A New Look at the Bearden MEG
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1. Flux v. Current Graphs

Most engineers are familiar with the classical B v. H curves characterizing magnetic material, figure1. Here any area represents magnetic energy-density (joules per cubic meter) within the material. The area within the hysteresis loop multiplied by the volume of material represents the energy lost to hysteresis for each cycle of operation. Note the loop is always traversed anti-clockwise.

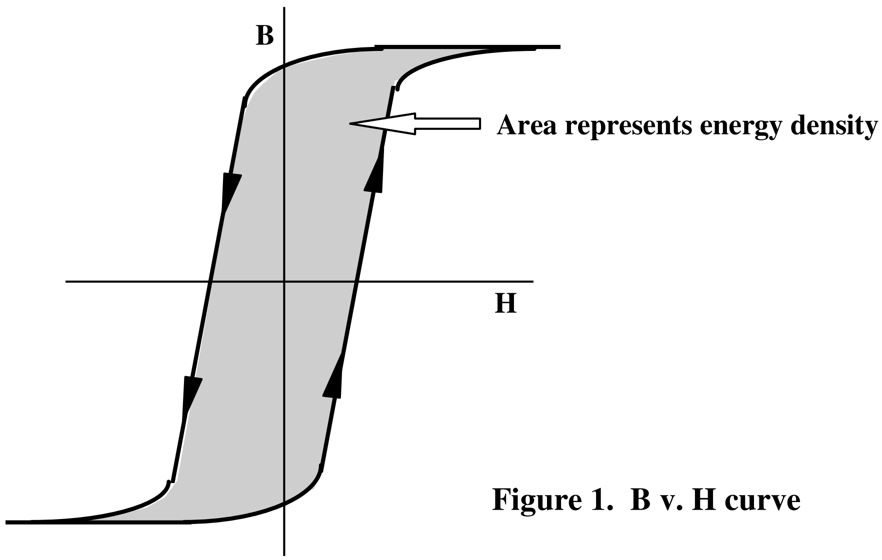

Figure 1. B v. H curve

A more useful characteristic can be constructed by plotting the total flux Φ against the current source for H, figure 2.

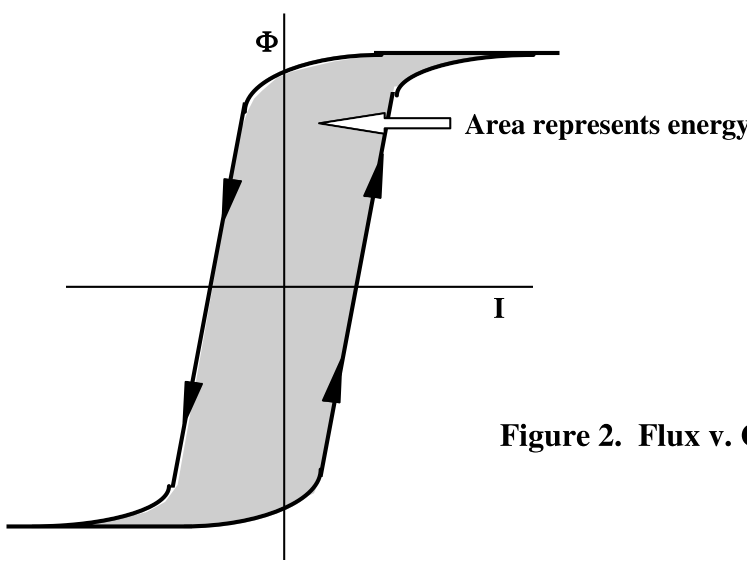

Figure 2. Flux v. Current Curve

The Φ v. I plot follows the same shape as the B v. H plot, but here any area represents energy directly. The usefulness of the Φ v. I plot is seen when it is noted that flux Φ follows the time integral of coil voltage, thus an area $\Delta\Phi\times\Delta I$ not only represents magnetic energy within the flux circuit but also electrical energy taken from the source or passed to a load. It is particularly useful when the flux passes through several materials having different magnetic characteristics (e.g. ferrous material and air) where it represents the overall system characteristic.

Consider now the Φ v. I plot for a simple inductor, figure 3.

