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Investigations on Magnetic Suspension System of Shock Absorber by Finite Element Method

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Abstract: The suspension system of two wheelers is depending upon spring type, hydraulic or pneumatic type of suspension systems. This present work gives deals with the magnetic suspension system and the magnetic suspension system is turning out to be the new option to the conventional suspension systems. The aim of this work is to study and investigate the response of two-wheeler suspension system, when it is subjected to road surface irregularities. This research work presents design, construction and working of magnetic suspension system. This system uses magnets and spring as passive dampers, which are used to reduce displacement and acceleration of spring mass in order to improve ride comfort. This type of Suspension has no problem of leakage of oil like hydraulic shock absorber. FEA analysis is carried out over the suspension spring with different materials such as Crome silicon, Carbon steel, NiCr, magnesium and Aluminium. With and without magnetic suspension is analysed for the stress and deformations. It is observed that the carbon steel has minimum deflection and the maximum stress induced in aluminium material.

Keywords: Magnetic, Suspension system, Spring, Spring Material, FEA

I. INTRODUCTION

In order to overcome the disadvantages of the conventional suspension system the magnetic suspension system can be used. The magnetic suspension system can be used in many applications of the suspension in automobile industries and in other industries too. The mechanical magnetic suspension system using permanent magnet also has some disadvantages of slow responsibility and difficult control. The present work is focused on developing the actively control mechanical magnetic suspension systems using a permanent magnet. Magnetic suspension system is mainly based on the property of magnets that like poles of magnets repel each other. This characteristic of magnets is used in suspension system. The suspension system also contains spring in between the two magnets to avoid direct contact of two magnets due to overloading. Such systems find large number of applications in automobile industry. In this modern world automobile sector has reached its peak. In two-wheeler suspensions systems the coil spring after utilizing for some time it becomes not only harder but also reduces cushioning effect. This limitation of the coil spring can be overcome by using magnetic suspension system. The cushioning effect provided by magnetic suspension will exist for long time. There is one magnet fixed at the top of the inner portion of the cylinder and the second magnet placed at bottom of the inner portion of cylinder that reciprocates up and down due to repulsion. The two magnets repel against each other to achieve the aspect of suspension. This system is having the tendency to eliminate the use of conventional suspension system due to its low cost and less maintenance capacity. The modern automobile has come a long way since the days when “just being self-propelled” was enough to satisfy the car owner. Improvement in suspension, increased strength & durability of components, and advances in tire design and construction has made large contributions to tiding comfort and driving safety. Basically, suspension refers to the use of front and rear springs to suspend a vehicles frame, body, engine, and power train above the wheels. These relatively heavy assemblies constitute what is known as sprung weight. Unspring weight, on the other hand, includes wheels and tire, break assemblies and other structural members not supported by the springs. The springs used in today’s cars and trucks are engineered in a wide variety of types, shapes, sizes and capacities. Types include leaf springs, coil springs and torsion bars. The functions of suspension system are, preventing the vehicle body and frame from road shocks, giving stability of the vehicle, safeguards the passengers and goods from road shocks, gives the good road holding while driving, cornering and braking. gives cushioning effect, provides comfort, shock forces are reduced as much as possible, maintains the proper ride height of your car, maintain proper alignment of the wheels, serves as weight support for the vehicle, maintain tire contact with the road, controls the vehicle’s travel direction. maintains a solid grip on the road while driving, cornering, or braking, maintains the correct steering geometry, torque and braking reflexes must be resisted, maintaining vehicle stability while traveling over uneven terrain or turning in order to reduce the tendency for rolling, pitching, or vertical movement, protects passengers from road shocks and give a comfortable ride. reduce the strains caused by road shocks on the motor vehicle’s mechanism and offer a cushioning effect. protects the vehicle’s structure from stress loading and vibration caused by road surface irregularities while maintaining its stability, achieve the necessary height for body structure, retain the right geometrical relationship between the body and the wheels. Magnetic suspension systems are an alternative automotive suspension system that utilizes magnetically controlled dampers, or shock absorbers, for a highly adaptive smooth ride. The absence of mechanical valves and small moving parts makes this type of suspension resistant to wear. Magnetic suspension systems generally consist of four nanotube dampers with magneto-rheological (MR) fluid, one on each wheel of the vehicle, a sensor set and an ECU (Electronic Control Unit) to control the system. Shock absorber device was used for reducing the effect of sudden shock by the dissipation at the shock's energy on an automobile springs and shock absorber are mounted between the wheels and the frame. When the wheel of vehicle comes across the surface irregularities on road, springs absorb the resultant shock by expanding and contracting. To prevent the spring from shocking the frame excessively, their motion is restrained by shock absorber, which are also known by the more descriptive term dumpers. The main types of suspension systems are Pneumatic suspension system, Hydraulic suspension system, spring type (Conventional suspension system) and Magnetic suspension system.

