Design of Electromagnetic Vehicle Suspension System

Tsion Mekonnen Geda

A Thesis Submitted to

The Department of Mechanical Systems and Vehicle Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for Master of Science in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

December, 2021

Adama, Ethiopia.

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By

Tsion Mekonnen Geda

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DECLARATION

I hereby declare that this Master Thesis entitled **“**Design of Electromagnetic Vehicle Suspension System” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Tsion Mekonnen Geda	________________	________________
Name of student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Design of Electromagnetic Vehicle Suspension System" prepared under our guidance by Tsion Mekonnen submitted in partial fulfillment of the requirements for Master of Science in automotive engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Mekonnen Liben (Asst.Prof.)	______________	______________
Major Advisor	Signature	Date
Dr. N.Ramesh Babu	______________	______________
Co-Advisor	Signature	Date

APPROVAL PAGE

We, the advisors of the thesis entitled “Design of Electromagnetic Vehicle Suspension System” and developed by Tsion Mekonnen, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

__________________	__________________	__________________
Major Advisor	Signature	Date
__________________	__________________	__________________
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Tsion Mekonnen have read and evaluated the thesis entitled “Design of Electromagnetic Vehicle Suspension System” and examined the candidate during open defence. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of Master of Science in Automotive Engineering.

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ACRONYMS

CFA	Consumption full active
DOF	Degree of freedom
ECU	Electronic control unit
Emf	Electromotive force
EMS	Electromagnetic suspension
FEM	Finite element method
HB	High-band width system
LB	Low band with system
LSTC	Livermore Software Technology Corporation
MR	Magneto-rheological
PM	Permanent magnet
RMS	Root mean square
RSA	Regenerative semi active system

NOMENCLATURES

A_c	cross-section area of the coil (mm^2)
A_{cc}	Cross-section area of the coil copper(mm)
B	Magnetic field (T)
b_s	Tooth width (mm)
C	Spring index
D	Wire diameter(m)
D	Mean diameter(m)
E	Energy (J), ElectroMotive force (J)
F	Normal force (N)
G	Air gap length(mm)
G	modulus of rigidity
h_t	length of the tooth (mm)
I	Current (A)
J	current density in winding (A/mm^2)
K	Diameter ratio
L	Total length(m)
LF	Free length of the spring (mm)
Ls	Solid length of the spring (mm)
N	Number of turns
P	Power (W), Pitch (m)

R	Resistance(ohm)
V	Voltage (v)
W	Load (N)
δ	Deflection (mm)

ABSTRACT

Suspension systems serve a dual purpose contributing to the vehicle's road holding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations. The shock absorbers duty is to absorb or dissipate energy. In conventional suspension there is oil inside the shock absorber which produces heat and friction during high compression is exist. The traditional approach is incapable of improving vehicle control and passenger safety, particularly in the event of a serious car accident caused by rollover. This thesis has, an objective of design of electromagnetic vehicle suspension system which replaces the current suspension system. To develop the goal of the thesis theoretical design case and analytical methods were used. Analytical modeling method were preliminary used to obtain the basic electromagnetic constraints such as; normal force, electromagnetic field density, electromagnetic field strength, length of the wire and total number of amperes turns. Geometric dimension and 3D modeling of the components has been defined by using CATIA software simulation by LS DYNA for existing shock absorber and ANSYS Maxwell for modified (electromagnetic shock absorber) software. The driving force that represented the dynamic force acting of shock absorber when the moving car meets the bump or during acceleration of pavement road was assumed F=11175 N. From the electromagnetic simulation of shock absorber, the dynamic condition of electromagnetic transient type simulation result has been generated and the existing shock also simulate. The performance of the Electromagnetic shock absorber obtained from simulations was compared with traditional shock absorber. Energy absorption is 360J and 422.4J for existing and modified shock absorber when compare with analytical 1.8% and 15% error respectively so the design is safe. Force analysis is 10990N and 13200N for existing and modified shock absorber when compare with analytical 1.6% and 18% error respectively so the design is safe. More force occur on modified shock absorber therefore electromagnetic suspension best.

Keywords: Electromagnet Suspension, Finite element analysis, Magneto-rheological, Permanent Magnet, Shock absorber, Suspension System

CHAPTER ONE
INTRODUCTION

1.1. Background of the study

Automobiles have proven to be the most significant generator of pollution in the atmosphere in the United States, for example, 45% of the No, 70% of the Co, 34% of the H pollution. Aside from engine cycle efficiency, vehicle dissipation of kinetic energy during vehicle vibration and motion is another key cause of energy loss in automobiles. Over the last century, the car industry has worked hard to convert motion and vibration energy into waste heat using active control systems like as anti-lock. Energy recovery from braking has seen considerable commercial success in hybrid vehicle during the last ten years. Electromagnetic vehicle suspensions, on the other hand, which provide continuous energy recovery, have yet to be implemented (Peng Li, Lei Zuo, 2017).The shock absorber, an energy dissipating mechanism, works in tandem with the suspension spring to dampen vibration caused by road irregularities or acceleration and braking.

Automobile research over the last year has aimed to improve passenger comfort and vehicle component economy. Energy losses must be reduced, especially in hybrid vehicle, by recovering as much energy from all installed devices as possible. In the case of brakes or suspensions, the kinetic energy is frequently released as heat. The quantity of braking energy can be recovered is substantially larger than what a suspension system can provide. However, several investigations have been conducted on the possibilities of energy harvesting by car suspensions employing compact and effective electromagnetic damper. As a result, rare-earth permanent magnets are used in the practically every electromagnetic damper system. Electromagnetic dampers are employed not only in the automotive industry, but also in civil constructions to damp vibrations and thereby minimize or eliminate noise. Furthermore, the wind or even earthquakes cause vibration that must be damped in order to recover the energy. These electromagnetic dampers are based on rotational actuators, which necessitate a motion converter with many moving parts (Peng Li, Lei Zuo, 2017).

Most cars today have passive hydraulic suspension. One of the most distinguishing characteristics of hydraulic suspension is the use of hydraulic oil as a damper. The damper absorbs the excitation force from the road surface whenever a vehicle encounters road imperfection.

Inside the damper, the energy absorbed is transformed to heat. The mechanical spring connected to the damper supports the vehicle's body weight. The hydraulic system, on the other hand, has significant drawbacks. Hydraulic damper pollutes the environment when hoses leak or tear, releasing poisonous hydraulic fluids. The hydraulic system is then deemed useless due to the requirement for a constantly pressurized system. Electromagnetic suspension system, on the other hand, required more than just hydraulic fluid. It's made up of permanent magnet set and succession of current coil. They can each function as a translator or static armature. The interaction of permanent magnet flux with the voltage supplied armature winding causes the translator to move or thrust. Tubular linear motors are ideal for designing (B.L.J Gysen, 2010)

1.2. Problem statement

The traditional approach is incapable of improving vehicle control and passenger safety, particularly in the event of a serious car accident caused by rollover. When the vehicle is going on the turn it feels unstable, this makes difficult to achieve because a soft spring allows for too much movement and a firm spring create passenger discomfort owing to road irregularities and its dumping system has not yet given a high performance where its vibration amplitude is still high and the time required terminating the vibration is quite longer. The most revel cause of vibration is problem with wheel and tires. The potential problem include improper wheel and tire balance, uneven tire wear, separated tire tread, out of round tire, damage the wheel. Sometimes the seal surrounding the shaft extending from the body of the shock will begin to leak and this loss of fluid will cause a loss in the ability of shock to perform. The perfect car suspension system would be able to absorb road shock quickly and gently return to its original position while maintaining excellent tire-to-road contact. By replacing hydraulic shock absorber with the same size of electromagnetic shock absorber this problem will be solved. As a result, electromagnetic suspension system becomes a better choice to keep the quality of the car comfortable on any road condition.

1.3. Objectives

1.3.1 General objective

The main objective of this thesis is to Design of Electromagnetic Vehicle Suspension System.

1.3.2 Specific objectives

The specific objectives are to:

- Design, the electromagnetic component
- Modeling of the designed parts using software, CATIA V5R20
- Simulation of the system using LS-DYNA and ANSYS Maxwell.
- Comparison between existing and new shock absorber

1.4 Significance of the Thesis

The electromagnetic suspension system can maintain the vehicle steady while in motion by ensuring good keeping during driving cornering and braking. It provides more comfortable and safer and irritation-free vibration vehicle control and reducing wear and tear due to having more road holding capacity. If there is a patient this system able to transport quickly and free of disturbance road surface vibration. And also it have greater life span.

1.5 Scope of the Thesis

The study covers design and modeling of the existing and modified parts and assembly of the shock absorber by CATIA software, then the existing assembly is imported to LS DYNA and the modified to ANSYS Maxwell software, applying simulation and running simulation for checking, validate the results with analytical. Compare the results existing with modified shock absorber.

1.6. Limitation of the Thesis

These are some of the limitations that we encounter while doing the thesis.

- Lack for high performance computer
- It is better to get a laboratory that is designed for suspension system to validate the result obtained from simulations.

1.7 Organization of the Thesis

The thesis is organized with the following chapters.

Chapter one: Introduction

This chapter includes background and types of suspension system, main and specific objectives, scope and significant of thesis.

Chapter two: Literature review

It discusses many literature reviews and summarized in to fluid dumper modeling, active with hydraulic and electromagnetic suspension system, electromagnetic suspension system. Finally, the research gap identified.

Chapter-3: Materials and methods

Describe the Materials and methods used in this thesis work. Data collection and analysis method, design procedure and flow chart of work necessary for the thesis are elaborated. Preliminary design of the Electromagnetic suspension system is described. Analytical method was applied and the electromagnetic properties of the electromagnetic suspension system are determined. Finally, component design and 3D modeling of the EMS system is carried out by using CAD software and simulation by LS DYNA and ANSYS software.

Chapter-4: Result and discussion

Explain results and discussion with the existing shock absorber.

Chapter-5: Conclusion and Recommendation

Summarizes the main results and conclusions of the thesis and recommendation for the future work direction.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Suspension systems serve a dual purpose contributing to the vehicle's road holding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations, etc. These goals are generally at odds, so the tuning of suspensions involves finding the right compromise. It is important for the suspension to keep the road wheel in contact with the road surface as much as possible, because all the forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wears (Dr. Kevin Craig, 2010).

2.1.1. Components of Suspension system

Coil springs, Leaf springs, shock absorbers, spring shackles and stabilizers are some of the basic and most important components of suspension system whose location in a conventional car are pictured in figure2.1.

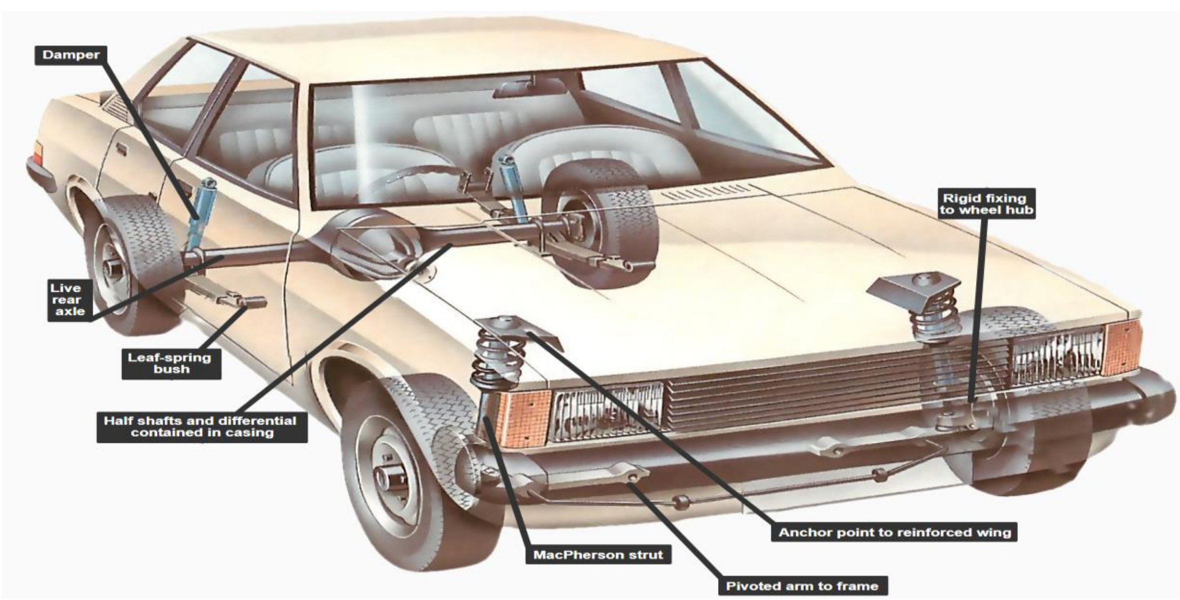


Figure 2.1: Illustration of suspension components in a car (William Harris, 2016).

When the springs are subjected to an additional load or the car hits a pothole, the springs contract to absorb the impact. The springs are very important components of the system that provides ride comfort. By releasing the energy held in the springs, shocks and struts assist control how fast the springs and suspension are permitted to move, which is vital in maintaining tires in firm contact (Robert Q. Riley E., 2016). Shackles are the parts that use fasteners to connect the springs to the body. During cornering, the stabilizer transfers load from the outer to the inner wheels, keeping the car body flat.

2.1.1.1. Shock absorbers

It absorbs spring shocks and releases the energy contained in the spring over time, as the name implies. They're also known as dampers since they reduce the vertical motion caused by driving over a bumpy surface. The car would bounce and pitch if it only had springs, until the spring spontaneously returned to its former position. Shock absorbers have two roles to play. They absorb any bumps on the road that are greater than typical, preventing the shock from being passed to the car's chassis. Second, they maintain as much travel in the suspension as possible for the road condition. Traction is provided by shock absorbers, which keep the wheels firmly on the road. They act in conjunction with the springs and are velocity-sensitive hydraulic dampening mechanisms. The spring permits the wheel to move, converting the energy from the road shock into kinetic energy of the un-sprung mass, which is then dissipated by the damper (Rudrakaanth et al., 2016).

Figure 2.2: Damper (shock absorber) and Coil spring (Rudrakaanth et al., 2016).

Dampers that are oil-filled, gas-filled, or reservoir-style. The most common form of shock absorber used in vehicle and motorcycle suspensions is an oil-filled shock absorber, which looks like the one shown in Figure 2.2. They have little one-way valves in the piston that open holes when it moves in one direction at varying speeds and close them when it moves in the opposite direction. When compressing to absorb a bump, the shock moves quickly before gently lengthening to release the energy trapped in the spring. There are different types of shock absorber these are: -

A. Twin Tube – Gas Charged Design

The prime function of gas charging is to minimize aeration of the hydraulic fluid. The pressure of the nitrogen gas compresses air bubbles in the hydraulic fluid as shown in Figure 2.3. This prevents the oil and air from mixing and creating foam. Foam affects performance because it can be compressed fluid. With aeration reduced, the shock can react faster and more predictably, allowing for quicker response time and helping keep the tire firmly planted on the road surface. The advantages of this shock absorber are improving handling by reducing roll, sway and dive. Also, can reduces aeration offering a greater range of control over a wider variety of road conditions as compared to non-gas units. This shock absorber reduced fade shocks can lose damping capability as they heat up during use. Gas charged shocks could cut this loss of performance.

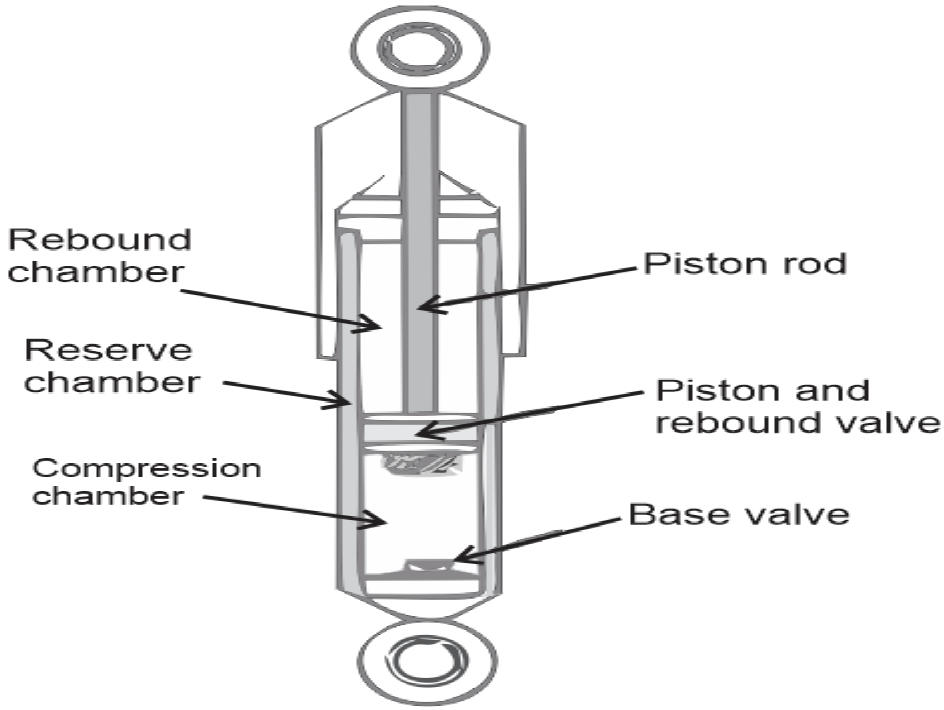


Figure 2.3: Gas Charged Design (Mohd Sufian Bin Jamaludin, 2012)

B. Twin Tube – PSD Design

Ride engineers had to compromise between soft valve and firm valve. With soft valve, the fluid flows more easily. The result is a smoother ride, but with poor handling and a lot of roll/sway. When valve is firm, fluid flows less easily. Handling is improved, but the ride can become harsh. With the advent of gas charging, ride engineers were able to open the orifice controls of these valves and improve the balance between comfort and control capabilities available in traditional velocity sensitive dampers. A leap beyond fluid velocity control is an advanced technology that takes into account the position of the valve within the pressure tube. This is called Position Sensitive Damping (PSD).

The key to this innovation is precision tapered grooves in the pressure tube. Every application is individually tuned, tailoring the length, depth, and taper of these grooves to ensure optimal ride comfort and added control. This in essence creates two zones within the pressure tube. The first zone, the comfort zone, is where normal driving takes place. The second zone, the control zone, is utilized during demanding driving situations as shown in Figure 2.4.

The advantages is allows ride engineers to move beyond simple velocity sensitive valve and use the position of the piston to fine tune the ride characteristic. Adjusts more rapidly to changing road and weight conditions than standard shock absorbers.

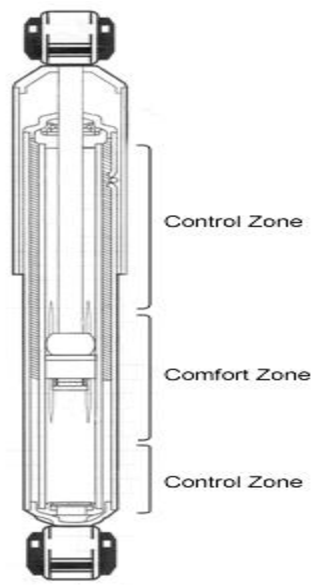


Figure 2.4: Twin Tube – PSD Design (Mohd Sufian Bin Jamaludin, 2012)

C. Twin Tube -ASD Design (Reflex)

A new twist on the comfort control compromise is an innovative technology which provides greater control for handling while improving ride comfort called Acceleration Sensitive Damping (ASD) as shown in Figure 2.5. This technology moves beyond traditional velocity sensitive damping to focus and address impact. This focus on impact is achieved by utilizing a new compression valve design. This compression valve is a mechanical closed loop system, which opens a bypass to fluid flow around the compression valve.

The advantage of this absorber is it can control the damping without reducing driver comfort. Valve automatically adjusts to changes in the road condition and reduces ride harshness.

Figure 2.5: Twin Tube -ASD Design (Reflex) (Mohd Sufian Bin Jamaludin, 2012)

D. Mono-tube design (Standard Types)

These are high-pressure gas shocks with only one tube, the pressure tube. Inside the pressure tube there are two pistons: a dividing piston and a working piston. The working piston and rod are very similar to the twin tube shock design as shown in Figure 2.6. The difference in actual application is that a mono-tube shock absorber can be mounted upside down or right side up and will work either way. In addition to its mounting flexibility, mono-tube shocks are a significant component, along with the spring, in supporting vehicle weight. Another difference you may notice is that the mono-tube shock absorber does not have a base valve. Instead, all the control during compression and extension takes place at the piston. During operation, the dividing piston moves up and down as the piston rod moves in and out of the shock absorber, keeping the pressure tube full all times.

The advantages for this absorber is that it can be mounted upside down, reducing the unsparing weight. May run cooler since the working tube is exposed to the air and can use original equipment many import and performance domestic passenger cars, SUV and light truck applications.

