Design and Implementation of Electromagnetic Suspension Systems using FEM Parameterized Linear Actuator

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***Abstract*—** In case of conventional suspension systems there is a combination of spring and piston. The dampness of the system is not variable which makes it stubborn for different conditions. Active suspension system comes with variable dampness which makes them adaptive to the environment. These systems are a more complex and power consuming which makes them quite expensive and only higher end vehicles preferred it to implement as BOSE industry invented the mechanism but never got it popular till 1990s. In this manuscript, an electromagnetic suspension system using FEM Parameterized Linear Actuator is designed and implemented in MATLAB/Simulink for advanced motion control and analysis. The simulated results are presented to validate the effectiveness of the proposed system. The proposed electromagnetic suspension system is faster and more responsive than conventional active suspension as it comprises of electrical circuits as compared to the forced fluid injection system.

Keywords: FEM, Electromagnetic Suspension Systems, MATAB Software, CAD software, BOSS Suspension systems**.**

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I. INTRODUCTION ON ELECTRICAL PROPULSION SYSTEM

The damper cylinder incorporates a loop that goes about an electromagnet in which the flow of electricity is through it. This occurs, when the metal particles inside the liquid are adjusted, significantly expanding its thickness (consistency) and actually solidifying the suspension to lessen body roll. The essential benefit over electromagnetic frameworks over mechanical frameworks, for example, the DCC portrayed above has to do with their responsiveness. Other well-known names for versatile suspension frameworks include: Magne-Ride (Ford), Adaptive Dynamics (Jaguar), Porsche Active Suspension Management - PASM, Adaptive Variable Suspension - AVS (Lexus) and Four-C Chassis Control (Volvo). Physically flexible versatile suspension is maybe the easiest, yet in addition the most un-normal, sort of versatile suspension. In these cases, the driver can lift the vehicle using a jack and physically change the launch of the damper stream valve through a scope of settings by turning a handle at each safeguard. Not many creation vehicles as of now presented with physically customizable suspension. It's typically saved for track specials, in spite of the fact that it is fitted in the Polestar 1 and 2 as an add-on.

A. *Versatile Air Suspension*

Air-suspension frameworks supplant the curl springs in an ordinary arrangement with inflatable elastic films that contain compressed air. The elastic layer swells or flattens the ride level of the car. There are four critical parts to any air suspension framework. These are an air blower that can supply air to a repository, the elastic films that utilization this air and a progression of ride level sensors to decide the ride level of the vehicle at each corner. Air suspension frameworks for the most part hold the dampers tracked down in ordinary auto suspension frameworks.

These frameworks come in both open and shut assortments. The murmur sound at whatever point we get a transport as its ride level brings down. That is normal for an outdoors suspension framework, by which the elastic layer basically gives abundance air access to the environment while decompressing. A shut air- suspension framework is more present-day elective where air can be gotten back to the repository when the elastic layer collapses to work with calmer, more proficient, faster altercation in ride levels. The capacity of air-suspension frameworks to alter the ride level of the vehicle likewise carries different advantages concerning optimal design, load dealing with benefits as well as possibly further developed rough terrain abilities for 4WD (Wheel Drive) vehicles. An air suspension framework can make up for any weighty burdens that may be put toward the rear of a vehicle, changing the ride level to guarantee that the vehicle sits in level and doesn't hang. What's more, current vehicles outfitted with air suspension frameworks can consequently bring down their ride level at higher paces to further develop proficiency and taking care of.

B. *Different Technologies*

The hydraulic-pneumatic suspension supported by Citron in its Hydractive-type suspension framework typically uses a mixture of pressure-driven liquids and nitrogen-filled circles, which are the standard hermeticity of ride comfort along with benefits, are met with suspension structure. Albeit as of now not accessible in Citroen vehicles sold today, Mercedes offers its own, high-level rendition in top of the reach vehicles, for example, the S-Class known as Active Body Control. A later improvement with this framework is the presentation of an Active Curve Tilting capability which empowers the vehicle to incline in corners like a motorbike reciprocally. It is claimed by the Mercedes-Benz that this framework further develops solace by decreasing the powers experienced by tenants in the lodge. 5 The Prescient suspension framework is another new suspension innovation called the flagbearer-system on the latest Rolls-Royce Phantom and Ghost.

The ideal vehicle suspension would quickly and independently absorb road bumps and slowly return to its normal position while maintaining optimal tire-to road contact. However, this is difficult to achieve passively, where a soft spring allows for too much movement and a hard spring makes passengers uncomfortable due to the bumps in the road. Passenger comfort (along with handling and safety) is an increasing demand in the automotive industry where everyone expects improvements in comfort and handling.

Numbers of demerits of shock absorbers are:
1. Damage to vehicle parts due to vibration.
2. Breaking elements due to strong impacts.
3. Distress to passengers due to vibration.
4. Damage to the floor of the machine due to vibration

II. OBJECTIVE

Therefore, electromagnets are used to elevate the upper part of the body from the lower. These electromagnets are arranged in such a way that the same poles are placed on the same side to repel each other, and when torque is applied in the horizontal direction, it tends to lift the body. However, as a result, the vehicles unsprung mass increases, which can be a disadvantage in terms of passenger comfort and handling. A mechanical system with magnetic force may come up against the shortcomings of a mechanism without relatively high information measurements (tens of hertz) and interest in constant power, simple management and the absence of fluid.

