Electromagnetism

Day 11

Tutorial on magnetic circuits

ILOs – Day 11 (Tutorial 1)

- Solve numerical problems related to magnetic circuits

#1) **An iron ring has cross section area of 100 mm² and mean diameter of 10 cm. Calculate the MMF required to produce a flux of 200 μWb. Assume relative permeability of iron as 800.**

Length of flux path = mean length of the ring $l = \pi d = \pi \times 10 \times 10^{-2} = 0.314$ m

Area of cross section of the ring, A = 100 $\times 10^{-6}$ m²

Relative permeability of iron, $\mu_r = 800$

$$\therefore \text{Reluctance} = \frac{l}{\mu_0 \mu_r A} = \frac{0.314}{4\pi \times 10^{-7} \times 800 \times 100 \times 10^{-6}} = 3.123 \times 10^6$$

$$\phi = \frac{MMF}{\text{Reluctance}} \Rightarrow MMF = \phi \times \text{Reluctance}$$

$$= 200 \times 10^{-6} \times 3.123 \times 10^6 = 624.6\ AT$$

#2) **An iron ring of mean length 30 cm has an air gap of 2 mm and a coil with 200 turns on it. If relative permeability of iron is 300 when a current of 1 A flows through the coil; find the flux density.**

Length of flux path = mean length of the ring $l = 30$ cm = 0.3 m

Relative permeability	$\mu_r = 300$
Length of air gap	$l_1 = 2$ mm = 0.002 m
Number of turns in coil	$N = 200$
Current through coil	$I = 1$ A

$$\therefore MMF = NI = 200 \text{ AT}$$

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Relative permeability $\mu_r = 300$

Length of air gap $l_1 = 2 \text{ mm} = 0.002 \text{ m}$

Let, cross sectional area of the ring is A m^2.

$$\therefore \text{Resultant flux} \quad \phi = \frac{MMF}{\text{Reluctance}} = \frac{NI}{S} = \frac{NI}{\dfrac{l_1}{\mu_0 \mu_{r1} A_1} + \dfrac{l_2}{\mu_0 \mu_{r2} A_2}}$$

Putting $l_1 = 0.002$ m, $l_2 = 0.298$ m, $\mu_{r1} = 1$, $\mu_{r2} = 300$, and $A_1 = A_2 = A$.

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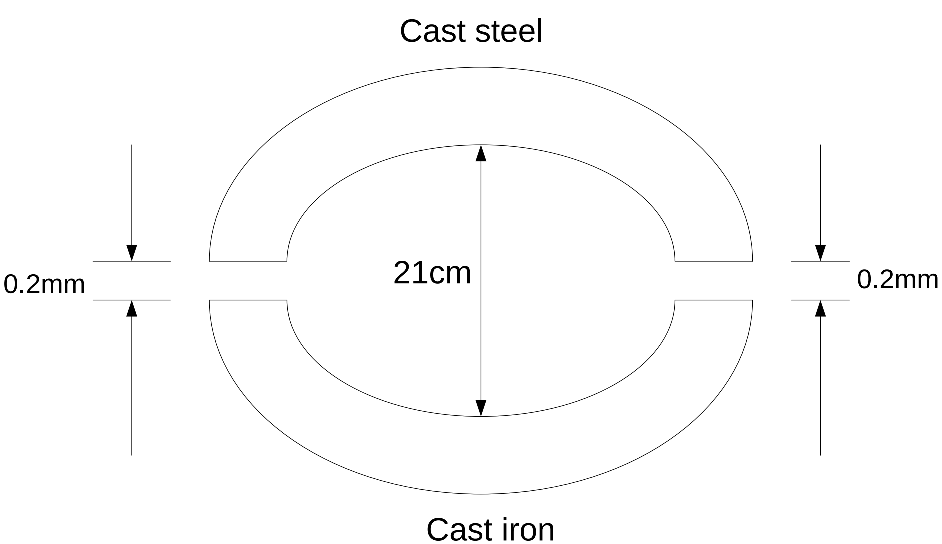
$l_1 = 0.002$ m, $l_2 = 0.298$ m, $\mu_{r1} = 1$, $\mu_{r2} = 300$, and $A_1 = A_2 = A$

$$\phi = \frac{200}{\dfrac{0.002}{4\pi \times 10^{-7} \times 1 \times A} + \dfrac{0.298}{4\pi \times 10^{-7} \times 300 \times A}} = 0.085A \text{ Wb}$$

