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Design & Analysis of Magnetic Suspension System for Two-Wheeler

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ABSTRACT

The suspension system of a two-wheeler helps improve comfort, stability, and safety by reducing the impact of bumps and uneven roads, so the rider feels less vibration and has better control of the vehicle. Conventional suspension systems - spring, hydraulic, or pneumatic - have limitations such as oil leakage, wear, and reduced long term efficiency. In order to mitigate the identified shortcomings, this work focuses on designing and analyzing a magnetic suspension system as a new alternative method to improve performance. Permanent magnets coupled with springs are employed in the proposed system to form a passive damping arrangement that mitigates vibration, displacement, and acceleration of the spring mass. A prototype model is developed where magnets are positioned within a cylindrical arrangement to generate repulsive forces, providing effective shock absorption. Structural and finite element analysis (FEA) is conducted on suspension springs made of different materials including Carbon Steel, Chrome Silicon, Aluminium, Magnesium, and NiCr. Comparative analysis of stresses and deflections indicates that Carbon Steel exhibits the least deflection and best performance, while Aluminium shows maximum stress under similar loading. The results highlight the potential of magnetic suspension systems to enhance ride comfort, reduce maintenance, and improve stability for two-wheeled vehicles.

1.INTRODUCTION

Magnetic suspension systems employ magnetic forces to levitate or support loads without physical contact, thereby offering provides notable improvements over traditional mechanical suspension systems. These advantages include decreased frictional resistance, lower noise levels, decreased maintenance requirements, and improved durability. In the context of two-wheelers, magnetic suspension technology holds particular promise for substantially enhancing ride quality and safety by providing superior shock absorption and vehicle stability. The compact and lightweight nature of two-wheelers presents unique design challenges that necessitate specialized suspension solutions.

This review consolidates and synthesizes existing research and technological developments related to magnetic suspension designs specifically tailored for two-wheelers, providing a comprehensive foundation for future innovation in this domain. The performance of modern vehicles is greatly improved by technologies like Modern automobiles use systems such as ABS, EBD, and ESP to provide safer braking performance, balanced brake force application, and[1]improved stability during driving, which help in better braking, control, and overall safety. Along with these improvements, modern vehicle designs focus on reducing weight, but this can raise the center of gravity and make the vehicle less stable overall. Over the past few years, increasing fuel prices and growing environmental awareness have driven rapid advancements in hybrid and electric vehicle technology. In electric vehicles, the heavy battery pack—typically weighing around 200 kg—along with the electric motor, significantly changes how the vehicle's weight is distributed. Optimal drivetrain efficiency is often achieved when the motor is integrated directly into the wheels, further influencing suspension design requirements. A suspension system mainly works to shield the vehicle's body from road impacts like pitching, rolling, and swaying. By doing so, it helps maintain better tire contact with the road, delivers smoother handling around corners, and improves overall braking efficiency.

In motorcycles and other two-wheelers, the front suspension commonly known as the fork system usually uses a single-rate spring along with an air spring, with fork oil sealed inside the unit. The amount of oil and its viscosity are key factors that influence how the suspension responds, particularly in terms of damping and overall ride behavior. Vibration control in mechanical systems is typically managed using approaches like reducing applied forces, adding mass, tuning system parameters, isolating components, and applying damping.

In motorcycles, hydraulically operated suspension assembly system consists of cylindrical tubes with a reciprocating piston filled with oil, which acts as a damper. Most Indian motorcycles use a **dual swing arm rear suspension system** with pivot mechanisms. These systems often incorporate coil springs with progressive or dual spring rates, and in some cases, concentric spring arrangements are used. However, a common limitation of such systems is that the damping oil loses its viscosity as temperature increases during prolonged use. This reduction in damping efficiency negatively impacts ride comfort and suspension performance over time.

