Understanding Magnetism

This section is included in response to the large number of e-mails received about free energy devices. We state categorically that electromagnetic devices cannot be used to generate free energy.

Introduction

Magnets, motors, generators, solenoids and transformers are highly engineered devices. The mathematics which describes their behaviour depends on their design and can disguise the raw physics. Indeed engineers strive to emphasise one characteristic and eliminate another. The early experimenters were no exception with Oersted's artificial creation of magnets with poles to Faraday's iron rings which contained and controlled the magnetic flux. Einstein's relativity tried to unite electricity and magnetism with the doctrine that magnetic fields are merely an artefact of observation caused by observing an electric field while in relative motion to it. Add to this the fact that several different systems of units are in use, based on different physical interpretations, and the result is general confusion. A veritable sea of confusion upon which float a set of equations which give the right answers.

Before the introduction of SI units, the author's generation were taught using 5 systems of units. Latter graduates were even taught an exaggerated form of Einstein's doctrine and believe that there is no such thing as a magnetic field!

Classical theory in SI

The two descriptors $\vec{B}$ and $\vec{H}$ of the magnetic field only become well defined in the SI system of units. Here their clear character can be seen and it is possible to express the magnetic intensity $\vec{H}$ in terms of the motion of electric fields. It becomes necessary to recognise that the electric fields of all elementary charged particles coexist in space. We may then write:

$$\vec{H} = \sum_i \vec{v}_i \wedge \vec{D}_i$$

Magnetic intensity is seen to be an action of moving electric fields. However, the equation introduces the concept of velocity which is ill defined. Velocity is a measure of relative motion which we commonly use as if it were an absolute measure. Since $\vec{H}$ is measurable and the charges on electrons and quarks are absolute, then velocity appears in this equation as an absolute quantity implying the existence of a preferred frame of reference against which absolute velocity can be measured. These difficulties lead Einstein to deny the existence of such a frame and insist that $\vec{H}$ was merely an artefact of observation of $\vec{D}$ while in relative motion to it. Needless to say, those who carry the concepts of relativity into their understanding of magnetism are the most confused of all.

In practice, the equation $\vec{H} = \sum_i \vec{v}_i \wedge \vec{D}_i$ is valid for the magnetic field generated by an electric current if the summation is taken over the conduction band electrons of the wires and the $\vec{v}_i$ measured relative to the wires.

The further equation

$$\vec{B} = \mu_0 \vec{H}$$

reveals the "magnetic induction" or "magnetic flux density" $\vec{B}$ to be a descriptor of the "substance" of

magnetic fields. This at once raises the question as what we mean by "substance". The most fundamental answer is that the "substance" of the universe is energy in its two stable forms of electric and magnetic flux, both of which are described by their "flux density" $\vec{D}$ and $\vec{B}$ respectively.

The other two descriptors $\vec{E}$ and $\vec{H}$ are both apparently measurable being defined by the force exerted by the electric and magnetic fields. Classical Physics defines the relationship between them with the equations:

$$\vec{D} = \varepsilon_0 \vec{E} \quad ; \quad \vec{B} = \mu_0 \vec{H}$$

defining permittivity ε_0 and permeability μ_0 as properties of space. It is however better to think of them as the properties of their respective fields related to their energy densities Q_E and Q_M by the equations:

$$Q_E = \tfrac{1}{2} \vec{D} \cdot \vec{E} = \frac{D^2}{2\,\varepsilon_0} \quad ; \quad Q_M = \tfrac{1}{2} \vec{B} \cdot \vec{H} = \frac{B^2}{2\,\mu_0}$$

and to think of permittivity ε_0 and permeability μ_0 as properties of electric and magnetic flux.

The permittivity ε_0 and permeability μ_0 of SI units are physical properties. In the earlier systems of units, they are just numbers giving the possible false impression that $\vec{B}$ and $\vec{H}$ are physically the same thing.

Our education system has a wonderful ability to take the most difficult things to understand, teach them incorrectly to children and then forget about them. Thus before progressing to university we learn about the permeability of iron and the equation:

$$\vec{B} = \mu\,\mu_0 \vec{H}$$

This simple equation is taken to define the relative permeability μ of a material. The author's old A level textbook even gives it as 5500 for iron! While the equation is widely used in engineering applications, it is not good physics because there is no such property of iron! That is to say that the graph of $\vec{B}$ against $\mu_0 \vec{H}$ is not that of linear proportion or of any other mathematical function. The result is often shown as a hysteresis loop, but even that is a distortion because different ranges over which $\mu_0 \vec{H}$ is cycled produce different shaped loops depending on the range and starting point.

