# B v H and Flux v. mmf Loops continuation

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Carrying on from the last paper [1] where the natural (thermally driven) decay of remanent magnetism is modelled as a decaying current flowing through an imaginary single layer closely wound coil covering the whole core that is transformer coupled to the output coil, Figure 1. This brings into focus the driving nature of this natural demagnetization as this current pulse is now seen as an input to this transformer.

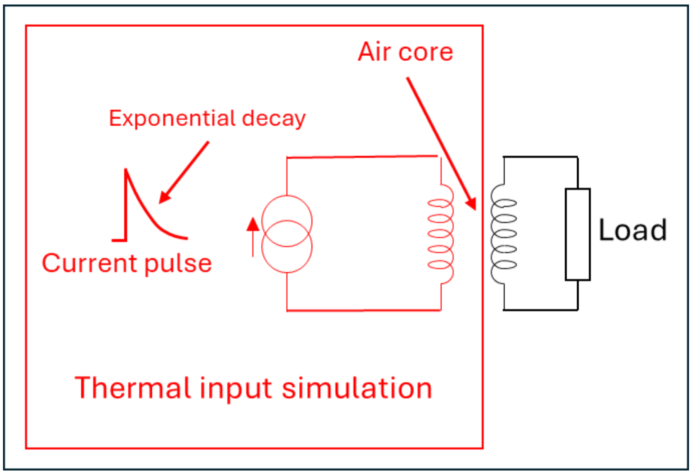


**Figure 1. Previous Circuit**

A problem with this model is that it offers ever increasing output energy with reducing values of load resistor, leading to energies approaching infinity! This is because the exponential decay function generator is modelled as a perfect current generator that can drive infinite power. Since the remanence decay is thermally driven, we should have a model that takes that into account and limits the maximum output energy accordingly, but such a model does not yet exist. One model that does limit the output energy is to assume the imaginary coil is charged with current but discharges into an imaginary resistor of value that creates the L/R time constant τ, where τ is the known natural decay time, Figure 2.

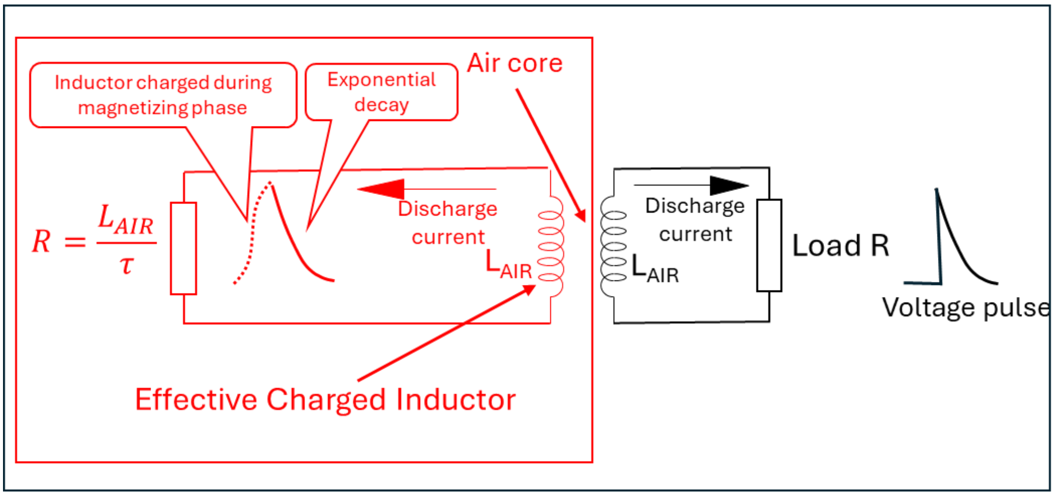


**Figure 2. New Circuit**

The imaginary inductor value $L_{AIR}$ is calculated for the core volume being air having relative permeability 1, since the effective surface current approach demands this and also the saturated inductance value at remanence has this value. This approach accounts for the natural decay time constant of τ without the load being present if the imaginary resistor $R$ discharging the imaginary inductor $L_{AIR}$ has a value $L_{AIR}/\tau$.

The peak discharge current value is given by

$$i_{pk} = \frac{B_R l}{\mu_0 N} \tag{1}$$

Where $B_R$ is the remanent field, $l$ is the core length and $N$ is the number of turns. Using the previous example where the core is a closed magnetic circuit of length 15cm and area 1 $cm^2$, remanent $B_R = 0.5$ Tesla (yielding a remanent magnetization $M$ close to 400,000 ampere-turns/m), N = 100 and τ = 2mS we obtain $L_{AIR}$ = 8.38μH, $i_{pk}$ = 600A and a $\frac{1}{2}Li^2$ energy of 1.5 Joules. In this equivalent circuit that energy is dissipated in the imaginary resistor during the natural decay without our load present and represents the best we can hope for into our load with low value load resistor.

