

DEVELOPMENT OF VARYING ORIFICE TYPE SEMI ACTIVE DAMPER

Submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering
degree in an Automobile Engineering

By

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**DEPARTMENT OF AUTOMOBILE ENGINEERING
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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with “A” grade by NAAC | 12B Status by UGC | Approved by AICTE

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of SRINI.M (39860022) and M.PONBARANI.R (39860015) who have done the Project work as a team, who carried out the project entitled “**DEVELOPMENT OF BEARING ORIFICE TYPE SEMI ACTIVE DAMPER**” under my supervision from November 2022 to April 2023

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I SRINI.M (39860022) and PONBARANI.R (39860015) hereby declare that the Project Report entitled “**DEVELOPMENT OF BEARING ORIFICE TYPE SEMI ACTIVE DAMPER**” done by us under the guidance of Dr.A.JAYAGANTHAN,M.E.,Ph.D at SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in AUTOMOBILE.

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ABSTRACT

Vibrations caused by external forces can lead to discomfort, instability, or even damage in vehicles and buildings. Dampers are devices that can absorb or dissipate the energy of the vibrations, and there are two main types: passive and active. Semi-active dampers combine the benefits of both types by providing adjustable damping force without requiring a constant external power source. One type of semi-active damper is the varying orifice type, which adjusts the size of the orifice through which the fluid flows to vary the damping force. This report focuses on the development of varying orifice type semi-active dampers using various techniques such as electro-rheological fluids, magnetorheological fluids, and piezoelectric materials. These dampers have several advantages over conventional dampers, including improved control over damping force and real-time adjustability.

ABBREVIATION

- m_1 - is the sprung mass,
- m_2 - is the unsprung mass,
- k_1 - is the stiffness coefficient of the suspension,
- k_2 - is the vertical stiffness of the tire,
- b_1 - is the damping coefficient of the suspension,
- b_2 - is the damping coefficient of the tire,
- x_1 - the vertical displacement of sprung mass,
- x_2 - is the vertical displacement of unsprung mass,
- w - is the road excitation.

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CHAPTER – 1

INTRODUCTION

Vehicles and buildings are often subjected to vibrations caused by external forces such as road irregularities. These vibrations can lead to discomfort, instability, or even damage. One way to manage these vibrations is using dampers, which are devices that absorb or dissipate the energy of the vibrations. There are two main types of dampers: passive and active. Passive dampers use a fixed mechanism to provide damping force, while active dampers use an external power source to actively adjust the damping force. A third type, semi-active dampers, combines the benefits of passive and active dampers by providing adjustable damping force without the need for a constant external power source. One type of semi-active damper is the varying orifice type semi-active damper, which is the focus of this report. [1].

The development of varying orifice type semi-active dampers involves several steps. The first step is to determine the damping force required for the damper. This is usually done based on the input signal, which is the force or motion that causes the vibration. The damping force required depends on the frequency and amplitude of the input signal, as well as the desired level of damping. The second step is to vary the orifice size, which is the opening through which the fluid flows in the damper. The orifice size determines the flow rate of the fluid and, consequently, the damping force provided by the damper. In a varying orifice type semi-active damper, the orifice size is varied according to the input signal. The orifice size can be varied using various techniques such as electro-rheological fluids, magnetorheological fluids, and piezoelectric materials [2]. Electro-rheological fluids (ERFs) are fluids that change their viscosity in response to an electric field. When an electric field is applied to an ERF, its viscosity increases, and the flow rate through the orifice decreases. Conversely, when the electric field is removed, the viscosity returns to its original value, and the flow rate increases. In a varying orifice type semi-active damper that uses ERFs, an electric field is applied to the ERF to decrease the flow rate through the orifice when damping force is required and removed when damping force is not required [3]. Magnetorheological fluids (MRFs) are fluids that change their viscosity in response to a magnetic field. When a magnetic field is applied to an MRF, its viscosity increases, and the flow rate through the orifice decreases. When the magnetic field is removed, the viscosity returns to its original

value, and the flow rate increases. In a varying orifice type semi-active damper that uses MRFs, a magnetic field is applied to the MRF to decrease the flow rate through the orifice when damping force is required and removed when damping force is not required.

Piezoelectric materials are materials that change their shape when a voltage is applied. In a varying orifice type semi-active damper that uses piezoelectric materials, the orifice size is varied by applying a voltage to the piezoelectric material, which changes its shape and alters the size of the orifice. The voltage is applied when damping force is required and removed when damping force is not required. [4].

CHAPTER – 2

LITERATURE SURVEY

2. STRUCTURE OF VEHICLE SUSPENSION SYSTEM:

A vehicle suspension system is a crucial component of a vehicle that provides a comfortable and stable ride. It is designed to absorb shocks and vibrations from the road surface and maintain contact between the tires and the road, thereby ensuring safety and stability while driving. The suspension system comprises various components that work together to achieve these goals.

The suspension system of a vehicle is responsible for providing a comfortable ride by absorbing shocks and vibrations from the road. It also ensures that the vehicle maintains stable contact with the road surface. The suspension system is made up of several components, including the chassis, springs, shock absorbers, struts, and tires. In summary, the suspension system of a vehicle is a complex arrangement of components that work together to provide a smooth and stable ride. It is essential to maintain and repair the suspension system regularly to ensure the safety and comfort of the driver and passengers.[5],

2.1 Vibration Control of a Semi-active Seat Suspension System using Magnetorheological Damper

The basic principle behind a semi-active seat suspension system using an MR damper is that the damping force is controlled by varying the current supplied to the damper's electromagnet. When a magnetic field is applied, the viscosity of the MR fluid changes, which affects the damping characteristics of the damper. The current supplied to the damper's electromagnet can be controlled by a semi-active control system that adjusts the damping force in real-time to mitigate vibrations. One of the advantages of a semi-active suspension system using an MR damper is its ability to provide a wide range of damping forces. This allows the system to respond to different vibration frequencies and amplitudes, providing effective vibration control over a broad range of conditions. Additionally, the system can adapt to changing road conditions and driver preferences in real-time, ensuring that the vehicle's passengers experience a comfortable ride.

