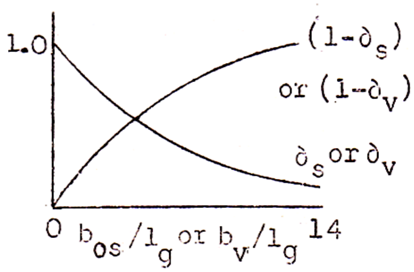
SOLVED PROBLEMS ON DC MACHINE MAGNETIC CIRCUIT

Example.1

Calculate the ampere-turns for the air gap of a dc machine given the following data.

Gross core length = 40cm, air gap length = 0.5cm, number of ducts = 5, width of duct = 1.0cm, slot pitch = 6.5cm, slot opening = 0.5cm, average value of flux density in the air gap =0.63T. Field form factor = 0.7, Carter's coefficient = 0.72 for opening/gap-length = 2.0 and Carter's coefficient=0.82 for opening/gap-length = 1.0.

Note: If the Carter's coefficient given is greater than 1.0, then it may be K_{gs} , K_{gv} or K_g. If the Carter's coefficient given is less than 1.0, then it may be δ_s or$(1-\delta_s)$, $\delta_v$or$(1-\delta_v)$. Therefore K_{gs} and K_{gv} are to be found out to find out K_g.When the ratio b_{os}/l_go r $b_v/l_g$is less like 1, 2 or 3 and the Carter's coefficient given is close to 1.0, then it may be $\delta_s$orδ_v. If it is close to zero, then it may be$(1-\delta_s)$, or $(1-\delta_v)$.



Carter's fringing coefficient curves

$AT_g = 800000 l_g K_g B_g$

K_g= Carter's gap expansion coefficient= $K_{gs} \times K_{gv}$

K_{gs}= Carter's gap expansion coefficient for the slots = $\dfrac{\lambda_s}{\lambda_s - b_{os}(1-\delta_s)}$

At $\dfrac{b_{os}}{l_g} = \dfrac{0.5}{0.5} = 1.0, \delta_s = 0.82$

$K_{gs} = \dfrac{6.5}{6.5 - 0.5(1-0.82)} = 1.014$

K_{gv}= Carter's gap expansion coefficient for the ducts = $\dfrac{L}{L - n_v b_v(1-\delta_v)}$

At $\frac{b_v}{l_g} = \frac{1.0}{0.5} = 2.0, \delta_v = 0.72$

$$K_{gv} = \frac{40}{40 - 5 \times 1(1 - 0.72)} = 1.04$$

$$K_g = 1.014 \times 1.04 = 1.054$$

Maximum value of flux density in the air gap$B_g = \frac{B_{av}}{K_f} = \frac{0.63}{0.7} = 0.9T$

$$AT_g = 800000 \times 0.5 \times 10^{-2} \times 1.054 \times 0.9 = 3794.4$$

Example.2

Calculate the ampere turns required for the air gap of a DC machine given the following data. Gross core length = 40cm, air gap length = 0.5 cm, number of ducts = 5, width of each duct = 1.0cm, slot pitch = 6.5cm, average value of flux density in the air gap = 0.63T. Field form factor = 0.7, Carter's coefficient = 0.82 for opening/gap length = 1.0 and Carter's coefficient = 0.82 for opening/gap length = 1.0, and Carter's coefficient = 0.72 for opening/gap length = 2.0.

$$AT_g = 800000 l_g K_g B_g$$

K_g= Carter's gap expansion coefficient= $K_{gs} \times K_{gv}$

K_{gs}= Carter's gap expansion coefficient for the slots = $\frac{\lambda_s}{\lambda_s - b_{os}(1-\delta_s)}$

Since $\frac{b_v}{l_g}$= 1.0/0.5 = 2.0, corresponds to ducts, opening/gap-length = 1.0, must correspond to slots.Therefore, opening of the slot $b_{os} = l_g$ x 1.0 = 0.5x1.0=0.5cm.

