Electromagnetic suspension prototype design

ABSTRACT

Electromagnetic suspension works where two or more electromagnets of the same polarity absorb all the bumps. The main problem is making the magnets strong enough when running off a cars electrical system.

This work describes techniques for the design & analysis of a prototype magnetic suspension system. The viability of future high temperature super conducting magnet designs for MAGLEV has been investigated with regard to their application to active secondary suspension. It has also analysed and compared the functions and performances of the magnetic suspension system with the hydraulic, and air suspension systems.

CONCLUSION

The design and modelling process of a 1/5-scale “ flux-cancelling” Maglev suspension has been described in this paper. Using approximate techniques, this design can be used to predict the analysis. With comparison to other types of suspension system, electromagnetic suspension system provides totally comfortable ride.

Chapter 1

INTRODUCTION

As the knees are the important part of the human body because of which he can walk, run, sit and jump properly, the suspension system is a knee of a vehicle, with which the vehicle can give us a comfortable ride.

The suspension system connecting a vehicle body to the wheels and its tyres allows the wheels to move in an essentially vertical direction in response to road surface irregularities, a spring temporarily stores energy, thus insulating the vehicle body from acceleration peaks. A shock absorber or damper ensures that oscillations induced by the road unevenness or aerodynamic forces (or by accelerating, braking or lateral forces), which would impair ride comfort and road holding.

1. 1 Background:

If all is well, the suspension dampers on a vehicle do their work quietly and without fuss. Like punctuating or acting, dampers at their best when they are not noticed. Drivers and passengers simply want the damper to be trouble free. For the designers, however, there is a satisfaction in creating a good, new damper for a racing car or rally car, and perhaps making some contribution to competition success. Less exiting but economically more important, there is also satisfaction in seeing everyday vehicle travelling safety, with comfortable occupants, at speed that could be quite impractical without good dampers. The current worldwide production of dampers is difficult to estimate with accuracy, but it is probably around 50 to 100 million units per year with retail value well in excess of one billion dollars per year.

The fitting of damping devices to the vehicle suspensions followed rapidly on the heels of the arrival of the motor car itself. Since those early days, the damper has passed through a century of evaluation, the basic stages of which may be considered as:

1. Dry friction (snubbers)
2. Blow-off hydraulics
3. Progressive hydraulics
4. Adjustable (manual alternation)

5. Adaptives (slow automatic alternation)
6. Semi active (fast automatic alternation)

The zeitgeist regarding dampers has changed considerably over the years, in roughly the following periods:

1. Up to 1910, dampers were hardly used at all. In 1913, Rolls Royce actually discontinued rear dampers on a Silver Ghost, illustrating just how different the situation was in the early years.
2. From 1910 to 1925, mostly dry snubbers were used.
3. From 1925 to 1980, there was a long period of dominance by simple hydraulics, initially simply constant force blow-off, then a proportional characteristics, then adjustables, leading to mature product.
4. From 1980 to 1985, there was excitement about the possibilities for the active suspension, which could effectively eliminate the ordinary dampers.
5. From 1985, it became increasingly apparent that good deal benefit of active suspension could be obtain much more cheaply by fast auto-adjusting dampers, and the damper suddenly became an interesting, developing component again.

Damper types which are explained fully later can be initially classified in two ways:

- Dry friction with solid elements.
- Hydraulic with fluid elements.

In 1966 Danby and Powell proposed an EDS system for high-speed transportation using super conducting magnets with a “ null flux” suspension. Other designs were later proposed using continues sheet guide ways. Subsequent researchers in the U. S., Japan, Germany, UK and Canada have developed further innovations (such as ladder type guide way for increased lift efficiency), but there are still a number of technical problems that needed resolution.

1. 2 Current Details Of Electromagnetic Suspension (Maglev):

There are three primary types of Maglev technologies:

1. superconducting magnets (electrodynamic suspension)
2. feedback controlled electromagnets (electromagnetic suspension)
3. Newer potentially more economical system using permanent magnets Inductract.

The several approaches and designs have been produced by Japan and Germany. These two countries are very active in maglev research. The design used for trains in which the train levitate by the repulsive force of the same poles of the magnets. A linear motor is used to propel the trainor on the locomotive or both. In this system massive electricalinduction coils produce the magnetic field which are placed along the tracknecessary to propelthe train, leading some to speculate that the cost of constructing such tracks would be enormous.

