B v H and Flux v. mmf Loops

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Anyone concerned with magnetism will be familiar with BH loops, Figure 1 being a typical loop.

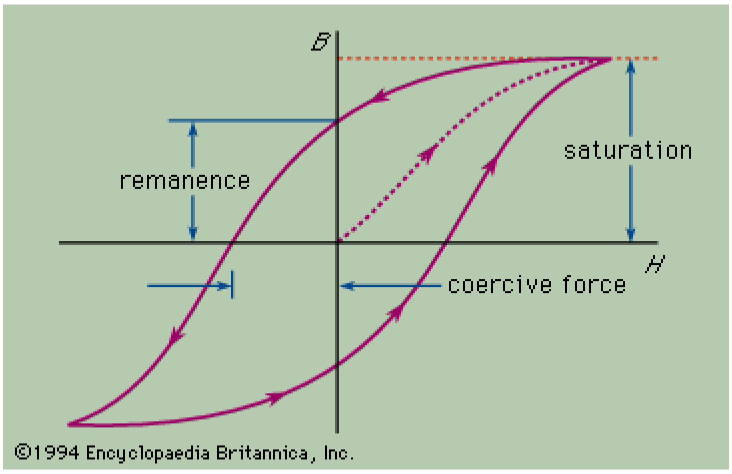

Figure 1.

The entire loop is traversed CCW representing an energy loss. The loop area gives this loss as an energy volume-density (in Joules/m^3 if B is in Tesla and H in ampere-turns/m). A more useful loop is Flux v. mmf shown in Figure 2 as Φ v. mmf.

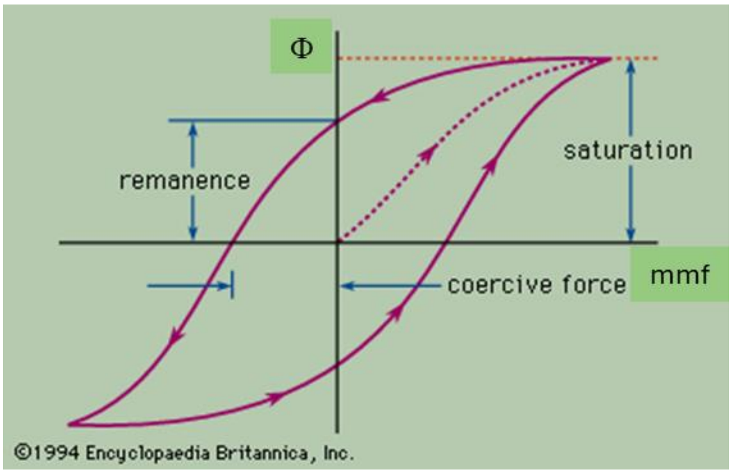

Figure 2.

Since Φ= B×Area and mmf=H×length the area of the loop now represents energy in Joules (Φ in Webers and mmf in Ampere-turns). Note that here the magnetic core is being driven with alternating current supplied to an input coil so we can apply this to the classical power transformer. Figure 3 shows mmf as a sine wave that is the magnetizing current component of the primary coil mmf. The area of the loop is energy loss per cycle.

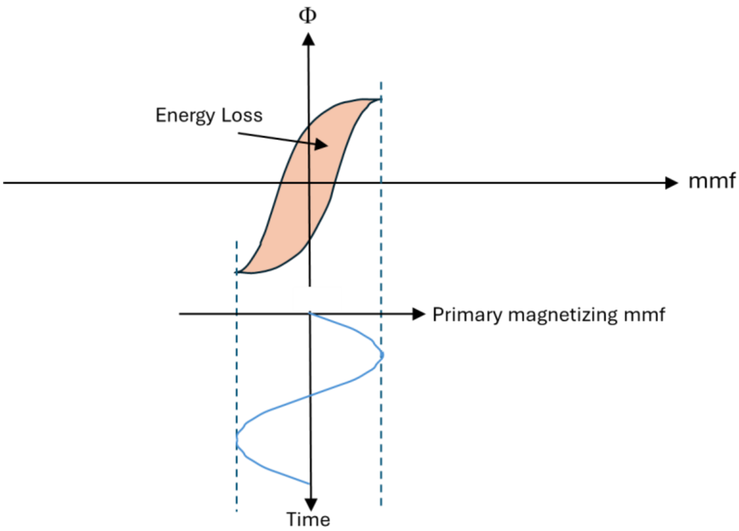

Figure 3

It is also possible to plot Flux against the load-current component of the primary coil mmf that is 90° shifted from the magnetizing component, Figure 4.

