PART-A

1. Name any two methods to reduce armature reaction [APRIL/MAY 2011]

   1. Compensating windings are provided to neutralize the effects of armature reaction.

   2. By increasing reluctance of pole tips, the distorting effects armature reaction can be reduced.

   3. By increasing the length of air gap at pole tips.

2. What is slot loading? [APRIL/MAY 2011]

   The slot loading is the number of ampere conductor per slot. This value should not exceed 1500 A \( I_Z < 1500 \text{ A} \) (\( Z_s – \text{No of conductors/slot} \))

3. Show how the specific magnetic loading and magnetic loading are independent. [NOV/DEC 2011]

   The output of a dc machine is proportional to the product of their specific magnetic loading (\( B_{av} \)) and specific electric loading (\( ac \))

\[
P_a \propto (B_{av} \times ac)
\]

   For a particular output, values of specific magnetic and electric loadings are independent. i.e., if one is chosen higher, the value of other has to be lower.
4. Mention any guiding factor for the choice of number of poles. [NOV/DEC 2011][MAY/JUNE2013]

- The frequency of flux reversals is in the armature core generally lies between 25 to 50 Hz. Lower values of frequency are used for large machines.
- The value of current per parallel path is limited to about 200 A. Thus the current brush arm should not be more than 400A.

5. Define field form factor [MAY/JUNE 2012]

Field form factor

\[
K_f = \frac{\text{Average gap density} - \text{pole pitch} (B_{av})}{\text{Maximum flux density in airgap}(B_{e})}
\]

6. What is meant unbalanced magnetic pull? [MAY/JUNE 2012] [APRIL/MAY 2010]

The unbalanced magnetic pull is the radial force acting on the rotor due to non-uniform air gap around armature periphery. In order to overcome unbalanced magnetic pull, the length of rotor is kept a small and ball bearing are employed.

7. Distinguish between real and apparent flux densities in a DC machines. [NOV/DEC 2012]

<table>
<thead>
<tr>
<th>Real flux density</th>
<th>Apparent flux density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. It is due to actual flux through a tooth</td>
<td>1. It is due to total flux that has to pass through the tooth.</td>
</tr>
<tr>
<td>2. It is always less than apparent flux density</td>
<td>2. It is always greater value than real flux density.</td>
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</table>

8. What are the factors that influence the choice of commutator diameter? [NOV/DEC 2012]

The choice of commutator diameter depends upon peripheral speed and the thickness of commutator segment.

9. Write down the output equation of a d.c machine. [MAY/JUNE2013]

Output equation of d.c machine is

\[
P_a = C_o D^2 L n
\]

The output coefficient \(C_o = \pi^2 B_{av,ac} x 10^{-3}\)
10. State any two guiding factors for the choice of number of poles in dc machine? [MAY/JUNE2013]

The guiding factors for choice of number of poles are,

1. The frequency should lie between 25 to 50 Hz

2. The value of current per parallel path is limited to 200 A, thus the current per brush arm should not be more than 400 A.

3. The armature mmf should not be too large. The mmf per pole should be in the range 5000 to 12,500 AT.

4. Choose the largest values of poles which satisfy the above three conditions.

11. Write guiding factors for choice of number of armature slots of D.C machine. [NOV/DEC 2009]

Guiding factors for choice of number of armature slots of D.C machine are as follows:

1. Slot pitch

2. Slot loading

3. Flux pulsations

4. Commutation

5. Suitability for winding.

12. Define brush contact loss. [NOV/DEC 2009]

The brush contact loss is one of the losses at the commutator surface. The brush contact loss depends upon the condition of the commutator and upon quality of commutation obtained. The brush contact drop is independent of load current. The typical value of brush drop are 1 V per brush arm for carbon/graphite brushes, 0.25 v for metal graphite and 0.1 V or less for small machines used for control applications.

13. Give the main parts of a d.c motor. [MAY/JUNE2009]

14. State the relation between the number of commutator segments and number of armature coils in a d.c generator. [MAY/JUNE 2009]

\[ \beta_c = \frac{\pi D_c}{C} \]

15. State the different losses in a machine. [APRIL/MAY 2009]

The losses in a d.c machine can be classified into two general types

a) Rotational losses  
b) \( i^2R \) losses

Rotational losses are made up of

i) Friction and windage losses

ii) Iron losses

16. What are the main parts of a d.c generator? [NOV/DEC 2010]

i) Field system

ii) Armature

iii) Commutator

17. What is window space factor? [NOV/DEC 2010]

It is defined as the ratio of copper area in windows to total area of window.

