ABSTRACT
Active suspension is a type of suspension systems which can vary its damping value in order to adjust the spring firmness in accordance with the road conditions. Real Active Suspension incorporates an external actuator which helps in raising or lowering of vehicle chassis independently at each wheel. Generally, the actuators that are used for active suspension are Hydropneumatic, Electro-hydraulic or Electromagnetic actuators. A new concept of two-way electromagnetic actuation with the help of magnetic damping is proposed in this paper, which can extend its arm on both sides to facilitate active suspension mechanism in both humps and potholes. This increases the ride quality while maneuvering not only in humps, but also in dumps. It also describes about the comparison of spring materials, sophisticated design, construction and working principle of newly proposed actuator, Catia V5 software has been used to design and simulate the actuator model, different spring materials are analyzed and their shear stress and deflections are compared.

Keywords-- Electromagnetic Actuator, Magnetic Damping, Double Wishbone Suspension

I. INTRODUCTION
Conventional Suspension system cannot fully eliminate the shocks and are inefficient in terms of controlling the vibration occurred due to uneven road surfaces which makes the ride uncomfortable. In order to increase the ride quality, the conventional passive suspension mechanism has been advanced to semi-active and active suspension systems [1-3] which enhances ride quality and vehicle handling capability during cornering, accelerating and braking. Semi-active suspension offers limited number of damping ratios which can be switched between riding modes such as comfort, sport, power etc. it does not contain an external actuator and hence cannot add energy into the system. On the other hand, Active Suspension system offers variable damping ratio with larger time response, it also accommodates an external actuator which increases the ride comfort by raising or lowering of vehicle chassis independently at each wheel.

Actuators plays a vital role in Active Suspension system as it exerts counter force to eliminate the body roll and pitch variation, this makes the vehicle stable and improves traction. Majority of the cars from Mercedes Benz and Citroen which are equipped with active suspension uses Hydropneumatic actuator [4] whereas, the cars having Electromagnetic actuator is not yet commercially available. In 2018 for the very first time, Bose has demonstrated active suspension mechanism using Electromagnetic actuator. [5-7] A two-way actuation mechanism, has been proposed, in order to facilitate the active suspension in both humps and dumps. The actuator works on the principle of electromagnetism where, a calculated amount of current is passed through the coil, which generates magnetic flux around the electromagnetic coil. This magnetic flux can attract or repel a permanent magnet based on the polarity of the current supplied through the coil. This attraction or repulsion constitutes for magnetic damping which makes the actuator arm to expand or compress, resulting in uplift movement or downward movement of vehicle wheels.

II. METHODOLOGY
The proposed electromagnetic actuator consists of a moving a cylinder called mover, which are attached with permanent magnets and two set of copper coils placed at both end of the cylinder as shown in figure 1. Mechanical springs are present to absorb the vibrations, when a vehicle navigates over uneven road surfaces.

![Figure1: Electromagnetic actuator](image)
both caster and camber have kingpin inclination of 47°. [8-9]

![Figure 2: Suspension mechanism](image)

**Table 1: Suspension design parameters**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm length</td>
<td>65 mm</td>
</tr>
<tr>
<td>Spring stiffness</td>
<td>24.5 N/mm</td>
</tr>
<tr>
<td>Spring wire Diameter</td>
<td>5 mm</td>
</tr>
<tr>
<td>Spring length</td>
<td>36 mm</td>
</tr>
<tr>
<td>No of turns</td>
<td>10</td>
</tr>
<tr>
<td>Nominal actuator length</td>
<td>90 mm</td>
</tr>
<tr>
<td>Max stroke length</td>
<td>105 mm</td>
</tr>
<tr>
<td>Min stroke length</td>
<td>70 mm</td>
</tr>
<tr>
<td>Max angle of elevation</td>
<td>+25°</td>
</tr>
<tr>
<td>Max angle of depression</td>
<td>-23°</td>
</tr>
<tr>
<td>Max wheel lift</td>
<td>±26 mm</td>
</tr>
</tbody>
</table>

The actuator has been designed for two-way actuation so that, the actuator arm can both expand and compress depending upon the polarity of current supplied through the coil. The cross section of proposed actuator is shown in figure 3 and working of actuator is demonstrated with help of flow chart in the figure 4.

