Parallel Magnetic Circuits

Fig. 7(a) shows a magnetic core with an air gap. A coil with ***N*** number of turns is wound around one limb of the core. If ***i*** is the current through the coil, it will produce a flux (***Φ***) in the core. This flux will link the core. A portion (***Φ₂***) of the flux will link the central limb with the air gap and the flux ***Φ₁*** links the other limb of the core. Fig. 7(a) shows the core with the coil and the flux paths. Fig. 7(b) shows the electrical equivalent of the magnetic circuit. It shows an example of a series-parallel magnetic circuit.

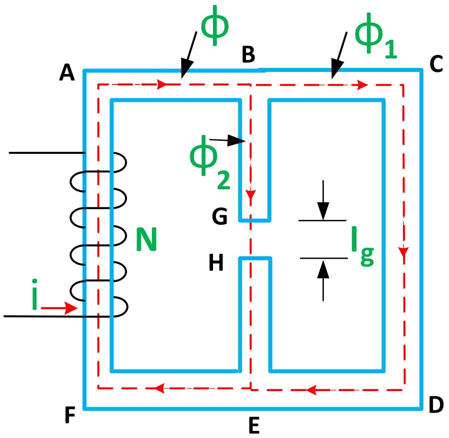

Fig. 7(a)

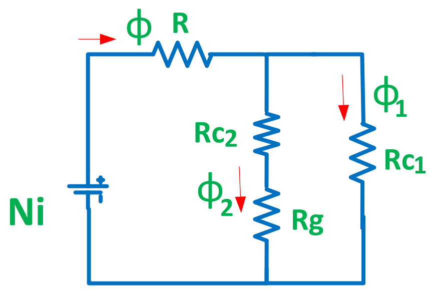

Fig. 7(b)

In Fig. 7(b), the source represents the mmf (***F* =*Ni***). The flux path (BAFE) with reluctance ***R*** has a flux ***Φ***. The flux ***Φ₁*** links the core BCDE. The reluctance of this flux path is ***R_C1***. The second path BGHE with flux ***Φ₂*** has two reluctances in series. In this, ***R_C2*** represents the reluctance of the core part and ***R_g*** is the reluctance of the air gap. The values of the reluctances depend on the dimensions, the effective length, the cross sectional area, and the permeability of the material.

Inductance

A coil wound on a magnetic core can be represented by an ideal circuit element, called inductance. Inductance is defined as the flux linkage of the coil per unit current. Flux linkage is given as

$$\lambda = N\phi$$

$$L = \frac{\lambda}{i} = \frac{N\Phi}{i} = \frac{NBA}{i}$$

where **λ** is the flux linkage, ***B*** is the flux density and ***A*** is the cross-sectional area. If ***H*** is the magnetic field intensity and ***lc*** is the length of the core, then

$$\boldsymbol{Hl_c = Ni}$$
$$\Rightarrow \boldsymbol{i = \frac{Hlc}{N}}$$

$$\boldsymbol{L = \frac{NBA}{i} = \frac{N\mu HA}{i} = \frac{N\mu HA}{Hlc/N}}$$

$$\boldsymbol{L = \frac{N^2}{l_c/\mu A} = \frac{N^2}{R}}$$

This represents the inductance in terms of the number of turns of the coil and the reluctance of the core.

Hysteresis (B-H Characteristic)

For various applications, a time-varying or ac current is applied to the coil. An ac current changes its amplitude with time. Hence, the magnetic field intensity changes as it is proportional to the current. The flux density is equal to the product of permeability and magnetic field intensity. It is expected that the flux density and the flux will increase with the increase of current and it should decrease with the decrease of current. Fig. 8 shows a typical B-H characteristic.

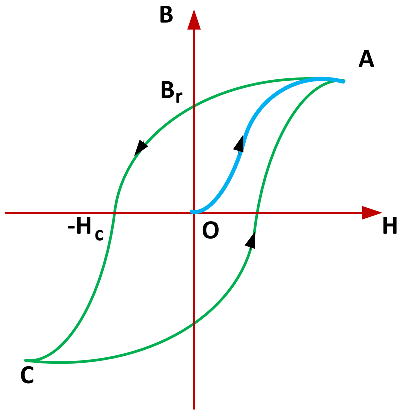

Fig. 8

The B-H characteristics of a magnetic material is non-linear. The flux density increases from zero value (0A path) to a maximum value when the material is magnetically saturated. If the field intensity is decreased then the flux density is decreased, but it follows a different path (AC). The flux density has a non-zero value even when the field intensity is zero. This non-zero value of flux density (***Br***) is called the residual flux density, Engineers have used this property of residual magnetism for the design of various electro-mechanical energy conversion devices. The non-zero value ***(Hc)*** of magnetic field intensity for zero flux density is called coercivity on coercive force. This magnetization and demagnetization of the magnetic material can cause loss of energy. This loss is known as Hysteresis loss. The power loss is given as