2.2 Study of semi-active suspension control strategy based on driving behaviour characteristics

The study of semi-active suspension control strategy based on driving behavior characteristics is a promising approach to improve ride comfort and handling performance by adapting the suspension system to the driver's behavior and road conditions. The approach involves identifying key driving behavior characteristics, developing a control algorithm, and implementing the control algorithm using a semi-active suspension system. While there are some limitations to this approach, it offers significant advantages over passive suspension systems and is becoming increasingly popular in the automotive industry. There are some limitations to this approach, such as the complexity of the control algorithm, the need for accurate sensor data, and the potential for increased system cost. Additionally, the system must be designed to operate safely within its safe operating limits to prevent damage to the suspension system or other vehicle components.

2.3 Analysis and Prediction of Performance of MR Damper at Different Currents and Control Strategies for Quarter Suspension System of a Roadway Vehicle

The analysis and prediction of performance of MR damper at different currents and control strategies for a quarter suspension system of a roadway vehicle involves studying the behavior of a semi-active suspension system that uses an MR damper to control the vibrations of the vehicle. The study aims to analyze and predict the performance of the MR damper under different current levels and control strategies, and to evaluate the system's effectiveness in improving ride comfort and handling performance. The analysis and prediction of performance of MR damper at different currents and control strategies for quarter suspension system of a roadway vehicle is an important area of research in the automotive industry. The use of mathematical models and simulation software allows researchers to evaluate the performance of semi-active suspension systems under different conditions and optimize their design for specific vehicle applications. The results of this research can lead to improvements in ride comfort, handling performance, and overall vehicle safety.

2.4 Evaluation of Whole-Body-Vibration Exposure to Cairo Subway (Metro) Passengers

The evaluation of whole-body-vibration exposure to Cairo subway (metro) passengers involves studying the levels of vibration exposure that passengers experience during their daily commutes. The study aims to evaluate the potential health effects of whole-body vibration exposure on passengers and to identify measures that can be taken to reduce vibration levels and improve passenger comfort. The researchers then use mathematical models to predict the vibration exposure levels that passengers are likely to experience based on the measured data. They can also evaluate the potential health effects of these exposure levels using established standards and guidelines. Overall, the evaluation of whole-body vibration exposure to Cairo subway (metro) passengers is an important area of research that can help to improve the safety and comfort of subway passengers. By identifying areas of high vibration exposure and developing strategies for reducing these levels, researchers can help to minimize the potential health effects of whole-body vibration exposure on subway passengers.

2.5 Semi-active H1 control of vehicle suspension with magneto-rheological dampers

Semi-active H1 control of vehicle suspension with magneto-rheological (MR) dampers is a control strategy used in vehicle suspension systems to improve ride comfort and handling performance. The system uses MR dampers that can adjust their damping force in real-time based on the current supplied to their electromagnet. The H1 control algorithm is used to optimize the performance of the MR dampers and improve the overall suspension system. The semi-active suspension system with MR dampers uses the H1 control algorithm to adjust the damping force of the MR dampers in real-time. The algorithm uses feedback from sensors, such as accelerometers and displacement sensors, to determine the road profile and the behavior of the vehicle. Based on this information, the algorithm adjusts the current supplied to the MR damper's electromagnet, which changes the damping force of the damper. The semi-active H1 control of vehicle suspension with magneto-rheological dampers is an effective and promising control strategy for improving ride comfort and handling performance in vehicles. By optimizing the performance of the MR dampers using the H1 control algorithm, the system can provide better suspension performance and enhance the safety and comfort of the vehicle's occupants.

2.6 Quasi-active suspension design using magnetorheological dampers

Quasi-active suspension design using magnetorheological (MR) dampers is a technology that aims to provide a balance between the high cost and complexity of fully active suspension systems and the limited performance of passive suspension systems. MR dampers contain a magnetorheological fluid that can change its viscosity in response to an applied magnetic field. By controlling the magnetic field, the damping force can be adjusted in real-time, providing a more responsive and adaptable suspension system. Quasi-active suspension systems using MR dampers typically rely on sensors to monitor the vehicle's motion and a control algorithm to adjust the magnetic field and damping force of the dampers accordingly. This allows the suspension system to respond quickly to changing road conditions, improving both ride comfort and handling performance. It's important to note that while the concept of quasi-active suspension design using MR dampers is not new, ongoing research and development in this area is focused on improving the technology and expanding its applications, including in electric and autonomous vehicles.

CHAPTER-3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

3. AIM AND SCOPE

The aim of the present investigation is to develop a bearing orifice type semi-active damper for use in mechanical systems. The scope of the investigation includes designing and analyzing the damper, simulating its behavior under different operating conditions, and testing its performance in a laboratory setting.

The development of this semi-active damper is motivated by the need for improved control over mechanical vibrations, which can have negative effects on equipment performance and lifespan. The bearing orifice design of the damper allows for greater adjustability and flexibility in damping characteristics compared to passive dampers, while still providing the benefits of lower power consumption and reduced complexity compared to fully active systems.

The investigation will focus on the following aspects:

- Design and modelling of the damper, including the bearing orifice mechanism and control system.
- Simulation of the damper's behaviour under different operating conditions and design parameters.
- Testing of the damper's performance in a laboratory setting, including measurements of damping force, displacement, and energy consumption.
- Comparison of the damper's performance to other types of dampers, including passive and fully active systems.
- Evaluation of the potential applications and benefits of the semi-active damper in various mechanical systems.

Overall, the goal of the investigation is to develop a more efficient and effective solution for controlling mechanical vibrations, with the potential to improve equipment performance, reduce maintenance costs, and increase safety and reliability.