18. What are the effects of open slots and ducts on magnetic circuit of a machine? [NOV/DEC 2010]

- Due to open slots, the flux will be crowded over the teeth.
- Reluctance of slotted armature with ducts will be increased.

19. What are the advantages of large length of air – gap in dc machine? [APRIL/MAY 2008]

In dc machine a larger value of air – gap results in lesser noise, better cooling, reduced pole face losses, reduced circulating currents, less distortion of field form and lesser armature reaction.
20. Why square pole is preferred? [APRIL/MAY 2008]

If the cross section of the pole body is square then the length of the mean turn of field winding is minimum. Hence to reduce the copper requirement a square cross section is preferred for the poles of the dc machines.

21. What are the factors that influence the choice of specific electric loading? [NOV/DEC 2008]

1. Temperature rise
2. Speed of the machine
3. Size of the machine
4. Voltage
5. Armature reaction
6. Commutation

22. What are the factors that influence the choice of specific magnetic loading? [APRIL/MAY 2008]

1. Flux density in the teeth
2. Frequency of flux reversals
3. Size of the machine

23. What are the factors to be considered in the design of commutator? [APRIL/MAY 2008]

- Peripheral speed
- Voltage between adjacent commutator segments
- Number coils in the armature
- The number of brushes
- Commutator losses

24. What are the effects of armature reaction?

The various effect of armature reaction are reduction in induced emf, increase in iron loss, delayed commutation, sparking and ring firing.

25. State the purpose of constructing the pole body by laminated sheets?
The laminated pole offers the homogeneous construction, (Because while casting internal blow holes may develop and while forging internal cracks may develop)

Also the laminated pole offers the flexibility of increasing the length by keeping the diameter fixed, in order to increase the power output (or capacity) of the machine.


Stacking factor is defined as the ratio of actual length of iron in stacks of assembled core plates to total axial length.

PART- B

1. Derive the output equation of DC machine.

Note: Output equation relates the output and main dimensions of the machine. Actually it relates the power developed in the armature and main dimensions.

Derivation:
Nomenclature: E : emf induced or back emf
Iₐ : armature current
ϕ : Average value of flux / pole
Z : Total number of armature conductors
N : Speed in rpm
P : Number of poles
A : number of armature paths or circuits
D : Diameter of the armature
L : Length of the armature core

Power developed in the armature in kW = E Iₐ x 10⁻³

\[ = \frac{\phi Z NP}{60 A} \times Iₐ \times 10^3 \]

\[ = (P\phi) \times \frac{Iₐ Z}{A} \times \frac{N}{60} \times 10^3 \quad .... \quad (1) \]

The term Pϕ represents the total flux and is called the magnetic loading. Magnetic loading/unit area of the armature surface is called the specific magnetic loading or average value of the flux density in the air gap \( B_{av} \). That is,
\[ B_{av} = \frac{P\phi}{\pi DL} \text{ Wb/m}^2 \text{ or tesle denoted by T} \]

Therefore \[ P\phi = B_{av} \pi DL \] \hspace{2cm} (2)

The term \( I_z Z/A \) represents the total ampere-conductors on the armature and is called the electric loading. Electric loading/unit length of armature periphery is called the specific electric loading \( q \). That is,

\[ q = \frac{I_z Z}{A \pi D} \text{ ampere - conductors / m} \]

Therefore \[ I_z Z/A = q \pi D \] \hspace{2cm} (3)

Substitution of equations 2 and 3 in 1, leads to

\[ kW = B_{av} \pi DL \times q \pi D \times \frac{N \times 10^3}{60} \]

\[ = 1.64 \times 10^4 B_{av} q D^2 LN \]

\[ = C_0 D^2 LN \]

where \( C_0 \) is called the output coefficient of the DC machine and is equal to \( 1.64 \times 10^4 B_{av} q \).

Therefore \[ D^2L = \frac{kW}{1.64 \times 10^4 B_{av} q N} \text{ m}^3 \]

The above equation is called the output equation. The \( D^2L \) product represents the size of the machine or volume of iron used. In order that the maximum output is obtained/kg of iron used, \( D^2L \) product must be as less as possible. For this, the values of \( q \) and \( B_{av} \) must be high.