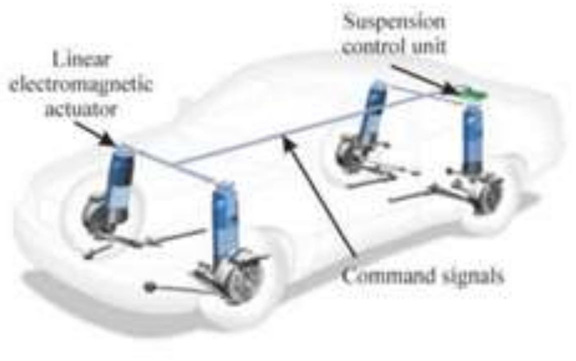

Fig.1: Bose Suspension system

II. LITERATURE SURVEY

India has the third largest road network in the world and about 60% of passengers preferred travel by it [1].

Suspension systems are categorized in three types passive, semi-active & active systems. Passive Systems have dampers and springs having fixed properties [2]. Most of the systems use springs to absorb shocks and jerks & dampers to control spring movement [3].

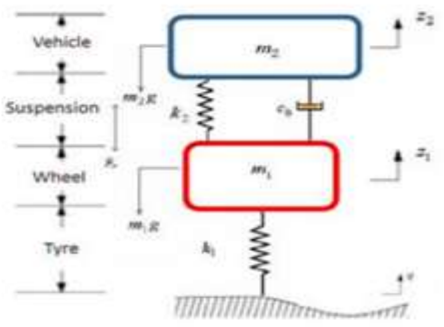

Fig.2: Passive System [11]

In semi-active its damping coefficient can be changed but dependent on the relative velocity of the masses present on the vehicle. The world's first electronically controlled semi-active system was implemented by Mitsubishi in 1987 [4].

In active systems an actuator is required to make effects on the relative velocity. The active suspension system is a bulky, expensive and power consuming which causes them to unviable in commercial uses [2].

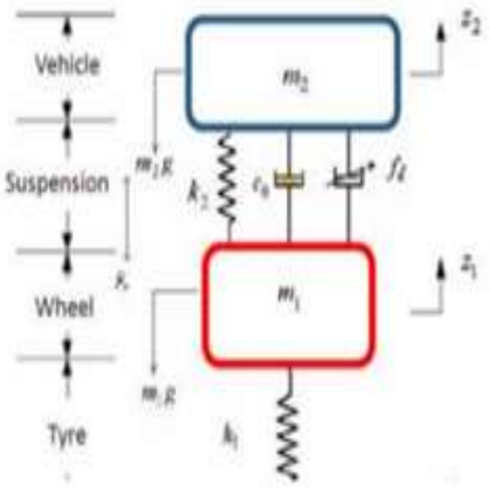

Fig.3: Semi-Active System [10]

In semi-active systems the damping coefficient can be altered within 100 milliseconds. The spring stores the energy damper dissipates it [5].

In active suspension system it works when the car is changing its speed or during cornering effectively to keep the vehicle steady at every instance which is not available in passive ones [6]. The zero-acceleration line is measured by an acceleration sensor mounted on the top of the vehicle [7]. The spring holds the static sprung mass of the vehicle and the actuator provide the compensatory force to make the surface irregularities null. If the spring and the actuator works in series it's called low bandwidth system and if they are in parallel then they are called as high bandwidth systems which costs more than earlier one [8]. The human endurance limit to vertical vibrations is 4-8 Hz which can be easily countered by the active systems [9].

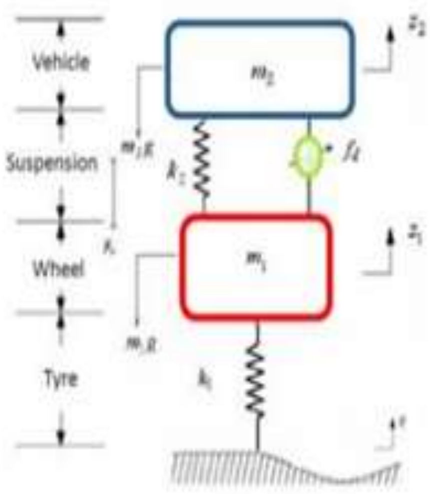

Fig.4: Active System [10]

These systems are more helpful in maintaining constant acceleration during curves (in high-speed railways).

The purpose of this paper is to devise electromagnetic suspension system which will takes input from various sensors mounted on the vehicle and be controlled using artificial neural network (ANN) as a controller to overcome the power and cost issues in active systems. Mobility gets comfy as passengers will get rid of lumbar problems, less expensive, more reliable, less power consumption, faster response.

In this proposed active system, a permanent strong electromagnet will be used and its repulsive power can be utilized to lift the body of the vehicle. To vary the stiffness of the suspension we use the magnetization and demagnetization of the permanent magnet by changing the direction of the current through the coil wound over it and the magnitude of current flowing is proportional to driving condition.

III. Concept of Electro-Magnet Suspension

In this proposed active system, a permanent strong electromagnet will be used and its repulsive power can be utilized to lift the body of the vehicle. To vary the stiffness of the suspension we use the magnetization and demagnetization of the permanent magnet by changing the direction of the current through the coil wound over it and the magnitude of current flowing is proportional to driving condition.