II. LITERATURE SURVEY

Redesigning of fundamental suspension using a magnetically-levitated spring mechanism is carried out to increase the recoverable energy significantly by directly coupling an electromagnetic transducer as the main damper. Magnetic restoring force was analysed to enhance the rider comfort. Analytical and numerical methods were used [1]. A regenerative electromagnetic shock absorber has been studied for effective recovery of energy due to the vibration from the road surface irregularities. Regeneration of energy was the main objective of the work [2]. An electromagnetic suspension system with an electromagnetic actuator has been studied for improvement in rider comfort and the stability of vehicle [3]. An actuator consisting of permanent magnets, soft iron rings, coils and springs has been implemented to reduce the vibrational effects and regeneration of energy from vibrations. FEA technique was used for analysis [4]. A quarter vehicle suspension system was analysed analytically and by simulation [5]. An energy harvesting based review was carried out for vehicle suspensions. Specifically, the study was focuses on an analytical and statistical study. The vehicle road tests were carried out i.e. an experimental method was used [6]. The research work presented a novel active vehicle suspension rocker-pushrod electromagnetic actuator (EMA) which has the features of easy manufacturing and modular design. The results shown that average regenerated power of the designed EMA is 50.11W with the system efficiency of 60%–70% [7] The different control strategies for electromagnetic active suspension was designed based on the system energy flow mechanism, so that the compatibility between ride comfort and energy recovery efficiency are achieved under different road conditions In this mechanism, not only the energy transmission path inside suspension system is considered, but also the vibration energy induced by road roughness is investigated [8].A novel flux control magnetic suspension system consisting of control plates beside the magnetic source that is a permanent magnet is analysed in this research work. A numerical and experimental method was used for the studies. From the numerical analyses it was concluded that the attractive force acting on the floator increases as the position of the lateral ring-shape control plate increases. For the stabilization of the suspension system, the variation of the attractive force was sufficient. It was also observed that lateral force can be generated by dividing the plates into halves and moving them differentially [9].bMagnetic spring design has been done by considering 2D finite element. An algorithm was developed using magnetostatics software. By considering one physical prototype and the multiple virtual designs, the design methodology was validated. The findings show that magnetic springs possess an energy density 50% higher than that of state-of-the-art reported mechanical springs for the gigacycle regime and accordingly a torque density significantly higher than that of state-of-the-practice permanently magnetic synchronous motors [10]. An active vibration isolation system using zero-power magnetic suspension was investigated by analytical and experimental method. negative stiffness properties were estimated by the force–displacement characteristics of the zero-power magnetic suspension system. By experimentation it was confirmed that combining a zero-power magnetic suspension with a normal spring generates high stiffness against static direct disturbances acting on an isolation table [11]. An active seat suspension system based on the passive seat suspension was designed by adding an electromagnetic levitation structure for the comfort of the passengers. It was found that the vibrations were reduced and the improved comforts [12]. In the research work, a neural network (NN) based event trigger control problem of electromagnetic active suspension system was solved [13] The studies show about the energy harvesting from off-road vehicles. hybrid electromagnetic based suspension system running independent from any on–off control strategy were considered. The effect of harvestable power on the ride comfort of the driver or passenger is investigated based on a filtered acceleration response of the chassis in both the frequency and time domains. A Monte Carlo sensitivity analysis is employed [14]. The paper focusses on design and fabrication of a fully embedded suspension system [15]. In this work, two different air spring models, classic air spring and the dynamic air spring model were presented. Both the dynamic air spring suspension and the passive suspension are compared in terms of RMS of body acceleration, suspension travel, and dynamic tire force. MATLAB/Simulink platform was used in the studies [16]. The work relates with the basic designing of a hybrid suspension system that was used on pick-ups. It is observed that the hybrid suspension system found to be better as the air spring part is easy to install and cheap but it makes system more complex [17]. The research work proposed a suspension consisting of a pneumatic system capable of changing the stiffness of the suspension and a semi-active magnetorheological damper capable of controlling the suspension damping. It was found the results that ride comfort was increased [18]. A comparative study and analysis of the vehicles various suspension systems were carried out by considering vibration absorber types used. Based on the analysis, electromagnetic vibration absorbers are the most suitable for vehicles. By this comparative study it was concluded that the use of vibration absorber types makes possible to recuperate the energy in road unevenness overcoming and improve the vehicle ride quality [19].