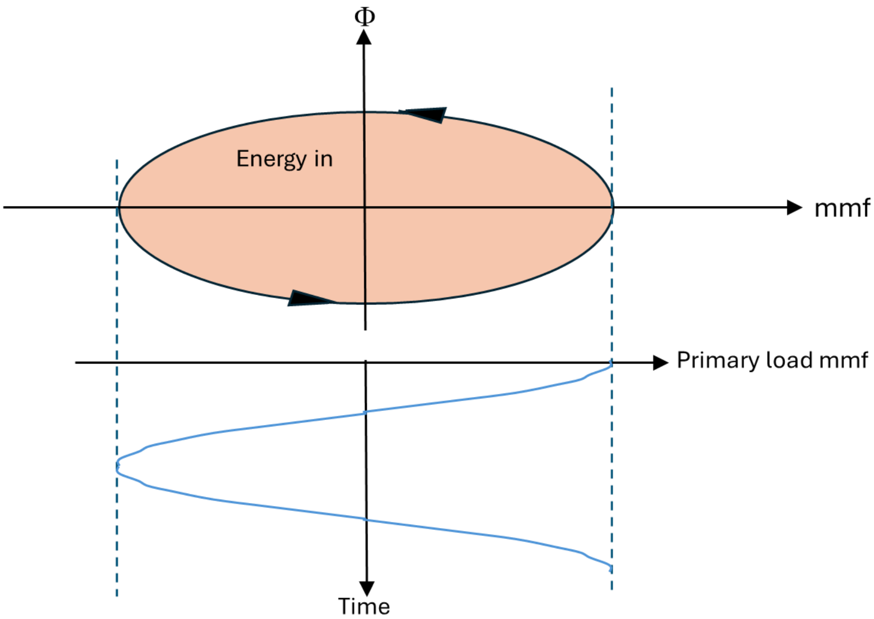

Figure 4

This creates an ellipse that is traversed CCW and represents the input energy per cycle. Note that this Φ v. mmf loop does not represent *magnetic* energy, it is the energy being transferred from primary to secondary. The total input energy is sum of Figures 2 and 3 energies.

In a similar vein we can plot Flux-linkage v. secondary current, Figure 5.

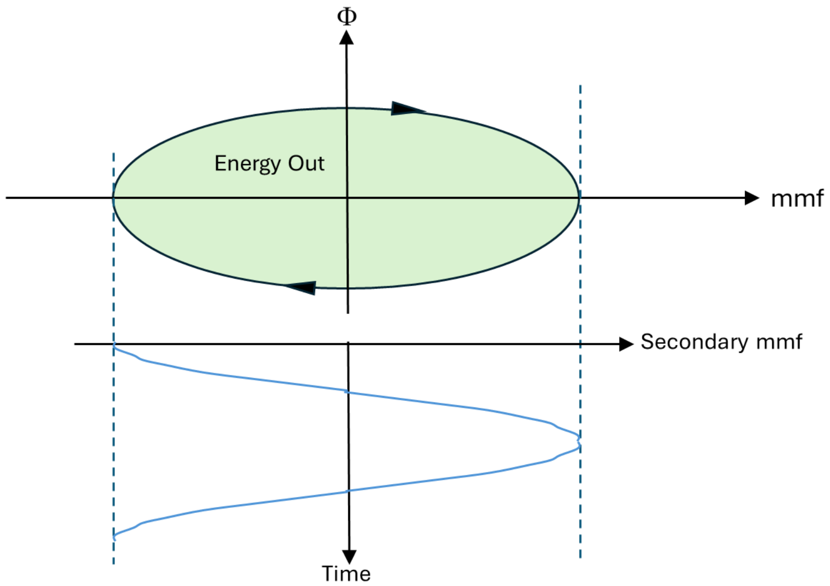

Figure 5.

