A PROJECT REPORT

ON

"MR FLUID BICYCLE SUSPENSION SYSTEM"

Submitted by

UTEKAR NANDITA RAJENDRA 17ME01

KHAN ASHFAQ SIRTAJ 17ME28

KHAN MASHUK EBNESAUD 17ME34

KHAN MOHD WASEEM MOHD RAIS 17ME35

In partial fulfillment for the award of the Degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

UNDER THE GUIDANCE

Of

Prof. MOMIN NAFE

DEPARTMENT OF MECHANICAL ENGINEERING

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL,

NAVI MUMBAI – 410206

UNIVERSITY OF MUMBAI

ACADEMIC YEAR 2020-2021

A PROJECT REPORT

ON

"MR FLUID BICYCLE SUSPENSION SYSTEM"

Submitted by

UTEKAR NANDITA RAJENDRA 17ME01

KHAN ASHFAQ SIRTAJ 17ME28

KHAN MASHUK EBNESAUD 17ME34

KHAN MOHD WASEEM MOHD RAIS 17ME35

In partial fulfillment for the award of the Degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

UNDER THE GUIDANCE

Of

Prof. MOMIN NAFE

DEPARTMENT OF MECHANICAL ENGINEERING

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL,

NAVI MUMBAI – 410206

UNIVERSITY OF MUMBAI

ACADEMIC YEAR 2020-2021

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL

(Approved by AICTE, recg. By Maharashtra Govt. DTE,

Affiliated to Mumbai University)

PLOT #2&3, SECTOR 16, NEAR THANA NAKA, KHANDAGAON, NEW PANVEL,NAVI MUMBAI-410206, Tel.: +91 22 27481247/48 * Website: www.aiktc.org

CERTIFICATE

This is to certify that the project entitled

"MR FLUID BICYCLE SUSPENSION SYSTEM"

Submitted by

UTEKAR NANDITA RAJENDRA

KHAN ASHFAQ SIRTAJ

KHAN MASHUK EBNESAUD

KHAN MOHD WASEEM MOHD RAIS

To the Kalsekar Technical Campus, New Panvel is a record of bonafide work carried out by him under our supervision and guidance, for partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering as prescribed by **University Of Mumbai**, is approved.

Internal Examiner (Prof.______)

External Examiner (Prof.____)

Head of Department (Prof. **Zakir Ansari**)

Principal (Dr.**Abdul Razzak Honnutagi**)

ANJUMAN-I-ISLAM
KALSEKAR TECHNICAL CAMPUS NEW PANVEL
(Approved by AICTE, recg. By Maharashtra Govt. DTE,
Affiliated to Mumbai University)
PLOT #2&3, SECTOR 16, NEAR THANA NAKA, KHANDAGAON, NEW PANVEL,NAVI MUMBAI-410206, Tel.: +91 22 27481247/48 * Website: www.aiktc.org

APPROVAL OF DISSERTATION

This is to certify that the thesis entitled

"MR FLUID BICYCLE SUSPENSION SYSTEM"

Submitted by

UTEKAR NANDITA RAJENDRA
KHAN ASHFAQ SIRTAJ
KHAN MASHUK EBNESAUD
KHAN MOHD WASEEM MOHD RAIS

In partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering, as prescribed by University of Mumbai approved.

(Internal Examiner) **(External Examiner)**

____________________ ____________________

Date: ___________

ACKNOWLEDGEMENT

After the completion of this work, we would like to give our sincere thanks to all those who helped us to reach our goal. It's a great pleasure and moment of immense satisfaction for us to express my profound gratitude to our guide **Prof. Momin Nafe** whose constant encouragement enabled us to work enthusiastically. His perpetual motivation, patience and excellent expertise in discussion during progress of the project work have benefited us to an extent, which is beyond expression.

We would also like to give our sincere thanks to **Prof. Zakir Ansari**, Head Of Department, **Prof. Rahul Thavai**, Project Co-Guide and Prof. **Rizwan Shaikh** , Project coordinator from Department of Mechanical Engineering, Kalsekar Technical Campus, New Panvel, for their guidance, encouragement and support during a project.

I am thankful to **Dr. Abdul Razzak Honnutagi**, Kalsekar Technical Campus New Panvel, for providing an outstanding academic environment, also for providing the adequate facilities.

Last but not the least I would also like to thank all the staff of Kalsekar Technical Campus (Mechanical Engineering Department) for their valuable guidance with their interest and valuable suggestions brightened us.

UTEKAR NANDITA RAJENDRA
KHAN ASHFAQ SIRTAJ
KHAN MASHUK EBNESAUD
KHAN MOHD WASEEM MOHD RAIS

CONTENTS

List of Figures :

1. INTRODUCTION

Bicycles are an important element of society, and they are becoming more popular in industrialised countries as a result of climate change concerns. Suspension systems come in a variety of configurations on cross-country, downhill, and mountain bikes. Bicycle suspension technology has progressed from seats with suspension springs in the early 1900s to the numerous complicated designs of today's bicycles. Suspension design receives a lot of research and development money in the competitive cycling industry. Designers of bicycles have recently begun to use electrically controlled components such as drive systems and gears.

Hydraulic damping is a typical design in bicycle suspension systems, and it works by squeezing a viscous fluid through a valve or a small gap in a plunger connecting the bicycle frame to the wheel, creating a force in the opposite direction of motion, decreasing the suspension's rate of motion.Electromagnetic magnetorheological (MR) suspension systems are now being used in automobiles, resulting in improved ride quality and control. Adding ferrous particles to the oil and applying a magnetic field to align the particles, decreasing the flow velocity of the oil and increasing oil viscosity in accordance to the strength of the electric field, is known as magnetorheological suspension.

This final-year Mechanical Engineering project attempts to design an electromagnetic magnetorheological bicycle front suspension by combining two working technologies. To contrast it to conventional hydraulic bicycle suspension, the suspension system was created, manufactured, and tested.

2. OBJECTIVES

The project's goal is to build and test a successful electromagnetic magnetorheological suspension system, with the following goals in mind:

1. Electromagnetic Magnetorheological Suspension System Design
2. In comparison to existing hydraulic bicycle suspension systems, a study of the system response is conducted

Because of the competitive nature of bicycle design, new solutions that improve riding ability are in high demand. Traditional suspension methods have been shown to have slower response times and wider frequency bandwidths for vibration mitigation than electromagnetic suspension solutions.

Consequently, a successful design would provide riders with new competitive possibilities. Downhill cycling races are decided by hundredths of seconds, demonstrating how minor design modifications can have a significant impact on the outcome.

The use of electromagnetic suspension allows for damping control while riding. Damping controllers are already available that vary the mechanical properties of the damper to vary damping while riding. Below is a comparison of electromagnetic and mechanical damping.

- Due to the time necessary to adjust the locations of mechanical components, mechanically controlled dampers have slower response times than electromagnetic dampers (Fengchen Tu, 2011)
- Electromagnetic dampers have a wider damping bandwidth than mechanically operated dampers, allowing for a wider variety of damping levels to be used (Fengchen Tu, 2011)
- Electromagnetic controllers do not require moving parts to change suspension damping, reducing the likelihood of design wear failure and increasing reliability.
- Electronic damping control provides a framework for precise suspension system measurement and control, as well as the integration of a complicated control system for constant optimal damping.
- Electromagnetic damping is more complicated, and it will take more research to catch up to mechanical damping

3. LITERATURE REVIEW

3.0 Bicycle Suspension :

Bicycles may be equipped with both front and rear suspension, or solely front suspension. Only the front suspension system is changed in this project. A spring and a damper are the two basic components of traditional bicycle suspension. The components of most front shock absorber designs are separate and can be found on either side of the wheel, as seen in figure 1.

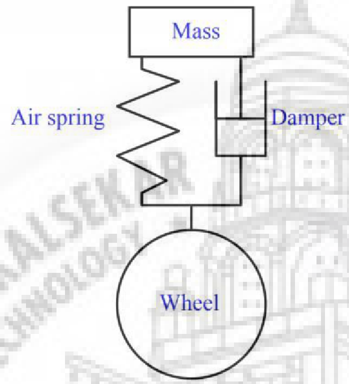


Figure 1: Suspension system

Air suspension is used to replace the spring component in current designs. To keep a plunger in a central equilibrium position, this device applies pressure on both sides of the plunger in a pressure chamber. As the plunger moves, the pressure in one side of the chamber rises while falling in the other, providing a force in the opposite direction of displacement. Without a frictional or viscous damping component, this component of a suspension system delivers a force to bring the system to equilibrium, but it does not diminish oscillations.Dashpots are used in bicycle dampers. By using viscous damping, a plunger with holes is driven into oil in a chamber to slow down the system's motion. The viscosity, or shear strength, of the oil is used to generate an opposing force corresponding to the velocity of an object moving through the oil in viscous damping.