III. TYPES OF THE SUSPENSION SYSTEM

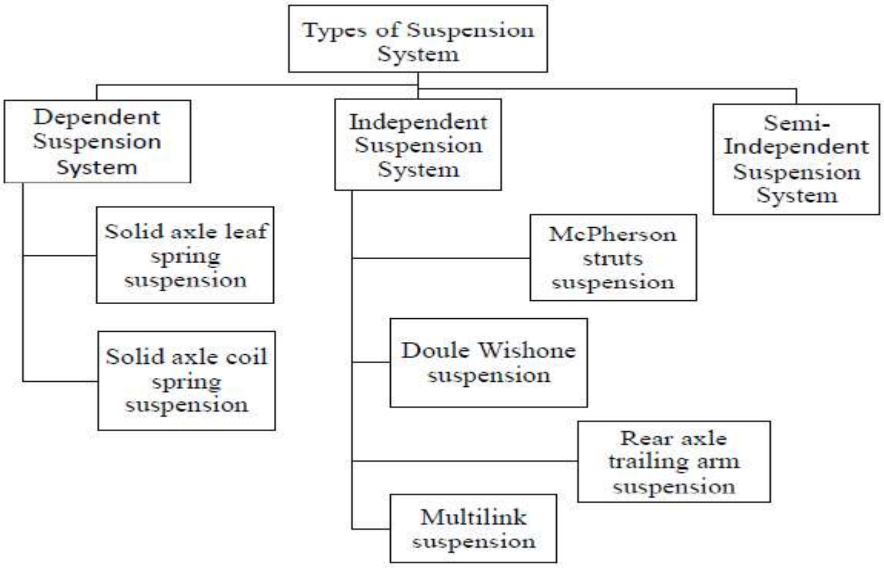

Figure No 1: Types of the suspension system

IV. WORKING PRINCIPLE

Unlike poles of a magnet attract each other and like poles repel each other. When we place two south poles or north poles facing each other and when they are brought closer, they are repelled. This same concept is used in magnetic suspension. A set of magnets having like poles are placed in a hollow cylinder. One magnet is fixed at the top of the inner portion of the cylinder, which in turn to the piston. The other one is placed at the bottom. The top magnet has the North Pole facing down, fixed to the upper part of the suspension. The two magnets are separated by a spring, the lower magnet which is movable has its north pole facing upwards. Since both magnets have same polarity, a repulsion force is created between the magnets. So, the movable magnet opposes the rod action and moves the top magnet away. By using this type of shock absorber, the suspension will be more effective and impact of vibration will be very less as compared to the conventional counterparts.

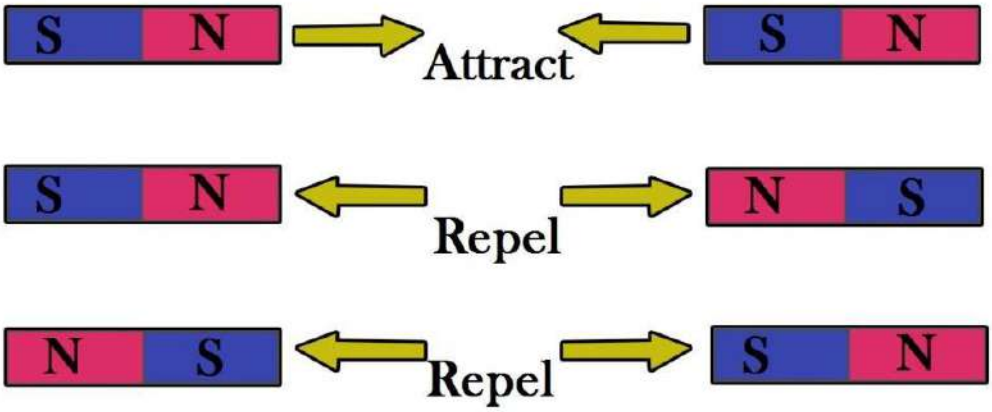

Figure No 02: Repulsion and attraction of magnet

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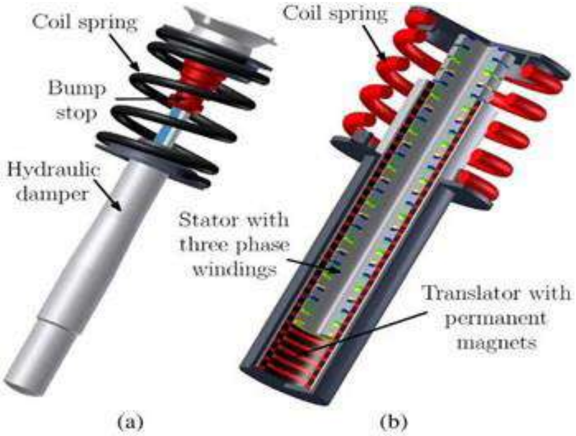

Figure No. 03: Magnetic Suspension

When the vehicle weight increases or vehicle climbs an uneven slope, or rocky roads, the wheel goes upwards and shock absorber is compressed, at this time piston moves downwards. The magnets are brought closer to each other due to the increase of weight. The additional support for the magnets is the spring which was compressed. Thus, vibrations and shocks are absorbed. When the vehicle returns to original position, the shock absorber expands. The piston moves upwards due to the magnetic flux power of the magnet. The stainless-steel spring provided between the magnets helps in slowly moving the magnets to their original position. Thus, a magnetic suspension system absorbs the shock, when vehicle moves on an irregular surface.