With 100% coupling between our coil and the imaginary one with the same number of turns we obtain the simple equivalent circuit Figure 3. This is our actual coil at its saturated inductance value discharging into our load resistor in parallel with the imaginary one.

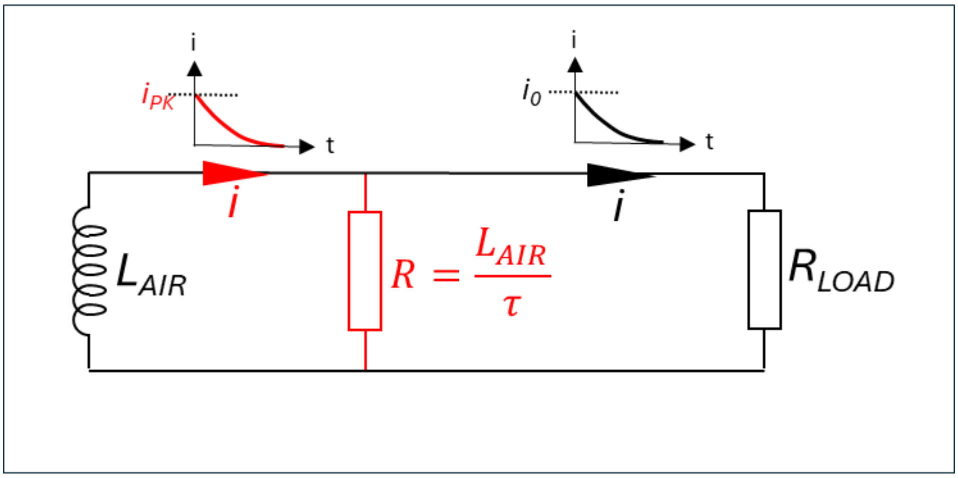


**Figure 3. Effective New Circuit**

With the parallel resistors shunting the coil with an effective resistance $R_{EFF}$ given by

$$R_{EFF} = \frac{R_{LOAD}L_{AIR}}{\tau R_{LOAD}+L_{AIR}} \tag{2}$$

the new L/R decay time constant $T$ is given by

$$T = \tau + \frac{L_{AIR}}{R_{LOAD}} \tag{3}$$

This satisfies the assumption used in the earlier document where we used that sum.

The actual current into $R_{LOAD}$ has a starting value $i_0$ given by

$$i_0 = \frac{i_{pk}L_{AIR}}{\tau R_{LOAD}+L_{AIR}} \tag{4}$$

Yielding a power waveform

$$P = \frac{i_{pk}^2 R_{LOAD} L_{AIR}^2}{(\tau R_{LOAD}+L_{AIR})^2} exp\left(-\frac{2t}{T}\right) \tag{5}$$

Integrating this power pulse from t = 0 to t = ∞ gives its maximum energy value as

$$W_{max} = \frac{i_{pk}^2 L_{AIR}^2}{2(\tau R_{LOAD}+L_{AIR})} \tag{6}$$

This approaches the $\frac{1}{2}L_{AIR}i_{pk}^2$ energy stored in the imaginary inductor at very low values of $R_{LOAD}$. Although we have used the term "imaginary" that energy value has real foundation, the large 600A $i_{pk}$ current in our example has real meaning and represents energy stored in the magnet. No one doubts that magnets have stored energy that can be used to do work. Perhaps the simplest example is attracting a ferrous object and using the force×movement to do useful work. To illustrate this, we take a horse-shoe magnet as a ring magnet with a small air gap and attract a ferrous object into the gap. Figure 4 shows the B v. H characteristic with a load-line (sometimes called a shearing line) that determines the operating point with an air gap.