This is also an ellipse but this time it is traversed CW, indicating output energy per cycle. In this power transformer illustration, the output energy equals the load-component input energy and is far greater than the magnetic loss energy. If the loss energy is insignificant, Φ v. mmf is a straight line passing through zero, the primary inductive energy that is supplied to the primary and fed back twice per cycle is shown in Figure 6. This averages to zero over complete cycles. Note that in power transformers connected to voltage generators the peak-to-peak value of flux Φ is constant, irrespective of the load, having a value $\Phi = {}^{V}/_{\omega N}$ where N is the primary turns.

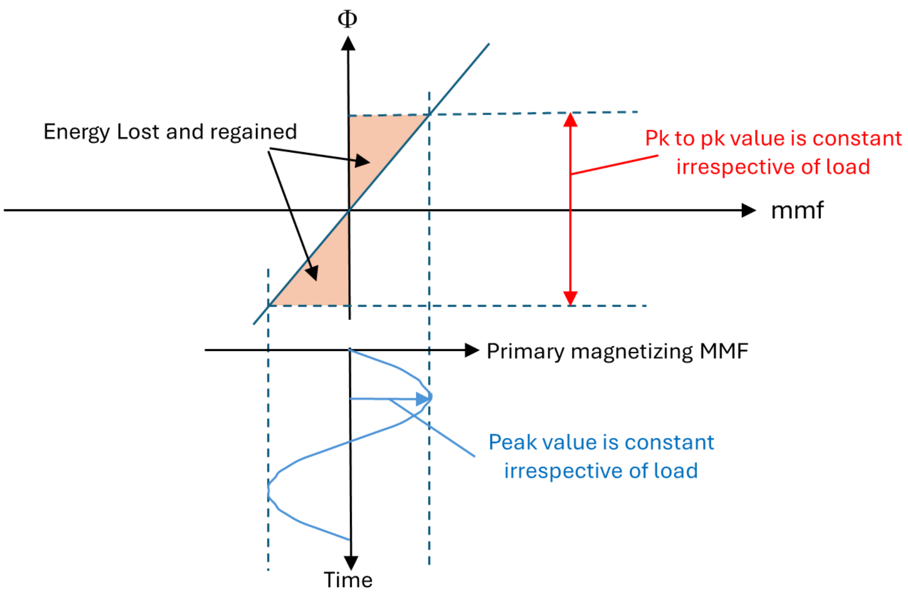

Figure 6.

The point being made here is that the areas of Φ v mmf loops in Figures 4 and 5 correctly give energy per cycle, but don't indicate magnetic energy stored or lost. Another point of interest is that at any point in time the primary and secondary mmfs in those figures are exactly equal and opposite, they cancel out regarding creating flux, Figure 7. The only current that does create flux is the magnetizing component of primary current.

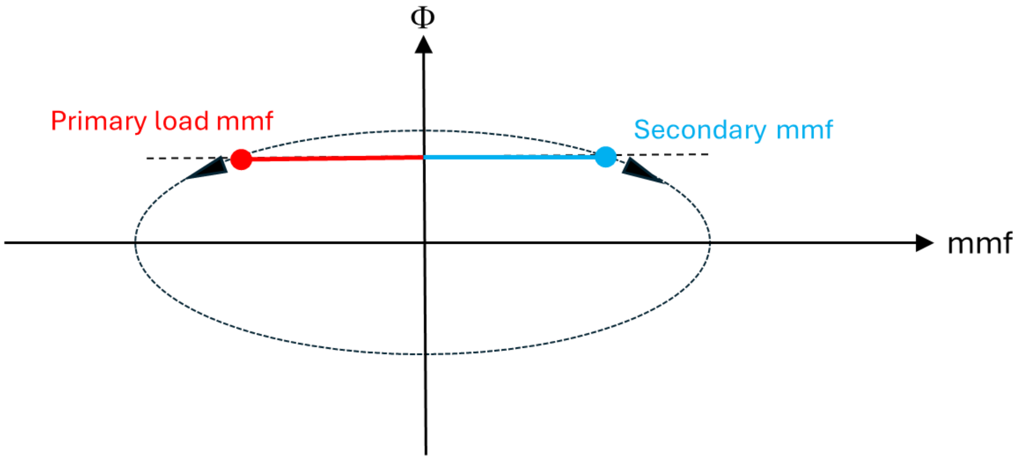

Figure 7

If we plot for different load resistor values, we get a series a series of loops as shown in Figure 8.

