5.4 ARMATURE DESIGN

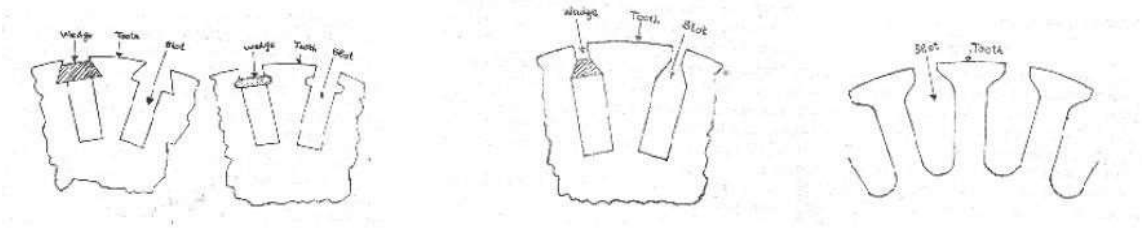
Shape of pole face

Stator slots: In general, two types of stator slots are employed in induction motors viz, open clots and semi closed slots. Operating performance of the induction motors depends upon the shape of the slots and hence it is important to select suitable slot for the stator slots.

(i) Open slots: In this type of slots the slot opening will be equal to that of the width of the slots as shown in Fig. In such type of slots assembly and repair of winding are easy. However such slots will lead to higher air gap contraction factor and hence poor power factor. Hence these types of slots are rarely used in 3Φ synchronous motors.

(ii) Semiclosed slots: In such type of slots, slot opening is much smaller than the width of the slot as shown in Figs. Hence in this type of slots assembly of windings is more difficult and takes more time compared to open slots and hence it is costlier. However the air gap characteristics are better compared to open type slots.

(iii) Tapered slots: In this type of slots also, opening will be much smaller than the slot width. However the slot width will be varying from top of the slot to bottom of the slot with minimum width at the bottom as shown below.



(i) Open type (ii) Semiclosed type (iii) Tapered type

Figure 5.4.1 Various types of slots

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-11.20]

Armature design

Armature windings are rotating-field windings, into which the rotating-field-induced voltage required in energy conversion is induced. According to IEC 60050-411, the armature winding is a winding in a synchronous machine, which, in service, receives active power from or delivers active power to the external electrical system. This definition also applies to a synchronous compensator if the term ‘active power’ is replaced by ‘reactive power’. The air-gap flux component caused by the armature current linkage is called the armature reaction.

An armature winding determined under these conditions can transmit power between an electrical network and a mechanical system. Magnetizing windings create a magnetic field required in the energy conversion. All machines do not include a separate magnetizing winding; for instance, in asynchronous machines, the stator winding both magnetizes the machine and acts as a winding, where the operating voltage is induced. The stator winding of an asynchronous machine is similar to the armature of a synchronous machine; however, it is not defined as an armature in the IEC standard. In this material, the asynchronous machine stator is therefore referred to as a rotating-field stator winding, not an armature winding. Voltages are also induced in the rotor of an asynchronous machine, and currents that are significant in torque production are created. However, the rotor itself takes only a rotor’s dissipation power (I^2R) from the air-gap power of the machine, this power being proportional to the slip.

Armature parameters

- Number of Slots
- Turns per phase
- Single turn bar windings
- Dimensions
- Depth
- Mean length

Number of Slots:

The number of slots are to be properly selected because the number of slots affect the cost and performance of the machine. There are no rules for selecting the number of slots. But looking into the advantages and disadvantages of higher number of slots, suitable number of slots per pole per phase is selected. However the following points are to be considered for the selection of number of slots.

Advantages:

(i) Reduced leakage reactance

(ii) Better cooling

(iii) Decreased tooth ripples

Disadvantages:

(i) Higher cost

(ii) Teeth becomes mechanically weak

(iii) Higher flux density in teeth

(b) Slot loading must be less than 1500 ac/slot

(c) Slot pitch must be with in the following limitations

(i) Low voltage machines 3.5 cm

(ii) Medium voltage machines up to 6kV 5.5 cm

(iv) High voltage machines up to 15 kV 7.5 cm

Considering all the above points number of slots per pole phase for salient pole machines may be taken as 3 to 4 and for turbo alternators it may be selected as much higher of the order of 7 to 9slots per pole per phase In case of fractional slot windings number of slots per pole per phase may be selected as fraction 3.5.