2. Determine the main dimensions, number of poles, number of conductors per slot and air gap length subjecting the results to design checks for a 600kW, 500V 900rpm dc generator.

Assume:

Average flux density 0.6T, ampere-conductors per meter 35000. The ratio pole arc to pole pitch 0.67, efficiency 91%.
Peripheral velocity should not exceed 40m/s
Armature mmf per pole should be below 7500A
Current per brush arm should not exceed 400A
Frequency of the flux reversal should not exceed 50Hz

The mmf required for air gap is 50% of armature mmf and gap contraction factor is 1.15.

Armature current \( I_a \approx I_L = \frac{600 \times 10^3}{300} = 1200 \text{A} \)

In order that current per path is not greater than 200A or current per brush arm is not greater than 400A, a lap winding is to be used having parallel paths,

\[ A = \frac{1200}{200} = 6 \]

Since for a simplex lap winding, \( A = p, \ p = 6 \)

Check: Frequency \( f = \frac{PN}{120} = \frac{6 \times 900}{120} = 45 < 50 \text{Hz} \) and the condition is satisfied.

\[ D^2L = \frac{kW}{1.64 \times 10^{-4}B_{av}qN} \]

Power developed in kW \( \frac{\text{Output}}{\eta} = \frac{600}{0.91} = 659.4 \)

\[ D^2L = \frac{659.4}{1.64 \times 10^{-4} \times 0.6 \times 3500 \times 900} = 0.213 \text{m}^3 \]

Since the peripheral velocity should not be greater than 40 m/s, let it be 36 m/s.

Since \( v = \frac{\pi DN}{60}, \ D = \frac{60v}{\pi N} = \frac{60 \times 36}{\pi \times 900} = 0.76 \text{m} \)

\( L = \frac{0.213}{0.76^2} = 0.28 \text{m} \)

Since the minimum number of slots per pole is 9 from commutation point of view, minimum number of slots for the machine is

\[ = 9 \times 6 = 54 \quad \text{--------(1)} \]

\( \lambda_s = \frac{\pi D}{S} \), lies between 2.5 and 3.5 cm, the number of slots lies between \( \frac{\pi \times 76}{3.5} \approx 68 \) and \( \frac{\pi \times 76}{2.5} \approx 96 \quad \text{---------(2)} \)
From 1 and 2 the number of slots lies between 68 and 96.

Since for a lap winding the number of slots may be multiple of number of poles i.e. 6 or multiple of number of pair poles i.e. 3, let the number of slots $S = 72$.

Number of armature conductors $Z = \frac{E60A}{\varphi NP}$

$$\varphi = \frac{B_m \pi DL}{P} = \frac{0.6 \times \pi \times 0.76 \times 0.28}{6} = 0.067 \text{Wb}$$

$$Z = \frac{60 \times 500 \times 6}{0.067 \times 900 \times 6} \approx 498$$

Conductors per slot $= \frac{498}{72} = 6.9$ and is not possible. Let it be 6.

$Z_{\text{revised}} = 72 \times 6 = 432$

Check:

Armature mmf per pole $AT_a/\text{pole} = \frac{I_z Z}{2AP} = \frac{1200 \times 432}{2 \times 6 \times 6} = 7200 \text{A} < 7500 \text{A}$

and the condition is satisfied.

Air gap mmf $AT_g = 800000l_g K_g B_g = 0.5 AT_a/\text{pole}$

Carter’s gap expansion or contraction coefficient $K_g = 1.15$

Maximum gap density $B_g = \frac{B_{av}}{\Psi} = \frac{0.6}{0.67} = 0.895 \text{T}$

Air gap length $l_g = \frac{0.5 \times 7200}{800000 \times 1.15 \times 0.895} = 0.0043 \text{m}$
3. Explain the various factors that the affected by the selection of number of poles in dc machines.

In order to decide what number of poles (more or less) is to be used, let the different factors affecting the choice of number of poles be discussed based on the use of more number of poles.

1. Frequency

As the number of poles increases, frequency of the induced emf \( f = \frac{PN}{120} \) increases, core loss in the armature increases and therefore efficiency of the machine decreases.

2. Weight of the iron used for the yoke

Since the flux carried by the yoke is approximately \( \phi/2 \) and the total flux \( \phi_T = p\phi \) is a constant for a given machine, flux density in the yoke

\[
B_y = \frac{\phi/2}{\text{cross sectional area of the yoke} A_y} = \frac{\phi}{2PA_y} \propto \frac{1}{P A_y}.
\]

It is clear that \( A_y \) is \( \propto 1/P \)
as \( B_y \) is also almost constant for a given iron. Thus, as the number of poles increases, \( A_y \) and hence the weight of iron used for the yoke reduces.

