Definition of MMF, Flux and Reluctance - Leakage Factor

Magneto motive force(MMF)

Magnetomotive force, also known as magnetic potential, is the property of certain substances or phenomena that gives rise to magnetic fields. Magnetomotive force is analogous to electromotive force or voltage in electricity .The standard unit of magnetomotive force is the ampere-turn (AT), represented by a steady, direct electrical current of one ampere (1A) flowing in a single-turn loop of electrically conducting material in a vacuum .

$$\text{Magnetomotive force (mmf)}F = NI(\text{ampere} - \text{turns})$$

Sometimes a unit called the gilbert (G) is used to quantify magnetomotive force. The gilbert is defined differently, and is a slightly smaller unit than the ampere-turn. To convert from ampere-turns to gilberts, multiply by 1.25664. Conversely, multiply by 0.795773.

Flux

Magnetic flux (most often denoted as Φ_m), is the amount of **magnetic field** (also called "**magnetic flux**density") passing through a surface (such as a conducting coil). The SI unit of **magnetic flux** is the weber (Wb) (in derived units: volt-seconds). The CGS unit is the maxwell.

Reluctance

Magnetic reluctance, or **magnetic resistance**, is a concept used in the analysis of magnetic circuits. It is analogous to resistance in an electrical circuit, but rather than dissipating electric energy it stores magnetic energy. In likeness to the way an electric field causes an electric current to follow the path of least resistance, a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. It is a scalar, extensive quantity, akin to electrical resistance. The unit for magnetic reluctance is inverse henry, H^{-1}.Reluctance depends on the dimensions of the core as well as its materials.

$$\text{Reluctance} = l/\mu A.(\text{A-t/Wb})$$

Leakage flux

The total magnetic flux in an electric rotating machine or transformer divided by the useful flux that passes through the armature or secondary winding. Also known as leakage coefficient.

There are three categories of magnetic materials: *diamagnetic*, in which the material tends to exclude magnetic fields; *paramagnetic*, in which the material is slightly magnetized by a magnetic field; and *ferromagnetic*, which are materials that very easily become magnetized. The vast majority of materials do not respond to magnetic fields, and their permeability is very close to that of free space. The materials that readily accept magnetic flux—that is, ferromagnetic materials—are principally iron, cobalt, and nickel and various alloys that include these elements. The units of permeability are webers per amp-turn-meter (Wb/A-t-m).

The permeability of free space is given by

$$\text{Permeability of free space } \mu_0 = 4\pi \times 10{-}7 \text{ Wb/A-t-m}$$

Oftentimes, materials are characterized by their *relative permeability*, μ_r, which for ferromagnetic materials may be in the range of hundreds to hundreds of thousands. As will be noted later, however, the relative permeability is not a constant for a given material: It varies with the magnetic field intensity. In this regard, the magnetic analogy deviates from its electrical counterpart and so must be used with some caution.

$$\text{Relative permeability} = \mu_r = \mu\mu_0$$

Magnetic flux density

Another important quantity of interest in magnetic circuits is the magnetic flux *density*, *B*. As the name suggests, it is simply the "density" of flux .Unit is Tesla.

$$\text{Magnetic flux density } B = \varphi/A \text{ webers/m}^2 \text{ or tesla (T)}$$

Magnetic field intensity

The magnetic field intensity is defined as the magnetomotive force (mmf) per unit of length around the magnetic loop. With *N* turns of wire carrying current i, the mmf created in the circuit is *Ni* ampere-turns. With *l* representing the mean path length for the magnetic flux, the magnetic field intensity is therefore

$$\text{Magnetic field intensity } H = NI/L \text{ ampere-turns/meter}$$

We arrive at the following relationship between magnetic flux density *B* and magnetic field intensity as $B = \mu H$

Problems:

1.Given a copper core with: Susceptibility as $-9.7*10^6$,Length of core L = 1 m, Gap length g = .01 m, Cross sectional area A = .1 m, Current I = 10A,N = 5 turns. Find: B_g