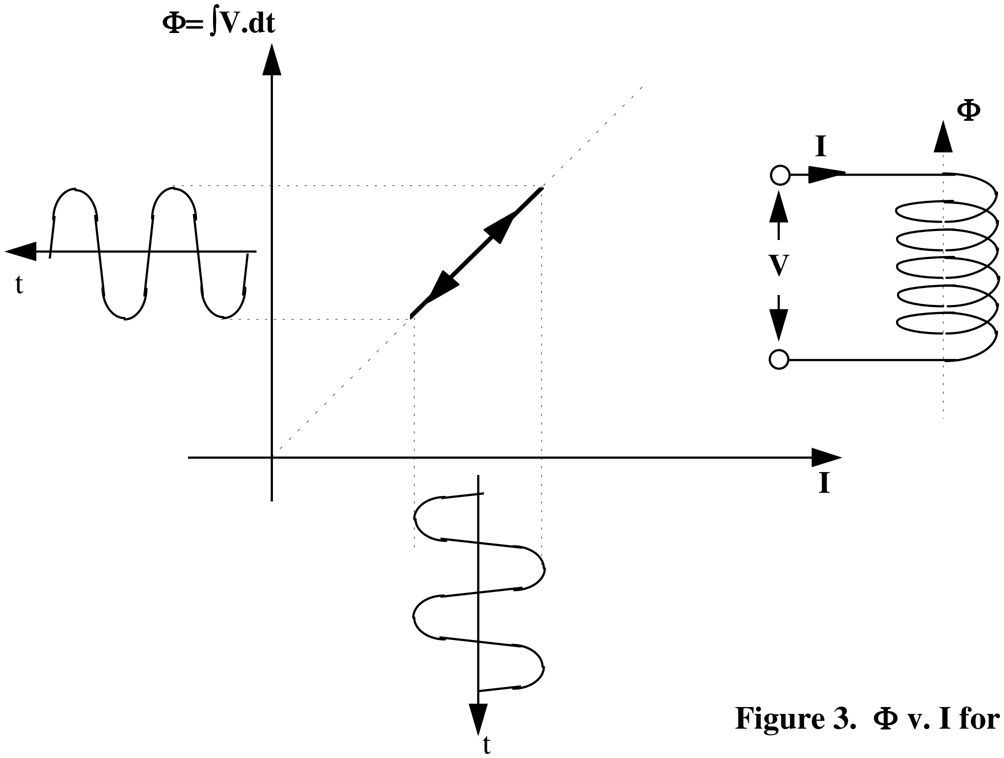

Figure 3. Φ v. I for an Inductor

When driven by an AC source, voltage and current are in phase quadrature, hence the voltage integral is in phase with the current. The Φ v. I plot yields a straight line whose slope is the inductance L.

Now if we include a loss resistor we get a change in the phase angle, which appears on the Φ v. I plot like a Lissajoux figure.

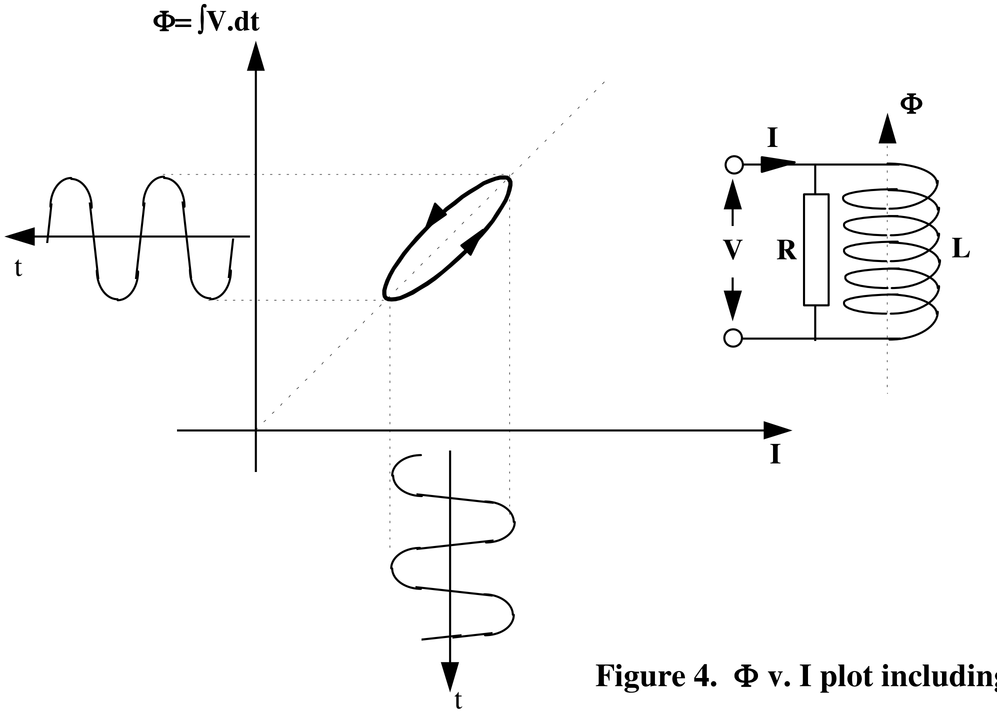

Figure 4. Φ v. I plot including Resistor

The plot forms an ellipse whose area represents the energy lost per cycle. Note the area is traversed anti-clockwise.

Of interest to OU researchers is the concept of negative resistance, since this represents a source of energy rather than a sink. The next figure shows the Φ v I plot for an inductor shunted by a negative resistor.