3. Weight of iron used for the armature core (from the core loss point of view)

Since the flux carried by the armature core is \( \phi/2 \), eddy current loss in the armature core

\[
\propto B_c^2 f^2 \propto \left[ \frac{\phi/2}{A_c} \right]^2 f^2 \propto \left[ \frac{\phi_T}{2PA_c} \right]^2 \times \frac{PN}{120} \propto \frac{1}{A_c^2}.
\]

is independent of the number of poles.

On the other hand, since the hysteresis loss in the armature core is

\[
\propto B_c^{1.6} f \propto \left( \frac{\phi_T}{2PA_c} \right)^{1.6} \times \frac{PN}{120} \propto \frac{1}{P^{0.5} A_c^{1.6}}, \text{ the armature core area } A_c
\]

\[
\propto \frac{1}{P^{0.5} A_c} \text{ decreases as the number of poles increases for a given hysteresis loss. Thus the weight of iron used for the armature core reduces as the number of poles increases.}
\]
4. Weight of overhang copper

For a given active length of the coil, overhang $\propto$ pole pitch $\pi D/P$ goes on reducing as the number of poles increases. As the overhang length reduces, the weight of the inactive copper used at the overhang also reduces.

5. Armature reaction

Since the flux produced by the armature $\Phi_a = \frac{AT_a}{\text{pole}}$, and armature ampere turns $AT_a$ / pole $= \frac{1}{2} \frac{Z}{A P}$ is proportional to $1/P$, $\Phi_a$ reduces as the number of poles increases. This in turn reduces the effect of armature reaction.

6. Overall diameter

When the number of poles is less, $AT_a$/pole and hence the flux, produced by the armature is more. This reduces the useful flux in the air gap. In order to maintain a constant value of air gap flux, flux produced by the field or the field ampere-turns must be increased. This calls for more field coil turns and size of the coil defined by the depth of the coil $d_f$ and height of the coil $h$ increases. In order that the temperature rise of the coil is not more, depth of the field coil is generally restricted. Therefore height of the field coil increases as the size of the field coil or the number of turns of the coil increases. As the pole height, is proportional to the field coil height, height of the pole and hence the overall diameter of the machine increases with the increase in height of the field coil.

Obviously as the number of poles increases, height of the pole and hence the overall diameter of the machine decreases.
7. **Length of the commutator**

Since each brush arm collects the current from every two parallel paths, current / brush arm 
\[ A_b = \frac{2I_a}{A} \] and the cross sectional area of the brush / arm 
\[ A_b = 2I_a / A \delta_b = 2I_a / P \delta_b \]
\[ \propto 1 / P \]
reduces as the number of poles increases.

As \( A_b = t_b w_b n_b \) and \( t_b \) is generally held constant from the commutation point of view, \( w_b n_b \)
reduces as \( A_b \) reduces. Hence the length of the commutator
\[ L_c = (w_b n_b + clearances) \] reduces as \( A_b \) reduces or the number of poles increases.

\( w_b \) – width of the brush, \( t_b \) – thickness of the brush, \( n_b \) – number of brushes per spindle

![Diagram of a commutator](attachment:diagram.png)

A portion of the commutator

8. **Flash over**

As the number of poles increases, voltage between the segments
\[ E_b = \frac{voltage\ between\ positive\ and\ negative\ brushes}{number\ of\ segments / pole} \]
increases. Because of the increased value of \( E_b \) and carbon dust collected in the space where the mica is undercut, chances of arcing between commutator segments increases. The arc between the segments in turn may bridge the positive and negative brushes leading to a dead short circuit of the armature or flash over.

9. **Labour charges**

As the number of poles increases cost of labour increases as more number of poles are to be assembled, more field coils are to be wound, placed on to the pole, insulate, interconnect etc.

It is clear that, when the number of poles is more, weight of iron used for yoke and armature core, weight of inactive copper, overall diameter, length of commutator and effect of armature reaction reduces. On the other hand efficiency reduces chances of flash over increases and cost of machine increases.

Since the advantages outnumber the disadvantages, more number of poles is preferable.

