Design and Experimental Analysis of Electromagnetic Suspension System

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***Abstract*-Vehicle suspension systems have been extensively explored in the past decades, contributing to ride comfort, handling and safety improvements. The new generation of powertrain and propulsion systems, as a new trend in modern vehicles, poses significant challenges to suspension system design. Consequently, novel suspension concepts are required, not only to improve the vehicle's dynamic performance, but also to enhance the fuel economy by utilizing regeneration functions. However, the development of new-generation suspension systems necessitates advanced suspension components, such as springs and dampers. The ultimate goal of this project is to conduct feasibility study of the development of electromagnetic dampers for automotive suspension system applications. The proposed electromagnetic damper has energy harvesting capability. Unlike commercial passive/semi-active dampers that convert the vibration kinetic energy into heat, the dissipated energy in electromagnetic dampers can be regenerated as useful electrical energy.**

I.INTRODUCTION

Suspension systems, in the automotive application context, are designed to maintain contact between a vehicles tires and the road, and to isolate the frame of the vehicle from road Variation. Dampers, or shock absorbers, as the undeniable heart of suspension systems, reduce the effect of a sudden bump by smoothing out the shock. In most shock absorbers, the energy is converted into heat through the help of viscous fluid. In hydraulic cylinders, the hydraulic fluid is heated up due to the movement. In air cylinders, the hot air is emitted into the atmosphere by means of vent. There are several approaches for shock absorption, including material hysteresis, dry friction, fluid friction, compression of gas, and eddy currents.

In the past years, improvements in power electronics and magnetic materials have resulted in significant improvements in electro-mechanical devices, reducing their volume, weight, and cost, and improving their overall efficiency and reliability. These developments satisfy an analysis and implementation of electromagnetic devices in suspension systems. In most dampers, the energy is converted into heat and dissipated without being used, in electromagnetic suspension; the dissipated energy can be stored as electrical energy and used later. The use of electromagnetic dampers in suspension systems has benefits compared to hydraulic, pneumatic, or other mechanical dampers. Electromagnetic dampers can function as sensors and actuators. The spring effect can be added to the system by means of electromagnets, powered by Permanent Magnets (PMs). Moreover, electromagnetic suspension can work under very low static friction. Here, the damping effect is controlled rapidly and reliably through electrical manipulations.

Active suspensions have superb performance; they have high energy consumption, are not fail-safe in case of power failure, and are heavy and expensive compared to conventional variable dampers, using other technologies such as electromagnetic-valve and Magneto-Rheological (MR) fluid dampers.

II.SUSPENSION ANALYSIS

Nonlinear control for electromagnetic suspension systems on elastic guideway guowen dai, yougang sun, dashan dong and haiyan qiang: In this paper, a nonlinear mathematical model and novel control method have been presented for the nonlinear EMS system with flexible guide way. The open-loop instability of the coupling system has been proved by Hurwitz stability criterion. The vibration of guide way is introduced into the control system and the simulation results have been presented to demonstrate that the designed controller can not only ensure the electromagnet suspend steadily , but also eliminate the vibration of guide way, which means a lower request for the quality of guide way in maglev lines and the lower construction cost. Furthermore, future efforts will be directed at applying the proposed control strategy to the practice.

Air Gap Control Simulation of Maglev Vehicles with Feedback Control System Ki-Jung Kim1 , Hyung-Suk Han2 and Seok-Jo Yang: It is confirmed that the proposed air gap simulation model including all the mechanical and electrical components well represents the actual magnetic train under consideration. With the model, peak variation of air gaps, at maximum speed of 110km/h, are predicted to see whether exceeds the allowed deviation, ±3mm. It can be noted that the resulting air gap deviations obtained by simulations are within ±3mm, which means the magnetic train could run without physical contact up to 110km/h. The model providing more realistic air gap simulation could be employed to optimize the magnetic train system

Bose Automotive Suspension, Rakshith M, Yathin Kumar L, Vikas S. G: Active suspension offers many benefits over conventional and semi-active suspension systems. Electromagnetic suspension is a high bandwidth and efficient solution for improving handling and comfort. Direct drive tubular permanent magnet actuator technology with integrated damping offers a high force density and fail-safe solution. In-lab and on-road experimental verification proved the performance and efficiency of the proposed solution.