At $\frac{b_{os}}{l_g} = \frac{0.5}{0.5} = 1.0, \delta_s = 0.82$

$$K_{gs} = \frac{6.5}{6.5 - 0.5(1 - 0.82)} = 1.014$$

K_{gv}= Carter's gap expansion coefficient for the ducts = $\frac{L}{L - n_v b_v(1 - \delta_v)}$

At $\frac{b_v}{l_g} = \frac{1.0}{0.5} = 2.0, \delta_v = 0.72$

$$K_{gv} = \frac{40}{40 - 5 \times 1(1 - 0.72)} = 1.04$$

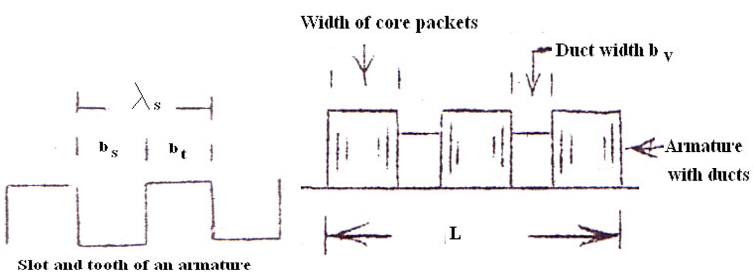
$$K_g = 1.014 \times 1.04 = 1.054$$

Maximum value of flux density in the air gap $B_g = \frac{B_{av}}{K_f} = \frac{0.63}{0.7} = 0.9T$

$$AT_g = 800000 \times 0.5 \times 10^{-2} \times 1.054 \times 0.9 = 3794.4$$

Example.3

Find the ampere-turns/pole required for a dc machine from the following data. Radical length of the air gap = 6.4mm, tooth width = 18.5 mm, slot width = 13.5mm, width of core packets = 50.8mm, width of ventilating ducts = 9.5mm, Carter's coefficient for slots and ducts = 0.27 and 0.21, maximum gap density = 0.8T. Neglect the ampere turns for the iron parts.



$$\text{AT/pole} = \text{AT}_\text{Y} + \text{AT}_\text{p} + \text{AT}_\text{g} + \text{AT}_\text{t} + \text{AT}_\text{c}$$

$$= AT_{iron} + AT_g$$

$= AT_g$ as the ampere turns for the iron parts is to be neglected

$$= 800000 l_g K_g B_g$$

$$K_g = K_{gs} \times K_{gv}$$

$$K_{gs} = \frac{\lambda_s}{\lambda_s - b_{os}(1-\delta_s)}$$

Slot pitch $\lambda_s = b_t + b_s = 18.5 + 13.5 = 32\text{mm}$

Opening of the slot $b_{os} = b_s = 13.5\text{mm}$ if an open slot is assumed.

At $\frac{b_{os}}{l_g} = \frac{13.5}{6.4} = 2.1, (1 - \delta_s) = 0.27$

$$K_{gs}= \frac{32}{32 - 13.5 \times 0.27} = 1.13$$

$$K_{gv}= \frac{L}{L - n_v b_v(1-\delta_v)}$$

$L =$ width of the core packets + width of ventilating ducts i.e.$n_v b_v$

$$= 50.8 + 9.5 = 60.3 \text{ mm}$$

$$K_{gv}= \frac{60.3}{60.3 - 9.5 \times 0.21} = 1.03$$

$$K_g= 1.13 \times 1.03 = 1.17$$

$$AT/pole = 800000 \times 6.4 \times 10^{-3} \times 1.17 \times 0.8 = 4792.3$$

Example.4

Find the ampere turns required for the air gap of a 6pole, lap connected dc machine with the following data. No load voltage = 250V, air gap length = 0.8cm, pole pitch = 50cm, pole arc = 33cm, Carter's coefficient for slots and ducts = 1.2, armature conductors = 2000, speed = 300RPM, armature core length = 30cm.

$$AT_g = 800000 l_g K_g B_g$$

$$K_g= K_{gs} \times K_{gv}$$

$$B_g = \frac{B_{av}}{K_f \ or \ \psi}$$

$$B_{av} = \frac{P\phi}{\pi DL}$$

$$\phi = \frac{60EA}{ZNP} = \frac{60 \times 250 \times 6}{2000 \times 300 \times 6} = 0.025\text{Wb}$$