$\therefore$ Flux density $B = \dfrac{\phi}{A} = \dfrac{0.085A}{A} = 0.085$ Wb/m^2

#3) **A ring having a mean diameter of 21cm, and a cross section of $10cm^2$ is made of two semi circular sections of cast-iron and cast-steel respectively with each joint having reluctance equal to air-gap of 0.2mm as shown in figure. Determine the ampere-turns required to produce a flux of 0.8mWb. The relative permeabilities of cast-iron and cast-steel are 166 and 800 respectively. Neglect fringing and leakage effects. .**



$$\phi = \frac{MMF}{\text{Reluctance}} = \frac{NI}{S} = \frac{AT}{S}$$

$$\therefore AT = \phi \times S$$

For a series magnetic circuit, the total AT required will be summation of ATs required for steel, iron, and air separately:

$$AT = \phi \times \left[S_{St} + S_{Fe} + S_{air} \right] = \phi \times \left[\frac{l_1}{\mu_0 \mu_{r1} A_1} + \frac{l_2}{\mu_0 \mu_{r2} A_2} + \frac{l_3}{\mu_0 \mu_{r3} A_3} \right]$$

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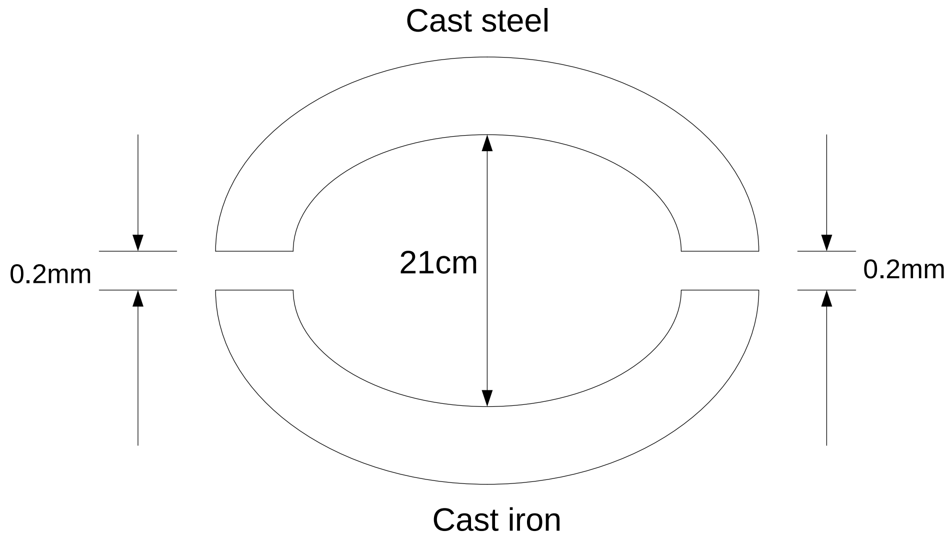
$A_1 = A_2 = A_3 = 10\ cm^2 = 10\text{x}10^{-4}\ m^2$

$l_3 = 2\text{x}0.2\ mm = 2\text{x}0.0002\ m$

$l_1 = l_2 \approx \pi\text{x}21\text{x}10^{-2}/2 = 0.33\ m$



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$$AT = \phi \times \left[S_{St} + S_{Fe} + S_{air} \right] = \phi \times \left[\frac{l_1}{\mu_0 \mu_{r1} A_1} + \frac{l_2}{\mu_0 \mu_{r2} A_2} + \frac{l_3}{\mu_0 \mu_{r3} A_3} \right]$$

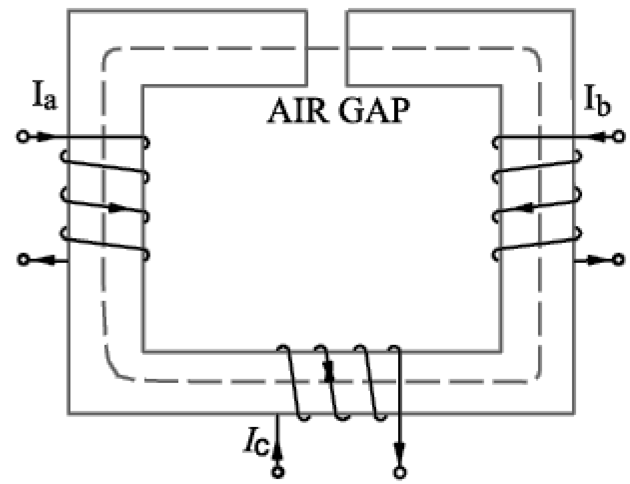
$A_1 = A_2 = A_3 = 10\ cm^2 = 10x10^{-4}\ m^2$
$l_3 = 2x0.2\ mm = 2x0.0002\ m$
$l_1 = l_2 \approx \pi x21x10^{-2}/2 = 0.33\ m$