2. PRINCIPLES OF MAGNETIC SUSPENSION

This paper demonstrates techniques applied in the design; The magnetic suspension system includes two magnets in a cylindrical housing. One magnet is fixed permanently to the inside of the top of the cylinder and the other magnet is fixed to the inside of the bottom of the cylinder and is free to move up and down. The like poles of the magnets repel each other, so a force is set up and the lower magnet reciprocates up and down in the cylinder. The magnetic interaction supplies the required cushioning and damping effect for the suspension to work. The papers discuss the design and creation of a magnetic suspension system. The authors mention that in a coil spring suspension system, over time the coils become stiffer and lose their ability to provide cushioning. This issue is addressed by the new idea of a "magnetic suspension system", which offers long-lasting cushioning. The materials used are chosen based on their mechanical properties. The purpose of the suspension system of a vehicle is to reduce the effect of the uneven surface of the road; thus, it provides for a smoother ride and increases the comfort of the passengers by reducing the intensity of the vibrations and shocks. Without shock absorbers the vehicle would bounce too much as the springs store and release energy over and over. The suspension movement would go beyond its safe operating limit. Controlling too much movement in the suspension without making the shock absorber hit its limit needs stiffer, gradually increasing springs. This can make the ride feel harsh and uncomfortable. Shock absorbers help by allowing the use of softer, less stiff springs, while still managing the suspension's movement when the vehicle hits bumps. They also work with the natural resistance of the tires to minimize the bouncing motion of the parts not supported by the suspension, which happens because of the tires' flexibility. Since tires are not as flexible as suspension springs, it usually takes firmer shock absorbers to effectively control wheel bounce, compared to what is needed just to control the vehicle's body movement.

3. DESIGN CONSIDERATIONS FOR TWO-WHEELER MAGNETIC SUSPENSION

Compactness and Weight: Two-wheelers impose strict limitations on additional weight and volume to maintain maneuverability and fuel efficiency. Magnetic suspension designs must therefore prioritize compact coil geometries, lightweight magnetic materials, and integration strategies that minimize the impact on overall vehicle mass.

Integration with Existing Components: Magnetic suspension systems must be designed for seamless integration with the two-wheeler's frame, wheel assemblies, and braking mechanisms. This requires careful consideration of mechanical interfaces, electromagnetic interference mitigation, and maintenance accessibility to ensure compatibility and reliability.

4. ANALYSIS TECHNIQUES

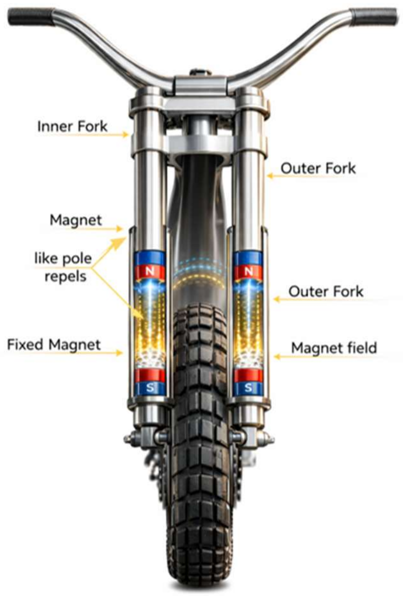
Dynamic Simulation: Advanced simulation tools such as MATLAB/Simulink and ANSYS enable detailed analysis of suspension system responses to various inputs, including road irregularities and

rider-induced forces. These simulations facilitate evaluation of transient and steady-state behaviors, allowing designers to predict ride comfort and system stability before physical prototyping.

Stability Analysis: Stability under dynamic conditions is paramount for safe operation. Analytical methods, including eigenvalue analysis and Lyapunov stability criteria, assess system robustness against parameter variations and external disturbances. Such analyses inform controller design and system tuning to prevent undesirable oscillations or loss of levitation.

4. MECHANISM OF OPERATION

The same poles repel each other, while opposite poles attract. If two north poles are placed near each other, or two south poles, there is a Opposing magnetic force. This phenomenon is the functional principle behind magnetic suspension systems. In this configuration, magnets of the same polarity are positioned inside a hollow cylinder. A fixed magnet is placed on the upper part of the inner cylinder and coupled with a piston. Another magnet is placed on the lower part. The upper magnet has its north pole facing down and is attached to the suspension assembly. Between the two magnets is a spring. The spring separates them. The lower magnet is free to move and is oriented with its North pole up. The magnetic force is repulsive as both magnets are of the same polarity. So, the movable magnet pushes up the fixed magnet and hence it is displaced and it absorbs shocks. The arrangement of this magnetic shock absorber provides better suspension performance and is more effective to reduce vibration effects than the conventional suspension systems.