Since $\tau = \frac{\pi D}{P}, \pi D = \tau \times P = 50 \times 6 = 300\text{cm}$

$$B_{av} = \frac{6 \times 0.025}{\pi \times 0.3} = 0.17\text{T}$$

$$\psi = \frac{pole\ arc}{pole\ pitch} = \frac{33}{50} = 0.66$$

$$B_g = \frac{0.17}{0.66} = 0.25T$$

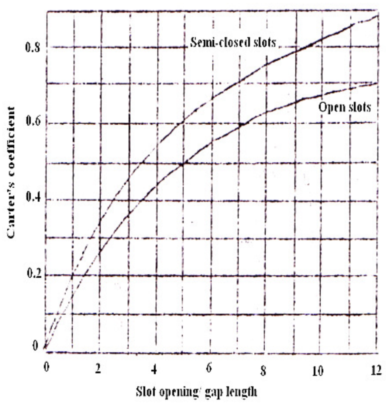
OR

$$B_g = \frac{P\phi}{\psi \pi D L} = \frac{\phi}{\psi \frac{\pi D}{P} L} = \frac{\phi}{\psi \tau L} = \frac{0.025}{0.33 \times 0.3} = 0.25\text{T}$$

$$AT_g = 800000 \times 0.8 \times 10^{-2} \times 1.2 \times 0.25 = 1920$$

Example.5

Calculate the ampere turns for the air gap of a machine using the following data. Core length = 32cm, number of ventilating ducts = 4, width of duct = 1.0cm, pole arc of ventilating ducts = 4, width of duct = 1.0cm, pole arc = 19cm. Slot pitch = 5.64 cm, semi-closed slots with slot opening = 0.5cm, air gap length = 0.5cm, flux/pole = 0.05Wb.



Carter's coefficient curves

$$AT_g = 800000 l_g K_g B_g$$

$$K_g = K_{gs} \times K_{gv}$$

$$K_{gs} = \frac{\lambda_s}{\lambda_s - b_{os}\,(1-\delta_s)}$$

At $\frac{b_{os}}{l_g} = \frac{0.5}{0.4} = 1.0, (1 - \delta_s)$ obtained from Carter's fringing coefficient curve is 0.18

$$K_{gs} = \frac{5.64}{5.64 - 0.5 \times 0.18} = 1.016$$

$$K_{gv} = \frac{L}{L - n_v\, b_v (1 - \delta_v)}$$

At $\dfrac{b_v}{l_g} = \dfrac{1.0}{0.5} = 2.0, (1-\delta_v)$ obtained from Carter's fringing coefficient curve

corresponding to open slots is 0. 28. Curve corresponding to open slot is considered because ducts are similar to open type of slots.

$$K_{gv} = \frac{32}{32 - 4 \times 1 \times 0.28} = 1.04$$

$$K_g = 1.016 \times 1.04 = 1.06$$

$$B_g = \frac{B_{av}}{\psi} = \frac{P\phi}{\psi \pi D L} = \frac{\phi}{\psi \frac{\pi D}{P} L} = \frac{\phi}{\psi \tau L} = \frac{0.05}{0.19 \times 0.32} = 0.82\text{T}$$

$$AT_g = 800000 \times 0.5 \times 10^{-2} \times 1.06 \times 0.82 = 3476.8$$

Example.6

A DC machine has an armature diameter of 25cm, core length of 12cm, 31 parallel slots 1.0cm wide and 3.0cm deep. Insulation on the lamination is 8.0%. The air gap is 0.4cm long and there is one radial duct 1cm wide in the core. Carter's coefficient for the slots and the duct is 0.68. Determine the ampere turns required for the gap and teeth if the flux density in the gap is 0.7T. The magnetization curve for the iron is:

Flux density in tesla	1.4	1.6	1.8	2.0	2.1	2.2	2.3
ampere- turns/cm	18	30	65	194	344	630	1200

$$AT_g = 800000 l_g K_g B_g$$

$$K_g = K_{gs} \times K_{gv}$$

$$K_{gs} = \frac{\lambda_s}{\lambda_s - b_{os}(1-\delta_s)}$$

$$\text{Slot pitch}\lambda_s = \frac{\pi D}{S} = \frac{\pi \times 25}{31} = 2.53\text{cm}$$

$$Since\ Carter's coefficient\ is\ same\ for\ both\ slots\ and\ duct, ratio\ \frac{b_{os}}{l_g} = \frac{b_v}{l_g}.$$

$$Therefore\ b_{os} = b_v = 1.0.$$

$$K_{gs} = \frac{2.53}{2.53 - 1.0(1-0.68)} = 1.15$$

$K_{gv}= \dfrac{L}{L - n_v\, b_v(1-\delta_v)} = \dfrac{12}{12 - 1 \times 1(1-0.68)} = 1.03$

