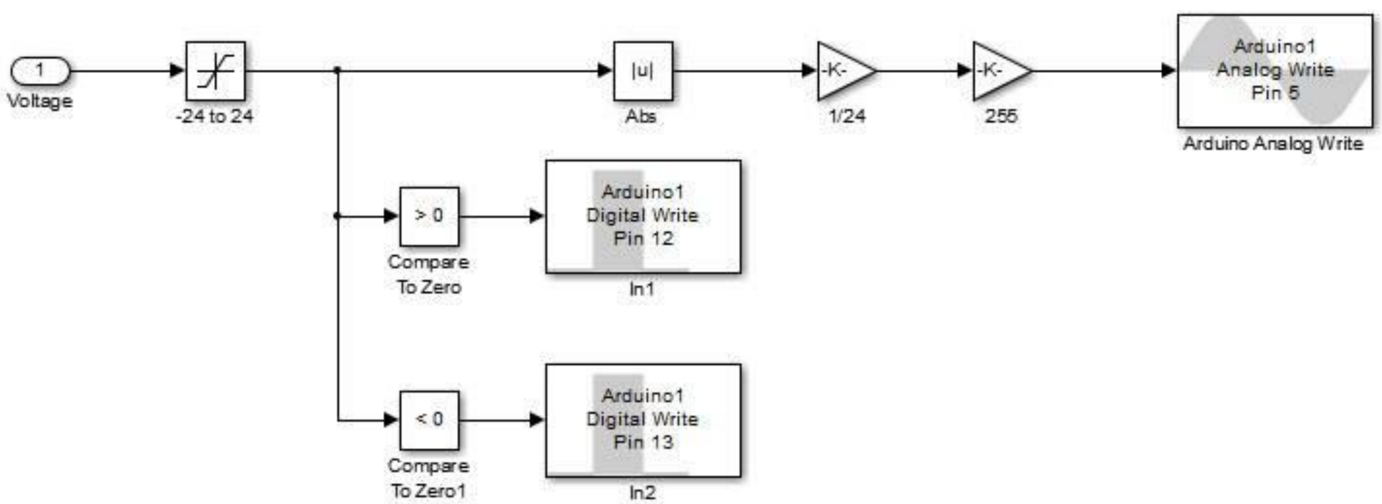


Figure 22 (SIMULINK block Diagram 1)

- The signal received is converted to digital signal.

- The value is compared with error signal of 24 v
- Butter filter is used to remove noise.
- The kp value is set at 1 as increase in kd and ki values increase noise in signal.

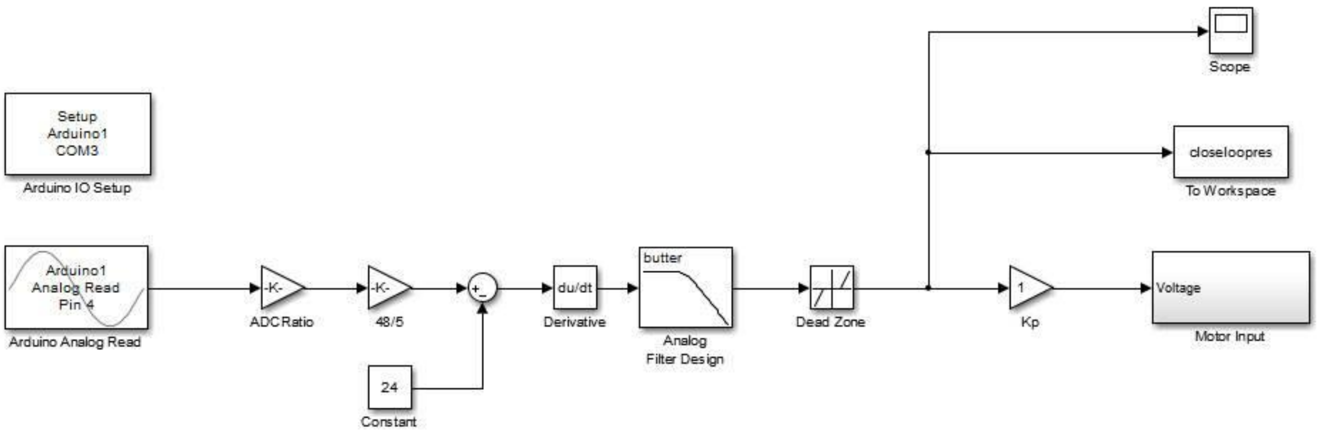
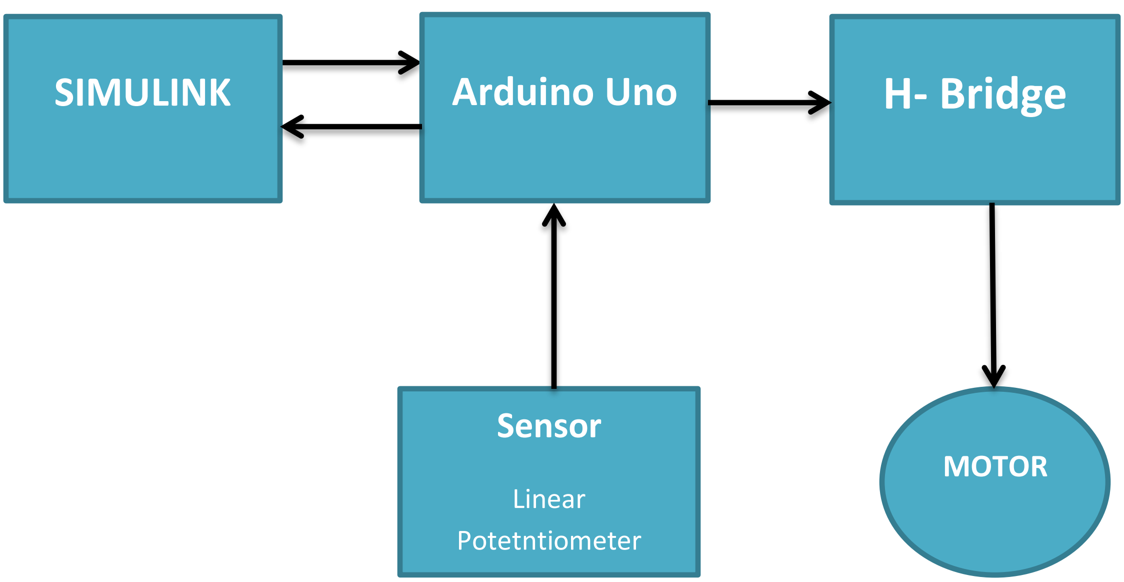