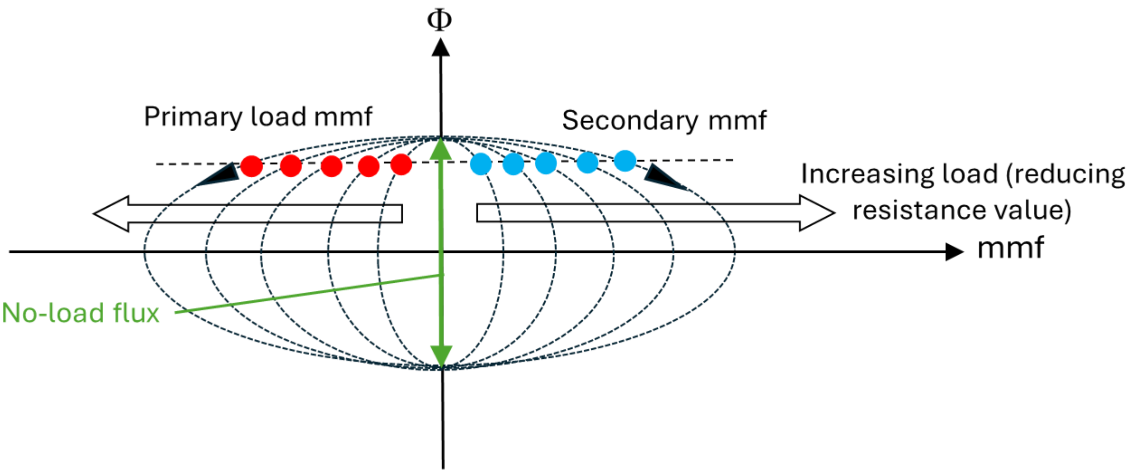

Figure 8

As we demand more power by lowering the secondary load-resistance the system automatically demands more power from the primary power source ***but the magnetic energy flows to and from the core do not change***.

Now we wish to look into using natural decay of remanent magnetism as an energy source to see whether output energy can exceed that needed for the magnetization. Since this is a pulsed system where input and output are separated in the time domain, where the load resistor is switched into circuit for short periods of time, it is useful to examine how the AC transformer could react to a switched load during only part of a cycle. This is illustrated in Figure 9.

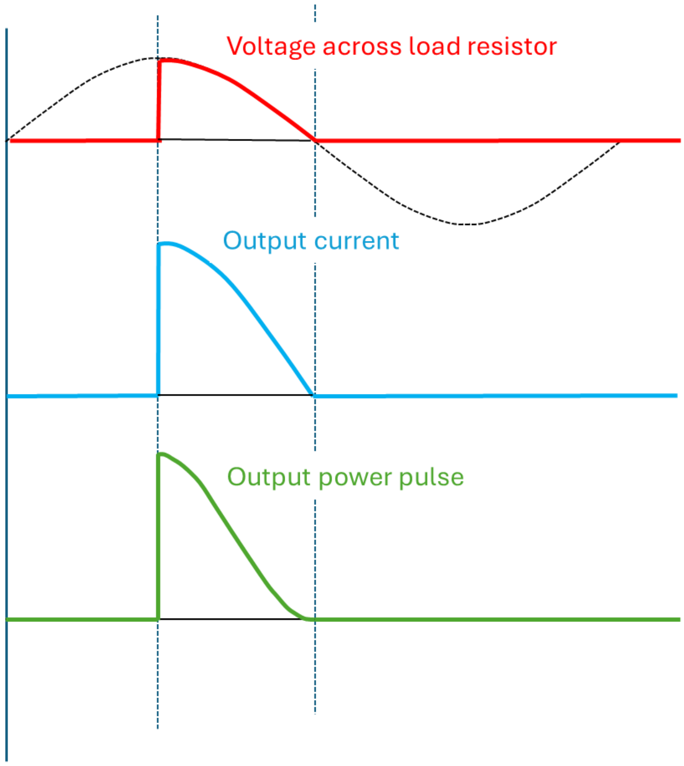

Figure 9

We have chosen to switch in the load resistor where Φ is going negative at the fastest rate corresponding to maximum positive voltage, then the voltage decays with time as the Φ negative rate decreases. We have done this is because, with the exponential remanent decay, the voltage pulse is similar except its decay is exponential and not part sine wave. The Φ v. mmf loops are shown in Figure 10.