$K_g = 1.15 \times 1.03 = 1.18$

$B_g = \dfrac{B_{av}}{\psi} = \dfrac{0.7}{0.7} = 1.0\text{T}$, with the assumption that $\psi = 0.7$

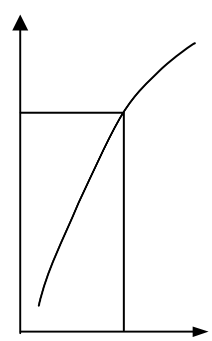
$AT_g = 800000 \times 0.4 \times 10^{-2} \times 1.18 \times 1.0 = 3776$

$AT_t = at_t \times h_t$

Flux density in the tooth at $\dfrac{1}{3}$ height from the root of the tooth,

$$B_{t^1/_3} = \frac{\phi}{bt_{1/_3} \times L_i \times \frac{S}{P}}$$

$\phi = \frac{B_{av}\pi DL}{P} = \frac{0.7\times\pi\times0.25\times0.12}{P} = \frac{0.066}{P}\text{Wb}$



Width of the tooth at $\dfrac{1}{3}$ height from the root of the tooth,

$$bt_{1/_3} = \frac{\pi(D - \frac{4}{3}h_t)}{S} - b_S = \frac{\pi\left(25 - \frac{4}{3}\times 3\right)}{31} - 1.0 = 1.13\text{cm}$$

$L_i = K_i(L - n_v b_v) = 0.92(12 - 1\times 1) = 10.12cm$

$$B_{t^1/_3} = \frac{0.066/_P}{0.0113 \times 0.1012 \times \frac{31}{P}} = 1.86T$$

At 1.86T, at_t, the ampere-turns obtained from the magnetization curve

drawn to scale is 140/cm.

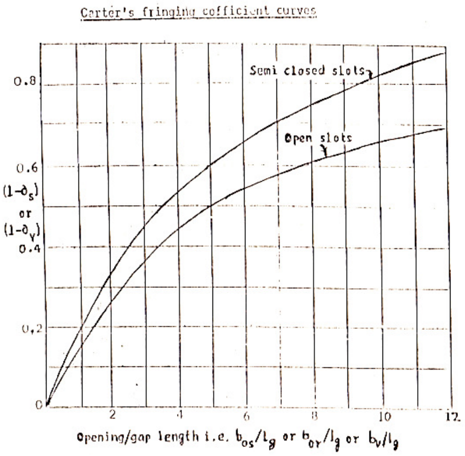
Therefore, $AT_t = 140 \times 3 = 420$

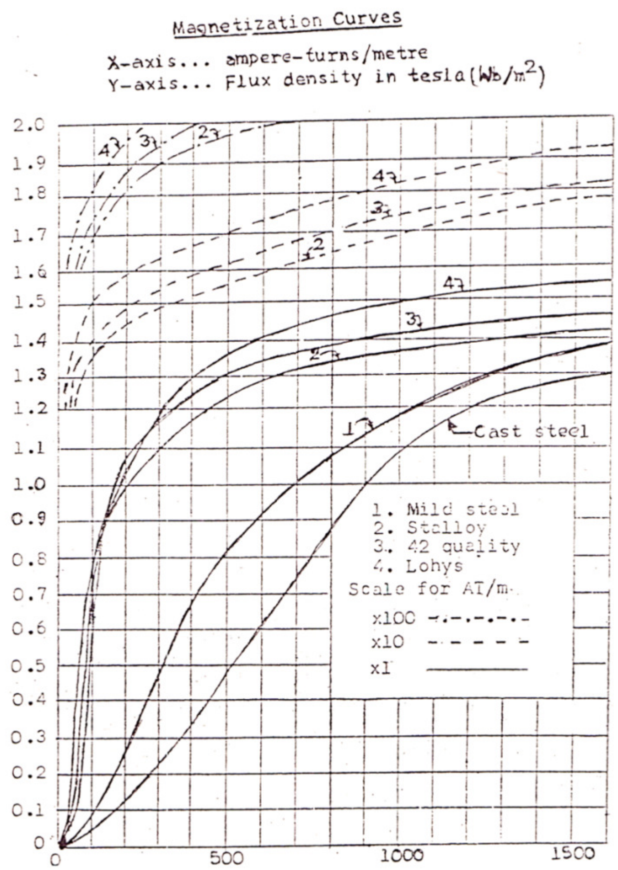
Example.7

A shunt generator with lap connected armature rated 100kW, 125V, 450rpm, and 4pole has the following data relating to its magnetic circuit.