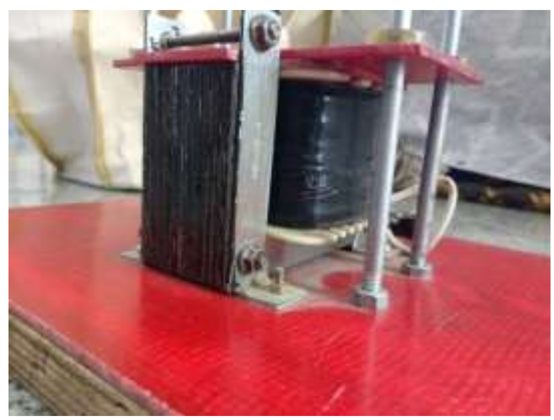
The Simulation of Electromagnetic Suspension System Based on the Finite Element Analysis, Zhengfeng Ming, Tao Wen and Tuo Chen: This paper analyzes the electromagnetic field of mixed suspension electromagnet with finite element analysis method. We model and analyze the suspension electromagnet to study the relationship between the electromagnetic force, current, and suspension gap. Then, the change law of the electromagnetic force with horizontal offset electromagnetic field is also studied. Then the calculated dates are fitted by the least square method. Finally, we compare the fitting formula with the theory one. These results lay the foundation for the further experimental study.

Experimental investigation of magnetic suspension system, manish k. Mistry1, rana hiteshkumar c: It is observed that vertical acceleration of upper-mount is less with respect to lower-mount when electromagnets are active as compared to the case in which electromagnets are not active. So, it is concluded that vertical acceleration of sprung mass is reduced and comfort is improved by using purposed magnetic suspension system.

III. EXPERIMENTAL

The suspension system is used to provide a good quality ride and better comfort. This is done by absorbing the vibration of vehicle which comes from the road due to uneven road or pot holes etc., the vibration which the vehicle take through the wheel goes to the chassis. In between the chassis and the wheel there is a system which tries to absorb these vibrations and are called suspension system.The suspension system, now days consist of a damper system which includes a spring and oil which provides the necessary damping action. This suspension is cheap and can be easily found in the market and very much easy to install in the vehicles. The necessary damping is provided by fluid and spring which take almost all the vibration from the vehicle. This damper system has to be tuned in order to provide a good ride quality. While tuning it has to be tuned such as it should give better ride handling and comfort. While doing so this damper system has to make a compromise between these comfort and ride quality. If the damper system is tuned to comfort then the ride quality would be poor and if it is tuned to ride quality then the comfort would come down. So due to this a compromised tuning is to be done so that the vehicle could be used better.To overcome this problem several different types of suspension came in to existence, like hydraulics, pneumatics etc. In hydraulics hydraulic fluid is used and in pneumatic pressurized air is used to have the result. Among all this there is another suspension system which uses magnetism which is known as electromagnetic damper system.

DevelopmentElectromagnet: Electromagnets are a type of magnet which has magnetic property as same as of a magnet. The difference between the magnet and electromagnet is that we can switch it on whenever we want the flux and vary according to the requirement in the electromagnet but the same is not possible in magnet. The varying magnetic flux makes it best for such type of damper system.



Electromagnet made up of Transformer

The electromagnet made in this project was from a transformer. The transformer was from 440V stabilizer, which is used by Television, refrigerator, audio amplifiers etc. the transformer from stabilizer was taken out, and then it was broken down to remove the plates which were reinserted in them. They had E type plate which was better used for usual conduction between the wires and the core. The plates were placed opposite to each other completing two rectangles and small plates for the supports. The plates were removed by care and the wire which was wrapped was taken out known as the bobbins. The bobbins were winded up with different types of wires as it was required for the mutual conduction purpose for the transformer. The insulated wire was removed from it and the bobbins were taken out of it. Later the transformer plate which was of E type were assembled and placed as show in the fig. first when they were in the transformer they placed opposite to each other, but for electromagnetic property they are placed in the same E position (all facing in the same direction). The middle part of the E is main part as the flux originates from that point.The bobbins then it were took and wrapped with wires or winding was done on to it. The winding wire was of 36 gauges, it was a thin wire which should be taken care of while winding and it is weak and could break easily. As per the electromagnetic theory, more the turn more the amount of flux and more the current more the amount of power. So keeping this in mind the wire was wrapped around the bobbins for 1.5 ohms, but doing so reduced the amount of the current the conductor can take in, so a new idea was too developed. The winding had all the thing to do with the electromagnet, keeping in mind the number of turns and current rating of the conductor, the wire was wrapped around the bobbin in 10 different phase, each phase was of 100 ohms, the amount current flowing in these wire was enough for current rating. All the 10 phases were soldered at both the ends. The amount of current flowing through the phases was added up to final calculation. Now the number of turns as well as the current rating was good to get and appropriate lift of the weight. After this the electromagnet was wrapped with paper which was done to protect the winding from external surface erosion or to prevent the winding from getting damaged by external sources, a little amount of fluid is also used to hold the wire together. Then the contact pair had to be made, the soldered wire was taken out and it was connected to the contact pins for external connection. The plates of electromagnet were tightening up with the help of a nut and bolt, for proper mutual conduction it was necessary to hold the plates together tightly so that the electron in conductor could pass through easily.