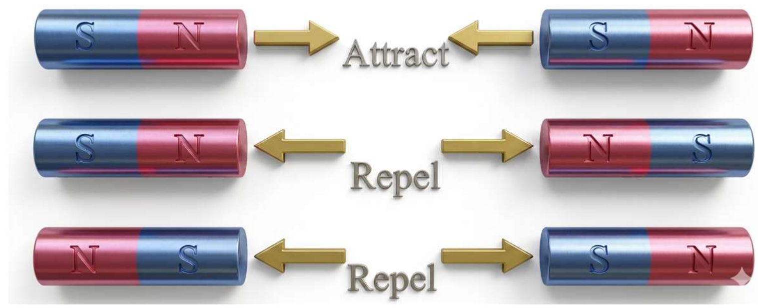


Fig. No 01: Repulsion and attraction of magnet Fig. No. 02: Front Magnetic Suspension setup to Motorbike

The wheel goes up when the vehicle's weight goes up, when the vehicle goes up a hill that isn't smooth, or when the road is rocky. At this point, the suspension compresses during loading and the piston undergoes linear motion down. Increasing the weight causes the magnets to approach each other, whereas the compressed spring enhances the supporting force. So, vibrations and shocks are taken in. The shock absorber gets bigger when the car goes back to its original position. Because of the magnet's magnetic flux power, the piston moves up. Between the magnets is a stainless-steel spring that helps to return the magnets to their original position. Hence the magnetic suspension system can effectively absorb shocks when the vehicle runs on uneven road surfaces.

5. MATERIALS & METHODOLOGY

5.1 Subsystems:

The new magnetic levitation design is made up of two N4518 magnets that are friction-welded to struts with their respective poles facing each other and having an air gap between them. The last function that was being carried out by these magnets with the struts was acting as a piston-cylinder arrangement. You will have access to data that is updated until October 2023. In this configuration the upper strut eye is attached to the chassis and the lower strut eye is attached to the wheel axle, representing the static un-sprung mass and dynamic sprung mass respectively.

5.2 Neodymium-based permanent magnet:

The magnetic levitation of objects was realized with a neodymium-based ferromagnetic alloy. The neodymium magnets have the strongest magnetic flux density among all permanent magnets found naturally, Operating between magnetic intensity ranges from 1.0 to 1.4 Tesla. However, certain types of neodymium magnets are somewhat more costly. As such, considering our requirements and the fact that it is feasible to do so, we settled on using the N4518 alloy since it is less costly. The alloy consisted of Neodymium, Iron, and Boron. It was referred to as Nd2Fe14B. There were several varieties of the alloy. The lattice structure had a tetragonal crystalline shape. Based on the chemical properties of Neodymium. Neodymium quickly turns into Neodymium Oxide (Nd203) when it comes into contact with air or moisture. Iron, on the other hand, oxidizes to form Iron Oxides (Fe2O3 or Fe3O4). Nickel is used to cover the glamorous suspense system to keep it from rusting. This coating acts as a guard against oxidation. The current study gathered N4518 grade for its levitation design, taking into account its easy availability and necessary properties as shown in Table 1. There were many types of magnets for sale, However, the latest study adopted a laminated circular geometry.

5.3. Helical spring:

The selected spring was a Axial compression helical structure type manufactured from Oil-hardened low-carbon steel, chosen for its reliable mechanical performance and durability. The material properties of the spring, which play a significant role in determining its strength and operational characteristics.

5.4. Round-section structural strut:

he Round-section structural struts were of round cross-section and were made of non-magnetic materials to support the magnet on both sides and hold it in place. The suspension levitation system improved the oscillatory motion of the spring to reduce the vibrations better than the traditional spring-loaded shock absorber systems. However, the problem of hitting dead ends could not be avoided when passing over rough roads (Striking potholes). This limitation can be overcome with the use of bumpers which reduce the shock load on the sprung mass. Another possibility to reduce vibrations above 20Hz is to fit rubber bushes between the suspension elements. Fig. 3 and Fig. 4, respectively.