$$\therefore AT = 0.8 \times 10^{-3} \times \left[\frac{0.33}{4\pi \times 10^{-7} \times 800 \times 10 \times 10^{-4}} + \frac{0.33}{4\pi \times 10^{-7} \times 166 \times 10 \times 10^{-4}} + \frac{2 \times 0.0002}{4\pi \times 10^{-7} \times 1 \times 10 \times 10^{-4}} \right]$$

$$AT = 0.8 \times 10^{-3} \times \left[328125 + 1581325 + 318310 \right] = 1782.2$$

#4) **A rectangular iron core has a mean length of magnetic path of 100 cm, cross-section of (2 cm × 2 cm), relative permeability of 1400 and an air-gap of 5 mm cut in the core. The three coils carried by the core have number of turns N_a = 335, N_b = 600 and N_c = 600 ; and the respective currents are 1.6 A, 4 A and 3 A. The directions of the currents are as shown. Find the flux in the air-gap.**

By applying the Right-Hand Thumb rule, it is found that fluxes produced by the current I_a *and* I_b *are directed in the* clockwise direction through the iron core whereas that produced by current I_c *is directed in the anticlockwise direction through the* core.

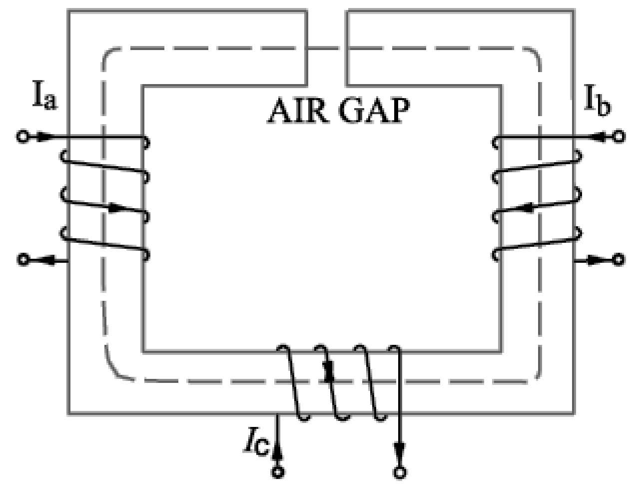


$\therefore$ Total MMF = $N_aI_a + N_bI_b - N_cI_c = 335\times1.6 + 600\times4 - 600\times3 = 1136\ \text{AT}$

Reluctance of the air-gap $= \dfrac{l_G}{\mu_0 A} = \dfrac{5\times10^{-3}}{4\pi\times10^{-7}\times4\times10^{-4}} = 9.95\times10^6\ \text{AT/Wb}$

Reluctance of iron path $= \dfrac{l_i}{\mu_0 A} = \dfrac{100\times10^{-2} - 5\times10^{-3}}{4\pi\times10^{-7}\times1400\times4\times10^{-4}} = 1.414\times10^6\ \text{AT/Wb}$

#4) **A rectangular iron core has a mean length of magnetic path of 100 cm, cross-section of (2 cm × 2 cm), relative permeability of 1400 and an air-gap of 5 mm cut in the core. The three coils carried by the core have number of turns N_a = 335, N_b = 600 and N_c = 600 ; and the respective currents are 1.6 A, 4 A and 3 A. The directions of the currents are as shown. Find the flux in the air-gap.**