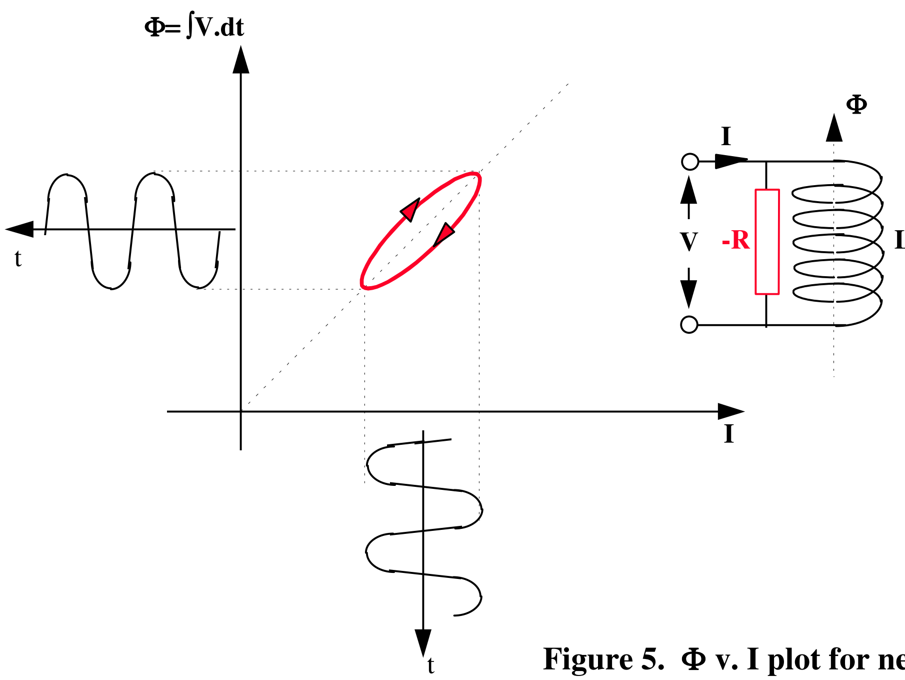

Figure 5. Φ v. I plot for negative resistor

Note that now the area is traversed *clockwise*. It represents the energy per cycle flowing backwards from the –R source.

2. Synthesizing a Clockwise Φ v. I Loop

It is known that, by the use of short-circuited coils, it is possible to divert flux from a magnetic material. Thus it may be possible to synthesize the clockwise loop by stitching together two different characteristics. Consider the following typical Φ v. I characteristic for a saturating material.

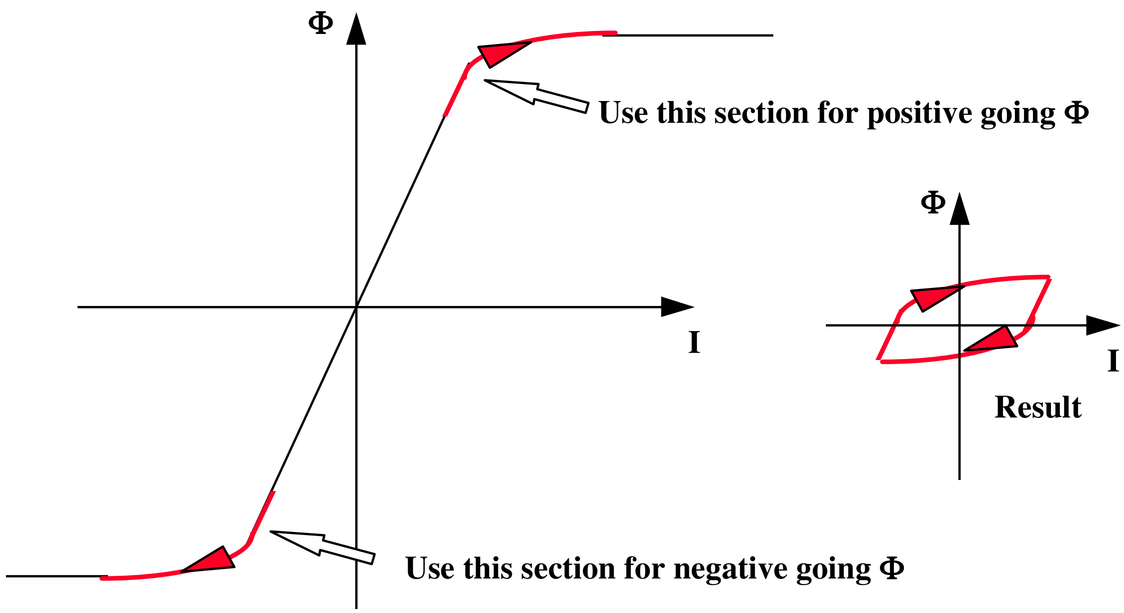

Figure 6. Φ v. I plot for saturating material

If we could arrange for flux within a coil to be positive-going while also going over the positive saturation knee, then when negative-going it does not trace its original steps, but passes over the negative saturation knee, we would get the combined characteristic we desire. The following section is devoted to this possibility.