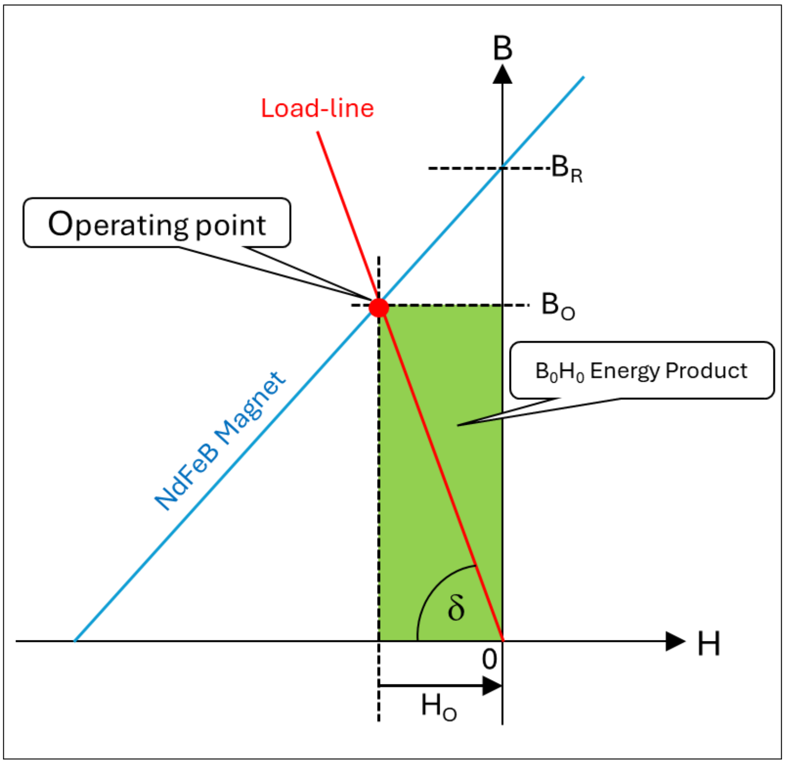


**Figure 4. Magnet Load-line**

We have chosen a material like NdFeB as that has a slope close to $\mu_0$ and M v. H is square loop. The load-line is at an angle δ to the H axis as given by

$$\tan(\delta) = \mu_0 \frac{R_M}{R_G} \quad (7)$$

$R_M$ is the reluctance *of the free space occupied by the magnet* and $R_G$ is the reluctance of the air gap. Note *the free space occupied by the magnet* is that used for the value of the imaginary inductor $L_{AIR}$.

Also shown is the area representing the so-called energy product of the magnet.

During the attraction of the ferrous piece into the gap the gap reluctance changes, the load-line changes angle as shown in Figure 5. The energy product of the magnet is reduced by the value represented by the area shown. That area multiplied by the volume of the magnet is energy lost from the magnet, it is also the work done by the moving ferrous piece, the mechanical energy output.

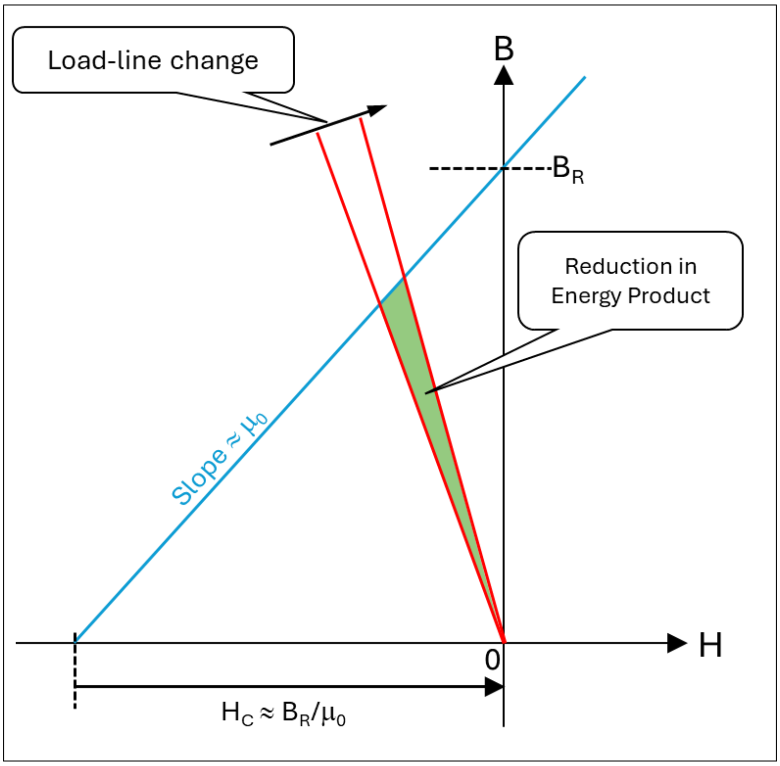


**Figure 5. Load-line change**

Hopefully this wander into magnetic motor territory will convince people that the starting value for the current pulse given by (4) has some merit and that the actual pulse given by

$$i_{(t)} = i_0 exp\left(-\frac{t}{T}\right) \quad (8)$$

is OK for the early part of the decay process. Figure 6 shows the B v H chart for our example with a 1Ω load over a decay time of 7.84mS. The output energy is 34 times the input energy!