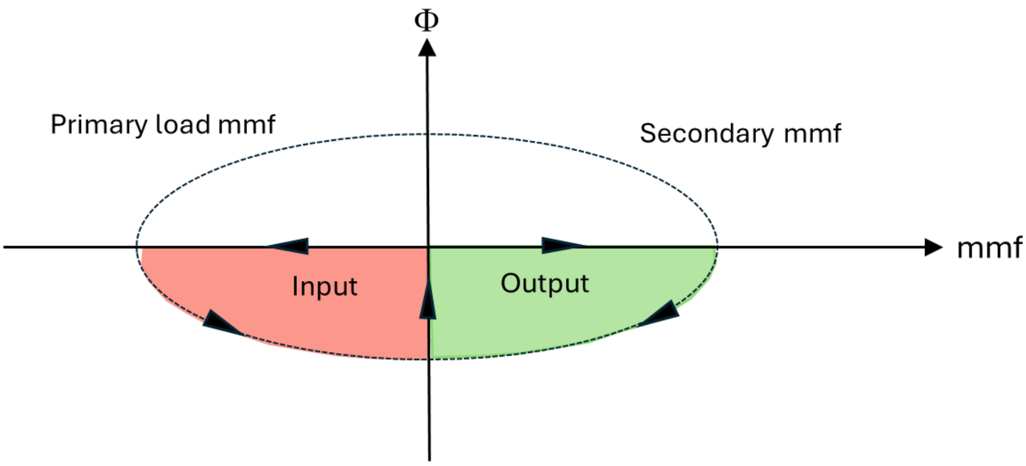

Figure 10

Turning now to the problem at hand, the input energy needed to magnetize a core is easily determined, see Figure 11.

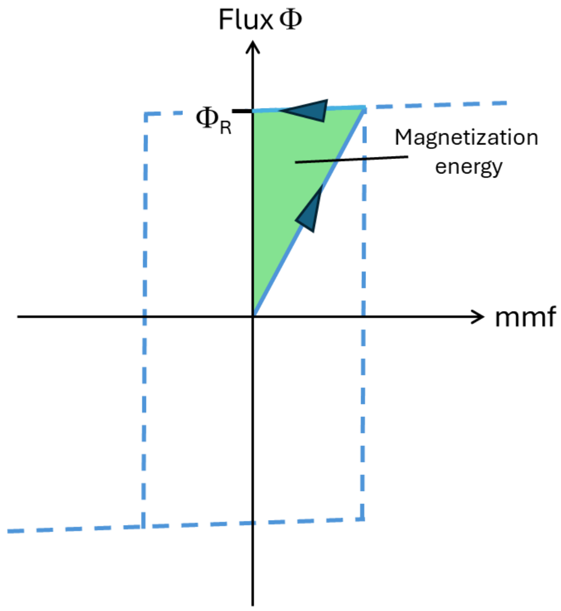

Figure 11.

As an example, a practical core of say length 15cm and area 1cm^2 having a remanence B_R of 0.5 Tesla and a coercive force H_C of 50 A/m would require only 1.88×10^{-4} Joules to magnetize it.

Now we allow Φ_R to decay naturally inducing voltage into a coil and driving current through a load. We know it is an external force that is driving that exponential decay, not an electric force or a magnetic force. It is thermal agitation of the electron spins as depicted in Figure 12.