5.5. Cylindrical housing

Since the magnetic suspension system does not include any hydraulic or pneumatic components, it does not place any direct load on the casing from the suspension assembly. This is because the design of the case is automatically taken care of through this process. But it has been observed that the suspension system in automobiles often operate under exposure to rain, mud, and dust, making them vulnerable to corrosion and wear. Therefore, an appropriate corrosion resistant material must therefore be included. Moreover, the casing material should be non-magnetic as the system is based on the principles of magnetic suspension. In the present study, Mild Steel Alloy with 9% Chromium is used as material for the casing, making the material non-magnetic and providing stability to its film coating so as to avoid corrosion. The structure of the casing includes non-magnetic struts fitted with N4518 grade laminated magnets configured in a circular array, as depicted in Fig. 3 and Fig. 4.

6. DESIGN AND DEVELOPMENT OF SUBSYSTEMS

Recent design approaches such as magnetic flux repulsion have been used as the main mechanism for levitation. In addition to the levitation system, there was a softening spring arrangement to improve rider comfort. Magnetic levitation was achieved with a laminated assembly of ten circular N4518 grade permanent magnets arranged to produce a repulsive magnetic flux. This way one side of the levitation setup was firmly held in place while the other side was kept suspended. In the development stage individual attention was given to the design and analysis of each subsystem separately.

The key assumptions considered during the design process included the average weight of the rider, the motorcycle, the distribution of cargo load, and the number of suspension deflections, while the buckling effect was ignored.

Average rider weight= 110 kg

Average motorcycle weight= 125 kg.

The load was assumed to be uniformly distributed among all suspension units through the vehicle's center of gravity.

The influence of lateral deformation failure has been ignored.

A total of four suspensions is provided at the vehicle's front and rear portions.

Strut Design Calculations

Standard dimensional specifications of Indian motorcycles, along with data from mechanical design handbooks, were used in designing the struts.

The analysis was carried out under pure bending conditions by adopting a factor of safety of 1.5.

Design Specifications

- Strut length L=165 mm
- Strut diameter, Ds=20 mm
- Boundary condition: One end of the strut is fixed while the opposite end is hinged
- Selected material: Mild Steel
- Load applied on the strut, W=1152.675 N

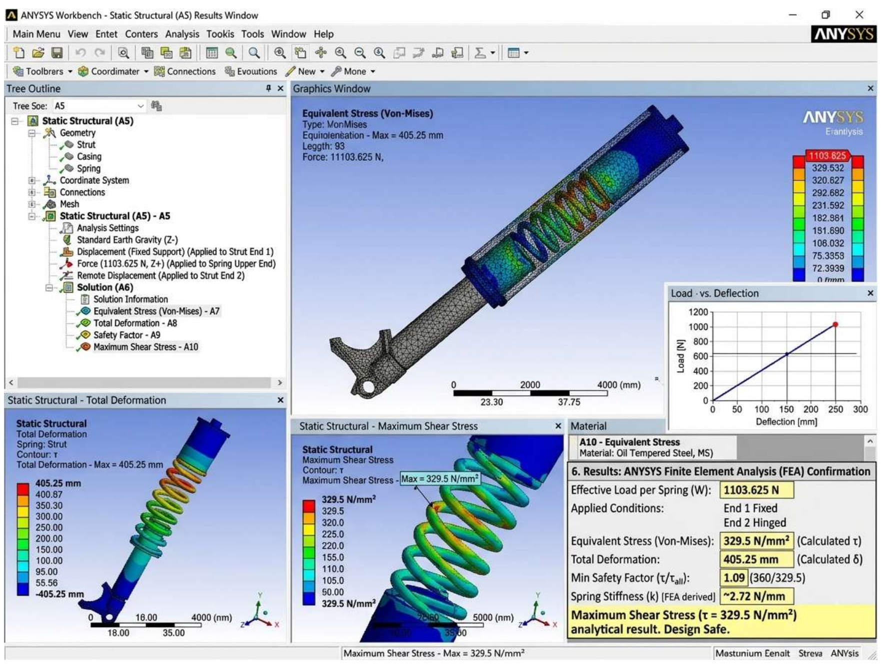


Fig.06 Simulation Results Generated in the ANSYS Static Structural Environment

Sectional Characteristics of the Strut

The area of the strut section is evaluated by applying the formula for a circular cross-section.