Magnetic bearings are unstable because ofEarnshaw’s theorem; Conventional maglev systems are stabilized with electromagnets that have electronic stabilization. The electromagnets and electronics tend to be large, power-hungry, and expensive.

To levitate the train a very strong magnetic field is required but large electromagnet is also a big issue for the design, so instead of using the large magnets, superconductor for an efficient electromagnet.

Inductrack is a new and less expensive system. The system depends on the current induced in the passive electromagnetic array by permanent magnets, so that it provides the better load carrying capacity related to the speed. In the prototype, thepermanent magnetsare in a cart; horizontally to provide lift, and vertically to provide stability. The array of wire loops is in the track. The magnets and cart are unpowered, except for the speed of the cart. Inductrack was originally developed as a magnetic motor and bearing for a flywheel to store power. With only slight design changes, the bearings were unrolled into a linear track. Inductrack was developed by physicist William Post atLawrence Livermore National Laboratory.

For stabilization Inductrack uses Halbach arrays. The function of the Halbach arrays is to stabilize the loops of wires with the help of permanent magnets without electronic stabilization. Halbach arrays were originally developed for beam guidance ofparticle accelerators.

Currently, some space agencies, such as NASA, are researching the use of maglev systems to launchspacecraft. In order to do so, the space agency would have to get a maglev-launched spacecraft up toescape velocity, a task which would otherwise require elaborate timing of magnetic pulses or a very fast, very powerfulelectric current.

1. 3 Aims and Objectives:

Aim: To design and analyse a prototype Magnetic Suspension System.

Objectives:

1. Literature Review
2. Research the principles of the various types of suspension systems and analysing their functions and performances.
3. Investigate the application of the magnetic suspension system.
4. Design a prototype Magnetic Suspension System.
5. Analyse the designed Magnetic Suspension System.
6. Compare with the other type of Suspension Systems.
7. Conclusion.

Chapter 2

Literature Review

2. 1 Principle:

The basic principle is to develop a contact less spring; the instability will be corrected with electromagnetic actuators.

Electromagnetic suspension works where two or more electromagnets of the same polarity absorb all the bumps. The main problem is making the magnets strong enough when running off a cars electrical system.

Electrodynamics magnetic suspension called EDS maglev and referred to as repulsive Maglev because it relies on repulsive magnetic

Forces, has the capability of allowing high speed transportation with a relatively large gap between the vehicle and guide way .

2. 2 Basic Concept:

Have a set of shock with magnet inside them that are used as the fork setup. There is one magnet at the top of the inner portion of the cylindrical shock sleeve with the north polarity facing down towards the ground. The second magnet sits on the top of the inner shock that pivots up and down. This magnet has the north polarity upwards so it's parallel with the other magnet. The two magnet fights against each other giving the forks travel. There is also an adjustment at the top of the shock, which allow the magnet to become closer . together for a stiffer travel or further apart for softer travel.

2. 3 Dynamics of the magnetic suspension system:

The basic principle of a simple electromagnetic suspension system is shown in Fig. 1. The magnetic force applied by the electromagnet is opposite to gravity and maintains the suspended steel ball in a levitated position. The magnetic force Fm depends on the electromagnet current I, electromagnet characteristics, and the air gap X between the steel ball and the electromagnet. The motion of the steel ball in the magnetic field is expressed as

Where m is the mass of the suspended steel ball, G = mg is the gravity force, and X is the air gap between the steel ball and the electromagnet. The magnetic force Fm is a nonlinear function of the current I and the air gap X. The linearization of the static characteristic near the set point (F0 , X0 , I0) is given as

The voltage equation of the electromagnetic coil is expressed as

Where U is the controlled voltage applied to the electromagnet, R is the coil resistance, and L is the inductance of the electromagnet. Inductance L= f (X, t) is a function of the air gap, the coil, the core, and the steel ball. The steady state of the operating point air gap between the mass and the electromagnet is maintained by generating the magnetic force which is adjusted so that the gravitational force of the steel ball is balanced. The small differences from the operating point are normalized over operating spaces (G, D, Imax , Umax) and they are defined as follows:

Where f is the normalized resultant force, x is the normalized air gap, i is the ormalized current, and u is the normalized voltage. X0 , I0 , and U0, are the steady-state values. Substituting Eq. 4 into Eqs. 1, 2, and 3 the dynamics of the system can be presented as follows:

The block diagram of the linearized model of the electromagnetic suspension system is shown in Fig. 2. The linear system described in the block diagram in Fig. 2 is unstable and controllable.