BUMPY CONDITION – In this we need to push the body downwards proportional to the axle, as it goes upside.

POTHOLE CONDITION – In this condition we need to pull the body of the vehicle upwards proportional to the axle, as it goes downwards.

All the calculations regarding the magnetization and demagnetization will be done by the ECU (Electronic Control Unit) in which it processes the inputs from a Camera, RADAR (Radio Detection & Ranging) & LIDAR (Light Detection & Ranging) unit all mounted on the front of the Vehicle.

A. *Designing Utilities*

First of all, all the corresponding parts have to be made in CAD (Computer Aided Design) software's like SOLIDWORKS, CATIA, Inventor, etc., using suitable technique of CAD viz. extrude, chamfer, draft, drill, etc. to make the connecting parts come to the virtual world of simulation before exporting it to the MATLAB/Simulink for advanced motion control and analysis.

Firstly, design and develop the individual parts in SOLIDWORKS. Secondly, assemble all the respective parts through SOLIDWORKS assembly using different-different joints and finalize the assembly by making it ready to export using Simulink Multibody Link mechanism for MATLAB integration.

After this we get a compatible file with (.xml) as an extension for linking it.

Open MATLAB and use command to load the file into the software using the command smimport ("Name_of_the_file.xml").

A new Simulink multibody model will be opened in the new window. This will give us an uncontrolled and non-constrained model where every joint is not defined for environment or just present physically there.

IV. DESIGNING, IMPLEMENTATION & RESULTS

A. *MATHEMATICAL MODELLING OF (FEM) PARAMETERIZED LINEAR ACTUATOR*

The FEM-Parameterized Linear Actuator implements a linear actuator defined in terms of magnetic flux. To model custom solenoids and linear motors where magnetic flux depends on both distance and on current. We parameterize the solenoid using data from a third-party magnetic finite-element method (FEM).

The solenoid has two electrical equations. The first defined in terms of dΦ(i, x)/dx and dΦ(i, x)/di, defines the current in terms of partial derivatives of the magnetic flux (Φ) with respect to distance (x) and current (i), the equations for which are:

The core of an electromagnet is an inductor and voltage across an inductor can be defined as a function of current flowing through it.

$$V_L = L\frac{di}{dt} \qquad (1)$$

"iR" is the power loss in the electromagnet as heat where R is the resistance of the electromagnet. Here net back emf generated is flux can be said as function of distance "x" and flux (Φ), multiplied by acceleration.

$$a = \frac{dx}{dt} \qquad (2)$$

The self - inductance "L" can be written as property of its change in flux due to selfcurrent flowing through it. Hence,

$$L = \frac{\partial \emptyset}{\partial i} \qquad (3)$$

Upon substitution and simplification, we get:

$$\frac{di}{dt} = \frac{\left\{v - iR - \frac{d\emptyset}{dx}\frac{dx}{dt}\right\}}{\frac{d\emptyset}{di}} \qquad (4)$$

This is the net voltage across the electromagnet. The second defined in terms of Φ (i, x), defines the voltage across the component directly in terms of the flux, the equation for which is:

$$V = iR + \frac{d\emptyset(x,i)}{dt} \qquad (5)$$

Numerically, defining the electrical equation in terms of flux partial derivatives is better because the back-emf is piecewise continuous. If using the flux directly, using a finer grid size for current and position will improve results, as will selecting cubic or spline interpolation.

In both cases, we have an option to either directly specify the force as a function of current and position. If entering the electromagnetic force data directly, you can either use data supplied by the finite element magnetic package (which you used to determine the flux) or calculate the force from the flux with following equation:

$$F = \int_0^i \frac{d\emptyset(x,i)di}{dx} \qquad (6)$$

The force is calculated by numerically integrating the rate of change of flux linkage with respect to position over current, according to the preceding equation. In the Electrical model to define in terms of Φ (i, x), then the block must first estimate the Flux partial derivative with respect to displacement, dΦ (i, x)/dx parameter value from the flux linkage data.

B. *BLOCK AND SIMSCAPE DIAGRAMS*

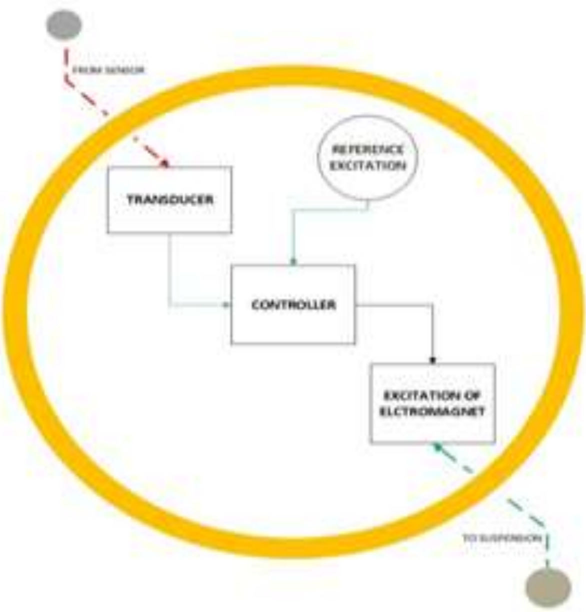

Fig.5: Block diagram for the proposed logic circuitry

Here Fig. 5 shows the block diagram or the block mechanism for our system to work for different conditions. The Ultrasonic sensors gives output as the measured distance to the hall sensor which acts as a transducer which consequently gives output in the form of voltage to the controller which proportionally controls the dependent source. That further excites the electromagnets shown in Fig. 6 & Fig.7 of the ego vehicle and feeds to the system. Fig.8 shows the target vehicle and root system.