First consider a magnetic core having two coils connected in series aiding, yielding an inductance L.

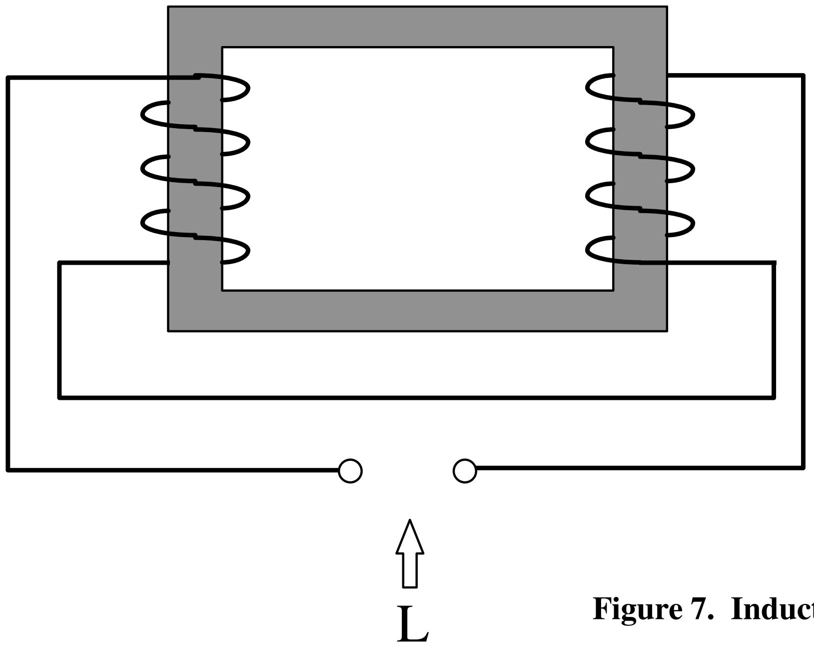

Figure 7. Inductor with two coils

Next put another coil onto the core, connected to a short circuit. We know that L will reduce in value, but it does not go to zero. The shorted coil has induced in it current which opposes any change of flux, so if we could make this coil from super-conducting material it would exclude all flux (in practice we can't yet use superconductors, but we can still proceed on the basis of looking at short time frames where the flux exclusion is valid).

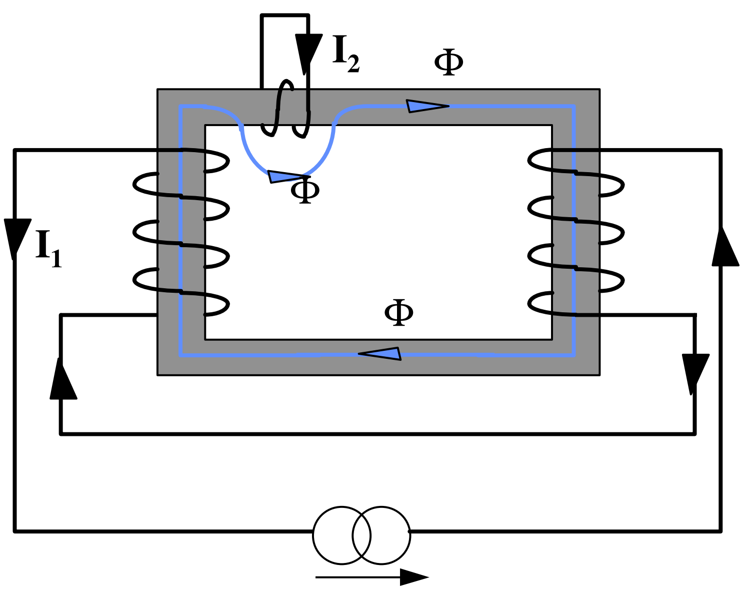

Figure 8. Inductor with shorted coil

The flux is not excluded from the entire core, but mainly in the local region around the shorted coil, the induced current I_2 creates the mmf necessary to force the flux through the air reluctance. We can move the shorted coil along the core with the same result.