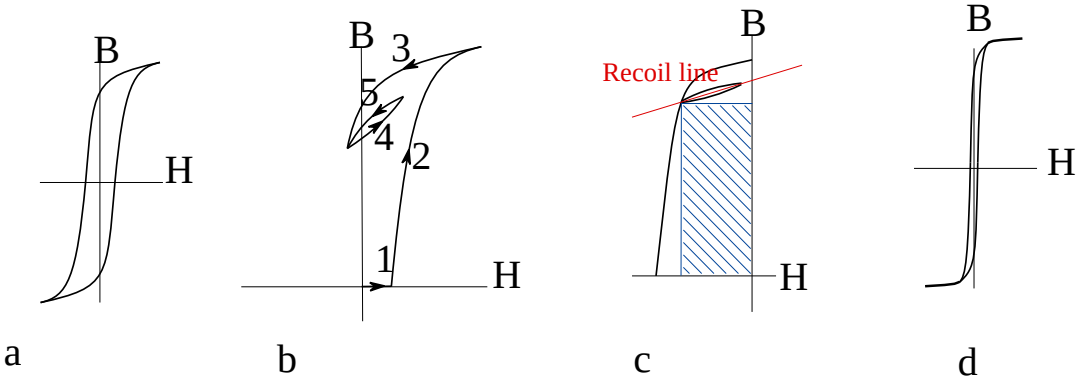


Fig (a) shows a typical hysteresis curve, fig (b) (at twice the scale) the sort of path taken when nails are picked up with a powerful magnet (1) and (2). The effect of removing the nail (3) takes it into the negative H region. If H is now increased, the curve now follows the minor loop (4) returning along (5) when H is removed.

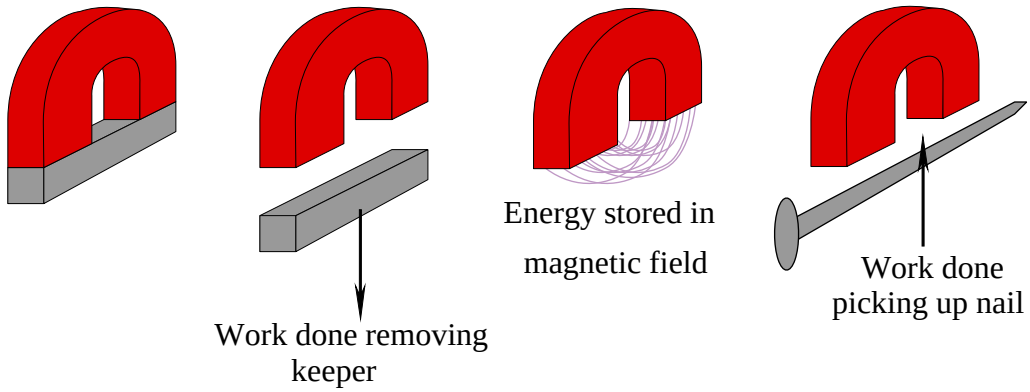
The engineer seeks to create order from this chaos and produce designs where the behaviour approximates to that of linear proportion. Fig. (c) shows the part of the hysteresis diagram called the "de-magnetisation curve" for a magnet in some application like a door catch. The minor loop is approximated to by a line called the "recoil line". Modern ceramic magnets have a very much flatter minor loop making the recoil line a much more accurate approximation.

The point where the recoil line meets the hysteresis curve is called the "operating point". The rectangle represents the product BH. The air gap between the poles of the magnet is designed to give the maximum energy density in the magnet when the keeper is removed and this is achieved by setting the operating point to give the maximum value of BH.

At the other extreme, alloys and ferrites developed for use in transformer cores have very narrow hysteresis loops as in (d) giving a reasonable approximation to $\vec{B} = \mu\mu_0\vec{H}$ behaviour. Assembly of the laminated core with resin to electrically insulate the laminates from each other and avoid eddy current loss has the same effect as introducing an air gap in the magnetic circuit giving an even better approximation to linear behaviour.

Picking up nails

Some people think that there is something magic or science-fiction-ish about the way a magnet provides the energy to pick up a nail. Conventional wisdom has it that the energy exists in the magnetic field through the air between the poles of the magnet. This energy was provided by the physical work done in removing the keeper from the magnet.



Nails can also be picked up using an electromagnet. This is a much simpler situation for the engineer to analyse because the magnetic properties of the soft iron core of the electromagnet play only a minor role compared with the air gap and can be neglected. Since we can measure the current and the voltage needed to maintain it, detailed analysis of energy flow is made possible. If we try to mimic the act of picking up a nail, we find that an electromagnet requires about twice as much electrical energy compared with the energy we calculate to be stored in the field of the magnet's air gap. Clearly, classical theory is wrong. Well, not exactly wrong: it just leaves things out when they make equal and opposite contributions.