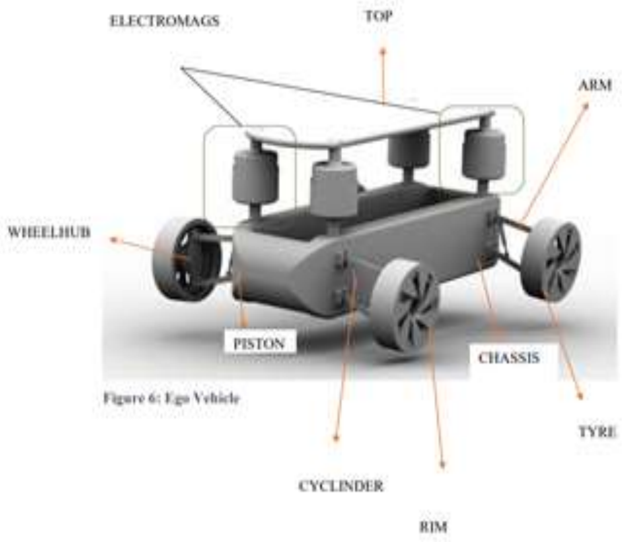

Fig.6: Ego Vehicle

Fig.7: Real-View Ego Vehicle

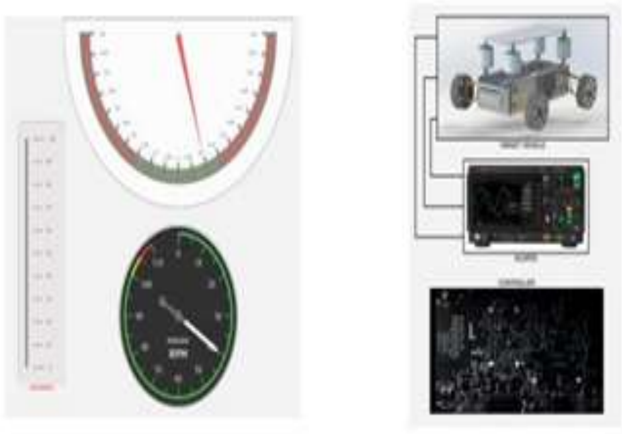

Fig.8: Target Vehicle and Root System

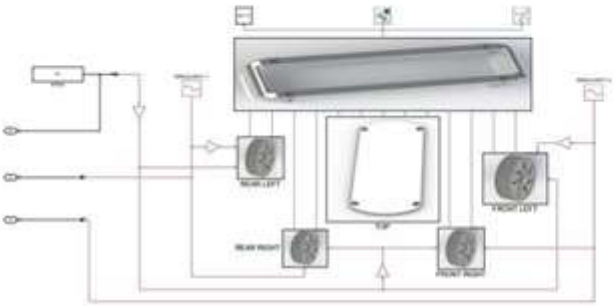

Fig.9: Multibody Simulink Diagram for the Ego Vehicle

Here the Fig. 9 shows the various components used in our system or ego vehicle viz. tyres, rim, top chassis, etc. are linked through the multibody simulink connection s to the system.

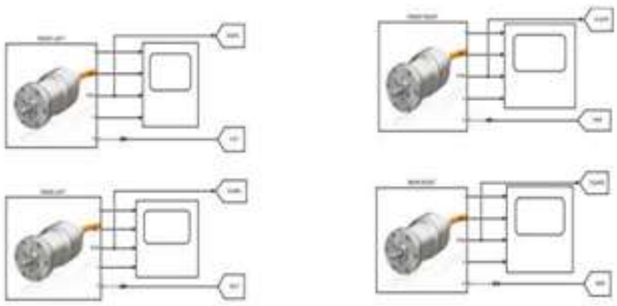

Fig.10: Linear Electromagnets

Fig. 10 shows the linear electromagnets. Fig. 11 shows the control circuitry for our ego vehicle's suspension system. In this a controlled voltage source is been implemented and controlled through the output of the hall sensor's output which is a function of the distance of movement of the piston. The final excitation is been generated by the FEM actuator.

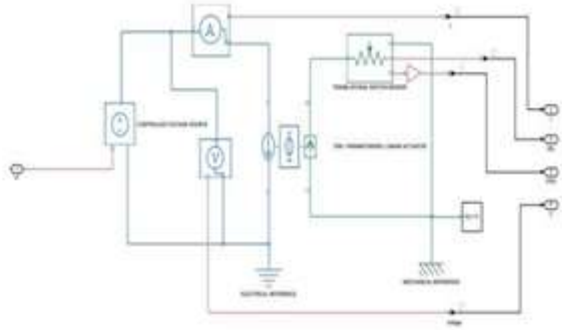

Fig.11 Control circuitry for linear electromagnets

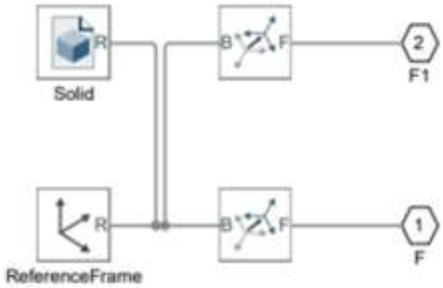

Fig.12 Rim

Fig 12 shows the Rim assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference.