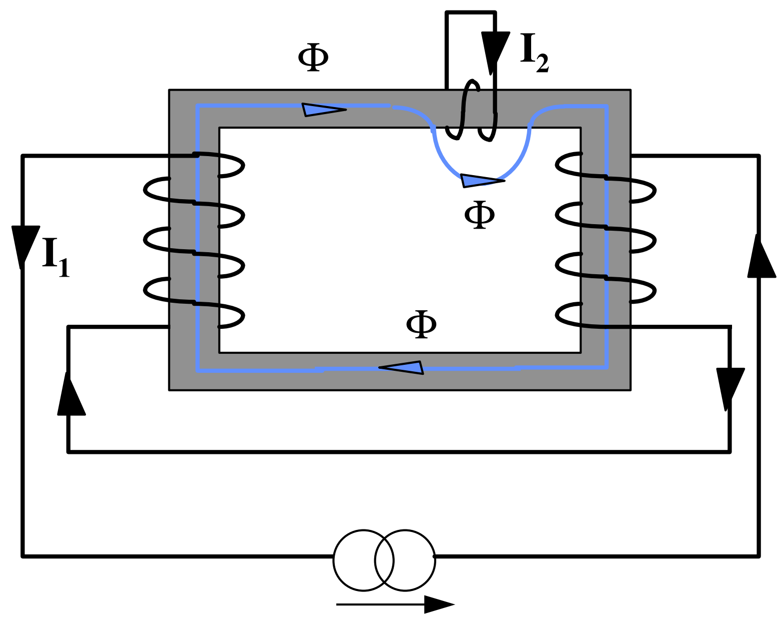

Figure 9. Short in a new position

We can also have two switching coils, with flux initially forced out of one.

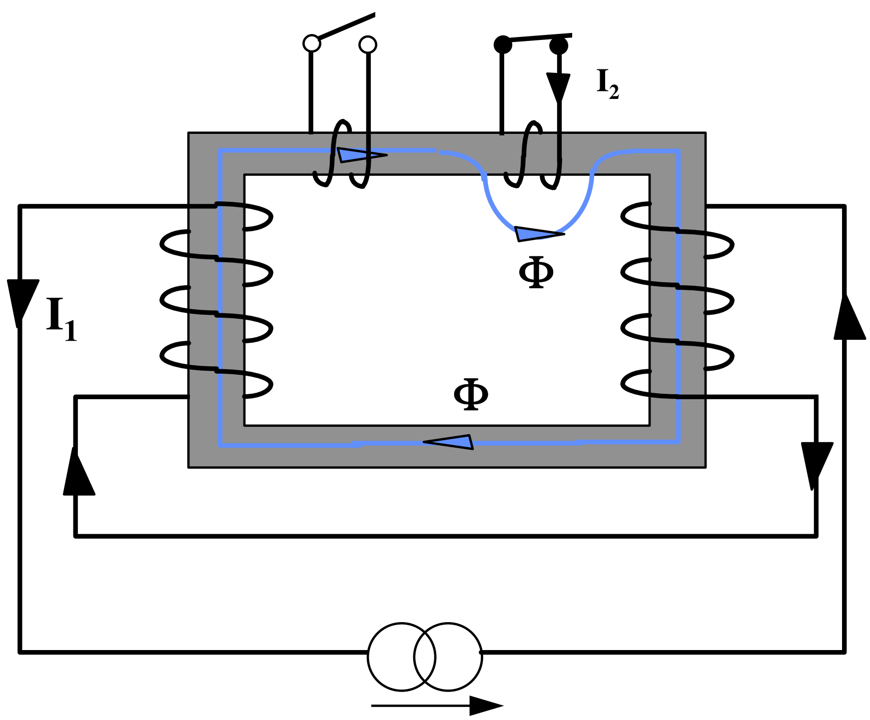

Figure 10. Two switching coils with one shorted

Then we can supply a short to the other before open circuiting the first coil, the flux exclusion zone simply jumps from one coil to the other.

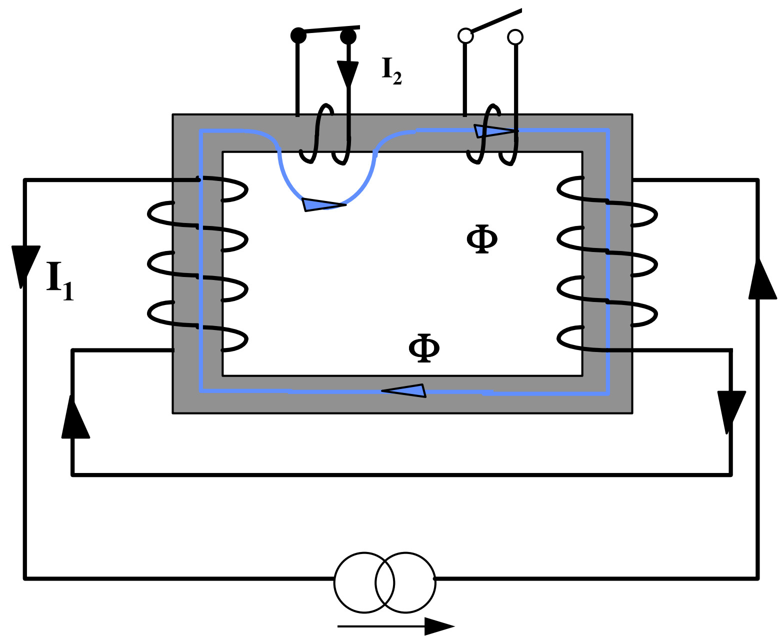

Figure 11. Short transferred to second coil

Note the flux through the two main exciter coils remains the same, the switching action is not "seen" by the current source.

