

Comparative Study of Active and Passive Suspension Systems Using 7 Degree of Freedom Full Car Model

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

By

LIKITH KUMAR KILARI (Reg. No. 39860008)

SANJAI RAGHU (Reg. No. 39860018)



**DEPARTMENT OF AUTOMOBILE ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

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

Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

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DEPARTMENT OF AUTOMOBILE ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **LIKITH KUMAR KILARI (Reg. No. 39860008)**, and **SANJAI RAGHU (Reg. No. 39860018)** who carried out the project entitled "**COMPARATIVE STUDY OF ACTIVE AND PASSIVE SUSPENSION SYSTEMS USING 7 DEGREE OF FREEDOM FULL CAR MODEL**" under my supervision from November 2022 to April 2023.

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Submitted for Viva voce Examination held on 26.04.2023

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DECLARATION

We, **LIKITH KUMAR KILARI (Reg No. 39860008)** and **SANJAI RAGHU (Reg No. 39860018)** hereby declare that the Project Report entitled “**COMPARATIVE STUDY OF ACTIVE AND PASSIVE SUSPENSION SYSTEMS USING 7 DEGREE OF FREEDOM FULL CAR MODEL**” done by me under the guidance of **Dr. S. AROCKIA SUTHAN, M.E., Ph.D.**, is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Automobile.

DATE: 26.04.2023

PLACE: CHENNAI

1. 

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SIGNATURE OF THE CANDIDATE

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ABSTRACT

The suspension of the machine is essential for minimizing excursions and preserving road holding. It works by absorbing shocks and vibrations induced by uneven ground and prohibiting them from being passed to the vehicle's body, where they can create discomfort and impact handling. A properly working damping system can also increase safety by lowering the likelihood of sliding or losing control in difficult driving situations. MATLAB/Simulink was used to create a seven-degrees-of-freedom complete car model with an active as well as a passive suspension system for this inquiry. The model was developed to compare the performance of both active as well as passive suspension systems under numerous driving circumstances. When compared to the passive system, the results revealed that the active suspension system was more successful at minimising vehicle body vibration and enhancing ride comfort. This paper includes the researchers' previous research that compared the control capabilities of passive and active suspension systems. The study's findings imply that active suspension systems outperform passive suspension systems in terms of control. This has the potential to have a substantial impact on the automobile industry in terms of enhancing ride comfort and safety. The findings show the simulation outputs that were used to determine the sine and step of the avenue input. We discovered that an active gadget generated superior results. Additionally, exploring the impact of varying input parameters on the device's output could help optimise its performance.

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LIST OF ABBREVIATIONS

S. No.	ABBREVIATION	
1	l_f	Distance between centre of gravity and front axle
2	l_r	Distance between centre of gravity and rear axle
3	t_{fl}	Distance between roll axis and front left tire
4	I	Roll inertia
5	F_i	Actuator forces
6	Z_i	Tire vertical positions
7	m_b	Body mass
8	k_{ui}	Tire spring constants
9	$c_{1,2}$	Front suspension damping coefficients
10	Z_{bi}	Suspension and body link point positions
11	$\emptyset$	Roll angle
12	θ	Pitch angle

CHAPTER 1

INTRODUCTION

Any vehicle's suspension system is an essential part since it controls how smoothly and comfortably the ride is delivered while absorbing shocks and vibrations. The vehicle's stability and safety are also greatly influenced by the suspension system, especially while driving at high speeds or over irregular terrain. A mixture of springs, dampers, and other mechanical parts have traditionally been used in passive suspension systems in cars to absorb shocks and vibrations. However, in recent years, there has been a growing trend toward active suspension systems, which use electronic controls to adjust the suspension in real-time, based on road conditions and driving style. In this paper, we will explore the differences between active and passive suspension systems, and explain why active suspension is generally considered to be superior. Passive suspension systems are the traditional type of suspension used in most vehicles. They rely on a combination of springs and dampers to absorb shocks and vibrations from the road. The springs are typically made from steel or another resilient material, and they compress and expand in response to bumps in the road. The dampers, or shock absorbers, are designed to dampen the oscillations of the spring, ensuring that the vehicle remains stable and does not bounce excessively. Passive suspension systems are generally reliable and cost-effective, but they have a number of drawbacks. Firstly, they are limited in their ability to adapt to different road conditions and driving styles. They are designed to provide a consistent level of performance, regardless of the driving environment. This means that they may be too firm for rough roads, or too soft for high-speed driving. Secondly, passive suspension systems are reactive rather than proactive, meaning that they can only respond to bumps in the road after they have occurred. This can result in a less comfortable ride for passengers and can also affect the stability of the vehicle during cornering or other manoeuvres.

Active suspension systems, on the other hand, use electronic controls to adjust the suspension in real-time, based on road conditions and driving style. They typically use sensors to detect changes in the road surface and other variables such as speed, acceleration, and braking. These sensors send signals to a control unit, which then adjusts the suspension in real-time, using hydraulic or pneumatic

actuators. There are several types of active suspension systems, including semi-active and fully-active systems. Semi-active systems use adjustable dampers, which can be adjusted in real-time to provide a more comfortable ride. Fully-active systems, on the other hand, use hydraulic or pneumatic actuators to actively adjust the suspension, providing a much more dynamic and responsive ride.

There are several advantages to using an active suspension system in an automobile. Active suspension systems are much more adaptable than passive systems. They can adjust to different road conditions and driving styles, providing a more comfortable and stable ride in all situations. For example, when driving over rough roads, the suspension can be adjusted to provide a softer ride, while during high-speed cornering, the suspension can be adjusted to provide a stiffer ride, improving the stability of the vehicle. Secondly, active suspension systems are much more proactive than passive systems. They can detect changes in the road surface and other variables in real time, allowing them to adjust the suspension before the bump is encountered. This can result in a much smoother ride for passengers and can also improve the stability of the vehicle during cornering or other manoeuvres. Finally, active suspension systems can improve the overall performance of the vehicle. By adjusting the suspension in real-time, they can improve the handling and stability of the vehicle, allowing it to perform better in high-speed or high-performance situations.

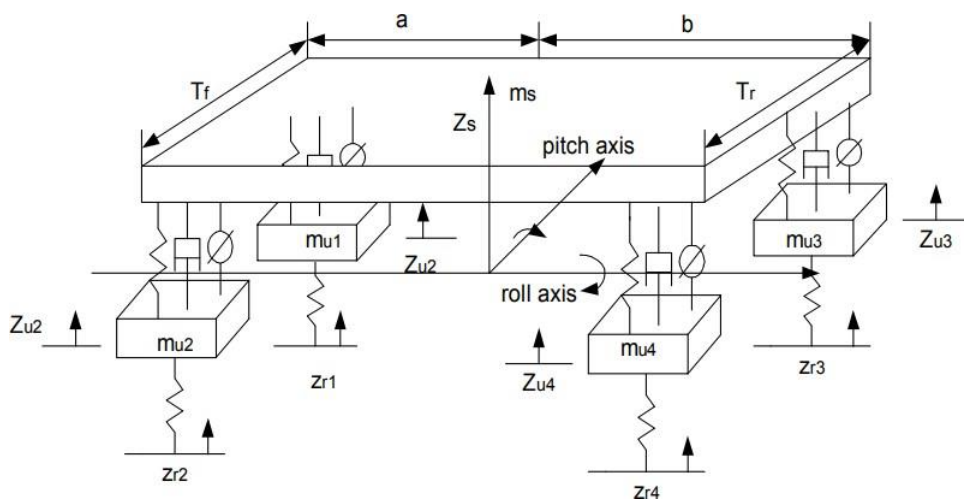


FIG 1.1: Suspension system for a full car model

1.1. BIODYNAMICS OF PASSENGER COMFORT USING THE SUSPENSION SYSTEM

Active suspension systems have become increasingly popular in the automotive industry over the past few decades. These systems are designed to improve the ride quality and passenger comfort by actively controlling the suspension components of a vehicle in real time. In this essay, we will discuss the importance of passenger comfort in active suspension systems and how these systems work to provide a smoother, more comfortable ride. Passenger comfort is one of the most important aspects of vehicle design, especially for long journeys. Active suspension systems aim to provide a smoother ride by actively controlling the movement of the wheels and suspension components. Traditional passive suspension systems rely on springs and dampers to absorb shocks and vibrations, but they are not always able to provide a smooth ride, especially on rough or uneven roads. Active suspension systems, on the other hand, use sensors and control systems to monitor the vehicle's movements and adjust the suspension components accordingly. This means that the suspension can adapt to different road conditions, providing a smoother and more comfortable ride for passengers.

There are several benefits to having a more comfortable ride. Firstly, it can reduce the risk of motion sickness and fatigue, which can be a major problem for some passengers, especially those who are prone to motion sickness. Secondly, a more comfortable ride can reduce the likelihood of back pain and other discomforts associated with prolonged periods of sitting in a vehicle. Active suspension systems work by constantly monitoring the vehicle's movements and adjusting the suspension components in real time. This is achieved through the use of sensors that measure the position, velocity, and acceleration of the vehicle, as well as the road conditions. The control system then uses this information to adjust the suspension components, such as the spring stiffness and damping rate, to provide a smoother ride. One of the key components of an active suspension system is the actuator. The actuator is responsible for adjusting the suspension components, and it can take many forms, such as hydraulic pistons or electric motors. These actuators are controlled by the control system, which uses complex algorithms to determine the optimal settings for the suspension components based on the sensor data.

Another important component of active suspension systems is the electronic control unit (ECU). The ECU is the brain of the system and is responsible for processing the sensor data and controlling the actuators. The ECU uses advanced algorithms to determine the best suspension settings based on the road conditions and the driver's inputs.

Active suspension systems can provide a wide range of benefits for passengers, including improved ride quality, reduced motion sickness and fatigue, and reduced discomfort associated with prolonged periods of sitting in a vehicle. These systems are particularly useful for luxury vehicles, where passenger comfort is a top priority, but they can also be found in more affordable vehicles. One of the main challenges associated with active suspension systems is their complexity. These systems require a high degree of precision and control, and they can be expensive to manufacture and maintain. However, as technology continues to improve, we can expect to see more advanced and affordable active suspension systems in the future.

Passenger comfort is an essential aspect of vehicle design, and active suspension systems are a powerful tool for improving ride quality and reducing discomfort for passengers. These systems use sensors and control systems to monitor the vehicle's movements and adjust the suspension components in real time, providing a smoother and more comfortable ride. While these systems can be complex and expensive, their benefits are clear, and we can expect to see more advanced and affordable active suspension systems in the future.

1.2. PASSIVE SUSPENSION SYSTEM

Passive suspension system in automobiles is a vital component that contributes to the ride quality, stability, and handling of the vehicle. The suspension system primarily works to absorb shocks and vibrations caused by uneven road surfaces, bumps, and rough terrain. It is essential to ensure the safety and comfort of passengers and prevent damage to the vehicle. Passive suspension systems are the most common type of suspension system used in automobiles. These systems do not require external power sources to function and work through the vehicle's motion. Passive suspension systems consist of springs and dampers that work together to absorb shocks and vibrations. The springs are designed to support the

weight of the vehicle and maintain its height, while the dampers are responsible for controlling the motion of the suspension.

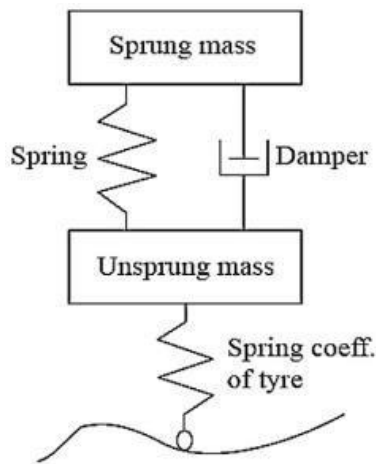


FIG 1.2: Suspension system classification (Passive suspension)

1.2.1. Advantages Of Passive Suspension System

Cost-Effective: One of the significant advantages of passive suspension systems is that they are cost-effective. These systems do not require any external power sources, which makes them relatively inexpensive to manufacture and maintain. Passive suspension systems are commonly used in mass-produced vehicles and provide a comfortable ride quality at an affordable cost.

Improved Handling: Passive suspension systems are designed to improve the vehicle's handling and stability. The suspension system works to keep the wheels in contact with the road surface, which provides better traction and improves the vehicle's stability. This results in improved handling and control, especially in challenging driving conditions.

Reliable: Passive suspension systems are known for their reliability and durability. These systems are designed to withstand harsh road conditions and can last for a long time with proper maintenance. The simple design of passive suspension systems makes them less prone to failure and requires minimal maintenance, which makes them a popular choice among automobile manufacturers.