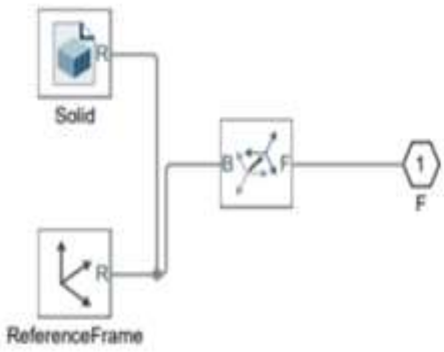

Fig.13 Tyre

Fig. 13 shows the tyre assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part.

Fig.14: Top Assembly

Fig 14 shows the top assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part.

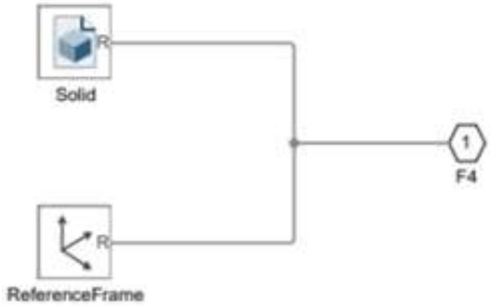

Fig.15: Top Assembly Internal

Fig. 15 shows the top assembly internal and consists of a reference frame and the solid part.

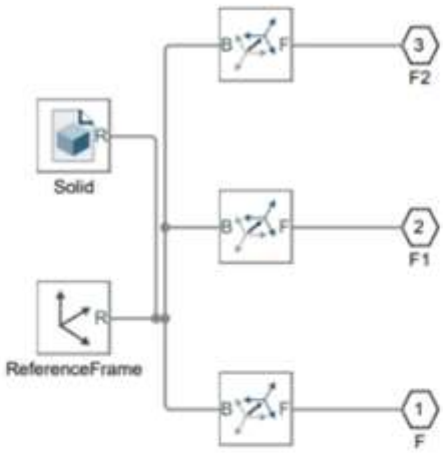

Fig.16: Wheel-hub

Fig. 16 shows the wheel-hub assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part.

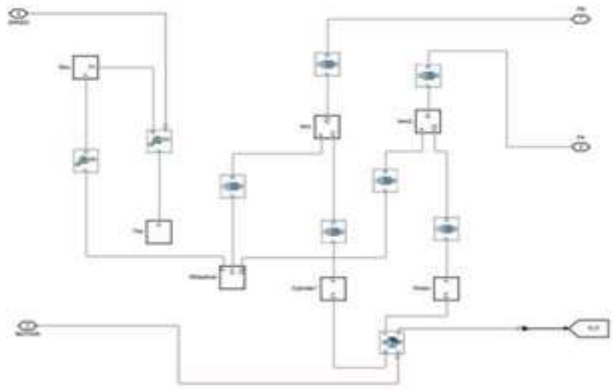

Fig.17: Quarter Car Assembly

Fig. 17 shows the quarter car assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part. Some joints like cylindrical, pivot, revolute etc. are linked to multibody Simulink to express the movements between the various components.

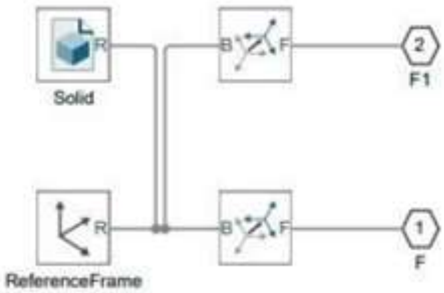

Fig.18: Piston Assembly

Fig. 18 shows the piston assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part.

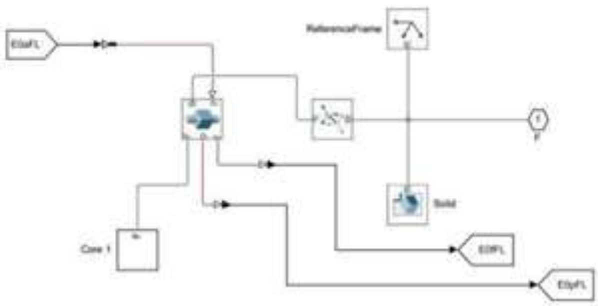

Fig.19: EMS with Vehicle

Fig. 19 shows the electromagnetic suspension assembly and consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference, the solid part and the cylindrical joint

Fig.20: EMS Linking

Fig. 20 shows the electromagnetic suspension linking with the rest of the car using two solid part and one revolute joint which has one degree of freedom.