Thus, though more number of poles is preferable, it is not advisable from the cost point of view. In general the number of poles should be so selected that good operating characteristics are obtained with minimum weight of active material and minimum cost of construction.
4. A 250kw, 500v, 6 pole, 600 rpm, dc generator is built with an armature of 0.75m and core length of 0.3 m. the lap connected armature has 720 conductors. Using the data obtained from this machine, determine the armature diameter, core length, number of armature slots, armature conductors and commutator segments for 350kW, 440v, 720RPM, 6 pole generator.

Assume a square pole face with ratio pole arc to pole pitch is equal to 0.66. The full load efficiency is 0.91 and the internal voltage drop is 4% of rated voltage. The diameter of the commutator is 0.7 of the armature diameter. The pitch of the commutator segments should not be less than 4mm. the voltage between admittance segments should not exceed 15V no load.

\[ q = \frac{l_a Z}{\pi D} \]

\[ l_a = \frac{\text{Power developed in the armature}}{\text{induced emf}} \]

Power developed in the armature = \( \frac{250}{0.91} = 274.7 \text{ kW} \)

emf induced \( E = 500 + 0.04 \times 500 = 520 \text{ V} \)

\[ l_a = \frac{274.7 \times 10^3}{520} = 528.3 \text{ A} \]

\[ q = \frac{528.3 \times 720}{6 \times \pi \times 0.75} \approx 26906 \text{ ampere-conductors per meter} \]

\[ B_{av} = \frac{P\phi}{\pi DL} \]

\[ \phi = \frac{60EA}{ZNP} = \frac{60 \times 520 \times 6}{720 \times 600 \times 6} \approx 0.072 \text{ Wb} \]

\[ B_{av} = \frac{6 \times 0.072}{\pi \times 0.75 \times 0.3} = 0.61 \text{ T} \]
OR

\[ B_{av} = \frac{kW}{1.64 \times 10^{-4}qND^2L} = \frac{274.7}{1.64 \times 10^{-4} \times 26906 \times 600 \times 0.75^2 \times 0.3} = 0.61T \]

II machine:

\[ D^2L = \frac{kW}{1.64 \times 10^{-4}B_{av}qN} = \frac{350}{0.91} \times \frac{1}{1.64 \times 10^{-4} \times 0.61 \times 26906 \times 720} \approx 0.195 \]

For a square pole face, \( L = \frac{\psi \tau}{0.66 \times \pi D/6} = 0.35D \)

\[ D^3 = \frac{0.195}{0.35} = 0.564m^3 \]

Therefore \( D = 0.83m \) and \( L = 0.35 \times 0.83 = 0.29m \)

Since the minimum number of slots per pole is 9 from commutation point of view, minimum number of slots for the machine is

\[ 9 \times 6 = 54 \text{ ------(1)} \]

Since slot pitch \( \lambda_s = \frac{\pi D}{S} \), lies between 2.5 and 3.5 cm, the number of slots

lies between \( \frac{\pi \times 83}{3.5} \approx 74 \) and \( \frac{\pi \times 83}{2.5} \approx 104 \text{ ---------(2)} \)

From 1 and 2 the number of slots lies between 74 and 104.

If a lap winding is assumed then for a lap winding the number of slots may be multiple of number of poles i.e. 6 or multiple of number of pair poles i.e. 3, let the number of slots \( S = 78 \)

Number of armature conductors \( Z = \frac{E_{60A}}{\varphi NP} \)

emf induced \( E = 440 + 0.04 \times 440 = 457.6V \)

Flux per pole \( \varphi = \frac{B_{av} \pi DL}{P} = \frac{0.61 \times \pi \times 0.83 \times 0.29}{6} = 0.078Wb \)

\[ Z = \frac{60 \times 457.6 \times 6}{0.078 \times 720 \times 6} \approx 488 \]

Conductors per slot = \( \frac{488}{78} = 6.2 \) and is not possible. Let it be 6
A 150 Hp, 500V, 6 pole, 450rpm dc shunt motor has following data.

Armature diameter is = 54 cm, length of armature core = 24.5 cm, average flux density in the air gap = 0.55 T, number of ducts = 2, width of each ducts = 1.0 cm, staking factor = 0.92.

Obtain the number of armature slots and work the details of a suitable armature winding. Also determine the dimension of the slot. The flux density in the tooth at one third height from the root should not exceed 2.1 T.
\[ I_a = \frac{hp \times 746}{\eta \times V} = \frac{150 \times 746}{0.9 \times 500} = 248.7 \text{A} \]

For this armature current, a lap or wave winding may be used. Let a lap winding be used.