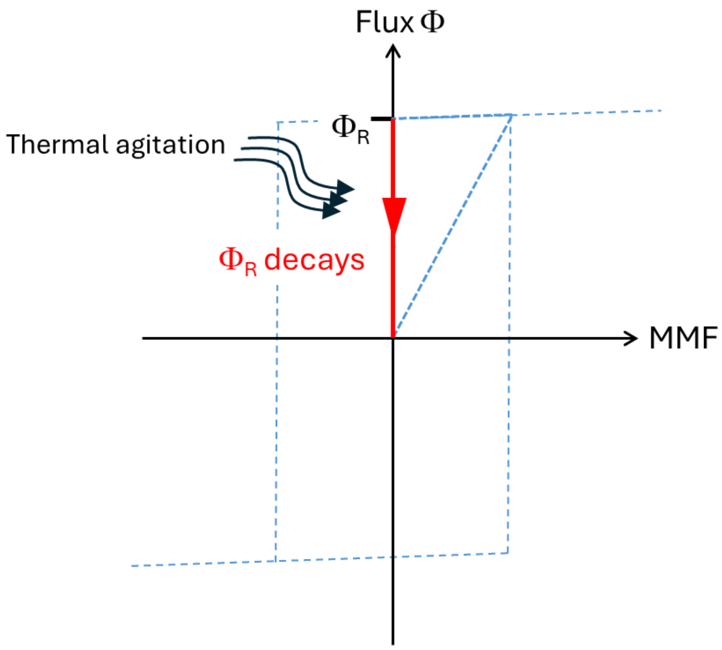

Figure 12

If we use this natural decay to induce current into a coil connected to a load resistor we expect to see a sudden rise in output coil mmf followed by an exponential decay as shown in Figure 13.

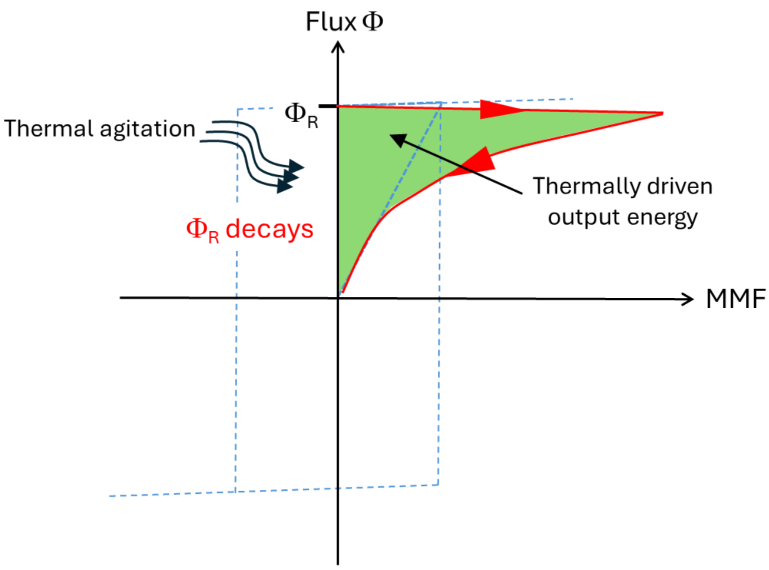

Figure 13

The loop area does not represent magnetic energy in the core, it represents the output energy driven by the thermal agitation. The lower the value of resistor the greater the area of the loop, but can it exceed the input energy of Figure 11?

We need some method for bringing that external force into consideration. One method is to use the equivalent surface-current concept for the remanent magnetism which can be represented by an imaginary close-wound single-layer current-carrying coil wound over the full length of the core that couples to our output coil, an imaginary transformer, Figure 14.

