ELECTRO-MAGNETIC SUSPESION SYSTEM FOR VEHICLES

A thesis submitted to the department of Mechanical and Chemical Engineering (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering.

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This is to certify that the work presented in this thesis is an outcome of the analysis, simulation and research carried out by the author under the watchful supervision of Dr. Md. Zahid Hossain.

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Kazi Moshiur Rahman

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ABSTRACT

A conceptual model of electro-magnetic suspension system is presented. The goal is to provide better performance and smooth operation than the conventional one. Two electro-magnets are used to use the repulsive force to withstand and suspend the vehicle and riders loads. The system is set up on the basis of simple magnetic principal that same poles repeal each other while opposite poles attract each other. Two electro-magnets have been set up facing same poles. They were allowed to slide up and down along a guide. Electricity has been supplied to the electro-magnets to magnetize them. While being magnetized, they tend to repel each other. Then, measured small cumulative masses have been added on top of the upper magnet. By doing this, maximum force generated by the electromagnets has been measured. The force generated is also measured by Simulation tool ANSYS. Then both the experimental results and simulated results have been compared.

CHAPTER ONE

Suspension System

1.1.Suspension System Fundamentals:

Suspension system of any vehicle is the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. It isolates the body from road shocks and vibrations which would otherwise be transferred to the passengers and load. When a tire hits an obstruction, there is a reaction force. Suspension system Provides the car's road holding and braking for safety in this situation and ensures passengers comfort.

1.2.Types of Conventional Suspension System:

The suspension system used today are basically of two types:

Coil Spring Suspension System: Coil spring, a mechanical device, which is typically used to store energy and subsequently release it, to absorb shock, or to maintain a force between contacting surfaces. They are made of an elastic material formed into the shape of a helix which returns to its natural length when unloaded.

Coil springs are a special type of torsion spring: the material of the spring acts in torsion when the spring is compressed or extended.

Metal coil springs are made by winding a wire around a shaped former - a cylinder is used to form cylindrical coil springs.

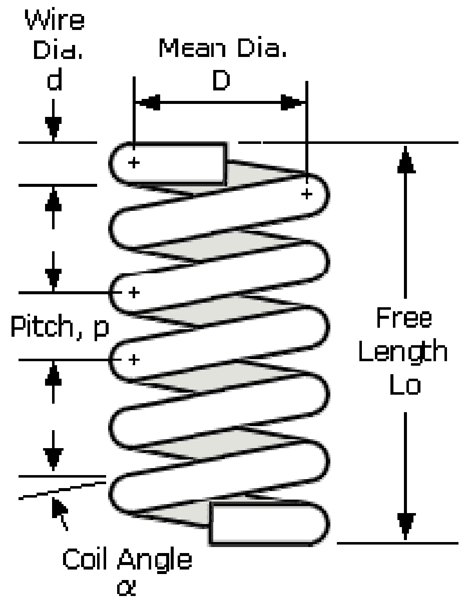

Figure 1: Coil Spring

Leaf Spring Suspension System: Originally called *laminated* or *carriage spring*, a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It consists of several layers metal called “leaves” bound together to act as a single unit. An advantage of a leaf spring over a helical spring is that the end of the leaf spring may be guided along a definite path.Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end.

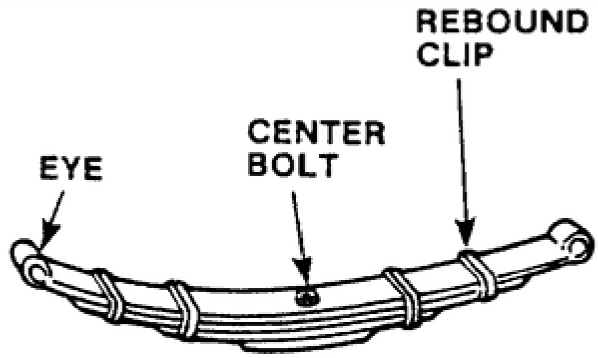

Figure 2:Leaf Spring

1.3.Dampers:Shock Absorbers:

Unless a damping structure is present,a car spring will extend and release energy it absorbs from a bump at an uncontrolled rate.The spring will continue to bounce at its natural frequency until all the energy originally put into it is used up.A suspension built on springs alone would make for an extremely bouncy ride and depending on the terrain , an uncontrollable car.So a shock absorber is used which slows down and reduce the magnitude of vibratory motions by turning the kinetic energy of suspension movement into heat energy that is dissipated through hydraulic fluid.