CHAPTER – 4

MATERIALS AND METHODS

4. MATLAB

A high-level programming language and numerical computing environment called MATLAB is often used in applications in engineering, science, and mathematics. It provides a wide range of functions and tools for data analysis, visualization, and algorithm development. MATLAB also has a variety of toolboxes that allow users to perform specialized tasks such as signal processing, control system design, and image processing. It is widely used in academia and industry for research, development, and simulation.

4.1 MATHAMATICAL EQUATION OF PASSIVE IN QUATOR CAR:

The system shown in figure is a quarter car system were

- m_1 - is the sprung mass,
- m_2 - is the unsprang mass,
- k_1 - is the stiffness coefficient of the suspension,
- k_2 - is the vertical stiffness of the tire,
- b_1 - is the damping coefficient of the suspension,
- b_2 - is the damping coefficient of the tire,
- x_1 - the vertical displacement of sprung mass,
- x_2 - is the vertical displacement of unsprang mass,
- w - is the road excitation.

We will consider only mass movements on the vertical axis ignoring the rotational movement of the vehicle.

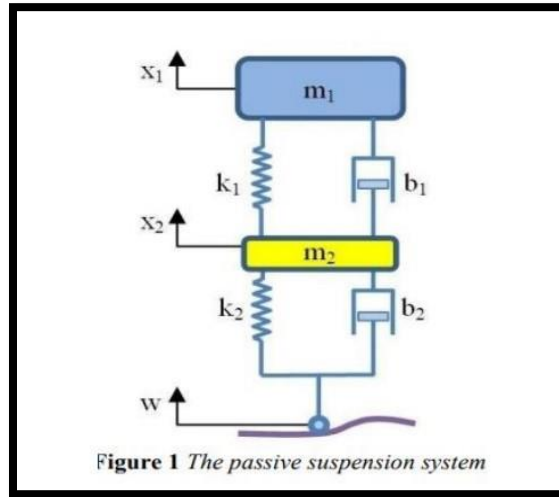


Figure 1: Passive suspension system

We may utilise the displacement $x_1 - x_2$ as an input size to analyse the behaviour of the suspension system because the distance $x_1 - w$ is difficult to measure and the tire's deformation, $x_2 - w$, is little.

$$M_1 \ddot{x}_1 + b_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_2) = 0 \quad (1)$$

$$M_2 \ddot{x}_2 + b_1(\dot{x}_1 - \dot{x}_2) + k_1(x_2 - x_1) + b_2 \dot{x}_2 + k_2 x_2 = 0 \quad (2)$$

Separate terms $\ddot{x}_1$ and $\ddot{x}_2$:

$$M_1 \ddot{x}_1 = -b_1(\dot{x}_1 - \dot{x}_2) - k_1(x_1 - x_2) \quad (3)$$

$$M_2 \ddot{x}_2 = b_1(\dot{x}_1 - \dot{x}_2) + k_1(x_2 - x_1) - b_2 \dot{x}_2 - k_2 x_2 \quad (4)$$

Equations (3) and (4). Due to the complexity of these equation systems, Matlab Simulink tools can be used to solve them. The system will be solved using three techniques, and its verification will follow:

- i. write the equations in Mat lab using Simulink library blocks
- ii. using the "transfer function"
- iii. using the "state-space" model.

4.2 PARAMETERS FOR EQUATION:

To analyse the behaviour of the quarter car suspension system were used as input parameters the next values:

Parameter	Symbol	Value(unit)
Mass vehicle body	m_2	240(kg)
Mass vehicle wheel	m_1	36(kg)
Suspension stiffness	k_1	16000(N/m)
Damping coefficient	b	980(Ns/m)
Tyre stiffness	k_2	160(kN/m)

Table 1: Parameters for equation.

4.3 MATLAB PRESENTATION:

Corresponding to the above equation, we get:

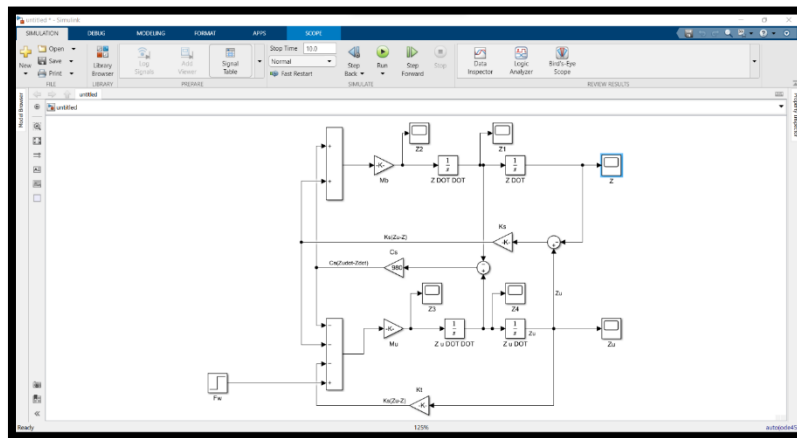


Figure 2: Simulation connection represented with parameters.

4.4 SUSPENSION MODELS:

In general, there are three categories of vehicle suspension models: quarter-car, half-car, and full-car versions. The interaction between the quarter-car body and the single wheel serves as the basis for the quarter-car model. For the half-car model, the motion is limited in the vertical direction, and the interactions are between the vehicle body and the wheel as well as between the two ends of the car body. In the half-car models, the initial interaction created a vertical motion, and the second interaction generated an angle motion. Here in this study, we taken the quarter car model.

4.5 PASSIVE SUSPENSION SYSTEM:

A passive suspension system is a type of suspension system used in vehicles that is designed to absorb shocks and vibrations from the road surface. Unlike active suspension systems, which use electronic controls to adjust the suspension in real-time, passive suspension systems rely on mechanical components to provide the necessary damping and stiffness.