Turns per phase:

Turns per phase can be calculated from emf equation of the alternator.

Induced emf, $E_{ph} = 4.44 \, f\Phi T_{ph} K w$

Hence turns per phase $T_{ph} = E_{ph} / 4.44 \, f\Phi Kw$

E_{ph} = induced emf per phase

Z_{ph} = no of conductors/phase in stator

T_{ph} = no of turns/phase

kw = winding factor may assumed as 0.955

Conductor cross section: Area of cross section of stator conductors can be estimated from the stator current per phase and suitably assumed value of current density for the stator windings.

Sectional area of the stator conductor as = Is /δ where δ is the current density in stator windings Is is stator current per phase A suitable value of current density has to be assumed considering the

Advantages of higher value of current density:

(i) reduction in cross section
(ii) reduction in weight
(iii) reduction in cost

Disadvantages of higher value of current density

(i) increase in resistance
(ii) increase in cu loss
(iii) increase in temperature rise
(iv) reduction in efficiency

Hence higher value is assumed for low voltage machines and small machines. Usual value of current density for stator windings is 3 to 5 amps/mm^2.

Stator coils:

Two types of coils are employed in the stator windings of alternators. They are single turn bar coils and multi turn coils. Comparisons of the two types of coils are as follows

(i) Multi turn coil winding allows greater flexibility in the choice of number of slots than single turn bar coils.
(ii) Multi turn coils are former wound or machine wound where as the single turn coils are handmade.
(iii) Bending of top coils is involved in multi turn coils where as such bends are not required in single turn coils.
(iv) Replacing of multi turn coils difficult compared to single turn coils.
(v) Machine made multi turn coils are cheaper than hand made single turn coils.
(vi) End connection of multi turn coils are easier than soldering of single turn coils.
(vii) Full transposition of the strands of the single turn coils are required to eliminate the eddy current loss.
(viii) Each turn of the multi turn winding is to be properly insulated thus increasing the amount of insulation and reducing the space available for the copper in the slot.

From the above discussion it can be concluded that multi turn coils are to be used to reduce the cost of the machine. In case of large generators where the stator current exceeds 1500 amps single turn coils are employed.

Single turn bar windings:

The cross section of the conductors is quite large because of larger current. Hence in order to eliminate the eddy current loss in the conductors, stator conductors are to be stranded. Each slot of the stator conductor consists of two stranded conductors as shown in Fig. he dimensions of individual strands are selected based on electrical considerations and the manufacturing requirements. Normally the width of the strands is assumed between 4 mm to 7 mm. The depth of the strands is limited based on the consideration of eddy current losses and hence it should not exceed 3mm. The various strand of the bar are transposed in such a way as to minimize the circulating current loss.