As a function of the oil viscosity, velocity, and plunger hole diameters, a plunger travelling through this oil will feel this opposing force. This component of suspension systems is employed to absorb big impacts or high frequency oscillations quickly, although it has limited influence on low frequency oscillations or tiny displacements.

The spring and damper combination allows the suspension system to return to its centre position without oscillating indefinitely, and the shock is absorbed with no oscillation when the entire rider and bicycle mass, spring force, and damper force are all correct impacts of vibrations both the system and the suspended mass are affected by vibrations.

The key damping point is a combination of these factors that is regarded the best scenario for most suspension systems since it reduces unfavourable effects both the system and the suspended mass are affected by vibrations

The faster a vibration is fully absorbed by a bicycle suspension system, the faster a rider can recover from the impact's effects, boosting the overall speed and comfort of the bicycle over rough terrain.

3.1 Control of Suspension Systems:

Suspension control is accomplished in three ways:

- Passive Suspension is conventional, single damping ratio suspension
- Semi-active Suspension controls the damping of the suspension system
- Active Suspension controls the exact position of the suspension system

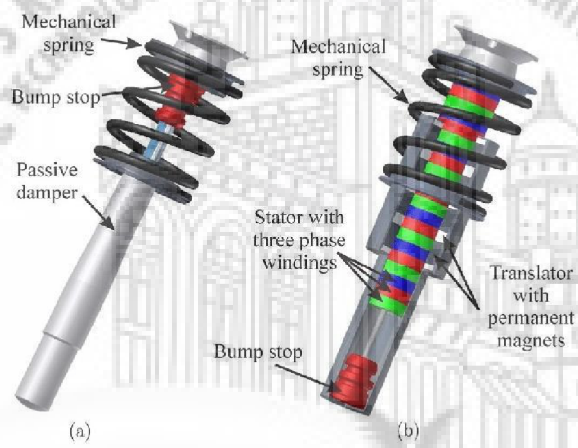


Figure 2:Passive vs. Active suspension. (Gysen, et al., 2008)

3.2 Passive Suspension

Passive suspension refers to traditional bicycle suspension. This indicates that the system is only set up for critical damping and has no control over damping or suspension position. The proper dampening of a bicycle's suspension is essential for obtaining riding comfort. Figure 3 depicts several damping reactions, with the responses discussed.

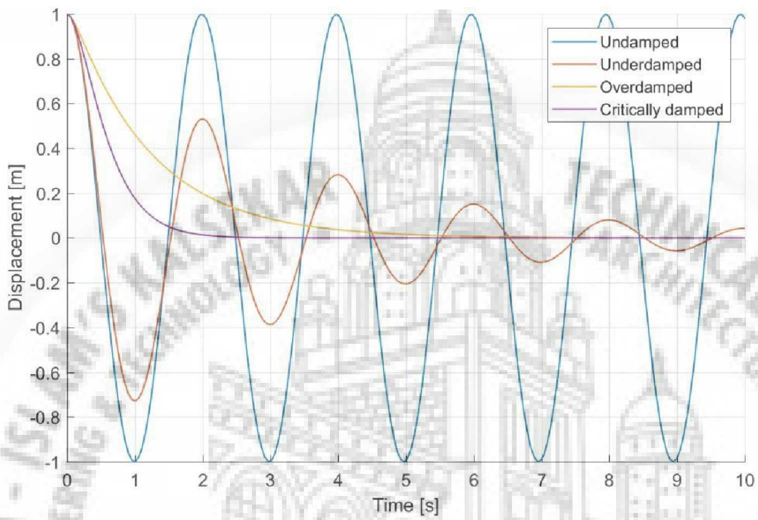


Figure 3: Suspensions system response for different damping combinations

The motion caused by an impact or displacement of the system when left undamped continues continuously, intensifying rather than lessening the effect of the disturbance. The impact is communicated to the rider as a strong bump in an overdamped system with damping set too high. Because the damper absorbs the shock too soon and the suspension does not go through its complete range of motion to absorb the impact, this happens.

At critical damping, the system entirely absorbs the impact and settles at the equilibrium position in the shortest possible period, with no overshoot.

Traditional suspension must be tuned to a critical damping ratio that can absorb all hits within a particular frequency range at a safe level. This single damping setting is unable to absorb bumps of all frequencies and sizes efficiently, and it is a tradeoff between high and low frequency impact mitigation.

Conventional dampers that use shim/wave washers to discharge oil pressures on the plunger above a mechanical limit established by the shim washer are an exception to the single damping tradeoff. This is done as a safeguard to prevent the damper from being damaged by dangerously high fluid pressures outside of the system's functioning range. Conventional dampers are demonstrated to use a single damping ratio at a time, as there is not an in-use alternative damping ratio.

3.3 Semi-active Suspension :

Semi-active suspension adjusts the damping of a suspension system to the best possible settings at any given time. This suspension is reactive, relying on sensors to determine when to increase or decrease damping based on the speed and position of the shock. Semi-active suspension changes a suspension system damping to the optimal settings available at any given time. This suspension is reactive, relying on sensors to identify when damping should be increased or decreased based on the shock's speed and position.

Impact absorption can be tailored for specific hits by changing damping. For example, the maximum transfer of force from the ground to the suspension system happens during a collision; this can be absorbed by lowering the damping and allowing the suspension to travel the complete stroke while underdamped until the impact is absorbed. The system should then return to equilibrium as rapidly as feasible, which is accomplished by restoring the damping to the critical level.

Semi-active suspension has been successfully deployed in a variety of forms and in a wide range of sectors, demonstrating the technology's commercial potential. A semi-active system's strength comes from the combination of suspension control and low power density. Control is restricted to impact reduction rather than active terrain interaction, but this is sufficient for most applications. Because the system's control merely modulates the damping around a base level determined by the damper's mechanical qualities and the viscosity of the oil, rather than supplying all of the damping force in the system, a low power density is required. Low power density means fewer control components are needed, which reduces the system's overall mass.

3.4 Active Suspension :

Positional control of the wheel position in relation to the body is part of active suspension. To shift stator magnets in relation to translator electromagnets, electromagnetic active suspension employs a linear actuator architecture. This control necessitates a big energy source, such as a car engine, as well as predictive control code that maps the road surface and moves the wheel to reduce body motion. This style of suspension is quite good at attaining near-complete suspension body stability in terms of bump avoidance, turning, and braking stability.

3.5 Magnetorheological Fluid (MRF) :

In the presence of a magnetic field, MRF is a smart fluid that alters local viscosity. Only the section of the fluid that is influenced by the magnetic field changes viscosity, which is determined by the strength of the magnetic field at that location. Micron-scale particles suspended in a fluid are aligned by a magnetic field, which opposes motion perpendicular to the field lines.

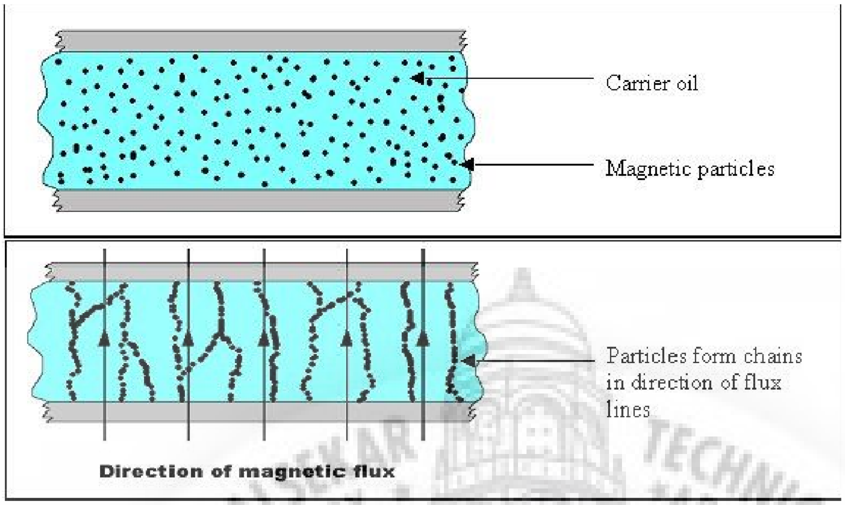


Figure 4: MR Fluid in magnetic field (Mechanics Stack Exchange, 2016)

Each particle creates north and south poles that attract particles around it, preventing perpendicular change from the magnetically aligned state and causing shear yield stress. By adjusting the magnetic field strength, which alters the fluid viscosity, the yield stress of the magnetised fluid may be altered.Shear resistance qualities fluctuate throughout time. During the increase in magnetic field intensity, the properties of a liquid change to those of a semi-solid.

While the magnet is non-saturated, the viscosity of an MRF increases as the magnetic field intensity increases. The viscosity of the un-magnetized MR fluid mixture rises, and the consequent yield stress r of the fluid follows the same pattern. 2015 (Khumbar, Patil, & Sawant)

$$r = r_{\gamma} + \mu\dot{\gamma}^{\cdot}$$

Where r_{γ} is the yield stress due to the magnetic field, μ is the plastic viscosity and $\dot{\gamma}^{\cdot}$ is the shear-strain rate.