Part	Area in cm^2	Length in cm
Yoke (Cast iron)	350	40
Pole (Stalloy)	650	22
Gap (Effective)	900	0.86
Teeth (Mean)	380	2.9
Armature core (Stalloy)	300	15.2

Leakage coefficient = 1.2. Calculate the ampere turns/pole required for 125V at no load. The armature has 232 conductors.





$$\text{AT/pole} = \text{AT}_Y + \text{AT}_p + \text{AT}_g + \text{AT}_t + \text{AT}_c$$

$a)\ AT_y$:

Flux density in the yoke $B_y = \dfrac{\phi \times LC/2}{A_y}$

$$\phi = \frac{60EA}{ZNP} = \frac{60 \times 125 \times 4}{232 \times 450 \times 4} \approx 0.072\text{Wb}$$

$$B_y = \frac{0.072 \times 1.2/2}{350 \times 10^{-4}} = 1.23T$$

The ampere turns per metre at_y, obtained from the magnetization curve corresponding

to cast steel at $\text{B}_y = 1.23T\ is\ 1350$.

$AT_y = at_y \times$ mean length of the flux path in the yoke l_y

$$= 1350 \times 0.4 = 540$$

$b)\ AT_P$:

Flux density in the pole $B_P = \dfrac{\phi \times LC}{A_P} = \dfrac{0.072 \times 1.2}{650 \times 10^{-4}} = 1.33T$

The ampere turns per metre at_P, obtained from the magnetization curve corresponding

to stalloy at $\text{B}_\text{P} = 1.33T\ is\ 800$.

$AT_P = at_P \times$ mean length of the flux path in the pole h_P

$$= 800 \times 0.22 = 176$$

$c)\ AT_g$:

$AT_g = 800000 l_g K_g B_g$

Effective air gap length $L_g K_g = 0.86\text{cm}$

$$B_g = \frac{B_{av}}{\psi} = \frac{\phi}{\psi \tau L} = \frac{\phi}{\text{effective gap area /pole}} = \frac{0.072}{900 \times 10^{-4}} = 0.8\text{T}$$

$$AT_g = 800000 \times 0.86 \times 10^{-2} \times 0.8 = 5504$$

$d)\ AT_t$:

Flux density in the tooth at $\frac{1}{3}$ height from the root of the tooth,

$$B_{t1/3} = \frac{\phi}{bt_{1/3} \times L_i \times \frac{S}{P}} = \frac{\phi}{\text{mean area of the teeth / pole}} = \frac{0.072}{380 \times 10^{-4}} = 1.89T$$

The ampere turns per metre $\mathrm{at_t}$, obtained from the magnetization curve corresponding to stalloy at $B_{t1/3} = 1.89T\ is\ 30000$.

$AT_t = at_t \times \text{mean length of the flux path in the tooth} h_t$
$= 30000 \times 0.029 = 870$

$e)\ AT_C$:

Flux density in the armature core $B_C = \frac{\phi/2}{A_C} = \frac{0.072/2}{300 \times 10^{-4}} = 1.2T$

The ampere turns per metre $\mathrm{at_C}$, obtained from the magnetization curve corresponding to stalloy at $\mathrm{B_C} = 1.2T\ is\ 400$.