2. 4THEORY OF VIBRATION:

Any motion that repeats itself after an interval of time is called vibration or oscillation. The swinging of a pendulum and the motion of a plucked string are typical examples of vibration. The theory of vibration deals with the study of oscillatory motions of bodies and the forces associated with them.

Free vibration without damping

Simple Mass Spring Model

To start the investigation of the mass-spring-damper we will assume the damping is negligible and that there is no external force applied to the mass (i. e. free vibration).

The force applied to the mass by the spring is proportional to the amount the spring is stretched “ x” (we will assume the spring is already compressed due to the weight of the mass). The proportionality constant, k, is the stiffness of the spring and has units of force/distance (e. g. lbf/in or N/m)

The force generated by the mass is proportional to the acceleration of the mass as given byNewton’s second law of motion.

If we assume that we start the system to vibrate by stretching the spring by the distance ofAand letting go, the solution to the above equation that describes the motion of mass is:

This solution says that it will oscillate withsimple harmonic motionthat has an amplitudeofAand a frequency offn. The numberfnis one of the most important quantities in vibration analysis and is called theundamped natural frequency. For the simple mass-spring system, fnis defined as:

Note: Angular frequency?(? = 2pf) with the units of radians per second is often used in equations because it simplifies the equations, but is normally converted to “ standard” frequency (units ofHzor equivalently cycles per second) when stating the frequency of a system.

If you know the mass and stiffness of the system you can determine the frequency at which the system will vibrate once it is set in motion by an initial disturbance using the above stated formula. Every vibrating system has one or more natural frequencies that it will vibrate at once it is disturbed. This simple relation can be used to understand in general what will happen to a more complex system once we add mass or stiffness. For example, the above formula explains why when a car or truck is fully loaded the suspension will feel “ softer” than unloaded because the mass has increased and therefore reduced the natural frequency of the system.

What causes the system to vibrate: from conservation of energy point of view

Vibrational motion could be understood in terms ofconservation of energy. In the above example we have extended the spring by a value ofxand therefore have stored somepotential energy(12kx2) in the spring. Once we let go of the spring, the spring tries to return to its un-stretched state (which is the minimum potential energy state) and in the process accelerates the mass. At the point where the spring has reached its un-stretched state all the potential energy that we supplied by stretching it has been transformed intokinetic energy(12mv2). The mass then begins to decelerate because it is now compressing the spring and in the process transferring the kinetic energy back to its potential. Thus oscillation of the spring amounts to the transferring back and forth of the kinetic energy into potential energy.

In our simple model the mass will continue to oscillate forever at the same magnitude, but in a real system there is always something calleddampingthat dissipates the energy and therefore the system eventually bringing it to rest.

The solution to this equation depends on the amount of damping. If the damping is small enough the system will still vibrate, but eventually, over time, will stop vibrating. This case is called underdamping – this case is of most interest in vibration analysis. If we increase the damping just to the point where the system no longer oscillates we reach the point ofcritical damping(if the damping is increased past critical damping the system is called overdamped). The value that the damping coefficient needs to reach for critical damping in the mass spring damper model is:

To characterize the amount of damping in a system a ratio called thedamping ratio(also known as damping factor and% critical damping) is used. This damping ratio is just a ratio of the actual damping over the amount of damping required to reach critical damping. The formula for the damping ratio (?) of the mass spring damper model is:

For example, metal structures (e. g. airplane fuselage, engine crankshaft) will have damping factors less than 0. 05 while automotive suspensions in the range of 0. 2-0. 3. The solution to the underdamped system for the mass spring damper model is the following:

The value ofX, the initial magnitude, andf, thephase shift, are determined by the amount the spring is stretched. The formulas for these values can be found in the references.

2. 5 HALBACH ARRAYS

Another way of stabilizing the repulsive effect is to use fields that move in space, rather than just time. This effect can be demonstrated with a rotating conductive disc and a permanent magnet, which will repel each other.