Figure 23 (SIMULINK block Diagram 2)

6.4 Hardware implementation with SIMULINK



CHAPTER 7

Results and Conclusion

The objective of this project was to achieve an efficient suspension system which could come to rest faster than an ordinary suspension system, after a disturbance is fed to it in the form of a bumpy road profile. We modeled a system using P type controller and implemented it using motor on the suspension system. We formulated transfer functions and modeled results using MATLAB. The results we got after implementing made settling time 70% less and steady state error 40 % less. Hence, it proved that the use of control systems on suspension system greatly effects the results and provides us with a much more comfortable ride. Also, the system now developed is much cheaper. We also came to conclusion that this can not only be used in automotives but also in vibrating structures to reduce vibrations and in aerospace to provide a smoother breaking system.

Open loop Response

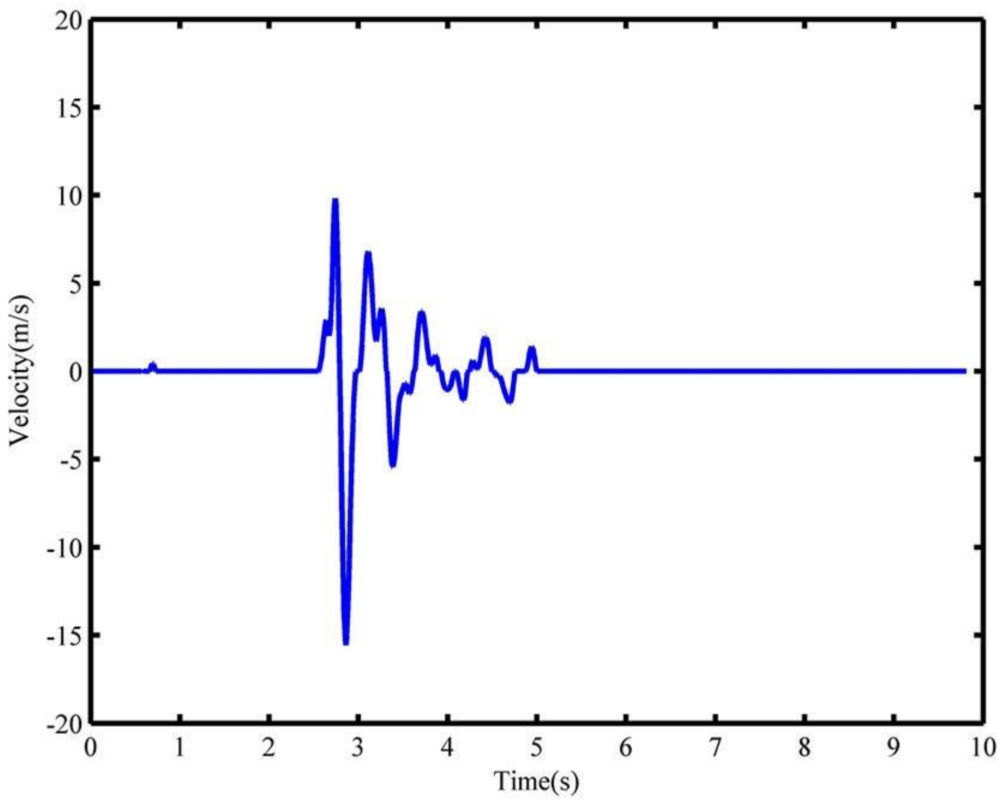


Figure 24 (open loop response)