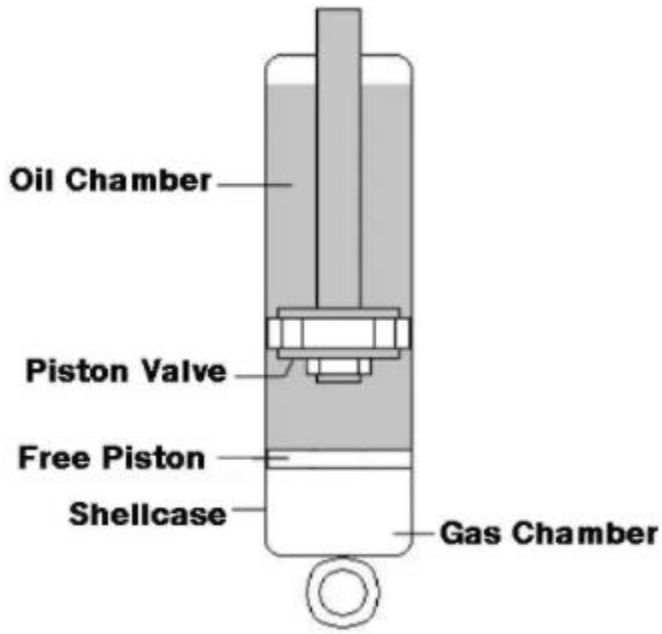


Figure 2.6: Mono-tube design (Standard Types) (Mohd Sufian Bin Jamaludin, 2012)

2.1.1.2. Strut

The strut is an active component of the suspension system that serves as a shock absorber and may support sideways loads. It’s used for load bearing in off-road vehicle suspension and aircraft wing support, among other things.

2.1.1. 3.Sway bar

It's also known as a stabilizer, anti-roll bar, or torsional bar since it joins the opposing wheels as seen in figure 2.7. During cornering, it helps to reduce body roll. The car's outer wheels compress and the inner wheels rise off the road surface while cornering, reducing road traction and steering control. Sway bars to reduce this effect by transmitting vertical forces and keeping the body level.

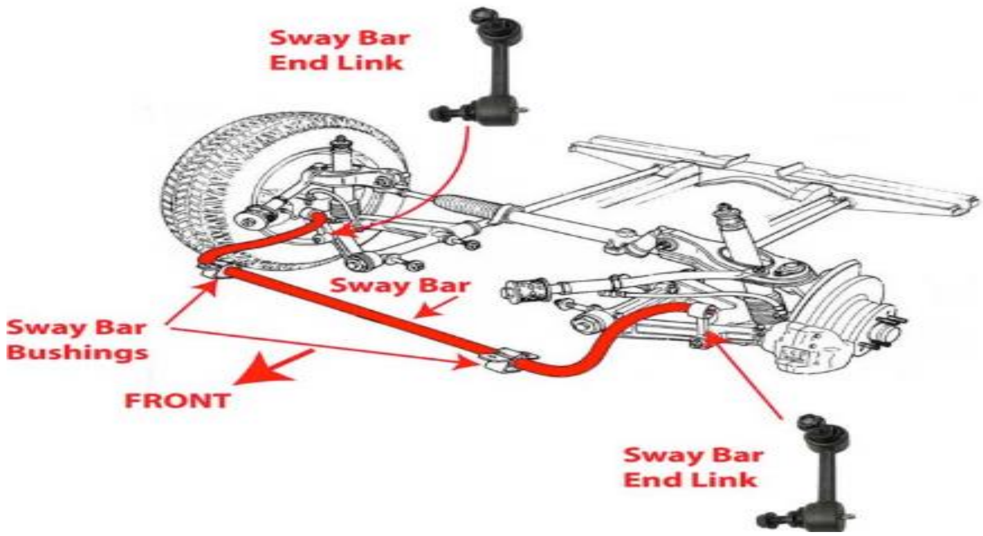


Figure 2.7: Sway bar (Rudrakaanth et al., 2016).

2.1.2. Suspension Types

Suspension systems, based on the ability of a wheel's counterpart to move correspondingly, are broadly classified as dependent and independent systems.

2.1.2.1. Dependent suspension system

Which have simple beam axles that hold both wheels parallel to each other, are also known as solid axle suspension systems changes in chamber angle of wheel have an impact on the chamber angle of the other wheel. This occurs more frequently in live axle than dead axles. A solid ale can be mounted in a variety way. Some examples are

I. Four links suspensions

Some of the disadvantages of Hotchkiss suspension can be solved with this technique. Helical coil springs are used instead of leaf springs, and they provide a superior ride. Lower control arms support the axle while upper control arms absorb braking and acceleration torques. Its construction is as shown in figure 2.8.

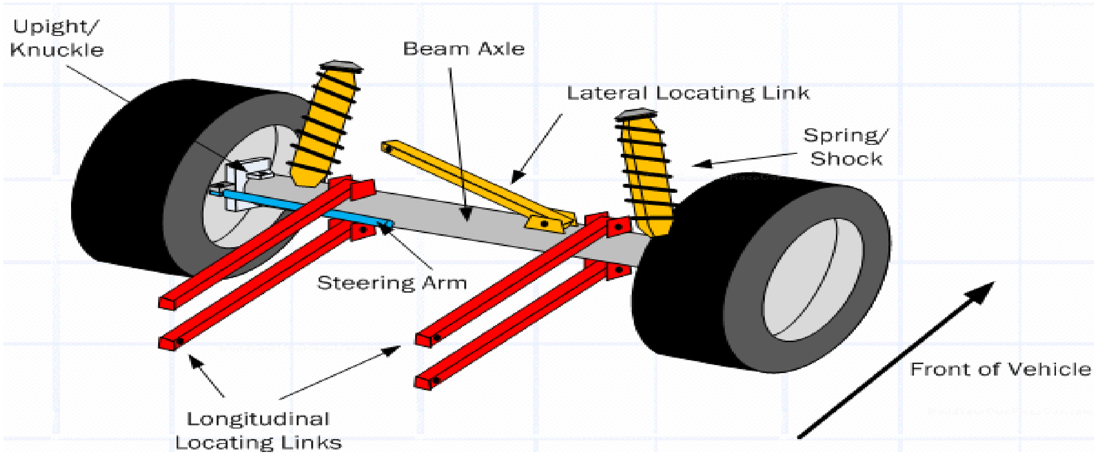


Figure 2.8: Four links suspensions (Julian Happian-Smith, 2012).

II. De Dion suspensions:

The two partner wheels are linked by de Dion tube, which prevents camber shift during rebound, making the system extremely traction-friendly. Because the differential is attached to the chassis rather than suspension (as in figure 2.9), and the weight of un-sprung masses is reduced (Christopher J Longhurst, 2016). The system's drawbacks include the fact that, each axle requires two CV joints, which adds weight to the sprung mass.

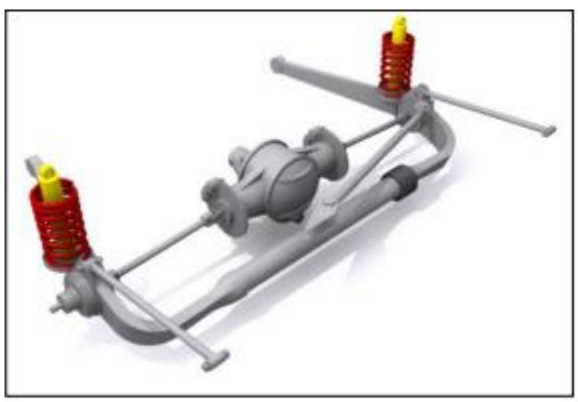


Figure 2.9: De Dion suspension (Christopher J Longhurst, 2016).

2.1.2.2. Independent suspension systems:

It allows the wheels to rise and fall on their own without affecting the opposite wheel, as they are not connected to one another by any means. The system includes some of the sub-categories discussed in the following.

I. Double wishbone suspension:

It has two 'A' shaped arms parallel to one another and is also known as double an arm or short length arm suspension. The upper arm is shorter than the bottom arm due to geometric constraints. The arm is attached to the steering knuckle on one end and two joints to the chassis on the other. Any of the two arms works as the principal load carrier, depending on where the spring is located: between the arms or above the top arm as shown in figure 2.10 (Julian Happian-Smith, 2012).

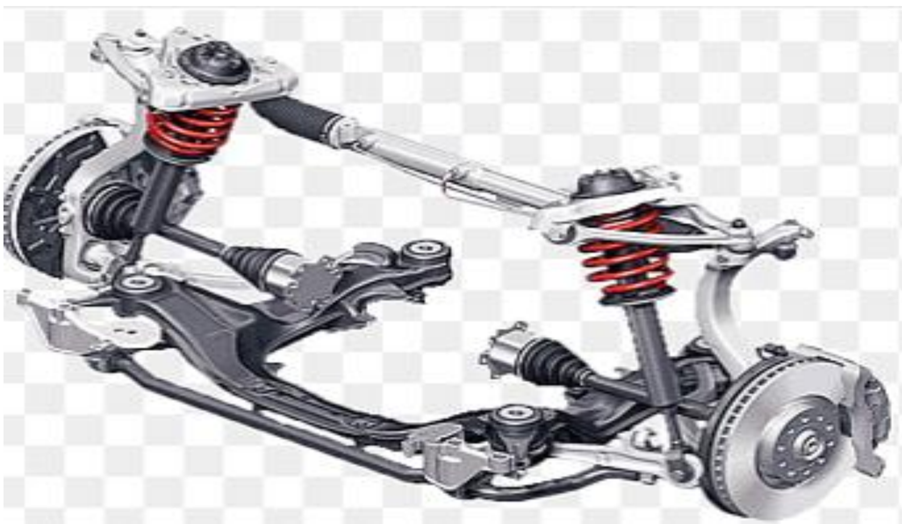


Figure 2.10: Double Wishbone suspensions (Julian Happian-Smith, 2002).

II. McPherson strut suspension

As shown in Figure 2.11, it is a coil spring and shock absorber combination with only one control arm in a single assembly. It is more likely to be utilized in front-wheel-drive axles because it enables a more compact and lighter suspension. The fact that it allows for camber angle adjustment and sideways movement when the wheel is moving vertically is one of its key downsides. When compared to this arrangement, double arm and multi-link suspensions appear to offer better handling (Julian Happian-Smith, 2012).

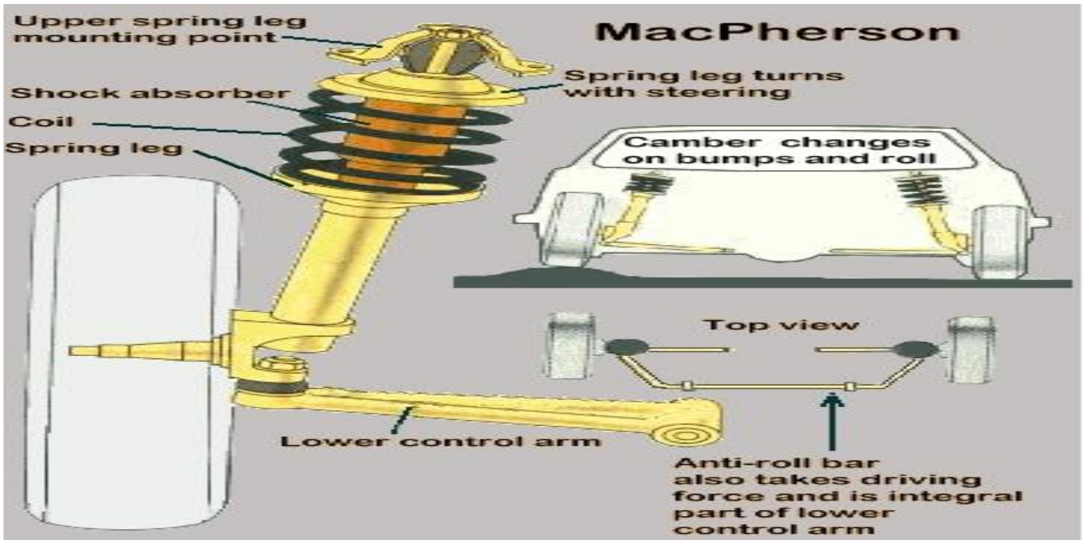


Figure 2.11: McPherson Strut suspension (Julian Happian-Smith, 2012).

III. Trailing arm suspensions:

The differential is linked to the chassis in the same way that it is in the De Dion to reduce unsprung bulk. The pivot axis of the control arm, which controls squat and dive, is perpendicular to the vehicle's longitudinal axis as shown in figure 2.12 (Rudrakaanth et al., 2016). It absorbs braking and accelerating forces well.

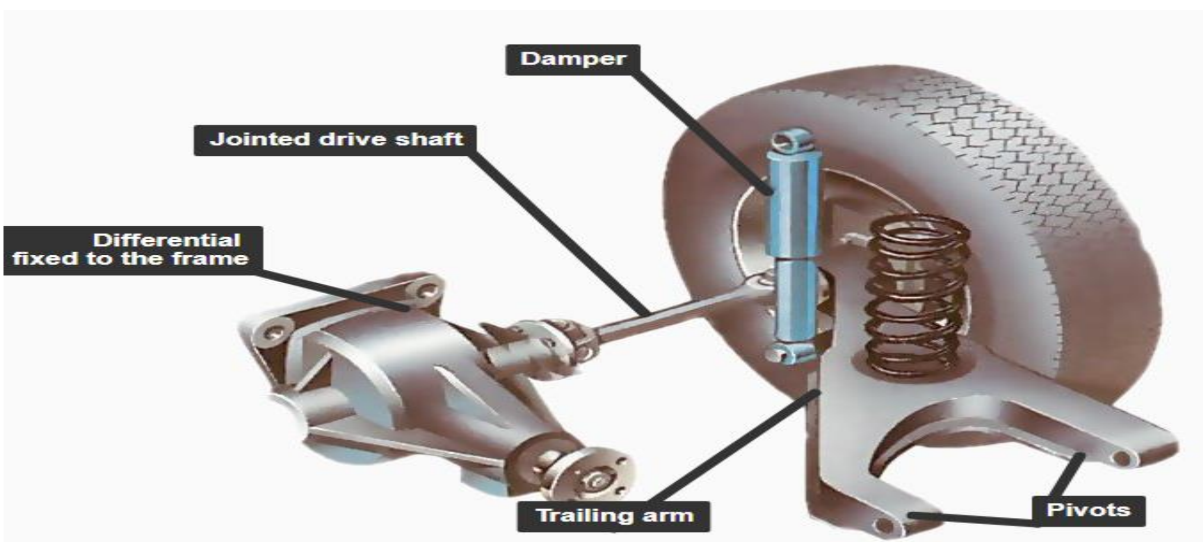


Figure 2.12: Trailing arm suspensions (Rudrakaanth et al., 2016).

IV. Multi-link suspensions:

This is the most recent innovation in double wishbone technology. Instead of having stiff upper and lower control arms, each arm is made into its own component. The suspension geometry is changed as the car turns by torqueing all four arms (Christopher J Longhurst, 2016). Because every joint is changeable, this system outperforms all others in terms of road holding. With changes in the number of joints, arms, and their positions, this has a lot more permutations as shown in figure 2.13.

Figure 2.13: Multi link suspension (Christopher J Longhurst, 2016).

V. Swing arm suspensions:

It has a suspension arm that is pivotally attached to the suspension member and rotates around the horizontal pivot axis. At the end, a lateral rod is attached to the arm, which the other end connected to the suspension member. Rolling force and steering effects can be compensated by the rod's position (Richard S., et al. 2014).

2.1.3. Classification of suspension

Suspension systems can be categorized as passive, semi-active, and full-active suspensions system (X.D.Xue, et al, 2011).

2.1.3. 1.Passive Suspension System

Lot of common vehicles today uses passive suspension system to control the dynamics of a vehicle's vertical motion as well as spinning (pitch) and tilting (roll). Passive indicates that the suspension elements cannot provide energy to the suspension system. The passive suspension system limits the motion of the body and wheel by limiting their relative velocities to a rate that gives the required ride comfort.

This is achieved by using some type of damping element placed between the body and the wheels of the vehicle, such as hydraulic shock absorber. Properties of the dampers are desired to reduce the vertical body acceleration and to provide good tire-road contact force. That is, for a comfortable ride, it is desirable to limit the body acceleration by using a soft absorber, but this allows more variation in the tire-road contact force that in turn reduces the handling performance. Also, the suspension travel, commonly called the sprung mass (the mass of body and other components supported by suspension system) displacement, limits allowable deflection, which in turn limits the amount of relative velocity of the absorber that can be permitted. By comparison, it is desirable to reduce the relative velocity to improve handling by designing a stiffer or higher rate shock absorber. This stiffness decreases the ride quality performance at the same time increases the body acceleration, detract what is considered being good ride characteristics.

An early design for automobile suspension systems focused on unconstrained fulfilment of results for passive suspension system which shows the desirability of low suspension stiffness, reduced un-sprung mass, and better damping ratio for the best controllability. Thus, the passive suspension systems, which approach optimal values, had offered an appealing choice for a vehicle suspension system and had been widely used for car. However, the conventional shock absorbers do not provide energy to the suspension system and control only the displacement of the vehicle body and wheel by limiting the sprung and un-sprung velocity according to the rate determined by the engineers. Hence, the optimization of a passive suspension system is varied according to the road profiles. Passive suspension system representation diagram is shown in Figure 2.14 (Ankita R et al, 2016).

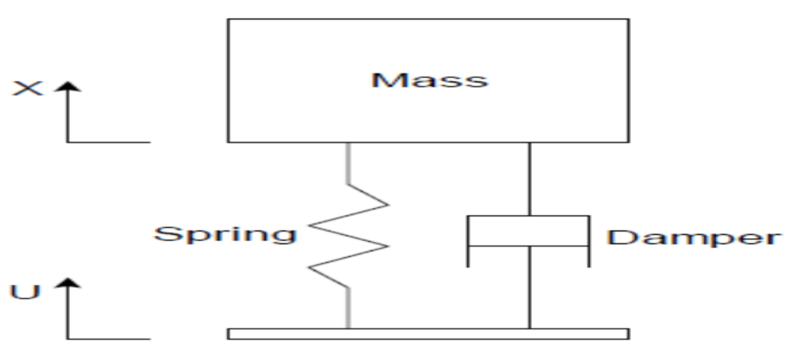


Figure 2.14: Schematic Diagram of Passive Suspension System (Ankita R et.al, 2016)

2.1.3.2. Semi-Active Suspension System

Semi-active systems can only vary the viscous damping co-efficient of shock absorber and do not add energy to the suspension system. They require less energy to function and are less expensive. Among semi-active control devices, magneto-rheological (MR) dampers are particularly interesting because of the high damping force they can produce with low power (being possible to operate with batteries), simple mechanical design and low production costs. Semi-active suspension system representation diagram is shown in Figure 2.15 (Ankita R et al, 2016). Semi-active suspension system employs the same elements that used in the passive suspension system and it uses the same application of the active suspension system where external energy is needed in the system. The difference is the damping coefficient can be controlled. The fully active suspension is modified so that the actuator is only capable of dissipating power rather than supplying it as well. The actuator then becomes a continuously variable damper which is theoretically capable of tracking force demand signal independently of instantaneous velocity across it (Ankita R et al, 2016).

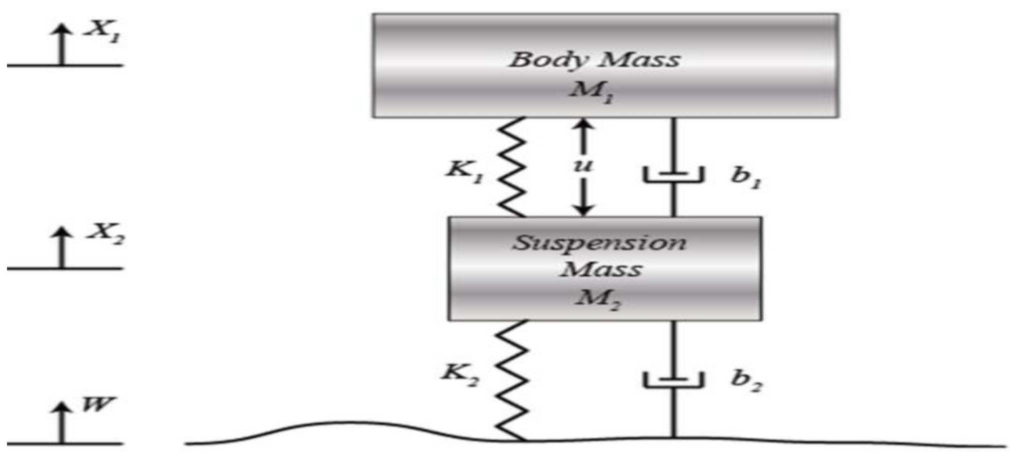


Figure 2.15: Schematic Diagram of Semi-Active Suspension System (Ankita R et al, 2016).

2.1.3. 3.Active suspension

The concept of active suspension system was introduced as early as 1958. The major difference occurs while comparing it to conventional suspension systems is that active suspension system can inject energy into vehicle dynamic system via actuators rather than dissipates that energy.

Active suspension can make use of more degrees of freedom in assigning transfer functions and thus improve performance.

The active suspension system contains an extra element above the conventional suspension which is basically an actuator that is controlled by a high frequency response servo valve and which involves a force feedback loop. The demand force signal, typically generated in a microprocessor, is governed by a control law which is normally obtained by application of various forms of optimal control theory as shown in Figure 2.16. Theoretically, this suspension provides optimum ride and handling characteristics. It is done by maintaining an approximately constant tire contact force, maintaining vehicle geometry level and by minimizing vertical accelerations to the vehicle. However due to its complexity, cost and power requirements, but it has not yet put into mass production. Most of the active suspensions, which have reached the stage of hardware development and production, have used some form of electrohydraulic actuator. Two forms of active suspension are commonly recognized. The first is the fast-active suspension or high-bandwidth system (HB), often referred to as fully active. The second is the slow active suspension or low-bandwidth system (LB). In an active suspension, the passive damper or both the passive damper and spring are replaced with a force actuator (Elattar et al., 2016).