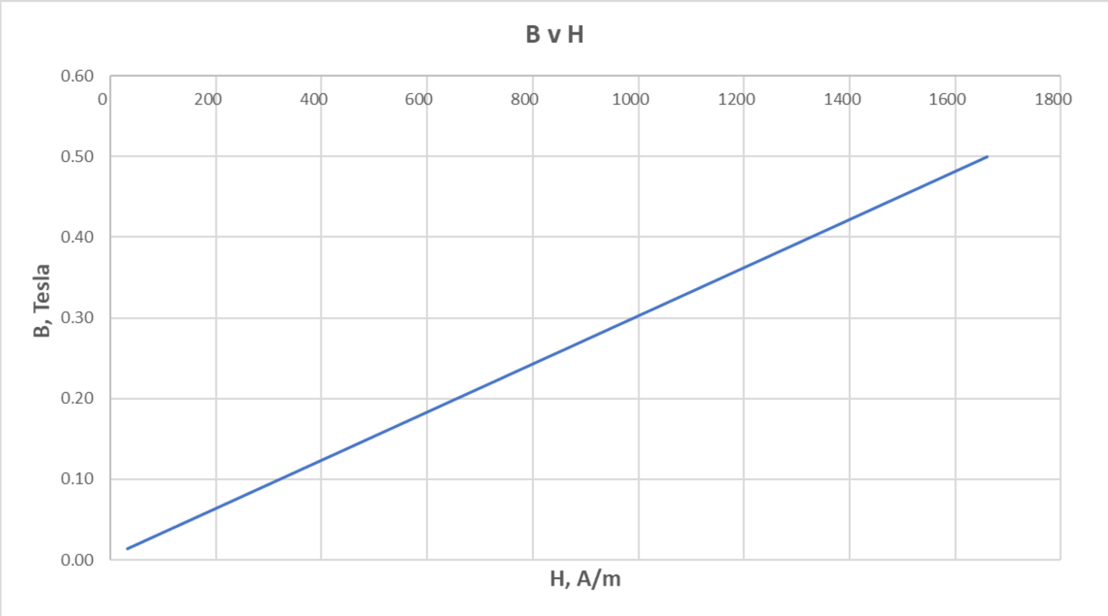


**Figure 6. B v. H Chart**

The full decay assumes the core acts like air continually whereas that may not be the case. To solve this, we turn to the magnetic domain circuit where flux $\Phi$ acts like magnetic current flowing through the core reluctance $R_M$ acting like a magnetic resistor, and mmf $U$ acts like magnetic voltage. A coil of N turns connected across a resistor appears as a magnetic inductor $L_M$ (obeying $U = -L_M \frac{d\Phi}{dt}$) having a value $L_M = \frac{N^2}{R}$ where here $R$ is the resistor value. Figure 7 shows the magnetic domain circuit with $U_0$ as the starting value for the mmf.

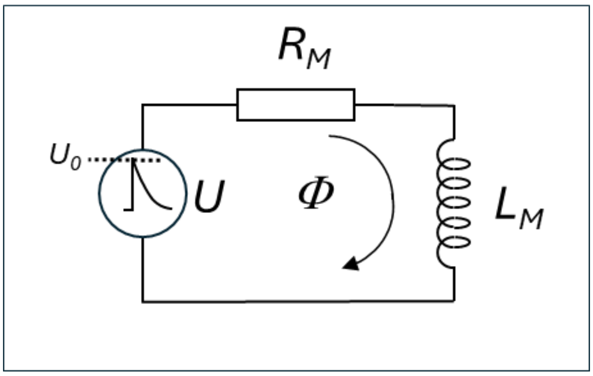


**Figure 7. Magnetic Domain Circuit**

Summing the mmfs around this circuit gives:-

$$L_M \frac{d\Phi}{dt} + \Phi R_M = U_0 exp\left(-\frac{t}{\tau}\right)$$

Where $U_0$ is the peak mmf value at $t = 0$ and $\tau$ is the time-constant. This can be arranged into the differential equation:-

$$\frac{d\Phi}{dt} + \frac{R_M}{L_M}\Phi = \frac{U_0}{L_M} exp\left(-\frac{t}{\tau}\right)$$

That is a linear equation of first order having the general form $\frac{dy}{dx} + Py = Q$ that has a known solution that involves the integrals of $P$ and $Q$.

