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Study of Magnetic levitation and levitation of an object electromagnetically via magnetic suspension

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Magnetic levitation is the process of levitating an object by exploiting magnetic fields. In other words, it is overcoming the gravitational force on an object by applying a counteracting magnetic field. Either the magnetic force of repulsion or attraction can be used. In the case of magnetic attraction, the experiment is known as magnetic suspension. Using magnetic repulsion, it becomes magnetic levitation.

In the past, magnetic levitation was attempted by using permanent magnets. Attempts were made to find the correct arrangement of permanent magnets to levitate another smaller magnet, or to suspend a magnet or some other object made of a ferrous material. It was however, mathematically proven by "Earnshaw" that a static arrangement of permanent magnets or charges could not stably magnetically levitate an object

Apart from permanent magnets, other ways to produce magnetic fields can also be used to perform levitation. One of these is an electrodynamic system, which exploits Lenz's law. When a magnet is moving relative to a conductor in close proximity, a current is induced within the conductor. This induced current will cause an opposing magnetic field. This opposing magnetic field can be used to levitate a magnet. This means of overcoming the restrictions identified by Earnshaw is referred to as oscillation.

ELECTROMAGNETIC MAGNETIC SUSPENSION

The easiest way to levitate an object electromagnetically (from a control perspective) is via magnetic suspension. The object that is to be levitated is placed below an electromagnet (only one is required), and the strength of the magnetic field produced by the electromagnet is controlled to exactly cancel out the downward force on the object caused by its weight. This method circumvents Earnshaw's theorem by making use of feedback.

Thus the system only has to contend with one force, the levitating object's weight. This system works via the force of attraction between the electromagnet and the object. Because of this, the levitating object does not need to be a magnet; it can be any ferrous material. This further simplifies the design considerations. To prevent the object

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from immediately attaching itself to the electromagnet, the object's position has to be sensed and this information fed back into the control circuit regulating the current in the electromagnet. This produces the basic feedback arrangement depicted below.

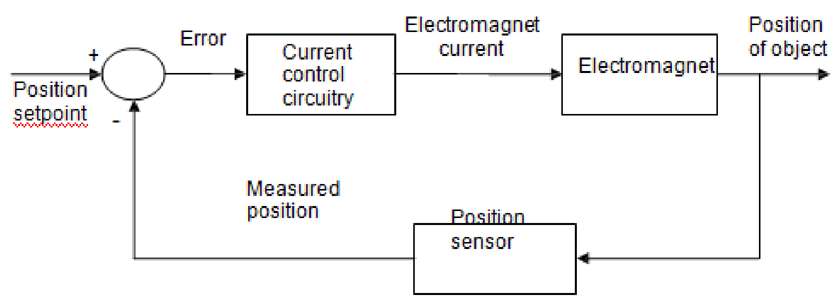

Fig 4.3: Diagram showing the basic control arrangement of a magnetic suspension system.

If the object gets too close to the electromagnet, the current in the electromagnet must be reduced. If the object gets too far, the current to the electromagnet must be increased. A possible physical arrangement is shown below.