We believe that things become much clearer when we take into account that fact that the apparently solid magnet is made of nuclei and electrons and a vast amount of empty space. This fact implies that the magnetic field within the magnet is really in space which has a permeability of μ_0.

The magnet is a magnet because of the aligned electron orbits within it which sum to give a net surface current [called the Amperian current] which results in an *mmf*. This "magnetomotive force" $\mathcal{F}$ acts around the full length of the flux strands. When the keeper is removed, the reluctance $\mathcal{R}$ of the magnetic circuit is increased and the flux density is reduced. The energy content $\mathcal{E}$ of the magnetic flux Φ is:

$$\mathcal{E} = \tfrac{1}{2}\mathcal{F}\Phi = \frac{\mathcal{F}^2}{2\mathcal{R}}$$

This is analogous to the power dissipated by a resistor $W = \frac{I^2}{R}$. When we connect a bulb to a battery, the battery has an *emf* V and an internal resistance R_i. The maximum power is delivered to the bulb when the resistance of the bulb is equal to the internal resistance of the battery. We say that the "impedances are matched" and in this condition, equal amounts of power are dissipated in the load (bulb) and the source

(battery). The maths in the two situations is the same. The magnet is designed so that its operating point with the keeper removed is such that equal amounts of energy are stored in flux within the core and the flux in the air gap.

The keeper on the other hand is made of soft iron. In its demagnetised state, most of its domains are still magnetised. Magnetisation rearranges the domain boundaries, but all that happens to the iron within a domain is that its direction of magnetisation changes. Magnetisation of the keeper involves only a small change in the total magnetic energy stored in it!

Reversible demagnetization of a magnet does not affect the domain boundaries or the $\vec{H}$ field due to its aligned electron orbits. What it does effect is the magnetic flux as described by the $\vec{B}$ field. A well designed new magnet is manufactured such that at its operating point with the keeper removed, the flux density within the core is half its value when the keeper is in place. In this condition, with the keeper removed, half of its *mmf* overcomes the reluctance of the air gap and half the reluctance of the space within and between its atoms.

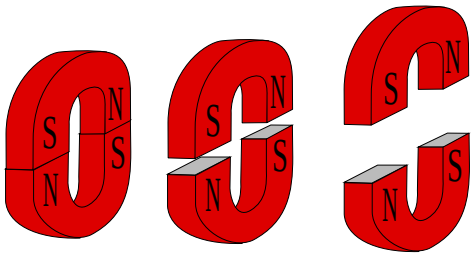
In designing electro-mechanical devices, engineers always use the empirical law that the mechanical work done is equal to the change in the energy content of the magnetic flux within the air gap and have found no reason to question its accuracy. There is a great danger that we accept a rule of thumb like this and apply it to other situations without understanding the relationship between the physics and the engineering. Engineers seldom include magnets in their electro-mechanical devices. They much prefer to use electromagnets and when they do use a magnet, they replace it with an electromagnetic in their theoretical analysis. The energy stored in the magnetic flux within the soft magnetic material of an electromagnet remains virtually constant because within each domain B remains virtually constant. What changes is the average flux density $\vec{B}$ which is the vector sum over a cross sectional area of all the $\vec{B}_i\ \delta A_i$:

$$\vec{B} = \frac{\sum_i \vec{B}_i\ \delta A_i}{\sum_i\ \delta A_i}$$

So while $\vec{B}$ is reduced by demagnetization, the B_i within the domains remain virtually constant.

Reversible demagnetization

We need a nice clean example to analyse. Such an example is provided by two horseshoe magnets placed pole to pole in attraction. We assume that each consist of a length L and cross sectional area A and that the magnetisation is uniform within the body of each magnet. If the magnets are then pulled apart a small distance d, such that the magnetic field in the air gaps remains uniform, the path length of the magnetic circuit increases from $2L$ to $2\,(L\ +\ d)$.



a **b** **c**

The magnets each have an *mmf* and in the joined state (a), it overcomes the reluctance of the circuit to produce a flux $\Phi\ =\ BA$. Once we represent the *mmf* as an Amperian current and regard the body of the magnet as the empty space within which the electrons and nuclei exist, then we can calculate the reluctance $\Re$ and the *mmf* in terms of the dimensions and the flux content Φ_0.

$$B_0 = \frac{\Phi_0}{A} \qquad H_0 = \frac{B_0}{\mu_0} = \frac{\Phi_0}{\mu_0 A} \qquad mmf = 2\,L\,H_0 = \frac{2L\,\Phi_0}{\mu_0 A} \qquad \Re_0 = \frac{mmf}{\Phi_0} = \frac{2L}{\mu_0 A}$$