1.2.2. Disadvantages of Passive Suspension System

Limited Adjustability: Passive suspension systems have limited adjustability, which makes it difficult to tune the system for specific driving conditions. These systems are designed to provide a comfortable ride quality under normal driving conditions, but they may not be suitable for high-performance driving.

Poor Performance on Rough Terrain: Passive suspension systems may not be suitable for rough terrain, as they do not have the ability to adapt to changing road conditions. The system's inability to adjust to rough terrain can result in a bumpy and uncomfortable ride for passengers and cause damage to the vehicle.

Lack of Customization: Passive suspension systems are designed to provide a comfortable ride quality for the average driver. However, some drivers may require a suspension system that is tailored to their specific needs. Passive suspension systems do not offer customization options, which can limit their suitability for certain drivers and driving conditions.

Passive suspension systems play a crucial role in ensuring the safety and comfort of passengers and preventing damage to the vehicle. These systems are cost-effective, and reliable, and improve the vehicle's handling and stability. However, they also have some limitations, including limited adjustability, poor performance on rough terrain, and lack of customization. It is essential to consider the driving conditions and requirements before choosing a suspension system for a vehicle.

1.3. SEMI-ACTIVE SUSPENSION SYSTEM

Semi-active suspension is a type of suspension system that is designed to provide a comfortable and stable ride for vehicles such as cars, trucks, and motorcycles. Unlike traditional passive suspension systems, which rely on mechanical components like springs and shocks to absorb the shocks and vibrations of the road, semi-active suspension systems use electronic and hydraulic components to adjust the suspension on the fly in response to changing road conditions. One of the key benefits of semi-active suspension is that it can provide a more comfortable and stable ride than traditional passive suspension systems. Because the system is constantly adjusting the suspension in real time, it can respond more quickly to changes in road conditions like bumps, potholes, and uneven surfaces. This means

that the vehicle can maintain a more stable and comfortable ride, even at high speeds or on rough terrain. There are several different types of semi-active suspension systems, each with its own unique set of features and benefits. One common type of semi-active suspension is known as electromagnetic suspension. This type of suspension uses powerful electromagnets to adjust the suspension in real-time, based on data from sensors that measure the position and movement of the vehicle. By adjusting the magnetic field in the suspension, the system can provide a smoother, more stable ride. Another type of semi-active suspension is known as hydraulic suspension. This type of suspension uses hydraulic fluid to adjust the suspension in real-time, based on data from sensors that measure the position and movement of the vehicle. By adjusting the flow of fluid in the suspension, the system can provide a smoother, more stable ride. A third type of semi-active suspension is known as pneumatic suspension. This type of suspension uses air pressure to adjust the suspension in real-time, based on data from sensors that measure the position and movement of the vehicle. By adjusting the air pressure in the suspension, the system can provide a smoother, more stable ride.

Regardless of the type of semi-active suspension used, these systems all work by using sensors to measure the position and movement of the vehicle, and then adjusting the suspension in real time to provide the best possible ride. This means that the vehicle can maintain a more stable and comfortable ride, even under challenging conditions like high speeds or rough terrain. There are several key advantages to using semi-active suspension in vehicles. One of the biggest advantages is that it can help to reduce driver fatigue and increase safety. By providing a more stable and comfortable ride, semi-active suspension can help to reduce the amount of vibration and jarring that drivers experience, which can help to reduce fatigue and improve concentration on the road. This, in turn, can help to reduce the risk of accidents and improve overall safety.

Another advantage of semi-active suspension is that it can help to improve fuel efficiency. By providing a more stable and efficient ride, semi-active suspension can help to reduce the amount of fuel that is consumed by the vehicle. This can be particularly important for larger vehicles like trucks and buses, which can consume significant amounts of fuel over long distances. Finally, semi-active suspension can help to improve the overall comfort and convenience of the vehicle. By providing a

more stable and comfortable ride, these systems can make it easier and more enjoyable to drive or ride in the vehicle, which can be particularly important for long journeys or for vehicles that are used for commercial purposes. Semi-active suspension is an important technology that is used in a wide range of vehicles, from cars and trucks to motorcycles and buses. By using electronic and hydraulic components to adjust the suspension in real-time, these systems can provide a more stable, comfortable, and efficient ride, while also helping to improve driver safety and reduce fatigue. Whether you are a professional driver or simply looking for a more comfortable and enjoyable ride, a semi-active suspension can help to make your driving experience smoother and more enjoyable.

1.4. ACTIVE SUSPENSION SYSTEMS

An active suspension system is a form of car damper system that actively adjusts a vehicle's suspension features using electronic controls. It is a cutting-edge technology that is intended to improve a vehicle's drive ease, utilising, equilibrium, and reliability. The active suspension system monitors the movement of the vehicle with digital gauges and adjusts the suspension components accordingly. This technology can be utilised in a variety of vehicles, including cars, lorries, and buses.

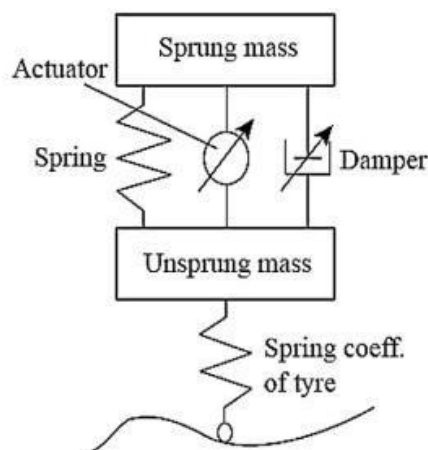


FIG 1.3: Suspension system classification (Active suspension)

Active suspension is a sophisticated technology that has revolutionized the automotive industry, allowing for enhanced ride comfort, stability, and handling. Active suspension systems work by using sensors and onboard computers to monitor the road and vehicle conditions, and then adjusting the suspension settings in real time to provide the optimal driving experience. One of the primary benefits of

active suspension is improved ride comfort. By constantly adjusting the suspension, the system can reduce the impact of bumps and road irregularities on the vehicle occupants, resulting in a smoother ride. This can be particularly important for luxury vehicles, where a comfortable ride is a key selling point. Another significant advantage of active suspension is improved handling and stability. By adjusting the suspension in real-time, the system can help to reduce body roll and improve cornering performance. This can be particularly important for sports cars, where precise handling is essential for optimal performance.

To alter the damping settings, active suspension systems typically employ an arrangement of pneumatic actuators and electrical sensors. Changes in the road surface and vehicle dynamics are detected by the gauges, and the springs modify the suspension correspondingly. The system can also be designed to react differently depending on vehicle circumstances, such as high speed, cornering, or rough road surfaces. While active suspension systems have many advantages, they can also be costly and difficult to maintain. They have a large number of digital and mechanical gadgets that can be difficult to fix or replace if they fail. Furthermore, the more complex nature of the system can make it harder to identify and remedy problems as they develop. Active damping is a revolutionary innovation that has significantly enhanced modern car ride comfort, stability, and handling. While there are some potential downsides to the technology, such as expense and complexity, the benefits are strong enough that active adjustment is now conventional on many high-end automobiles.

1.4.1. Advantages of Active Suspension System

Improved Ride Comfort: One of the main advantages of an active suspension system is improved ride comfort. The system can adjust the suspension components to provide a smooth and comfortable ride even on rough roads. This is achieved by reducing the vibrations and shocks that are transmitted to the vehicle's body, resulting in a more comfortable ride for the passengers.

Better Handling and Stability: Another advantage of an active suspension system is better handling and stability. The system can adjust the suspension components in real-time to provide optimal handling and stability even in challenging driving

conditions such as high-speed turns, sudden braking, and uneven terrain. This results in better vehicle control, improved safety, and reduced risk of accidents.

Enhanced Safety: An active suspension system can improve safety by reducing the risk of accidents. The system can adjust the suspension components to compensate for changes in the road surface, such as potholes, bumps, and curves, ensuring that the vehicle remains stable and safe to drive. This reduces the risk of accidents caused by loss of control or instability.

Improved Performance: An active suspension system can also improve the performance of a vehicle. By adjusting the suspension components, the system can improve the vehicle's acceleration, braking, and cornering abilities. This results in better overall performance and a more enjoyable driving experience for the driver.

1.4.2 Disadvantages of Active Suspension System

Cost: One of the main disadvantages of an active suspension system is cost. The system is more expensive to install and maintain compared to conventional suspension systems. This can make the vehicle more expensive to purchase and may also increase the cost of repairs and maintenance.

Complexity: Another disadvantage of an active suspension system is complexity. The system consists of several electronic components that need to work together to provide optimal performance. This can make the system more difficult to repair and maintain, and may also increase the risk of system failure.

Energy Consumption: An active suspension system requires more energy to operate compared to conventional suspension systems. This is because the system relies on electronic components that consume energy to function. This can result in reduced fuel efficiency and increased operating costs.

Reliability: An active suspension system may be less reliable compared to conventional suspension systems. This is because the system consists of several electronic components that may be prone to failure over time. This can result in increased repair and maintenance costs, and may also reduce the overall lifespan of the system.

An active suspension system is an advanced technology that can provide several benefits for vehicles, including improved ride comfort, better handling and stability,

enhanced safety, and improved performance. However, the system also has some disadvantages, including cost, complexity, energy consumption, and reliability. Before deciding to install an active suspension system, it is important to carefully consider these advantages and disadvantages and determine if the benefits outweigh the costs.

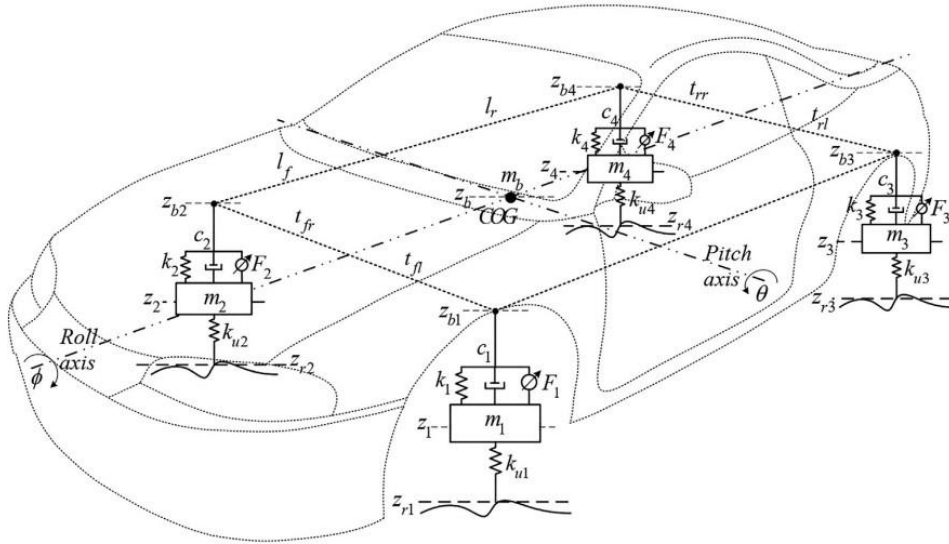


FIG 1.4: 7 degrees of freedom active suspension model

Table 1.1 – Model Parameters for Active Suspension System

Symbols	Units	Definition
l_f	m	The gap between the front axle and the centre of gravity (COG).
l_r	m	The gap between the rear axle and the centre of gravity (COG).
t_{fl}	m	The distance existing in the front left tire and roll axis
t_{fr}	m	Distance existing in front right tire and roll axis
t_{rl}	m	Distance existing in the rear left tire and roll axis
t_{rr}	m	Distance existing in rear right tire and roll axis
m_b	kg	Mass of the body
$m_{1,2}$	kg	Masses of the front wheels
$m_{3,4}$	kg	Masses of the rear wheels

k_{ui}	N/m	Tire spring constants
$k_{1,2}$	N/m	Suspension spring constants (Front)
$k_{3,4}$	N/m	Suspension spring constants (Rear)
$c_{1,2}$	Ns/m	Suspension damping coefficients (Front)
$c_{3,4}$	Ns/m	Suspension damping coefficients (Rear)
I	kgm^2	Roll inertia
J	kgm^2	Pitch inertia
F_i	N	Force of actuator
Z_i	m	Vertical position of the tire
Z_b	m	Vertical position of the body
Z_{ri}	m	Road excitations
Z_{bi}	m	Suspension and body link point positions
ϕ	radian	Roll angle
θ	radian	Pitch angle

1.5. STRUCTURAL MODEL OF THE ACTIVE SUSPENSION SYSTEM

Dynamic damper is a form of vehicle suspension system that uses cutting-edge technology to continuously control the movement of a vehicle's wheels in real time, resulting in a more seamless and controlled ride. It varies from passive suspension systems in that it incorporates sensors, actuators, and electronic control units (ECUs) to continually alter equilibrium settings based on numerous inputs such as driving circumstances, vehicle velocity, and human inclinations. In this post, we will look in depth at the structural model of active suspension. Active suspension structure models often include numerous vital parts, including as actuators, sensing components, ECUs, and mechanical elements. Let us examine each of these components in greater detail:

Sensors: Active suspension systems rely on sensors to gather data about the vehicle's motion, road conditions, and other relevant parameters. These sensors can include accelerometers, gyroscopes, position sensors, ride height sensors, wheel speed sensors, and other types of sensors. The data collected by these sensors is used by the ECUs to make real-time adjustments to the suspension settings.