A magnetic resonance imaging (MRI) equipment may be utilised in a variety of modes, the most common of which is shear mode. In shear mode, the fluid is sandwiched between two parallel moving surfaces, with field lines flowing perpendicularly between them. The magnetizable particles that collect along magnetic field lines resist motion out of these lines induced by shear motion between the plates, and this resistance grows as the magnetic strength increases.

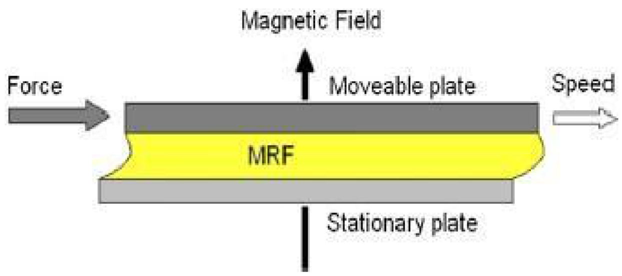


Figure 5: Shear mode MRF control. (Khumbar, Patil, & Sawant, 2015)

MR Fluid should not be confused with ferrous fluids, which include microscopic, nanometer-scale magnetizable particles in a fluid. Although ferrous fluids are attracted to a magnetic field, they lack the viscosity control characteristics required for damper use. Ferrous fluids are widely used in audio speakers. (RM Cybernetics, 2019)

3.6 MRF Carrier Fluid :

The ability to sustain magnetic particles is the key criteria for an MRF carrier fluid, and many fluids can do so. The most popular carrier fluids are mineral oil, synthetic oil, and silicone oil. Mineral oils aren't biodegradable, thus they're not allowed in this project.

Synthetic oils are more costly than natural oils, yet they offer several advantages for usage as MRF carrier fluids (Khumbar, Patil, & Sawant, 2015)

- Low off-state viscosity — This is the oil's basic viscosity when no magnetic field is present. The carrier fluid's viscosity has an impact on this size of the particles low off-state viscosity is preferable because it permits a wider range of suitable viscosities to be achieved within the range of the magnetorheological viscosity rise.
- Does not thicken at high temperatures – this is critical for correct management because the oil must be predictable and steady.
- Low friction - This decreases system friction and improves viscous control.
- High shear strength - At high forces and speeds, this results in a more stable MRF.

The following are some of the advantages of silicone oil (Khumbar, Patil, & Sawant, 2015)

- The fluid has a low viscosity temperature slope and steady physical characteristics across a wide temperature range of -40 to 204 degrees Celsius.
- Good heat transmission properties - this minimises the amount of heat retained in the system and allows for appropriate cooling.
- Low vapor pressure
- High flash points
- If employed in a harsh environment, corrosion resistance with corrosion-prone particles in fluid can increase system life.

In this project, both silicone synthetic and silicone oils can be used. An existing synthetic bicycle suspension fluid was employed to decrease unknown influences impacting the system.

3.7 MRF Particles :

A typical MRF contains between 20 and 50 percent MR particles. These particles must meet the following conditions (Khumbar, Patil, & Sawant, 2015):

- Low retentivity and coercivity - when the electromagnet is switched off, the latent magnetic field in the fluid is reduced. High retentivity increases hysteresis and lowers controllability and repeatability of the system. Figure 6 shows the various magnetising and demagnetizing pathways that were taken.
- High saturation magnetization limits the useful operating range of an electromagnet since the magnetic field plateaus at a constant saturation value. The saturation points are depicted in Figure 6.
- High magnetic permeability is a measurement of a particle's capacity to establish magnetic flux.

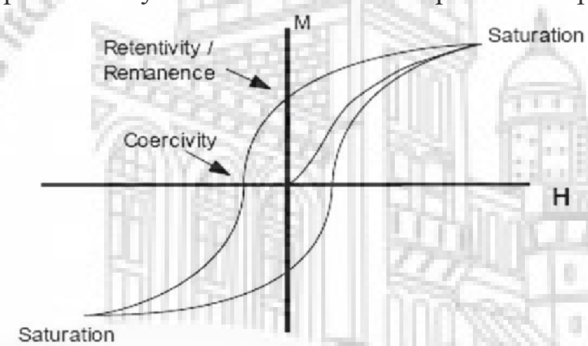


Figure 6: M-H Curve for particles (Khumbar, Patil, & Sawant, 2015)

Carbonyl iron particles are often used for this purpose because they match the requirements, are inexpensive, and are readily available. Particles with a diameter of 1 to 10 micrometres are the most effective (Khumbar, Patil, & Sawant, 2015)

Property	Typical value
Initial viscosity	0.2–0.5 [Pa s] (at 25 °C)
Density	3–4 [g/cm³]
Magnetic field strength	150–250 [kA/m]
Yield point	50–100 [kPa]
Reaction time	15–25 ms
Work temperature	−50 to 150 °C
Typical supply voltage and current intensity	2–25 V, 1–2 A

Figure 7: Properties of typical carbonyl particle MR fluids (Shah, 2018)

The study used 25 micrometre particles since they were the closest to ideal particles that could be discovered.

3.8 MRF Surfactant :

Sedimentation happens soon once the MR fluid is mixed due to the substantial density differential between the carrier fluid and the magnetizable particles. By minimising the density difference between the components, a surfactant is required to reduce sedimentation.Surfactants have a lower density than magnetizable particles and are used to coat them in order to reduce the average density of the particle-surfactant combination (See figure 8).

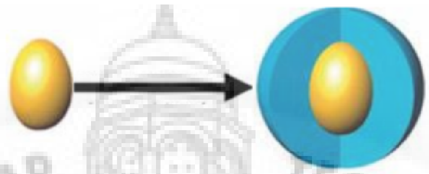


Figure 8: Coating of a particle with a surfactant. (Shah, 2018)

3.9 Magnetorheological Suspension System :

A typical damper consists of a plunger with holes that creates drag on the shock shaft as it is pushed through a viscous Newtonian fluid. Because quicker plunger motion produces a larger resistive force on the plunger, the damper absorbs high velocity motion while enabling the spring to return the shock to its original position once the motion stops.

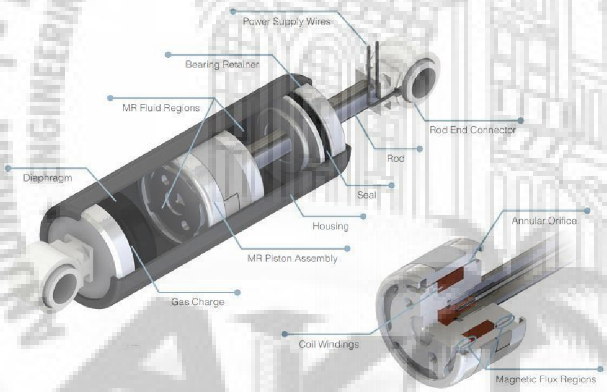


Figure 9: LORD Magnetorheological Damper (LORD Corporation, 2019)

Magnetorheological suspension governs the fluid's different damping characteristics at the plunger holes, and MRF is suspended in a typical damper utilising it. The viscosity of the fluid is controlled as it flows through the holes by adjusting the local magnetic field of an electromagnet near to the holes. Because the majority of the damper's stopping force is created by the fluid's off-state viscosity, and the magnetic field only raises the force from this base point and for brief periods of time, this technique of control takes relatively little energy.

3.10 MR Electromagnet :

Electromagnets are used in MR suspension systems to control the local fluid viscosity at the plunger holes. The magnetic circuit is completed by bridging a gap filled with MR fluid when the fluid is electrified and local viscosity is increased. The fluid annular gap is usually between 0.5 and 2mm. An electromagnet system that is well-designed focuses the majority of electromagnetic power in the annular gap while minimising energy losses in other places. An electromagnet's strength increases as the current is increased until saturation is reached. To maximise comprehensive range of control, this saturation point should be just above the maximum damping required.(Farjoud & Bagherpour, 2016)

Finite element modelling software, such as the **Finite Element Magnetic Modelling (FEMM)** tool, helps in the design of electromagnet settings by allowing visualisation of magnetic field lines and field density.