Next let there be a permanent magnet across the center of the core.

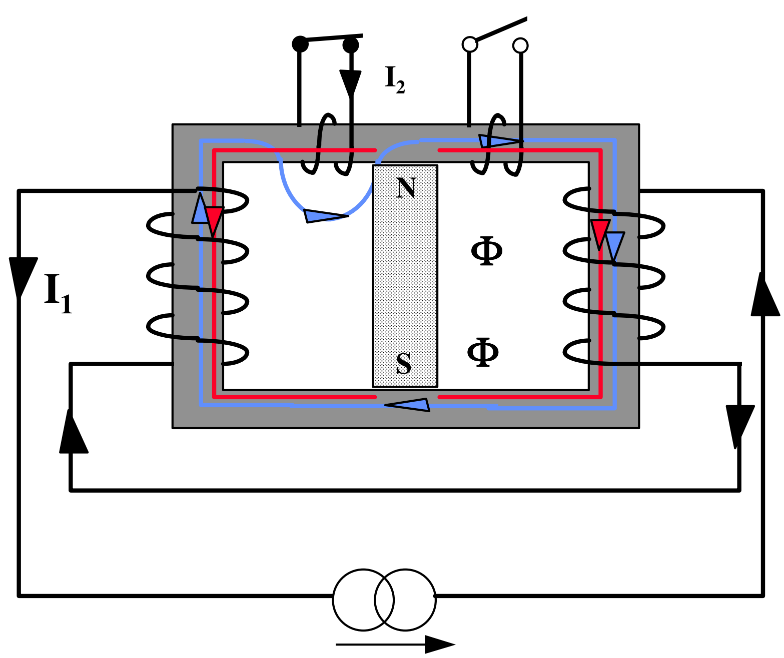

Figure 12. Addition of permanent magnet

The magnet flux divides between the two core halves, and adds to the excited flux, but at this stage there is no OU, even when the core is driven to saturation.

Now let the core section below the switched coils be thinned down so as to deliberately saturate in those regions.

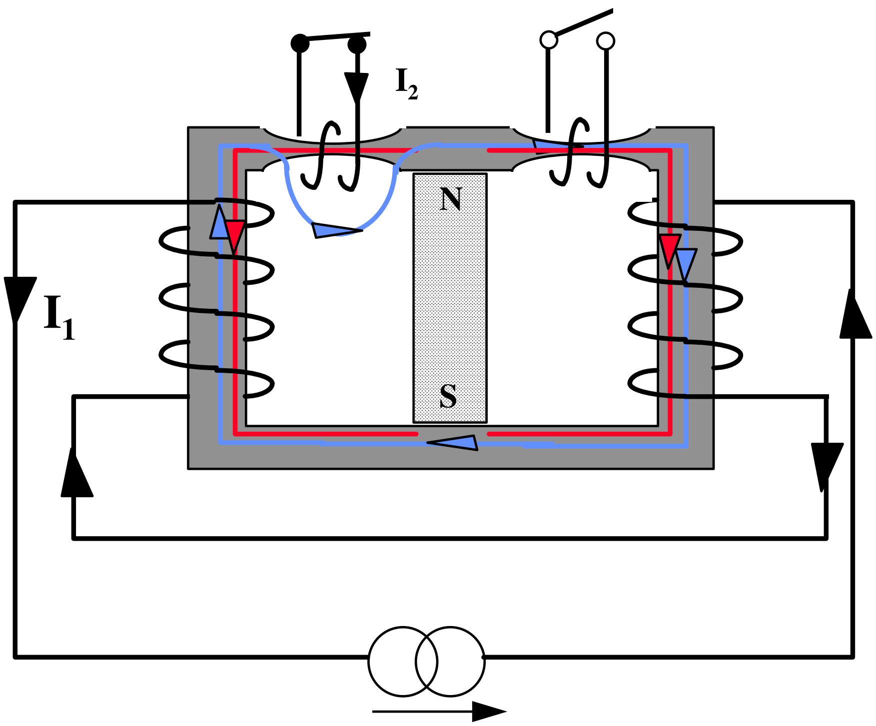

Figure 13. Saturating regions below switching coils

We arrange to short-circuit the left hand coil while, in the right hand region, exciter flux (blue) adds to magnet flux (red) so as to saturate. In this positive-going flux phase the left hand saturation region does not contribute because the flux change is excluded from it. We get one half of the synthesized characteristic.