Electromagnet Fixed to the Base

Development of base: For proper working of this magnetic suspension a base is needed which was the necessary part of the project. The electromagnet was placed on this base. The base was drilled by a 6mm drill so as to fit a 6mm bolt, which is fitted tight with help of nut. The bolt is used as guidance for suspension system to go up and down. The bolt was fitted with nut at the top so that the suspension should not fly off because of magnetic field.

Base made up of Wood for Experimental Purpose

Development of guidance mechanism: As the suspension should go only up and down there is need to prepare a proper guidance mechanism to guide the damper system up and down and not deviate from the line of force acting on the magnet. The guiding of the magnet was done by the four bolts. These four bolts were tightening at the bottom with the nut. This bolt had to straight throughout the length and had to be equally spaced o that the guidance could go in a line. To do this a plate was fixed at the bottom which would hold these four bolts, and another plate with same dimension was used to be fixed at the top to support the bolt and to keep in a straight line, and to keep them equally spaced.

Guidance Mechanism using Four Bolts (Bottom)

Guidance Mechanisms (Top)

Fixation of Magnet to the plate: The magnet had to be fixed to the movable plate, to fix the magnet a plate was taken and drilled with four holes, so that it goes smooth in a line with the guidance bolt, once it is done, again a small holes are drilled at the center of the plate, and two holding material are taken which are screwed to the small holes. The magnet is placed between them and the magnet is held tight. The face of the plate which contain magnet is exposed to the electromagnet, because as distance increases the between the magnet and the electromagnet, weaker will be the force.

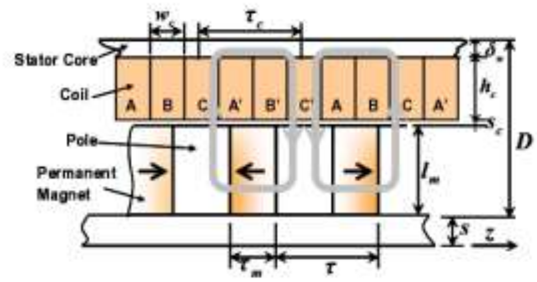
Fixation of Magnet

Working of the suspension system: Once all the required things are ready, the model is put into used and it is tested for the optimum result. The working of the modeled is explained below. The electromagnet is at the bottom of the setup, it is bolted to the base and it is fixed to it, the electromagnet is the stationary member in this setup and the magnet is movable. The current coming to the electromagnet should be direct current, so that the current flows through the conductor are in one direction and a single pole is developed at the electromagnet. The pole at the electromagnet is the most important one, the pole at the electromagnet should be the one which is at the bottom of the magnet, if this situation occurs then and only then the magnet will repel the electromagnet and can carry the weight. If the three are opposite poles at the electromagnet and the magnet then there will be an attractive force which can be of no use. And instead to carry weight the magnet will stick to the electromagnet, which is undesirable. The current in the electromagnet can be changed if we reverse the direction of flow of current. Reversing the current is an easy task the connection from the supply has to be interchanged. Changing the current direction in the loop changes the pole at the surface of the electromagnet. This can be done to check which pole is at the top of electromagnet so as to change the current and make the magnet to repel the electromagnet. As the power supply is given to the electromagnet the poles are created and the pole at the magnet repel the electromagnetic field create by it, and a lift is observed which is guided by the bolts. Now the lift is govern by the amount of current coming to electromagnet and the amount magnetism produced by the electromagnet or flux production. For a definite amount of electron flow there is a certain amount of lift observed, as the current increase in the conductor the lift increases. The same can be used to change the current in the field, to determine the lift of the vehicle from the ground clearance or increasing the ground clearance of the vehicle. More the current in the conductor stronger the magnetic field will be and lift will be high enough and can carry more amount of the load. This can used in the vehicle and can be used as the damper system.The downward force of vehicle is taken by the magnet and equal amount of upward force is produced by both the magnet and the electromagnet, which level the vehicle giving a comfortable ride and good quality handling. The movement of the vehicle can be sensed by the sensor which can be used as input signal to determine the amount of current to the electromagnet should get to list the required amount of load and to absorb the vibration from the road which comes from the road to the wheel. With good quality of magnets and précises design of the electromagnet, the same concept can be used to change the ride height of the vehicle, which will allow the vehicle to change according to the road condition.The development of this concept can change the suspension system in the automobile sector.