Actuators: Actuators are responsible for physically adjusting the suspension settings based on the inputs received from the sensors and the commands from the ECUs. These can include hydraulic or pneumatic actuators, electric motors, or electromagnetic actuators. Actuators can be placed at various locations in the suspension system, such as the dampers, springs, or anti-roll bars, to provide precise control over the suspension movement.

ECUs: Electronic Control Units (ECUs) are the "brains" of the active suspension system. They receive data from the sensors, process it, and send commands to the actuators to adjust the suspension settings accordingly. ECUs can be located in various parts of the vehicle, such as the chassis, suspension components, or central processing unit (CPU) of the vehicle's overall electronic control system. They can also communicate with other ECUs in the vehicle to coordinate the overall performance of the active suspension system.

Mechanical Elements: The mechanical elements of an active suspension system include the springs, dampers, and anti-roll bars. These components work together with the sensors, actuators, and ECUs to provide a smooth and controlled ride. Springs are responsible for absorbing energy from the road impacts and supporting the vehicle's weight, while dampers control the rate of suspension movement and provide damping force to control the vehicle's motion. Anti-roll bars help to reduce body roll during cornering and provide stability to the vehicle.

The structural model of active suspension can be further categorized into several types based on the design and operation of the system:

Active Damping Suspension: This type of active suspension system uses actuators in the dampers to adjust the damping force in real-time. The ECUs receive data from sensors, such as accelerometers and wheel speed sensors, to detect the road conditions and adjust the damping force accordingly. This type of system provides excellent ride comfort and handling performance by minimizing body movements and vibrations.

Active Spring Suspension: In this type of active suspension system, actuators are used in the springs to adjust the stiffness of the springs in real-time. This allows for fine-tuning of the suspension settings based on the road conditions and driving

conditions. Active spring suspension systems can provide improved ride comfort, stability, and handling performance.

Active Roll Control Suspension: Active roll control suspension systems use actuators in the anti-roll bars to adjust the stiffness of the bars in real-time. This allows for active control of body roll during cornering, which can improve vehicle stability and handling performance. This type of system is commonly used in high-performance and sports vehicles.

Active Height Control Suspension: This type of active suspension system uses actuators to adjust the ride height of the vehicle

1.6. ACTUATORS MAJORLY USED IN ACTIVE SUSPENSION

Actuators play a crucial role in active suspension systems, as they are responsible for physically adjusting the suspension settings in real-time based on inputs from sensors and commands from Electronic Control Units (ECUs). Actuators are used to control various components in the suspension system, such as the dampers, springs, anti-roll bars, and ride height, to provide a smooth and controlled ride, improved handling, and enhanced stability. Let's explore the different types of actuators used in active suspension systems in detail.

Hydraulic/Pneumatic Actuators: Hydraulic or pneumatic actuators are commonly used in active suspension systems due to their ability to generate high forces and provide precise control over the suspension movement. These actuators use hydraulic or pneumatic pressure to adjust the damping force, stiffness of the springs, or stiffness of the anti-roll bars. They can be controlled by valves that regulate the flow of fluid or gas, allowing for quick and accurate adjustments to the suspension settings.

Electric Motors: Electric motors are another type of actuator used in active suspension systems. These motors can be brushless DC motors or stepper motors and are typically used for adjusting the stiffness of the springs or the ride height of the vehicle. Electric motors provide fast response times, high precision, and can be easily integrated into the vehicle's electrical system. They are also known for their efficiency and low noise levels, making them suitable for automotive applications.

Motors are another form of actuator seen in active suspension systems. These motors, which can be brushless DC or stepper motors, are often employed to alter the stiffness of the springs or the vehicle's ride height.

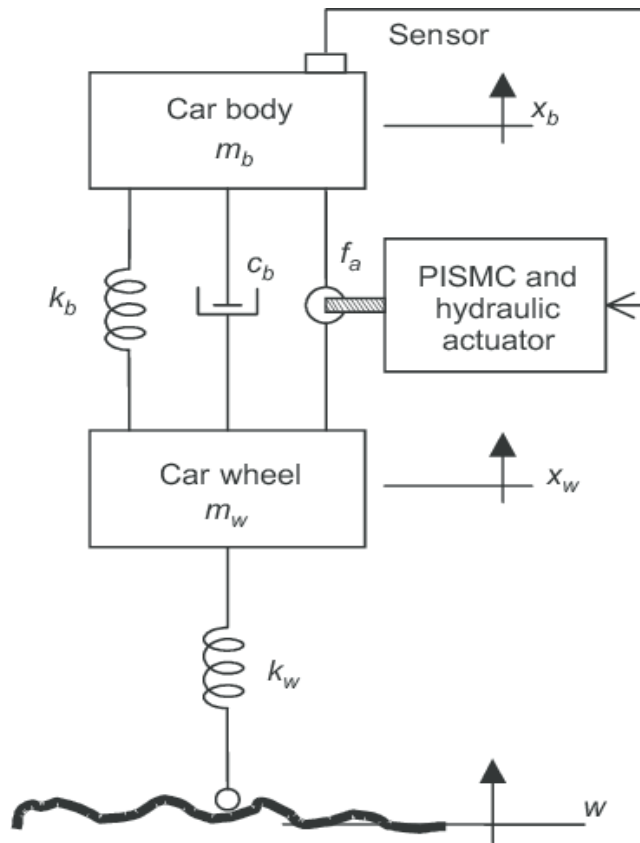


FIG 1.5: Hydraulic actuator for a quarter-car model with active suspension system

Electromagnetic Actuators: Electromagnetic actuators use the principles of electromagnetic fields to generate mechanical motion. These actuators typically consist of a coil and a magnet, and when an electric current is passed through the coil, it generates a magnetic field that interacts with the magnet to produce motion. Electromagnetic actuators can be used to adjust the damping force, stiffness of the springs, or stiffness of the anti-roll bars in active suspension systems.

Electrohydraulic Actuators: Electrohydraulic actuators combine the benefits of hydraulic and electric actuators, as they use both hydraulic and electrical components to generate motion. These actuators typically consist of a hydraulic cylinder driven by an electric motor, which allows for precise control over the damping force or other suspension settings. Electrohydraulic actuators are known for their high force capabilities, fast response times, and accurate control, making them suitable for demanding applications like active suspension systems.

Magnetorheological (MR) Dampers: MR dampers are a special type of actuator commonly used in active suspension systems. These dampers use a fluid

The diagram illustrates a vehicle chassis model with front and rear sections. The front section (left) features a steering knuckle assembly with a spring-damper system (c_{sf}, k_{sf}) and a lower control arm assembly (c_{uf}, k_{uf}). The rear section (right) features a similar spring-damper system (c_{sr}, k_{sr}) and a lower control arm assembly (c_{ur}, k_{ur}). The chassis is represented by a rigid body with mass m_s and moment of inertia I_{sL}. The diagram shows vertical displacements z_{sf}, z_{sr}, z_{uf}, z_{ur}, z_{rf}, and z_{rr}, as well as steering angles i_{mrf} and i_{mrr}. The center of gravity is marked with a green dot, and the roll angle φ_{sp} is indicated.

In addition to these types of actuators, other advanced technologies such as piezoelectric actuators and shape memory alloys (SMAs) are also being explored for use in active suspension systems. Piezoelectric actuators use the properties of piezoelectric materials to generate mechanical motion when subjected to an electric field, while SMAs can change their shape and stiffness when heated or cooled. These technologies offer unique advantages such as high precision, compact size, and lightweight, which can be beneficial in certain applications. Actuators are critical components of active suspension systems, providing the ability to adjust the suspension settings in real time and enhance the performance of the vehicle.

CHAPTER 2

LITERATURE SURVEY

The maximum sprung mass acceleration of a semi-active suspension system and a passive suspension system are 93.9% and 63.70%, respectively, as per the the Bingham model. A semi-dynamic MR damper is a new way for circulating the reaction of a quarter-vehicle model driving over uneven ground. The MR damper outperforms the standard passive damper system in terms of efficiency.

This study explored the challenge of constructing adaptivity of sliding-mode controllers for active suspension systems that is nonlinear using a T-S fuzzy approach. This model handles the uncertainty raised by the spring and damper accomplishing this task load variations. We incorporate an adaptive sliding-mode controller to rectify the well-known dynamic actuator that's nonlinear. The above-mentioned controller ensured that the required switching surface was reachable. Following that, we provided sufficient conditions to verify that the dynamics were asymptotically stable on the needed switching surface and performed well under H norm constraints.

These conditions, which were resolved using standard procedures, were presented utilising convex enhancement. A disturbance observer is used to develop a down slipping method control approach for dynamic suspension. The technique properly assesses the effects of uncertainties and unusual road characteristics. The simulation results for the three distinct surface profiles and load changes exhibited in the D-O-S-M-C technique, with a solo level of handling parameters, greatly develops performance of sprung mass displacement and acceleration while comparing handling standards. It is feasible to enhance the DOSMC variant by using a approximation of the retired component of use. The suggested control law is tested in an experimental context, which supports the proposal.

The effect of vehicle vibrations on the physiology and psychology of passengers remains a complex problem. As a result, one of the most challenging aspects of vehicle design has been determining how to make the ride comfortable for passengers, which is dependent on heave and pitch. A FLC mechanism that is used for an dynamic vehicle is proposed in this study. Counterforce is achieved using a

suspension system to separate vibration from uneven terrain. The first step is to describe a mathematical model of a half-car with four degrees of freedom (DOF). Furthermore, the translation and pitch motions go through a "decoupling transformation." The hydraulic actuator is then added. Using MATLAB/Simulink software, the equational model of a dynamic damped one-fourth part of the vehicle suspension system was developed for testing. Based on the ideal sky-hook system behaviour, the mentioned controller is used to mimic the performance of a perfect reference system. The proposed SMC algorithm's system performance is contrasted with that of the passive suspension system.

The half-car model is employed in this study to account for the car's vertical and pitch movements. The investigation's goals are as follows. The main purpose is to make the journey more comfortable. ISO 2631 uses vertical acceleration and pitch acceleration to assess how enjoyable the ride is. These speeds should be reduced by the controller. The second objective is to increase driving steadiness. The relationship between both front and rear wheel vertical forces and driving stability is widely established. Vertical forces should be reduced by the controller. The ultimate objective is to keep the system stable in the presence of confusing parameters. This study describes the synthesis of a dynamic suspension controller.

In this work, a 6-DOF half-vehicle model is required to apply and quantify the mentioned suspension system idea. The idea for a dynamic suspension design is based on a phenomenon known as a postponed resonator. This process provides a handling signal that is the opposite to the to and fro motion that requires to be quieted and stabilized. Every harmonic output loses strength when it is objected to its opposite. "Oscillation" refers to a disturbance caused by the road that affects the vehicle, and the dampening system's aim is to remove oscillations at the same time. The endeavours is difficult in part because the frequency and amplitude of the oscillations vary widely.

The study presents a robust H-two controller structural limits on the dynamic suspension utilising the one of two parts of a vehicle model by resolving a limited amount of LMIs. The frequency filter and the H2 controller collaborate to improve ride comfort. Time-domain limitations are employed to adjust for wheel vertical torque restrictions, suspensionally stroke limits, and controlling accepting

constraints. Using the polytopic formulation ensures that the car body remains stable even if both the front and rear weights shift. Alternatively, the effectiveness of the suggested controller is evaluated through simulations and experiments. The study goes over the Spencer MR damper model as well as vibration management for a 4-DOF 1/2-car model.

The validation of numerous control methods—control techniques, non-linear control approaches, and LQ control based on quadro pendro feedback—was achieved. The efficiency of vibration control was investigated using two road excitation settings, out-of-phase excitation of the F and R vehicle components. The control gains gained by overcoming the L-Q problem were additionally tweaked to improve control quality.

The basic function of the car's damper mechanism is to keep the main frame of the automobile free of all morphologies of the road, imperfections, therefore increasing comfort for travellers and keeping the vehicle's equilibrium. The present research offers a four-degree-of-freedom asymmetric permanent suspension system representation for a half-vehicle, as well as an architecture for dual loop PID management of generated force and correction variables. The inside fluid actuator PID force management loop and the outside damping variables controlled by the PID loop comprise the two loop configurations. A numerical simulation combining irregular active PID-based suspension structures with complex passive shock systems was performed using a comparable variable model for both types of suspension.