$AT_C = at_C \times \text{mean length of the flux path in the armature core } l_C$
$= 400 \times 0.153 = 60.8$

Therefore $\mathrm{AT/pole} = 540 + 176 + 5504 + 870 + 60.8 = 7150.8$

Example.8

Find the ampere turns/pole required to drive the flux through the teeth using Simpson's rule with the following data: flux/pole = 0.07Wb, core-length = 35cm, number of ducts = 4, width of each duct = 1.0cm, slot pitch at the gap surface = 2.5cm, slot pitch at the root of the tooth = 2.3cm, dimensions of the slot = 1.2cm x 5cm, slots/pole-pitch = 12

$At_t = H_{av} \times h_t$

$According\ to\ Simpsons\ rule\ H_{av} = \frac{1}{6}(H_1 + 4H_2 + H_3)$

$Flux\ density\ at\ section\ 1, B_{t1} = \frac{\phi}{bt_1 \times L_i \times \frac{S}{P}}$

$L_i = K_i(L - n_v b_v) = 0.9(35 - 4 \times 1) = 27.9cm$

$$B_{t1} = \frac{0.07}{0.013 \times 0.279 \times 12} = 1.6T$$

The ampere turns per metre H_1, obtained from the magnetization curve corresponding to stalloy at $B_{t1} = 1.6T$ is 6000.

$$Flux\ density\ at\ section\ 2, B_{t2} = \frac{\phi}{bt_2 \times L_i \times \frac{S}{P}}$$

Over a slot depth of 5cm,the tooth width changes by (1.3-1.0)=0.2cm. Therefore for a slot depth of 2.5 cm, the tooth width changes by $\frac{0.2 \times 2.5}{5.0}$=1.0cm. Thus the tooth width at section 2 is B_{t2}=1.3-0.1=1.2cm.

$$B_{t2} = \frac{0.07}{0.012 \times 0.279 \times 12} = 1.742T$$

The ampere turns per metre H_2, obtained from the magnetization curve corresponding to stalloy at $B_{t2} = 1.742T$ is 15000.

$$Flux\ density\ at\ section\ 3, B_{t3} = \frac{\phi}{bt_3 \times L_i \times \frac{S}{P}} = \frac{0.07}{0.011 \times 0.279 \times 12} = 1.9T$$

The ampere turns per metre H_3, obtained from the magnetization curve corresponding to stalloy at $B_{t3} = 1.9T$ is 30000.

$$Therefore\ H_{av} = \frac{1}{6}(6000 + 4 \times 15000 + 30000) = 16000$$

$$AT_t = 16000 \times 0.05 = 800$$

Example.9

Find the ampere turns required to drive the flux through the teeth with the following data using graphical method. Minimum tooth width = 1.1cm, maximum tooth width = 1.5cm, slot depth = 4.0cm, maximum value of flux density at the minimum tooth section = 2.0T. Material used for the armature is Stalloy.

Since the height of the tooth is 4cm, let the tooth be divided into 4 parts. Therefore, according to graphical method,

$$AT_t = \frac{H_1 + H_2}{2} \times \frac{h_t}{4} + \frac{H_2 + H_3}{2} \times \frac{h_t}{4} + \frac{H_3 + H_4}{2} \times \frac{h_t}{4} + \frac{H_4 + H_5}{2} \times \frac{h_t}{4}$$

$Flux\ density\ at\ section\ 5, B_{t5} = 2.0T$

The ampere turns per metre H_5, obtained from the magnetization curve corresponding

to stalloy at $B_{t5} = 2.0T\ is\ 65000.$

$$Since\ B_{t5} = \frac{\phi}{bt_5 \times L_i \times \frac{S}{P}} \quad and\ \ B_{t4} = \frac{\phi}{bt_4 \times L_i \times \frac{S}{P}}\ ,$$

Flux density at section 4, $B_{t4} = \frac{B_{t5} \times bt_5}{bt_4}$

Over a tooth height of 4cm,the tooth width changes by (1.5-1.1)=0.4cm. Therefore

for every 1.0cm the tooth width changes by $\frac{0.4\times1.0}{4.0}$=0.1cm.

Thus the tooth width at

section 3 is b_{t3}=1.2+0.1=1.3cm

section 2 is b_{t2}=1.3+0.1=1.4cm

$$B_{t4} = \frac{2.0 \times 1.1}{1.2} = 1.83T$$

$$Similarly\ B_{t3} = \frac{2.0 \times 1.1}{1.3} = 1.7T,\ B_{t2} = \frac{2.0 \times 1.1}{1.4} = 1.57T\ and\ \ B_{t1} = \frac{2.0 \times 1.1}{1.5} = 1.46T$$

The ampere turns per metre H_4, H_3, H_2 and H_1 obtained from the magnetization curve

corresponding to stalloy at respective flux densities are20000, 10800,5000 and 2500.