Passive suspension systems typically consist of several components, including springs, shock absorbers, and anti-roll bars. The springs are responsible for absorbing and dissipating energy from the road surface, while the shock absorbers provide additional damping to reduce the amount of bounce and oscillation in the suspension system. Anti-roll bars, also known as sway bars, are used to prevent the vehicle from rolling excessively during cornering or turning [7].

4.6 ACTIVE SUSPENSION SYSTEM:

An active suspension system is a type of suspension system used in vehicles that utilizes electronic controls to adjust the suspension in real-time. This system monitors various factors such as road conditions, vehicle speed, and driver input, and makes adjustments to the suspension accordingly to provide optimal handling, stability, and comfort.

Active suspension systems typically consist of several components, including sensors, actuators, and control modules. Sensors are used to collect data about the vehicle and the environment, while actuators are used to adjust the suspension components in response to this data. Control modules process the data from the sensors and use algorithms to determine the best course of action for the suspension system.

4.7 SEMI-ACTIVE SUSPENSION:

Semi-active suspension is a type of suspension system used in vehicles that utilizes both mechanical and electronic components to adjust the suspension in real-time. Unlike passive suspension systems that rely solely on mechanical components, and active suspension systems that use electronic controls, semi-active suspension systems use a combination of the two [7].

Semi-active suspension systems typically utilize electronically controlled shock absorbers or dampers, which can be adjusted in real-time based on data from sensors and other input. These shock absorbers or dampers can be adjusted to provide a softer or stiffer ride depending on the driving conditions and can also be used to compensate for body roll during cornering.

One of the main advantages of semi-active suspension systems is that they provide a balance between the simplicity and low cost of passive suspension systems and the advanced capabilities of active suspension systems. They are typically more affordable than active suspension systems, while still providing many of the same benefits such as improved handling, stability, and comfort [8].

4.7.1 ROLE OF SEMI-ACTIVE SUSPENSION:

The role of semi-active suspension in vehicles is to provide a balance between the simplicity and low cost of passive suspension systems and the advanced capabilities of active suspension systems. By utilizing both mechanical and electronic components, semi-active suspension systems can adjust the suspension in real-time based on driving conditions, providing improved handling, stability, and comfort for the driver and passengers.

One of the main advantages of semi-active suspension systems is their ability to adapt to changing driving conditions, such as uneven road surfaces, sudden maneuvers, or emergency situations. By adjusting the suspension in real-time, these systems can provide a smoother ride, reduce body roll during high-speed cornering, and improve stability and control during sudden maneuvers.

4.8 DAMPERS AND ITS TYPES:

Semi-active dampers are a type of damper used in automobiles that can adjust their resistance to spring movement based on driving conditions. They are typically more expensive than passive dampers, but less expensive than fully active dampers.

There are two main types of semi-active dampers used in automobiles

- Servo/Solenoid valve dampers
- Magnetorheological (MR)/electrorheological (ER) dampers
- Electromagnetic dampers

Semi-active dampers offer several advantages over passive dampers, including improved ride comfort and handling, as well as better safety and stability. However, they are more expensive and complex to maintain than passive dampers. The choice of damper type depends on the vehicle's intended use, performance requirements, and budget.

4.8.1 SOLENOID/SERVO VALVE DAMPER*S:

Solenoid valve dampers are a type of semi-active damper used in automobiles that use solenoid valves to adjust the damping force of the shock absorber. They are also known as solenoid valve shock absorbers.

In a solenoid valve damper, the solenoid valve is mounted on the damper cylinder and is controlled by an electronic control unit (ECU). The ECU receives input from various sensors, including wheel speed sensors, acceleration sensors, and steering angle sensors. Based on these inputs, the ECU sends a signal to the solenoid valve to adjust the damping force of the shock absorber [9-10] Solenoid valve dampers offer several advantages over other types of semi-active dampers. They are very responsive and can quickly adjust to changing road conditions, providing a smoother and more comfortable ride. They are also more energy-efficient than other types of semi-active dampers, as they only require power when adjusting the damping force [11-12].

A two-stage selectable damper that bridges the gap between simple electronic continuously variable dampers and traditional passive shock absorbers. However, solenoid valve dampers can be more expensive than other types of dampers and can require more maintenance due to their complex electronic and mechanical components. They are also typically only found in high-end luxury cars and sports cars. [13] Overall, solenoid valve dampers are a highly advanced and effective type of damper that can significantly improve the ride comfort and handling of a vehicle. However, their high cost and maintenance requirements may limit their use to high-end vehicles [14]

4.8.1.1ADAPTIVE DAMPING SYSTEM:

An adaptive damping system, also known as adaptive suspension, is a type of suspension system used in automobiles that adjusts the damping force of the shock absorber based on driving conditions. This allows the suspension to adapt to different driving situations, providing a smoother and more comfortable ride [15] In an adaptive damping

system, sensors continuously monitor the vehicle's speed, acceleration, and road conditions. Based on these inputs, an electronic control unit (ECU) adjusts the damping force of the shock absorber to optimize the vehicle's handling and ride quality. The damping force can be adjusted independently for each wheel, allowing the suspension to respond to uneven road surfaces and other driving conditions.

There are several types of adaptive damping systems used in automobiles, including:

- Magnetic ride control: Magnetic ride control uses a magnetorheological fluid and electromagnetic coils to adjust the damping force of the shock absorber. When a current is passed through the coils, the magnetorheological fluid changes its viscosity, allowing the damping force to be adjusted quickly and precisely.
- Air suspension: Air suspension uses air springs and an air compressor to adjust the ride height and damping force of the suspension. Air suspension systems can provide a very smooth ride but can be expensive and require more maintenance than other types of adaptive damping systems.
- Active hydraulic suspension: Active hydraulic suspension uses hydraulic cylinders and an electric pump to adjust the damping force of the shock absorber. The hydraulic system can respond quickly to changing road conditions, providing a very smooth ride [16]

Adaptive damping systems offer several advantages over traditional suspension systems. They can improve ride comfort, handling, and stability, and can provide a more enjoyable driving experience. However, they can be more expensive and complex to maintain than traditional suspension systems.