$\therefore$ Total MMF = 1136 AT

Reluctance of the air-gap $= 9.95\times 10^6$ AT/Wb

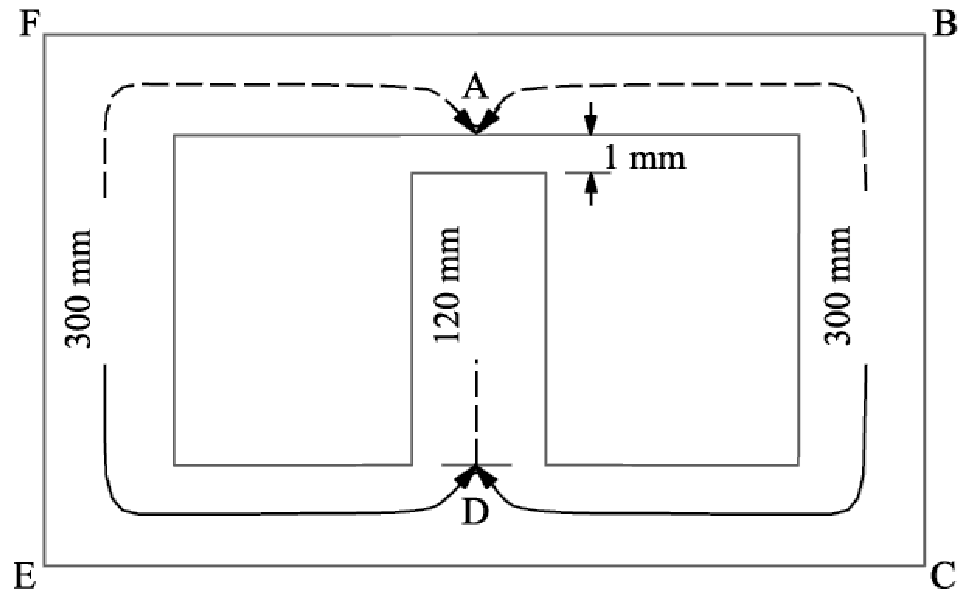
Reluctance of iron path $= 1.414\times 10^6$ AT/Wb

$\therefore$ Total reluctance, $S = 9.95\times 10^6 + 1.414\times 10^6 = 11.36\times 10^6$ AT/Wb

In the series circuit, flux in the air-gap is the same as in the iron core

$$\therefore \text{Air-gap flux, } \phi = \frac{MMF}{\text{Reluctance}} = \frac{1136}{11.36\times 10^6} = 100\times 10^{-6}\ \text{Wb} = 100\ \mu\text{Wb}$$

#5) A magnetic circuit made of mild steel is arranged as shown in Fig. The central limb is wound with 500 turns and has a cross-sectional area of 800 mm^2. Each of the outer limbs has a cross-sectional area of 500 mm^2. The air-gap has a length of 1 mm. Calculate the current required to set up a flux of 1.3 mWb in the central limb assuming no magnetic leakage and fringing. Mild steel required 3800 AT/m to produce flux density of 1.625 T and 850 AT/m to produce flux density of 1.3 T.



Central limb

Flux in the central limb, $\phi_c = 1.3\times10^{-3}$ Wb

Area of central limb, $A_c = 800\times10^{-6}$ m^2

∴ Flux density in central limb:

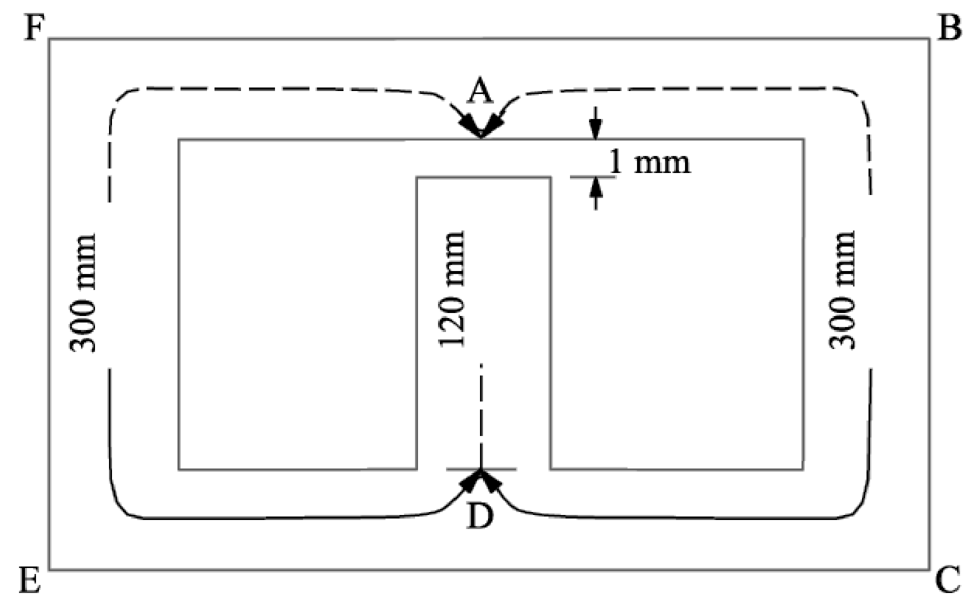
$$B_c = \frac{\phi_c}{A_c} = \frac{1.3\times10^{-3}}{800\times10^{-6}} = 1.625\ \text{T}$$

Corresponding value of H for this flux density is given as 3800 AT/m.