An adaptive vibration management approach for a fraction-vehicle suspension mechanism is provided on the standpoint of remotely predicting lacking information data. The live estimation of perturbation trajectory created by unbalanced pavements and velocity status factors is studied using a novel signal splitting approach. Position observations are considered to be used only for dynamic disruption mitigation control implementation. The development of control forces or extensive computational representations of specific fluid structures is not required for immediate form data discrimination. Actuators are devices that use magneto or hydraulic energy to operate can offer the ability to regulate forces. The mathematical and simulation results demonstrate the efficacy and quickness of the online output

estimation, as well as an appropriate dynamic noise abatement on a fraction-vehicle active system.

The mechanical model on Simulink is claimed to accurately represent the dynamic features of the actuators because the results of simulation obtained using the computational model created on Simulink agree with the findings of the experimental test performed using the designed solenoid actuator. Tests employing the solenoid actuator simulation model can be used to fully understand the motion-related occurrences that arise during actuator activity. This research produced an electromagnetic actuator and matching PID controller to improve the handling and part-holding ability of a quarter-car model of a passenger car.

To increase the ride's road holding capabilities and convenience, a variety of mechanical changes are done. The article describes an innovative mathematical framework and trustworthy control approach for the development and management of a suspension system that is active with fluid mechanics for a qtr-car model. The suspension component of a car's purpose is to increase comfort during acceleration while keeping strong operating skills on a range of road conditions. By directly modulating settlement forces to fit roadway and driving circumstances, the controller for an automobile vehicle's suspension is intended to increase passenger comfort without sacrificing handling attributes.

A novel computational framework is constructed in this paper in order to offer a far more comprehensive statistical depiction of a dynamically operated stabilisation system for a quarter automobile prototype. Because it effectively separates the structure of the vehicle from the automobile's axles, the mechanism for suspension is considered to be one of among the most critical parts of an automobile. The car's axle system employs an innovative technology which delivers exceptional convenience and security to both drivers as well as travellers, particularly when the motor vehicle encounters an obstruction, a gap, or a bend in the road. In order to achieve the best functioning suspension for an extended period a multitude of factors related to the control of torso and suspend motions, as well as power transportation, must be addressed.

In this research investigation, we present a novel adaptive management technique for HCASS considering unknown slain-zone information. To begin, novel

estimates type flexible approach is used to overcome the unidentified kicked the bucket-zone intake issue encountered by HCASS. In accordance with the conclusions reported previously mentioned, a unique dynamic PPC control technique is devised to cope against a situation like this, given that transducer dead-zone feedback may hamper the system's effectiveness. Thorough computational simulations are done in order to confirm the efficacy of the suggested control mechanism.

The next generation of studies will focus on the limited abilities of sensors, time-dependent settings, and incident-triggered control. To address the control issue for an uncertain entire car autonomous suspension framework, this study developed an end-point control of the sliding mode solution. Instead of concentrating exclusively on the development of the controller to the axle system, we developed a flexible approach for the model used as a reference that use the fuzzy technique of control to achieve an optimum state. The TSMC was created methodically, including constantly improving the regulation algorithm with both nonlinear and linear components and creating the requisite Lyapunov functions, which ensured that the system maintained eschatological consistency while taking into consideration uncertainties. In addition, the surface that slides was created in a relatively short amount of time.

Electromagnetic motors operate air or hydraulic pistons in dynamic suspension systems, which are supplied with electricity by a pack of batteries or regular ICE. Hydraulic mechanisms are becoming more prevalent in movement management systems because of their architectural straightforwardness, substantial force population density, mechanical development, trustworthiness, and plentiful supply of commercial parts. BMW, for instance, is currently working on a known to inhibit-roll management system that employs a hydraulically-powered revolving actuator positioned in the automobile's militant-roll bar center. Yet another instance is Benz' dynamic chassis control framework, which uses high-pressure locations hydraulic components to that was before the-stress the suspension components, which causes known to inhibit-roll forces without linking both the axles. Nevertheless, there are significant drawbacks to adopting a system with hydraulics, including inefficient functioning due to the constant need for a pressurised system.

This study thoroughly evaluated the existing literature on car damper examinations and their recent advancements. Because of their power rejuvenation, simple construction, broad bandwidth function, flexible and precise force management, superior ride quality, and handling performance, electromagnetism dynamic dampers were expected to be the next trend in car suspension design. In recent years, advancements in power gadgets, electronic components, and materials with permanent magnets have permitted significant advancements in the electrically powered domain. Consistent and flexible state effectiveness, weight as well as volume reduction, unrestricted inclusion of electronic control systems in vehicles, dependability, and downsizing are all key factors in rationalizing towards more universal electrical drive utilizations.

CHAPTER 3

AIM AND SCOPE OF THE INVESTIGATION

The primary goal of this project and experiment was to compile all previously published papers on suspension systems into one comprehensive study. The study aimed to provide a better understanding of the current state of suspension systems and identify potential areas for future research. Additionally, the study sought to analyse the active and passive suspension systems. The study aimed to provide a thorough analysis and comparison of the various types of suspension systems used in different vehicles and identify their strengths and weaknesses. The findings from this study could potentially lead to improvements in vehicle design and performance. This would aid in the development of more efficient and effective suspension systems for various applications.

The efforts of many researchers and scholars have been taken as a reference for a better understanding. Their research has contributed to a better understanding of the dynamics and performance of suspension systems, which can lead to improved ride comfort and handling in vehicles. Additionally, their findings may have practical applications in the design and development of suspension systems for future cars. Their research has contributed to the advancement of knowledge in the field and may have practical implications for improving vehicle safety and performance. We have reached a number of advanced conclusions that are justified by thorough literature reviews. Furthermore, the findings of their research have been published in reputable academic journals and have been presented at international conferences, which indicates their significant impact on the scientific community. Evidently, their work can shape future research in this field and inform policy decisions related to vehicle safety and performance. Furthermore, policymakers could use their findings to develop more effective regulations and guidelines for the automotive industry. Future studies could build upon their research to further enhance our understanding of vehicle safety and performance.

CHAPTER 4

EXPERIMENT, MATERIALS, AND METHODS

4.1 MODELLING

The first step was the discussion and division of labour, during which we organized our tasks so that we could understand the project's goals and the experiment's results. Afterward, we noted the sections that needed extensive work.

4.1.1. Discussion

This project's main objective was to gather all previously published articles on suspension systems into one thorough research. The purpose of the study was to clarify the situation of suspension systems today and to suggest prospective directions for further investigation. The analysis of the active and passive suspension systems was another goal of the study. The purpose of the study was to compare and thoroughly analyse the various types of suspension systems utilised in various cars in order to pinpoint their advantages and disadvantages. The results of this study might influence changes in vehicle performance and design. This would support the creation of suspension systems for diverse applications that are more effective and efficient.

4.1.2. Simulation

Quarter-car, half-car, and full-car models are prepared in the active and passive suspension systems using MATLAB/SIMULINK simulation. The thought of using MATLAB for this project came with an understanding of its advantages in a project like this. MATLAB allows you to simulate a wide range of suspension system designs, making it a flexible tool for studying different types of suspension systems. MATLAB simulations can provide highly accurate results that closely match real-world data. This can help researchers to validate their suspension system designs and make more informed decisions about their performance. By using MATLAB simulations, researchers can quickly test and iterate through various suspension system designs, without having to spend time building and testing physical prototypes. Simulation in MATLAB can save the cost of developing and testing

physical prototypes. MATLAB's graphical interface makes it easy to visualize the results of the simulations. This can help researchers to gain a better understanding of how the suspension system is working and identify potential areas for improvement. MATLAB allows for the easy parameterization of the suspension system components, which can help researchers quickly evaluate the effect of changing different parameters on the system's performance. Using MATLAB simulations can help researchers to develop better suspension system designs that are more efficient, effective, and cost-efficient.

4.1.3. Fabrication

We developed a miniature model that exhibits the working condition of the actuator system. Actuators play a crucial role in the design and operation of active suspension systems. These systems are designed to improve the ride quality of vehicles by actively controlling the suspension system in response to changing road conditions. Active suspension systems with actuators can adapt to changing road conditions in real-time, resulting in a smoother and more comfortable ride for passengers. Actuators can respond quickly to sudden changes in road conditions, such as potholes or bumps, reducing the risk of accidents. Active suspension systems with actuators can improve the handling of vehicles by reducing body roll, pitch, and dive. This results in more stable and predictable handling, particularly at higher speeds. Actuators in active suspension systems can be programmed to adjust the suspension system to meet the specific needs of the vehicle and the driver. This can improve the overall performance of the vehicle, particularly in challenging driving conditions. Active suspension systems with actuators can reduce the wear and tear on other components of the suspension system, such as the shocks and struts. This can extend the lifespan of these components and reduce maintenance costs over time. The use of actuators in active suspension systems offers several benefits that can improve the overall performance, safety, and comfort of vehicles. These benefits make active suspension systems with actuators an attractive option for a wide range of vehicles and driving conditions.

4.2. ANALYSIS

The comparative study between active and passive suspension systems is a study and research-based experiment. Here we studied thoroughly the attested topics,

along with an apt literature survey. A glimpse of the work from the literature survey is shown above in chapter two. The simulations of the active and the passive suspension models are compared to show the difference in the vibrational disturbances. After collecting all the data from modelling, now in the analysis, we arrange it properly for better understanding. From the simulations and literature survey, we gather the information that Active suspension systems are an innovative technology designed to improve the performance and ride quality of vehicles by reducing vibrational disturbances caused by uneven road surfaces, acceleration, braking, and cornering. Compared to passive suspension systems, active suspension systems offer several advantages in reducing vibrational disturbances.

Active suspension systems use sensors and control algorithms to adapt the suspension system in real-time to changes in road conditions. This allows for a more responsive and precise adjustment of the suspension system, which can effectively reduce the effects of vibrational disturbances on the vehicle. Passive suspension systems, on the other hand, rely on mechanical components such as springs and dampers to absorb the shocks and vibrations, which are not as effective in reducing vibrational disturbances. Active suspension systems have the ability to actively counteract vibrational disturbances through the use of actuators that can adjust the suspension system independently for each wheel. This results in a smoother and more comfortable ride for passengers, even in challenging driving conditions. Passive suspension systems, on the other hand, can only provide limited adjustment and are not capable of actively counteracting vibrational disturbances. Active suspension systems can adjust the suspension system based on the specific needs of the vehicle and the driver. This allows for a more customized and optimized suspension system that can effectively reduce vibrational disturbances. In contrast, passive suspension systems are designed to provide a general level of comfort and performance and are not customizable to the specific needs of the vehicle and the driver. Active suspension systems can provide better handling and stability by reducing body roll, pitch, and dive. This results in more stable and predictable handling, particularly at higher speeds, which can help to reduce the effects of vibrational disturbances. Passive suspension systems, on the other hand, are not as effective in providing better handling and stability. Active suspension systems offer several advantages over passive suspension systems in reducing vibrational

disturbances. The use of sensors, control algorithms, actuators, and customization options make active suspension systems a superior choice for vehicles that require a higher level of performance, comfort, and stability.