HALBACH CYLINDERS are well-suited to magnetic levitation of gyroscope, motor and generator spindles. They use only permanent magnets and unpowered conductors to provide levitation. The energy of suspension comes entirely from rotational motion, efficiency is good, and no extremely low temperature suspension magnets or electronics are required. The only restriction is that the linear speed at the bearing race must be above a meter per second to levitate.

This is also the principle of the inductract maglev train system, which avoids the problems inherent in actively supported systems.

Halbach Cylinder:

A Halbach cylinder is a magnetized cylinder composed of ferromagnetic material producing (in the idealised case)a magnetic field confined entirely within the cylinder with zero field outside. The cylinders can also be magnetized such that the magnetic field is entirely outside the cylinder, with zero field inside. Several magnetization distributions are shown below:

Ideally, these structures would be created from an infinite length cylinder of magnetic material with the direction of magnetization continuously varying. The magnetic flux produced by this ideal design would be perfectly uniform and be entirely confined to the bore of the cylinder. Of course, the ideal case of infinite length is not realisable and in practice the finite length of the cylinders producesend effectswhich introduce non-uniformities in the field within the bore. The difficulty of manufacturing a cylinder with a continuously varying magnetization also usually leads to the design being broken into segments.

These cylindrical structures are used in devices such as brushless AC motors, magnetic couplings and high field cylinders. Both brushless motors and coupling devices use multipole field arrangements:

Brushless motors typically use cylindrical designs in which all the flux is confined to the centre of the bore (such ask = 4above, a six pole rotor) with the AC coils also contained within the bore. Such self-shielding motors designs are more efficient and produce higher torque than conventional motor designs.

Magnetic coupling devices transmit torque through magnetically transparent barriers (that is the barrier is non-magnetic or is magnetic but is not affected by an applied magnetic field), for instance between sealed containers or pressurised vessels. The optimal torque couplings consists of a pair of coaxially nested cylinders with opposite +kand -kflux magnetization patterns, as -k magnetization patterns produce fields entirely external to the cylinder. In the lowest energy state, the outer flux of the inner cylinder exactly matches the internal flux of the outer cylinder. Rotating one cylinder relative to the other from these state results in a restoring torque.

where the inner and outer cylinder radii areRoandRi, respectively. His in theydirection. This is the simplest form of the Halbach cylinder, and it can be seen that if the ratio of outer to inner radii is greater than'e'the flux inside the bore actually exceeds theremanenceof the magnetic material used to create the cylinder.

This cylindrical design is only one class of design which produces a uniform field inside a cavity within an array of permanent magnets. Other classes of design include wedge designs, proposed by Abele and Jensen in which wedges of magnetized material are arranged to provide uniform field within cavities inside the design as shown below.

Three designs producing uniform magnetic fields within their central air gap

The direction of magnetization of the wedges in (A) can be calculated using a set of rules given by Abele, and allows for great freedom in the shape of the cavity. Another class of design is the magnetic mangle (B), proposed by Coey and Cugat, in which uniformly magnetized rods are arranged such that their magnetization matches that of a Halbach cylinder, as shown for a six rod design. This design greatly increases access to the region of uniform field, at the expense of the volume of uniform field being smaller than in the cylindrical designs (although this area can be made larger by increasing the number of component rods). Rotating the rods relative to each other results in many possibilities including a dynamically variable field and various dipolar configurations. It can be seen that the designs shown in A and B are closely related to thek = 2Halbach cylinder. Other very simple designs for a uniform field include separated magnets with soft iron return paths, as shown in figure (C).

High Uniform Field Designs:

If the two dimensional magnetic distribution pattern of the Halbach cylinder is extended to three dimensions, the result is the Halbach sphere. These design have extremely uniform field within the interior of design, as they are not affected by the ‘ end effects’ prevalent in finite length cylinder design. The magnitude of the uniform field for a sphere also increases to 4/3 the amount for the ideal cylinder design with the same inner and outer radii. However, being spherical access to the region of uniform field is usually restricted to a narrow hole at the top and bottom of the design.