![Figure 3: Cross section of actuator](image)

When the vehicle wheels encounter an elevation in road surface. Radar sensor gathers information and gives input to processor. Processor calculates the average height, with which the actuator needs to compress, so that vehicle wheels can be lifted by keeping the vehicle chassis at constant level. Both the copper coils are energized by supply of current with negative polarity, to induce south pole so that, electromagnet and permanent magnet present in top position repels each other. This entire combination constitutes for magnetic damping and pushes the mover inside the upper coil, resulting in uplift movement of the actuator.

![Figure 4: Flow chart](image)

Similarly, when the vehicle wheels encounter bumps or potholes which are below the road surface, both the coils are energized by supply of current with positive polarity, to induce north pole so that, the repulsion takes place in top portion and attraction takes place in bottom portion of the actuator. This combination pushes the mover inside the below coil, resulting in downward movement of actuator.

Electromagnet [EM] is constructed by winding a copper coil of length ‘L’ on a solenoid with ‘N’ turns, current ‘I’ is allowed to flow through solenoid as shown in figure 5. From Amphere’s law, the magnetic flux (B) produced by solenoid is given by,
is best suited for automobile suspension for taking heavy loads.

Table 2: Comparison of Spring material

<table>
<thead>
<tr>
<th>property</th>
<th>Chromium Vanadium</th>
<th>Chrome Silicon</th>
<th>Stainless steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus</td>
<td>30 MPa</td>
<td>30 MPa</td>
<td>29.5 MPa</td>
</tr>
<tr>
<td>Min Tensile Strength</td>
<td>1310 - 2068 MPa</td>
<td>1620 - 2068 MPa</td>
<td>2068 - 2309 MPa</td>
</tr>
<tr>
<td>Density</td>
<td>7860 kg/m³</td>
<td>7861 Kg/m³</td>
<td>7800 Kg/m³</td>
</tr>
<tr>
<td>Modulus Torsion (G)</td>
<td>11.5 * 10⁶ psi</td>
<td>11.5 * 10⁶ psi</td>
<td>11 * 10⁶ psi</td>
</tr>
<tr>
<td>Max operating Temperature</td>
<td>218⁰C</td>
<td>246⁰C</td>
<td>340⁰C</td>
</tr>
</tbody>
</table>

III. RESULTS & DISCUSSIONS

The actuator lifts up or lifts down the wheel depending upon the control signal given by ECU. Results are discussed with different scenarios involved.

A. Actuator Analysis

Depending upon the attraction or repulsion of EM’s and PM’s, the vehicle wheel moves up or down. At Maximum stroke length, the vehicle wheel can be lifted down to 26 mm below road surface and at minimum stroke length, vehicle wheel can be lifted up to 26 mm above road surface. The actions of actuator are discussed below in following cases and is represented in figure 6.

B. Vehicle Maneuvering over Flat Road

All the vehicle wheels are in contact with road surface, there is no movement involved in actuator. The mechanism rests at constant position.

C. Vehicle Encountering Humps

When vehicle encounters humps, there is uplift movement of vehicle wheel keeping chassis at constant level. Suspension mechanism has been designed to raise the wheel by maximum height of 26 mm by raising 250 with respect to chassis level. Figure 7, represents
variation in suspension mechanism when vehicle encounters humps in different scenarios.

**Case 1:** Vehicle over humps, where hump height ‘h’ ≥ 20mm

The actuator fully compresses in order to lift the wheels up. This can be achieved by supplying maximum voltage of 5 V with negative polarity across both coil 1 and coil 2, which makes both the coil as south pole. This attracts PM in top portion and repels PM in bottom portion resulting in compression of actuator. Suspension mechanism raises its arm up to 25° enabling wheel lift up to 26 mm.