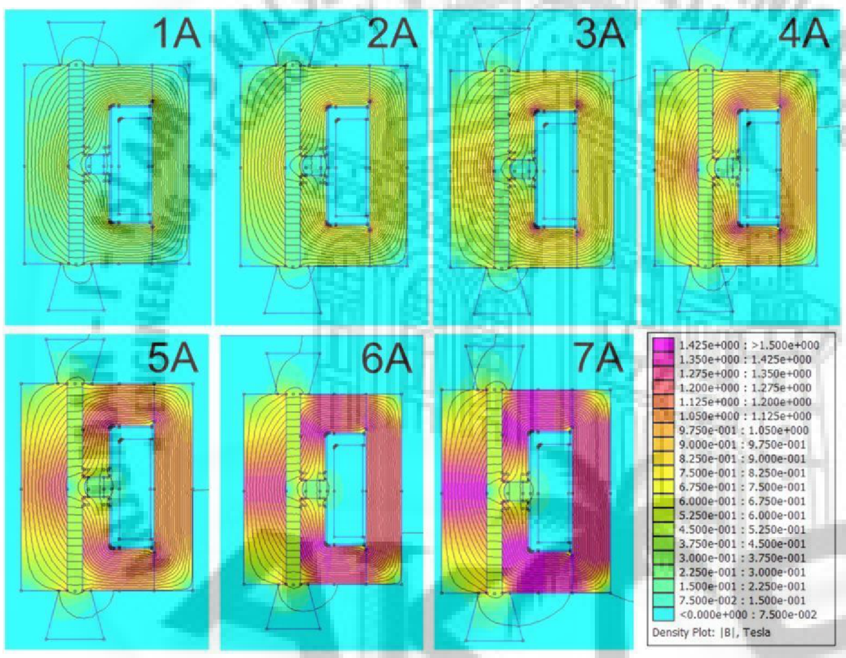


Figure 10: Magnetic field lines and density of an MR plunger cross section at different currents. (Farjoud & Bagherpour, 2016)

The electromagnet winding is represented by the light blue rectangle in the middle right of the diagrams, with the magnetic field created around it in figure 10. The annular gap with perpendicular field lines is the vertical slit from top to bottom with horizontal lines passing through it.

Figure 10 depicts the impact of increasing currents in the electromagnetic circuit on magnetic field densities. As the field across the remainder of the components grows from 1A to 4A, the field in the annular gap rises. From 5A to 7A, the magnetic field in the fluid reaches saturation and remains constant, while the rest of the components experience substantially greater magnetic field concentrations. When the magnetic circuit reaches saturation, it becomes inefficient for higher currents.

3.11 MR Electromagnet Electrical Characteristics :

The resistance and inductance of the electromagnet must be known when modelling an electric circuit to regulate the electromagnet in an MR damper. These may be computed using electromagnetism's basic principles, or datasheets of similar electromagnets can be utilised to obtain acceptable values.

The electrical values of resistance, inductance, and capacitance must be established in order to simulate the electromagnet's electric circuit. The equation can be used to approximate the eddy resistance (Farjoud & Bagherpour, 2016)

$$R_e = \frac{8\pi N^2}{\sigma h}$$

where N is the number of coil turns, σ is the electromagnet material electrical conductivity and h is the contact length of electromagnet and electromagnet core.

The inductance of an electromagnet is calculated using the number of windings N, the permeability of free space and relative permeability μ0 and μr respectively, the average loop diameter D and the wire diameter d.

$$L = N^2 * \mu_0 * \mu_r * \left(\frac{D}{2}\right) * [\ln\left(\frac{8 * D}{d}\right) - 2]$$

The voltage and current may be calculated by plugging these estimated numbers into the electric circuit in figure 11.

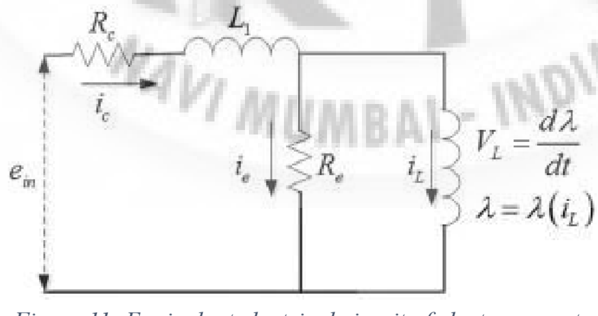


Figure 11: Equivalent electrical circuit of electromagnet

λ Is the flux linkage of the electromagnet. The voltage at inductance L is calculated as a changing property due to the non-linear magnetic properties of the core and MR fluid. (Farjoud & Bagherpour, 2016)

$$V_L = \frac{d\lambda(i_L)}{dt}$$

With the standard electrical equations for figure 14:

$$e_{in} = R_c i_c + L_1 \frac{di_c}{dt} + \frac{d\lambda}{dt}$$

$$R_E i_E = \frac{d\lambda}{dt}$$

$$i_c = i_E + i_L$$

Combining equations,

$$e_{in} = \frac{L_1}{R_E}\frac{d^2\lambda}{dt^2} + \left(\frac{R_c}{R_E} + 1\right)\frac{d\lambda}{dt} + L_1\frac{di_L}{dt} + R_c i_c$$

Which gives a solution for the magnetizing current i_c as a function of time with an input e_{in} to the system (Gysen, et al., 2008).

A basic control system is suggested by Farjoud & Bagherpour for Basic transient MR dampers in figure 12

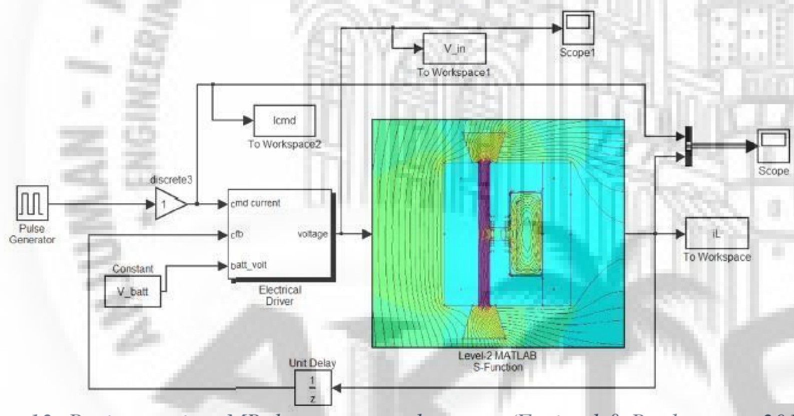


Figure 12: Basic transient MR damper control system. (Farjoud & Bagherpour, 2016)

The goal of this project is to build a successful magnetorheological element for bicycle suspension, thus a sophisticated control system isn't in the cards. Manually regulating the current to desired levels and analysing the system reaction at these levels will be used to control the electromagnet.

4. SYSTEM DESIGN

4.0 MRF :

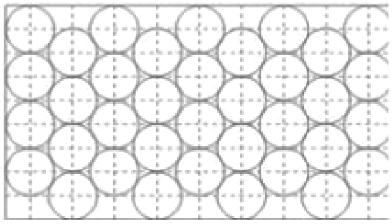
Because MRF is not mass manufactured for any large-scale industrial or commercial application, it is an expensive product to purchase so we took the data from the reference research paper. The mixture of magnetic paste (Grease and magnetic particles) binds with the oil with no separation over time and in a magnetic field at a ratio of approximately 1/1. At a higher oil percentage MRF binds initially and gradually separates over time until the 1/1 mixture lies below the oil due to higher density. For a lower viscosity mixture, a higher percentage of oil will be suitable for a shorter time period. With superior surfactant and particle choices the fluid could be stable with a wider range of mixtures.

4.1 Electromagnet Winding :

Figure 13 : Electromagnet Winding

The electromagnet wire was a deciding element in the electromagnet's features. Maximum current and the number of turns that can be placed in the given area are limited by wire diameter. To work properly, an electromagnet must have 1000 or more spins. Assuming a wire of 0.2mm and a current limit of 510mA tha number of turns is calculated using an online calculator in the engineering toolbox website.

More advanced construction of the controller is out of scope of this report hence different datas results from references were taken.



```
For circles with radius r:
Blue lines are r*sqrt(2) apart and r from
the edges, and red lines r apart and r from
the edges.
For m circles in each column and n columns
the rectangle is (2m+1)*r tall and
(2+(n-1)*sqrt(3))*r long

In this case the rectangle is 11mm long and
3.5mm high with circles of 0.1mm radius.
```

$l := 3.5\ \text{mm}$

$h := 11\ \text{mm}$

$r := 0.1\ \text{mm}$

$$m := \frac{\left(\frac{h}{r} - 1\right)}{2} = 54.5 \qquad \textit{rows}$$

$$n := \frac{\left(\frac{l}{r} - 2\right)}{\sqrt{3}} + 1 = 20.0526 \qquad \textit{columns}$$

$$N := \text{round}(n, 0) \cdot \text{round}(m, 0) = 1080$$

```
This calculation is confirmed by using the online
calculator in The Engineering Toolbox website. With
the given rectangle 1080 circles fit.

With loose packing assume a packing factor of 20%
less circles, the number of turns in the electromagnet
is:
```

$N_t := N \cdot 0.8 = 864$

The electromagnet's fundamental electrical properties were computed using the number of turns and other known properties,

Electromagnet Resistance and Inductance Calculation:

Eddy Resistance:

$N := 864$	Number of turns (From Calculation 1)
$\sigma_{copper} := 5.96 \cdot 10^{7}\ \frac{\text{S}}{\text{m}}$	Copper electrical conductivity
$h := 11\ \text{mm}$	Length of electromagnet contacting core
$R_e := \frac{8 \cdot \pi \cdot N^2}{\sigma_{copper} \cdot h} = 28.6173\ \Omega$	Equation 2

Inductance:

$D := 15\ \text{mm}$	Average loop diameter
$d := 0.2\ \text{mm}$	Wire diameter
$\mu_r := 0.999994$	Copper relative permeability
$L := N^2 \cdot \mu_0 \cdot \mu_r \cdot \left(\frac{D}{2}\right) \cdot \left(\ln\left(8 \cdot \frac{D}{d}\right) - 2\right) = 0.0309\ \text{H}$	Equation 3

4.2 Damper Design :

Damper Cylinder

DamperPiston

The Final MR Damper Design is explained in figure using the original damper design as a reference. The dotted green lines indicate the magnetic field slowing the fluid movement in the damper.