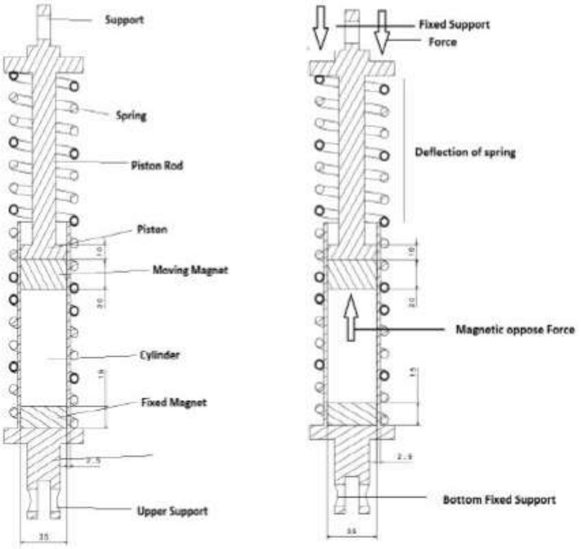

Figure No. 04: Magnetic Suspension

Magnetic Suspension system

Magnetic suspension system is mainly based on the property magnets that like poles of magnets repel each other. This characteristic of magnets is used for suspension work of system. This system also contains spring in between these two magnets to avoid direct contact of two magnets due to overloading.

Material Selection Process:

While springs can be made from a variety of materials, one of the top choices is steel alloys. Springs comes in a wide range of formulations and grades, each of which offers distinct characteristics that make it suitable for different applications.

Material selection description:

The material selected are compressive in nature compared to other grades have higher rigidity to absorb compressive loads and can withstand more shocks while in irregular road terrine. The materials chosen are of the best suited material to analyse for the suspension spring material comparison using FEA Static Structural analysis. From the literature survey the chosen materials have not been analysed for the suspension spring so by identifying gap of literature surveys we have found these materials and from each specific spring alloy highest graded material is selected. The materials selected are **Alloy Steel (**Chrome Silicon), **Carbon Steel** (AISI 1095 Spring Steel) , **Stainless Steel** (NiCr A286 Spring) , **Magnesium** and **Aluminium**

The spring of the magnetic suspension system is designed. The analysis magnetic suspension system is done by varying spring wire dimeter, pitch of the spring and the material of the spring. CAD modelling is done using CATIA and analysis is done using ANSYS and the results are predicted.

V. SUSPENSION SPRING MATERIALS AND ITS PROPERTIES

Alloy Steel: Chrome silicon - Chrome Silicon is a high strength alloy steel which offers excellent, cost-effective performance and good fatigue life. It is frequently used in automobile, aircraft, and general industrial springs

Table No. 1: Specification of Alloy Steel

E Mpa	207,000	Min Size (in)	0.020
E psi	30,000,000	Max Size (in)	0.375
G Mpa	79,300	Min Size (mm)	0.500
G psi	11,500,000	Max Size (in)	9.500
Density g/cm^3	7.860	Surface Min	Maximum defect depth: 0 to 0.5%
Density lb/in^3	0.284	Max Temp °C	245
Conductivity	5	Max Temp °F	475

Chrome Silicon – ASTM A 401- Spring Wire Properties: The alloy spring Steels have a definite place in the field of spring material, particularly applications where shock or impact loading occurs. Alloy spring steels also can with carbon steels and are obtainable in either the annealed or pre tempered conditions.

Table No 02: Specification of Chrome Silicon

Material Composition	C 0.51-0.59% Cr0.60-0.80% SI 1.20-1.60%
Minimum Tensile Strength (psi × 10^3)	235-300
E- Modulus of Elasticity (psi × 10^6)	30
Design Stress % Minimum Tensile	45
G- Modulus in Torsion (psi × 10^6)	11.5
Maximum Operating Temperature (°F)	475
Rockwell Hardness	C48.55
Density (lb/in^3)	0.284
Shear Modulus (C GPa)	1160080.0

Carbon steel: AISI 1095 Spring Steel- these springs are cold rolled and are available in annealed or tempered conditions. Suited for high stress flat springs and hot coiled rings, AISI 1095 steel is meant for high strength and hardness.

Table No. 03: Specification of Carbon Steel

E Mpa	207,000	Min Size (in)	0.003
E psi	30,000,000	Max Size (in)	0.125
G Mpa	79,300	Min Size (mm)	0.080
G psi	11,500,000	Max Size (in)	3.000
Density g/cm3	7.860	Surface Min	Maximum defect depth: 0 to 0.5%
Density lb/in3	0.284	Max Temp °C	120
Conductivity	7	Max Temp °F	250

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Stainless steel: NiCr A286 Spring – Good corrosion resistance at elevated temperatures. A Nickel-Chromium alloy with the addition of aluminum to give outstanding resistance to oxidation and other forms of high temperature corrosion with the ability to maintain high mechanical properties at elevated temperatures.