We swap over the shorting switches when the exciter flux begins to fall, this ensures that the falling flux cannot retrace its steps down the positive saturation curve. Instead, the falling flux follows the linear inductive slope until it gets towards the negative peak where saturation now occurs at the left hand region. We now have the second half of the synthesized loop. The loop is traversed clockwise thus delivering energy to the exciter coils.

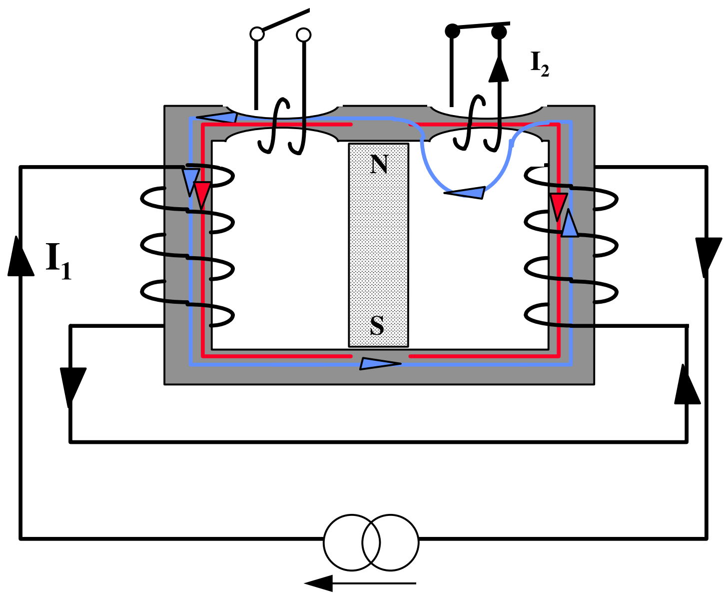

Figure 14. Short transferred to other coil

If we put a capacitor and load resistor across the exciter coils, figure 15, the resonant circuit will be sustained by this output energy. We might also use some input energy to the switching coils to (a) get the system going and (b) make good the losses affecting the current induced into these coils as shown in Figure 15.

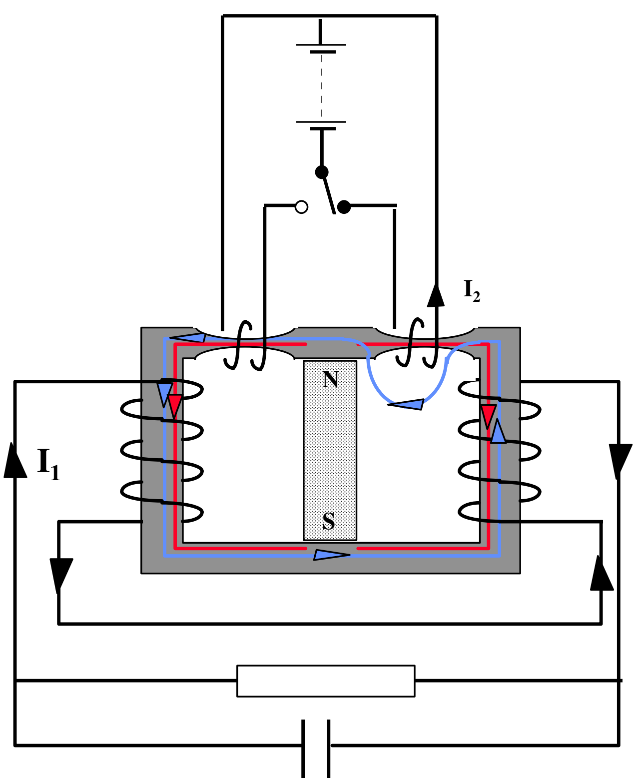

Figure 15. Complete system showing drive circuit.

The above system will be recognized as similar to the Bearden MEG, figure 16, but note one important feature:

- The saturating regions *must* be underneath the switching coils. Saturation outside these regions will not contribute to OU.