$$P_H = k_h B_{\max}^n f$$

where ***Kh*** is the hysteresis constant, ***Bmax*** is the maximum value of the flux density and ***f*** is the frequency of the ac current in the coil. ***n*** is a constant which defends on the magnetic material and its value varies between 1.5 to 2.5 for a typical magnetic material. There is another form of power loss in a magnetic material. This loss is termed as eddy current loss. It is given as

$$P_e = K_e B_{\max}^2 f^2$$

where ***Ke*** is the eddy current loss constant. The eddy current loss is proportional to the square of the flux density and square of the frequency. Voltages are induced in the magnetic material when it experiences a time varying flux. A current will flow in the magnetic material if a closed path is present. Based on the resistance of the path, there will be power loss which is known as eddy current loss. Eddy current loss has been used for design of induction cookers.

Example: Fig. 9(a) shows a parallel magnetic circuit. The core material has a relative permeability of 4000. The number of turns is given as $N = 700$ and the cross-sectional area of the core is $A_c = 4 \times 4\ cm^2$. The length of the air gap is $l_g = 0.02\ cm$. Find the required exciting current if the flux in the central limb is **0.02 Wb**.

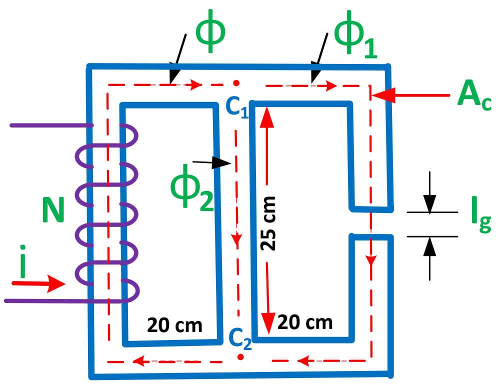

Fig. 9(a)

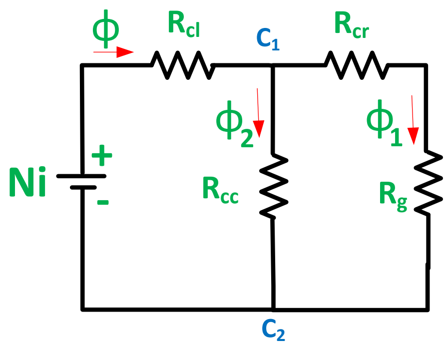

Fig. 9(b)

The equivalent electrical circuit is shown in Fig. 9(b). $\boldsymbol{R_{cl}}$ is the reluctance of the left portion of the core (left from $\boldsymbol{c_1 c_2}$). $\boldsymbol{R_{cc}}$ is the reluctance of the central limb and $\boldsymbol{R_{cr}}$ is the reluctance of the right portion of the core (right from $\boldsymbol{c_1 c_2}$). $\boldsymbol{R_g}$ is the reluctance of the air gap.

Length of the left side (left from $\boldsymbol{c_1 c_2}$) of the core $\boldsymbol{l_l = 2 \times (20+4) + (25+4) = 77\ cm}$

Length of the right side of the core $\boldsymbol{l_r = 2 \times (20+4) + (25+4) - 0.02 = 76.98\ cm}$

Length of the central limb of the core $\boldsymbol{l_c = 25 + 4 = 29\ cm}$

Length of the air gap $\boldsymbol{l_g = 0.02\ cm}$

$$\boldsymbol{R_{cl} = \frac{77 \times 10^{-2}}{4\pi \times 10^{-7} \times 4000 \times 16 \times 10^{-4}} = 0.0957 \times 10^6}$$

$$\boldsymbol{R_{cr} = \frac{76.98 \times 10^{-2}}{4\pi \times 10^{-7} \times 4000 \times 16 \times 10^{-4}} = 0.0957 \times 10^6}$$

$$\boldsymbol{R_{cc} = \frac{29 \times 10^{-2}}{4\pi \times 10^{-7} \times 4000 \times 16 \times 10^{-4}} = 0.0361 \times 10^6}$$

$$\boldsymbol{R_g = \frac{0.02 \times 10^{-2}}{4\pi \times 10^{-7} \times 16 \times 10^{-4}} = 0.0995 \times 10^6}$$

Mmf of the central limb = $\boldsymbol{F_{c1c2} = \phi_2 \times R_{cc} = 0.02 \times R_{cc} = 722\ AT}$

Mmf of the central limb is equal to the mmf of the right side of the core. Hence,

$$\boldsymbol{\phi_1 = \frac{F_{c1c2}}{R_{cr} + R_g} = 3.699 \times 10^{-3}\ Wb}$$

Total flux $\boldsymbol{\phi = \phi_1 + \phi_2 = 23.699 \times 10^{-3}\ Wb}$

Total mmf required is $\boldsymbol{F = \phi \times R_{cl} + F_{c1c1} = 2989.99\ AT}$

The required exciting current will be $\boldsymbol{i = \frac{F}{N} = 4.27\ A}$