The solution is:-

$$\Phi = \frac{U_0}{R_M - \frac{L_M}{\tau}} exp\left(-\frac{t}{\tau}\right)$$

Turning now to the electrical domain where the output voltage $V = -N\frac{d\Phi}{dt}$ we get

$$V = N\frac{U_0}{(\tau R_M - L_M)} exp\left(-\frac{t}{\tau}\right)$$

Using output power $P = \frac{V^2}{R}$ and maximum output energy $W = \int_0^\infty P.dt$ gives the energy as

$$W_{MAX} = \frac{{U_0}^2 N^2}{(\tau R_M - L_M)^2 R}$$

Using the previous example where the core is a closed magnetic circuit of length 15cm and area 1 cm$^2$, remanent $B_R = 0.5$ Tesla yielding a remanent magnetization $M$ close to 400,000 ampere-turns/m giving $U_0 = 60{,}000$, and τ = 2mS we obtain an energy of 6.3 Joules. That may be compared to the magnetization energy of only 0.19 millijoules! Achieving that maximum involves time going to infinity and infinitely small load resistance so it is impracticable, we must truncate the time axis to allow a repetitive process and use practical values. Figure 8 shows the B v. H result for this calculation method over the same decay time as in Figure 6.

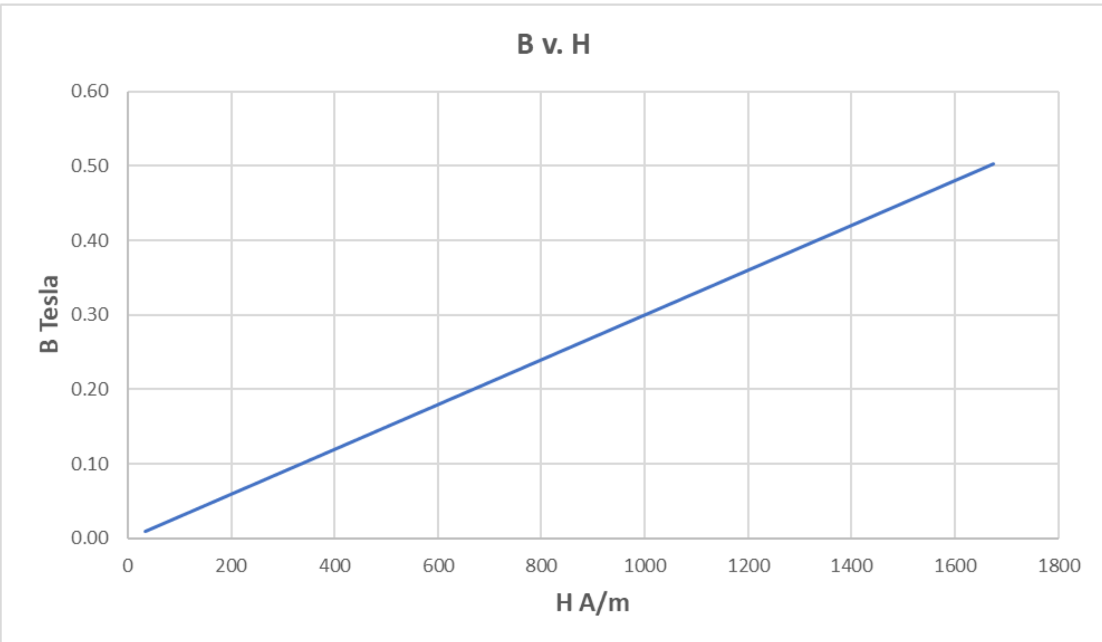


**Figure 8. B v. H Chart**

The two methods give virtually the same results with the same COP. The calculation in the original paper[2] gave the same peak value of H but a reduced output energy and reduced COP. Without experimental evidence to back these calculations it remains to be seen whether any are correct. The interesting thing is that they all predict COPs much greater than unity, indicating some external source of energy that must be the thermal agitation of the electron spins responsible for the magnetization of the core. If so then we have a method for extracting thermal energy from the environment and turning it into electrical energy.

**References**


[1] B v. H and Flux v. mmf Loops

https://www.overunityresearch.com/index.php?action=dlattach;topic=4659.0;attach=51158

[2] Using Natural (thermally driven) Demagnetization to Create Electrical Energy.

https://www.overunityresearch.com/index.php?action=dlattach;topic=4659.0;attach=51084