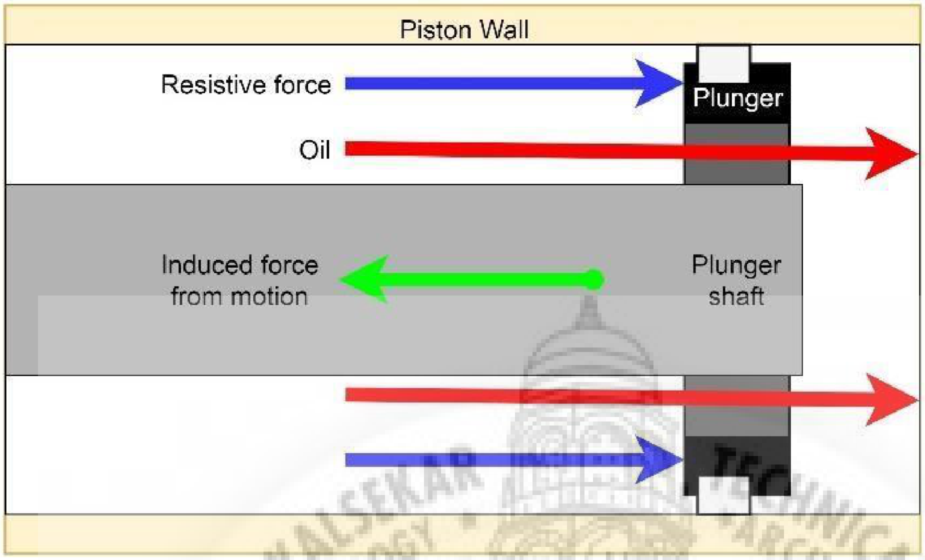


Figure : Existing Damper Design Section View

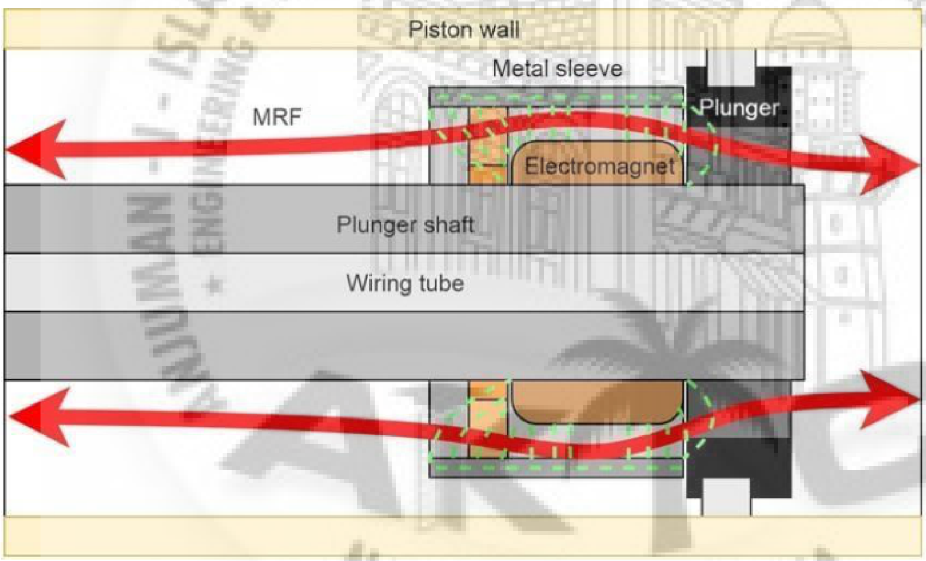
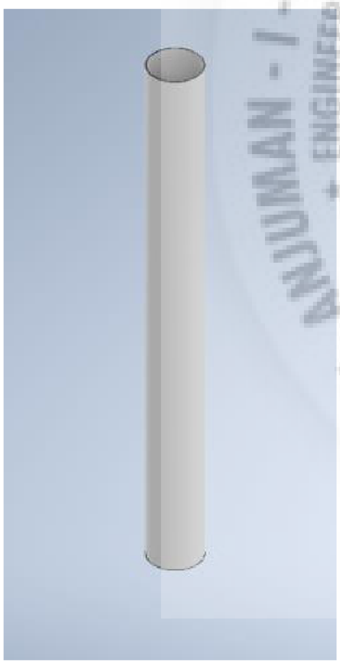


Figure : Final MR Damper Design Section View

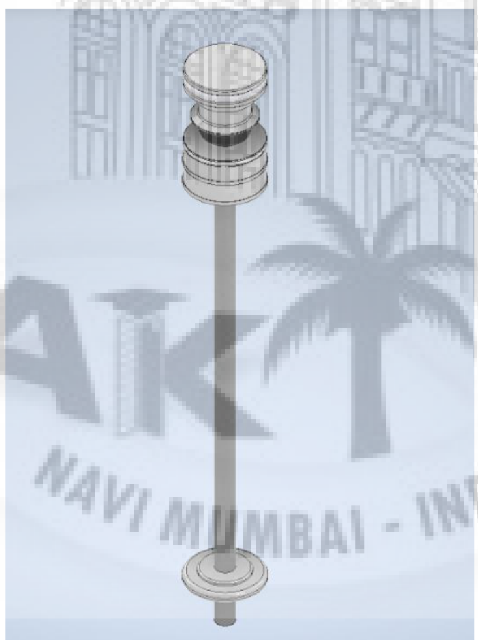
5. Autodesk Inventor Design for different components of the assembly