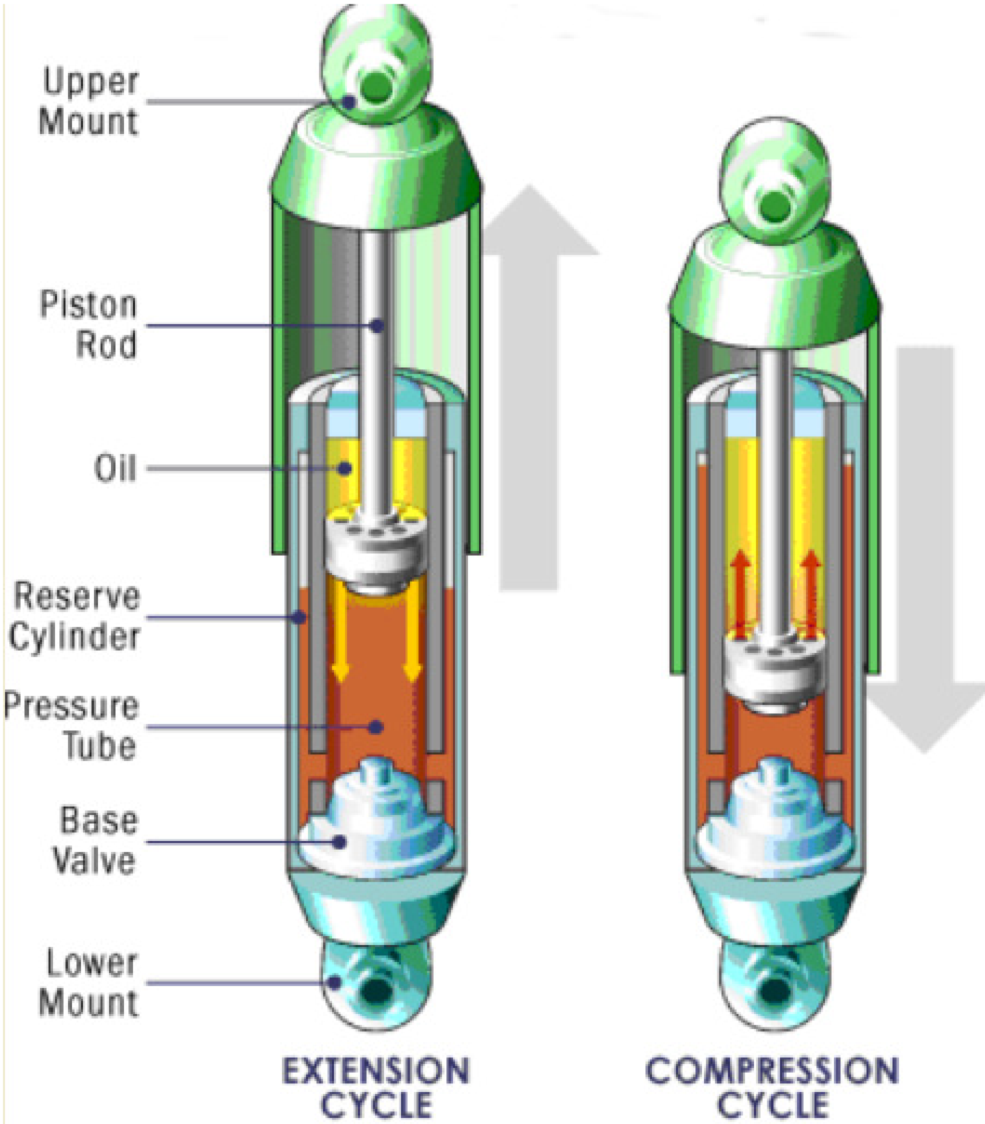

Figure 3: Shock Absorber

CHAPTER TWO

Electromagnetic Suspension System

2.1.Electromagnetic Suspension:

Electromagnetic Suspension is not widely in use. It is used only in precision sports cars like Audi TT, Ferrari Enzo etc. Ferromagnetic fluid is used in these cases which might Detroit under frequent magnetization and de-magnetization. The proposed model here eliminates the use of ferromagnetic fluids which is less complex to use.

2.2.Audi Magnetic Ride-Operating Principles:

Electromagnetic Suspension is used in Audi Magnetic Ride. When the magnetic coils are not activated electrically, the magnetic particles are arranged irregularly in the damper oil. During the piston stroke, the individual particles are forced with the fluid through the piston bores. The particle-laden suspension damping fluid has a low resistance to the movement of the piston. As a result the damping force is low. When the magnetic coil is activated electrically, the magnetic particles are aligned with the magnetic field lines. Thus, long particle chains form in the vicinity of the piston. These particle chains are aligned cross-wise before the fluid enters the piston bores. During the piston stroke, individual particles break up and are forced with the fluid through the piston bores. To "break up" these chains, force must be applied, i.e. work must be done. The resistance which the piston must overcome is greater than in the case of a non-energized magnetic coil, and is dependent on the amount of electrical current and the strength of the magnetic field. This allows greater damping forces to be achieved. The damping function is based on the magneto-rheological effect. The prerequisite for this is the use of a special damping fluid. This magneto-rheological fluid is a suspension consisting of a hydrocarbon based synthetic oil in which soft magnetic particles with a diameter of 3-10 µm are held in suspension. To stabilize the fluid, various additives are added. Applying a magnetic field changes the properties of the magneto-rheological fluid. The magnetic particles are aligned in the direction of the magnetic field lines. This alters the flux voltage of the fluid. [1]