Since the minimum number of slots per pole is 9 from commutation point of view, minimum number of slots for the machine is

\[ = 9 \times 6 = 54 \quad \text{-------(1)} \]

Since slot pitch \( \lambda_s = \frac{\pi D}{S} \), lies between 2.5 and 3.5 cm, the number of slots lies between \( \frac{\pi \times 54}{3.5} \approx 48 \) and \( \frac{\pi \times 54}{2.5} \approx 68 \) \quad \text{---------------(2)}

From 1 and 2 the number of slots lies between 54 and 68.

Since a lap winding is assumed and for a lap winding the number of slots may be multiple of number of poles i.e. 6 or multiple of number of pair poles i.e. 3, let the number of slots \( S = 60 \).

Details of winding: Type of winding (already fixed), number of slots (also fixed), number of conductors, cross-sectional area of the conductor, back pitch, front pitch etc.

\[ \text{Flux per pole } \phi = \frac{B_{av} \pi DL}{P} = \frac{0.55 \times \pi \times 0.54 \times 0.245}{6} = 0.038 \text{Wb} \]

Since a lap winding is assumed, \( Z = \frac{60 \times 500 \times 6}{0.038 \times 450 \times 6} \approx 1754 \)

Conductors per slot = \( \frac{1754}{60} = 29.2 \) and is not possible

let the number Conductors per slot be 30. Therefore \( Z_{\text{revised}} = 30 \times 60 = 1800 \).

Back pitch \( Y_B = \frac{Z}{P} \pm K = \frac{1800}{6} \pm K = \frac{1800}{6} \pm 1 = 301 \) say.

Front pitch \( Y_F = Y_B \pm 2 = 301 \pm 2 = 299 \) for a progressive winding

Since the current density lies between 4.5 and 7A/mm², let it be 5A/mm²

\[ \text{Cross-sectional area of the conductor } a = \frac{I_a}{A_0} = \frac{248.7}{6 \times 5} = 8.3 \text{mm}^2 \]

Since \( a \) is less than 10mm², let a round conductor be used of bare diameter
\[ \frac{4a}{\pi} = \frac{4 \times 8.3}{\pi} = 3.25\text{mm} \]

Since only double layer winding is used for a dc machine, number of conductor per layer is \((30/2) = 15\) and can be arranged in any one of the following ways.

(A)- 15 conductors are arranged one below the other in each layer. Slot is not proportionate.

(B)- 15 conductors are arranged one beside the other in each layer. Slot is not proportionate.

(C) and (D)- arrangement of conductors as shown in (C) or (D), leads to proportionate slots.

If the conductors are arranged as shown in (D), then,

Slot width \(b_s = (\text{diameter of the conductor} + \text{insulation on it}) \) number of conductors along the
slot width + (insulation over the coil side or group of coil sides + slot liner + clearance)\\
= \( (3.25 + 2 \times 0.075)3 + 1.5 \\\n= 11.7 \text{mm} \)

Slot depth \( h = (\text{diameter of the conductor + insulation on it) number of conductors along the slot depth + (insulation over the coil side or group of coil sides + slot liner + separator + clearance}) + \text{wedge} 3 \text{ to } 5 \text{ mm} + \text{lip} 1 \text{ or } 2 \text{mm} \).

\( = (3.25 + 2 \times 0.075)10 + 4 + 4 + 2 \\\n= 44 \text{mm} \)

Flux density in the tooth at one third height from the root of the tooth \( B_{t/3} = \frac{\phi}{b_{t/3} \times L_t \times \frac{S}{p}} \)

width of the tooth at \( \frac{1}{3} \) height from the root of the tooth \( b_{t/3} \)

\( = \frac{\pi (D - \frac{4b_L}{3})}{S} - b_s = \frac{\pi \left(54 - \frac{4 \times 4.4}{3}\right)}{60} - 1.17 = 1.35 \text{cm} \)

Net iron length \( L_i = K_I(L - n_e b_L) = 0.9(24.5 - 2 \times 1) = 20.7 \text{cm} \)

\[ Therefore, B_{t/3} = \frac{0.038}{0.0135 \times 0.207 \times \frac{60}{6}} = 1.36T. \]

\[ B_{t/3} = 1.36T \text{is the average flux density in the tooth} \]

with assumption, that the flux per pole is uniformly distributed in all the teeth under one pole. However, because of higher value of flux under pole arc, the flux density in the tooth will be more than the average value. Thus maximum value of the average flux density (\( B_{t/3} \)max)

\[ \frac{\left(B_{t/3}\right)_{\text{ave}}}{\text{Field form factor or per unit enclosure}} \]