Axle

Lower Leg

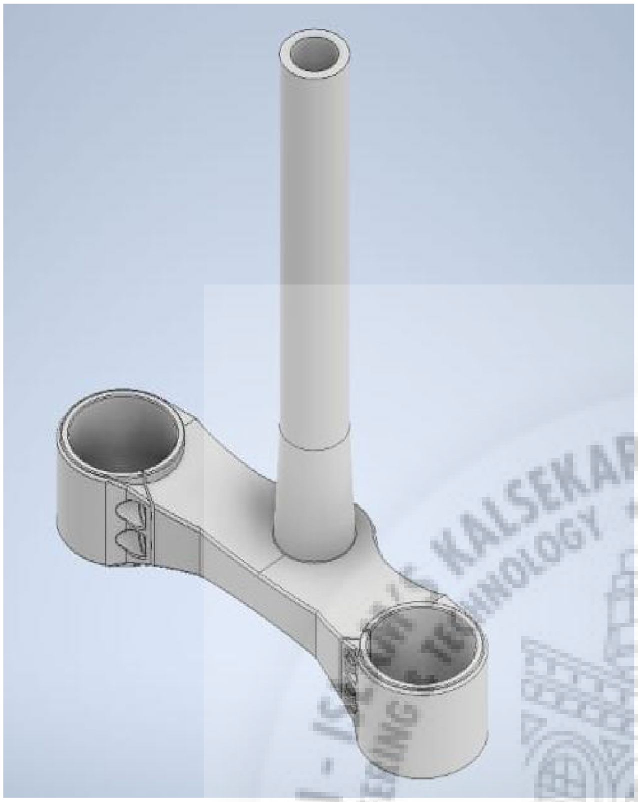


Stanchtion



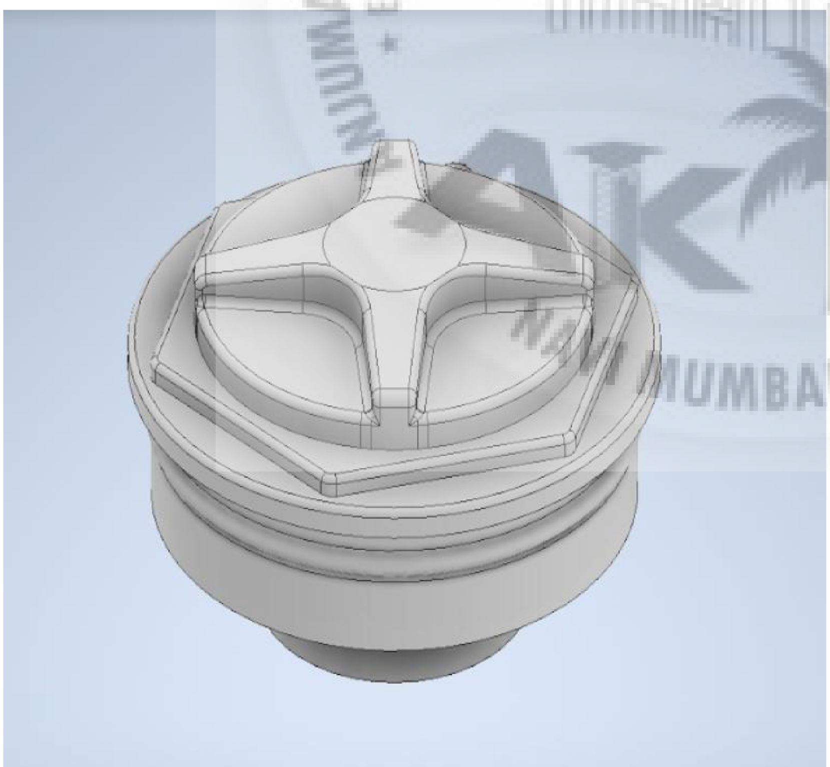
Air Piston

Damper Cylinder

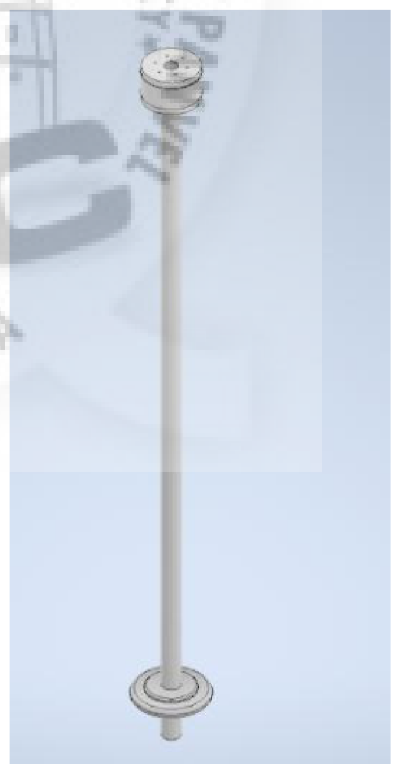


STEM

AIR VALVE



Air Valve Cap

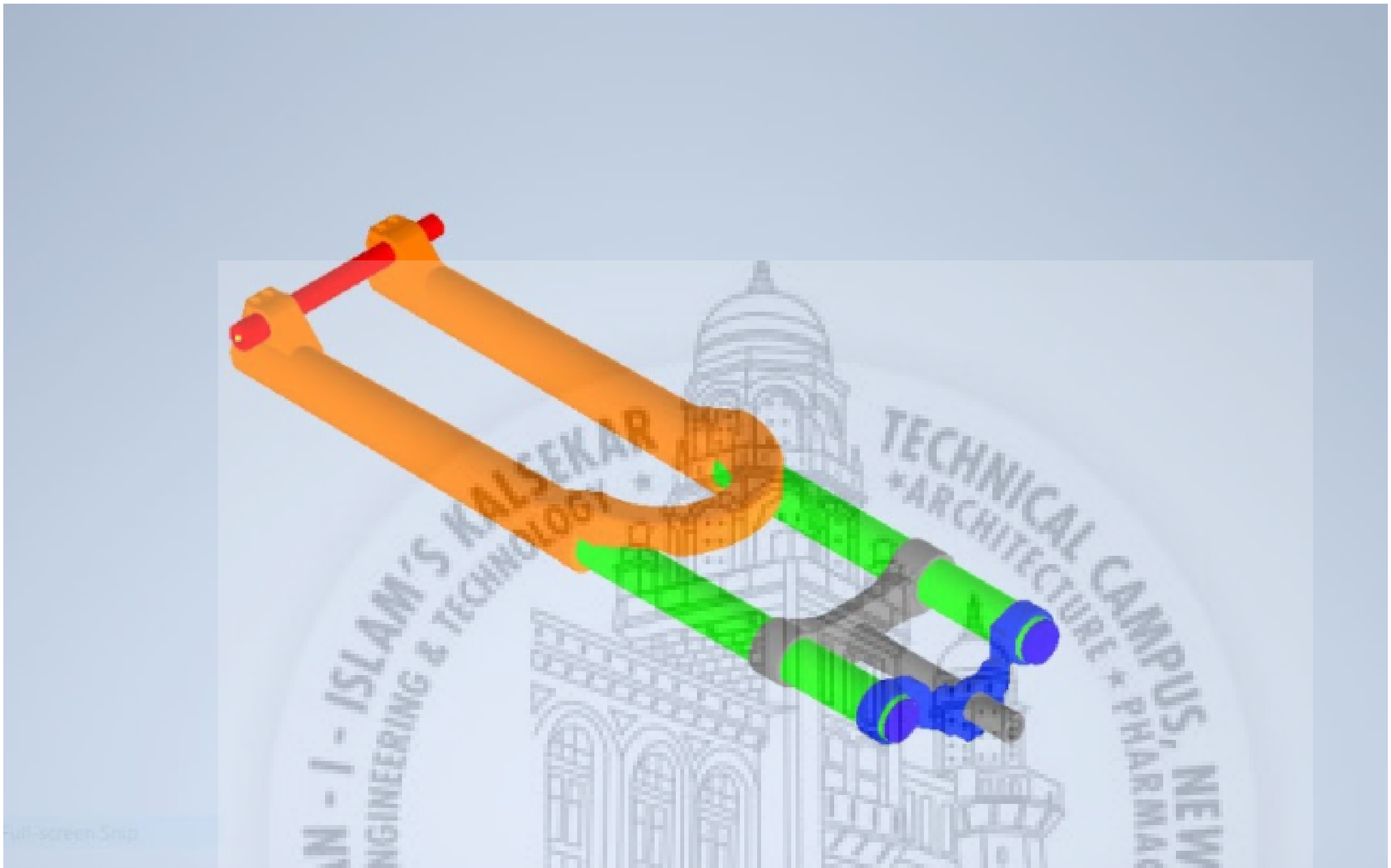


Damper Piston

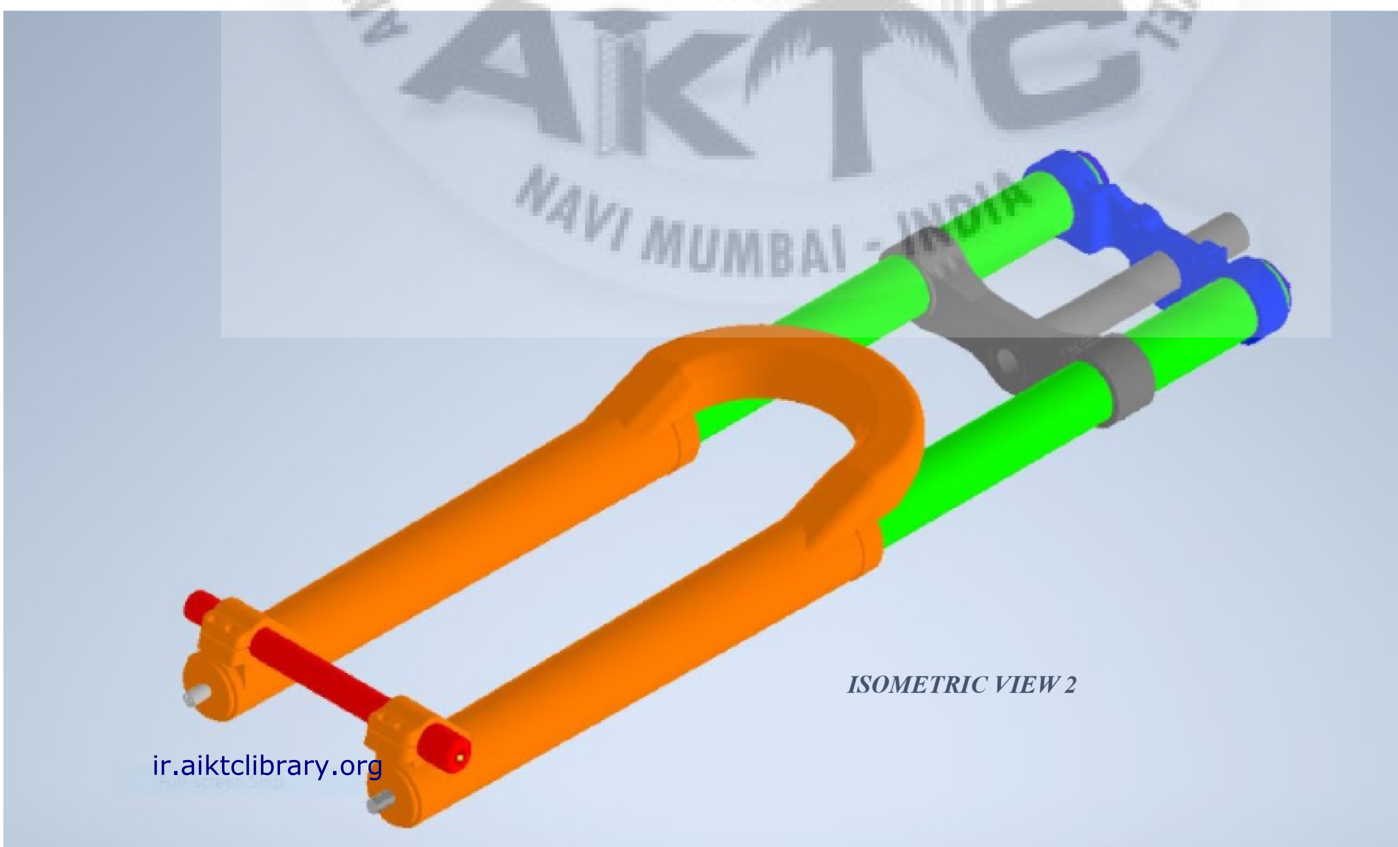
HIGH & LOW SPEED COMPRESSION KNOB

MAGNETIC WINDING HORIZONTAL

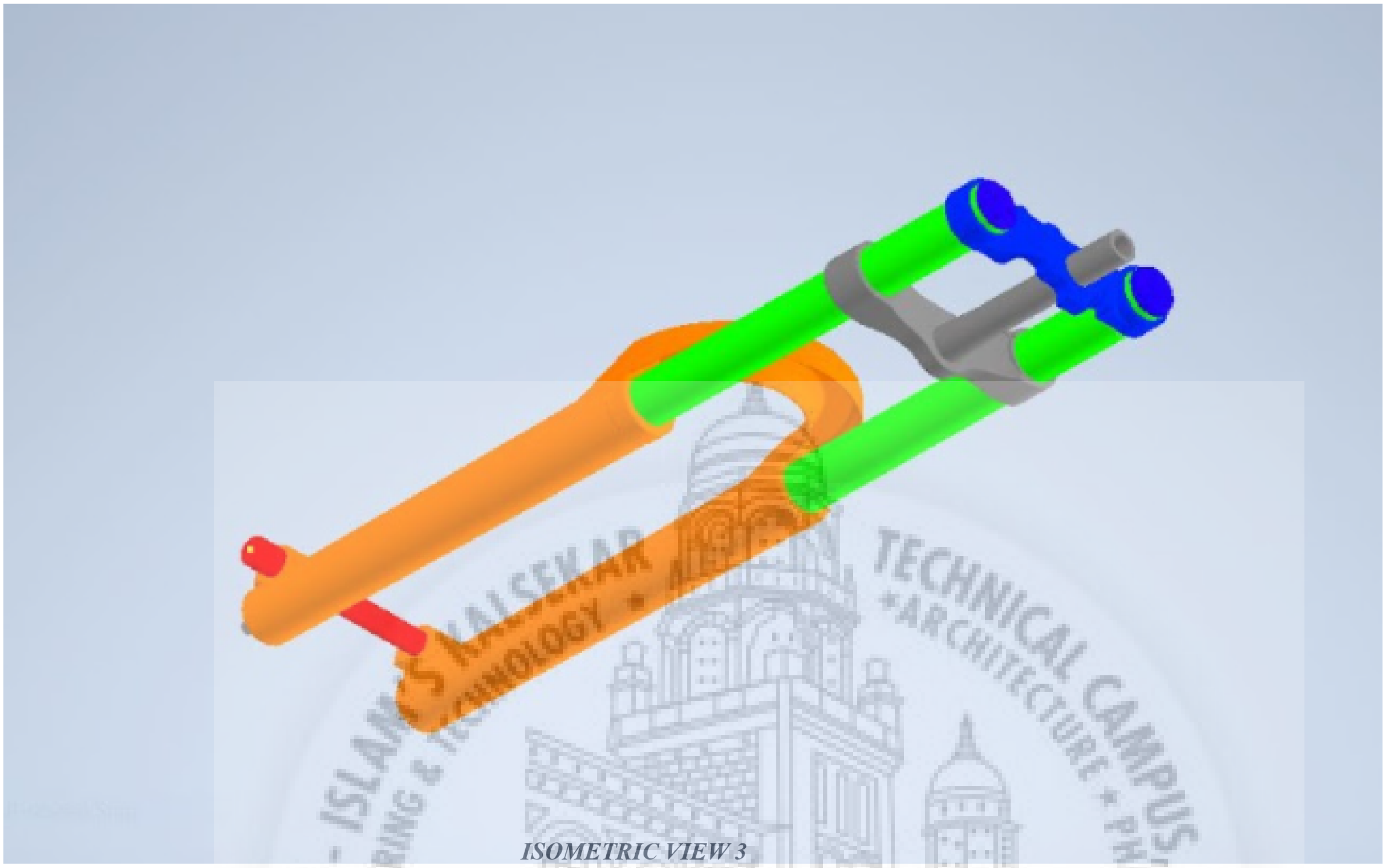
Crown



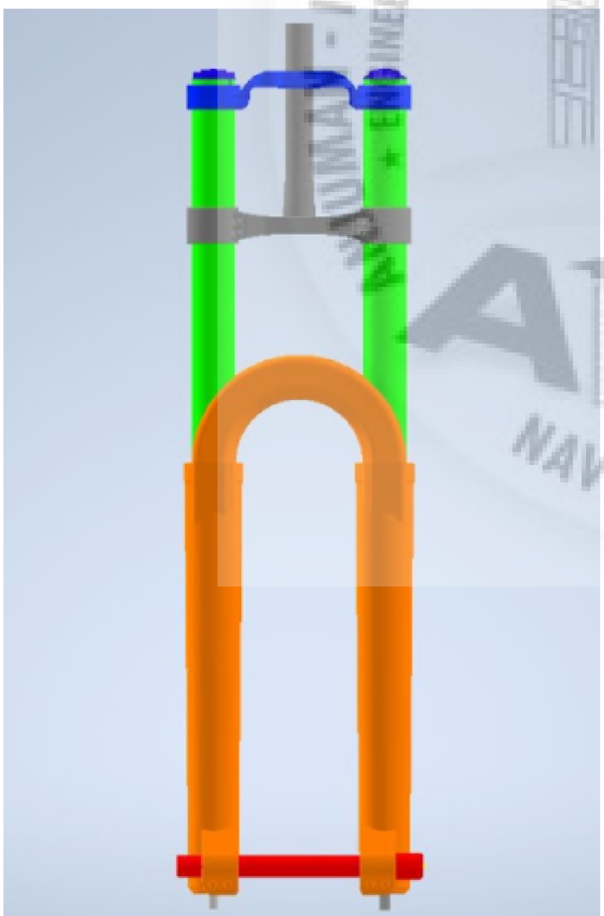
ISOMETRIC VIEW 1

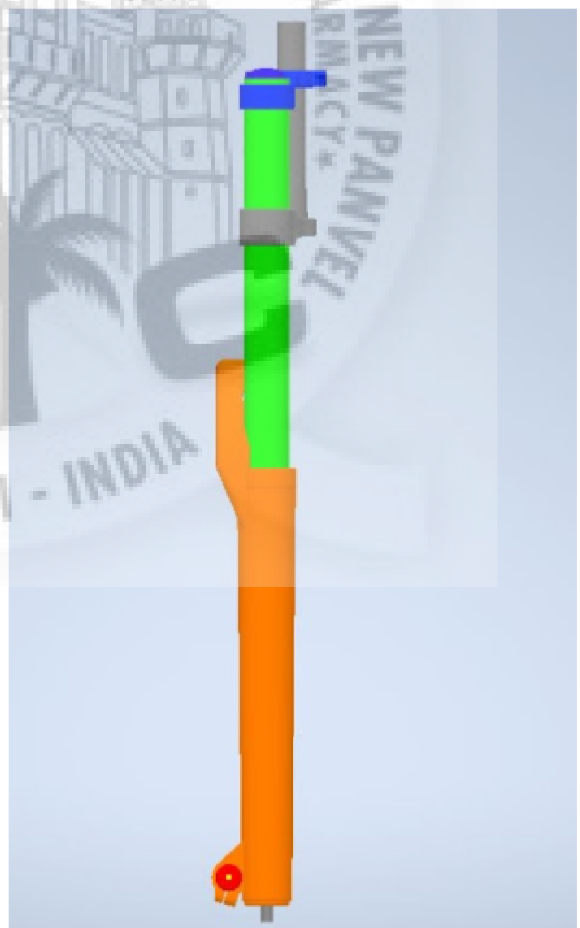


ISOMETRIC VIEW 2



ISOMETRIC VIEW 3





FRONT VIEW

SIDE VIEW

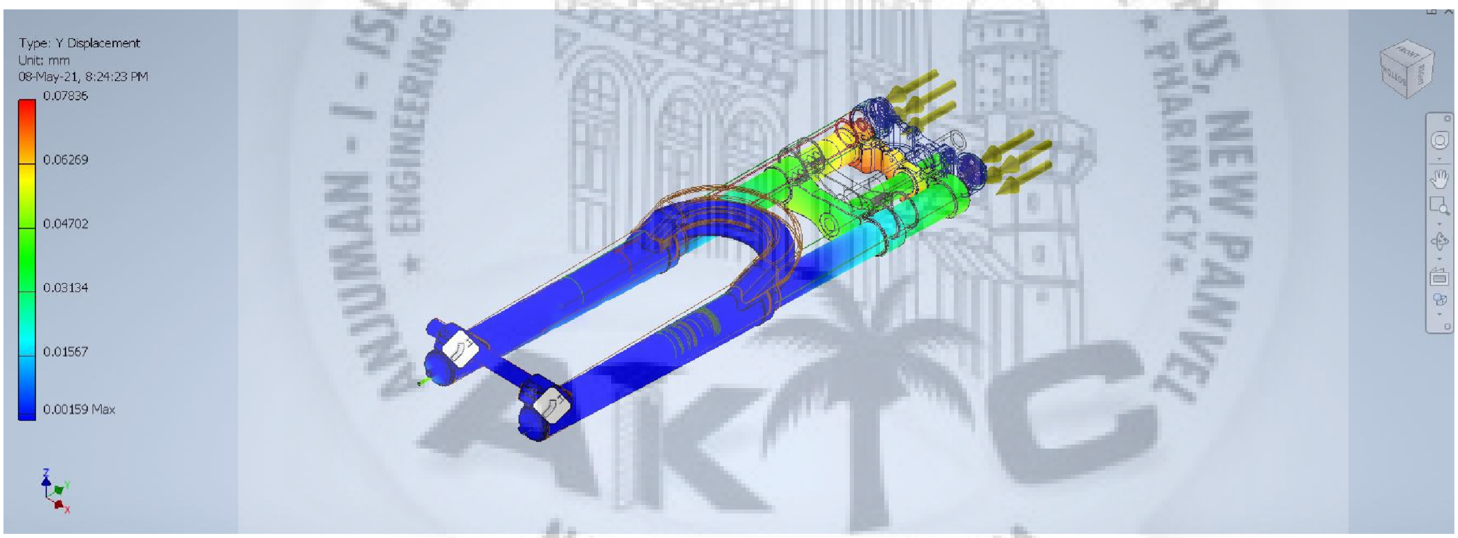
5. STRUCTURAL ANALYSIS IN AUTODESK INVENTOR

load = 0.6kN

6.0 Steps Involved :

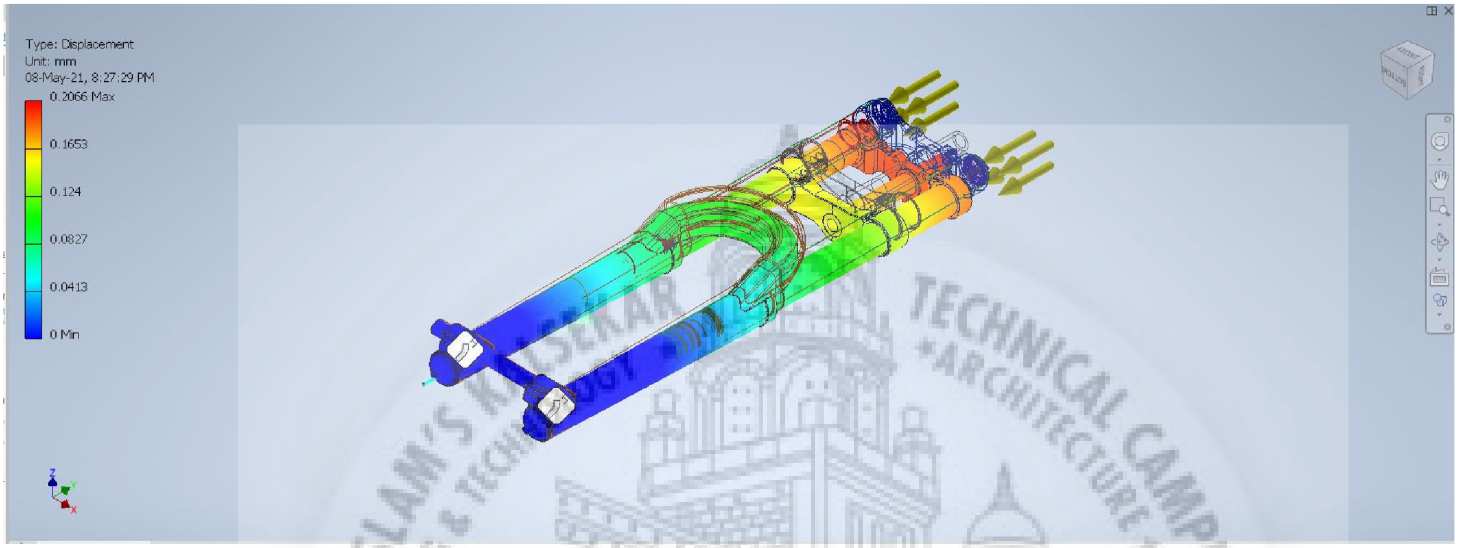
- Step 1: Starting a Stress Analysis
- Step 2: Defining Your Parts Material.
- Step 3: Constraints for Your Part
- Step 4: Defining Input Forces
- Step 5: Run the Stress Analysis

6.1 Equivalent Stress (Von-Mises Stress) :



Equivalent Stress (Von-Mises Stress)

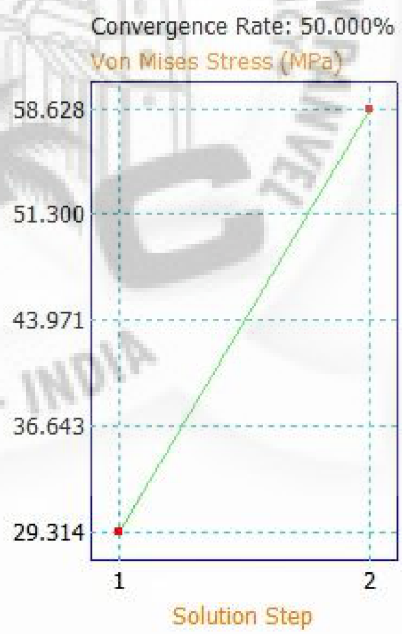
6.2 Displacement in Y-direction :



Convergence Plot

Boundary Condition :

The two holes of lower leg is fixed



7. CONCLUSION