Assembled Electromagnetic Damper

IV.RESULTS

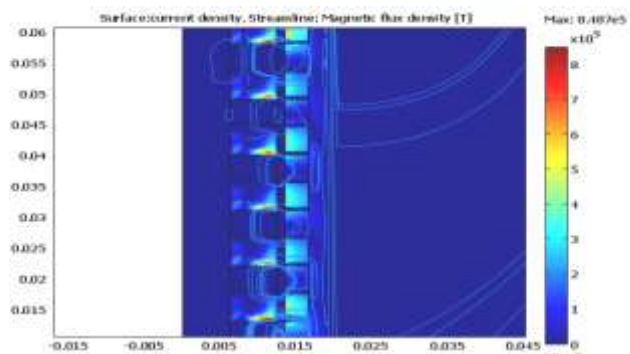
Placement of component:



Sketch of the Slot Less, Tubular, Linear Interior PM Motor

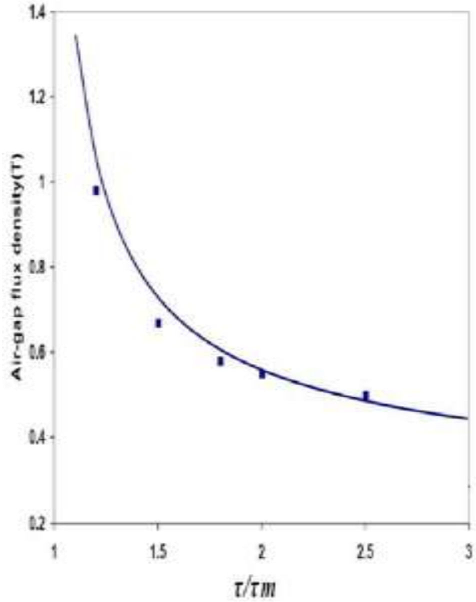
The analysis of the above electromagnetic damper system is done and result are obtained, in doing so, a software is used which is comsol 3.0. The analysis report is shown below and magnetic field around the magnet is shown in the below analysis report.

Analysis Report:



Magnetic Field Streamlines of a 2D Generated Model using Comsol 3.3

The below graph shows the comparison between the analytical and finite element result, the result shows the magnetic flux at the air gap which deviates slightly from the analytical result which is so small that it can be considered almost to be the same.



Comparisons of the Analytical and Finite Eelement Results for the Air Gap Magnetic Flux Density

Specification: The specification of the electromagnetic damper system is given below; the required specification is hold good as compared to the finite element result and analytical results.

Quantity	Value (Unit)
Peak Force	1200 N
Overall Length	350 mm
Max. Diameter	120 mm
Weight	11.8 kg
Max. Stroke	160 mm

Final Specs of Electromagnetic Suspension System

V.CONCLUSION

In this report, the concept of the Electromagnetic Damper system is introduced and the design procedure for an active stand-alone Electromagnetic Damper for a suspension system is presented in this chapter. Among various potential technologies, the linear motor concept is chosen. Several design approaches are considered, and a tubular, interior, slotless Permanent Magnet motor is selected to achieve greater efficiency and simple in manufacturing. An analytical approach based on magnetic circuit principles, is employed for the initial design of a working model Electromagnetic Damper, and non-dimensional, geometrical design parameters are optimized to obtain the highest damping coefficient in the passive mode. Next, the Finite Element approach is used to validate the analytical method, which confirms the consistent results for the air-gap magnetic flux density. After a prototype Electromagnetic Damper is fabricated, experiments are carried out to verify and check the numerical model for the induced emf in each stator coil.

Finally, an active full-scale ED for an automotive suspension application is designed, and the maximum achievable damping coefficient and force in the semi-active and active modes are found out. The key non-dimensional parameters for the design of the ED are described to achieve the highest force/weight ratio. Finite Element analysis is coupled with analytical models to estimate/simulate the real size damper performance. The design procedure presented is based on an analytical model, while the Finite Element technique is utilized at some stages to guarantee the modeling accuracy, enhancing the simulation and correction. A good agreement between the results of the analytical model with data obtained from Finite Element analysis is recognized, comparing the magnetic field quantities. The final specifications of the designed Electromagnetic suspension are listed in Table. According to the required specifications listed in Table, the geometry and force requirements are satisfied with the proposed design. Also, the mechanical time-constant around 3 micro second is much less than that of semi-active dampers.

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