Solution:

First we need to find the permeability of copper given by the equation $\mu = \mu_0(1+\chi_m)$, Now using the length, cross sectional area, and permeability of the core we can solve for reluctance R_c by:

$$R_c = \frac{L}{\mu A} = \frac{1}{1.2566 \times 10^{-6} \times .1} = 7.96 \times 10^6$$

Similarly, to get the reluctance of the gap

$$R_g = \frac{g}{\mu_0(\sqrt{A}+g)^2} = \frac{.01}{4 \times \pi \times 10^{-7}(\sqrt{.1}+.01)^2} = 74.8 \times 10^3$$

Now recall the equation for the magnetic field of a gap as seen in

$$B_g = \frac{NI}{(R_g R_c)((\sqrt{A}+g)^2}$$

$$B_g = \frac{5 \times 10}{74.8 \times 10^3 \times 7.96 \times 10^6 \times (\sqrt{.1}+.01)^2} = .789 \times 10^{-9}$$

2.A coils of 200 turns is wound uniformly over a wooden ring having a mean circumference of 600 mm and a uniform cross sectional area of 500 mm2 . If the current through the coil is 4 A, calculate: (a) the magnetic field strength, (b) the flux density, and (c) the total flux

Answer: 1333 A/m, 1675×10-6 T, 0.8375 mWb

3.A mild steel ring having a cross sectional area of 500 m2 and a mean circumference of 400 mm has a coil of 200 turns wound uniformly around it. Calculate: (a) the reluctance of the ring and (b) the current required to produce a flux of 800 mWb in the ring. (Given that mr is about 380).

Answer: 1.677×106 A/Wb, 6.7 A.

Reluctance in Series (Composite Magnetic Circuit)

A magnetic circuit having a number of parts of different magnetic materials and different dimensions carrying the same magnetic field is called a Series Magnetic Circuit. It is also known as Composite Magnetic Circuit. One such circuit is shown in figure 2.1

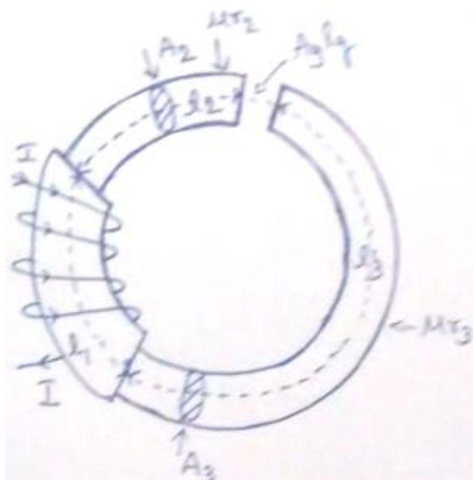

Figure 2.1 Reluctance in series

It consist of 3 different magnetic material and one air gap . Since materials are different the permeability are different. Assume that the length and the areas of cross-section are also different . Then the reluctance of each path will be different.

As the reluctance are in series, the total reluctance is the sum of the reluctance of different paths.

Total reluctance = $S = S_1 + S_2 + S_3 + Sg$

Total mmf = flux x reluctance

$$= \varnothing \times S = \varnothing\,(l_1/\mu_0\mu_{r1}A_1 + l_2/\mu_0\mu_{r2}A_2 + l_3/\mu_0\mu_{r3}A_3 + l_g/\mu_0A_g)$$

$$= l_1\varnothing / A_1\mu_0\mu_{r1} + l_2\varnothing / A_2\mu_0\mu_{r2} + l_3\varnothing / A_3\mu_0\mu_{r3} + l_g\varnothing / A_g\mu_0$$

$$= l_1B_1/\mu_0\mu_{r1} + l_2B_2/\mu_0\mu_{r2} + l_3B_3/\mu_0\mu_{r3} + l_gB_g/\mu_0$$

Total mmf = $H_1l_1 + H_2l_2 + H_3l_3 + H_gl_g$

Note: The following formulae are used in the above expression

1. $\phi / A = B$
2. $B/\mu_0\mu_r = H$

Reluctance in Parallel (Parallel Magnetic Circuits)

If a magnetic circuit has 2 or more paths for the magnetic flux, it is called a parallel magnetic flux.