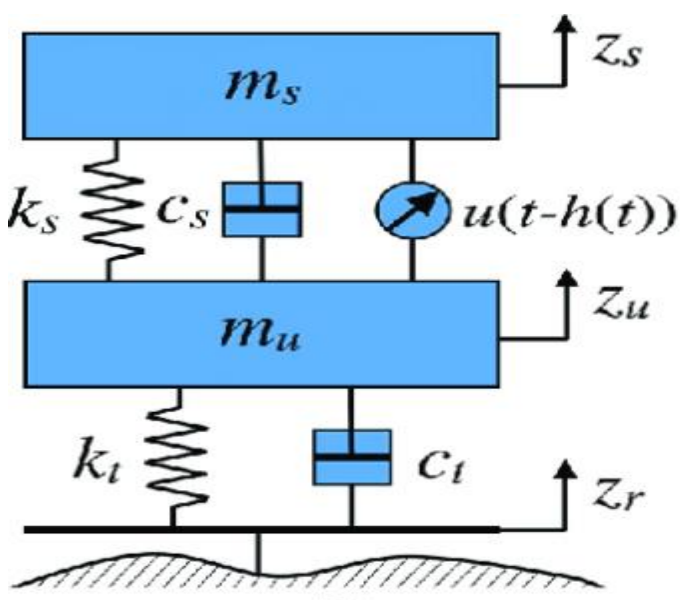


Figure 2.16: Active suspension system (Sayel M. Fayyad, 2012).

2.2. Electromagnet, Permanent Magnet, Power and Materials

When current flows through a conductor, a magnetic field forms around it, turning the conductor into a magnet as shown in Figure 2.17. This phenomenon is called electromagnetism (Jack Erjavec, 2010).

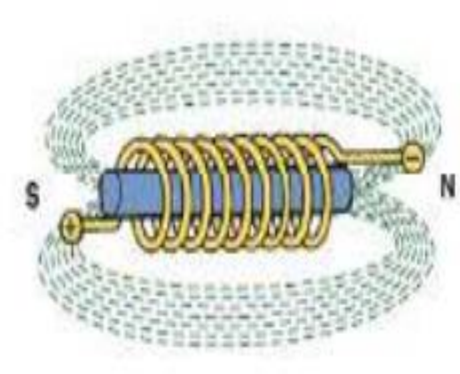


Figure 2.17: Electromagnetism (Jack Erjavec, 2010)

The Right-Hand Grip Rule or the Maxwell Screw Rule can be used to determine the direction of the magnetic field created by a current carrying straight wire as shown in Figure 2.18A. The right -hand grip rule states that the wire should be held in the right hand with the thumb pointing in the current's direction as shown in Figure 2.18B. The direction of the magnetic field around the wire is indicated by the other fingers. (Bodine hand book, 2011). Consider turning a right-handed screw so that it bores into the wire in the same direction as the current. The magnetic field's direction is determined by the rotational direction. (Bodine hand book, 2011).

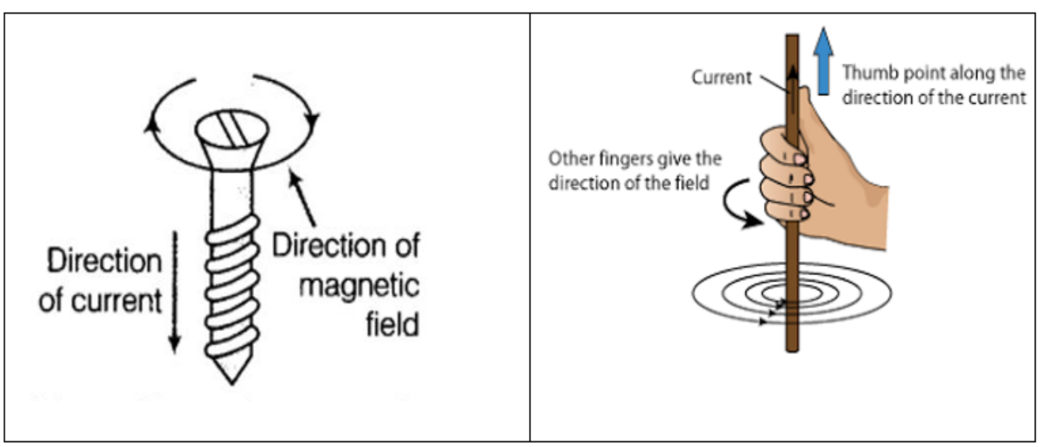


Figure 2.18: A. Maxwell Screw Rule B. Right hand grip rule

Advantage and dis advantage of Electromagnetic suspension

Advantages

- ✓ It has high life span
- ✓ Eliminate friction
- ✓ It has very low maintenance
- ✓ Accurate force control
- ✓ Increase efficiency
- ✓ Dissipated energy can be used later

Disadvantages

- ✓ Relatively high current for 12 to 24 v system

2.2.1. Electromagnet

Electromagnets are transient magnets that are created using an electric current. An electromagnet is a device that uses the magnetic effect of current to create a magnetic field as shown at figure 2.19. Because iron ore is magnetized by induction, it has been discovered that if a soft iron rod called a core is inserted within a solenoid, the strength of the magnetic field increases dramatically. (Prof.R.P.Kattimani et al, 2018).

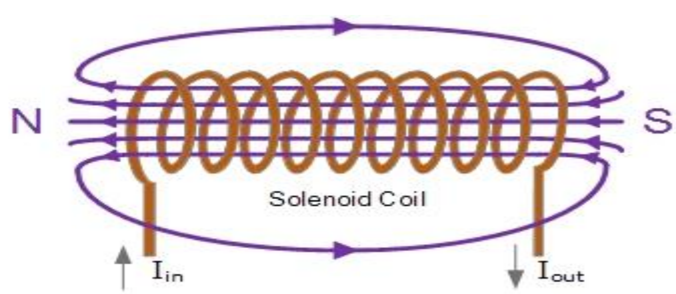


Figure 2.19: Magnetic field lines (Prof.R.P.Kattimani et al, 2018).

When a piece of iron is attracted to a magnet, it becomes a magnet for a brief period, and a sequence of pieces of iron will attract one another in a chain reaction if the first piece is impacted by the magnet. Magnetic Induction is the cause of this occurrence. The pieces of iron in this scenario tend to provide an excellent con ducting channel for the lines of force; thus, the more perfectly they tend to close the magnetic circuit, the stronger their attraction for one another will be (Charles, 2010). Reluctance is a feature of a material that prevents the formation of magnetic flux. It is akin to resistance in an electric circuit in that it measures the resistance supplied to the passage of magnetic flux through a material. In other terms, the number of amp-turns required per Weber of magnetic flux in a magnetic circuit is its reluctance as shown in figure 2.20. (Prof.R.P.Kattimani et al, 2018).

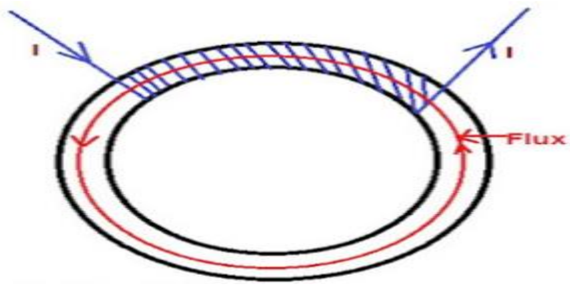


Figure 2.20: Magnetic circuit (Prof.R.P.Kattimani et al, 2018).

2.2.2. Demagnetization Curve and Magnetization Parameters

The B-H curve of a permanent magnet, which normally has a large hysteresis loop, can be used to explain it (Fig. 2.21). The second quadrant of the B-H curve referred to as the demagnetization curve, is vital for permanent mag net. There are two significant points on this curve: one at H= 0, where the magnetic flux density is equal to Br (Permanent magnetic flux density, or Permanence), another point $H_c = 0$ at point, where a reverse magnetic field intensity is applied to a magnetized permanent magnet.

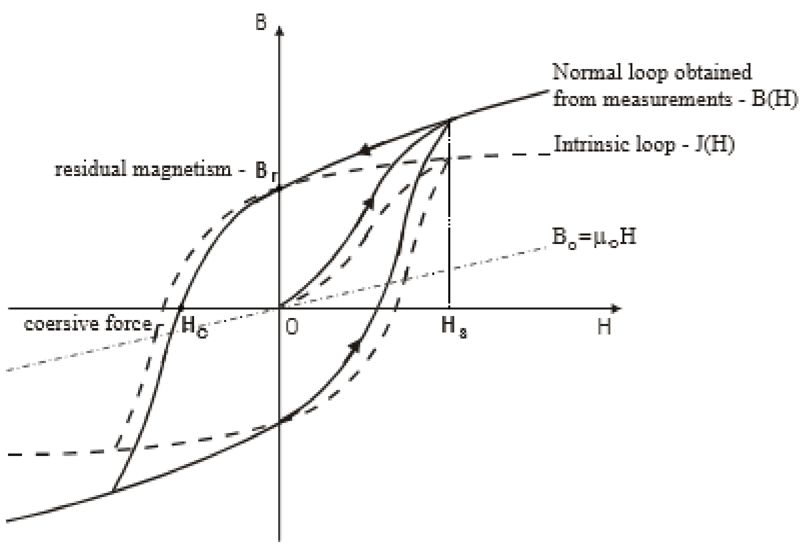


Figure 2.21: Normal and intrinsic hysteresis loops of a permanent magnet material (Oly D. Paz, 2014).

In electric machines technology, the following PM materials are used (see Fig. 2.18and Table 2.1): −

- Alnico (Al, Ni, Co, Fe)
- Ferrites (ceramics), e.g., barium ferrite BaO ×$6Fe_2O_3$and strontium ferrite SrO × $6Fe_2O_3$
- Rare-earth materials, i.e., samarium-cobalt SmCo and neodymium-iron-boron B-Fe-Nd

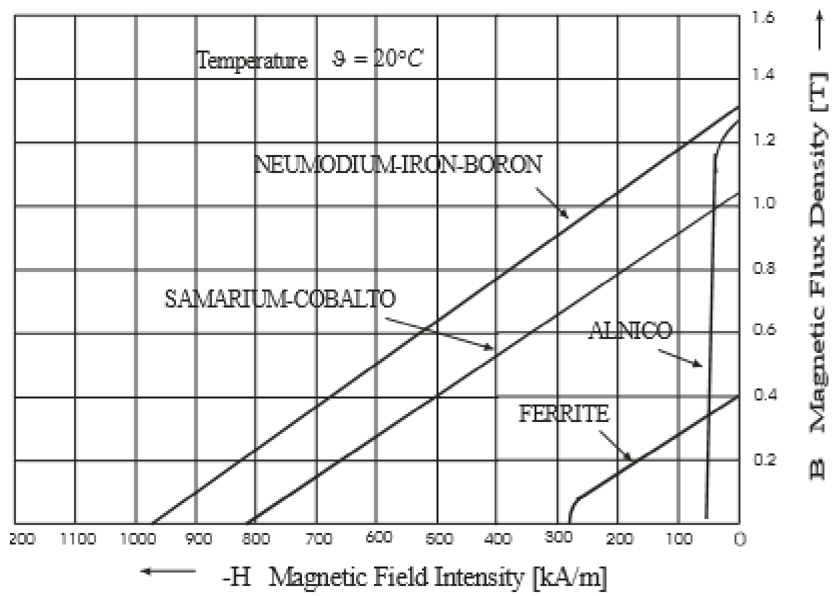


Figure 2.22: Demagnetization curves for different permanent magnet materials (Oly D. Paz, 2014). .

There are two significant points on this curve: one at H= 0, where the magnetic flux density is equal to Br (Permanent magnetic flux density, or Permanence), another point $H_c = 0$ at point, where a reverse magnetic field intensity is applied to a magnetized permanent magnet.

From the mid-1940s to around 1970, the PM machine industry employed Alnico magnets. They exhibit low temperature coefficients and magnetic Permanent flux but low coercive force and very non-linear demagnetization curve.

Rare earths PMs have advanced significantly in terms of accessible energy density over the previous three decades. The first generation of the rare earths PMs has a composition $SmCo_5$, which has Permanent flux density, strong coercive force, high-energy product, linear demagnetization curve, and low temperature coefficient. The only drawback is high cost, which is caused by Sm and Co supply constraints.

A second generation of rare earth, neodymium Nd and iron, has been discovered based on the cost. The Nd is substantially more plentiful than Sm. B-Fe-Nd magnets offer greater qualities than $SmCo_5$, however the drawback is their demagnetization curves is temperature dependent, and they are also prone to corrosion. The greatest technique of corrosion Protection for B-Fe-Nd magnets is coat them with metallic or organic coating (Oly D. Paz, 2014).

Table 2.1: Permanent magnet materials parameters (Menderela et al, 2012).

Material	$(B\ .H)_{max}$ [KJ / m^3]	B_r [T]	H_c [KA /m]
Ceramics	27-35	0.4	240
Alnico	70-85	1.1	130
-$SmCo_5$	160-200	0.9-1.0	660-750
-Sm_2Co_{17}	205-240	1.04-1.12	760-820
- B-Fe-Nd	190-385	1.0-1.4	760-980

The permanent magnets degrade as the temperature rises, and the Curie temperature, they vanish totally. Table 2.2 shows these changes. Coefficients $C_B$and $C_C$show in percent the reversible changes in permanence and coercive force.

Table 2.2: The effect of temperature on permanent magnet materials (Menderela et al, 2012).

Material	Temperature Curie [o_C]	Max. Operat. Temp. [o_C]	C_B [% / K]	C_C [% / K]
Ceramics	450	300	-0.2	+0.40
Alnico	830	500	-0.02	+0.01
Rare earth magnets:				
-$SmCo_5$	720	250	-0.045	-0.25
-Sm_2Co_{17}	800	300-350	-0.045	-0.25
-B-Fe-Nd	310	210-100	-0.13	-0.60

The material B-Fe-Nd is recommended for the model in this thesis because it enhance the performance-to-cost ratio significantly. Because Ferrites would increase the size of the shock absorbers, they are not employed and $SmCo_5$ would raise the price.

2.2.3. Carbon

Carbon is usually considered to be the most important contributor to the hardness and strength of ferrous steel. Even when other alloying element are not present, high carbon content can result in high local hardness's.

However, other alloying element also contribute to overall hardenability of the steel (P. Flenner, 2010). based on the modelling and analyses conclude that the low carbon structure steel material is best suitable foe production of helical spring compared to chromo vanadium steel material which are in motor vehicle (N Lavanya et al, 2014).

2.2.4. Resistance current and voltage

The current density over the conductor surface is homogeneous in linear materials such as metals and at low frequencies. The current is directly proportional to the potential difference between two ends (across) of the metal (ideal) resistor (other ohm device) at such conditions, according to Ohm's law: Ohm's Law is a law that governs the flow of electrons in a circuit This asserts that the p.d. formed between the two ends of a resistor is proportional to the amount of current flowing through it, assuming all other variables (such as temperature) remain constant (Dr. F.M.Spieksma, 2016). We can write this in mathematical language as follows:

$$V \propto I \qquad 2.1$$

However, this expression is of limited use since we need an equation. This can only be achieved by introducing a constant of proportionality; in this case the resistance value of the resistor (Dr. F.M.Spieksma, 2016).

$$I = \frac{V}{R} \qquad 2.2$$

$$R = \frac{V}{I} \qquad 2.3$$

$$I = IR \quad 2.4$$

where I is the current, measured in amperes; V is the potential difference, measured in volts; and R is the resistance, measured in ohms. For alternating currents, especially at higher frequencies, skin effect causes the current to spread unevenly across the conductor cross-section, with higher density near the surface, thus increasing the apparent resistance (Dr. F.M.Spieksma, 2016).

2.2.5. Energy (W)

This is a system's property that allows it to perform tasks. Every time labor is completed, energy is moved from one system to another. Heat is the most common form of energy transformation. As a result, one of the impacts of an electric current is that it generates heat (e.g., an electric kettle). J. P. Joule conducted research on this phenomenon. He came to the conclusion that the amount of heat created was proportional to the square of the current flowing and the length of time it was flowing. Once again, a proportionality constant is necessary, and this time the resistance of the circuit is employed. As a result, the equation gives the amount of heat created (or energy dissipated) (A.salih, 2013).

$$W = F \times S \quad 2.5$$

And applying Ohm's law as shown in equations (1.3) to (1.5)

$$W = \frac{V^2 \, t}{R} \quad 2.6$$

$$W = VIt \quad 2.7$$

2.2.4. Power

This is the rate at which work is done, or at which energy is dissipated. The unit in which power is measured is the watt (W) (A.salih, 2013).

$$P = \frac{W}{t} \quad 2.8$$

From equation 2.2, 2.3 and 2.4

$$P = I^2 R \quad 2.9$$

$$P = \frac{V^2}{R} \quad 2.10$$

$$P = VI \quad 2.11$$

2.3. LS-DYNA

Livermore Software Technology Corporation (LSTC) created LS-DYNA, a finite element program that is widely used in a variety of fields (e.g., construction, manufacturing, bioengineering, automobile and marine industries). Its key selling point is a highly nonlinear transient dynamic finite element analysis that employs explicit time integration. LSTC defines "nonlinear" as a condition characterized by at least one of the following issues:

Nonlinear boundary conditions – contact between parts that changes over time

Nonlinear geometry – parts geometry changes during the simulation

Nonlinear materials – materials that do not exhibit linear elastic behavior

Different keyword cards offer input to various solvers in a typical LS-DYNA model. LS-Pre-Post or keyword files can be used to modify most of the keyword cards. The pre- and post-processor for LS-DYNA is known as LS-Pre-Post. All the inputs are contained in the keyword files, which can be categorized into the following groups based on their intended use:

Geometry - This section contains the model's precise geometric data, such as shapes and measurements. LS-pre- post and post-processor, LS-Pre-Post, or other CAD applications can be used to generate the geometric models. The LS-Pre-Post program was used to create all the 2D and 3D geometric models in this thesis.

Parts information - All the cards for specifying parts, element types, element parameters, and material kinds are in this category. By providing the keywords in the various cards, material attributes and element kinds can be applied to the corresponding components.

Execution - This category consists of all the execution cards for the simulation, for example, the starting time, termination time, and the time step.

Contact - The contact cards are used by the user to define the different types of contacts. For different scenarios, several contact kinds can be used. Different types of approaches for calculating contact stiffness or improving convergence can be chosen by modifying the parameters.

Boundary conditions - In LS-DYNA, user can set the boundary conditions by defining point, line, or surface constraint on the parts. Prescribed motions can be also applied.

Output - This category includes the output cards that start with database for the desired output for the simulations; for example, displacement, velocity, acceleration, and force can all be recorded with a pre-set time step (St. John's, 2016).

2.4. Fluid dumper modeling

Magneto rheological (MR) fluid in industrial shock absorber which, monitor moving object stoppage. The proposed solution allows the braking force (by electronic controller) to be adjusted to the kinetic energy of moving object (Andrzej M. et al, 2012). A control strategy is presented aimed at reducing road damping without penalized driver comfort. A half truck model is used and several simulations are carried out. The magnitude of total road damage reduction (over three axles) on a simulation road varies with speed. The reduction was found to be 6% at 7.5m/s, 19% at 17.5m/s and 25m/s (Georgios T., et al, 2010).

Optimize design of MR damper by means of finite element analysis of fluid dynamic and magnetic field. The aim of the study was to geometrically optimize MR damper according to two objective, target damper as 1000N and maximum magnetic damper. The optimal studied was performed using finite element method using ANSIS electromagnetic and CFD tools. The FEM analysis was used to obtain desired optimal value in ANSIS goal driven to optimize tools (Zekariye P., et al 2012).

Dynamic Model For a damper at Magneto rheological, the model includes friction and temperature effects, and consists of piston differential inclusion coupled with temperature equation f energy balance. The fluid viscosity believed to be a function of temperature and electrical current, which can be used in practice as the control variable specificity, the initial impact simulation shows how the oscillation can be effectively damped (zalewski,et al, 2013).

2.5. Electromagnetic suspension system

Vehicles vibrate during running condition by means suspension by using shock absorber movement to produce electricity. As a result, they proposed to use this electricity headlamps and indicators because of this of this producing electricity from this system. They also suggested using certain electro-magnets for prevent the vehicles tires from puncturing due to nails by attracting them to the magnets (Mr,V.V. ,et al, 2015).

To improve the efficiency of the active suspension system without raising unnecessarily complexity and expense, the implementation of the electromagnetic actuator in the active suspension system was analyzed (Aniket Thosar, 2014). Magnetic shock absorber operates on the simple magnet concept that attracts each other from opposite pole and repels each other from the same pole. Both magnets are face the same pole and both are similar pole. The rod moves inside the piston, the moving magnet moves towards the fixed magnet. Since both magnets are created between the magnet with the same pole repulsion force (Milica.B.et, al, 2012).