The invention of an electromagnetic suspension system will fill a gap in the cycling industry and might eventually replace traditional bicycle suspension systems. A good design will yield a light front suspension system for bicycles with a wide range of variable damping and a rapid response time. The prototype was built to test the suspension's real-world performance and to serve as the world's first electromagnetic magneto-rheological bicycle front suspension. The findings imply that, with some tweaks, an electromagnetic bicycle suspension system might be a viable alternative for traditional bicycle suspension.

The project proves that continued research and funding of electromagnetic bicycle suspension systems is feasible. Predictive damping control, for example, might be added in the future to supply the rider with the best possible damping force at any given moment.

8. REFERENCES

- *Autoevolution. (2009, 07 20). How Magnetorheological Suspension Works. Autoevolution. Retrieved 3 2, 2019, from https://www.autoevolution.com/news/how-magnetorheological- suspension-works-8947.html*

- *Charles R Goulding, P. S. (2017). Bicycle Designers & Manufacturers Obtain R&D Tax Credits for Innovation. R&D Tax Savers*

- *Farjoud, A., & Bagherpour, E. (2016). Electromagnet design for magnetorheological. Journal of Intelligent Material Systems, 51-70.*

- *Fengchen Tu, Q. Y. (2011). Experimental Study and Design on Automobile Suspension Made of Magneto-Rheological Damper. 2012 International Conference on Future Energy, Environment, and Materials (pp. 1, 2). Elsevier.*

- *Gysen, B., Paulides, Johannes, Jansen, J.L.G, & Lomonova. (2008). Active electromagnetic suspension system for improved vehicle dynamics. Transactions on Vehicular Technology.*

- *Incompliance Magazine. (2019, 10 10). Why Bose's Electromagnetic Car Suspension System Never Made it to Market. Retrieved from Incompliance Magazine: https://incompliancemag.com/bose-electromagnetic-car-suspension-system/*

- *Khumbar, B. K., Patil, S. R., & Sawant, S. M. (2015). Synthesis and characterization of magneto-rheological (MR) fluids. Engineering Science and Technology,.*

- *Mechanics Stack Exchange. (2016, 01 09). Magnetic Active Suspension or Magnetorheological Damper. Retrieved from Motor Vehicle Maintenance & Repair:*
  - *https://mechanics.stackexchange.com/questions/24456/magnetic-active-suspension-or-magnetorheological-damper/36860*

- *Muiyser, J. (2019, April). Vibration and noise 354. Retrieved from SUNLearn: https://learn.sun.ac.za/course/view.php?id=36814*

- *Powersteam. (2019, 07 26). Powersteam. Retrieved from Wire Guage and Current Limits: http://www.powerstream.com/Wire_Size.html*