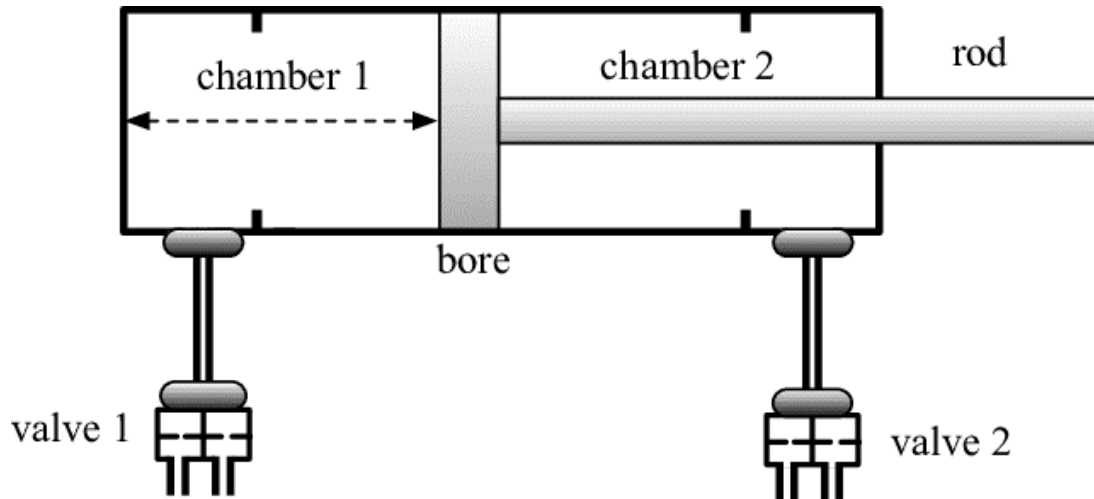


FIG 4.1: Schematic diagram of the actuator

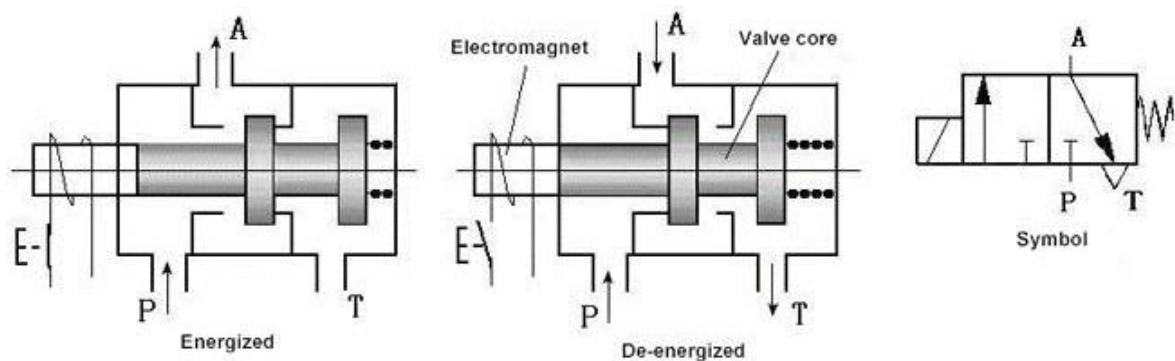


FIG 4.2: Schematic diagram of a normally closed solenoid valve

4.3. RESULTS

Resultant of this experiment is stating this information in research papers and journals for future use by students, researchers, and scholars. For the photographic results of the graph and simulation refer to chapter five.

The exact goals and constraints of the experiment will determine how well it performs in a research study on suspension systems. Improving ride comfort by lessening the effects of vibrations and road shocks is one of the main goals of suspension system development. A suspension system design that offers

passengers a smoother and more comfortable ride may be the result of a research endeavours. Research on suspension systems also aims to increase a vehicle's stability and handling, especially at high speeds. A research experiment might lead to a suspension system design that offers superior stability and handling, making driving safer and more pleasurable. Particularly in terms of fuel efficiency, suspension systems can have a considerable impact on a vehicle's energy usage. A suspension system design that optimizes the usage of energy-absorbing materials and lowers friction could be the result of a research experiment. Suspension systems can be costly to maintain, especially if they need replacement or repairs frequently. A suspension system design that uses more durable materials, enhances the component designs or eliminates the need for maintenance completely could be the result of a research trial. The performance of a vehicle's suspension systems is a key factor therefore research tests may focus on enhancing the system's overall performance. The outcome of a research experiment could be a suspension system design that offers improved performance in multiple areas, such as ride comfort, stability, handling, energy consumption, and maintenance costs.

CHAPTER 5

RESULTS AND DISCUSSION

In this section all the graphs and diagrams are arranged. Also, the discussion about the diagram is mentioned below.

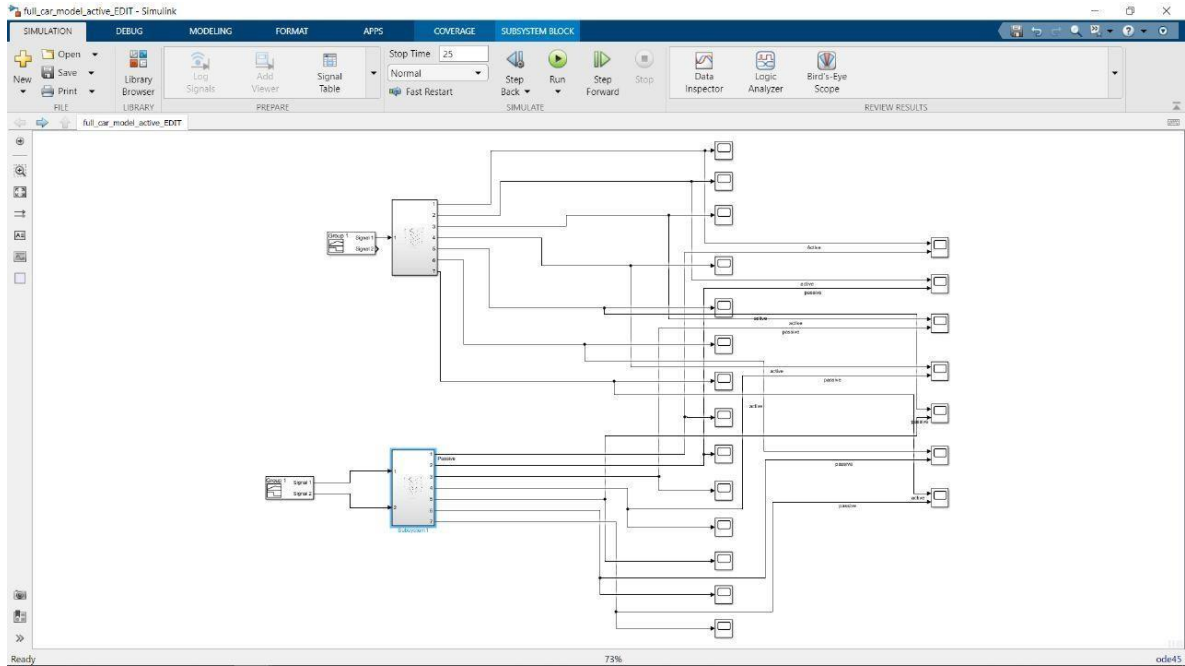


FIG 5.1: MATLAB simulation of the comparison between the active suspension system and passive suspension system

A comprehensive automobile model simulation of active and passive suspension systems using MATLAB is an efficient technique to evaluate and analyse a vehicle's behaviour under various driving circumstances. MATLAB is an extremely strong tool for creating a dynamic model of a vehicle's suspension system and simulating its response to external forces. Figure 7 depicts the modelling and analysis of both active and passive suspension systems. The passive suspension system consists mostly of springs and dampers, whereas the active suspension system contains additional components such as actuators and sensors.

The simulation entails providing various inputs to the vehicle, such as displacement [FIG 8], acceleration [FIG 9], pitch angle [FIG 10], roll angle [FIG 11], and bounce [FIG 12], and then analysing the reaction of the suspension system. The usage of graphs and animations in MATLAB enables for the visualisation of the suspension system's reaction. The blue line in the graph depicts vibrations induced by active

suspension, whereas the yellow line reflects vibrational disturbances caused by passive suspension.

The simulation results can be used to optimise the suspension system's design, find the optimal suspension settings for a particular driving situation, or compare the performance of several suspension systems. Engineers and researchers working on vehicle dynamics will benefit from a comprehensive automobile model simulation of active and passive suspension systems using MATLAB. It enables the controlled and cost-effective investigation and optimisation of suspension systems.

5.1. GOVERNING EQUATIONS USED FOR MODELLING

The governing equations for the entire automobile model's active and passive suspension systems are complicated and incorporate many variables. A car's suspension system is crucial to delivering a comfortable ride while also preserving stability. The suspension system is in charge of absorbing road imperfections' shocks and vibrations, as well as minimising excessive body roll while cornering. Suspension systems are classified into two types: passive and active.

Passive Suspension System: This system is made up of springs and dampers. The springs are in charge of sustaining the weight of the vehicle and ensuring a smooth ride. The dampers, on the other hand, are in charge of moderating the springs' mobility.

Sensors, controllers, actuators, and springs/dampers are all part of an active suspension system. The sensors monitor the car's displacement, velocity, and acceleration, and the controllers utilise this data to determine the best force to apply to the springs and dampers. The force necessary to modify the suspension system is generated by the actuators.

Understanding the behaviour of the automobile on the road requires understanding the governing equations for the whole car model of active and passive suspension systems. Engineers may use the equations to create suspension systems that give a smooth and comfortable ride while preserving stability and control. The equations and parameters utilised in the simulation of the whole automobile model of active and passive suspension systems are listed below. The equations for vertical vibration motion, pitching motion, and rolling motion for a cabin are Equations. (1),

(2), and (3), in that order. The equations of motion for rolling motion, pitching motion, and vertical vibration for chassis are described in Equations (4), (5), and (6), respectively. Equations (7) and (8) show the vertical vibration of the left and right wheels on the front axle, respectively, whereas equations (9) and (10) show the vertical vibration of the left and right wheels on the rear axle.

$$\begin{aligned}
& m_{cab}\ddot{z}_{cg} + k_{ss11}[z_{cg} - \theta a + \phi d - (z_{cg1} - \theta_1 a_1 + \phi_1 d_1)] + c_{ss11}[\dot{z}_{cg} - \dot{\theta} a + \dot{\phi} d - \\
& (\dot{z}_{cg1} - \dot{\theta}_1 a_1 + \dot{\phi}_1 d_1)] + k_{ssr1}[z_{cg} - \theta a - \phi c - (z_{cg1} - \theta_1 a_1 - \phi_1 c_1)] + \\
& c_{ssr1}[\dot{z}_{cg} - \dot{\theta} a - \dot{\phi} c - (\dot{z}_{cg1} - \dot{\theta}_1 a_1 - \dot{\phi}_1 c_1)] + k_{ss12}[z_{cg} + \theta b + \phi d - (z_{cg1} + \theta_1 b_1 + \\
& \phi_1 d_1)] + c_{ss12}[\dot{z}_{cg} + \dot{\theta} b + \dot{\phi} d - (\dot{z}_{cg1} + \dot{\theta}_1 b_1 + \dot{\phi}_1 d_1)] + k_{ssr2}[z_{cg} + \theta b + \phi d - \\
& (z_{cg1} + \theta_1 b_1 + \phi_1 d_1)] + c_{ssr2}[\dot{z}_{cg} + \dot{\theta} b + \dot{\phi} c - (\dot{z}_{cg1} + \dot{\theta}_1 b_1 + \dot{\phi}_1 c_1)] = 0 \quad (1)
\end{aligned}$$

$$\begin{aligned}
& I_{yy(cab)}\ddot{\theta}_{cg} - k_{ss11}[z_{cg} - \theta a + \phi d - (z_{cg1} - \theta_1 a_1 + \phi_1 d_1)] \times a - c_{ss11}[\dot{z}_{cg} - \dot{\theta} a + \\
& \dot{\phi} d - (\dot{z}_{cg1} - \dot{\theta}_1 a_1 + \dot{\phi}_1 d_1)] \times a - k_{ssr1}[z_{cg} - \theta a - \phi c - (z_{cg1} - \theta_1 a_1 + \phi_1 c_1)] \times a - \\
& c_{ssr1}[\dot{z}_{cg} - \dot{\theta} b + \dot{\phi} d - (\dot{z}_{cg1} - \dot{\theta}_1 b + \dot{\phi}_1 c_1)] \times a + k_{ss12}[z_{cg} - \theta b + \phi d - (z_{cg1} - \\
& \theta_1 b_1 + \phi_1 d_1)] \times b + c_{ss12}[\dot{z}_{cg} - \dot{\theta} b + \dot{\phi} d - (\dot{z}_{cg1} - \dot{\theta}_1 b_1 + \dot{\phi}_1 d_1)] \times b + k_{ssr2}[z_{cg} \\
& - \theta b + \phi c - (z_{cg1} - \theta_1 b_1 + \phi_1 c_1)] \times b + c_{ssr2}[\dot{z}_{cg} - \dot{\theta} b + \dot{\phi} c - (\dot{z}_{cg1} - \dot{\theta}_1 b_1 + \\
& \dot{\phi}_1 c_1)] \times b = 0 \quad (2)
\end{aligned}$$

$$\begin{aligned}
& I_{xx(cab)}\ddot{\phi}_{cg} + k_{ss11}[z_{cg} - \theta a + \phi d - (z_{cg1} - \theta_1 a_1 + \phi_1 d_1)] \times d + c_{ss11}[\dot{z}_{cg} - \dot{\theta} a + \\
& \dot{\phi} d - (\dot{z}_{cg1} - \dot{\theta}_1 a_1 + \dot{\phi}_1 d_1)] \times d - k_{ssr1}[z_{cg} - \theta a - \phi c - (z_{cg1} - \theta_1 a_1 + \phi_1 c_1)] \times c - \\
& c_{ssr1}[\dot{z}_{cg} - \dot{\theta} b + \dot{\phi} d - (\dot{z}_{cg1} - \dot{\theta}_1 b + \dot{\phi}_1 c_1)] \times c + k_{ss12}[z_{cg} - \theta b + \phi d - \\
& (z_{cg1} - \theta_1 b_1 + \phi_1 d_1)] \times d + c_{ss12}[\dot{z}_{cg} - \dot{\theta} b + \dot{\phi} d - (\dot{z}_{cg1} - \dot{\theta}_1 b_1 + \dot{\phi}_1 d_1)] \times d -
\end{aligned}$$