Additional stability and maneuverability of the active suspension system by performing active roll and pitch control when cornering and braking and reducing ground irregularities, thus increasing safety of vehicle and passenger driving comfort. The calculated moment of a passive suspension is replicated by an electromagnetic quarter car model, demonstrating the dynamic potential of the electromagnetic suspension system installed (Bart L.j Gysen, et al, 2010). Hydraulic and air suspension have leakage problem and this has been used because of magnetic suspension system which is unsafe for any suspension system (Ayman A, et al, 2013).

Experimentally work on the calculation of energy flow through the base. The energy flow, foundation’s strength and velocity are an appropriate measure of the effectiveness of a real vibration isolation system where the foundation is not perfectly rigid. The energy flow through the magneto-sensitive rubber isolators is measured directly by inserting a force transducer under each isolator and accelerometer on a closed base to each isolator (Alberdi M., et al, 2012)

For the model an electromagnetic suspension device it is important to model a feature of the magnetic force along with the current and the objective's location. So, 1D look-up tables are used to reflect inductance as an air gap feature from measured result. It is creating 2D look-up table to reflect electromagnetic force as a function of current and air gap. The electromagnetic suspension method is modeled in MATLAB/SIMULINK by using this lookup table (Bart L.j.Gysen et al, 2010). The development of suspension and steering geometry design that is appropriate to be used on off road circuit giving us suitable camber and caster variation, toe angles, Ackerman geometry, proper force transfer from chassis to ground and shock absorber characteristics while operating on the challenge posed by a rugged off-road track. The geometry concept discussed here has been achieved by studying its dimensions, installation location and use (Aridam Pal, et al, 2013).

By manipulating the magnetic field, this will be able to achieve varying stiffness and increased comfort. It will also help us save money by reducing wear and tear and requiring fewer maintenance. Two cylindrical tubular structures with electromagnets on both ends make up the magnetic suspension for motor cycle. The magnetic field will be induced by battery power, which will be generated by electromagnets via a feedback loop. A magnetic field is formed around a wire as current runs through it. When the current in the wire stops, so does the magnetic field that was previously generated. The resultant magnetic field's strength is proportional to the current flowing through the wire. When a wire is coiled, the magnetic field generated is focused in the coil's center. By adding a ferromagnetic substance in the coil's center, the field's strength can be boosted (Aniket Bharambe, 2015).

Elankovan M. 2015, This research aims to make use of suspension systems from the time they were first used following the advent of IC engines until they reached their current proportions. Typical dampers lose their efficiency over time due to energy dissipation into heat, which raises the temperature of the viscous oil, making it thinner. Many advancements, such as mono-shock suspension, improved motorbike suspension quality. However, the latter has a significant disadvantage in terms of putting it on operating vehicles with twin swing arm rear suspension, as the chassis must be redesigned. a new model is being developed intended to be used as a replacement for oil viscosity dampers, which are used in machines and automobiles. The idea of employing an electromagnet to adjust the magnetic field electronically makes the total suspension semi-active, with the possibility of energy harvesting. A highly conducting solenoid coil that is concentrically placed with a permanent cylindrical Alnico magnet is one of the components used in this design. Viscose damping is done via Faraday's induction law, and it has advantages over conventional shock absorbers in terms of reliability and stability.

2.6. Hybrid electromagnetic and eddy current damper

When a conductor moves through a non-uniform, external magnetic field, the magnetic flux varies through loops inside the conductor, thereby causing electromotive force around the loop and eddy currents flow (Kirk T. Mcdonald, 2012). Eddy currents are generated in a time-varying magnetic field. It is induced either by the conductor movement in static field or by changing magnetic field strength, initiating motional and transferring emfs. Since the generated eddy currents creates a repelling force proportional conductor's velocity, the moving magnet and conductor act like a viscous damper (Babak Ebrahim, 2010).

Just 10-16 percent of a car's fuel capacity is used to combat road friction and drag in daily driving. Under the excitation of road irregularity and vehicle acceleration and deceleration occurs one significant loss of vibration energy dissipation by shock absorber in the vehicle suspension. The aim of this paper is to design, characterize and test a retrofit regenerative shock absorber that can effectively recover vibration energy in small space. A four-phase linear generator with improved efficiency and reduced weight is built using rare-earth permanent magnets and high permeable magnetic loop. To analyze the magnetic field and direct optimization, the finite element method was developed. To analyze the waveforms and regenerated energy of the harvester at various vibration amplitudes, equilibrium position, frequencies and design parameters, a theoretical model is developed (Brian S. et al, 2010).

The creation of new electromagnetic hybrid damper that provide regenerative adaptive damping force for various application is presented in this paper. The application of electromagnetic technology to damping system has recently opened new possibilities for the development of adaptive semi-active damping systems with energy recovery. An electromagnet damper hybrid is suggested in this study. The viscous and electromagnetic subsystems of the hybrid damper are designed to work together.

The viscous medium provides a bias and fail-safe damping power, while the electromagnetic portion makes the hybrid design adaptable and generable. An analytical and the electromagnetic finite element method approach is used to shape and analyze the electromagnetic component. The geometric aspects of the electromagnetic aspects of the electromagnetic subsystem are optimized by combining all modeling approaches (Ehsan A. et al, 2015).

The suspension hydraulic shock absorbers are normally where vibration vehicle energy is dissipated. Shock absorbers are installed in automobiles and trucks to reduce vibrations caused by road imperfections. Traditional shock absorber, on the other hand, waste energy as heat and are never used. The energy dissipated shock absorber can be recovered using regenerative electromagnetic shock absorber. For this paper, two types of regenerative electromagnetic shock absorbers were developed: a linear and a rotary system. The performance of these shocks is defined in laboratory test stand and in small all-terrain vehicle. Researchers has been studying vibrational energy harvesting using various magnetic device for the past two decades. The main accomplishments of this research are reviewed in this article. The theoretical basis for the design of permanent magnet liner synchronous generators that are used as vehicle suspension dampers is presented. The use of linear generator as a damper in the vehicle shock absorber was explained using an empirical context. The generator dimensions for maximum flux density in the air gap are calculated using finite element simulation. The damping force is not exactly proportional to the excitation velocity, according to the writers, and there are few harmonics in the force (Hedlund, 2012).

The motor part of the established electromagnetic suspension actuator is subjected to three-phase mathematical model using parameters obtained from measured and test data. For active control, a main/inner loop configuration is used, and the constraints of control current and energy flow state of the actuator are investigated by simplifying the inner loop control scheme. There are two different control modes proposed, namely, consumption full active (CFA) and regenerative semi active (RSA), which emphasize vibration control sprung mass and vibration energy regenerative induced road roughness, respectively. The result shows that the CFA mode can boost vehicle ride comfort by more than 30% despite battery energy usage, while the RSA mode can improve ride comfort by up to 10% with regenerated energy charging (K.Huang et al, 2011).

The active actuator in this paper is an electromagnetic damper made up of a permanent magnet, direct current motor, ball screw and nut. The primary aim of this paper is increase to investigate electromagnetic suspension using a hybrid control strategy. In order to increase vehicle efficiency and energy recovery at the same time, the frequency domain genetic algorithm is used to perform the hybrid control strategy under nonlinear condition. Following that, the achievement coefficient is used to look at the design AEMSS in the real-world condition for the life. The simulation results show that the engineered AEMSS has the desired output while being able to be regenerated and converted in to electrical energy from the road excitation. Furthermore, it has been demonstrated that the ideal AEMSS regenerative energy during ascent and descent of the bump while consuming energy near the top (M Montazeri-Gh, O Kavianipour, 2014)

Hydraulic dampers dissipate vibration energy into non-recyclable heat, which is how traditional vehicle suspensions suppress the vehicle. This is a significant amount of energy that deserves to be recovered. To recover this dissipated energy and increase fuel efficiency, electromagnetic regenerative dampers, or shock absorbers, have been proposed. The suspension dynamic with these regenerative dampers can vary considerably from that of conventional dampers. To begin with, unlike traditional hydraulic dampers, electromagnetic regenerative dampers have a considerably higher inertia, which is introduced by the electromagnetic generator. This has a big effect on suspension dynamics. Second, the electromagnetic damping coefficient is associated to the electric load connected to the output generator and can be regulated. Despite the various concepts proposed, the impact of these types of regenerative dampers on the vehicle dynamics has yet to be fully studied. This paper compares the effects of two types of rotational electromagnetic regenerative dampers, one with and the other without a mechanical motion rectifier, on vehicle suspension performance. When the tires lose contact with the ground, the modeling in this paper takes that into account as well. In order to assess the effects of the equivalent damping coefficient, simulations were conducted with step road profile excitations and road profile excitations specified by the international standardization organization. Both types of electromagnetic dampers may achieve better ride comfort performance than a constant damper with an optimized equivalent inertia mass, according to findings (Peng Li, Lei Zuo, 2017).

This paper discusses the design and numerical simulation of a linear generator for use in an automotive shock absorber. To ensure efficient energy recovery, the design linear generator uses high-performance rare earth permanent magnets in a small package. The generator configurations are derived using a combination of finite element analysis and MATLAB simulation to ensure optimal magnet utilization and efficiency. To verify the numerical analysis, test was conducted on linear generator prototype and an electromagnetic shock absorber. The full-scale energy harvesting shock absorber with fluid damping and linear generator is then built using the numerical model. The use of fluid amplification to achieve energy dissipation and velocity amplification at the same time is novel feature of the present work.

Fluid amplification has no effect on the system's dynamics and doubles the coil velocity. Additional advantage of the system includes smooth variance in damping power, improved fail-safe characteristics, and the lack of transmission elements like mechanical gear (Shankar S. et al, 2015).

2.7. Research gap

The literature reveals that different significant role in the automotive sector. Electromagnetic suspension provides safe and irritate free vibration control and reducing wear and tear. And maintaining the vehicle steady while by ensuring good keeping during driving, cornering, and braking. From the above review and researches, it can be observed that most of the researches was done on the design and analysis of electromagnetic shock absorber focusing on numerical methods. Most of the results obtained were not validated using analytic method. In addition, most of electromagnetic shocks absorber were studied for the application of racing car, luxuries vehicles, and motor bikes. The application of electromagnetic shock absorber for off road vehicle which are highly available in our country was not studied. More over while determining the loads, the load due to the weight transfer of the vehicles as a result of the road conditions were not considerd.so that this paper discuss the analytic and numerical analysis of the electromagnetic shock absorber for off road vehicles by considering the load transfer due to the road condition.

CHAPTER THREE

MATERIALS AND METHODS

To achieve the prerequisite objective this study will try to use different methods journals and thesis. The data were analyzed by the necessary design of Analytical design. CATIAV521 is used for modeling the geometry, LS-DYNA for Existing shock absorber and ANSYS Maxwell used to simulate electromagnetic suspension system, to determine the energy dissipation.

3.1 Materials and components

Materials and their properties which are used for design of electromagnetic suspension system.

Table 3.1. Materials and components

Electromagnetic shock absorber Components	Mass density (kg/mm^3)	Young's Modulus (KN/mm^3)	Poisson's ratio	Materials
Coils	7.80e-06	210	0.3	copper (Joy Gohil, Karan Jani ,2017)
Permanent magnets	6.9e-07	210	0.3	Neodymium-boron(Oly D. Paz, 2014)
Springs	7.80e-06	210	0.3	Carbon steel(N Lavanya et al, 2014)
Reservoir	7.80e-06	210	0.3	Steel (N Lavanya et al, 2014)
Outer reservoir	7.80e-06	210	0.3	Steel(N Lavanya et al, 2014)
Piston	7.80e-06	210	0.3	Steel(N Lavanya et al, 2014)

3.2. Methods

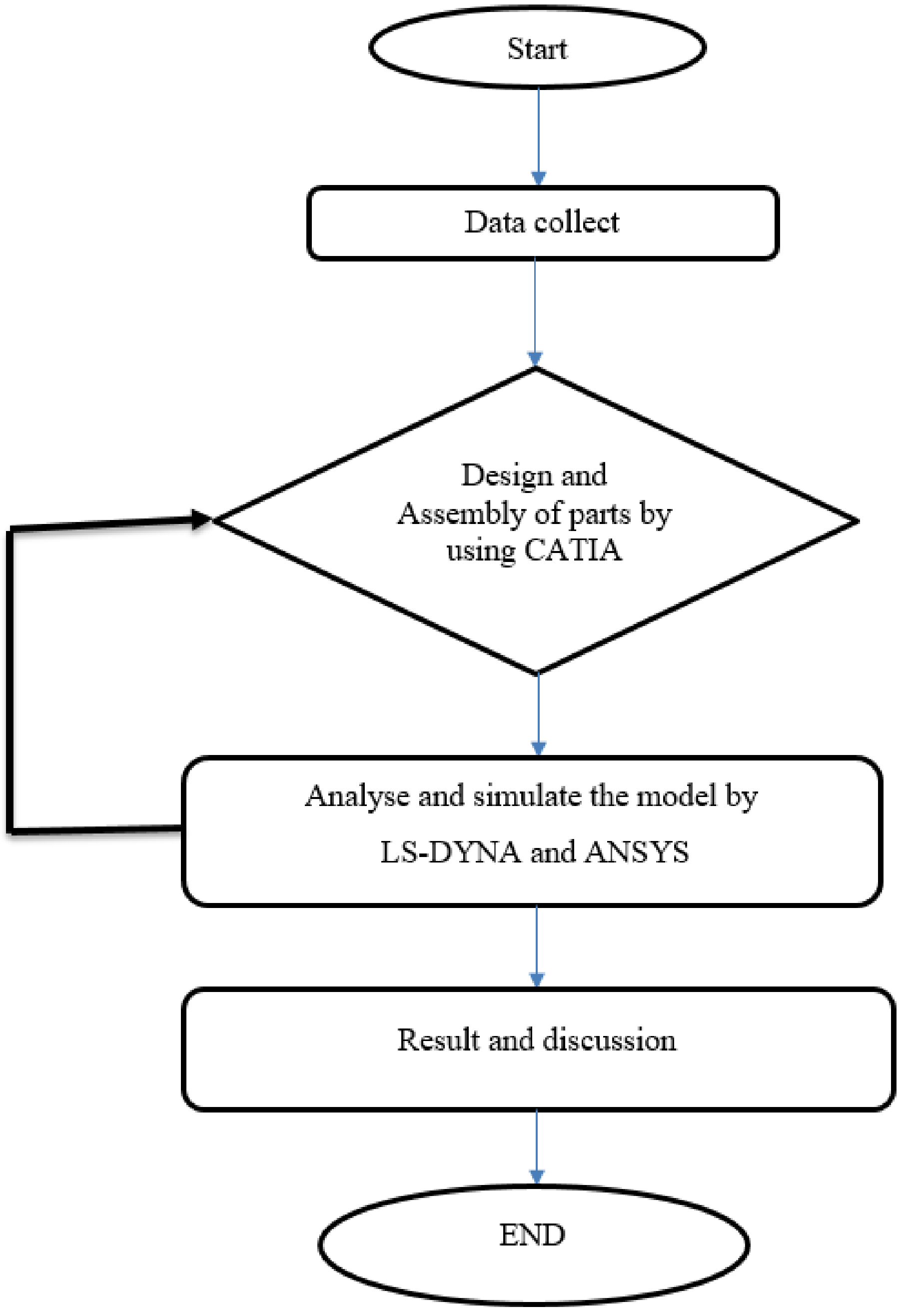


Figure 3.1: Block diagram of the proposed research methodology

3.2.1. Data collection and analysis method

In this thesis work both primary and secondary information source are used. The primary data are gathered by measuring the coil spring of Toyota Hilux double Cap 4x4, which is available in the Adama Garage. The main dimensions of the shock absorber are measured by using Vernier caliper and the values are given at table 3.2 and specification of the vehicle is shown at figure 3.2:

- Total Number of turns=8
- Wire diameter= 17mm
- Outer diameter = 78mm
- Free height =316mm

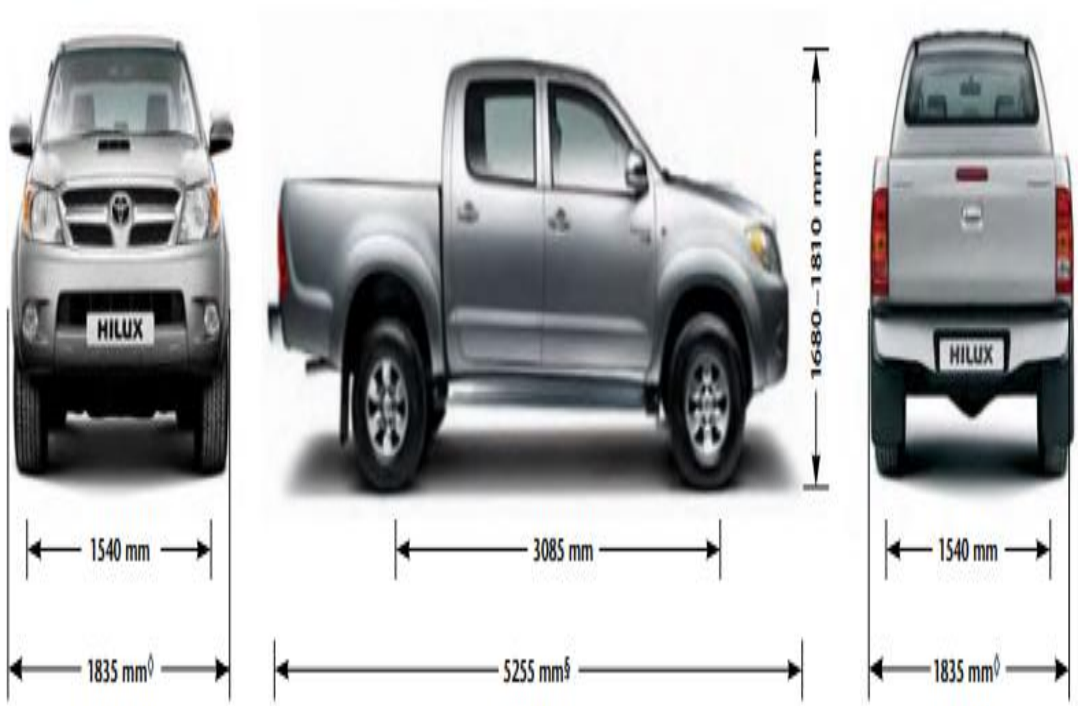


Figure 3.2: Toyota Hilux 4x4 double Cab (Dinesh Nadarajah, 2021)

Table 3.2: vehicle and coil spring Specification of Toyota Hilux 4x4 (Dinesh Nadarajah, 2021)

No	Parameters	Dimension	SI	Remarks
1	Gross Weight	2940	Kg	Toyota Hilux manual
2	Kerb Weight	1885	Kg	Toyota Hilux manual
3	Wheel base	3085	mm	Toyota Hilux manual
4	Height	850	mm	Toyota Hilux manual
5	Front tread	1540	mm	Toyota Hilux manual
6	Rear tread	1540	mm	Toyota Hilux manual
7	Total number of coils	8	-	count
8	Outer diameter	78	mm	Measured
9	Free length	316	mm	Measured
10	Diameter of the wire	17	mm	Measured

3.2.2. Modeling of the proposed Electromagnetic suspension system

Once the EMS system is configured, CATIA software will be carried out. The derivation of the ANSYS maxwell for the EMS system is achieved using equivalent model of complete system representation. The electromagnetic constraints of the EMS system such as electromagnetic force, electromagnetic field density, current, resistance and main dimensions of integrated EMS system will be defined. Finally, the designs of the complete system will be performed to predict behavior of the EMS system.

3.2.2.1. The proposed Electromagnetic suspension system concept

The proposed Electromagnetic suspension (EMS) system is designed to be integrated into a Toyota Hilux. A new type of car suspension is being developed. They are replacing the spring and damper system used in all vehicles today with linear electromagnetic motors controlled by microprocessors and special mathematical equations. The system is assumed to be connected on electric power when the vehicle is running; when the vehicle encounters bump the SP moves up being compressed and this action will bring up the EM into damping operation due to repulsive forces of similar poles; the same action takes place when it encounters a pit on the ground. Electromagnetic suspension works by constantly sensing changes in the road surface and feeding that information, via the ECU, to the outlying components. Because of electronic system ECU is better to control the system.These components then act upon the system to modify its character, adjusting shock stiffness, spring rate and the like, to improve ride performance, drivability, and responsiveness. The ECU collects, analyzes and interprets the data. The force is produced by moving linear electromagnetic field acting on conductors that maintain a sort of electromagnetic equilibrium with the others to carry other words, each electromagnetic actuator acts as both a spring (with variable-rate damping characteristics) and a variable rate shock absorber .active suspension use electronic monitoring of vehicle conditions, couple with the means to impact vehicle suspension and behavior in real time to directly control the motion of the car. Thus, if one uses, for instance, frameless, permanent magnet, three phase, brush-less servo motor in the place of traditional shocks, the system includes extremely complex servo control algorithms and super quick sending and receiving of signals throughout the vehicle, so that the linear motor reacts instantaneously to driving condition that change constantly. The vehicle's weight, while maintaining the desired body attitude. At the same time, each electromagnetic linear Actuator serves as its own shock absorber, it is by replacing the hydraulic system in to well-developed electromagnet shock absorber.