Higher fields are possible by optimising the spherical design to take account of the fact that it is composed of point dipoles (and not line dipoles). This results in the stretching of the sphere to an elliptical shape and having a non-uniform distribution of magnetization over the component parts of the sphere. Using this method, as well as soft pole pieces within the design, 4. 5 T in a working volume of 20mm3was achieved by Blochet al. in 1998 and this was increased further to 5 T in 2000, although over a smaller working area of 0. 05mm3. As hard materials are temperature dependent, refrigeration of the entire magnet array can increase the field within the working area further as shown by Kumadaet al. This group also reported development of a 5. 16 T Halbach dipole cylinder in 2003.

Chapter 3

MAGNETIC MATERIALS

Magnets are attracted to, or repelled by, other materials. A material that is strongly attracted to a magnet is said to have permeability. Iron and steel are two examples of materials with very high permeability, and they are strongly attracted to magnets. Liquid oxygen is an example of something with a low permeability that it is actually slightly repelled by magnetic fields. Everything has a measurable permeability like people, gases and even the vacuum of outer space.

The SI unit of magnetic field strength is the tesla, and SI unit of total magnetic flux is the Weber. 1 Weber = 1 tesla following through 1 square meter, and is a very large amount of magnetic flux.

Material can be classified according to their permittivity and conductivity. Materials with a large amount of loss inhibit the propagation of electromagnetic waves. In this case, generally whens/(? e)>> 1, we consider the material to be a good conductor. Dielectrics are associated with lossless or low-loss materials, wheres/(? e)<< 1. Those that do not fall under either limit are considered to be general media. Aperfect dielectricis a material that has no conductivity, thus exhibiting only a displacement current. Therefore it stores and returns electrical energy as if it were an idealcapacitor. In the case of lossy medium, i. e. when the conduction current is not negligible, the total current density flowing is:

3. 4 Measurement:

The dielectric constant of material can be found by a variety of static electrical measurement. The complex permittivity is evaluated over a wide range of frequencies by using different variants of dielectric spectroscopy, covering 21 orders of magnitude from 10-6to 1015Hz. Also, by usingcryostatsand ovens, the dielectric properties of a medium can be characterized over an array of temperatures. In order to study systems for such diverse exciting fields, a number of measurement setups are used, each adequate for a special frequency range.

- Low-frequencytime domainmeasurements (10-6-103Hz)
- Low-frequencyfrequency domainmeasurements (10-5-106Hz)
- Reflective coaxial methods (106-1010Hz)
- Transmission coaxial method (108-1011Hz)
- Quasi-optical methods (109-1010Hz)
- Fourier-transform methods (1011-1015Hz)

3. 5 Magnet used for Inductrack

Inductrack is a completely passive, fail-safe magnetic levitation system, using only unpowered loops of wires in the track and permanent magnets (arranged into Halbach Arrays) on the vehicle to achieve magnetic levitation. The track can be in one of two configurations, a “ ladder track” and a “ laminated track”. The ladder track is made of unpowered Litz-wire cables, and the laminated track is made out of stacked copper or aluminium sheets.

Description: Inductrack was invented by a team of scientists at Lawrence Livermore National Laboratory, headed by physicist Richard F. Post, for use in maglev trains. The only power required is to push the train forward against air and electromagnetic drag, with increasing levitation force generated as the velocity of the train increases over the loops of wire. Its name comes from the wordinductanceorinductor; an electrical device made from loops of wire. As the magnet array (with alternating magnetic field orientations) passes over the loops of wire, it induces a current in them. The current creates its own magnetic field which repels the permanent magnets.

Whenneodymium-iron-boron permanent magnetsare used, levitation is achieved at low speeds, allowing it to lift 50 times the magnet weight. The test model levitated at speeds above 22 mph, but Richard Post believes that on real tracks, levitation could be achieved at “ as little as 1 to 2 mph”. Below the transition speed, the magnetic drag increases as the vehicle’s speed increases and approaches the transition speed, but above this transition speed, the magnetic drag decreases as the vehicle’s speed increases. The Inductrack II variation uses two Halbach arrays, one above and one below the track to double the levitating magnetic field without substantially increasing the weight or footprint area of the Halbach arrays, while having lower drag forces at low speeds.

Several maglev railroad proposals are based upon Inductrack technology. The U. S. National Aeronautics and Space Administration(NASA) is also considering Inductrack technology for launching rockets.