4.9 MR DAMPERS:

Magneto-rheological (MR) dampers are a type of semi-active damper used in automobiles that use a magnetized fluid to adjust the damping force of the shock absorber. MR dampers are highly effective at quickly adapting to changing road conditions, providing a smoother and more comfortable ride.



Figure3: DAMPER UNIT

In an MR damper, the fluid is made up of tiny particles of iron suspended in a fluid. When subjected to a magnetic field, the particles align and create a viscous resistance to movement, which can be used to adjust the damping force of the shock absorber. The strength of the magnetic field can be controlled by an electric current, allowing the damping force to be adjusted quickly and precisely.

MR dampers offer several advantages over traditional dampers. They can quickly and accurately respond to changing road conditions, providing improved handling, stability, and ride comfort. They are also more energy-efficient than traditional dampers, as they only require power when adjusting the damping force.

However, MR dampers can be more expensive than traditional dampers and can require more maintenance due to their complex mechanical and electronic components. They are also typically only found in high-end luxury cars and sports cars.

Overall, MR dampers are a highly advanced and effective type of damper that can significantly improve the ride quality and performance of a vehicle. However, their high cost and maintenance requirements may limit their use to high-end vehicles. [17]

4.9.1APPLICATION OF MR DAMPERS:

Numerous writers have also employed the MR dampers as semi-active components in automobile suspension systems.

Magneto-rheological (MR) dampers are commonly used in high-end luxury cars, sports cars, and performance vehicles. They are also used in applications where precise and quick adjustments to the damping force are necessary, such as in military and industrial vehicles.[18]

In the automotive industry, MR dampers are used to provide a smoother and more comfortable ride, as well as improved handling and stability. They are particularly effective in sports cars and performance vehicles, where fast response times and precise control of the suspension are essential for optimal performance.

MR dampers are also used in military vehicles, such as tanks and armored personnel carriers, to provide improved ride comfort and stability over rough terrain. They can quickly and accurately adjust the damping force to provide maximum stability and control, even in the most challenging conditions [20]

In the industrial sector, MR dampers are used in applications such as bridge and building construction, where vibration damping, and stability are critical. They can be used to reduce vibrations and oscillations in structures, providing improved safety and stability [21].

Overall, MR dampers have a wide range of applications in various industries where precise and quick adjustments to the damping force are necessary. Their ability to quickly and accurately adjust to changing conditions makes them an ideal choice for applications where stability, safety, and performance are essential. [23].



Figure 4: HYDRAULIC UNIT

Analytical methods are used to determine an MR damper's parameters. By comparing the performance of the quarter-car model with the MR damper with that of a fully active suspension based on LQR control, the ideal settings are established. Both the Bingham and modified Bouc-Wen models simulate the hysteretic behaviour of the MR damper. The Bingham model is a straightforward model, and the analysis is similarly straightforward because it only calls for two parameters to describe the behaviour of the MR damper. The updated Bouc-Wen model requires eight parameters, which makes the model and its analysis more difficult. The MR damper behaviour is, however, better captured by the modified Bouc-Wen model [25].

4.10 SKYHOOK EQUATION:

Skyhook control is used to shield the sprung mass from outside vibration. Between the sprung mass and inertial inference in this scenario, a virtual damper is established. However, for practical use, a comparable damper is created between the sprung and unsprung mass. The following control rules must be followed to reproduce the behaviour of optimal skyhook damping. [26-30]

$$F_{sky} = \begin{cases} c_{sky} (\dot{x}_b) , & \text{if } (\dot{x}_b - \dot{x}_w) \cdot \dot{x}_b \geq 0 \\ c_{min} (\dot{x}_b - \dot{x}_w) , & \text{if } (\dot{x}_b - \dot{x}_w) \cdot \dot{x}_b < 0. \end{cases}$$

4.10.1 GROUNDHOOK METHOD:

A groundhook control may be used to enhance road handling. A virtual damper is positioned between the unsprung mass and inertial interference, much as the skyhook control. As shown in [33], the control algorithm may be written.

$$F_{grd} = \{c_{grd} (\dot{x}_w) , \text{ if } -(\ddot{x}_b - \ddot{x}_w) \cdot \dot{x}_w \geq 0$$

$$\{c_{min} (\ddot{x}_b - \ddot{x}_w) , \text{ if } -(\ddot{x}_b - \ddot{x}_w) \cdot \dot{x}_w < 0.$$

4.11 HYBRID METHOD:

The hybrid method is a combination of the Skyhook and Groundhook methods used in semi-active suspension systems. The method aims to reduce the vibrations and shocks in a system by combining the benefits of both the Skyhook and Groundhook methods.

The Skyhook method provides a high level of isolation from vibrations and shocks, but it has limitations in handling large shock inputs due to the weight of the suspended mass. The Groundhook method, on the other hand, can handle large shock inputs due to the mass being firmly fixed to the ground, but it may not provide as much isolation as the Skyhook method. [31] The hybrid method addresses these limitations by incorporating both methods into the design of the suspension system. In this approach, the suspended mass is attached to a flexible coupling that is anchored to the ground. The flexible coupling allows the mass to move relative to the ground, while also providing isolation from vibrations and shocks through the principles of the Skyhook method.

The hybrid method can be implemented using various types of flexible couplings, such as air springs or hydraulic mounts. The damping force in the system is adjusted based on the relative velocity between the vehicle body and the suspended mass, using the Skyhook equation. In addition, the flexible coupling provides additional damping and stiffness to the system, which helps to reduce the effects of large shock inputs.