$$k_{ssr2}[z_{cg} - \theta b + \emptyset c - (z_{cg1} - \theta_1 b_1 + \emptyset_1 c_1)] \times c - c_{ssr2}[\dot{z}_{cg} - \theta \dot{b} + \emptyset \dot{c} - (\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{c}_1)] \times c = 0 \quad (3)$$

$$\begin{aligned} & m_{cg1}\ddot{z}_{cg1} - k_{ss11}[z_{cg} - \theta a + \emptyset d - (z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1)] - c_{ss11}[\ddot{z}_{cg} - \theta \ddot{a} + \emptyset \ddot{d} - (\ddot{z}_{cg1} - \theta_1 \ddot{a}_1 + \emptyset_1 \ddot{d}_1)] - k_{ssr1}[z_{cg} - \theta a - \emptyset c - (z_{cg1} - \theta_1 a_1 - \emptyset_1 c_1)] - c_{ssr1}[\dot{z}_{cg} - \theta \dot{a} - \emptyset \dot{c} - (\dot{z}_{cg1} - \theta_1 \dot{a}_1 - \emptyset_1 \dot{c}_1)] - k_{ss12}[z_{cg} + \theta b + \emptyset d - (z_{cg1} + \theta_1 b_1 + \emptyset_1 d_1)] - c_{ss12}[\dot{z}_{cg} + \theta \dot{b} + \emptyset \dot{d} - (\dot{z}_{cg1} + \theta_1 \dot{b}_1 + \emptyset_1 \dot{d}_1)] - k_{ssr2}[z_{cg} + \theta b + \emptyset d - (z_{cg1} + \theta_1 b_1 + \emptyset_1 d_1)] - c_{ssr2}[\dot{z}_{cg} + \theta \dot{b} + \emptyset \dot{c} - (\dot{z}_{cg1} + \theta_1 \dot{b}_1 + \emptyset_1 \dot{c}_1)] + k_{s11}[z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - z_{wr1}] + c_{s11}[\dot{z}_{cg1} - \theta_1 \dot{a}_1 + \emptyset_1 \dot{d}_1 - \dot{z}_{wr1}] + k_{sr1}[z_{cg1} - \theta_1 a_1 + \emptyset_1 c_1 - z_{wr1}] + c_{sr1}[\dot{z}_{cg1} - \theta_1 \dot{a}_1 + \emptyset_1 \dot{d}_1 - \dot{z}_{wr1}] + k_{s12}[z_{cg1} - \theta_1 b_1 + \emptyset_1 d_1 - z_{w12}] + c_{s12}[\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{d}_1 - \dot{z}_{w12}] + k_{sr2}[z_{cg1} - \theta_1 b_1 + \emptyset_1 c_1 - z_{wr2}] + c_{sr2}[\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{c}_1 - \dot{z}_{wr2}] = 0 \quad (4) \end{aligned}$$

$$\begin{aligned} & l_{yy1}\theta_1 + k_{ss11}[z_{cg} - \theta a + \emptyset d - (z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1)] \times a_1 + c_{ss11}[\dot{z}_{cg} - \theta \dot{a} + \emptyset \dot{d} - (\dot{z}_{cg1} - \theta_1 \dot{a}_1 + \emptyset_1 \dot{d}_1)] \times a_1 + k_{ssr1}[z_{cg} - \theta a - \emptyset c - (z_{cg1} - \theta_1 a_1 - \emptyset_1 c_1)] \times a_1 + c_{ssr1}[\dot{z}_{cg} - \theta \dot{b} + \emptyset \dot{d} - (\dot{z}_{cg1} - \theta_1 \dot{b} + \emptyset_1 \dot{c}_1)] \times a_1 + k_{ss12}[z_{cg} - \theta b + \emptyset d - (z_{cg1} - \theta_1 b_1 + \emptyset_1 d_1)] \times b_1 - c_{ss12}[\dot{z}_{cg} - \theta \dot{b} + \emptyset \dot{d} - (\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{d}_1)] \times b_1 - k_{ssr2}[z_{cg} - \theta b + \emptyset c - (z_{cg1} - \theta_1 b_1 + \emptyset_1 c_1)] \times b_1 + c_{ssr2}[\dot{z}_{cg} - \theta \dot{b} + \emptyset \dot{c} - (\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{c}_1)] \times b_1 - k_{s11}[z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - z_{wr1}] \times a_1 - c_{s11}[\dot{z}_{cg1} - \theta_1 \dot{a}_1 + \emptyset_1 \dot{d}_1 - \dot{z}_{wr1}] \times a_1 + k_{sr1}[z_{cg1} - \theta_1 a_1 + \emptyset_1 c_1 - z_{wr1}] \times a_1 + c_{sr1}[\dot{z}_{cg1} - \theta_1 \dot{a}_1 + \emptyset_1 \dot{d}_1 - \dot{z}_{wr1}] \times a_1 + k_{s12}[z_{cg1} - \theta_1 b_1 + \emptyset_1 d_1 - z_{w12}] \times b_1 + c_{s12}[\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{d}_1 - \dot{z}_{w12}] \times b_1 + c_{sr2}[\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{c}_1 - \dot{z}_{wr2}] \times b_1 + c_{sr2}[\dot{z}_{cg1} - \theta_1 \dot{b}_1 + \emptyset_1 \dot{c}_1 - \dot{z}_{wr2}] \times b_1 = 0 \end{aligned}$$

$$\begin{aligned} & \emptyset_1 d_1 - \dot{z}_{w12}] \times b_1 + k_{sr2}[z_{cg1} - \theta_1 b_1 + \emptyset_1 c_1 - z_{wr2}] \times b_1 + c_{sr2}[\dot{z}_{cg1} - \theta_1 b_1 + \emptyset_1 c_1 - \\ & \dot{z}_{wr2}] \times b_1 = 0 \end{aligned} \quad (5)$$

$$\begin{aligned} & I_{xx1} \emptyset_1 - k_{ss11}[z_{cg} - \theta a + \emptyset d - (z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1)] \times d_1 - c_{ss11}[\dot{z}_{cg} - \theta a + \emptyset d - \\ & (\dot{z}_{cg1} - \theta_1 a_1 + \emptyset_1 d_1)] \times d_1 + k_{ssr1}[z_{cg} - \theta a - \emptyset c - (z_{cg1} - \theta_1 a_1 + \emptyset_1 c_1)] \times c_1 - \\ & c_{ssr1}[\dot{z}_{cg} - \theta b + \emptyset d - (\dot{z}_{cg1} - \theta_1 b_1 + \emptyset_1 c_1)] \times c_1 + k_{ss12}[z_{cg} - \theta b + \emptyset d - \\ & (z_{cg1} - \theta_1 b_1 + \emptyset_1 d_1)] \times d_1 + c_{ss12}[\dot{z}_{cg} - \theta b + \emptyset d - (\dot{z}_{cg1} - \theta_1 b_1 + \emptyset_1 d_1)] \times d_1 + \\ & k_{ssr2}[z_{cg} - \theta b + \emptyset c - (z_{cg1} - \theta_1 b_1 + \emptyset_1 c_1)] \times c_1 + c_{ssr2}[\dot{z}_{cg} - \theta b + \emptyset c - \\ & (\dot{z}_{cg1} - \theta_1 b_1 + \emptyset_1 c_1)] \times c_1 + k_{s11}[z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - z_{wr1}] \times d_1 - c_{s11}[\dot{z}_{cg1} - \\ & \theta_1 a_1 + \emptyset_1 d_1 - \dot{z}_{w11}] \times d_1 + k_{sr1}[z_{cg1} - \theta_1 a_1 + \emptyset_1 c_1 - z_{wr1}] \times c_1 + c_{sr1}[\dot{z}_{cg1} - \theta_1 a_1 + \\ & \emptyset_1 d_1 - \dot{z}_{wr1}] \times c_1 + k_{s12}[z_{cg1} - \theta_1 b_1 + \emptyset_1 d_1 - z_{w12}] \times d_1 + c_{s12}[\dot{z}_{cg1} - \theta_1 b_1 + \\ & \emptyset_1 d_1 - \dot{z}_{w12}] \times d_1 + k_{sr2}[z_{cg1} - \theta_1 b_1 + \emptyset_1 c_1 - z_{wr2}] \times c_1 + c_{sr2}[\dot{z}_{cg1} - \theta_1 b_1 + \emptyset_1 c_1 - \\ & \dot{z}_{wr2}] \times c_1 = 0 \end{aligned} \quad (6)$$

$$\begin{aligned} & m_{w11} \ddot{z}_{w11} - k_{s11}(z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - z_{w11}) - c_{s11}(\dot{z}_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - \dot{z}_{w11}) + \\ & k_{w11}(z_{w11} - z_{r11}) + c_{w11}(\dot{z}_{w11} - \dot{z}_{r11}) = 0 \end{aligned} \quad (7)$$

$$\begin{aligned} & m_{wr1} \ddot{z}_{wr1} - k_{sr1}(z_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - z_{wr1}) - c_{sr1}(\dot{z}_{cg1} - \theta_1 a_1 + \emptyset_1 d_1 - \dot{z}_{wr1}) + \\ & k_{wr1}(z_{wr1} - z_{rr1}) + c_{wr1}(\dot{z}_{wr1} - \dot{z}_{rr1}) = 0 \end{aligned} \quad (8)$$

$$\begin{aligned} & m_{w12} \ddot{z}_{w12} - k_{s12}(z_{cg1} - \theta_1 b_1 + \emptyset_1 d_1 - z_{w12}) - c_{s12}(\dot{z}_{cg1} - \theta_1 b_1 + \emptyset_1 d_1 - \dot{z}_{w12}) + \\ & k_{w12}(z_{w12} - z_{r12}) + c_{w12}(\dot{z}_{w12} - \dot{z}_{r12}) = 0 \end{aligned} \quad (9)$$

$$m_{wr2}\ddot{z}_{wr2} - k_{sr2}(z_{cg1} - \theta_1 b_1 + \phi_1 c_1 - z_{wr2}) - c_{sr2}(\dot{z}_{cg1} - \dot{\theta}_1 b_1 + \dot{\phi}_1 c_1 - \dot{z}_{wr2}) + k_{wr2}(z_{wr2} - z_{rr2}) + c_{wr2}(\dot{z}_{wr2} - \dot{z}_{rr2}) = 0 \quad (10)$$

Table 5.1 – Parameters of the system
Model Parameters

S.No.	Unit	Parameter	Value
1.	kg	$m_{wl1} = m_{wr1} = m_{wl2} = m_{wr2}$	60
2.	kg	m_{cab}, m_{cg1}	1000, 1200
3.	N/m	$k_{wl1} = k_{wr1} = k_{wl2} = k_{wr2}$	37,0000
4.	N-s/m	$c_{wl1} = c_{wr1} = c_{wl2} = c_{wr2}$	700
5.	N/m	$k_{sl1} = k_{sr1} = k_{12} = k_{sr2}$	55,000
6.	N-s/m	$c_{sl1} = c_{sr1} = c_{sl2} = c_{sr2}$	4,000
7.	N-s/m	$k_{ss11} = k_{ssr1} = k_{ss12} = k_{ssr2}$	67,000
8.	N-s/m	$c_{ss11} = c_{ssr1} = c_{ss12} = c_{ssr2}$	6,000
9.	m	$a = b, c = d$	1.1, 1
10.	m	$a_1 = b_1, c_1 = d_1$	1.5, 1
11.	Kg- m^2	I_{xx}, I_{yy}	3200, 800
12.	Kg- m^2	I_{xx1}, I_{yy1}	4000, 950