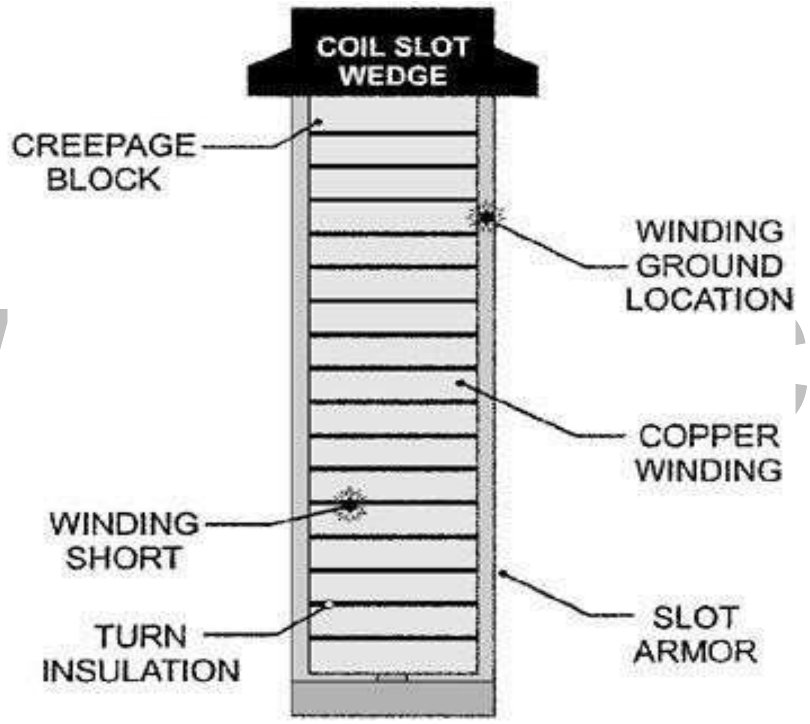


Figure 5.4.2 Single turn bar coil

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-11.23]

Multi turn coils:

Multi turn coils are former wound. These coils are made up of insulated high conductivity copper conductors. Mica paper tape insulations are provided for the portion of coils in the slot and varnished mica tape or cotton tape insulation is provide on the overhang portion. The thickness of insulation is decided based on the voltage rating of the machine. Multi turn coils are usually arranged in double layer windings in slots as shown in Fig.

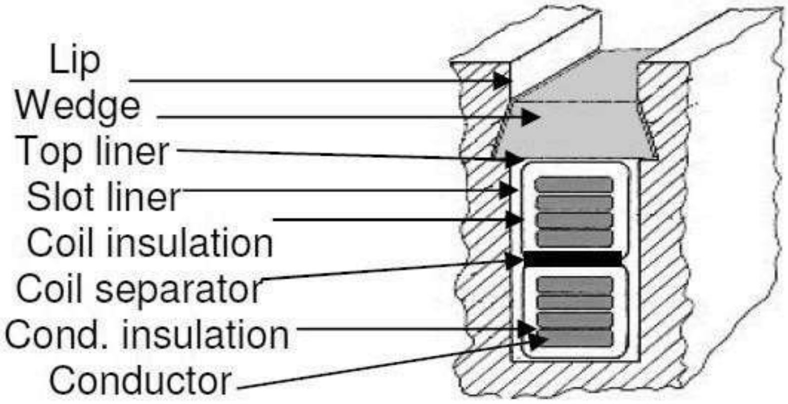


Figure 5.4.3 Multi - turn coils.

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-11.25]

Dimensions of stator slot:

Width of the slot = slot pitch – tooth width

The flux density in the stator tooth should not exceed 1.8 to 2.0 Tesla. In salient pole alternators internal diameter is quite large and hence the flux density along the depth of the tooth does not vary appreciably. Hence width of the tooth may be estimated corresponding to the permissible flux density at the middle section of the tooth. The flux density should not exceed 1.8 Tesla. However in case of turbo alternators variation of flux density along the depth of the slot is appreciable and hence the width of the tooth may be estimated corresponding to the flux density at the top section of the tooth or the width of the tooth at the air gap. The flux density at this section should not exceed 1.8 Tesla.

For salient pole alternator:

Flux density at the middle section = Flux / pole /(width of the tooth at the middle section x iron length x number of teeth per pole arc)

Number of teeth per pole arc = pole arc/slot pitch

For turbo alternators:

Flux density at the top section = Flux / pole /(width of the tooth at the top section x iron length x number of teeth per pole pitch)

As the 2/3rd pole pitch is slotted the number of teeth per pole pitch = 2/3 x pole pitch/(slot pitch at top section)

Slot width = slot pitch at the top section – tooth width at the top section.

Once the width of the slot is estimated the insulation required width wise and the space available for conductor width wise can be estimated.

Slot insulation width wise:

(i) Conductor insulation

(ii) Mica slot liner

(iii) Binding tape over the coil

(iv) Tolerance or clearance

Space available for the conductor width wise = width of the slot – insulation width wise We have already calculated the area of cross section of the conductor. Using above data on space available for the conductor width wise depth of the conductor can be estimated. Now the depth of the slot may be estimated as follows.