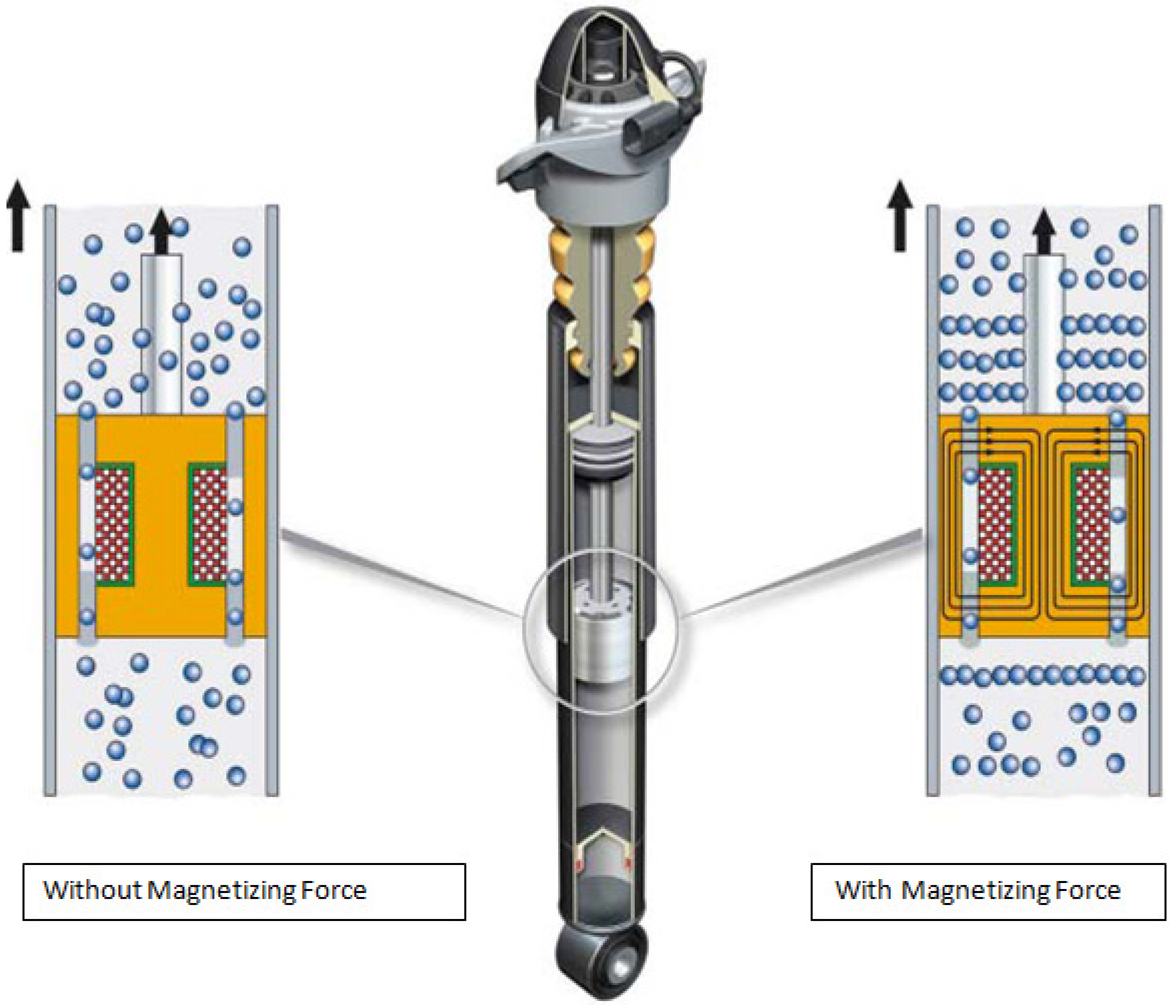

Figure 4: The Suspension System with and without magnetizing force

Ferro Fluids have a limitation.Ferro fluids lose their magnetic properties at sufficiently high temperatures, known as the Curie temperature.

Ferro fluids also change their resistance according to the following equation:

$$\rho = Ve^{-B^2} + p$$

With:

- ρ as the resistance in MΩ
- V as the Vollema Value, different for each ferro fluid,
- B as the strength of the magnetic field in mT,
- p as the Pietrow constant, currently measured at 0.09912 [2]

Hence, A suspension system without usage of ferro fluids might be more efficient.

2.2:Works on Electromagnetic Suspension:

One literature [3] demonstrates the design of magnetic suspension system where experiments carried out for 0.8 kg sphere to levitate 6 cm and PD control has been used to keep its balance. Another literature [4] used the sliding mode control to balance the magnetic force and the steel ball. The literature [5] also levitates a ball but designed three types of levitation control such as Jacobi linearization, feedback linearization and sliding mode control.

This Model introduces the two electro magnetic coils to use the repulsive forces for suspending the upper body. No control is used here and free air environment has been used. The main objective is to find the lifting force consequently the lifting mass can be achieved corresponding to the current density by the simulation tool ANSYS. Then it has been verified and checked by the experiments and tried to check the variations of those results.

CHAPTER THREE

Electromagnetic Theory

3.1.Solenoid:Magnetic Field of an Infinite Solenoid:

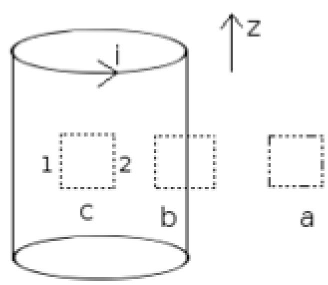

Figure 5:A Solenoid with Three Amperian loops:a,b and c

In short: the magnetic field inside an infinitely long solenoid is homogeneous and its strength does not depend on the distance from the axis, nor on the solenoid cross-sectional area.

This is a derivation of the magnetic flux density around a solenoid that is long enough so that fringe effects can be ignored. In the diagram to the right, we immediately know that the flux density vector points in the positive z direction inside the solenoid, and in the negative z direction outside the solenoid. We see this by applying the right hand grip rule for the field around a wire. If we wrap our right hand around a wire with the thumb pointing in the direction of the current, the curl of the fingers shows how the field behaves. Since we are dealing with a long solenoid, all of the components of the magnetic field not pointing upwards cancel out by symmetry. Outside, a similar cancellation occurs, and the field is only pointing downwards.

Now consider the imaginary loop *c* that is located inside the solenoid. By Ampère's law, we know that the line integral of B (the magnetic flux density vector) around this loop is zero, since it encloses no electrical currents (it can be also assumed that the circuital electric field passing through the loop is constant under such conditions: a constant or constantly changing current through the solenoid). We have shown above that the field is pointing upwards inside the solenoid, so the horizontal portions of loop *c* doesn't contribute anything to the integral. Thus the integral of the up side 1 is equal to the integral of the down side 2. Since we can arbitrarily change the dimensions of the loop and get the same result, the only physical explanation is that the integrands are actually equal, that is, the magnetic field inside the solenoid is radially uniform. Note, though, that nothing prohibits it from varying longitudinally, which in fact it does.

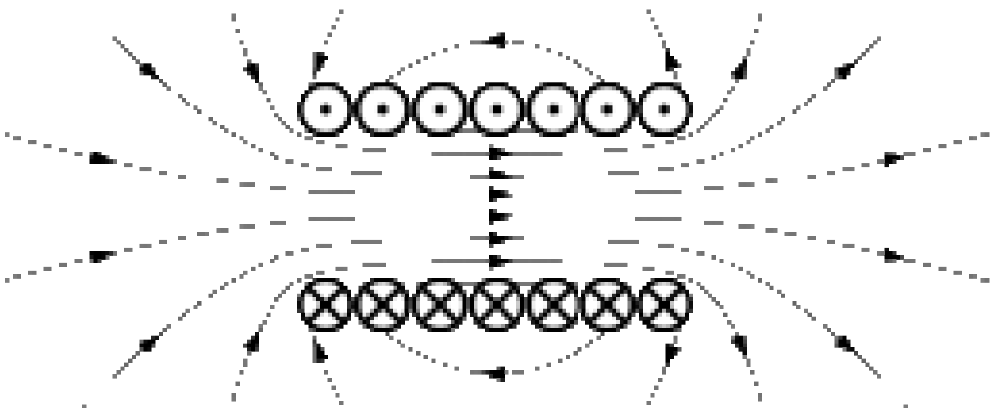

Figure 6:Magnetic Field created by a Solenoid(cross-sectional view)

A similar argument can be applied to the loop *a* to conclude that the field outside the solenoid is radially uniform or constant. This last result, which holds strictly true only near the centre of the solenoid where the field lines are parallel to its length, is important inasmuch as it shows that the flux density outside is practically zero since the radii of the field outside the solenoid will tend to infinity.