If per unit enclosure \( \psi \) is taken as 0.7, then, \( B_{t/3} \)max = \( \frac{1.36}{0.7} = 1.94T \) and less than 2.1T
6. For a preliminary design of 1500KW, 275V, 300rpm, dc shunt generator determine the number of poles, armature diameter and core length, number of slots and number of conductor per slot. Assume average flux density over the pole arc is 0.85T. Output co efficient 276, efficiency 0.91. slot loading not exceed 1500A.

Since the number of parallel paths must be an even integer, it can be 26 or 28. Let A = 28. Therefore, with a simplex lap winding considered P = 28.

Check: \( f = \frac{PN}{120} = \frac{28 \times 300}{120} = 70\text{Hz} \) and is on the higher side as frequency generally considered between 25 and 50Hz. In order to reduce the frequency and to have A = 28, a duplex lap winding can used with P = 14 and \( f = 35\text{Hz} \).

\[
D^2L = \frac{kW}{1.64 \times 10^{-4}B_{av}qN} = \frac{kW}{C_o N}
\]

Power developed in the armature in kW = \( \frac{\text{output}}{\eta} = \frac{1500}{0.91} = 1648.1 \)

[Note: a) When the speed is in rpm in the expression, \( D^2L = \frac{kW}{C_o N} \), the output coefficient \( C_o = 1.64 \times 10^{-4}B_{av}q \) lies between

\[
1.64 \times 10^{-4} \times 0.45 \times 15000 = 1.0 \quad \text{and} \quad 1.64 \times 10^{-4} \times 0.75 \times 50000 = 6.0.
\]

On the other hand if the speed is in rpm, \( C_o = \pi^2 \times 10^{-3}B_{av}q \) lies between

\[
\pi^2 \times 10^{-3} \times 0.45 \times 15000 = 60 \quad \text{and} \quad \pi^2 \times 10^{-3} \times 0.75 \times 50000 = 360.
\]

Since the given value of \( C_o \) lies in the range of 60 and 360, the speed must be in rps when substituted in the output equation.]

\[
D^2L = \frac{1648.4}{276 \times 300} \approx 1.2m^3
\]

[Note: In order to split up \( D^2L \) product into D and L, a value for \( \frac{L}{D} \) ratio or peripheral velocity has to be assumed.]

Let \( L = \tau \). Therefore, \( L = \frac{\pi D}{14} = 0.23D \)

\[
D^3 = \frac{1.2}{0.23} = 5.2m^3 \quad \text{and therefore} \quad D = 1.7m \quad \text{and} \quad L = 0.23 \times 1.7 \approx 0.39m
\]

Since the minimum number of slots per pole is 9 from commutation point of view, minimum number of slots for the machine is

\[ = 9 \times 44 = 126 \quad \text{------(1)} \]
Since slot pitch $\lambda_s = \frac{\pi D}{S}$, lies between 2.5 and 3.5 cm, the number of slots lies between
\[ \frac{\pi \times 170}{3.5} \approx 152 \quad \text{and} \quad \frac{\pi \times 170}{2.5} \approx 214 \]  

\[ \text{----------(2)} \]

From 1 and 2 the number of slots lies between 152 and 214.

Since a lap winding is assumed and for a lap winding the number of slots may be multiple of number of poles i.e. 14 or multiple of number of pair poles i.e. 7, let the number of slots $S = 196$.

Number of armature conductors $Z = \frac{E60A}{\varphi NP}$

Flux per pole $\varphi = \frac{B_{av} \pi DL}{P} = \frac{\psi B_{av} \pi DL}{P}$

\[ = \frac{0.7 \times 0.85 \times \pi \times 1.7 \times 0.39}{4} = 0.089 \text{ Wb with the assumption } \psi = 0.7 \]

\[ Z = \frac{60 \times 275 \times 28}{0.089 \times 300 \times 14} \approx 1236 \]

Conductors per slot = $\frac{1236}{196} = 6.3$ and is not possible as Conductors per slot must always be an even integer for a double layer winding. Let the number Conductors per slot be 6.