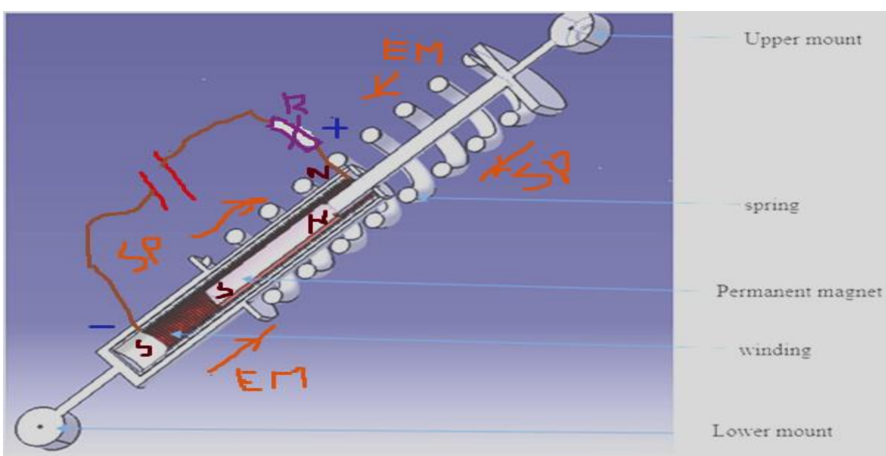


Figure 3.3: Operation of designed EMS

3.2.3. Design of spring

3.2.3.2. Solid length

When the compression spring is compressed until the coils meet each other, then the spring is said to be solid (A.C.bhasha, 2017).

$$l_s = n' \times d \qquad 3.1$$

$$Ls = n \times d = 8 \times 17 = 136mm$$

The compression of the spring which, the coil is touch is other is 136mm.

Where Ls solid length (mm)

n´ Total number of coils

d Diameter of the wire (mm)

3.2.3.2. Pitch

The pitch of the coil is defined as the axial distance between adjacent coils is uncompressed state (A.C.bhasha, 2017).

$$P = \frac{Free\ length}{n' - 1} \qquad 3.2$$

$$P = \frac{LF - Ls}{n'} + d$$

$$= \frac{316 - 136}{8} + 17 = 39.5mm$$

The distance between the two adjacent coils which can measured from midpoint of the spring material at free length is 39.5mm.

Where P Pitch (mm)

LF Free length of the spring (mm)

Ls Solid length of the spring (mm)

n´ Total number the coil

d Diameter of the wire (mm)

3.2.3.3. Spring index: is the ratio of mean diameter the coil to dimeter of the wire (A.C.bhasha, 2017).

$$C = \frac{D}{d} \quad 3.3$$

$$C = \frac{78}{17}$$

$$C = 4.6$$

D outer dimeter (mm)

d Diameter of the wire (mm)

C spring index

3.2.3.4. Deflection of helical spring of circular wire

$$\frac{W}{\delta} = \frac{G \times d^4}{8D^3 n} = \text{constant} \quad 3.4$$

$$\delta = \frac{8WD^3 n}{Gd^4}$$

$$\frac{8 \times 7210.35 \times 78^3 \times 8}{80 \times 10^3 \times 17^4}$$

$$= 32.77\text{mm}$$

The maximum movement of the spring when the load is applied to the spring is 32.77mm.

Where G modulus of rigidity $\left(\mathrm{KN}/\mathrm{M}^2\right)$ by taking from Appendix A-1.

δ Deflection (mm)

W Load (N)

D outer dimeter (mm)

n´ Total number of coils

3.2.3.5. Spring rate

The rate (stiffness or spring constant) is defined as the load required per unite deflection of the spring (A.C.bhasha, 2017).

$$K = \frac{W}{\delta} \qquad 3.5$$

$$K = \frac{W}{\delta} = \frac{7210.35}{32.77} = 220 N/_{mm}$$

The amount of weight a spring is designed to carry when deflected to a certain height is $220 N/_{mm}$.

Where K Spring rate ($N/_{mm}$)

W Load (N)

δ Deflection (mm)

3.2.3.6. Maximum shear stress

$$\tau = K \times \frac{8 \times W \times C}{\pi d^2} \qquad 3.6$$

$$\tau = K \times \frac{8 \times W \times C}{\pi d^2}$$

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C}$$

$$K = \frac{4 \times 4.6 - 1}{4 \times 4.6 - 4} + \frac{0.615}{C}$$

$$K = 1.34$$

$$\tau = K \times \frac{8 \times 7210.35 \times 4.6}{\pi 17^2}$$

$$\tau = 394\ {}^{N}/_{mm^2}$$

The maximum shear stress is $197\ {}^{N}/_{mm^2}$.

3.2.4. Force analysis

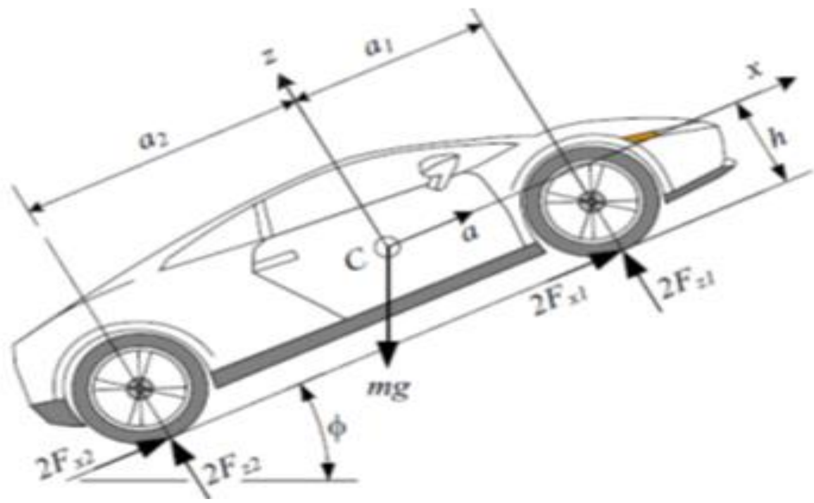


Figure 3.4: Four-wheel acceleration on inclined pavement

$$\sum Fx = 0 \qquad 3.7$$

$$\sum Fz = 0 \qquad 3.8$$

$$\sum My = 0 \qquad 3.9$$

From equation 3.5, 3.6, and 3.7 we get

$$2F_{x1} + 2F_{X2} - mg \sin\emptyset = 0$$

$$2F_{z1} + 2F_{z2} - mg \cos\emptyset = 0$$

$$2F_{z1}a_1 + 2F_{z2}a_2 - (2F_{x1} + 2F_{X2})\ h = 0$$

The reaction forces under the front and rear tire are

$$F_{z1} = \frac{1}{2}\,mg\,\frac{a_2}{L}\,COS\emptyset - \frac{1}{2}\,mg\,\frac{h}{L}\sin\emptyset$$

$$F_{z2} = \frac{1}{2} \text{mg} \frac{a_2}{L} \text{COS}\emptyset + \frac{1}{2} \text{mg} \frac{h}{L} \sin \emptyset$$

$$F_{x1} + F_{X2} = \frac{1}{2} \text{mg} \sin \emptyset$$

At the ultimate angle $\emptyset = \emptyset_M$ all wheel will begin to slide simultaneously and there for: -

$$F_{x1} = \mu x_1 F_{z1}$$

$$F_{x2} = \mu x_2 F_{z2}$$

The equilibrium equation is

$$2\mu_{x1} F_{z1} \frac{a}{g} + 2 \mu_{x2} F_{z2} \frac{a}{g} - \text{mg} \sin \emptyset_M = 0$$

$$2F_{z1} + 2 F_{z2} - \text{mg} \cos \emptyset_M = 0$$

$$-2F_{z1} a_1 + 2F_{z2} a_2 \frac{a}{g} - (2 \mu x_1 F_{z1} + 2\mu x_2 F_{z2}) \text{h} \frac{a}{g} = 0$$

There for: -

$$\left(\frac{a_{4wd}}{g}\right) = \mu_x \qquad 3.10$$

The value of μ for dry road is 0.6

a = 0.6× 9.81

a= 5.88 m/s^2

tan $\emptyset = \mu$

tan^{-1} = 0.6

$\emptyset = 31^0$

$$F_{z1} = \frac{1}{2} \text{mg} \frac{a_2}{L} \text{COS}\emptyset - \frac{1}{2} \text{mg} \frac{h}{L} \sin \emptyset$$

$$=\frac{1}{2} \times 2940 \times 9.81 \times \frac{1.54}{3.08} \cos 31^0 - \frac{1}{2} \times 2940 \times 9.81 \times \frac{0.85}{3.08} \sin 31^0$$

$= 4130.8$ N

$$F_{z2} = \frac{1}{2} \text{mg} \frac{a_2}{L} \text{COS}\emptyset + \frac{1}{2} \text{mg} \frac{h}{L} \sin \emptyset$$

$$=\frac{1}{2} \times 2940 \times 9.81 \times \frac{1.54}{3.08} \cos 31^0 + \frac{1}{2} \times 2940 \times 9.81 \times \frac{0.85}{3.08} \sin 31^0$$

F = 8230.2 N

- ✓ ***On level road***

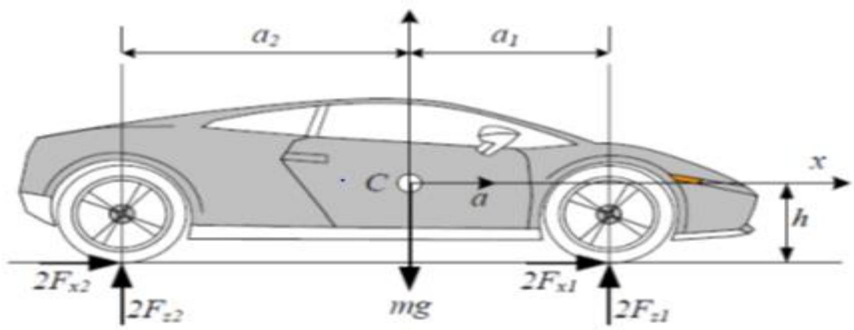


Figure 3.5. Acceleration on a level pavement

$$\sum Fx = 0 \quad (3.11)$$

$$\sum Fz = 0 \quad (3.12)$$

$$\sum My = 0 \quad (3.13)$$

From equation 3.5, 3.6, and 3.7 we get

$$2F_{x1}+2F_{X2}\text{-mg} = 0$$

$$2F_{z1}+2F_{z2}\text{-mg} = 0$$

$$2F_{z1}a_1 + 2F_{z2}a_2 - (2F_{x1}+2F_{X2})\ h = 0$$

However, it is possible to eliminate (F_{x1}+F_{X2}) between the first and third equation and solve for normal Force F_{z1} ,F_{z2}

$$F_{z1} = \frac{1}{2}\,\text{mg}\,\frac{a_2}{L} + \frac{1}{2}\,\text{mg}\,\frac{h}{L}\frac{a}{g}$$

$$F_{z2} = \frac{1}{2}\,\text{mg}\,\frac{a_2}{L} - \frac{1}{2}\,\text{mg}\,\frac{h}{L}\frac{a}{g}$$

$$F_{z1} = \frac{1}{2} \times 2940 \times 9.81\,\frac{1.54}{3.08} + \frac{1}{2} \times 2940 \times 9.81\,\frac{0.85}{3.08}\frac{5.88}{9.81}$$

$$F_{z1} = 11175N$$

$$F_{z1} = \frac{1}{2} \times 2940 \times 9.81\,\frac{1.54}{3.08} - \frac{1}{2} \times 2940 \times 9.81\,\frac{0.85}{3.08}\frac{5.88}{9.81}$$

$$F_{z1} = 3245.7N$$

The reaction forces when the vehicle is in inclined pavement are 4130.08N and 8230.2N and for level pavement are 3245N and 11175N then we can take the maximum force for the design safe 11175N.

3.2.5. Design of electromagnet

The Effective area of the EM of a system is

$$A = \pi r^2 \qquad 3.14$$

$$A = 3.14 \times 0.04^2$$

$$= 0.005024m^2$$

Where A is area of effective EM

r radius of the reservoir

The magnitude of the electromagnetic force required to couple rotor and armature plate can be calculated as follows (Tomasz, 2009).

$$F_m = \frac{B^2 s}{8\pi} \times 10^7 \qquad 3.15$$

$$F_m = \frac{B^2 s}{8\pi} \times 10^7$$

$$1152879 = \frac{B^2 \times 0.001256}{8\pi} \times 010^7$$

$$= \sqrt{\frac{0.0280733}{0.005024}}$$

$$B = 2.36T$$

Where F_m Electromagnetic force [N]

B Electromagnetic field [Tesla]

μo Vacuum magnetic permeability and its value is 4π x 10-7 Web/Am

S Effective area of the EMS system [m^2]

3.2.5.1. Preliminary Design of Magnetic Circuit Coil

Calculation of ampere-turns per pole for the magnetic circuit is given by IN / pole = Sum of the ampere turns required to overcome the reluctance of the, pole, Pole shoe and air gap. For small PM synchronous motors, the air gap (mechanical clearance) between the stator core and rotor poles or pole shoes should be 0.3 to 1.0 mm (J.F. Gieras, 2009).

$$IN = \frac{B_p}{\mu_p} l_p + \frac{B_g}{\mu_g} l_g + \frac{B_m}{\mu_m} l_m \qquad 3.16$$

Continuity of magnetic flux requires that the total flux through each section of the circuit be the same. With the flux densities expressed using

$$\emptyset = A\mu H \;\; = C \qquad 3.17$$

$$\emptyset = A_p \mu_p H_p = A_o \mu_o H_g = A_m \mu_m H_m \qquad 3.18$$

$$\frac{\mu_p H_p}{\mu_g} = H_g$$

$$A_p \approx A_g$$

$$IN = H_p l_p + H_g l_g + H_m l_m = H_p \left(l_p + \frac{\mu_p l_g}{\mu_g} \right) + H_m l_m \quad 3.19$$

$$IN = 2228.2 \left(8 + \frac{6.3\text{x}10^{-4}}{1.25\text{x}10^{-6}} x1 \right) - 890000x3 = 2651.67$$

By assuming the worst scenario

$$IN = 3200$$

3.2.6. Design of area of coil

The cross-section area of the coil is

$$A_c = b_s h_t \quad 3.20$$

Where A_c cross-section area of the coil (mm^2)

b_s Tooth width (mm)

h_t length of the tooth (mm)

$$A_c = b_s h_t$$

$$A_c = 25 \times 8$$

$$= 200\ mm^2$$

The cross-section area of the coil (with insulation) (Oly D. Paz, 2014).

$$A_{\ c} = \left(\frac{A_{cc}}{K_{CU}} \right) \quad 3.21$$

$$A_{\ cc} = 0.7 \times 200$$

$$A_{\ cc} = 140\ mm^2$$

Where K_{CU} (0.4 – 0.7) is the coefficient of copper density in the coil.

A_{cc} Cross-section area of the coil copper

N_c Number of turns of the coil

$$A_{cc} = N_c A_w \tag{3.22}$$

$$A_w = \frac{A_{\ cc}}{N_c}$$

$$A_w = \frac{140}{3200}$$

$$A_w = 0.293\ mm^2$$

The area of the wire is

$$A_w = \pi \left(\frac{D_w}{2}\right)^2 \tag{3.23}$$

Where A_w area of the wire (mm^2)

D_w Wire diameter (mm)

Then the wire diameter is

$$D_w = 2\sqrt{\frac{A_w}{\pi}} \tag{3.24}$$

Then the diameter of the wire is

$$D_w = 2\sqrt{\frac{A_w}{\pi}}$$

$$D_w = 2\sqrt{\frac{0.293}{\pi}}$$

$$D_w = 0.62mm$$

The American Wire Gauge (AWG) and electrical current load system is the industry standard for expressing wire size, ampacities and skin depth frequency. The diameter of the wire is 0.62mm from American standard of wire gauge22 has a dimeter of 0.6451mm. So, from the chart the current is: I=7A.

3.2.7. Electromotive force and Energy

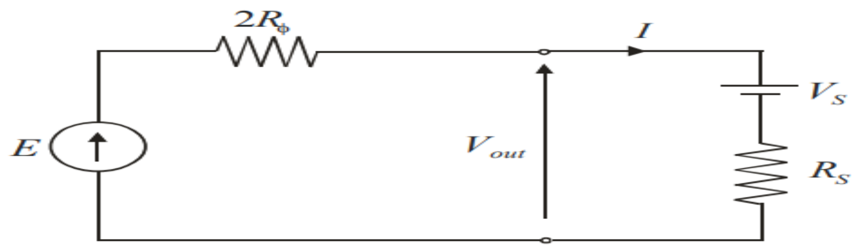


Figure 3.6: Simplified equivalent circuit of the electric shock absorber (Oly D. Paz, 2014).

The electromotive force can be expressed as an increase of the output voltage

$$E = K_e V_{out} \qquad 3.25$$

Where E electromotive force (V)

V_{out} Output voltage (V)

$K_e \geq 1$ is the emf coefficient, and it should be corrected after calculation.

A maximum phase electromotive force

$$E_\emptyset = K_e \frac{\pi}{3\sqrt{3}} V_{out} \qquad 3.26$$

The rms value of the phase current

$$I_\emptyset = \sqrt{\frac{2}{3}} \times I \qquad 3.27$$

Where $I_\emptyset$ rms current (A)

I wire current (A)

Then from equation 2.3, the resistance is

$$R = \frac{V}{I}$$

$$R = \frac{24v}{7A}$$

$$R = 3.42\ ohm$$

The electromotive force can be expressed as an increase of the output voltage

$$E = K_e V_{out}$$

$$E = 2.5 \times 24\text{v}$$

$$E = 60v$$

A maximum phase electromotive force

$$E_{\emptyset} = K_e \frac{\pi}{3\sqrt{3}} V_{out}$$

$$E_{\emptyset} = 2.5 \frac{\pi}{3\sqrt{3}} 24v$$

$$E_{\emptyset} = 36.25\ v$$

The rms value of the phase current

$$I_{\emptyset} = \sqrt{\frac{2}{3}} \times I$$

$$I_{\emptyset} = \sqrt{\frac{2}{3}} \times 7A$$

$$I_{\emptyset} = 5.72A$$

The rms value of the phase current

$$V_{\emptyset} = \sqrt{\frac{2}{3}} \times V$$

$$V_{\emptyset} = \sqrt{\frac{2}{3}} \times 24$$

$$V_{\emptyset} = 19.59V$$

The output powers

$$P_{out} = V_{out}I \qquad 3.28$$

The output powers

$$P_{out} = V_{out}I$$

$$P_{out} = 24 \times 7$$

$$P_{out} = 168watt$$

From equation 2.5 work done is

$$W = F \times S$$

$$W = 11175 \times 0.03277$$

$$W = 366.2\ J$$

3.2.8. Total wire length

From standard wire gauge table for 0.632diameter of wire resistance (ohm/1000m) is 52.9394

$$Lw = \frac{R}{r\text{esistance}(\text{ohm}/1000\text{m})} \qquad 3.29$$

$$Lw = \frac{3.42}{0.05294}$$

$$Lw = 64.6m$$

The total length of electromagnetic wire is 64.4mm.

3.2.9. Modeling and analysis of FEMs

The FEM is a general numerical method for solving partial differential equations in two or three space variables (i.e., some boundary value problems). To solve a problem, the FEM subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points.

Build Geometry: geometric dimension and 3D modeling of the components has been defined by using CATIA software of existing and modified deign a shown in figure below. Construct a two- or three-dimensional representation of the object to be modeled and tested using the work plane coordinates system within ANSYS and LS-DYNA.