Depth of the slot:

(i) Space occupied by the conductor = depth of each conductor x no. of conductor per slot

(ii) Conductor insulation

(iii) Mica slot liner

(iv) Mica or bituminous layers to separate the insulated conductors

(v) Coil separator between the layers

(vi) Wedge

(vii) Lip

(viii) Tolerance or clearance

Mean length of the Turn:

The length of the mean turn depends on the following factors

(i) Gross length of the stator core: Each turn consists of two times the gross length of stator core.

(ii) Pole pitch: The over hang portion of the coils depend upon the coil span which in turn depends upon the pole pitch.

(iii) Voltage of the machine: The insulated conductor coming out of the stator slot should have straight length beyond the stator core which depends upon the voltage rating of the machine.

Slot dimension: Length per turn depends on the average size of the slot.

Hence mean length of the turn in double layer windings of synchronous machines is estimated as follows.

$$l_{mt} = 2l + 2.5\,p + 5\,kV + 15\text{ cm.}$$

5.2 Choice of specific loadings

Specific magnetic loading:

Following are the factors which influences the performance of the machine.

(i) Iron loss:

A high value of flux density in the air gap leads to higher value of flux in the iron parts of the machine which results in increased iron losses and reduced efficiency.

(ii) Voltage:

When the machine is designed for higher voltage space occupied by the insulation becomes more thus making the teeth smaller and hence higher flux density in teeth and core.

(iii) Transient short circuit current:

A high value of gap density results in decrease in leakage reactance and hence increased value of armature current under short circuit conditions.

(iv) Stability:

The maximum power output of a machine under steady state condition is indirectly proportional to synchronous reactance. If higher value of flux density is used it leads to smaller number of turns per phase in armature winding. This results in reduced value of leakage reactance and hence increased value of power and hence increased steady state stability.

(v) Parallel operation:

The satisfactory parallel operation of synchronous generators depends on the synchronizing power. Higher the synchronizing power higher will be the ability of the machine to operate in synchronism. The synchronizing power is inversely proportional to the synchronous reactance and hence the machines designed with higher value air gap flux density will have better ability to operate in parallel with other machines.

Specific Electric Loading:

Following are the some of the factors which influence the choice of specific electric loadings.

(i) Copper loss:

Higher the value of q larger will be the number of armature of conductors which results in higher copper loss. This will result in higher temperature rise and reduction in efficiency.

(ii) Voltage:

A higher value of q can be used for low voltage machines since the space required for the insulation will be smaller.

(iii) Synchronous reactance:

High value of q leads to higher value of leakage reactance and armature reaction and hence higher value of synchronous reactance. Such machines will have poor voltage regulation, lower value of current under short circuit condition and low value of steady state stability limit and small value of synchronizing power.

(iv) Stray load losses:

With increase of q stray load losses will increase. Values of specific magnetic and specific electric loading can be selected from Design Data Hand Book for salient and non-salient pole machines.

Separation of D and L:

Inner diameter and gross length of the stator can be calculated from D^2L product obtained from the output equation. To separate suitable relations are assumed between D and L depending upon the type of the generator. Salient pole machines: In case of salient pole machines either round or rectangular pole construction is employed. In these types of machines, the diameter of the machine will be quite larger than the axial length.

5.6 DESIGN OF DAMPER WINDING

- Damper windings are provided in the pole faces of salient pole alternators. Damper windings are nothing but the copper or aluminum bars housed in the slots of the pole faces.
- The ends of the damper bars are short circuited at the ends by short circuiting rings similar to end rings as in the case of squirrel cage rotors.
- These damper windings are serving the function of providing mechanical balance; provide damping effect, reduce the effect of over voltages and damp out hunting in case of alternators.
- In case of synchronous motors they act as rotor bars and help in self-starting of the motor.