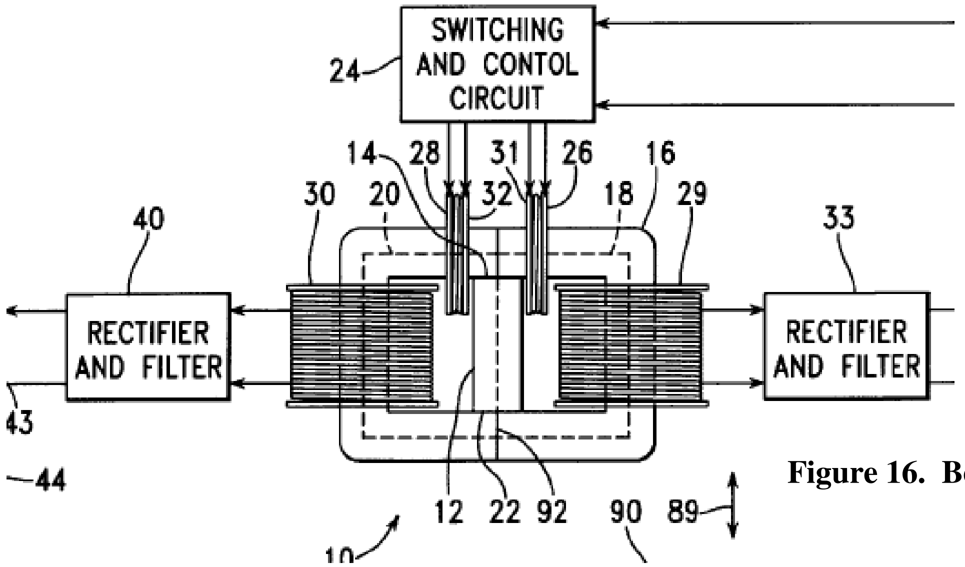

Figure 16. Bearden MEG

The MEG uses a tape-wound Metglas core which is effectively a large number of thin laminations. The mating surfaces of each tape layer form an effective air gap, thus increasing the reluctance for cross flux flowing into the core from the ends of the magnet. Hence the inner layers of tape carry most of the magnet flux, see FEMM simulation (provided by Stan Zuwala), Figure 17. This flux has maximum concentration close to the magnet poles, i.e. in the right place for the coil switching to have effect because there the core material is near to saturation. However this saturation effect does not apply to all the AC flux (from the LC resonant circuit) which mainly flows through the outer non-saturated regions of the core.

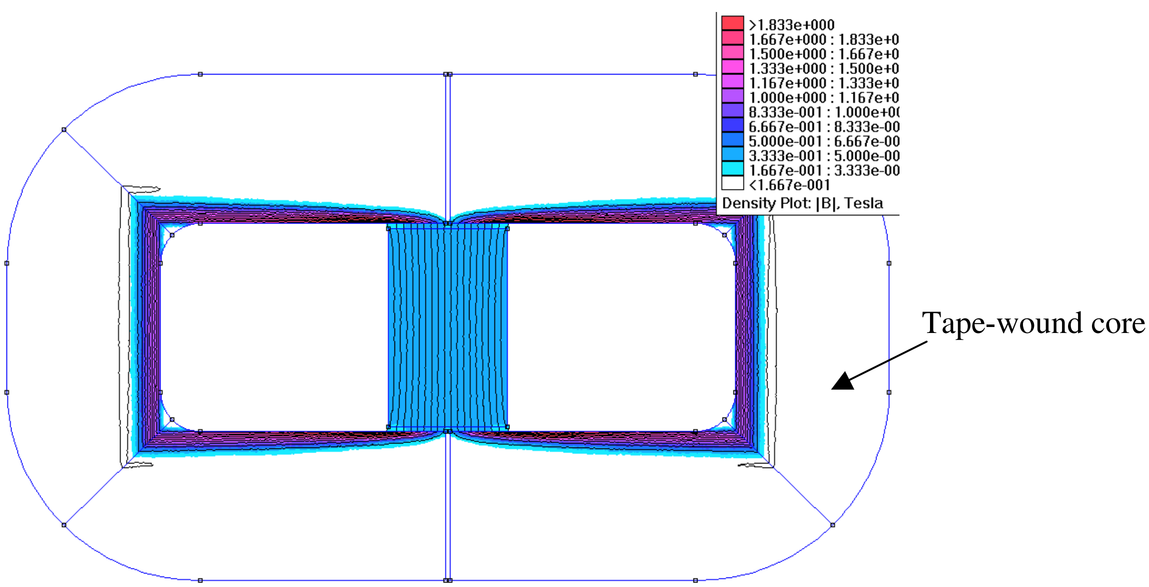

Figure 17. Simulation showing magnet flux flows only in the inner laminations.

The above simulation used the FEMM facility allowing different relative permeabilities in x and y directions in bulk material, hence the 45 degree joints at each corner. The top and bottom sections had maximum mu in the x direction while the side sections had maximum mu in the y direction. This simulated the effect of layered laminations.

3. Conclusion

We can now make some interesting observations about why some MEGs work and others don't.

- MEGs based on ferrite cores having uniform cross section are unlikely to show OU because either (a) they do not get into saturation or (b) any saturation occurs over the full length of each half core so the switched coil's contribution to OU is minimal.
- The pulse impedance of the DC power supply must be low else the shorting action and diversion of AC flux will not work.
- MEGs using tape wound cores show OU because the magnet flux is *not* uniformly distributed across the core cross-section, and saturation occurs close to the magnet.
- Most of the AC flux does not flow through the saturating regions, hence the control effect is minimal.
- *A MEG designed with saturating regions carrying the full AC flux (as in figure 15) should be more optimal.*