$$A_S = \frac{(\pi D^2)}{4} = \frac{(\pi \times 20^2)}{4} = 314.16 \text{ mm}^2$$

The moment of inertia is determined using:

$$I_C = \frac{(\pi D^4)}{64} = \frac{(\pi \times 20^4)}{64} = 7850 \text{ mm}^4$$

The radius of gyration is obtained from:

$$K = \sqrt{Ic / As} = 4.998 \text{ mm.}$$

Critical Load Calculation

The critical load considering the factor of safety becomes:

$$P_{cr} = \text{W} \times \text{F.S} = 1152.675 \times 1.5 = 1729.01 \text{ N.}$$

For a strut having one end fixed and the other hinged, the equivalent length is:

$$I_e = \text{L}/\sqrt{2} = 165/\sqrt{2}$$

$$I_e = 116.67 \text{ mm.}$$

The crushing stress developed in the strut is:

$$\sigma_c = \frac{P_{cr}}{A_S} = \frac{1729.01}{314.16}$$

$$\sigma_c = 5.50 \text{ N/mm}^2.$$

for mild steel, Rankine's constant is taken as:

$$\alpha_{ms} = \frac{1}{7500}$$

Using Rankine's formula, the actual critical load is calculated as:

$$P_{act} = \frac{(\sigma_c \times A_S)}{[1 + \alpha\text{ms (le / K)}^2]} \frac{(5.50 \times 314.16)}{[1 + (1/7500) \times (116.67 / 4.998)^2]}$$

$$= 1614.27 \text{ N}$$

The analysis confirms that the strut design is safe, as the permissible critical load is greater than the working load applied.

Magnet Design

The magnet design was carried out using Gilbert's magnetic theory model to estimate the equivalent stress produced due to Density of magnetic flux (Wb/m2)

The repulsive magnetic force is evaluated using the following relation:

$$\text{F} = \frac{[B^{02} A^2 (L^2 + r^2)]}{(\pi \mu_0 \text{ L}^2)]} \times \frac{[(1/(d^2 + 1)]}{(1 + 2\text{L})^2 - 2} \times \frac{1}{(\text{d} + \text{L})^2} \text{.......... (1)}$$

Where:

- F = Magnetic repulsion force
- B_0 = Magnetic field intensity at each pole measured in Tesla
- A = Cross-sectional pole area of the magnet
- L = Overall length of the magnet (m)
- r = Radius measured for the magnet
- μ_0 = The value of permeability of free space used for calculations is
  $\mu_0 = (4\pi \times 10^{-7}$ T-m/A)
- d = Clearance between the two magnetic elements (m)

In this calculation, the magnet separation is assumed to exceed the magnet radius by a significant margin. Therefore, the magnetic repulsive flux intensity per unit area for the selected N4518 magnet becomes:

According to the characteristics of N4518 grade magnets, the repulsive magnetic force per unit area is taken as 2 N/mm²

Considering the effective load acting on the magnet: W = 1152.675 N.

The required cross-sectional area of the magnet is obtained as:

$$A_m = \frac{W}{M_{rf}} = \frac{1152.675}{2} = 576.3375 \approx 576 \text{ mm}^2.$$

The diameter of the magnet is then determined from the area relation:

$$D_m \sqrt{\frac{576 \times 4}{\pi}} = \sqrt{\frac{2208}{\pi}} = 27.12 \text{ mm}.$$

Design of the enclosure (casing)

The enclosure dimensions were determined based on the calculated size of the magnetic array. Its primary function is to provide proper guidance and support for the magnetic levitation arrangement. As the levitation system operates without the involvement of fluid pressure, the requirement of an airtight enclosure was eliminated. The cylindrical casing dimensions were selected by maintaining sufficient clearance to ensure smooth and unrestricted levitation caused by the repulsion between similar magnetic poles.