Close loop Response

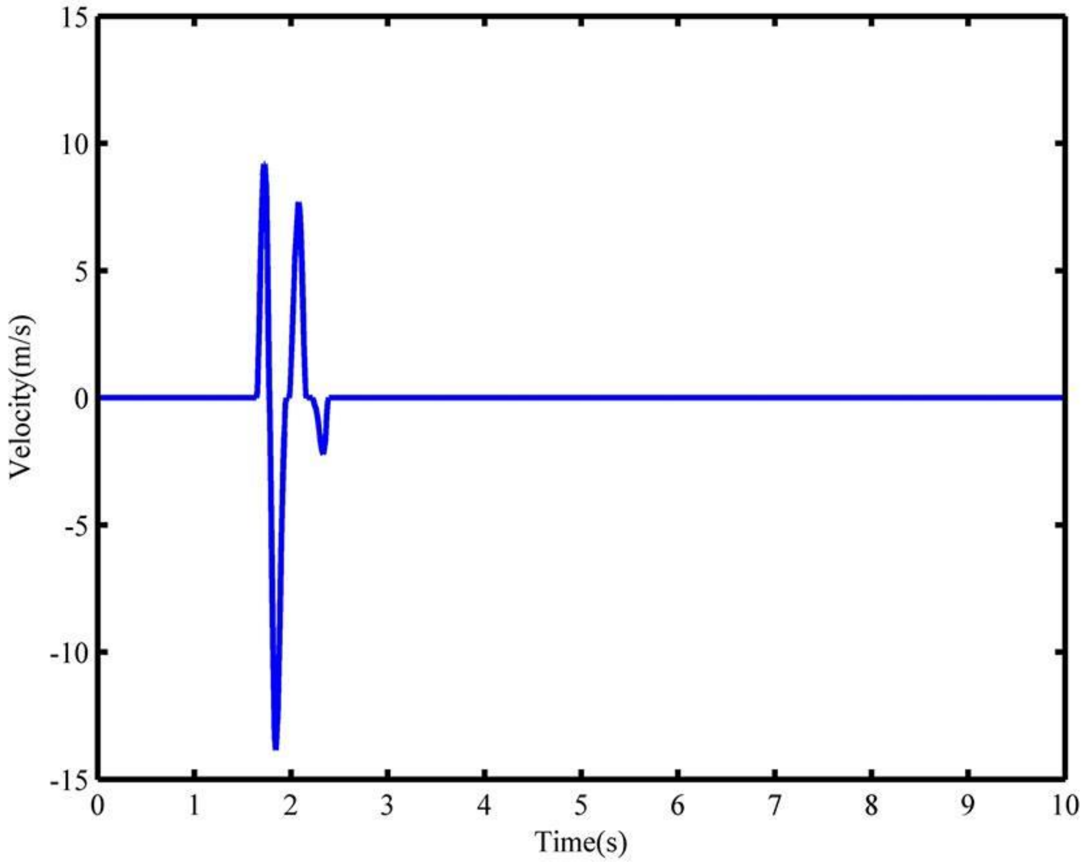


Figure 25 (closed loop response)

Future Recommendations

The current work is the first of its kind at SMME-NUST. In this project, research was focused on developing a controller for the control of an active suspension system. The development of active suspensions is among the top research interests of Mechanical, Automotive, Mechatronics, Control, and Biomedical engineers. Our designed controller has reduced the vehicle's body vertical displacement in agreeable ranges.
Some of the future recommendations to improve this project are as follows:

1. Designing of Controllers using different hybrid approaches for Active Suspension Systems.
2. Improvements in physical model to achieve open loop response for a larger sample time.
3. Experimentations using different type of springs in this project.
4. Joint Ventures can be carried out with Automotive Industry.
5. Fabrications of Active suspension system for heavy machinery.

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