The hybrid method offers significant improvements in ride comfort and handling performance, particularly in applications where the suspension system is subjected to both

high-frequency vibrations and large shock inputs. However, the design and implementation of the hybrid method can be complex, and careful consideration must be given to factors such as the mass and stiffness of the flexible coupling, as well as the control system used to adjust the damping force.

4.11.1 HYBRID EQUATION:

The idea of hybrid control is put out in order to combine the benefits of the two aforementioned systems. Skyhook and groundhook control techniques are combined linearly to form hybrid control.

A common example of hybrid control is

$$F_d = \eta F_{sky} - (1 - \eta) F_{grd},$$

where the hybrid control's weight factor is $[0, 1]$. The operator can subjectively change the value of η to determine which component is more crucial throughout the driving process. For example, if the driver wants to improve road handling performance at the price of ride comfort, a value of $\eta = 0.2$ can be employed.

4.12 DAMPING COEFFICIENT CALCULATION:

This section gives a basic overview of MOOP (Multi objective Optimization Problems) and explains how damping coefficients are calculated for various road levels.

Design, decision-making, and experimentation in engineering all heavily rely on optimization issues. An optimization issue may be referred to as a MOOP if it has more than one objective function. MOOP may be solved using a variety of techniques, including direct and gradient-based approaches [34]. However, these traditional approaches have several drawbacks [35].

1. The convergence of the objective functions to the optimal solutions is governed by their starting solutions.
2. The scope of an algorithm created using these techniques could be constrained, making it difficult to apply it to other kinds of situations.
3. Each repetition of these traditional approaches can only produce one result.

4.13 MOOP CONCEPT

Here, the idea of "Pareto optimum solutions" is demonstrated to better comprehend the MOOP. The Pareto optimum solution sets answers have the quality that no alternative practical solutions exist that may lower one criteria without raising any other criterion [36]. To be more precise, one of the solutions in the Pareto optimum solution set is the one reached by traditional methods after one iteration. To get around the restrictions, evolutionary algorithms have been developed [34].

4.14 NSGA algorithm:

The Non-dominated Sorting Genetic Algorithm (NSGA) is a multi-objective optimization algorithm that aims to find the Pareto-optimal set of solutions for a given optimization problem. The NSGA algorithm works by creating a set of solutions that are not dominated by any other solution in the population, and then sorting them into different levels or fronts based on their dominance [38]

The algorithm starts with an initial population of candidate solutions, which are then evaluated based on the objective functions of the problem. The solutions are then sorted into different levels based on their non-domination, where a solution is non-dominated if there does not exist another solution that is better in all the objectives and worse in none. [37].

After sorting the solutions, the algorithm proceeds to select the solutions for the next generation by assigning a fitness value to each solution based on their level of non-domination and crowding distance. Crowding distance is a measure of how crowded a solution is in the objective space, and it helps to maintain diversity in the population.

The NSGA algorithm then applies genetic operators such as crossover and mutation to the selected solutions to generate a new population of candidate solutions, which are then evaluated and sorted again based on their non-domination. This process continues until the desired convergence criterion is met.

Overall, the NSGA algorithm is an effective and widely used approach for solving multi-objective optimization problems, particularly in engineering and other applied fields where the optimization of multiple objectives is common.

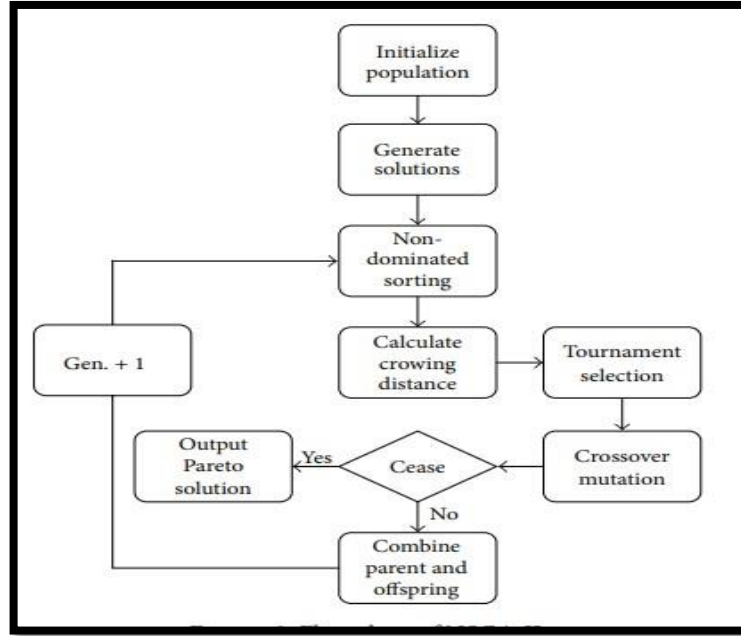


Figure 5: Flowchart of NSGA Algorithm

4.15 NONPARAMETRIC MR DAMPERS:

A non-parametric magneto-rheological (MR) damper is a type of damper that uses a magneto-rheological fluid to adjust its damping force. The damper works by controlling the rheological properties of the fluid through an applied magnetic field, which alters the viscosity and shear strength of the fluid, thereby changing its damping characteristics. [39]. Non-parametric MR dampers do not require an explicit model to describe their behavior, making them a flexible and adaptable solution for a variety of applications. Instead, they use a data-driven approach to determine the optimal damping force based on real-time measurements of the system's response [40].

Non-parametric MR dampers are often used in structural control applications, such as in buildings, bridges, and other civil engineering structures. They are also used in automotive and aerospace applications to improve ride comfort, stability, and handling [41]. One advantage of non-parametric MR dampers is their ability to adapt to changing conditions in real-time. This allows them to adjust their damping characteristics to compensate for variations in the system's response, such as changes in load or environmental conditions [42].