Design Procedure:

- MMF of Damper Winding = $0.143\ ac\ \tau$

  Where,

  ac – specific electrical loading

  τ- Pole pitch

- Total area of damper winding $A_d = 0.2\ ac\ \tau / \delta_d$

  Where,

  ac – specific electrical loading

  τ- Pole pitch

  δ_d - Current density

- Cross-sectional area of each damper winding $a_d = A_d/N_d$

  Where,

  A_d – Total area of damper winding

  N_d - Number of damper bars

- Number of damper bars $N_d = \frac{\text{Pole arc}}{0.8 * \text{Stator slot pitch}}$
- Diameter of each damper bar $D_d = \sqrt{\frac{4ad}{\pi}}$
- Length of each damper bar $L_d = 1.1\ L$

Where,

L – Length of core.

Height of pole shoe $h_s = 2\ D_d$

Where,

D_d – Diameter of each damper bar.

5.7 Design of field winding

Stator winding is made up of former wound coils of high conductivity copper of diamond shape. These windings must be properly arranged such that the induced emf in all the phases of the coils must have the same magnitude and frequency. These emfs must have same wave shape and be displaced by 1200 to each other. Single or double layer windings may be used depending on the requirement. The three phase windings of the synchronous machines are always connected in star with neutral earthed. Star connection of windings eliminates the 3rd harmonics from the line emf. Double layer winding: Stator windings of alternators are generally double layer lap windings either integral slot or fractional slot windings. Full pitched or short chorded windings may be employed. Following are the advantages and disadvantages of double layer windings.

Normally 70% of the rotor is slotted and remaining portion is unslotted in order to form the pole. The design of the field can be explained as follows.

(i) Selection of rotor slots:

Total number of rotor slots may be assumed as 50 – 70 % of stator slots pitches. However, the so found rotor slots must satisfy the following conditions in order to avoid the undesirable effects of harmonics in the flux density wave forms.

(a) There should be no common factor between the number of rotor slot pitches and number of stator slot pitches.

(b) Number of wound rotor slots should be divisible by 4 for a 2 pole synchronous machine. That means the number of rotor slots must be multiple of 4.

(c) Width of the rotor slot is limited by the stresses developed at the rotor teeth and end rings.

(ii) Design of rotor winding:

(a) Full load field mmf can be taken as twice the armature mmf.

ATfl = 2 x ATa = 2 x 1.35 x Iph x Tph x kw /p

(b) Standard exciter voltage of 110 - 220 volts may be taken. With 15-20 % of this may be reserved for field control. Hence voltage across each field coil Vf = (0.8 to 0.85) V/p

(c) Length of the mean turn lmt = 2L + 1.8 τp + 0.25 m

(d) Sectional area of each conductor af = ζ x lmt x (If x Tf) / vf

(e) Assume suitable value of current density in the rotor winding. 2.5 – 3.0 amp/mm2 for conventionally cooled machines and 8 – 12 amp/mm2 for large and special cooled machines.

(f) Find area of all the rotor conductors per pole = 2 x (If x Tf) /δf

(g) Find the number of rotor conductors per pole = 2 x (If x Tf) / (δf x af)

(h) Number of field conductors per slot = 2 x (If x Tf) / (δf x af x sr), where sr is the number of rotor slots.

(i) Resistance of each field coil Rf = ζ x lmt x Tf / af

(j) Calculate the current in the field coil If = vf/ Rf

Based on the above data dimensions may be fixed. The ratio of slot depth to slot width may be taken between 4 and 5. Enough insulation has to be provided such that it with stands large amount of mechanical stress and the forces coming on the rotor. The following insulation may be provided for the field coil.

(i) All field conductors are provided with mica tape insulation.

(ii) Various turns in the slots are separated from each other by 0.3 mm mica separators.

(iii) 0.5 mm hard mica cell is provided on all the field coil.

(iv) Over the above insulation, 1.5 mm flexible mica insulation is provided.

(v) Lastly a steel cell of o.6 mm is provided on the whole field coil.