![Figure 7a: Suspension in humps (case 1)](image)

**Case 2:** Vehicle over humps, where 0 ≤ h ≤ 20mm

The actuator partially compresses and also partially lifts up the wheel above road surface. This is achieved by supplying -4 V across the coil 1 and +1 V across coil 2. This makes coil 1 as south pole and coil 2 as north pole. The force of attraction is greater near coil 1 and lower near coil 2. The mover attains levitating state and remains constant near coil 1, resulting in partial compression of actuator. Suspension mechanism raises its arm up to 200 enabling maximum wheel lift of 20 mm.

![Figure 7b: Suspension in humps (case 2)](image)

**D. Vehicle Encountering Dumps**

Suspension has been designed to lower the wheel by maximum height of -26mm, which is below ground level. Active suspension cannot be fully functional in case of dumps because of its restriction in lowering of wheels is limited by design parameters, but there are plenty of potholes with different depths variation. Figure 8 represents variation in suspension mechanism while vehicle encountering dumps in different scenarios.

**Case 3:** Vehicle over dumps, where dump depth ‘d’ ≥ 20mm

The actuator fully expands in order to lift the wheels down. This can be achieved by supplying maximum voltage of +5 V across both coil 1 and coil 2, which makes both the coil as north pole. This repels PM in top portion and attracts PM in bottom portion in expansion of actuator and thus moving the vehicle wheels down. Suspension mechanism lowers its arm up to 23° enabling wheel lift down up to 26 mm.

![Figure 8a: Suspension in dumps (case 3)](image)

**Case 4:** Vehicle over dumps, where 0 ≤ d ≤ 20mm

The actuator partially expands and also partially lifts down the wheel below road surface. This is achieved by supplying -1 V across the coil 1 and +4 V across coil 2. This makes coil 1 as south pole and coil 2 as north pole. The force of attraction is greater near coil 2 and lower near coil 1. The mover attains levitating state and remains constant near coil 2, resulting in partial expansion of actuator. The arms are lowered up to 20° which will lower the wheel up to 20 mm.

![Figure 8b: Suspension in dumps (case 4)](image)

**A. Spring Deflection**

The Actuator spring is analyzed using Ansys tool, where different loads are applied on the spring and its corresponding shear stress is noted.
Chromium vanadium and hard carbon spring steel are analyzed by creating mesh model. [10] Mesh model contains number of nodes and elements which helps to analyze applied load under specific boundary conditions. Circular cross section spring are analyzed at different loads of 55 N, 65 N, 75 N, 85 N and 95 N. Figure 9a represents variation of shear stress and load. Figure 9b represents variation of deflection and load.

**Figure 9a:** Load vs shear stress

**Figure 9b:** Load vs deflection

IV. CONCLUSIONS

Electromagnetic actuator has various advantages over hydraulic actuators because of its characteristics. Both springs and dampers are combined together in electromagnetic actuator which impacts weight and compactness in the vehicle. Two-way actuation is most efficient in electromagnetic actuator as it can be easily controlled by varying the current through the coil. The mechanism has been designed and simulated using Catia V5 and Lotus software’s ensuring proper working of active suspension using electromagnetic actuator in both humps and dumps. Chromium vanadium steel, chrome silicon and stainless-steel spring materials are compared with their respective physical properties. It is found that chromium vanadium steel is best among all three because of its properties.

**A. Future Scope**

The firmware of this project can be upgraded to facilitate raising or lowering of vehicle chassis. Lowering of vehicle chassis has many advantages such as improved fuel economy, increase in aerodynamics and better comfort to passengers for easy boarding and de-boarding. Also, raising of vehicle chassis helps in increasing ground clearance. The suspension mechanism can be enhanced with high quality design to achieve greater stability during cornering, increasing of wheel lifting capacity and offering variable ride modes with different damping coefficients.

REFERENCES