Table No 04: Specification of Stainless steel

E Mpa	200,000	Min Size (in)	0.016
E psi	29,000,000	Max Size (in)	0.200
G Mpa	71,700	Min Size (mm)	0.400
G psi	10,400,000	Max Size (in)	5.000
Density g/cm3	8.030	Surface Min	b
Density lb/in3	0.290	Max Temp °C	510
Conductivity	2	Max Temp °F	950

Table No 05: Specification of Stainless steel

Property	Imperial	Metric
Ultimate Tensile Strength	89,000 psi	620 MPa
Yield Strength	39,900 psi	275 MPa
Elongation at reak	40%	40%
Modulus of Elasticity	29,200 ksi	201 GPa
Poisson's Ratio	0.3	0.3
Shear Modulus	11,200 ksi	77 GPa
Reduction of Area	20%	20%
Elongation in 4D	15%	15%

In this work – Material Comparison of Aluminium 7005 and Magnesium is done since these Materials are selected because it has lower mass density compared to steels and cast irons also Proposes equivalent strength with the steel alloys. Major goal of this work is to minimize the mass condition from the purposed design.

Table No 06: Specification of Aluminium 7005 and Magnesium alloy

Sr. No.	**Specifications**	**Aluminium 7005**	**Magnesium alloy**
01	Density	2.8 g/cm^3	1.80 g/cm^3
02	Elastic modulus	80 GPa	44.8 GPa
03	Poisson's Ratio	0.33	0.35
04	Thermal Conductivity	166 w/mK	76 w/mK

VI. DESIGN OF THE MAGNETIC SUSPENSION SPRING

The spring is mounted in between two magnets to avoid impact of magnets. The outer diameter of spring can be selected considering the clearance between casing diameter and spring which avoid jam of spring.
Outer diameter of the spring D_0 = 48mm
As per design data book for cold drawn wire steel wire diameter d = 6 mm,
Inner diameter of spring, Di = 48-12 = 36 mm
Calculating the load bearing capacity of spring for any service life,
Spring index C= Do/d = 48/6 =8
Then Wahl factor of spring, K= (4C-1)/(4C-4) +0.615/C
For C =8, K= 1.18, Now to Find load holding by spring P,
Shear stress = k (8PC/(d2)), P = 618:47N
Thus, spring hold the load of 708.54 N remaining load is absorbed by magnet.
Deflection of spring (δ) can calculate by, δ = (8PD3N) =(Gd4) = 56:04mm
Spring rate P= 11N/mm, Spring stiffness K = 11N/mm, Number of turns N = 17
As spring has square and ground ends number of Inactive turns = 2
Total number of turns, N= 17
Free length of spring, L_f = solid length + deflection + axial gap = 55 + 56 + 0.15(56) = 120mm:
Pitch of spring = 13.33mm

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VII. DESIGN OF MAGNET

Power Magnet Pair =**10,000GP** (Gauss Power)
Weight Vehicle Body =110kg = 1080N
Weight of Person Sitting on Vehicle = 140kg =1374N
Total Load = Weight Vehicle Body + Weight of Person Sitting on Vehicle =1080+1374
Total Load =2454 N
Rear Suspension = 65percentage2454 =1595.1 N
Considering Dynamic Loads Double (W)= 1595.12 × 2 = 3190.2 N
For Single Shock Absorber Weight (W/2) = 3190.1/2 = 1595.1 N
Taking Factor of Safety = 1.2, Design Load = (W/2) × 1.2 = 1595.1 × 1.2 =1914.12N
Magnetic Power Per Unit Area =2N/mm2
Area Required for Suspension of 300kg load = 1914.12=A , A = 957.06mm^2
A = 4d^2 , 957.06 =4d^2 , d = 34.90mm35mm , **d = 35mm**
Diameter of magnet = 35mm.

VIII. ANALYSIS OF MAGNETIC SUSPENSION SYSTEM

Iteration 1 – Without magnetic pull force Spring Material (Chrome Silicon ASTM A401)

Figure No 5: Meshing [Nodes-33912, Elements -13393]