Stationary cars: For use at embarkation/ debarkation areas, an implementation using a moving track would continue levitating the car while stationary. With a loop construction similar to a flat escalator by stationary track there would be no moving parts friction. Also, the elimination of the need for wheels during starting/ stopping of the cars simplify car construction and maintenance.

Neodymium magnet:

A neodymium magnet or NIB magnet (also, but less specifically, called a rare earth magnet) is a powerful magnet made of a combination of a combination of neodymium, iron and boron -$Nd_2Fe_{14}B$.

Neodymium magnet on a bracket from a hard drive

They have replaced marginally weaker and significantly more heat-resistant samarium-cobalt magnets in most applications, due mainly to their lower cost. These magnets are very strong in comparison to their mass, but are also mechanically fragile and the most powerful grades lose their magnetism at temperatures above 176 degrees fahrenheit or 80 degrees Celsius. High-temperature grades will operate at up to 200 and even 230 C but their strength is only marginally greater than that of samarium-cobalt. Neodymium magnets (or “ neo” as they are known in the industry) are graded in strength from N24 to the strongest N54. The number after the N represents the magnetic energy product, in mega gauss-oersteds (MGOe) (1 MGOe = 7, 958 TA/m = 7, 958 J/m). N48 has a remnant static magnetic field of 1. 38 teslas and an H (magnetic field intensity) of 13, 000 oersteds (1. 0 MA/m). By volume one requires about 18 times as much ceramic magnet material for the equivalent magnet strength. The neodymium magnet industry is continually working to push the maximum energy product (strength) closer to the theoretical maximum of 64 MGOe. Scientists are also working hard to improve the maximum operating temperature for any given strength.

A neodymium magnet lifting 1300 times its own mass

Used for stabilization and angular head motors in computer hard drives, neodymium magnets are also popular with hobbyists, and a small magnet can have amazing properties it exhibits magnetic braking when moved near a non-magnetic metal due to induced eddy currents. An excellent demonstration for students to see the effects of Lenz’s Law in non-ferrous metals may be performed by dropping a strong neodymium magnet through a copper pipe. The magnet will travel through the pipe remarkably slowly as it falls, the effect may be greatly enhanced by immersing the pipe in liquid nitrogen (thus increasing its conductivity even further) prior to dropping the magnet through. A somewhat larger magnet interacts strongly enough with the magnetic field of the Earth to allow its tendency to align with that field to be perceived directly when holding it, essentially forming a compass. Cylinder- and disc-shaped neodymium magnets are especially responsive to the Earth’s magnetic fields. Neodymium magnets are used for the transducers in many headphones.

Chapter 4

MAGLEV DESIGN

4. 1 Electromagnetic Suspension System: – (Concept)

The design of the electromagnetic suspension system can be done with two types: 1) By using a Hydraulic Damper or

2) By using Linear Motor as a Damper.

The concept is to design the magnetic suspension system on the front shock absorber of the motor bike to have a better performance with ease of handling and comfort ride. There are two cylinders installed on two separate arms of the front shock absorbing rods. The cylinder contains the pair of the cylindrical magnets having same pole facing each other to create the required repulsive force to have required levitation effect. The two cylindrical magnets having “ S” (South Pole) on the outer surface concentric with the inner circle having “ N” (North Pole) as shown in following figure:-

1) Working for the Hydraulic Damper:

The two disc magnets in a tube or two ring magnets on a shaft, as seen in above figure comprise our required magnet for a motor bike front suspension system. With unlike poles facing, the magnets repel each other & generate an air gap between them. The repulsive force restores displacement towards each other, and displacement away is restored by gravity. A hydraulic damper is fixed on the top of the cylinder and connected with the upper magnet with a shaft. The set of shocks used with magnets inside them that are used as the fork setup. One magnet is at the top of the inner portion of the shock with north polarity facing down towards the ground. The second magnet sits on the top of the inner shock that pivots up and down. This magnet has the north polarity upwards so it is parallel with the other magnet. The two magnets fight against each other giving the forks travel. There is also an adjustment at the top of the shock, which allows the magnets to become closer, together for a stiffer travel or further apart for softer travel.

The force from gravity, the force from repelling magnet & the radial instability is restrained by shaft. If the shaft is removed from the simple spring, it will be unstable naturally. The magnet will tend towards vertical motion, resulting in instabi