Since the length of the central limb is (l_c = 120-1 = 119) mm, MMF required is:

$$AT_c = H_c \times l_c = 3800 \times (119 \times 10^{-3}) = 452.2\ \ \text{AT}$$

#5) A magnetic circuit made of mild steel is arranged as shown in Fig. The central limb is wound with 500 turns and has a cross-sectional area of 800 mm^2. Each of the outer limbs has a cross-sectional area of 500 mm^2. The air-gap has a length of 1 mm. Calculate the current required to set up a flux of 1.3 mWb in the central limb assuming no magnetic leakage and fringing. Mild steel required 3800 AT/m to produce flux density of 1.625 T and 850 AT/m to produce flux density of 1.3 T.



Air gap

Since air gap is in the central limb, flux density in the air-gap is the same as that in the central limb, $B_{air} = 1.625\,\mathrm{T}$

Corresponding value of *H* for this flux density is given by:

$$H_{air} = \frac{B_{air}}{\mu 0} = \frac{1.625}{4\pi \times 10^{-7}} = 0.1293 \times 10^{7}\ \mathrm{AT/m}$$

Since the length of air gap is (l_{air} = 1) mm, MMF required for air gap is:

$$AT_{air} = H_{air} \times l_{air} = 0.1293 \times 10^{7} \times 1 \times 10^{-3} = 1293\ \mathrm{AT}$$

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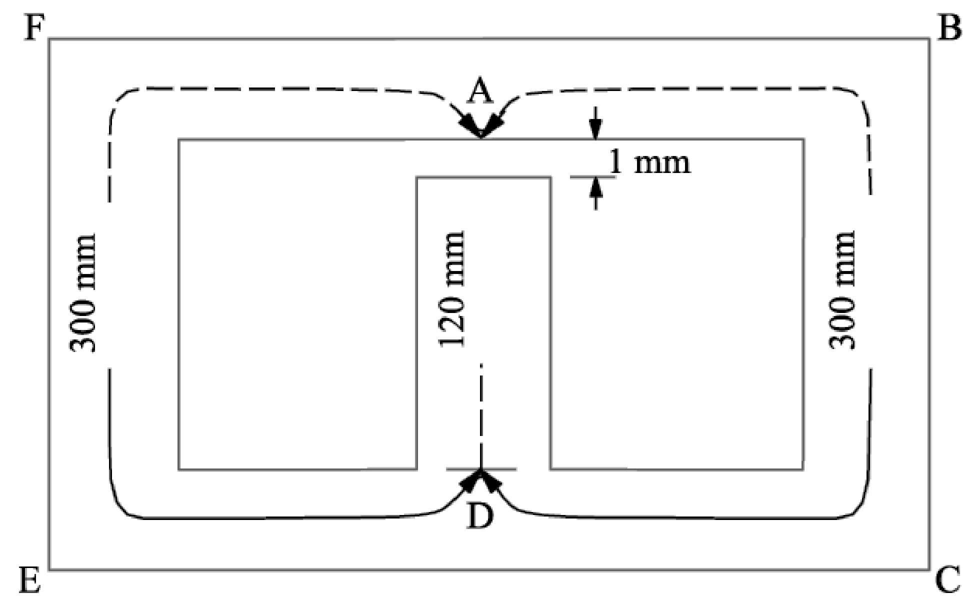

Outer limb

The flux of the central limb divides equally at point A in figure along the two parallel path *ABCD* and *AFED.* We may consider either path, say *ABCD* and calculate the MMF required for it. The same MMF will also send the flux through the other parallel path *AFED.*

Flux through *ABCD,* $\phi_o = \phi_c/2 = 1.3\times10^{-3}/2 = 0.65\times10^{-3}$ Wb

Area of outer limb, $A_o = 500\times10^{-6}$ m^2

$\therefore$ Flux density in outer limb: $B_o = \dfrac{\phi_o}{A_o} = \dfrac{0.65\times10^{-3}}{500\times10^{-6}} = 1.3\,\mathrm{T}$