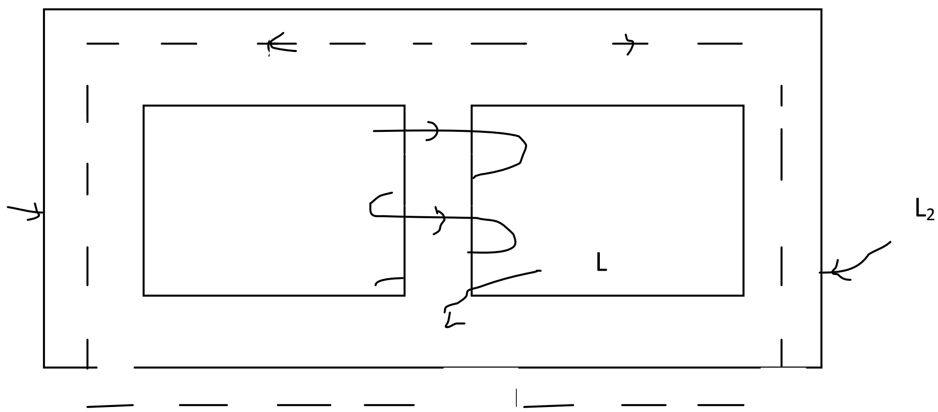

Figure 2.2 Reluctance in Parallel

On the central limb AB, a current carrying coil ia wound. The mmf in the coil sets up a magnetic flux ϕ_1 in the central limb. It is further divided in to 2 paths. They are

1. The path ADCB which carries flux ϕ_2 and
2. The path AFEB which carries flux ϕ_3

These 2 path are in parallel. The ampere turns (mmf) for this circuit is equal to the ampere turns required for any one of these paths.

$$\phi_1 = \phi_2 + \phi_3$$

Reluctance of path BA = $S_1 = l_1/\mu_0\mu_{r1}A_1$

Reluctance of path ADCB = $S_2 = l_2/\mu_0\mu_{r2}A_2$

Reluctance of path AFEB = $S_3 = l_3/\mu_0\mu_{r3}A_3$

Mmf required for path ADCB = $\phi_2 \times S_2$

Mmf required for path AFEB = $\phi_3 \times S_3$

Mmf for parallel path = $\phi_2 \times S_2 = \phi_3 \times S_3$

Mmf required for path BA = $\phi_1 \times S_1$

Total mmf required = mmf for path BA + mmf required for path ADCB or path AFEB

Total mmf (or) AT = $\phi_1 \times S_1 + \phi_2 \times S_2 = \phi_1 \times S_1 + \phi_3 \times S_3$

Analogy of Electrical and Magnetic Circuits

S.No.	Magnetic Circuit	Electric Circuit
1.	Magnetic Flux, ϕ webers	Electric current, I amperes
2.	Magnetomotive force, NI	Electromotive force, V Volts
3.	Reluctance, S AT/Wb	Resistance, R Ohms
4.	ϕ = NI/s	I = V/R
5.	$S = l/\ \mu_0\mu_{r2}A$	$R = \rho l/A$
6.	Magnetic Intensity H = NI/l AT/m	Electric Intensity, E = V/d Volts/m
7.	Magnetic Flux Density, B Wb/m^2	Current Density, J A/m^2
8.	Permeability $\mu = \mu_0\mu_r$	Permitivity $\epsilon = \varepsilon_0\ \varepsilon_r$
9.	Magnetic flux does not flow. It only links with the coil.	Electric current flows through the coil.
10.	Energy is required only for creating the magnetic flux, not for maintaining it.	Current flow involves continuous requirement for energy.
11.	The reluctance varies with flux density.	The resistance remains practically constant with the current strength.