5.1. Resultant Graphs

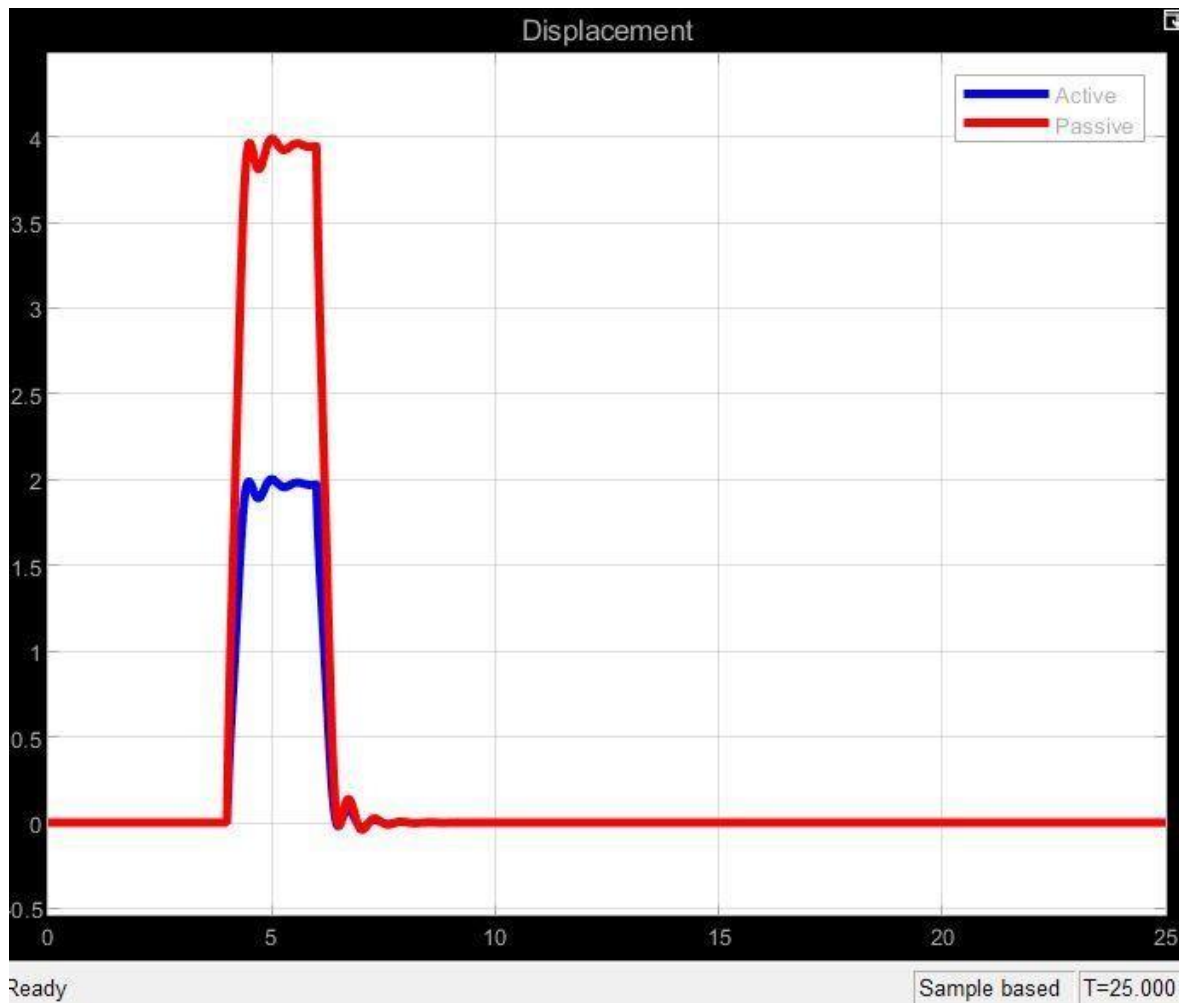


FIG 5.2: Input used as 'Displacement'

(Blue- passive suspension/yellow– active suspension)

In a passive suspension system, displacement of the vehicle's wheels due to uneven road surfaces or other external factors can cause the springs to compress or expand, which in turn affects the damping of the system. This can result in oscillations and vibrations that can be felt by the occupants of the vehicle. The damping forces generated by the shock absorbers may not be sufficient to counteract the displacement caused by road disturbances, resulting in reduced ride comfort and handling performance.

In an active suspension system, displacement can also cause disturbances that affect the performance of the system. However, the active suspension system can compensate for these disturbances by using sensors and actuators to adjust the

suspension settings in real time. The sensors detect the displacement of the wheels and send signals to the actuators, which adjust the damping forces and stiffness of the suspension system to counteract the disturbances. This results in improved ride comfort and handling performance, even on rough roads. Displacement can cause disturbances in both active and passive suspension systems, but active suspension systems are better equipped to compensate for these disturbances and maintain optimal performance.

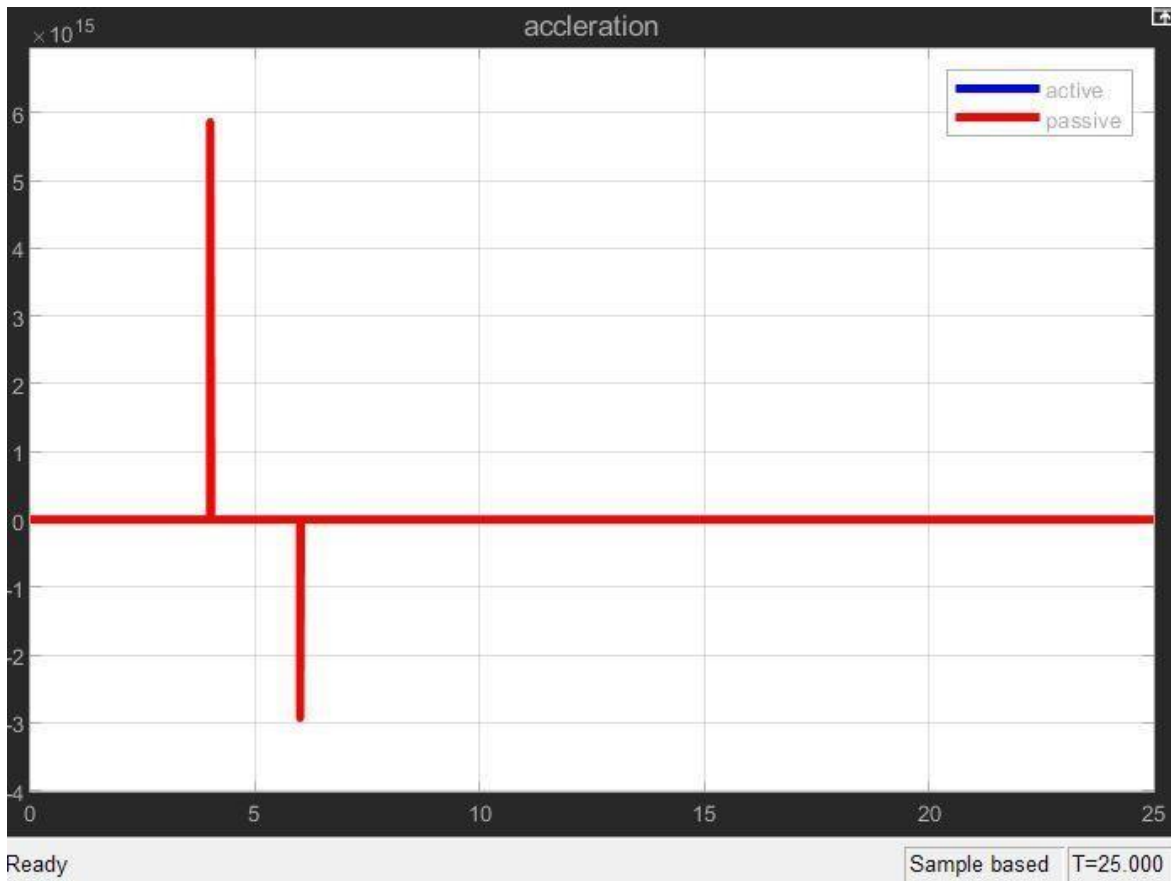


FIG 5.3: Input used as 'acceleration'

(Blue- passive suspension/yellow– active suspension)

Acceleration can cause disturbances in both active and passive suspension systems. In a passive suspension system, when the vehicle accelerates, the weight of the vehicle is transferred to the rear, causing the rear suspension to compress and the front suspension to extend. This can result in a change in the ride height and the handling of the vehicle. In an active suspension system, when the vehicle accelerates, sensors in the system detect the change in weight distribution and send signals to the actuators to adjust the suspension settings in real time. The actuators

can compress or extend the suspension components to maintain the optimal ride height and handling of the vehicle.

However, the response time of the active suspension system can sometimes be slower than the acceleration of the vehicle, which can cause some disturbances. The system may not be able to adjust the suspension settings quickly enough to compensate for the changes in weight distribution caused by acceleration, resulting in a temporary loss of stability. Overall, both passive and active suspension systems can be affected by disturbances caused by acceleration. While active suspension systems are designed to respond quickly to changes in weight distribution, they may not always be able to compensate for sudden changes in acceleration. It is important for engineers to consider these factors when designing and optimizing suspension systems for vehicles.



FIG 5.4: Input used as 'pitch angle'

(Blue- passive suspension/yellow– active suspension)

Pitch angle, which is the angle of rotation about the lateral axis of a vehicle, can cause disturbances in both active and passive suspension systems. In a passive

suspension system, pitch angle disturbances can cause the vehicle's body to pitch forward or backward, leading to changes in the vertical forces acting on the wheels. This can result in variations in the vehicle's handling and ride comfort. The suspension system may not be able to adequately absorb the shocks and vibrations caused by the pitch angle, leading to an uncomfortable ride and reduced vehicle stability. In an active suspension system, pitch angle disturbances can be actively controlled using sensors and actuators. The sensors detect the pitch angle and provide feedback to the control system, which then adjusts the suspension damping forces to counteract the effects of the pitch angle. This results in a more stable and comfortable ride, as the suspension system is able to quickly respond to changes in the pitch angle.

Pitch angle disturbances can have a significant impact on the performance of both passive and active suspension systems. While passive suspension systems may struggle to cope with the effects of pitch angle disturbances, active suspension systems can actively control and mitigate the impact of these disturbances, resulting in improved ride quality and stability. For Fig 5.5 The roll angle of a vehicle refers to the degree of lean that the vehicle experiences while turning. In a turn, the forces acting on the vehicle can cause it to lean to one side, which can affect the stability and handling of the vehicle. The suspension system plays an important role in minimizing the roll angle and improving the handling of the vehicle. In a passive suspension system, the roll angle disturbance is not actively controlled, and the vehicle's body roll is mainly resisted by the stiffness of the suspension components. This can lead to a bumpy and uncomfortable ride, especially during sharp turns or when the vehicle is loaded unevenly.

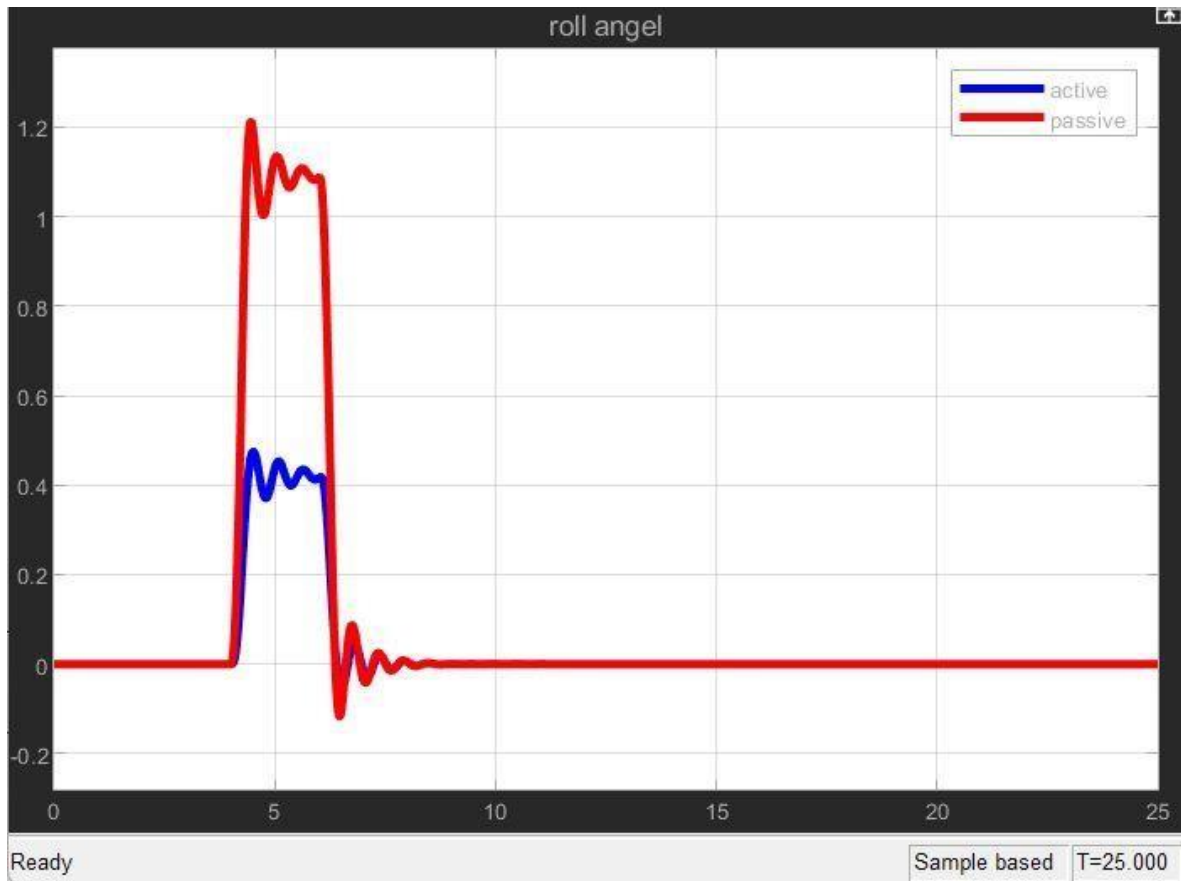


FIG 5.5: Input used as ‘roll angle’

(Blue- passive suspension/yellow– active suspension)

In contrast, an active suspension system can actively control the roll angle disturbance using sensors and actuators. The sensors can detect the roll angle of the vehicle and send this information to the controller, which can then adjust the damping forces of the suspension system to counteract the roll angle and improve the handling of the vehicle. This can result in a smoother and more comfortable ride, as well as improved stability and handling. The control of the roll angle disturbance is an important consideration when designing suspension systems for vehicles, and active suspension systems have the advantage of being able to actively control and minimize this disturbance.