Advantages:

(i) Better waveform: by using short pitched coil

(ii) Saving in copper: Length of the overhang is reduced by using short pitched coils

(iii) Lower cost of coils: saving in copper leads to reduction in cost

(iv) Fractional slot windings: Only in double layer winding, leads to improvement in waveform

Disadvantages:

(i) Difficulty in repair: difficult to repair lower layer coils

(ii) Difficulty in inserting the last coil: Difficulty in inserting the last coil of the windings

(iii) Higher Insulation: More insulation is required for double layer winding

(iv) Wider slot opening: increased air gap reluctance and noise

5.8 Computer program: Design of Stator main dimensions

Problem:

Calculate diameter of core, length, size and number of conductors for a 15000kVA; 50Hz; 11kV ; 2 – Pole star connected salient pole cylindrical rotor alternator with armature winding having 600 phase spread. Assume :

avg. magnetic flux Bav = .55Wb/m2

electrical loading ac = 36,000 amp/m

current density J = 5 amp/mm2

peripheral speed Va = 160m/sec

windings should be arranged to eliminate 5th harmonic.

Synchronous speed Ns = 50 r.p.s

Solution:

Given Ns = 50 r.p.s and P = 2 poles

Peripheral speed Va = 160m/sec

Va = pi*D*Ns

Therefore D = Va/(pi*Ns) = 160/(3.14*50) = 1 m

Now Distribution factor for 60o phase spread in order to eliminate 5th harmonic

Kd = .955

cos(5α/2) = 0

giving 5α/2 = 90

giving α = 36o

Pitch factor Kp = cos(α/2) = .951

Now Kw = Kp * Kd = .951 * .955 = .8595

Now Co = 1.11pi2*f*Bav*ac*Kw = 1.11*3.142*50*.55*36000*.8595 = 186.248

D2L = P/(Co*Ns)

L = 15000/(186.248*50*12) = 1.6m

Flux Φ = pi*D*L*Bav = 3.14*1*1.6*.55 = 2.76Wb

Φpole = Φ/pole = 1.38Wb/pole

Tph = Eph/(4.44*f*Kw*Φpole) = (11000/√3)/(4.44*50*.8595*1.38) = 24

Total conductors Z = 6*Tph = 144 = Ss

Conductor per slot = Z/(2*Poles) = 144/4 = 36

Program:

```
function calculate_D_L_size_number_alternator_cylindrical_rotor

%given

Bav = .55;

ac = 36000;

J = 5;

Va = 160;

Ns = 50;

pole = 2;

Q = 15000;

f = 50;

Eline = 11000;

%therfore D

D = Va/(pi*Ns);

%————-

%Now distribution factor for 60 degree phase spread in
```

```
%order to eliminate 5th harmonic
%———-
Kd = .955;
alpha = (2*acosd(0))/5;
%Why as cos(5*alpha/2) = 0 for 5th harmonic
fprintf(‘\nProgram to calculate D, L size and numer of conductors of Synch machine’);
fprintf(‘\n—————————’);
fprintf(‘\nFor 5th harmonic elimination we have alpha = ‘);
disp(alpha);
fprintf(‘\nUsing alpha we also get…..’);
% pitch factor Kp
Kp = cosd(alpha/2);
fprintf(‘\nPitch factor Kp = ‘);
disp(Kp);
% giving Kw
fprintf(‘\nStacking Factor Kw = ‘);
Kw = Kp*Kd;
disp(Kw);
% using Kw we get output coeffecient
Co = 1.11*pi*pi*f*Bav*ac*Kw*.001
fprintf(‘\nWe have Diameter D = ‘);
disp(D);
fprintf(‘\nLength L = ‘);
```

```
L = (Q)/(Co*Ns*D*D);
disp(L);
%Now flux phi
phi = pi*D*L*Bav;
fprintf(‘\nWe got Flux phi = ‘);
disp(phi);
phipole = phi/pole;
%Turn per phase
Eph = Eline/sqrt(3);
Tph = Eph/(4.44*f*Kw*phipole);
fprintf(‘\nTurns per phase Tph = ‘);
disp(Tph);
%total conductors Z
Z = 6*Tph;
fprintf(‘\nTotal conductors Z = ‘);
disp(Z);
%copnductors per slot
Ss = Z/(2*pole);
fprintf(‘\nConductors per slot = ‘);
disp(Ss);
end
```