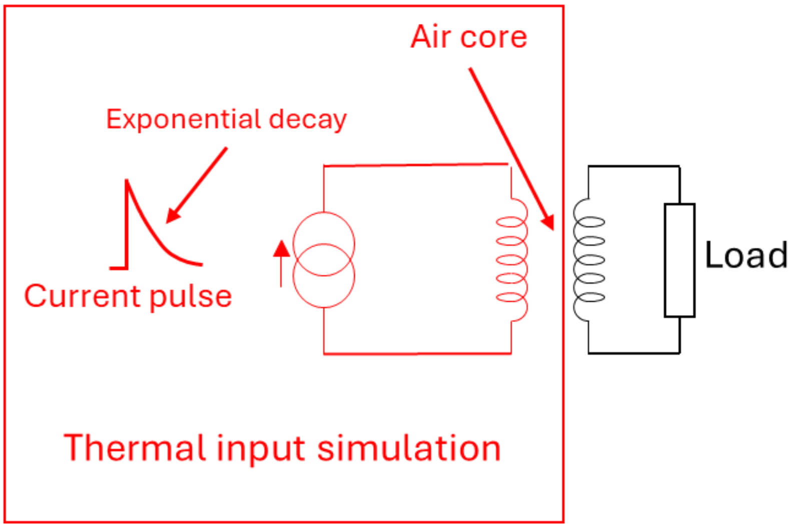

Figure 14

In this simulation the core volume has to be air, which is OK for the start of the decay at Φ_R in Figure 12 as at this saturation level the core permeability is that of air. The mmf value is given by $mmf = \frac{B_{R\times l}}{\mu_0}$ where B_R is the remanent field and l is the core length. To use the previous example where B_R is 0.5 Tesla and l is 15cm then the start value mmf is about 60,000 ampere-turns. This huge value is indicative of the hidden potential energy within magnetized material. If we take the energy value for this equivalent charged inductor it represents the magnetic energy within the inter-atomic space that is normally inaccessible to us (the 0.5T field within the air volume of the core). The thermal agitation that is reducing that field is giving us some access to that internal energy, something that is quite new to science. We see in Figure 14 a current driven transformer with the input being a pulse starting at that huge 60,000 ampere-turns value then decaying exponentially. If we calculate the energy of that equivalent inductor carrying the 60,000 ampere-turns we get about 1.5 Joules. Comparing that to the tiny 1.88×10^{-4} Joules needed to magnetize the core tells us that if this new scheme using natural remanent magnetism decay unlocks only a small percentage of that hidden energy it could still yield COPs greater than unity.

Calculations have been performed for the example system using a natural decay time-constant of 2mS. This has a 100-turn coil that is loaded with a 1Ω resistor. The result is shown in Figure 15 with the input loop area coloured brown and the output loop green. Quite clearly this has COP>1. The re-magnetizing energy is 5.25×10^{-5} J while the output energy is 8.14×10^{-4} J, a COP of 15.42. Note the core demagnetization is stopped (coil disconnected from load) at a high value of B.

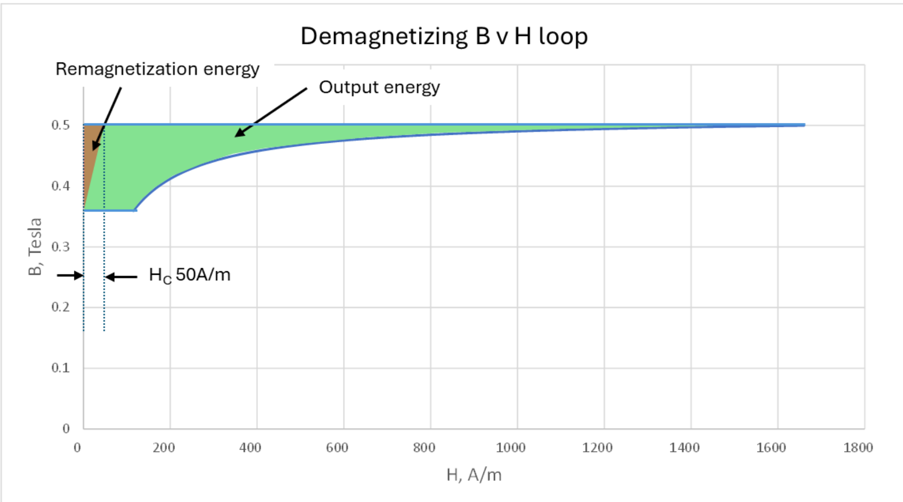

Figure 15

A repetitive sequence of input pulses each followed by an output pulse can yield a device where output power exceeds input power, COP>1 like a heat pump. For this example, the pulse sequence can repeat at a rate of 255 Hz yielding an output power of 208 mW from an input power of 13.4 mW. Unlike a heat pump this device converts thermal energy directly into electrical energy.