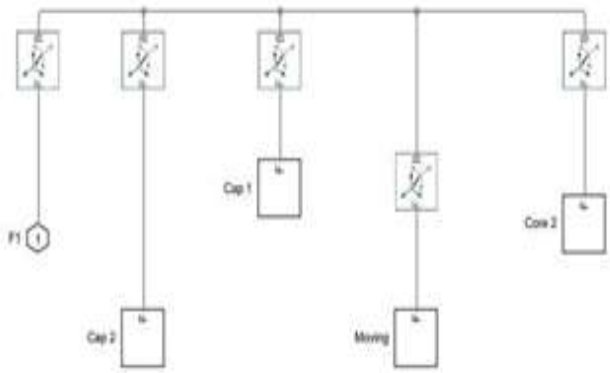

Fig.21: EMS Assembly

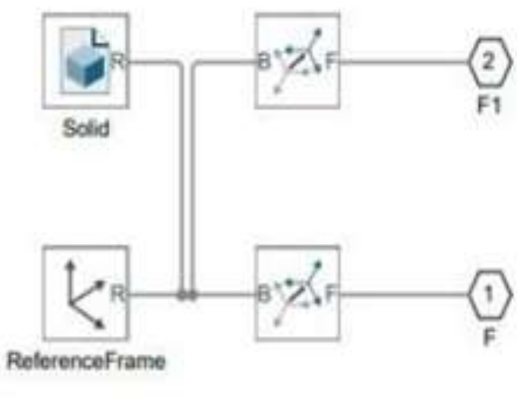

Fig.22: Cylinder Assembly

Fig. 21 and Fig. 22 shows the EMS assembly and the cylinder assembly which consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part and Fig 23 represents the core which consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the two solid parts.

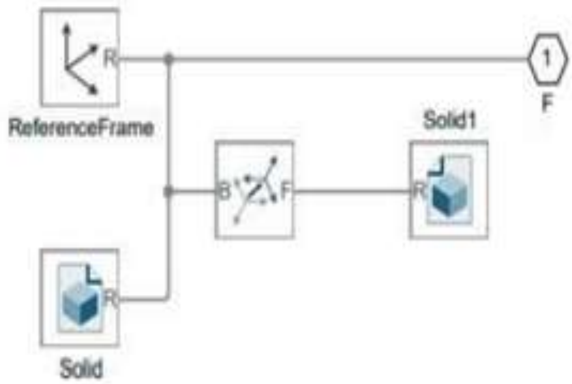

Fig.23: Core

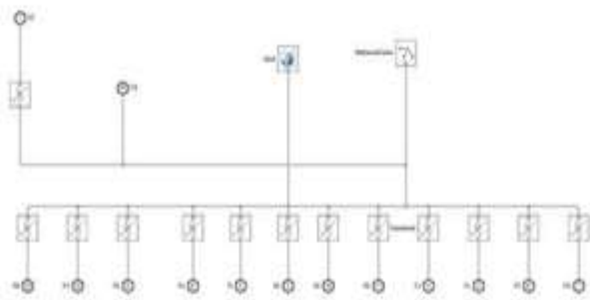

Fig.24: Chassis

Fig. 23 and Fig. 24 shows the core and the chassis assembly which consists of a reference frame, multiple transformation blocks to transform parameters from one frame of reference to the other frame of reference and the solid part and Fig.25 represents the top which consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the two solid parts.

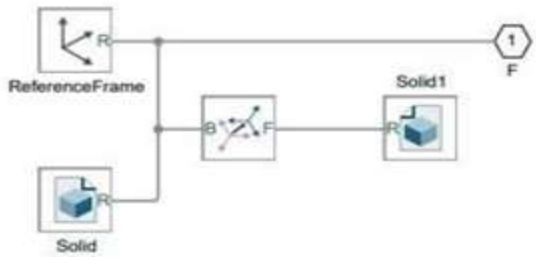

Fig.25: Top

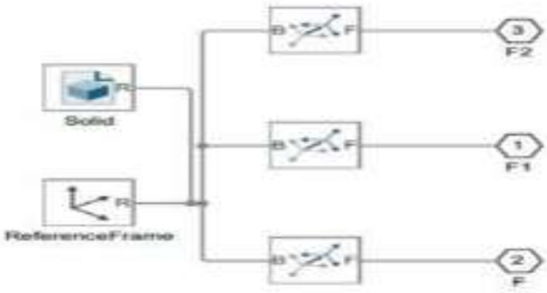

Fig.26: Right Arm

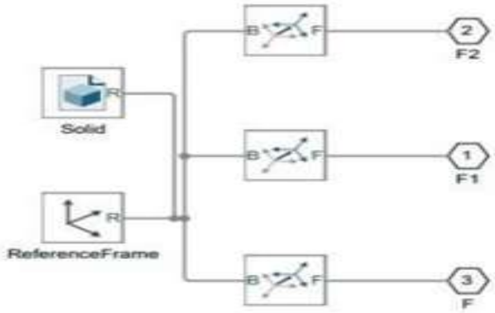

Fig.27: Left Arm

Fig. 25, Fig. 26 and Fig. 27 shows the arm assemblies and the top part which consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the solid part and Fig. 27 represents the left arm assembly which consists of a reference frame, transformation block to transform parameters from one frame of reference to the other frame of reference and the two solid parts.