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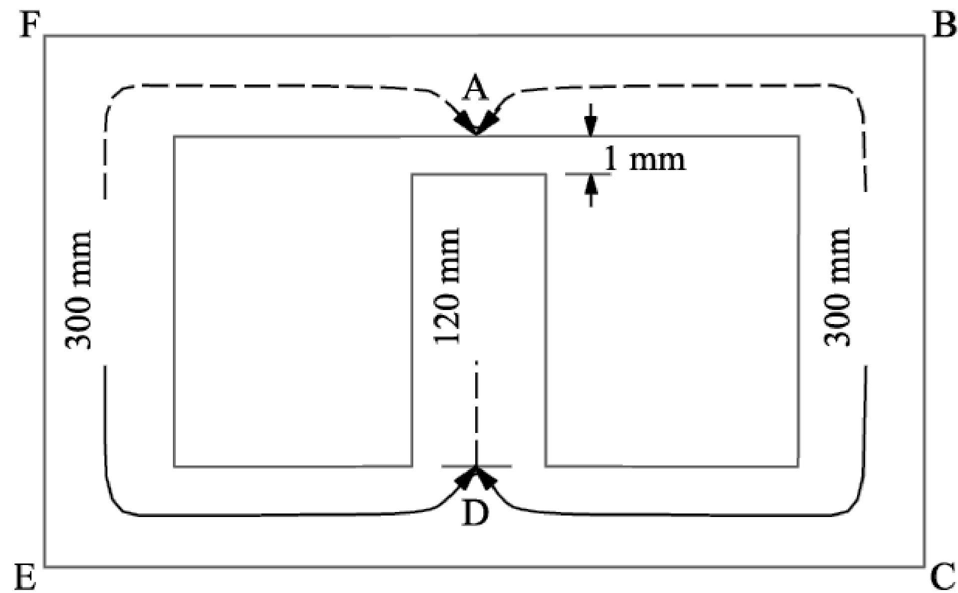

Outer limb

$$B_o = \frac{\phi_o}{A_o} = \frac{0.65\times10^{-3}}{500\times10^{-6}} = 1.3\,\mathrm{T}$$

The corresponding value of *H* for this value of B_o is given as 850 AT/m

Since the length of the outer limb ABCD is (l_o = 300) mm, MMF required is:

$$AT_o = H_o \times l_o = 850\times(300\times10^{-3}) = 255\ \text{AT}$$

Since the two outer limbs are in parallel, this MMF will also send the same flux in the parallel path *AFED* also.

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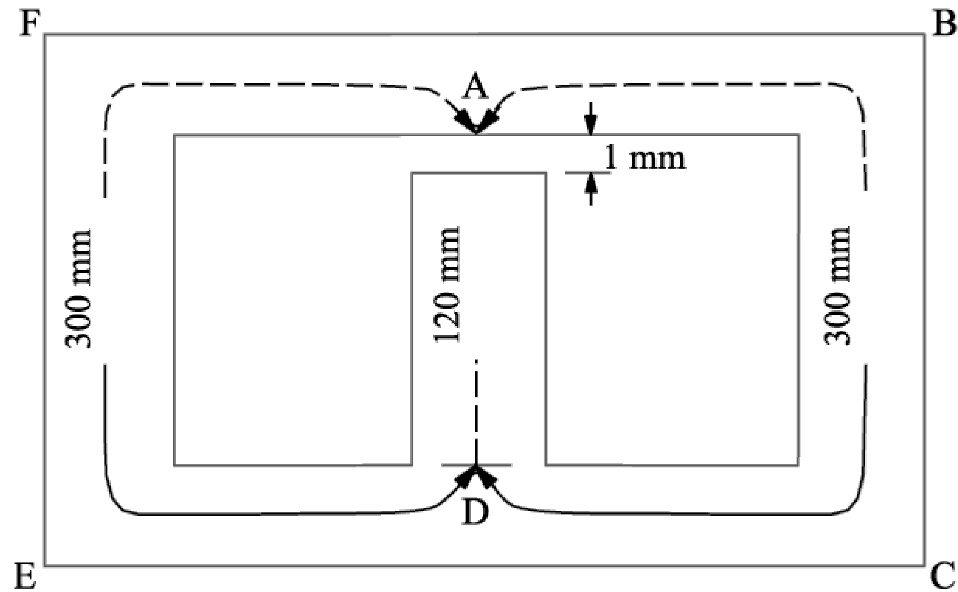
Total MMF

Central limb : $AT_c = 452.2$ AT

Air gap : $AT_{air} = 1293$ AT

Outer limb : $AT_o = 255$ AT

= 452.2+1293+255 = 2000.2 AT



Since the number of turns is 500, current required in coil: $I = 2000.2/500 \approx$ **4A**