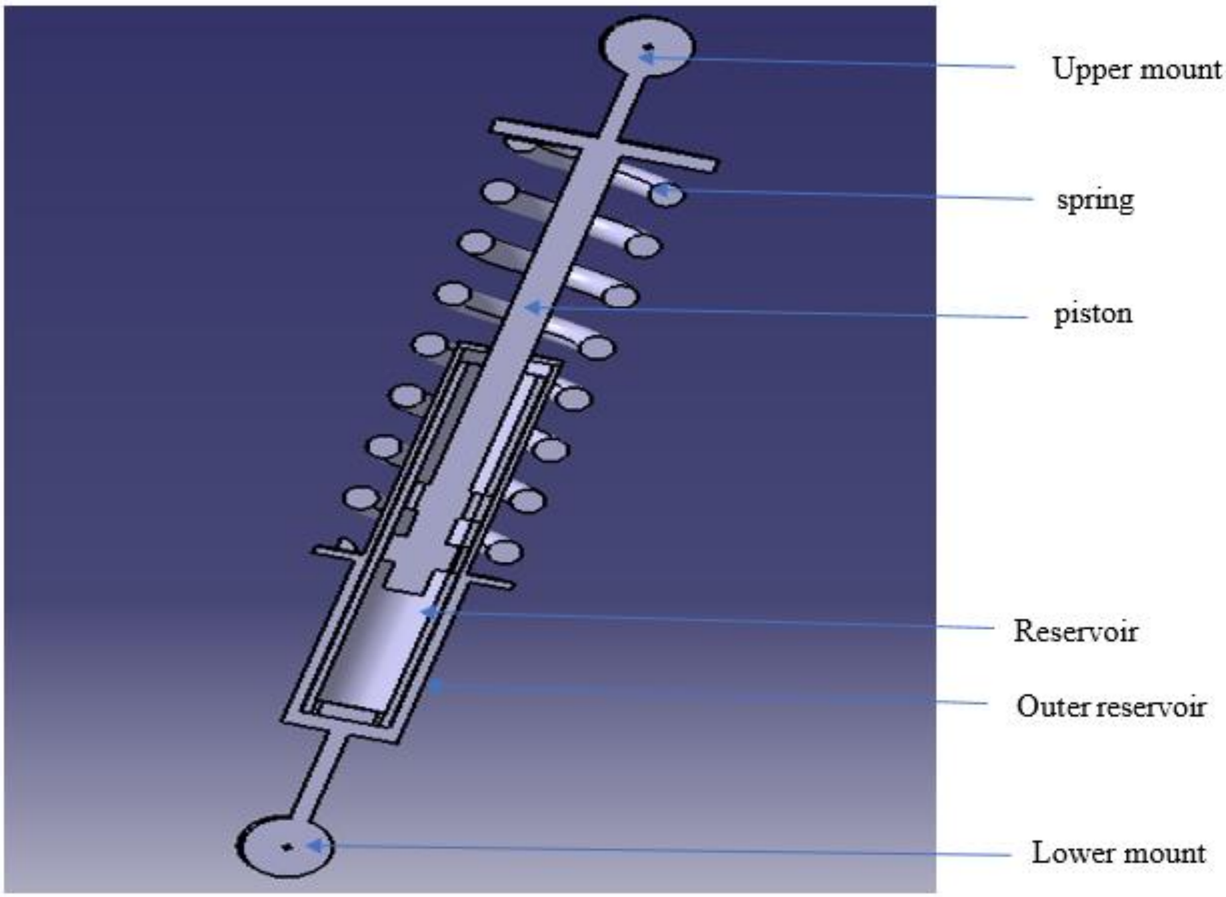


Figure 3.7: Existing shock absorber assembly design

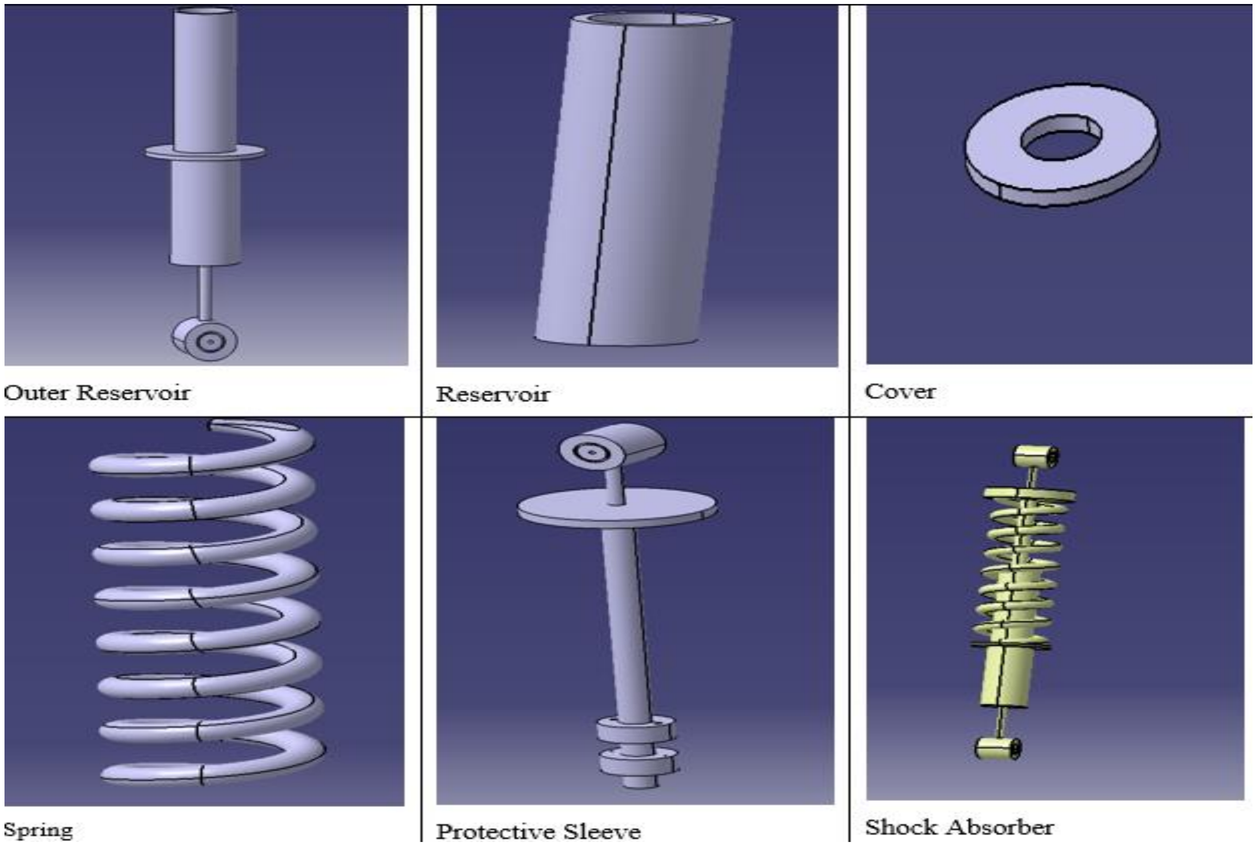


Figure 3.8.Modeled components of Existing Shock Absorber

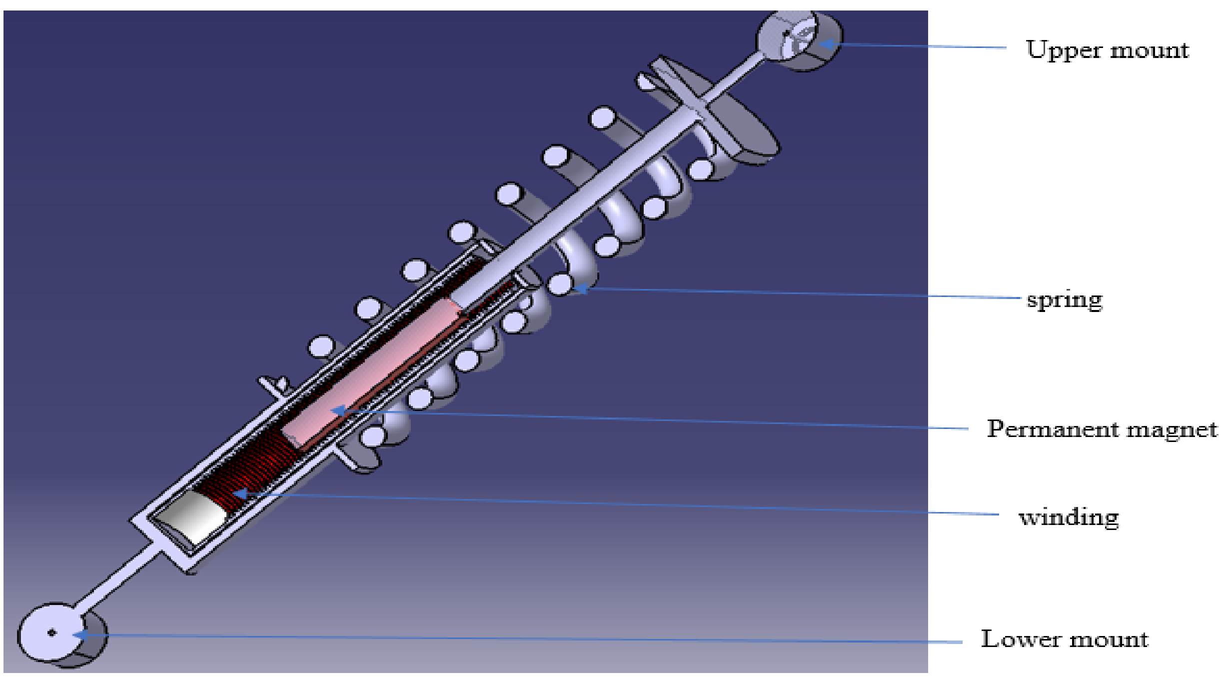


Figure 3.9: Modified shock absorber assembly design

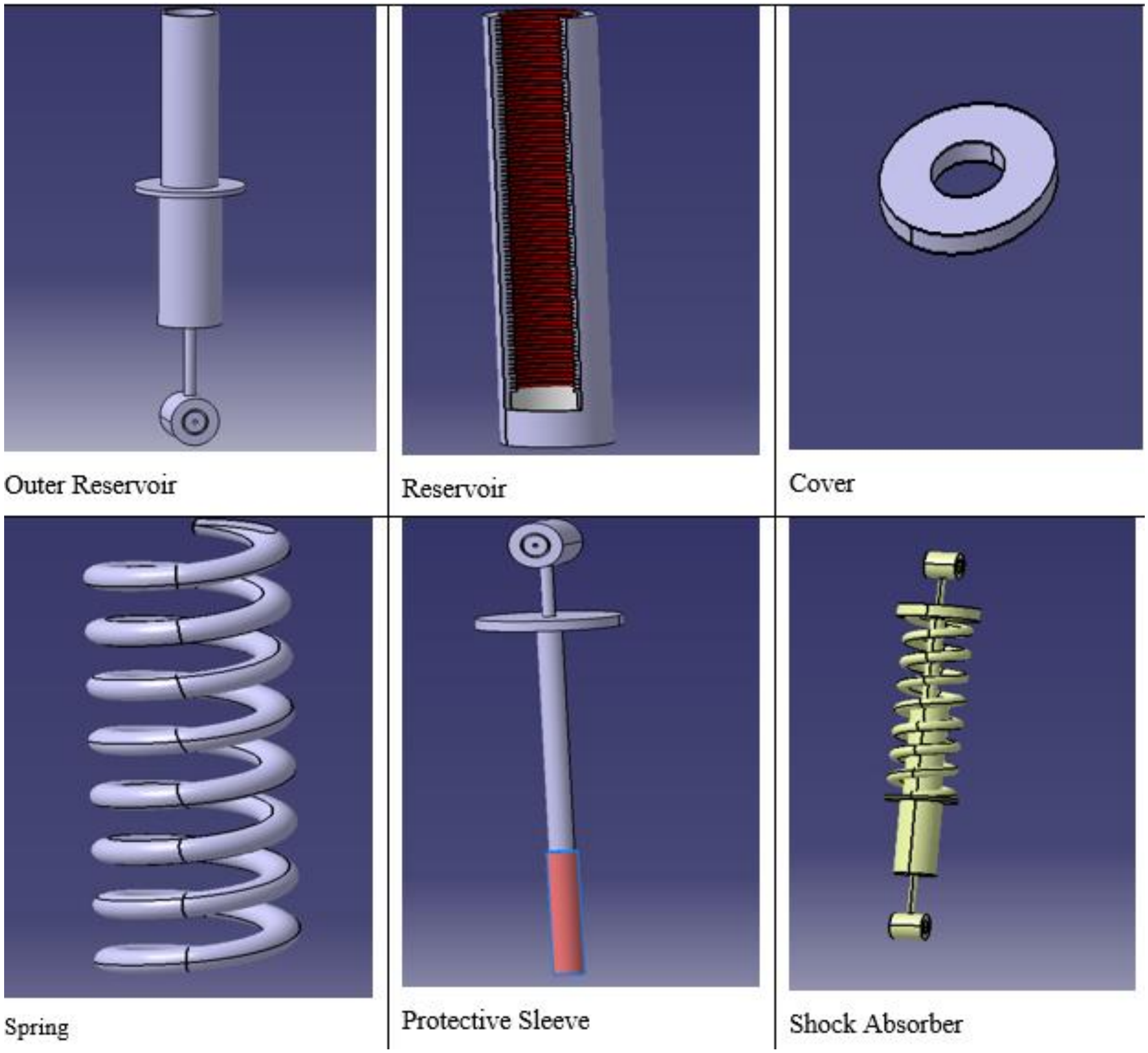


Figure 3.10.Modeled components of Existing Shock Absorber

3.2.9.1. Generate Mesh

LS-DYNA can automatically generate the mesh within the domain cylinder boundary. Which is to define the number of nodes for cylinder boundary. The nodes divide the boundary into several segments. This can be done by inputting the desired number of nodes or desired segment size, which having several elements is and several nodes is.

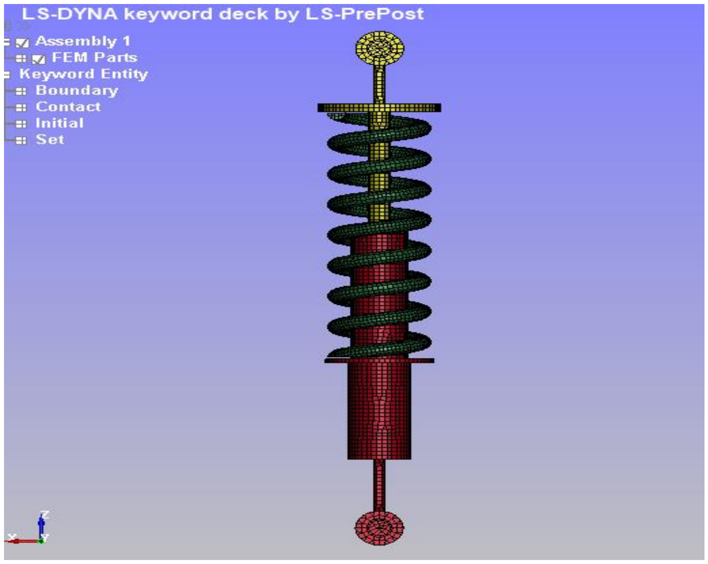


Figure 3.11: Existing shock absorber mesh

: At this point ANSYS understands the makeup of the part. Now define how the Modeled system should be broken down into finite pieces.

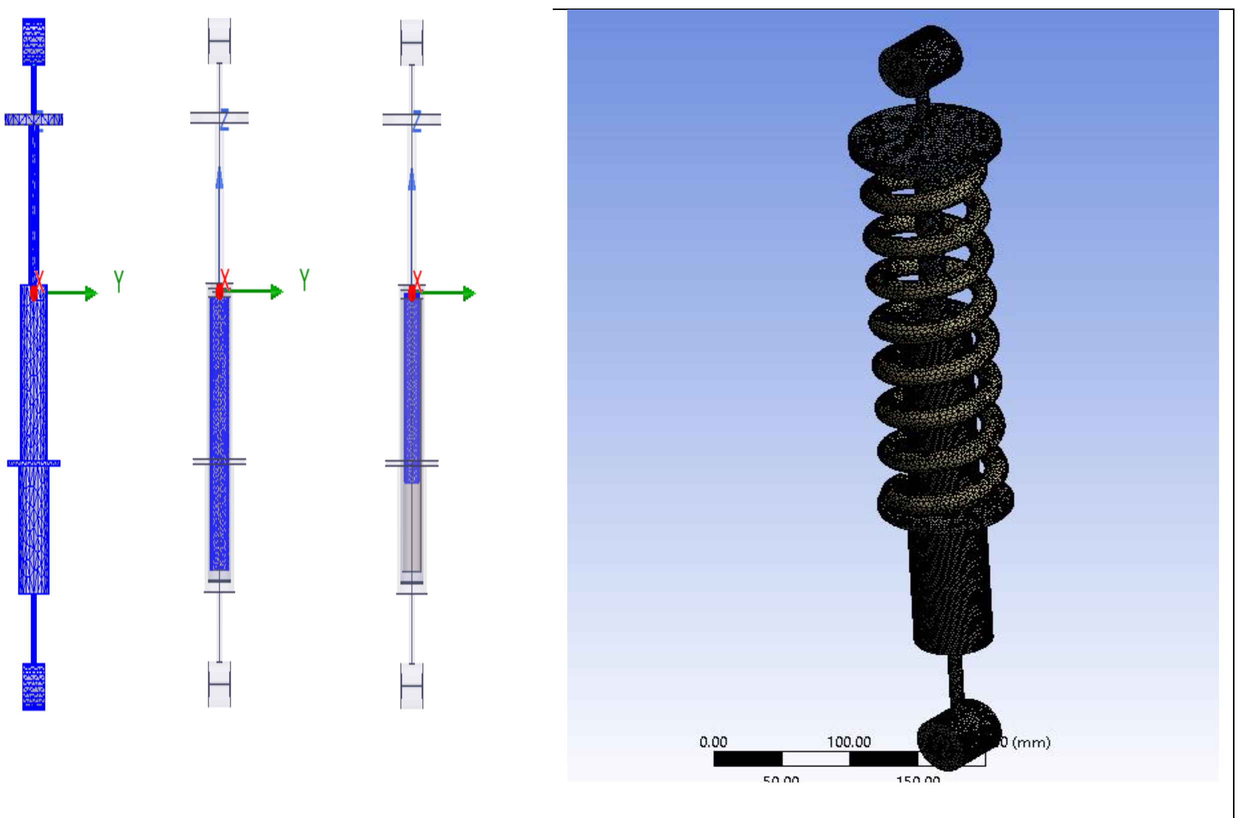


Figure 3.12: Electromagnetic shock absorber mesh

CHAPTER FOURE

RESULTS AND DISCUSSION

By applying boundary conditions and initial value generation we get the solution. After the solution has been obtained, the results, choose from many options such as tables, graphs, and contour plots.

Existing shock absorber

By running the program in order to impose the loads to the shock absorber, distribution of stress and displacement can be detective. Figure 4.1 shows the effective Von misses stress shock absorber. Low stress regions have been determined by blue color and respectively, high stress places have been determined by red color. Generally, at each counter of stress, it is obvious that the amount of highest stress has been occurred in some regions which are close to the fixed point and equals to 3.8Mpa.

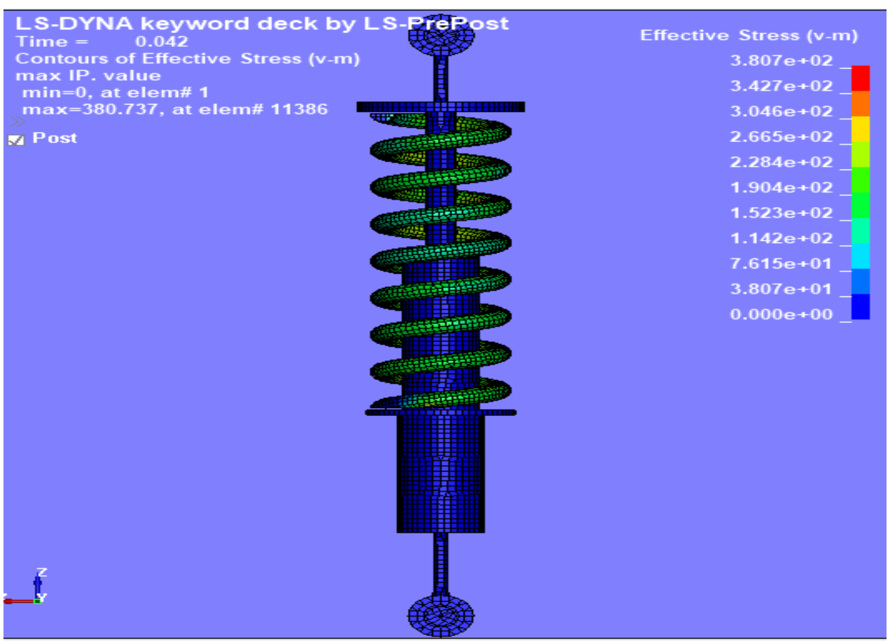


Figure 4.1: Effective Von-misses stress

The deformation of the structure under load depends on several variable. The nature of the load. The structure may be loaded by a compression of tensile force, by the moment or by combination of force and moments. If load by force, the deformation occurs. Force can affect an object's shape. A change in shape due to the application of a force is a deformation. For small deformations, two important characteristics are observed. First, the object returns to the original shape when force is removed that is the deformation of elastic for small deformation. Second, the size of the deformation is proportional to the force. From structural analysis the maximum deflection of the shock absorber is occur at 32.77mm.