C. SIMULATIONS & RESULTS

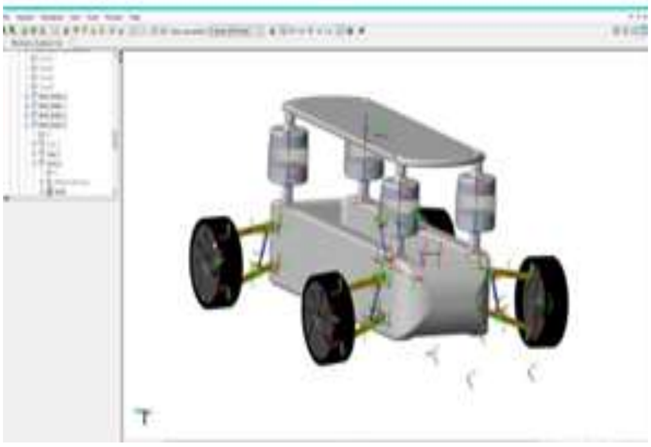

Fig.28: Simulation with Frame of References

Fig. 28 shows the reference frames for each part and their rotation in their desired direction viz. for tire and rim it circular, for piston and EMS it is translational, etc.

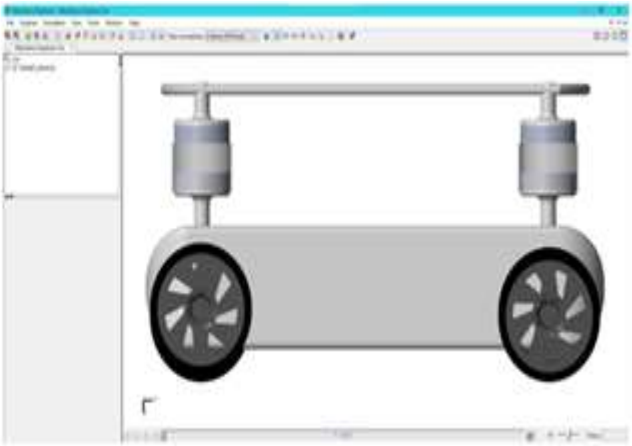

Fig.29: Left view of the Vehicle

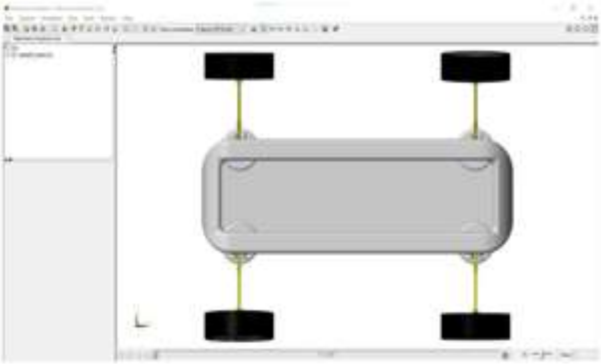

Fig.30: bottom view of the Vehicle

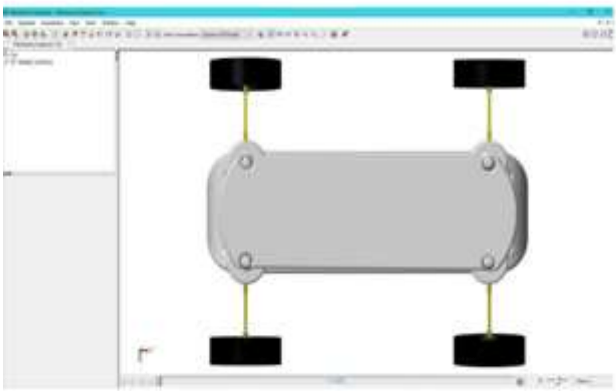

Fig.31: Top view of the vehicle

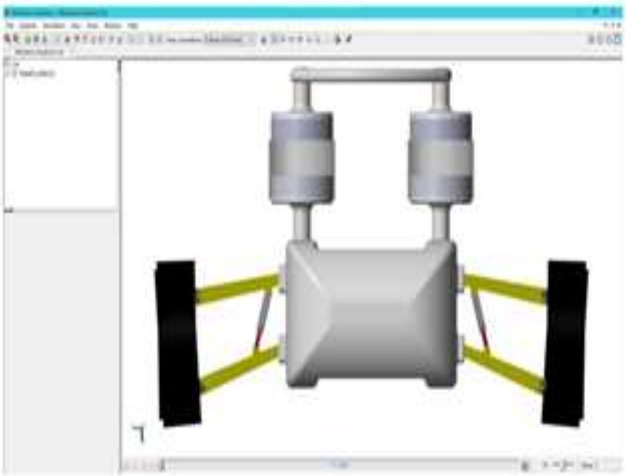

Fig.32: Front view of the vehicle

Figure 33:Isometric View of the Ego Vehicle.