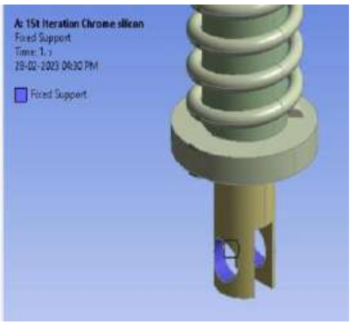

Figure No 6: Fixed Support

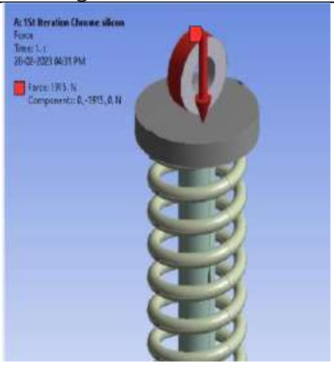

Figure No. 07: Loading Conditions

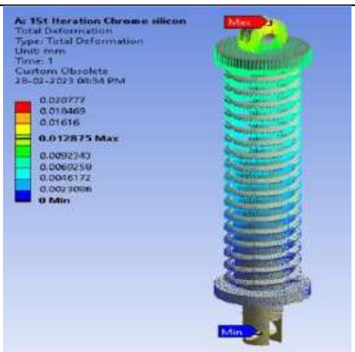

Figure No 08: Total Deformation

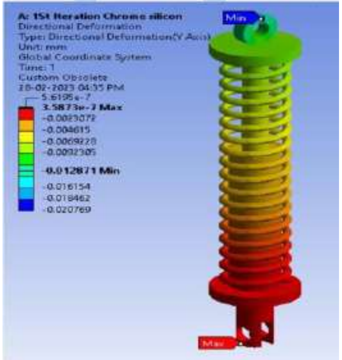

Figure No 09: Directional Deformation

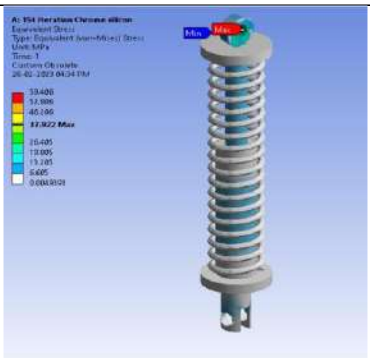

Figure No 10: Stress factors of the product

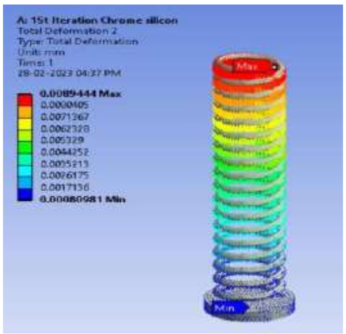

Figure No 11: Total deformation and Stress Factors of the spring Without magnetic pull force

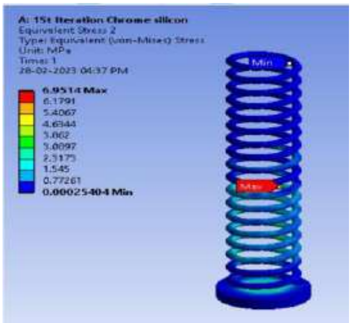

Figure No 12: Total deformation and Stress Factors of the spring Without magnetic pull

Iteration 2 – With magnetic pull force (300N) Spring Material (Chrome Silicon ASTM A401)

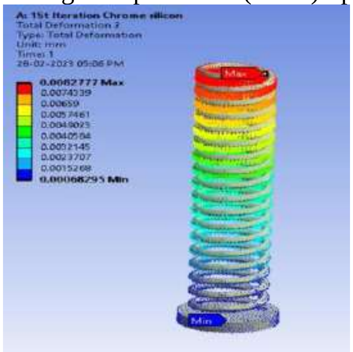

Figure No 13: Total deformation & Stress Factors of the spring with magnetic pull force

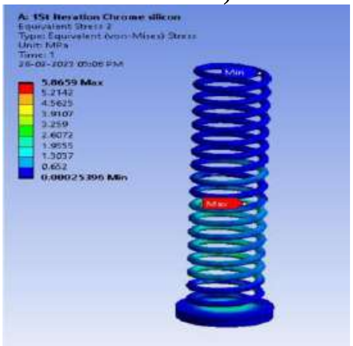

Figure No 14: Total deformation & Stress Factors of the spring with magnetic pull force

Iteration 3 – Material AISI 1095 Carbon Steel for spring

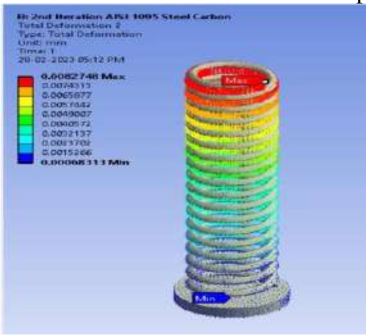

Figure No 15: Total deformation & Stress Factors of spring part for Carbon steel AISI 1095

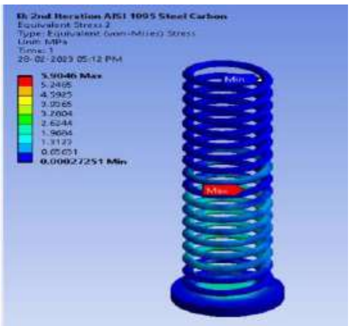

Figure No 16: Total deformation and Stress Factors of the spring part for Carbon steel AISI 1095