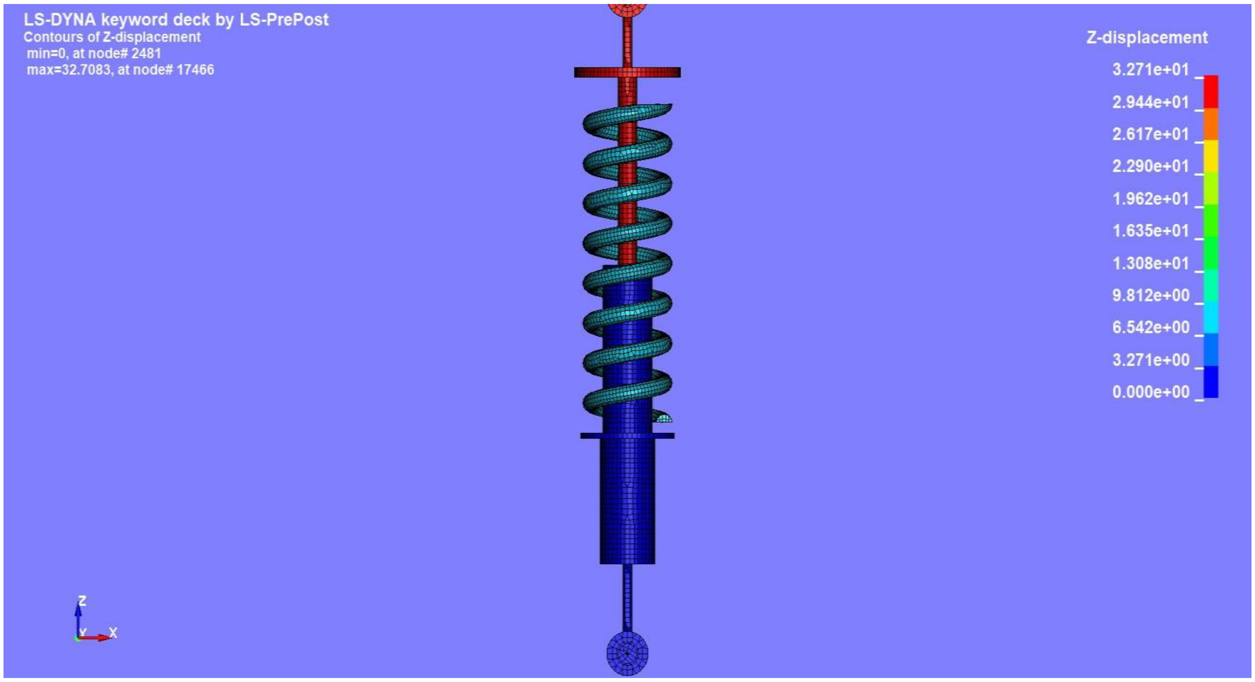


Figure 4.2: Deflection distance

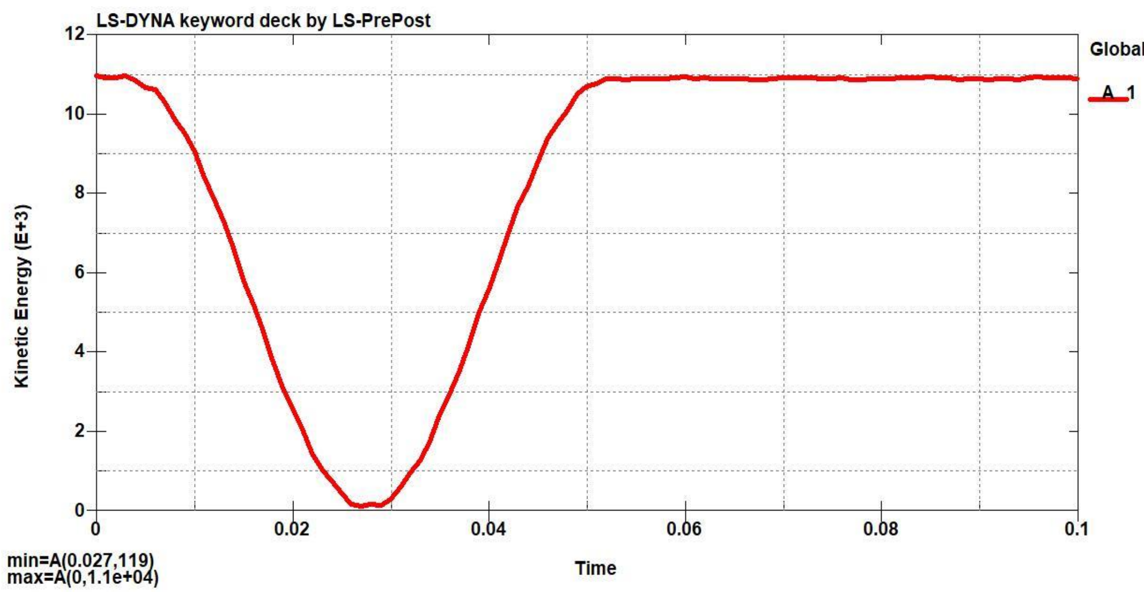
Energy curve

The energy balance of a system in an impact is governed by the law of conservation of energy. According to the Law of Conservation of Energy, Energy can neither be created nor be destroyed, but it can be converted from one form of energy to another form.

The amount of internal energy lost during impact of the road must be converted to other forms of energy such as kinetic energy, sliding energy and hourglass energy. Internal energy is the work input and Kinetic energy is the work output. Internal energy is the energy absorbed by the system and is directly proportional to the product of force and deformation.

- The total applied energy should be constant throughout the simulation.
- Total energy is the sum of kinetic energy and potential energy of the complete system.

➢ The kinetic energy should be decreasing and internal energy should be increasing; and ideally the sum of kinetic energy and internal energy should be equal to total energy.



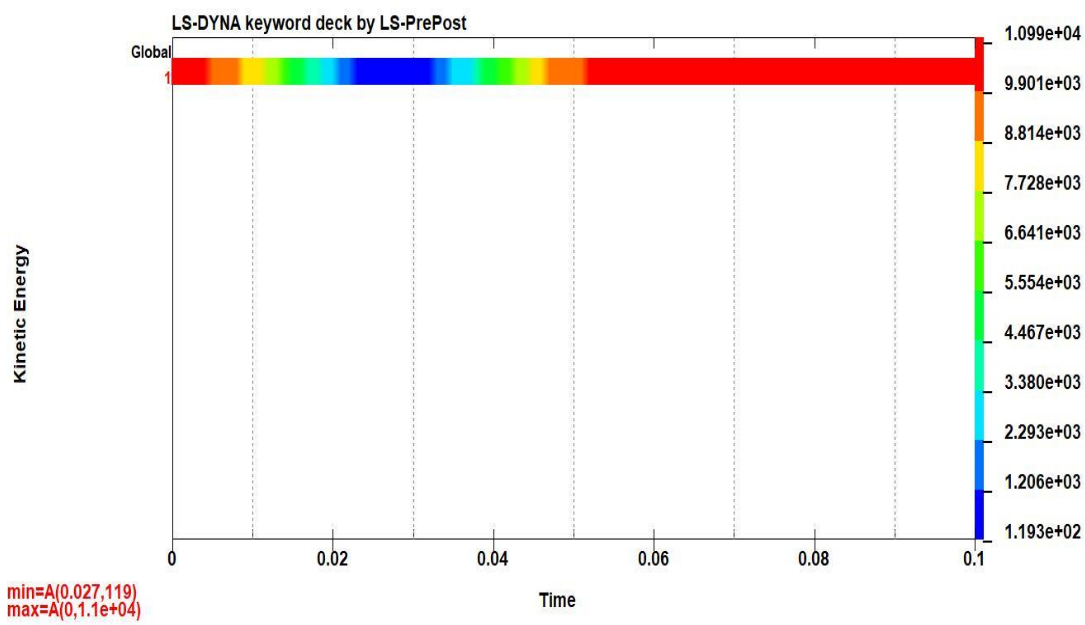


Figure 4.3: Internal energy of existing shock absorber

From the energy balance curve, it has been seen that the system energy is not fully conserved and this is due to zero energy form of some elemnts.so it may be noted that, all the processes in this universe are irreversible and some losses are always included which deviates energy ratio slightly from one. This can be observed in the energy ratio graph. From the graph maximum force analyze is 10990N and absorbed energy is 360J.

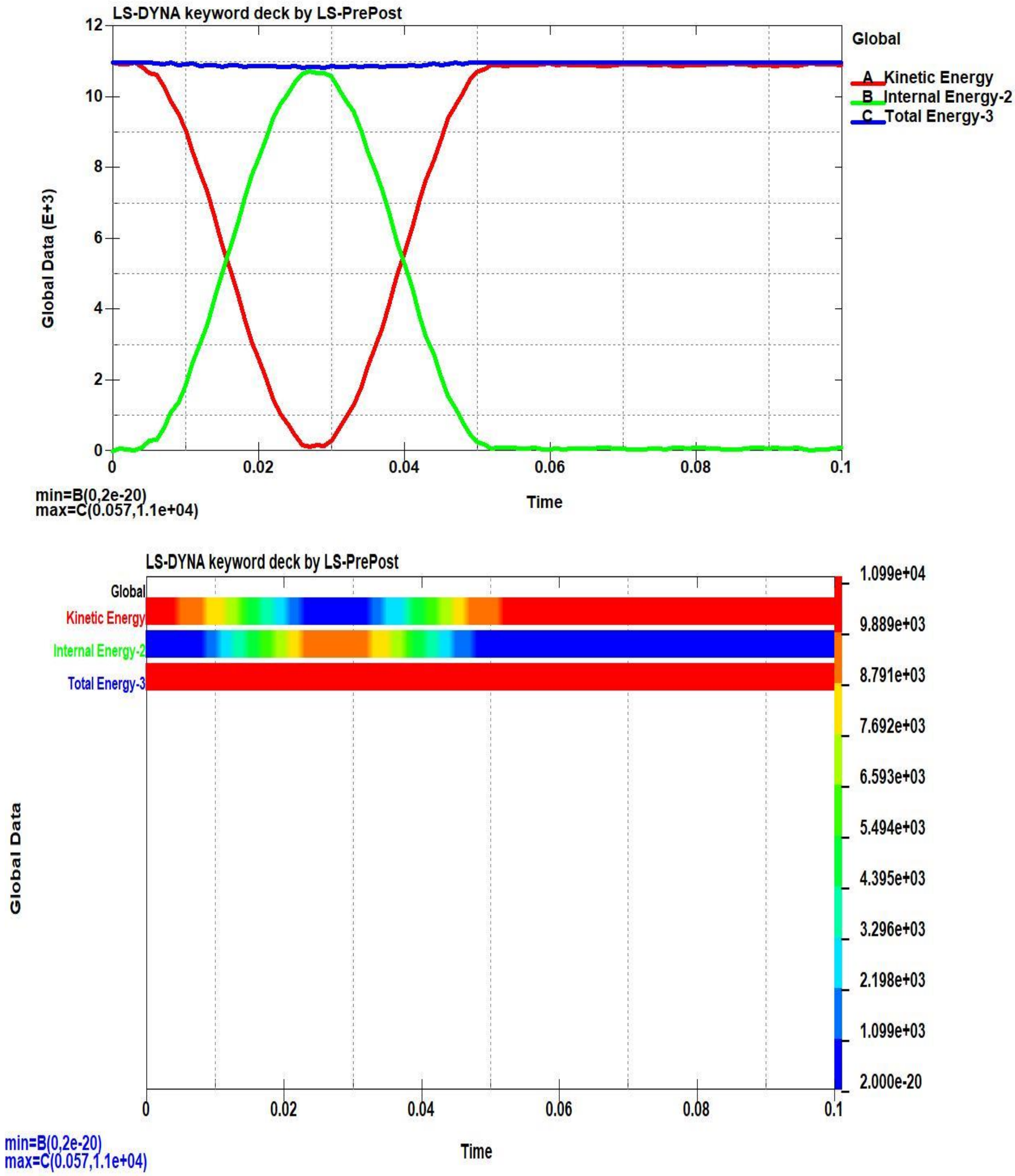


Figure 4.4: Total energy of existing shock absorber

The energy versus time plot of the total system is shown in Figure 4.4. As it is shown the total energy of the system remain constant for the whole simulation with value equal to the initial internal energy which is 0 and increases after bump the absorbs energy maximum energy at 360J then decreases and converted into kinetic energy.

Electromagnetic Results

The deformation of the structure under load depends on several variable. The nature of the load. The structure may be loaded by a compression of tensile force, by the moment or by combination of force and moments. If load by force, the deformation occurs. Force can affect an object's shape. A change in shape due to the application of a force is a deformation. For small deformations, two important characteristics are observed. First, the object returns to the original shape when force is removed that is the deformation of elastic for small deformation. Second, the size of the deformation is proportional to the force. From structural analysis the maximum deflection of the shock absorber is occur at 64mm.

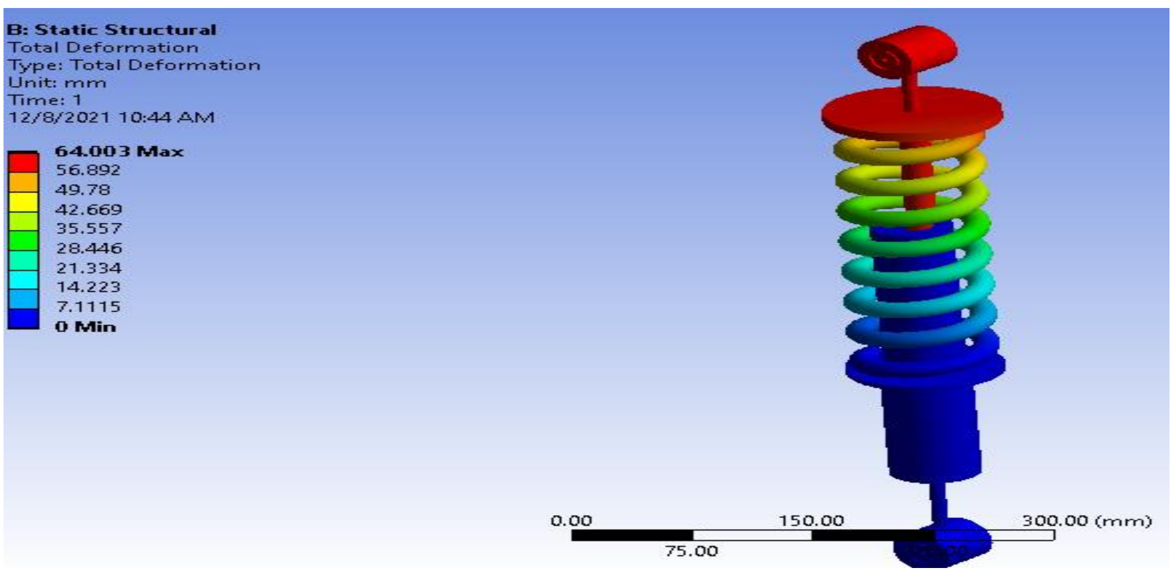


Figure 4.5: Deflection distance

Finite element method based on modeling and simulation software utilized to analyze the electromagnetic suspension system. Magnetic properties such as magnetic field, flux density and magnetic force are analyzed. The induced values are obtained from analytical results. The driving force that represented the dynamic force acting of shock absorber when the moving car meets the bump or during acceleration of pavement road was assumed F=11175 N.

From the electromagnetic simulation of shock absorber, the dynamic condition of electromagnetic transient type simulation result has been generated. The following table shows the detail of vertical force, induced voltage, flux linkage generated at different ampere turn at 2600A, 2800A, 30000A and 3200A.

Ampere Turn	Force Analysis Fz (kN)	Average Absorbed Energy J
2600	9.10	298.2
2800	9.9	316.8
3000	10.9	357.2
3200	13.2	422.4

Table 4.1: Electromagnetic simulation results

Energy balance curve

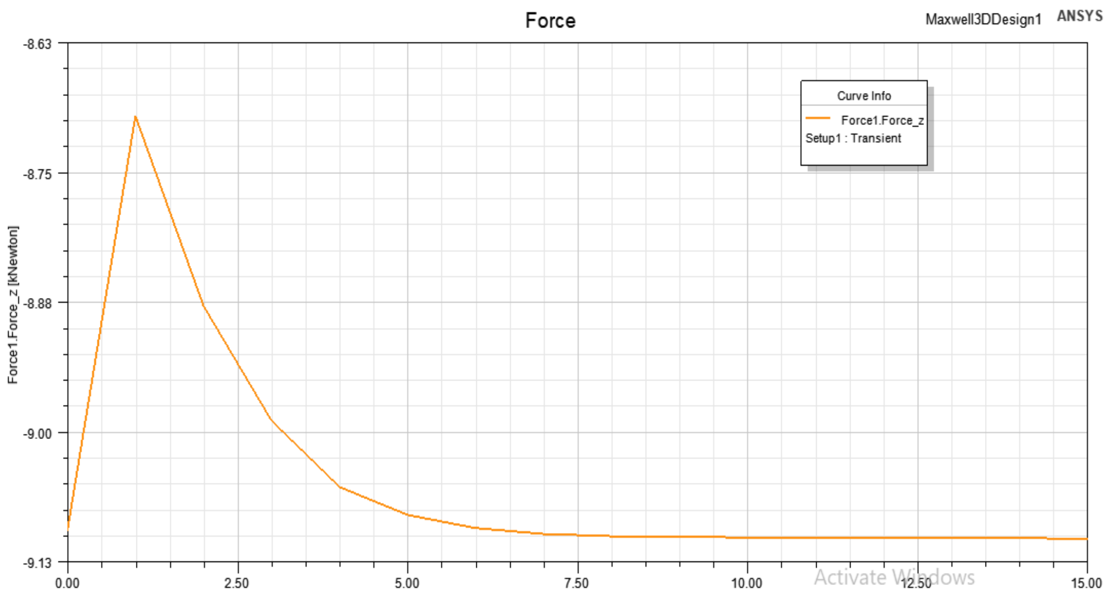


Figure 4.6: Electromagnetic converges results at 2600AN

The energy versus time plot of the total system is shown in Figure 4.6. As it is shown the total energy of the system remain constant for the whole 0.1s simulation with value equal to the initial internal energy which is 9.1KN.

On the hand the internal energy of the whole system starts to decrease as the pavement road bump process starts and converted into kinetic energy and maximum absorbed energy 298.2. Most of the absorbed energy is due to the deformation of the structure.

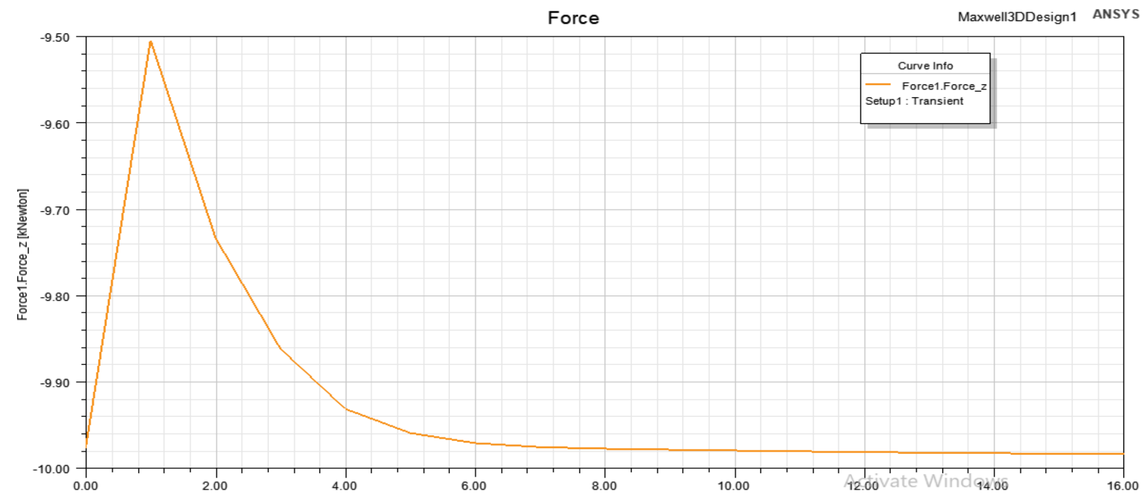


Figure 4.5: Electromagnetic converges results at 2800AN

The energy versus time plot of the total system is shown in Figure 4.7. As it is shown the total energy of the system remain constant for the whole 0.1s simulation with value equal to the initial internal energy which is 9.9KN. On the hand the internal energy of the whole system starts to decrease as the pavement road bump process starts and converted into kinetic energy and maximum absorbed energy 316.8. Most of the absorbed energy is due to the deformation of the structure.

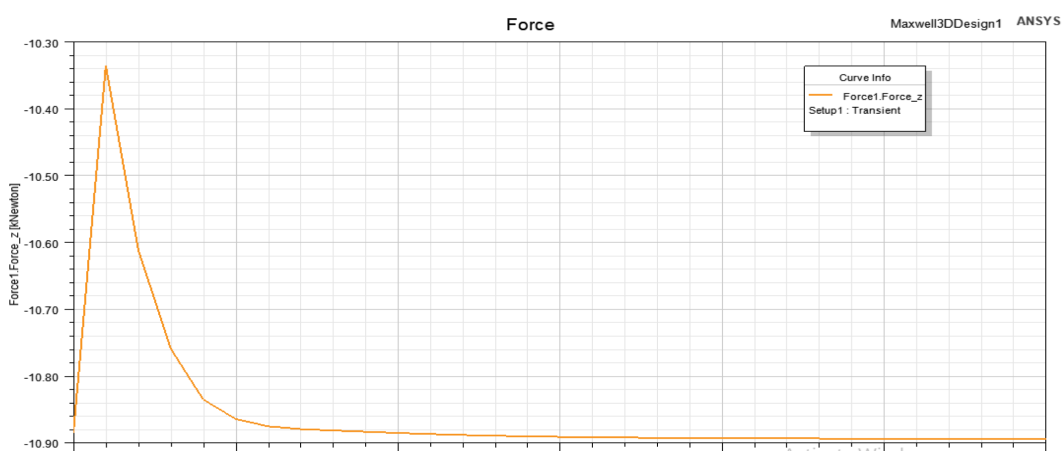


Figure 4.7 Electromagnetic converges results at 3000AN

The energy versus time plot of the total system is shown in Figure 4.7. As it is shown the total energy of the system remain constant for the whole 0.1s simulation with value equal to the initial internal energy which is 10.9KN.

On the hand the internal energy of the whole system starts to decrease as the pavement road bump process starts and converted into kinetic energy and maximum absorbed energy 357.2. Most of the absorbed energy is due to the deformation of the structure.