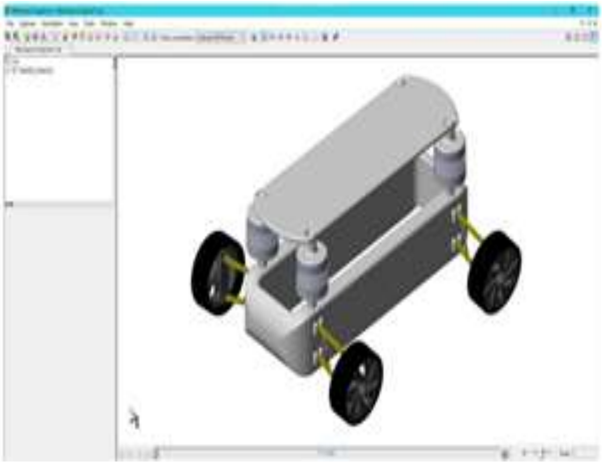

Fig.33: Isometric view of the vehicle

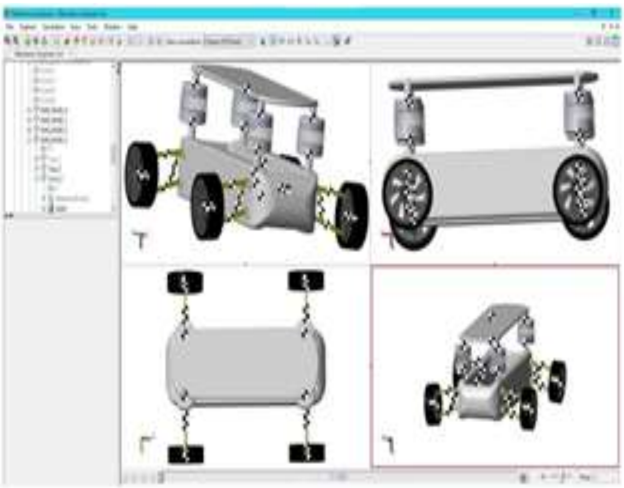

Fig.34: Centre of gravity in all possible views in the Ego Vehicle

Fig. 29 to Fig. 34 shows the various views and centre of gravity acting on various parts and their location to find the location of the centre of mass of the vehicle.

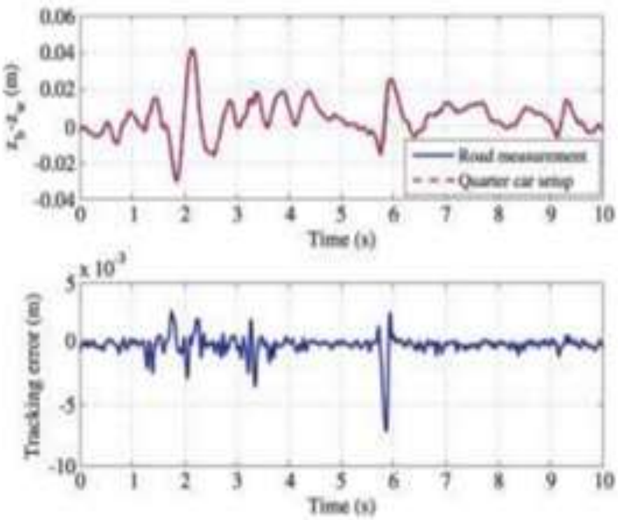

Fig.35: Off-Road measurements for EMS and its response [11]

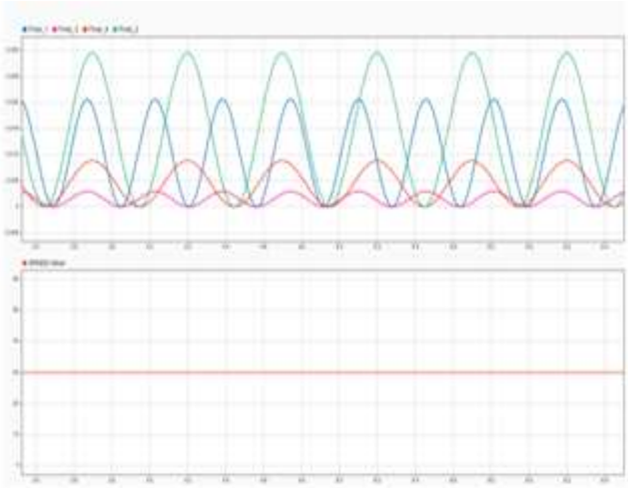

Fig.36: System Response for EMS under different conditions

Fig. 28 shows the reference frames for each part and their rotation in their desired direction viz. for tire and rims it circular, for piston and EMS it is translational, etc.

Fig. 35 shows the off-road measurement for Active suspension and it's response among other categories. Fig 36 shows our proposed system simulated response when exposed to different-different irregularities to all EMS acting on the vehicle body or the ego vehicle to improve the stability. As we can see the output is smooth and less jerky which makes our system to stand out among all other categories and gives a better scope for further implementation in the real-world applications.

V. CONCLUSIONS

This proposed system becomes more sensitive to the irregularities and gives a better response to the overall vehicular dynamics which leads to a better driving experience and comfort. Our proposed system simulated response when exposed to different irregularities to all EMS (Electro Magnetic Suspension) acting on the vehicle body or the ego vehicle to improve the stability. As we can see the output is smooth and less jerky which makes our system to stand out among all other categories and gives a better scope for further implementation in the real world applications. When our system faces any unevenness in the terrain the sensors will feed to the source and changes the excitation in proportion which subsequently gives a counter response to the unevenness which in combination dampens out the jerks and makes the ride comfortable. This proposed system not only limited to automobiles but can also be implemented to medical fields like persons suffering from motor diseases, those who are unable to walk or stand, unable to lift the things, requires prosthetics etc. Such diseases cannot be cured but can be helped using Nanotech and smart controls like this can makes their life better. Further in high speed railways when to pass a curvy terrain at the same speed this system could be a boon for it as without losing some speed in turning and consequently the energy. But this system is little bit more costly and higher current would be required for low voltage systems.

VI. REFERENCES

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