FIG 5.6: Input used as 'bounce'

(Blue- passive suspension/yellow– active suspension)

Bounce is a common disturbance in both active and passive suspension systems. In a passive suspension system, the disturbance caused by bounce is absorbed by the springs and dampers. However, the amount of bounce absorbed is limited by the design of the suspension system and the properties of the components used. In contrast, active suspension systems have the ability to actively control and reduce the amount of bounce. This is achieved through the use of sensors that detect the vehicle's motion and actuators that adjust the suspension system in real-time. By adjusting the damping force and spring stiffness, active suspension systems can reduce the amount of bounce and improve the ride comfort and handling of the vehicle. However, active suspension systems are not immune to bounce disturbances. The response time of the sensors and actuators, as well as the control algorithms used, can affect the system's ability to effectively reduce bounce. In addition, external factors such as road conditions and vehicle speed can also impact the system's performance. Both passive and active suspension systems can be

affected by bounce disturbances, but active systems have the ability to actively control and reduce the disturbance to a greater extent than passive systems.

5.2. PROTOTYPE MODEL

A pneumatic actuator is a type of actuator that uses compressed air to produce mechanical motion. It is commonly used in a variety of industrial applications, such as in manufacturing, automation, and robotics. The basic design of a pneumatic actuator consists of a cylinder, a piston, and a valve. Compressed air is supplied to the cylinder through the valve, causing the piston to move in a linear motion. The piston is connected to a rod, which can be used to apply force or perform work. Pneumatic actuators are known for their speed and efficiency, as they can quickly and easily produce a large amount of force using compressed air. They are also relatively simple in design and easy to maintain. One of the main advantages of pneumatic actuators is their ability to operate in harsh environments, such as high temperatures or corrosive atmospheres, without experiencing significant wear or damage. Additionally, they are often used in applications where precise positioning or control is not required, as their motion can be relatively linear and predictable. However, pneumatic actuators do have some limitations. They require a constant supply of compressed air to operate, which can be expensive to maintain. They are also not suitable for applications that require fine control or high precision, as their motion can be affected by changes in air pressure or temperature. The displacement sensor that is connected to this pneumatic actuator senses movement or an impending obstruction and adjusts the cylinder movement to maintain the stability of the vehicle's chassis.

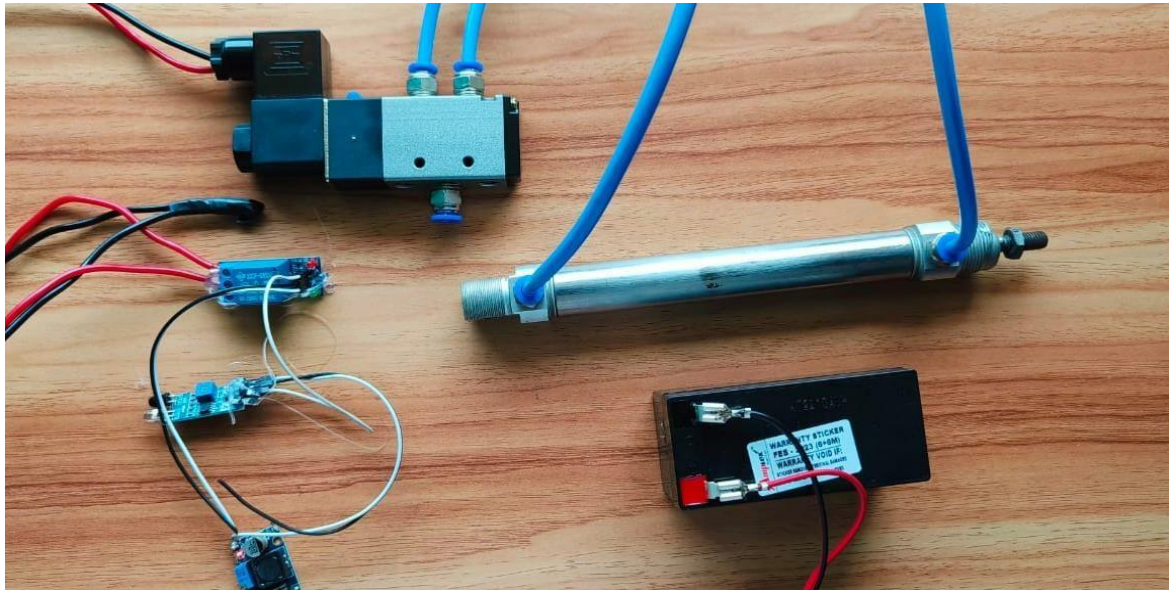


FIG 5.7: Prototype model of an actuator connected with the distance sensor

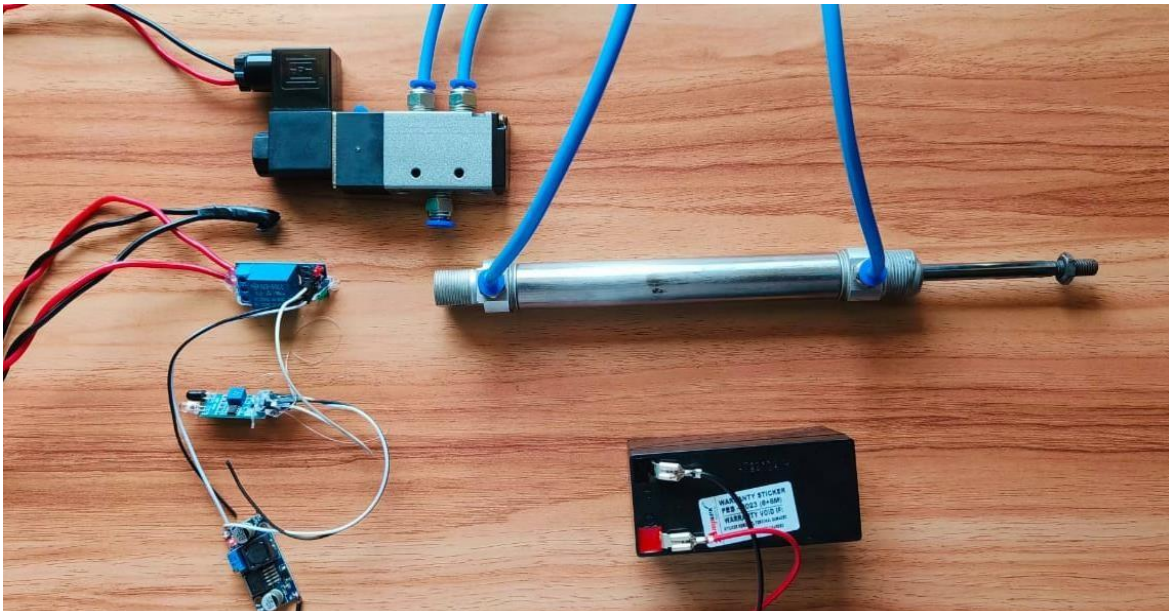


FIG 5.8: Prototype model with all connections and working piston



FIG 5.9: Actuator model

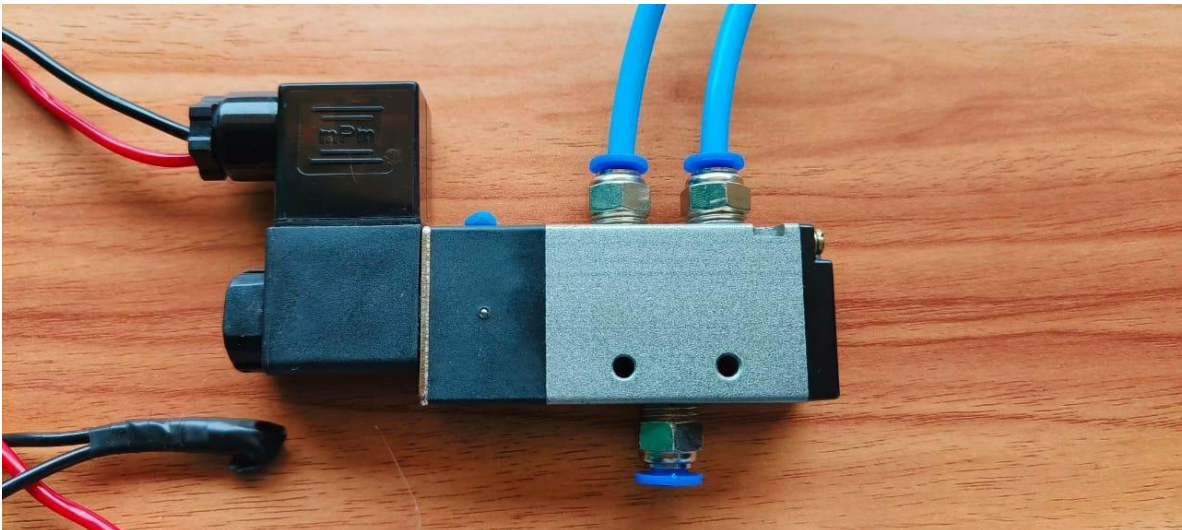


FIG 5.10: 3-way solenoid valve

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY OF THE REPORT

Dynamic suspension components are becoming growing in popularity in the automobile industry due to their potential to deliver improved ride comfort and handling when compared to standard passive suspension systems. In this article, we will look at the technical distinctions in the two types of suspension systems, as well as why a system with active suspension is thought to be superior. Passive suspension systems are meant to give a generally satisfactory degree of ride comfort and handling by absorbing shock and vibration from the road via springs and dampers. The springs and dampers are calibrated to create a combination of comfort and handling, although this balance can be difficult to attain due to the fact that changing road conditions necessitate varying suspension settings. As a result, the suspension may not always deliver the best comfort and handling. Active suspension systems, on the other hand, employ electronic control systems to alter suspension settings in real time based on the motion of the vehicle and external variables. This enables a considerably more accurate and sensitive suspension system capable of adapting to changing road conditions and driver inputs. Sensors monitor the motion of the vehicle and actuators alter the suspension settings in real time with active suspension systems. The ability of active suspension systems to decrease body roll, pitch, and dive during cornering, braking, and acceleration is one of its key advantages. This enables for more stable and predictable vehicle handling, which is especially vital for high-performance or racing cars. An active suspension system can also provide better traction control, as they can adjust the suspension settings based on the vehicle's speed and driving conditions. This can help to improve the vehicle's grip and handling, particularly in wet or slippery conditions.

Aside from these technological advantages, active suspension systems can increase overall vehicle safety. The technology can assist to minimise accidents and lower the risk of injury to passengers by offering superior handling and control of traction.

Comparative investigations of the two types of suspension systems are an essential element of vehicle dynamics research. Engineers may use these studies to examine the efficacy of various suspension systems under various driving circumstances and suggest areas for refinement. Scholars can establish the unique benefits and drawbacks of each system and optimise the design of future suspension systems through contrasting the performance of the two types of suspension systems.

6.2 CONCLUSION OF THE EXPERIMENT

In comparison research, the performance of a passive suspension system versus an active suspension system may be tested on a racing track or a bumpy road. The researchers would collect data on the vehicle's handling, riding comfort, and traction control and compare the results. This would enable them to determine the unique benefits and drawbacks of each system and optimise the design of future suspension systems.

In terms of engineering, active suspension systems are superior to passive suspension systems owing to their capacity to deliver greater ride convenience, dealing with, and traction control. Active suspension designs employ real-time electronic control systems to modify suspension settings, resulting in a more accurate and responsive suspension system that can react to changing road conditions and driver inputs. Comparative investigations between the two types of suspension designs are an essential aspect of vehicle dynamics research because they help researchers to optimise the design of future suspension systems and increase car efficiency.

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