Output:

```
For 5th harmonic elimination we have alpha = 36

Using alpha we also get…..

Pitch factor Kp = 0.9511

Stacking Factor Kw = 0.9083

Co =

9.8507e+003

We have Diameter D = 1.0186

Length L = 0.0294

We got Flux phi = 0.0517

Turns per phase Tph = 1.2194e+003

Total conductors Z = 7.3162e+003

Conductors per slot = 1.8290e+003
```

5.5 ESTIMATION OF AIR GAP LENGTH

Length of the air gap:

Length of the air gap is a very important parameter as it greatly affects the performance of the machine. Air gap in synchronous machine affects the value of SCR and hence it influences many other parameters. Hence, choice of air gap length is very critical in case of synchronous machines.

Following are the advantages and disadvantages of larger air gap.

Advantages:

(i) Stability: Higher value of stability limit

(ii) Regulation: Smaller value of inherent regulation

(iii) Synchronizing power: Higher value of synchronizing power

(iv) Cooling: Better cooling

(v) Noise: Reduction in noise

(vi) Magnetic pull: Smaller value of unbalanced magnetic pull

Disadvantages:

(i) Field MMF: Larger value of field MMF is required

(ii) Size: Larger diameter and hence larger size

(iii) Magnetic leakage: Increased magnetic leakage

(iv) Weight of copper: Higher weight of copper in the field winding

(v) Cost: Increase overall cost.

Hence length of the air gap must be selected considering the above factors.

Estimation of air gap length

Length of the air gap is usually estimated based on the ampere turns required for the air gap. Armature ampere turns per pole required $ATa = 1.35\ T_{ph} kw / p$

Where

Tph = Turns per phase,

Iph = Phase current,

kw = winding factor,

p = pairs of poles

No load field ampere turns per pole ATfo = SCR x Armature ampere turns per pole

$$ATfo = SCR \times ATa$$

Suitable value of SCR must be assumed.

Ampere turns required for the air gap will be approximately equal to 70 to 75 % of the no load field ampere turns per pole.

$$ATg = (0.7 \text{ to } 0.75)\ ATfo$$

Air gap ampere turns ATg = 796000 Bgkglg

Air gap coefficient or air gap contraction factor may be assumed varying from 1.12 to 1.18.

As a guide line, the approximate value of air gap length can be expressed in terms of pole pitch

For salient pole alternators:

$$lg = (0.012 \text{ to } 0.016) \times \text{pole pitch}$$

For turbo alternators:

$$lg = (0.02 \text{ to } 0.026) \times \text{pole pitch}$$

Synchronous machines are generally designed with larger air gap length compared to that of Induction motors.

5.1 Output equation of AC motor

Output equation is the mathematical expression which gives the relation between the various physical and electrical parameters of the electrical machine.

In an AC motor the output equation can be obtained as follows Consider an ‘m’ phase machine, with usual notations

Output Q in kW = Input x efficiency

Input to motor = mV_{ph} I_{ph} cos Φ x 10-3 k_W

For a 3 Φ machine m = 3 ,

Input to motor = $3V_{ph}$ I_{ph} cos Φ x 10-3 k_W Assuming

$V_{ph} = E_{ph}$, $V_{ph} = E_{ph} = 4.44$ f Φ $T_{ph}K_w$

= 2.22 f $\Phi Z_{ph} K_w$

f = $PN_S/120 = Pn_s/2$,

Output = 3 x 2.22 x Pns/2 x $\Phi Z_{ph} K_w$ I_{ph} η cos Φ x 10-3 k_W

Output = 1.11 x PΦ x $3I_{ph}$ Z_{ph} x ns Kw η cos Φ x 10-3k_W,

PΦ = BavπDL, and $3I_{ph}$ Z_{ph}/ πD = q

Output to motor = 1.11 x BavπDL x πDq x ns Kw η cos Φ x 10-3 kW

Q = (1.11 π2 Bav q Kw η cos Φ x 10-3) D^2L ns kW

Q = (11 Bav q K_w η cos Φ x 10-3) D^2L ns k_W

Therefore,

Output $\boxed{Q = Co\ D^2L\ n_s\ kW}$

where Co = (11 Bav q Kw η cos Φ x 10-3)

V_{ph} = phase voltage;

I_{ph} = phase current

Ns = Synchronous speed in rpm

ns = synchronous speed in rps

p = no of poles,

q = Specific electric loading

Φ = air gap flux/pole;

B_{av} = Average flux density

kw = winding factor.

