Recent Trends in Electric Traction

Magnetic levitation, **maglev**, or **magnetic suspension** is a method by which an object is suspended with no support other than magnetic fields. Magnetic pressure is used to counteract the effects of the gravitational and any other accelerations.

Earnshaw's theorem proves that using only static ferromagnetism it is impossible to stably levitate against gravity, but servomechanisms, the use of diamagnetic materials, superconduction, or systems involving eddy currents permit this to occur.

In some cases the lifting force is provided by magnetic levitation, but there is a mechanical support bearing little load that provides stability. This is termed **pseudo-levitation**.

Magnetic levitation is used for maglev trains, magnetic bearings and for product display purposes.

Mechanical constraint (pseudo-levitation):

With a small amount of mechanical constraint for stability, pseudo-levitation is relatively straightforwardly achieved.

If two magnets are mechanically constrained along a single vertical axis, for example, and arranged to repel each other strongly, this will act to levitate one of the magnets above the other.

Another geometry is where the magnets are attracted, but constrained from touching by a tensile member, such as a string or cable.

Another example is the Zippe-type centrifuge where a cylinder is suspended under an attractive magnet, and stabilized by a needle bearing from below.

Diamagnetism:

Diamagnetism is the property of an object which causes it to create a magnetic field in opposition to an externally applied magnetic field, thus causing a repulsive effect. Specifically, an external magnetic field alters the orbital velocity of electrons around their nuclei, thus changing the magnetic dipole moment. According to Lenz's law, this opposes the external field. Diamagnets are materials with a magnetic permeability less than μ0 (a relative permeability less than 1). Consequently, diamagnetism is a form of magnetism that is only exhibited by a substance in the presence of an externally applied magnetic field. It is generally quite a weak effect in most materials, although superconductors exhibit a strong effect. Diamagnetic materials cause lines of magnetic flux to curve away from the material, and superconductors can exclude them completely (except for a very thin layer at the surface).

Direct diamagnetic levitation:

A substance that is diamagnetic repels a magnetic field. All materials have diamagnetic properties, but the effect is very weak, and is usually overcome by the object's paramagnetic or ferromagnetic properties, which act in the opposite manner. Any material in which the diamagnetic component is strongest will be repelled by a magnet.

Earnshaw's theorem does not apply to diamagnets. These behave in the opposite manner to normal magnets owing to their relative permeability of $\mu_r < 1$ (i.e. negative magnetic susceptibility).

Diamagnetic levitation can be used to levitate very light pieces of pyrolytic graphite or bismuth above a moderately strong permanent magnet. As water is predominantly diamagnetic, this technique has been used to levitate water droplets and even live animals, such as a grasshopper, frog and a mouse. However, the magnetic fields required for this are very high, typically in the range of 16 teslas, and therefore create significant problems if ferromagnetic materials are nearby.

The minimum criterion for diamagnetic levitation is $B\frac{dB}{dz} = \mu_0 \, \rho \, \frac{g}{\chi}$, where:

- ☐ χ is the magnetic susceptibility
- ☐ ρ is the density of the material
- ☐ g is the local gravitational acceleration (−9.8 m/s^2 on Earth)
- ☐ μ_0 is the permeability of free space
- ☐ B is the magnetic field

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