An intuitive argument can also be used to show that the flux density outside the solenoid is actually zero. Magnetic field lines only exist as loops, they cannot diverge from or converge to a point like electric field lines can (see Gauss's law for magnetism). The magnetic field lines follow the longitudinal path of the solenoid inside, so they must go in the opposite direction outside of the solenoid so that the lines can form a loop. However, the volume outside the solenoid is much greater than the volume inside, so the density of magnetic field lines outside is greatly reduced. Now recall that the field outside is constant. In order for the total number of field lines to be conserved, the field outside must go to zero as the solenoid gets longer.[6]

3.2.Biot Savart Law:

The Biot–Savart law is used to compute the magnetic field generated by a *steady current*, i.e. a continual flow of charges, for example through a wire, which is constant in time and in which charge is neither building up nor depleting at any point. The equation in SI units is

$$\mathbf{B} = \int \frac{\mu_0}{4\pi} \frac{I d\mathbf{l} \times \hat{\mathbf{r}}}{|r|^2},$$

or, equivalently,

$$\mathbf{B} = \int \frac{\mu_0}{4\pi} \frac{I d\mathbf{l} \times \mathbf{r}}{|r|^3},$$

where

I is the current,

$d\mathbf{l}$ is a vector, whose magnitude is the length of the differential element of the wire, and whose direction is the direction of conventional current,

B is the net magnetic field,

μ_0 is the magnetic constant,

$\hat{\mathbf{r}}$ is the displacement unit vector in the direction pointing from the wire element towards the point at which the field is being computed, and

$\mathbf{r} = r\hat{\mathbf{r}}$ is the full displacement vector from the wire element to the point at which the field is being computed.

The symbols in boldface denote vector quantities.

To apply the equation, you choose a point in space at which you want to compute the magnetic field. Holding that point fixed, you integrate over the path of the current(s) to find the total magnetic field at that point. The application of this law implicitly relies on the superposition principle for magnetic fields, i.e. the fact that the magnetic field is a vector sum of the field created by each infinitesimal section of the wire individually.

The formulations given above work well when the current can be approximated as running through an infinitely-narrow wire. If the current has some thickness, the proper formulation of the Biot–Savart law (again in SI units) is:

$$\mathbf{B} = \int \frac{\mu_0}{4\pi} \frac{(\mathbf{J}\, dV) \times \hat{\mathbf{r}}}{r^2},$$ or (equivalently), $$\mathbf{B} = \int \frac{\mu_0}{4\pi} \frac{(\mathbf{J}\, dV) \times \mathbf{r}}{r^3},$$

where *dV* is the differential element of volume and **J** is the current density vector in that volume.

The Biot–Savart law is fundamental to magnetostatics, playing a similar role to Coulomb's law in electrostatics. When magnetostatics does not apply, the Biot–Savart law should be replaced by Jefimenko's equations.

In the magnetostatic approximation, the magnetic field can be determined if the current density **J** is known:

$$\mathbf{B} = K_m \int \frac{\mathbf{J} \times \hat{\mathbf{r}}}{r^2} dV$$

where:

dV is the differential element of volume.

$K_m = \frac{\mu_0}{4\pi}$ is the magnetic constant

Constant uniform current

In the special case of a constant, uniform current **I**, the magnetic field **B** is

$$\mathbf{B} = K_m I \int \frac{d\mathbf{l} \times \hat{\mathbf{r}}}{r^2}$$

Point charge at constant velocity

In the case of a charged point particle **q** moving at a constant velocity **v**, then Maxwell's equations give the following expression for the electric field and magnetic field:

$$\mathbf{E} = \frac{q}{4\pi\epsilon_0} \frac{1 - v^2/c^2}{(1 - v^2 \sin^2\theta/c^2)^{3/2}} \frac{\hat{\mathbf{r}}}{r^2}$$

$$\mathbf{B} = \mathbf{v} \times \frac{1}{c^2}\mathbf{E}$$

where $\hat{\mathbf{r}}$ is the vector pointing from the current (non-retarded) position of the particle to the point at which the field is being measured, and θ is the angle between $\mathbf{v}$ and $\mathbf{r}$.

When $v^2 \ll c^2$, the electric field and magnetic field can be approximated as

$$\mathbf{E} = \frac{q}{4\pi\epsilon_0} \frac{\hat{\mathbf{r}}}{r^2},$$

$$\mathbf{B} = \frac{\mu_0 q \mathbf{v}}{4\pi} \times \frac{\hat{\mathbf{r}}}{r^2}$$

These equations are called the "Biot–Savart law for a point charge"[5] due to its closely analogous form to the "standard" Biot–Savart law given previously. These equations were first derived by Oliver Heaviside in 1888.[7]

The right hand grip rule:

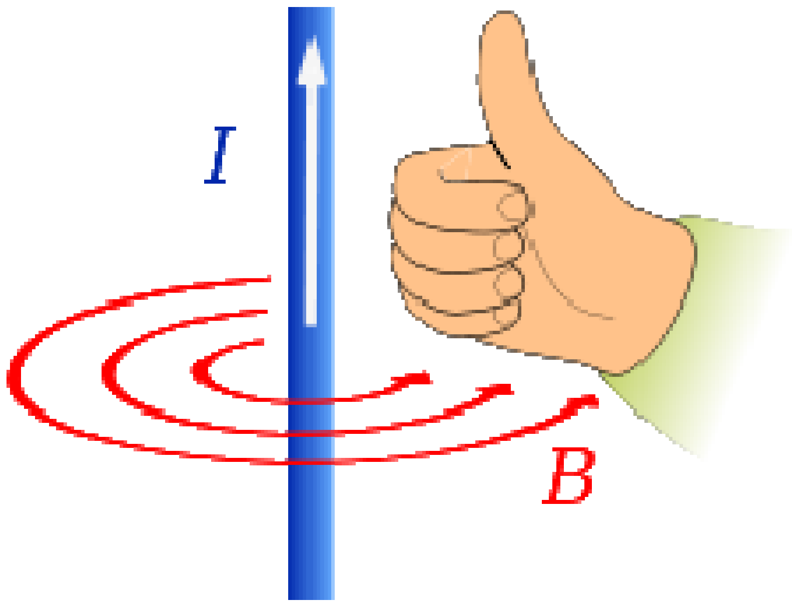

Figure 7:Prediction of direction of field(B),given that the Current I flows in the direction of the Thumb