Iteration 4 – Material NiCr A286 Spring

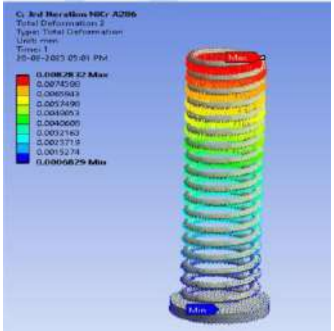

Figure No 17: Total deformation

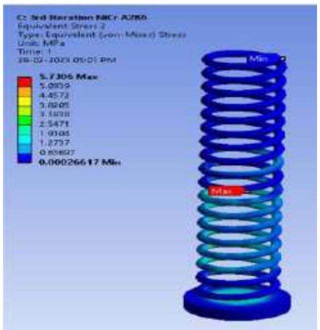

Figure No 18: Stress Factors of the spring part for NiCr

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Iteration 5 – Magnesium alloy

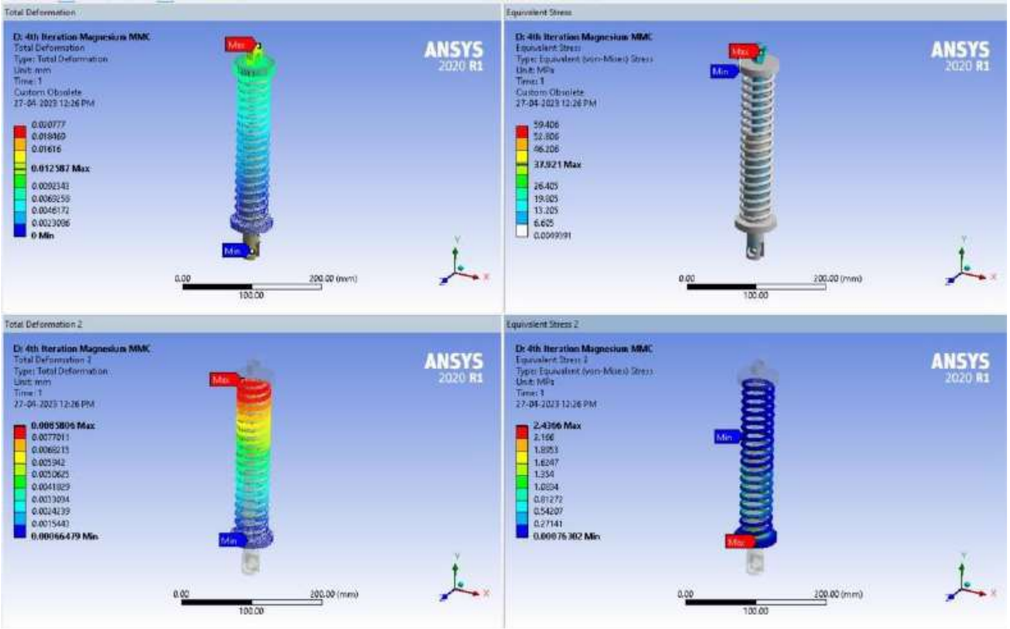

Figure No 19: Total deformation and Stress Factors of the spring part for Magnesium alloy

Iteration 6 –Aluminium

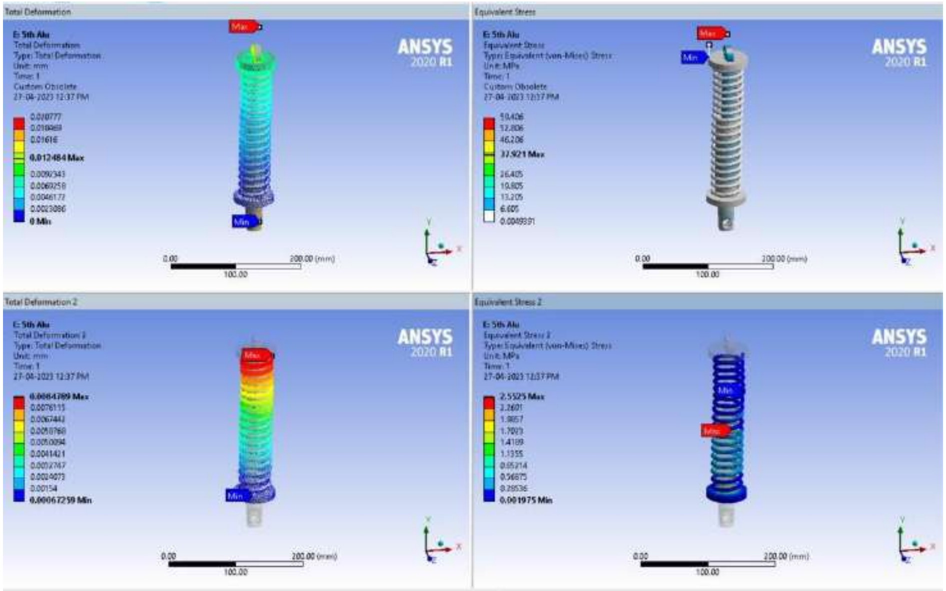

Figure No 20: Total deformation and Stress Factors of the spring part for Aluminum 7005

Loading condition F1 - 5000000 N
Opposite pull Force of Magnet F2 - 300 N
Maximum Stress on the part body - 59.406 MPa
Maximum deflection on the spring body - 24.008 mm = 2.4 cm
Maximum Stress on the Spring body - 7900.9 MPa
Spring Stress can be neglected because of its shock absorption condition.