Worked Example

1. Find the ampere turns required to produce a flux of 0.4 milliweber in the airgap of a circular magnetic circuit which has an airgap of 0.5mm. The iron ring has 4sq.cm cross section and 63cm mean length. The relative permeability of iron is 1800 and the leakage co-efficient is 1.15

Sol. Given Data:

Flux in the airgap = Øg= Øuseful= o.4 weber

Length of airgap lg = .5mm

Cross-section of the iron ring A = $4 \times 10^{-4} m^2$

Mean length of iron ring = l = 63 cm

Relative permeability of iron = 1800

Leakage co-efficient λ = 1.15

This magnetic circuit has two materials airgap and iron

Total mmf = mmf in airgap + mmf in iron

Flux = mmf/reluctance

Mmf = flux x reluctance

a) For airgap: mmf = Øuseful x S_g

$= 0.4 \times 10^{-4} \times (lg/\mu_0 A)$

$= 0.4 \times 10^{-4} ((0.5 \times 10^{-3})/(4\pi \times 10^{-7} \times 4 \times 10^{-4}))$

= 397.88 AT

b) For iron path flux = Øi = λ x Øuseful

$= 1.15 \times 0.4 \times 10^{-3}$

$= 0.46 \times 10^{-3}$wb

Reluctance, Si = $(l/(\mu_0 \mu_r A))$

$= 0.63/(4\pi x10^{-7}x1800x4x10^{-4})$

$= 696302.876$ AT/Wb

Mmf = $Ø_i$ x S_i

$= 0.46x10^{-3}x696302.876$

= 320.29AT

Total ampere turns required : 397.88+320.29 = 718 AT

Questions

Part A

1. What is a Series Magnetic circuit?
2. What is a parallel magnetic circuit?
3. Give the expression for the Total MMF of a composite magnetic circuit.
4. Give the expression for the Total MMF of a parallel magnetic circuit.
5. What is reluctance?
6. Define magneto motive force.
7. Define magnetic flux
8. What is leakage factor?
9. Give the correlation between flux, mmf and reluctance.
10. Write the correlation between magnetic flux density and magnetic field intensity.
11. Define magnetic flux density.

Part B

1. Find the ampere turns required to produce a flux of 0.4milliweber in the air gap of a circular magnetic circuit which has an air gap of 0.5mm. The iron ring has 4 sq.cm cross section and 63cm mean length. The relative permeability of iron is 1800 and the leakage co-efficient is 1.15.
2. Explain and derive the expression for the total MMF of a composite and parallel magnetic circuit.
3. An iron ring 100cm mean circumference is made from round rod of area of cross-section $10cm^2$.Its permeability is 500. If it is wound with 200 turns, What current will be required to produce a flux of 100,000 lines?
4. An iron ring of mean length 50cm has an air gap of 1mm and a winding of 200 turns. If the permeability of the iron is 400, when a current of 1.25 ampere flows through the coil, Find the flux density.
5. An iron ring of 1cm radius is bent to a ring of mean diameter 30cm and wound with 250 turns of wire. Assume the relative permeability of iron as 800. An air gap of 0.1cm is cut across the bent ring. Leakage factor is 1.1. Calculate the current required to produce a useful flux of $2x10-^{7}$ weber.
6. Derive the correlation between flux, mmf and reluctance.
7. An iron rod of 1 cm radius is bent to a ring of mean diameter 30cms and wound with 250 turns of wire.Assume the relative permeability of iron as 800.An air gap of 0.1 cm is cut across the bent ring.Leakage factor is 1.1.Calculate the current required to produce a useful flux of $2*10^{-7}$ weber.
8. An iron ring 100 cms mean circumference and of circular cross section 5 cm2 has a saw cut of 2mm length.It is wound with 500 turns of wire.If 0.5 milliweber flux exists across

the air gap ,what will be the value of the exciting current?Take coefficient of leakage =1.26. and relative permeability of iron is 500