Figure 8:Right Hand rule as applied to motion produced with screw threads

A different form of the right-hand rule, sometimes called the *right-hand grip rule*, is used in situations where a vector must be assigned to the *rotation* of a body, a magnetic field or a fluid. Alternatively, when a rotation is specified by a vector, and it is necessary to understand the way in which the rotation occurs, the right-hand grip rule is applicable.

This version of the rule is used in two complementary applications of Ampère's circuital law:

1. An electric current passes through a solenoid, resulting in a magnetic field. When you wrap your right hand around the solenoid with your fingers in the direction of the conventional current, your thumb points in the direction of the magnetic north pole.
2. An electric current passes through a straight wire. Here, the thumb points in the direction of the conventional current (from positive to negative), and the fingers point in the direction of the magnetic lines of flux.

The principle is also used to determine the direction of the torque vector. If you grip the imaginary axis of rotation of the rotational force so that your fingers point in the direction of the force, then the extended thumb points in the direction of the torque vector.

The right-hand grip rule is a convention derived from the right-hand rule convention for vectors. When applying the rule to current in a straight wire for example, the direction of the magnetic field (counterclockwise instead of clockwise when viewed from the tip of the thumb) is a result of this convention and not an underlying physical phenomenon.[8]

CHAPTER FOUR

Model and Experimental Setup

4.1.Model:

A conceptual suspension model is shown in Figure:9. Two electromagnets are made by wounding coils on separate bearings. The top portion of the upper bearing is attached to the sprung mass of the vehicle and it can move vertically up and down .The bottom portion of the lower bearing is attached to the sprung mass of the vehicle and it is fixed. A guide is used to control the moving bearings. As the upper bearing suspends due to the two coils' magnetic repulsive forces, the current flow through the coils must be in opposite direction.

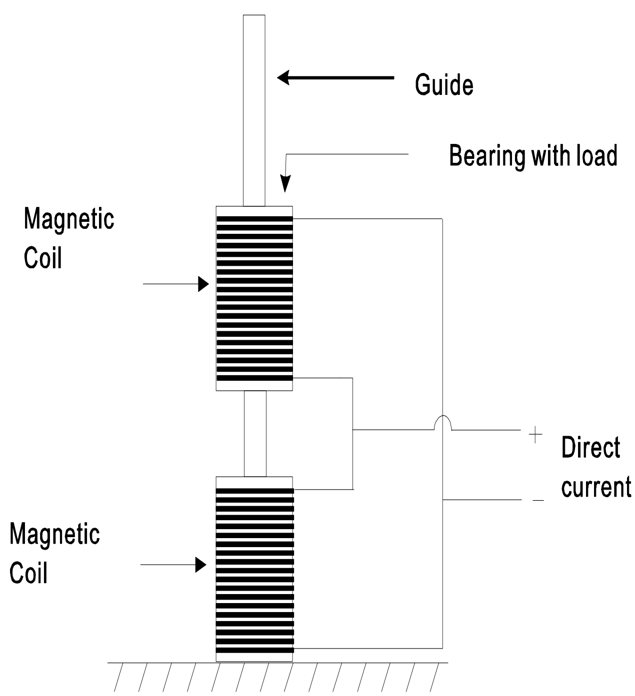

Figure: 9

4.2.Experimental Setup:

Components :

- IKO LBD6 Bearings(outer dia. 14mm)
- Aluminum bar(6mm dia.)
- AWG16 wire(.5mm dia.),350 windings per bearing(approx)
- Power Supply (12 volts,DC)
- Digital Ammeter,Voltmeter
- Power input and output wires
- Cooling Fan