$$AT_t = \frac{H_1 + H_2}{2} \times \frac{h_t}{4} + \frac{H_2 + H_3}{2} \times \frac{h_t}{4} + \frac{H_3 + H_4}{2} \times \frac{h_t}{4} + \frac{H_4 + H_5}{2} \times \frac{h_t}{4}$$

$$AT_t = [\frac{H_1 + H_2}{2} + \frac{H_2 + H_3}{2} + \frac{H_3 + H_4}{2} + \frac{H_4 + H_5}{2}] \times \frac{h_t}{4}$$

$$AT_t = [\frac{2500+5000}{2} + \frac{5000+10800}{2} + \frac{10800+20000}{2} + \frac{20000+65000}{2}] \times \frac{0.04}{4}$$

$$= 695.5$$

Example.10

Calculate the apparent flux density at a section of the tooth of the armature of a DC machine with the following data at that section. Slot pitch = 2.4cm, slot width = 1.2 cm, armature core length including 5 ducts each 1.0cm wide = 38cm, stacking factor = 0.92, true flux density in the teeth at the section is 2.2T for which the ampere turns/m is 70000.

$$B_{app} = B_{real} + \mu_o H(K_s - 1)$$

$$Slot\ factor\ K_S = \frac{\lambda_S L}{b_t L_i} = \frac{\lambda_S L}{(\lambda_S - b_s)K_i(L - n_v b_v} = \frac{2.4\ \times 38}{(2.4-1.2)\times 0.92(38 - 5\times 1)} = 2.5$$

$$B_{app} = 2.2 + 4\pi \times 10^{-7} \times 70000(2.5-1) = 2.33T$$

Example.11

Calculate the apparent flux-density at a particular section of a tooth from the following data. Tooth width = 12mm, slot width = 10mm, gross core length = 0.32mm, number of ventilating ducts = 4, width of the duct each = 10mm, real flux density = 2.2T, permeability of teeth corresponding to real flux density = 31.4x10-6H/m. Stacking factor = 0.9.

$$B_{app} = B_{real} + \mu_o H(K_s - 1)$$

$$Since\ B = \mu_o \mu_r H, H = \frac{2.2}{31.4\times 10^{-6}} = 70063.7$$

$$Slot\ factor\ K_S = \frac{\lambda_S L}{b_t L_i} = \frac{(1.2+1.0)\ \times 32}{1.2\times 0.9(32 - 4\times 1)} = 2.33$$

$$B_{app} = 2.2 + 4\pi \times 10^{-7} \times 70063.7(2.33-1) = 2.32T$$

Example.12

The armature core of a DC machine has a gross length of 33cm including 3 ducts each 10mm wide, and the iron space factor is 0.9.If the slot pitch at a particular section is 25 mm and the slot width 14mm, estimate the true flux density and the mmf/m for the teeth at this section corresponding to an apparent flux/density of 23T. The magnetization curve data for the armature stamping is,

B in tesla	1.6	1.8	1.9	2.0	2.1	2.2	2.3
At/m	3700	10000	17000	27000	41000	70000	109000

Since, $B_{app} = B_{real} + \mu_o H(K_s - 1)$

$B_{real} = B_{app} - \mu_o H(K_s - 1)$

Slot factor $K_S = \frac{\lambda_S L}{b_t L_i} = \frac{2.5 \times 33}{(2.5 - 1.4) \times 0.9(33 - 3 \times 1)} = 2.8$

$B_{real} = 2.3 - 4\pi \times 10^{-7} \times H(2.8 - 1)$

$= 2.3 - 2.26 \times 10^{-6} H$ and is an equation of a straight line.

The intersection ofthis line and the magnetization curve leads to B_{real} and H.

When $H = 0, B_{app} = B_{real} = 2.3T$ and when $B_{real} = 0, H = \frac{B_{app}}{2.26 \times 10^{-6}} = 1017.7 \times 10^3$

Since $H = 1017.7 \times 10^3$ is too a large value to locate on the x-axis, let a definite value of H be considered to locate another point and to draw the straight line. With that, when $H = 70000, B_{real} = 2.3 - 2.26 \times 10^{-6} \times 70000 = 2.14\text{T}$

It is clear at the intersection point, $B_{real} = 2.1T\ and \frac{mmf}{m} i.e. H = 59000.$

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