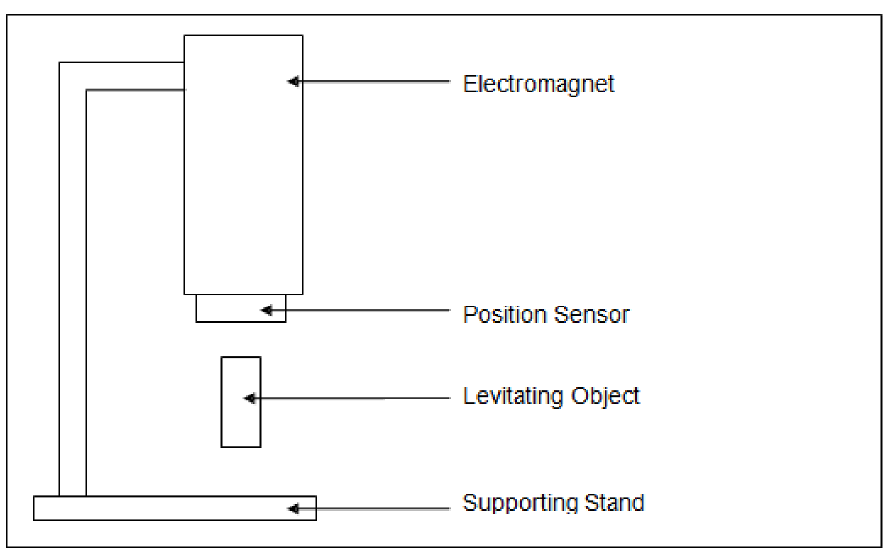

Fig 4.4: Diagram showing the physical model of a magnetic suspension system.

There are various ways to sense the position of the levitating object. One way is optically. A beam of light is shone across the bottom of the electromagnet and detected at the other side. As the object obscures more and more light (indicating that the object is getting closer to the electromagnet) the electromagnet controller limits the current more and more. As the object drops away from the electromagnet, more light is exposed to the sensor, and the current to the electromagnet is increased. This system can prove difficult to properly set up, as the alignment of the light source and the light sensor is critical. Also critical is the shape of the levitating object, because the rate at which light is obscured or exposed should be linear as the object rises and falls. This will produce the best results.

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The position can also be sensed capacitively. A small metal plate can be placed between the levitating object and the electromagnet. The capacitance between the levitating object and the metal plate can be sensed and used to determine the distance between the two. The advantage of this system is that the capacitance between the plate and the object is always linear regardless of the
shape of the levitating object. The capacitance is given by the following equation.

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

C = capacitance (farads)

A = area of capacitor plates (m^2)

ε_0 = permittivity of free space

ε_r = relative permeability

d = distance between plates (m)

The metal plate positioning is also not as critical as the sensor positioning in the optical solution, and is thus slightly easier to set up. The disadvantage of this solution is that the metal plate placed below the electromagnet may have undesired effects on the magnetic behaviour of the system. If the material is ferrous, its proximity to the electromagnet and its shape would alter the resultant magnetic field shape in the area of the levitating object. Also the circuitry required to sense the capacitance accurately is fairly complex and sensitive to circuit layouts.

Another means of position sensing is via ultra sonic sound transmitters. These work on the concept of sonar. A chirp sound signal is transmitted and the time taken for the signal to return after bouncing off the levitating object is used to determine its distance. This however, is a very complex solution given the simplicity of the system? Also because of the very short distance over which the ultrasonic sensors would have to transmit, this solution becomes unfeasible.

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The position can also be sensed with a Hall Effect sensor. For this solution, one hall sensor can be placed on the north pole of the electromagnet, and the other on the south pole. The hall sensor is a device which has a linearly increasing voltage response to an increasing magnetic flux. It can detect both north poles and south poles, by either raising its output voltage above its quiescent output voltage, or decreasing its output voltage below its quiescent output voltage. The outputs of both sensors can be sent to the inputs of a differential opamp in order determine the difference between them.

When there is no object to levitate, the outputs of both sensors will be equal. As an object approaches the bottom of the electromagnet however, it becomes magnetized by the magnetic field of the electromagnet. Thus, there would exist two magnetic fields on either side of the hall sensor on the bottom of the electromagnet. One would be due to the electromagnet and the other due to the magnetizing field in the levitating object. This would cause the bottom hall sensor to detect the net magnetic field, while the top hall sensor would still be detecting the magnetic field of the electromagnet only. The differential opamp would then output a signal which could be used to control the current to the electromagnet. Because the hall sensors have a linear response, the differential op-amp output would rise and fall linearly as the object rose and fell.

Conclusion : The main driving interest behind electromagnetic levitation is in its applications in mass transport. Much research is being done on the methods and complexities of this technology. In its applications in mass transport, particularly trains, this technology is loosely referred to as MagLev.

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