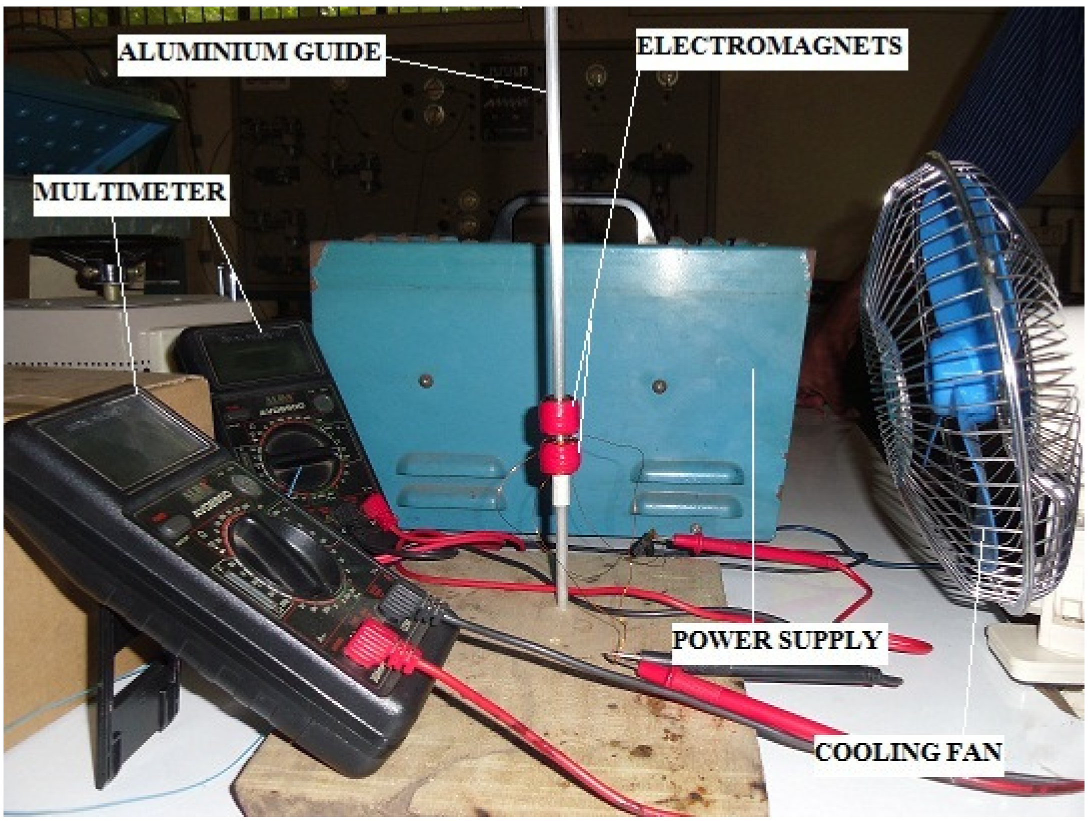

Figure 10:Experimental Setup

CHAPTER FIVE

Simulation by ANSYS

5.1.ANSYS MODEL:

An AZ plane Model has been developed as shown in Figure:11 to demonstrate the same setup for sake of simulation. 50mm air area has been considered around the bearings as the experiment has been done in free air condition. A 2D axisymmetric model has been considered for modeling the suspension system in ANSYS. Plane 53 8 quad node has been used for the simulation. Relative permeability for the air, coil and guide has been taken 1 and for the bearing material is 75. For meshing, element edge length has been taken as 0.25 mm. The air gap between the two bearings is 2mm for this model and this gap has been changed to different value in the simulation and experiments.

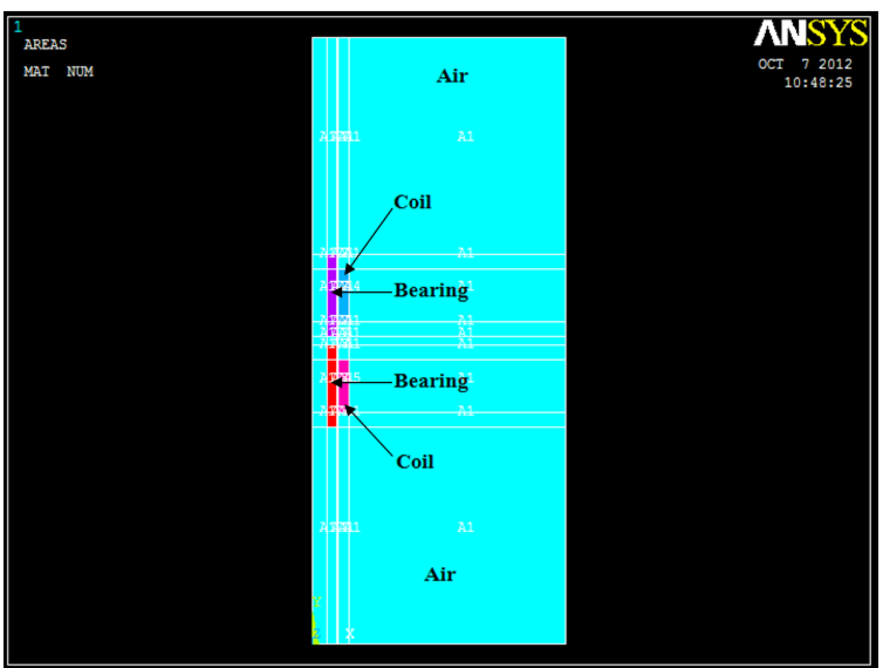

Figure 11: ANSYS Model

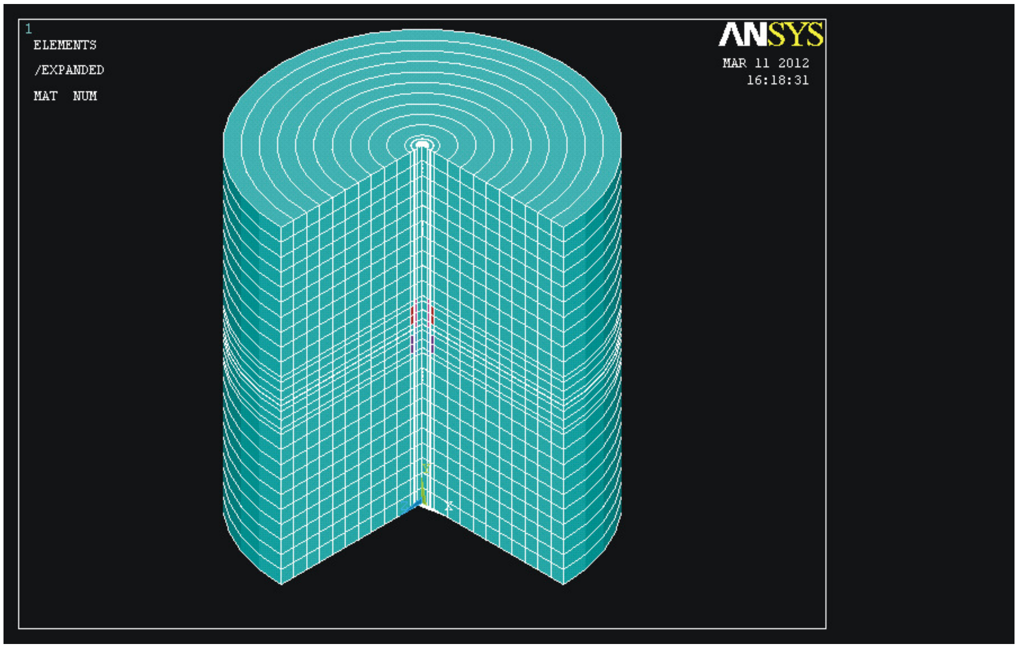

Figure 12: Isometric View

<u>5.2:CURRENT DENSITY AND FORCE</u>: The current density in coil has been calculated by the following formula,

$$J = {ni}/{A}$$

Where J is the current density, n is the number of turns around each bearing, A is the cross sectional area of the coil and i is the amount of current which is considered as a parameter .