Therefore $Z_{\text{revised}} = 196 \times 6 = 1176$.

Slot loading = conductors per slot $\times$ current through the conductor i.e. $\frac{I_v}{A}$

\[ = 6 \times \frac{545.5}{28} = 1168.8 < 1500 \text{ and the condition is satisfied.} \]

7. Calculate the armature diameter and core length for a 7.5KW, 4 pole, 1000rpm, and 220V shunt motor.

Assume full load efficiency = 0.83, filed current is 2.5% of rated current. The maximum at full load.
= Electrical input to the motor – field and armature copper losses  
= Electrical output of the motor + Iron, friction and windage losses  

Electrical input to the motor = \( \frac{\text{output}}{\eta} = \frac{7.5 \times 10^3}{0.83} \approx 9036 \text{W} \)

Losses at full load = \(\left(1 - \frac{\eta}{\eta}\right)\) output = \(\left(1 - \frac{0.83}{0.83}\right) \times 7.5 \times 10^3 = 1536 \text{W} \)

Since efficiency is maximum at full load and at maximum efficiency, the variable loss is equal to constant loss,

Variable loss = armature copper loss = \(\frac{1536}{2} \approx 768 \text{W} \)

Field copper loss = \((I_{sh})^2 R_{sh}\) or \(V I_{sh}\)

\(I_{sh} = 0.025 \text{ full load current} = 0.025 \times \frac{7.5 \times 10^3}{0.83 \times 220} = 1.03 \text{A} \)

Field copper loss = 220 \times 1.03 = 226.6 \text{W} \)

Power developed in the armature = 9036 – 768 – 226.6 = 8041.4 \text{W} \)

OR

Iron, friction and windage losses = Constant losses – field copper loss
= 768 – 226.6 = 541.4 \text{W} \)

OR  Power developed in the armature = 7500 + 541.4 = 8041.4 \text{W} \)

Since specific magnetic loading lies between 0.45 and 0.75 T, let it be 0.6T.

Since specific electric loading lies between 15000 to 50000 ampere-conductors, let it be 30

\(D^2 L = \frac{8.041}{1.64 \times 10^2 \times 0.6 \times 30000 \times 1000} = 0.0027 \text{m}^3 \)

Since \(\frac{L}{\tau}\) lies between 0.55 and 1.1, let it be 1.0.

Therefore \(L = \tau = \frac{\pi D}{4} = 0.785D \)

\(D^3 = \frac{0.0027}{0.785} = 0.0343 \text{m}^3 \) and \(D=0.33 \text{m, } L=0.785 \times 0.33 \approx 0.26 \text{m} \)
For a preliminary design of a 50Hp, 230V, 1400rpm dc motor, calculate the armature diameter and core length, number of poles and peripheral speed. Assume specific magnetic loading 0.5T, specific electric loading 25000ampere conductor per motor, efficiency =0.9

\[ I_a = I_L - I_{sh} \approx I_L = \frac{\text{Input in watts}}{\text{Voltage}} = \frac{hp \times 746/\eta}{V} = \frac{50 \times 747}{0.9 \times 230} = 180.2A \]

of paths and poles is two, 2 poles are sufficient for the machine. However, to gain more advantages of more number of poles, let P=4.

\[ f = \frac{PN}{120} = \frac{4 \times 1400}{120} = 46.7Hz, \text{ within the limits.} \]

\[ D^2L = \frac{kW}{1.64 \times 10^{-4} B_{av} q N} \]

Power developed in the armature

\[ = \left( \frac{1 + 2\eta}{3\eta} \right) \text{outputpower} \]

\[ = \left( \frac{1 + 2 \times 0.9}{3 \times 0.9} \right) 50 \times 0.746 = 38.7kW \]

\[ D^2L = \frac{38.7}{1.64 \times 10^{-4} \times 0.5 \times 25000 \times 1400} = 0.0134m^3 \]

Since \( \frac{L}{\tau} \) lies between 0.55 and 1.1, let it be 1.0.

Therefore \( L = \tau = \frac{\pi D}{4} = 0.785D \)

\[ D^3 = \frac{0.0134}{0.785} = 0.017m^3 \text{ and } D=0.26m, \quad L=0.785 \times 0.26 \approx 0.2m \]

Peripheral velocity \( v = \frac{\pi DN}{60} = \frac{\pi \times 0.26 \times 1400}{60} \approx 19m/s \)