7. ANALYSIS OF RESULTS AND DISCUSSION

Using the obtained design parameters, the levitation subsystem was created in CATIA V5R21 through the Part Design and Assembly modules, as depicted in Fig. 3. The completed levitation system assembly was imported the results were verified through simulation in ANSYS 15.0 Workbench software, where Finite Element Analysis (FEA) was carried out to validate the model and obtain an approximate solution to the design problem. In this analysis, hexahedral meshing was adopted, consisting of 29,380 elements. An equivalent material to oil-tempered low carbon steel was identified in the ANSYS material library by ensuring close similarity in its mechanical behavior and properties. The meshed assembly along with the applied boundary conditions, including supports, loading conditions, and component orientations, served as the primary inputs for the analysis and result interpretation, as shown in Fig. 6. Stress distribution across various regions of the assembly was represented using color contours in the simulation window, and the obtained results are summarized in Table 3.

8. CONCLUSION OF THE LEVITATION SYSTEM DESIGN

In this paper, the design and detailed study of the performance of the Magnetically levitated suspension mechanism with permissible shear stress of the selected materials and thus were successfully carried out along with primary loads in pure bending. The entire design methodology focused on achieving improved rider comfort, structural safety, and efficient load-bearing capability for motorcycle suspension applications. It was observed from the design evaluation that the spring experiences an induced shear stress of 329.5 N/mm^2 .This value remained within the permissible shear stress limit of the selected spring material, confirming the safety and reliability of the spring under operating conditions. Similarly, the strut analysis showed that the critical failure load was approximately: 1650.835N. which was higher than the effective working load acting on the suspension system. Hence, the structural design of the strut was found to be stable and safe against failure. For magnetic levitation, N4518 grade permanent magnets were selected. The magnetic flux density of: 2 N/mm^2 was found sufficient to generate the required repulsive force necessary for smooth levitation and vibration isolation. This magnetic arrangement contributed significantly toward reducing the transmission of road shocks and improving riding comfort. The analytical design results were further verified using Finite Element Analysis (FEA) in ANSYS Workbench.

Table 3. Simulated Stress Analysis of Levitation Subsystem Components

Subsystem Component	Materials Used	Shear Modulus, (G) (N/mm²)	Young's modulus N/mm2	Allowable Shear Stress N/mm2	Simulated Induced Stress
Top eye	Structural steel	78,500	1.965 x 10^5	1.965 x 10^5	17.126
Spring	ASTMA227 steel	78,500	1.965 x 10^5	1.965 x 10^5	3.6379 × 10−6
Magnets	N4518	-------	---------	---------	2.1402
Casing	Structural steel	78,500	1.965 x 10^5	1.965 x 10^5	14.980
Top Strut	Structural steel	78,500	1.965 x 10^5	1.965 x 10^5	17.126
Bottom Strut	Structural steel	78,500	1.965 x 10^5	1.965 x 10^5	12.840
Bottom eye	Structural steel	78,500	1.965 x 10^5	1.965 x 10^5	3.6379 × 10−6

The complete levitation assembly was subjected to appropriate boundary conditions, applied loading, support setup, and boundary constraint conditions to evaluate the stress distribution throughout the subsystem. Simulation outcomes showed that the stresses generated throughout the assembly stayed well within the acceptable material limits, ensuring safe operation. rom the stress contour results, it was observed that the peak stress occurs at the top eye (sprung mass area), where the maximum stress intensity is 17.126 N/mm^2

Whereas the minimum stress was observed at the bottom eye region with a value of: 3.6379 x 10^{-6} N/mm^2

The gradual reduction and damping of stress transmitted to the sprung mass confirmed the the performance of the proposed approach levitation suspension system. From the obtained data, it is observed that the system is capable of minimizing vibration transfer and enhancing rider comfort during vehicle operation. Overall, the designed magnetic levitation suspension assembly exhibited satisfactory structural strength, safe stress distribution, and effective damping characteristics, making it suitable for improving suspension performance in motorcycle applications.

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