The magnetic force has been calculated by Maxwell's stress tensor in Newton which is given by,

$$F = \int (pE + J \times B)dV$$

Where, V , ρ , E and B are the volume, charge density, electric field and magnetic field respectively. Boundary condition has been applied such as the flux lines cannot go beyond the volume of the model.

At the steady state condition of a DC current the force is:

$$F = mg$$

5.3. FLUX LINES AND CONTOUR PLOT:

The Flux lines are shown in Figure: for i =3amp.It's clearly understandable from it that the flux lines of one electromagnet don't go to the region of the other. The contour plot of Flux density in Figure: shows that the maximum flux density occurs at the mid section of the two electromagnets.

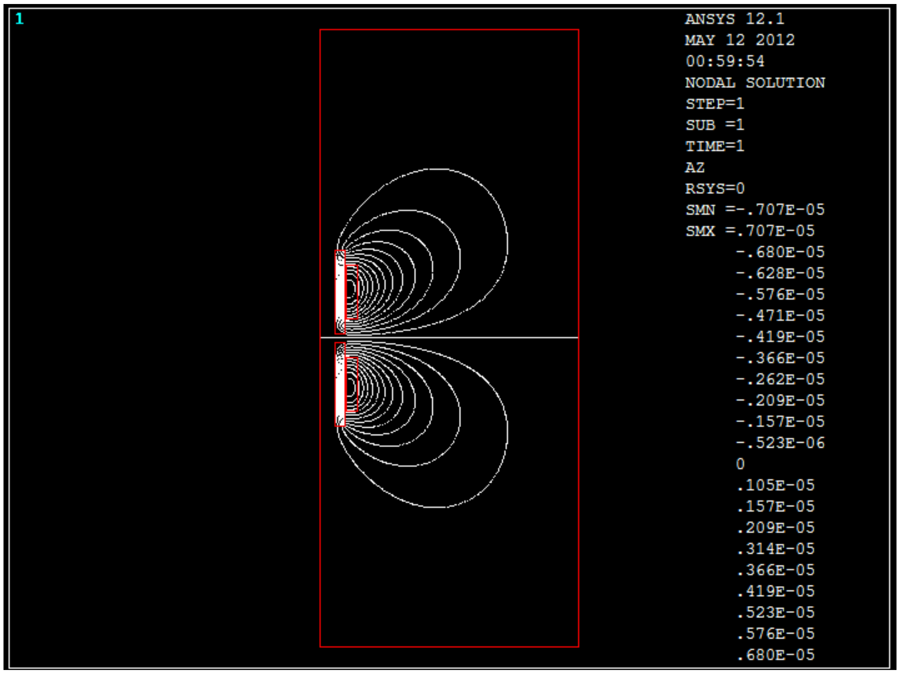

Figure 13:Flux lines around the bearings

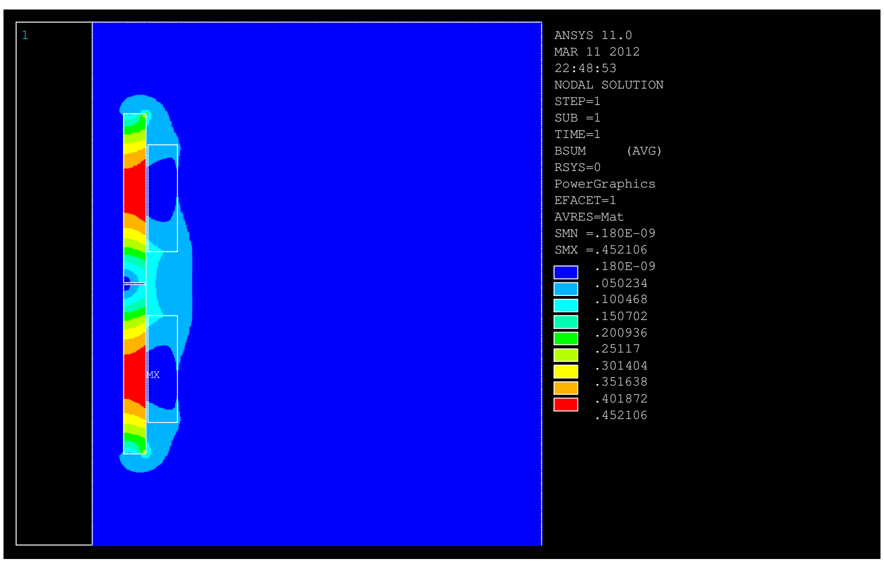

Figure 14:Contour plot of Flux density

CHAPTER SIX

Results by ANSYS and Experiments

6.1.DATA TABLE:

The force in terms of Lifting mass is calculated by ANSYS and Experiments for various current inputs and air gap between the two bearings.It is shown in the Following Table.

Air gap Between the two bearings(mm)	ANSYS			Experiment		Deviation of Experiment from Simulation (%)
	Current (amp)	Maxwell's Stress Tensor Force (F) (Newton)	Lifting Mass (m=F/g) gm	Current (amp)	Lifting Mass (m) gm	
.25	4.4	1.0058	102.53	4.4	59.58	41.9
2		.8379	85.41		49.68	41.83
5		.63043	64.26		37.29	41.97
10		.37862	38.6		18.66	51.65
.25	3.9	.7908	80.61	3.9	52.77	34.54
2		.6588	67.16		42.51	36.70
5		.4957	50.53		28.83	42.94
10		.29768	30.34		15.16	50.03
.25	3.4	.58638	59.77	3.4	38.71	35.24
2		.48847	49.79		32.96	33.80
5		.36754	37.47		24.48	34.37
10		.22074	22.50		12.00	46.67

.25	2.4	.2953	30.10	2.4	18.94	37.08
2		.2460	25.08		16.17	35.52
5		.1851	18.87		12	36.41

There are clear deviations in the experimental results compared to simulated results by ANSYS. These deviations are happening due to flux leakage, eddy current loss, mechanical loss etc.