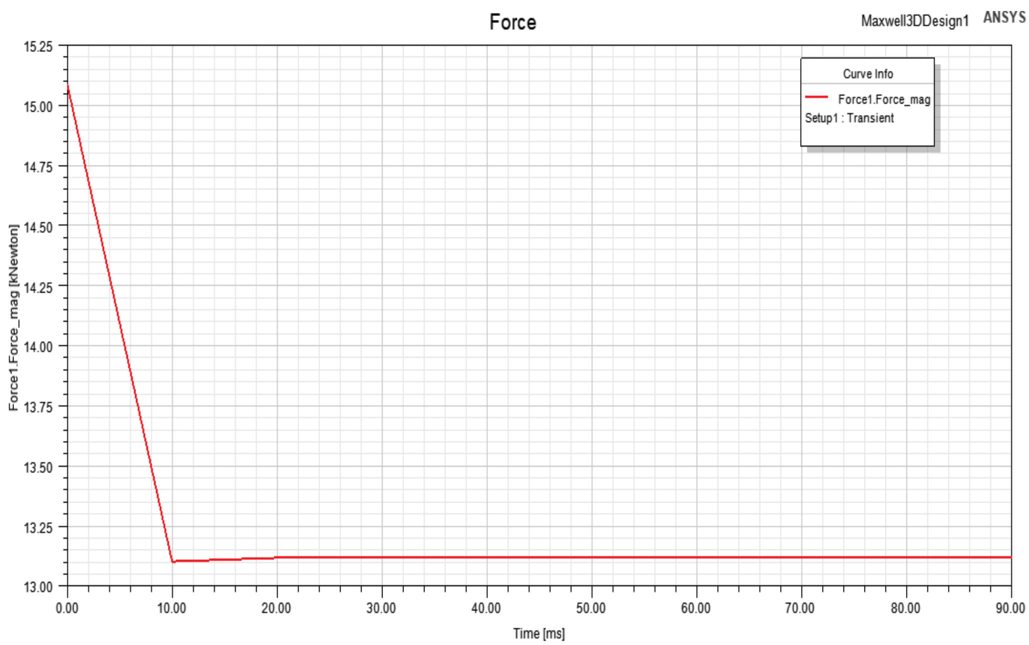


Figure 4.6: Electromagnetic converges results at 3200AN

The energy versus time plot of the total system is shown in Figure 4.8. As it is shown the total energy of the system remain constant for the whole 0.1s simulation with value equal to the initial internal energy which is 13.2kN. On the hand the internal energy of the whole system starts to decrease as the pavement road bump process starts and converted into kinetic energy and maximum absorbed energy 422.4. Most of the absorbed energy is due to the deformation of the structure.

Electromagnetic suspension design is based on its maximum saturation curve. As shown in Figure 4.7 the maximum design value for steel1010 is 1.4T.

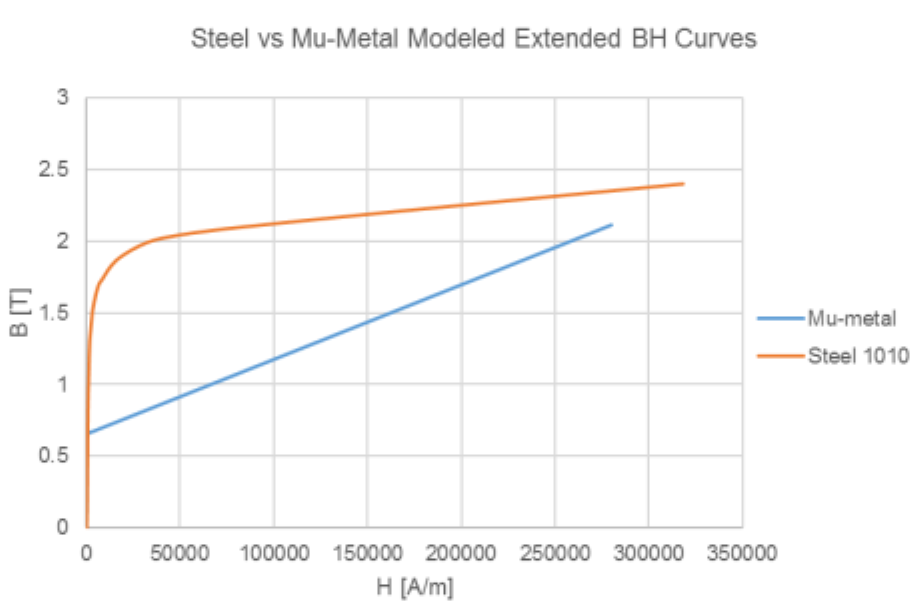


Figure 4.7: Modeled B-H curves for steel1010 and mu-metal (Edward Gonzales et al.2016)

The ASIYS Maxwell electromagnet software has been employed to analyses the distribution of the magnetic flux and energy per volume. The maximum flux density is obtained at 3200A turns as shown figure 4.12.

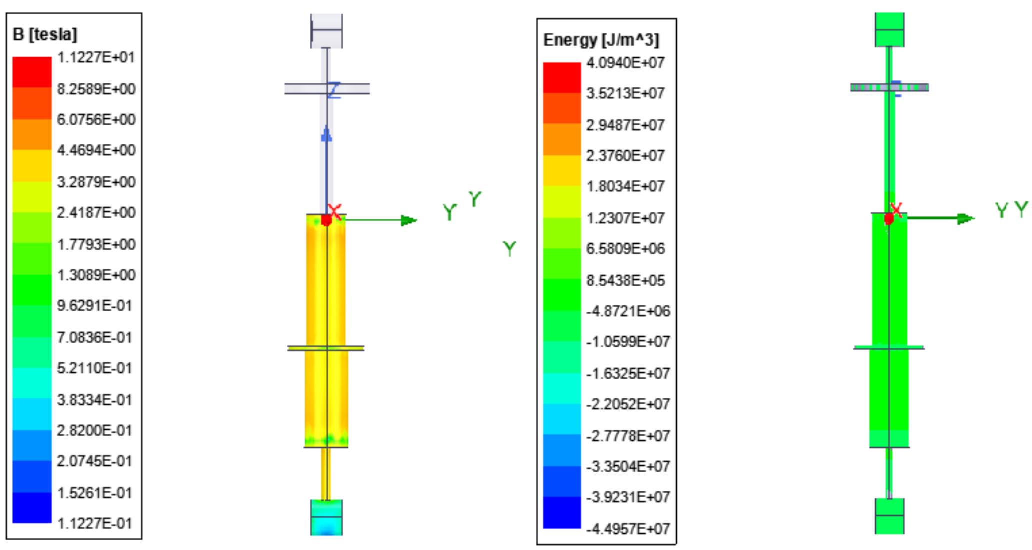


Figure 4.8: Electromagnetic converges results at 2600A

The total energy of the system remains constant for the whole simulation. Until the time reaches 0.01s, some portion of the kinetic energy is converted to internal energy. The Simulated Result average energy dissipation per volume is $40.94 MJ/m^3$ and the flux density at 2600A 11.22T.

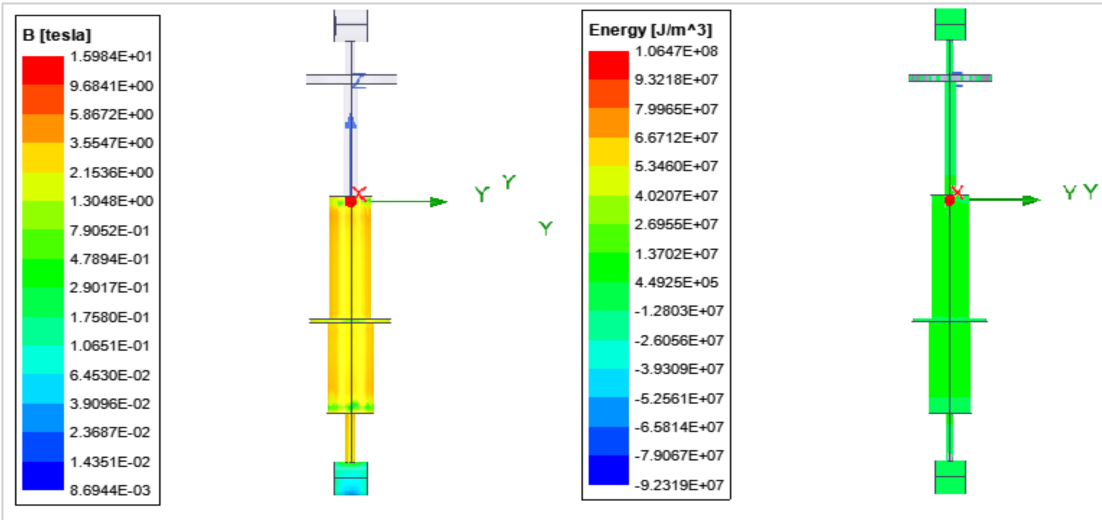


Figure 4.9: Electromagnetic converges results at 2800AN

The total energy of the system remains constant for the whole simulation. Until the time reaches 0.01s, some portion of the kinetic energy is converted to internal energy. The Simulated Result average energy dissipation per volume is 106.47MJ/m^3 and the flux density at 2800A is 15.98T.

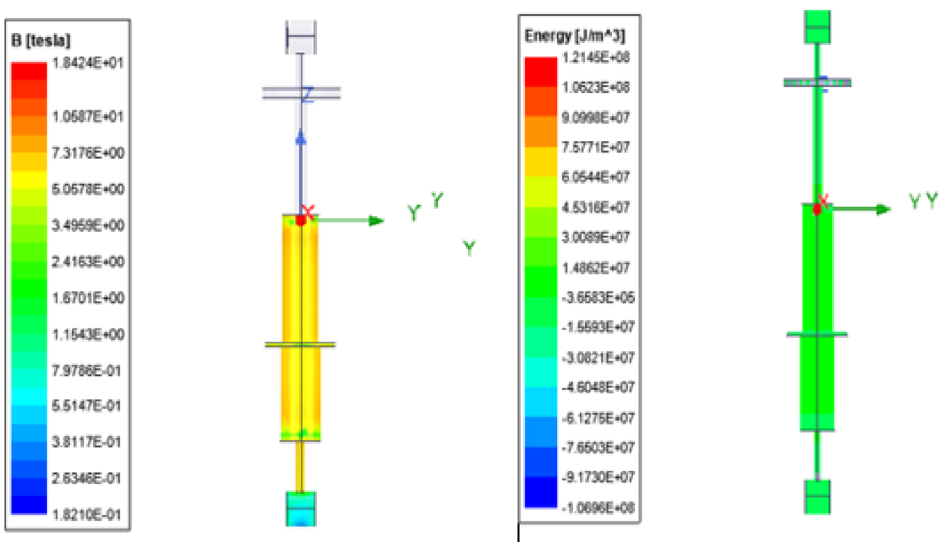


Figure 4.10: Electromagnetic converges results at 3000AN

The total energy of the system remains constant for the whole simulation. Until the time reaches 0.01s, some portion of the kinetic energy is converted to internal energy. The Simulated Result average energy dissipation per volume is 121.4MJ/m^3 and the flux density at 3000A is 18T

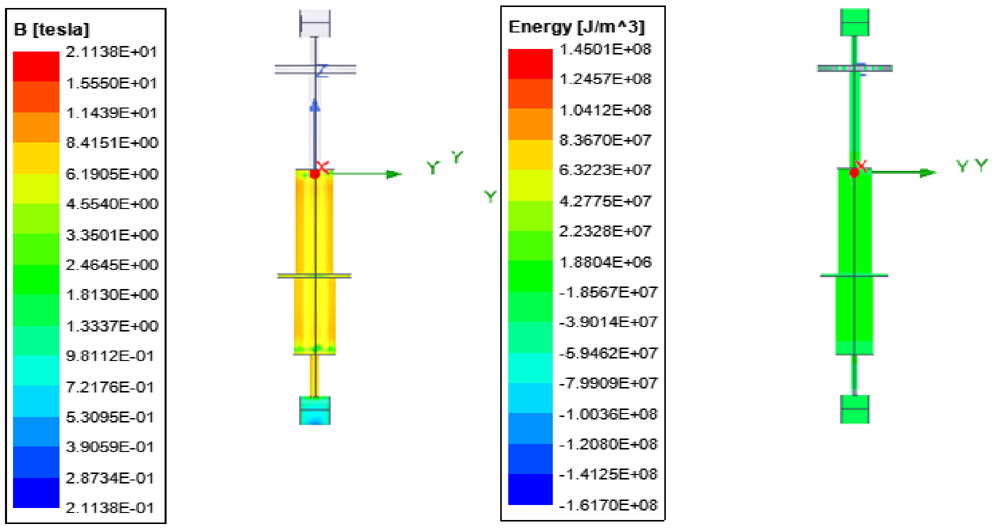


Figure 4.11 Electromagnetic converges results at 3200AN

The total energy of the system remains constant for the whole simulation. Until the time reaches 0.01s, some portion of the kinetic energy is converted to internal energy. The Simulated Result average energy dissipation per volume is 145MJ/m^3 and the flux density at 3200A is 21.1T.

Comparison between Existing and modified shock absorber

- ✓ The results for existing and modified design have deflection value of 32mm and 64mm respectively .when compare both values electromagnetic suspension is high and have more stiffness value.
- ✓ Energy absorption is 360J and 422.4J for existing and modified respectively. When we compare both results more energy absorbed on modified therefore electromagnetic suspension best.
- ✓ When we compare both results with analytical for energy absorption 1.8% and 15% error and for force analysis 1.6% and 18% foe existing and modified shock absorber respectively, so the design is safe.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATION

5.1. Conclusion

In this paper, an electromagnetic Toyota Hilux vehicle damper for applications is studied. Today the use of electromagnetic device is necessary in the vehicle construction to increase not only the driving but also safety and performance. The innovative suspension system, constituted by an electromagnetic damping system, allows harvesting energy, dissipated in the traditional shock absorbers. In most cases, the damping force is proportional to the relative velocity between the sprung mass and the un-sprung mass. As a result, when active electromagnetic suspension systems, the power consumption of existing shock absorber is extremely low. Regrettably, in terms of the passive shock absorber has the lowest force density.as a result, it is insufficient to offer passenger's desired level of comfort.

The damping force is controlled by an external control system in an active suspension system, which improves passenger comfort and stability. Unfortunately, active suspension systems use a lot of energy and are difficult to build. This research, on the other hand, emphasizes the dependability of an active suspension system in a Toyota Hilux vehicle. With advancements in technology, a completely active suspension could become one of the most promising active suspension trends. In this thesis all the design and analysis methods are discussed in terms of two major parts of the thesis work, namely existing and modified shock absorber. It has molded the shock absorber by CATIA, LS-DYNA and ANSYS Maxwell software. To validate the strength of this design we have done structural analysis and modal analysis and by varying ampere turns.

- ✓ The magnetic flux density increase linearly with the increase of ampere current .The electromagnet force increase remarkably as increase the ampere current so the design is safe at 3200AN.
- ✓ Energy absorption is 360J and 422.4J for existing and modified shock absorber when compare with analytical 1.8% and 15% error respectively so the design is safe. More energy absorbed on modified shock absorber therefore electromagnetic suspension best.
- ✓ Force analysis is 10990N and 13200N for existing and modified shock absorber when compare with analytical 1.6% and 18% error respectively so the design is safe. More force occur on modified shock absorber.

5.2. Recommendation

Given the time frame and the resources available, this thesis work establishes a theoretical base and analytical calculation for the design of the electromagnetic suspension system. Some recommendations are:

- The construction of a prototype of the shock absorber might be the next step of the research in order to validate the results obtained by the simulation verifying the performance and the harvesting capability of the system. Further development and investigation should be carried out in order to gain more understanding regarding on EMS system. Thus, interested ASTU staff may conduct further study and controlled experiment on the EMS system using professional search from Mechanical Engineering Department.
- This thesis tries to predict the performance of an active suspension system by means of loads induced by accelerating, braking, and cornering. This is clearly a simplification of a full car model and does not cover all aspects of a full car such as pitch, roll and yaw behavior. To achieve optimal results in these fields as well, a more detailed model should be considered that also incorporates these degrees of freedom.

5.3. Future work

- ✓ The most important work that must be done for the EMS system is to develop a test stand and record meaningful data that can be analyzed to understand its behavior operating region. Finally, it is important to characterize better control of damping cold be provided by using an independent control for electromagnetic suspension system.
- ✓ Full car model that covers loads induced by accelerating, braking, and cornering and pitch, roll and yaw behavior.

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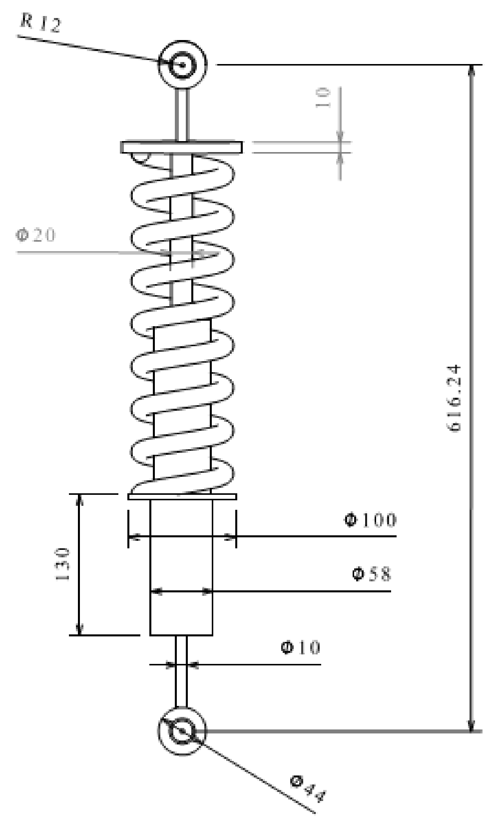
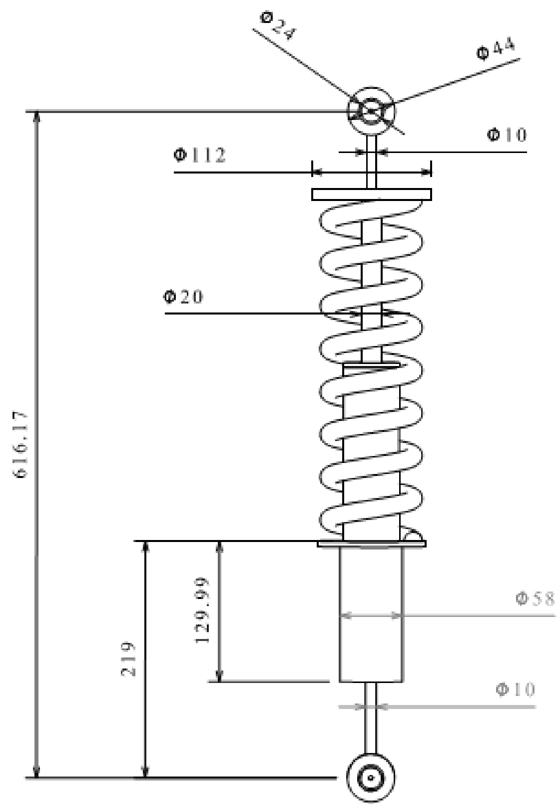
APPENDIX



All dimensions are in mm.

The existing shock absorber	ASTU		
	Front View		
Drawn By Tsion mekonnen	SIZE A4	Drawing Number 1/2	
Advisor Mr. Mekonnen Liben (Assistant Professor)	Scale 1:1		Sheet 1/2



All dimensions are in mm.

The modified shock absorber	ASTU Front View		
Drawn By Tsion mekonnen	SIZE A4	Drawing Number 2/2	
Advisor Mr. Mekonnen Liben (Assistant Professor)	Scale 1:1		Sheet 2/2

Table A-1 Value of allowable shear stress, Module of elasticity and Module of rigidity for variable spring materials.

Material	*Allowable shear stress (τ) MPa*			*Modulus of rigidity (G) kN/m²*	*Modulus of elasticity (E) kN/mm²*
	Severe service	*Average service*	*Light service*		
1. Carbon steel					
(*a*) Upto to 2.125 mm dia.	420	525	651		
(*b*) 2.125 to 4.625 mm	385	483	595		
(*c*) 4.625 to 8.00 mm	336	420	525		
(*d*) 8.00 to 13.25 mm	294	364	455		
(*e*) 13.25 to 24.25 mm	252	315	392	80	210
(*f*) 24.25 to 38.00 mm	224	280	350		
2. Music wire	392	490	612		
3. Oil tempered wire	336	420	525		
4. Hard-drawn spring wire	280	350	437.5		
5. Stainless-steel wire	280	350	437.5	70	196
6. Monel metal	196	245	306	44	105
7. Phosphor bronze	196	245	306	44	105
8. Brass	140	175	219	35	100

Input Values of LS- DYNA

Name	Count
BOUNDARY	4
SPC_SET	4
CONTACT	6
AUTOMATIC_SURFACE_TO_SURFACE	4
TIED_NODES_TO_SURFACE_OFFSET	2
CONTROL	3
ACCURACY	1
TERMINATION	1
TIMESTEP	1
DATABASE	7
ASCII_option	6
BINARY_D3PLOT	1
ELEMENT	14179
MASS_PART	2
SHELL	14177
HOURGLASS	1
HOURGLASS	1
INITIAL	2
VELOCITY	2
KEYWORD	1
KEYWORD	1
MAT	5
001-ELASTIC	2
020-RIGID	3
NODE	13996
NODE	13996
PART	4
PART	4
SECTION	2
SHELL	2
SET	4
NODE_LIST	4
TITLE	1