The energy content of the magnetic flux can be calculated as either $\frac{1}{2}\,\Phi_0\,mmf$ from the flux and *mmf*, or

$\frac{1}{2\mu_0} A L B^2$ from the volume and flux density:

$$E_0 = \frac{L \Phi_0^2}{\mu_0 A} \qquad : \frac{L \Phi_0^2}{2\mu_0 A} \text{ in each magnet}$$

The equation $\mathcal{R} = \frac{mmf}{\Phi_0}$ defining reluctance is equivalent to Ohm's law $R = \frac{V}{I}$ defining resistance. Once this is grasped, it is easy to see what happens when we pull the magnets a small distance d apart. We increase the the length of the magnetic path by $2d$ and since the whole of the path is essentially in space, so long as d is small enough for the field in the gap to retain its direction and cross sectional area, the reluctance is increased by the same fraction as the path length and the flux decreased by it:

$$\mathcal{R} = \frac{L + d}{L} \mathcal{R}_0 \qquad \Phi = \frac{L}{L + d} \Phi_0$$

The *mmf* remains the same, so the energy content of the magnetic flux is reduced by the same fraction:

$$E = \frac{L}{L + d} E_0$$

We can write this as the sum of the energy within the magnets and within the air gaps:

$$E = E_m + E_g \qquad E_m = \left(\frac{L}{L + d}\right)^2 E_0 \qquad E_g = \frac{d}{L + d} \frac{L}{L + d} E_0$$

Work was done against the tension of the magnetic field pulling the magnets apart. The tensile stress is equal to the energy density, so the work done is:

$$W = \int_0^d \frac{B^2}{2\mu_0} 2A\, dx = \int_0^d \frac{\left(\frac{\Phi}{A}\right)^2}{\mu_0} A\, dx = \int_0^d \frac{\left(\frac{L}{L+x} \Phi_0\right)^2}{\mu_0 A}\, dx = \frac{d}{L + d} \frac{L \Phi_0^2}{\mu_0 A} = \frac{d}{L + d} E_0$$

It is apparent that the energy in the air gap is not equal to the work done.

$$E_g = \frac{d}{L + d} W$$

The situation is that we started with E_0, did W of work and ended up with less energy in the magnetic field. This missing energy is stored in the atoms of the atom. Ferromagnetism exists because the presence of a magnetic field affects the orbits of the electrons reducing the energy levels of the atoms. Reducing the flux density reduces this effect and the energy levels of the atoms increase. The stored energy is given by:

$$E_s = E_0 - E + W = E_0 - \frac{L}{L + d} E_0 + \frac{d}{L + d} E_0 = \frac{2d}{L + d} E_0 = 2W$$

So the result of doing W work is to decrease the energy content of the magnetic flux by W and store $2W$ of energy within the atoms of the magnet. Although we have not given a general proof, we assert that this principle holds for all geometries. As the magnets are pulled further apart to (c), flux starts to find a shorter path between the poles of each magnet and the fields start to separate. For well designed magnets, the flux will be halved.

This bring the theory of magnets in line with the theory of electromagnetism in which the basic motor action produces W mechanical energy when $2W$ of electric energy increases the energy in the magnetic field by W. Both physicists and engineers have got away with this omission for generations because the stored energy is usually recovered latter in the cycle, so will never be missed.

However, if one creates a device which moves through part of the cycle recovering stored energy that is not accounted for in the theory, it can look as if free energy is being extracted from space.

Free energy devices

There are innumerable claims that it is possible to build so called "Over Unity Generators" which will extract free energy from space. At the point where the inventor claims that this is the way UFOs are powered, as in the case of the Searl Generator, we can stop taking it seriously and have a good laugh. In a conference in 2000, the author listened to many Russian physicists all claiming to have built a devise which consumed 3 kW of power and output 55 kW. Some of these devices were said to be mounted on springs and demonstrated the generation of antigravity!

Needless to say, a significant percentage of the population are willing to invest in such dreams to make it worth while for the fraudsters and the deluded to pedal their wares.

The usual trick is to sit the so called generator between the electricity mains and a set of lightbulbs, then use ammeters and voltmeters to measure the power input and output of the device. With AC electricity, power is not equal to volts x amps. It also depends on the shapes of the wave forms and the phase angle. Use true power meters and the devices are shown to loose energy.

At the more cleaver end of the market, we find the type of apparatus that high school students might use in a science lesson. Since classical theory ignores the potential energy stored in the body of a reversibly demagnetized magnet, there is room to recover some of that energy and claim to have extracted some of the fabled "zero-point energy" of space.