Another advantage of non-parametric MR dampers is their simplicity and ease of installation. They do not require extensive modeling or calibration, making them a cost-effective and efficient solution for a wide range of applications [43]. Overall, non-parametric MR dampers are a flexible, adaptable, and effective solution for controlling the response of a variety of mechanical and civil engineering systems. Their data-driven approach and real-time adaptability make them an attractive option for applications where precise control is critical. [45].

4.16 PROPERTIES NONPARAMETRIC DAMPERS:

Nonparametric dampers can also be used in automobiles to reduce the effects of vibrations caused by road irregularities and other dynamic loads. These dampers are typically made of elastomeric materials such as rubber and can be installed in various locations in the vehicle, such as the engine mounts, suspension system, and steering system. [49].

The properties of nonparametric dampers in automobiles are designed to improve the comfort and safety of the vehicle's passengers. These dampers are effective in reducing the transmission of vibrations from the road surface to the passenger compartment, which can lead to discomfort and fatigue. Nonparametric dampers also improve the stability and handling of the vehicle by reducing the effects of dynamic loads on the suspension and steering systems. [50]. The key properties of nonparametric dampers in automobiles include their stiffness, damping coefficient, and natural frequency. The stiffness of the damper determines how much it deflects under a given load, while the damping coefficient determines how much energy is dissipated as the damper returns to its original position. [51].

The natural frequency of the damper is the frequency at which it resonates and can be used to ensure that the damper is effective in reducing the vibrations in the target frequency range [52]. In summary, nonparametric dampers can be used in automobiles to improve passenger comfort, safety, and vehicle handling. The properties of these dampers are designed to reduce the transmission of vibrations and dissipate the energy of dynamic loads, resulting in a smoother and more stable ride.

4.17 MR DAMPERS ON MULTIPLE ORIFICE HOLE:

Magneto-rheological (MR) dampers are a type of nonparametric damper that use a fluid containing magnetizable particles to alter its viscosity in response to a magnetic field. Multiple orifice hole (MOH) configurations are a common design used in MR dampers to improve their performance.

In an MR damper with a MOH configuration, the fluid flows through multiple small orifices instead of a single large one. This design increases the number of surfaces in contact with the magnetic field, improving the responsiveness and range of the damper. The increased number of orifices also reduces the flow rate of the fluid, resulting in improved damping performance at low speeds [53].

The properties of MR dampers with MOH configurations can be optimized for specific applications by adjusting parameters such as the number and size of the orifices, the magnetic field strength, and the fluid viscosity. These dampers are commonly used in applications such as vehicle suspensions, robotics, and seismic protection systems.

In summary, MR dampers with MOH configurations offer improved damping performance compared to traditional MR dampers by increasing the number of surfaces in contact with the magnetic field and reducing the fluid flow rate. These dampers can be optimized for specific applications by adjusting their properties, making them suitable for a wide range of applications that require precise control of vibration and motion [54]

CHAPTER – 5

RESULTS AND DISCUSSION

5. RESULT

5.1 GRAPHICAL PRESENTATION:



Figure 6: Displacement of suspension (sprung mass) and car body

5.1.2 CHARACTERISTIC RESULT:

From the testing of the varying orifice semi active suspension, the characteristic of force velocity and force displacement are executed during compression stage. In this graph, the compression characteristic is in negative displacement, moreover the extension is in the positive region.

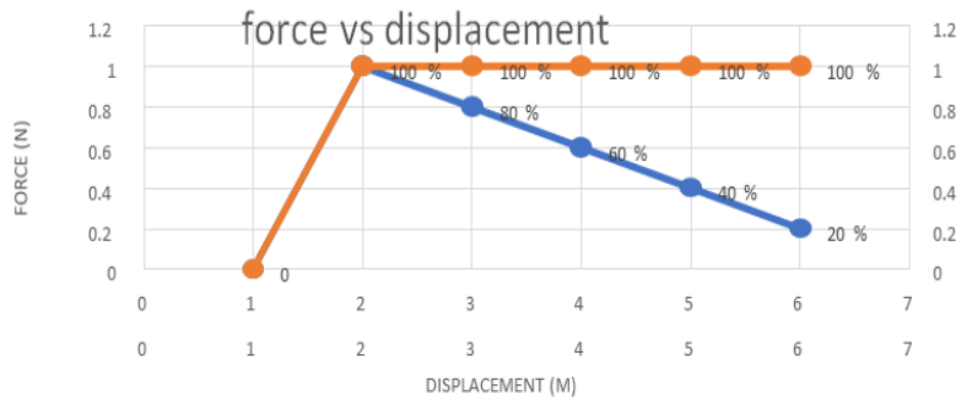


Figure 7: This Graph Shows the Characteristic Of force velocity for constant extension

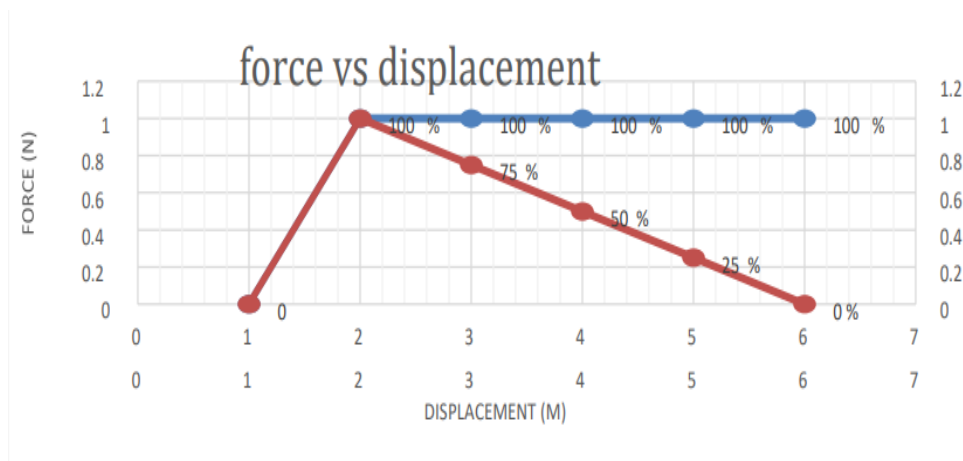


Figure 8: This Graph Shows the Characteristic Of force Displacement for constant extension.