6.2.GRAPHs:

A graph of Air gap between the bearings versus Lifting mass for *i=4.4 amp* has been shown in Figure:15 .It is clear from the graph that as the Lifting is increased the air gap decreases for a certain amount of current input. This will be same for any other certain current input.

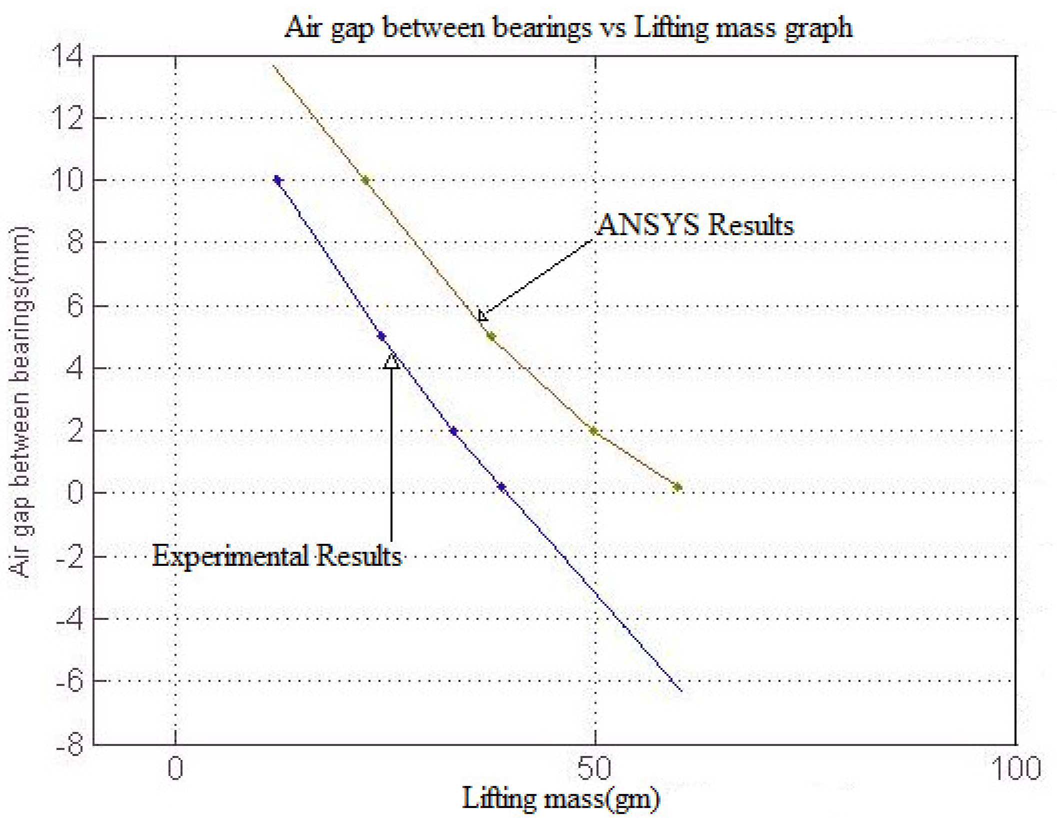

Figure 15: Air gap between bearings VS Lifting mass graph

Another graph of Lifting mass versus Current input for a certain air gap (in this case 2mm) between the bearings has been shown in Figure:16.It shows that if the Lifting mass is increased the current input must be increased to maintain the same air gap between the bearings.

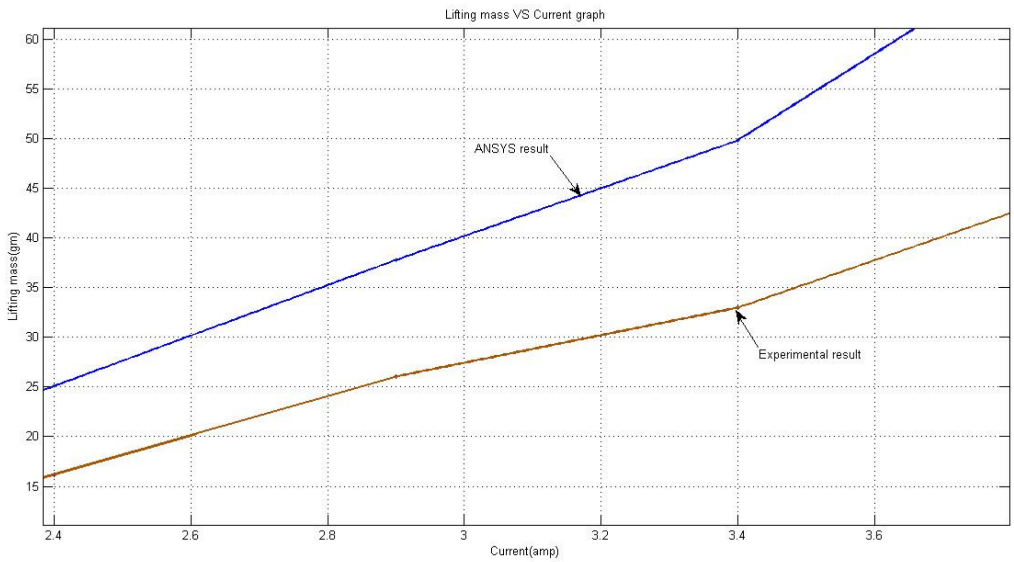

Figure 16:Lifting mass VS Current graph

CHAPTER SEVEN

Conclusion

In this small conceptual model, it has been tried to investigate the amount of Lifting force on the sprung mass. The deviations of the experimental results from the simulated results are reasonable. If proper contour and efficient winding is applied the deviations are expected to decrease significantly. The temperature of the electromagnets while magnetizing should be low. Otherwise increasing temperature will increase the resistance of the coil and the system will fail. No external damping has been used in this model. Air has acted as a viscous damper.

In this suspension system, control can easily be applied to control the current flow through the coils when there is road excitation on the lower bearing.

Further improvement of the system might lead to a level when there will be no vehicle without Electromagnetic suspension system.

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[8] http://en.wikipedia.org/wiki/Right_hand_grip_rule#Direction_associated_with_a_rotation