Iteration 7 - Material Aluminium 7005

Explicit dynamics is a time integration method used to perform dynamic simulations when speed is important. Explicit dynamics account for quickly changing conditions or discontinuous events, such as free falls, high-speed impacts, and applied loads. Because these nonlinear dynamics are integrated into the simulation, explicit dynamics is the preferred choice for simulating highly transient physical phenomena.

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Figure No 21: Total deformation and Stress Factors of the spring part for Aluminum 700

This the maximum shock loading applying on the spring to deflect for 2.5 cm.

Iteration 7 - Explicit dynamics

Explicit dynamics Boundaries condition - Moving vehicle Speed 50km/Hr.*e10-3
Solving time - 10e-6
Displacement - Piston part body - Z axis free
Load maximum - -1915 N

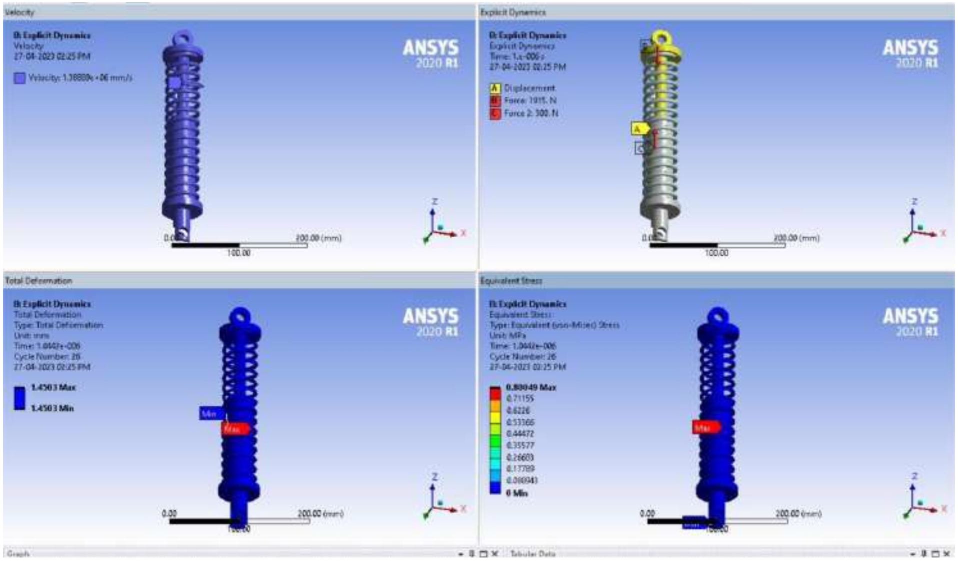

Figure No 22: Deformational results.

IX. RESULTS

Table No 06: Result Comparison of Suspension spring with different Boundary Condition

Sr. No	Analysis Type	Material	Deformation in mm	Stress in Mpa
1.	Without Pulling Force	Chrome Silicon A 401	0.0089444	6.9514
2.	With Pulling Force 300N	Chrome Silicon A 401	0.0082777	5.8695
3.	With Pulling Force 300N	Carbon steel AISI 1095	0.0082748	5.9046
4.	With Pulling Force 300N	NiCr A286	0.0082832	5.7306
5.	With Pulling Force 300N	Magnesium	0.008580	2.4366
6.	With Pulling Force 300N	Aluminium	0.00847	2.5525

7.	Maximum loading	Aluminium	24.08	7900.9
8.	Explicit dynamics	Aluminium	1.4325	-

X. CONCLUSION

This present work deals with design and analysis of a magnetic suspension system which can be used to study the deformational changes in spring behaviour during road bumps. A magnetic suspension system is designed and modelled using CATIA V5 software. Stress and deformation analysis is done using ANSYS workbench. About 15.564 % of stress is reduced with the help of magnetic pulling force compared to normal one. The suspension spring material comparison was done with different types of materials such as Chrome Silicon A 401, Carbon steel AISI 1095, NiCr A286, Magnesium & Aluminium 7005. In comparison with other materials, Magnesium and Aluminium have a lower stress factor under compression loading conditions in comparison to other materials. The maximum stress induced in aluminium material was found to be 7900 MPa. The minimum stress was found in magnesium material and its value is 2.43 MPa. By observing the results of all materials it can be concluded that carbon steel spring material is found to be best fitted for suspension system

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