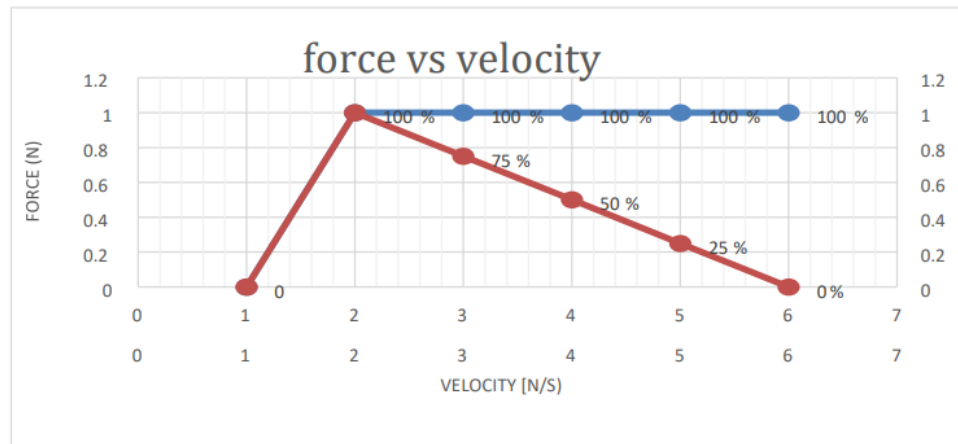


Figure 9: This Graph Shows the Characteristic Of force velocity for constant Compression.

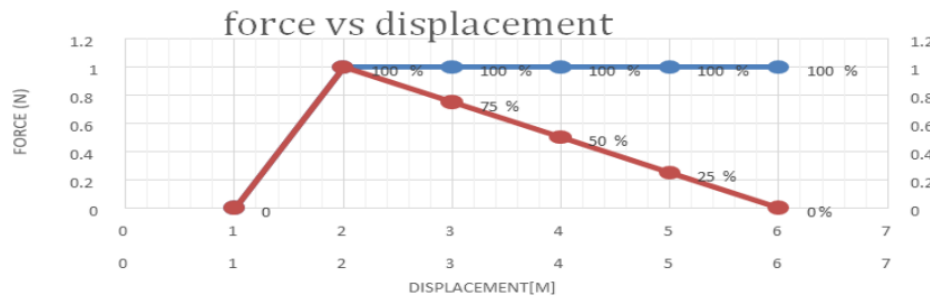


Figure 10: This Graph Shows the Characteristic Of force Displacement for constant Compression.

The force-displacement characteristic graph illustrated in Figure 9 was noted with the same observation. Since the orifice was maintained at 100% throughout each extension cycle, the damping force produced during each extension cycle of each combination was essentially the same. Due to the varying opening for each combination, variable force was observed throughout the compression cycle. It was discovered that the damping force's magnitude was External orifice semi-active suspension system design and characterization 85 rising magnitude is seen as the orifice opening ratio lowers, and the relationship is inverse. Thus, consistent results that can be used to explain the properties of the suggested damper have been seen throughout these experiments.

5.2 DISCUSSION

5.2.1 FUTURE SCOPE OF SEMI ACTIVE SUSPENSION

Semi-active suspension systems are a type of vehicle suspension that use electronically controlled dampers to adjust the stiffness and damping characteristics of the suspension in real-time. The future scope of semi-active suspension systems is promising, with several potential advancements in the field.

One potential area of development is the use of advanced sensors and control algorithms to improve the accuracy and speed of the system's response to changing road conditions. This could lead to improved ride comfort and handling performance, as well as better energy efficiency.

Another area of development is the integration of semi-active suspension systems with other vehicle systems, such as steering and braking. By coordinating the control of these systems, it may be possible to achieve even better ride and handling performance, as well as increased safety and stability.

The use of advanced materials and manufacturing techniques is also a promising area of development for semi-active suspension systems. New materials with improved properties, such as higher strength and lower weight, could lead to more effective and efficient suspension systems. Additionally, advances in 3D printing and other manufacturing techniques may enable the production of more complex and customized suspension components.

Finally, the development of autonomous vehicle technology may also have an impact on the future of semi-active suspension systems. As vehicles become more capable of driving themselves, the role of the suspension system may evolve to focus more on passenger comfort and less on driver control.

In summary, the future scope of semi-active suspension systems is broad, with potential advancements in sensor and control technology, system integration, materials and manufacturing, and autonomous vehicle technology. These developments could lead to improved ride comfort, handling performance, energy efficiency, and safety.

CHAPTER-6

SUMMARY AND CONCLUSION

6. CONCLUSIONS

In this paper, Using Matlab/Simulink software, a mathematical model of an active damped quarter-vehicle suspension system was developed and tested. Passive suspension and semi-active suspension systems often have predefined characteristics that were selected to strike a balance between comfort, load carrying, and road holding. To attain the ideal mix of ride comfort and road-holding control, suppliers or OEMs have created semi-active control algorithms, which are often based on the skyhook control technique.

From the studies of previous papers of the semi active suspension, it proved that solenoid valve dampers are mostly used in most of the semi active damper system. The controlling orifice valve design in semi active suspension is carried out and studied. The algorithms in semi active suspensions are mostly based on the skyhook control strategy for the correct balance of passenger comfort and road handling. The working principle of varying orifice semi active suspension system are showed experimentally by performing the characteristic force velocity and displacement. Hence it shows that the design of semi active suspension model having the ability to provide the required ride comfort and handling to the vehicle.

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