η = efficiency

cosΦ = power factor

D = Diameter of the stator,

L = Gross core length

Co = Output coefficient

From the output equation of the machine it can be seen that the volume of the machine is directly proportional to the output of the machine and inversely proportional to the speed of the machine. The machines having higher speed will have reduced size and cost. Larger values of specific loadings smaller will be the size of the machine.

Separation of D and L:

Inner diameter and gross length of the stator can be calculated from D^2L product obtained from the output equation. To separate suitable relations are assumed between D and L depending upon the type of the generator. Salient pole machines: In case of salient pole machines either round or rectangular pole construction is employed. In these types of machines, the diameter of the machine will be quite larger than the axial length.

Round Poles:

The ratio of pole arc to pole pitch may be assumed varying between 0.6 to 0.7 and pole arc may be taken as approximately equal to axial length of the stator core. Hence Axial length of the core/ pole pitch = L/ p = 0.6 to 0.7

Rectangular poles:

The ratio of axial length to pole pitch may be assumed varying between 0.8 to 3 and a suitable value may be assumed based on the design specifications. Axial length of the core/ pole pitch = L/ p = 0.8 to 3

Using the above relations D and L can be separated. However once these values are obtained diameter of the machine must satisfy the limiting value of peripheral speed so that the rotor can withstand centrifugal forces produced.

Limiting values of peripheral speeds are as follows:

- Bolted pole construction = 45 m/s
- Dove tail pole construction = 75 m/s
- Normal design = 30 m/s

Design of salient pole machines:

These type of machines have salient pole or projecting poles with concentrated field windings. This type of construction is for the machines which are driven by hydraulic turbines or Diesel engines.Rotor of water wheel generator consists of salient poles. Poles are built with thin silicon steel laminations of 0.5mm to 0.8 mm thickness to reduce eddy current laminations. The laminations are clamped by heavy end plates and secured by studs or rivets. For low speed rotors poles have the bolted on construction for the machines with little higher peripheral speed poles have dove tailed construction as shown in Figs. Generally rectangular or round pole constructions are used for such type of alternators. However the round poles have the advantages over rectangular poles.

In case of salient pole machines either round or rectangular pole construction is employed. In these types of machines the diameter of the machine will be quite larger than the axial length.

Round Poles:

The ratio of pole arc to pole pitch may be assumed varying between 0.6 to 0.7 and pole arc may be taken as approximately equal to axial length of the stator core. Hence

Axial length of the core/ pole pitch = $L/\tau p$ = 0.6 to 0.7

Rectangular poles:

The ratio of axial length to pole pitch may be assumed varying between 0.8 to 3 and a suitable value may be assumed based on the design specifications.

Axial length of the core/ pole pitch = $L/\tau p$ = 0.8 to 3

Using the above relations D and L can be separated. However once these values are obtained diameter of the machine must satisfy the limiting value of peripheral speed so that the rotor can withstand centrifugal forces produced.

Limiting values of peripheral speeds are as follows:

- Bolted pole construction = 45 m/s
- Dove tail pole construction = 75 m/s
- Normal design = 30 m/s

Design of turbo alternators

Turbo alternators: These alternators will have larger speed of the order of 3000 rpm. Hence the diameter of the machine will be smaller than the axial length. As such the diameter of the rotor is limited from the consideration of permissible peripheral speed limit. Hence the internal diameter of the stator is normally calculated based on peripheral speed. The peripheral speed in case of turbo alternators is much higher than the salient pole machines. Peripheral speed for these alternators must be below 175 m/s.

5.3 Short circuit ratio

It is defined as the ratio of field current required to produce rated voltage on open circuit to the field current required to circulate rated current on short circuit.

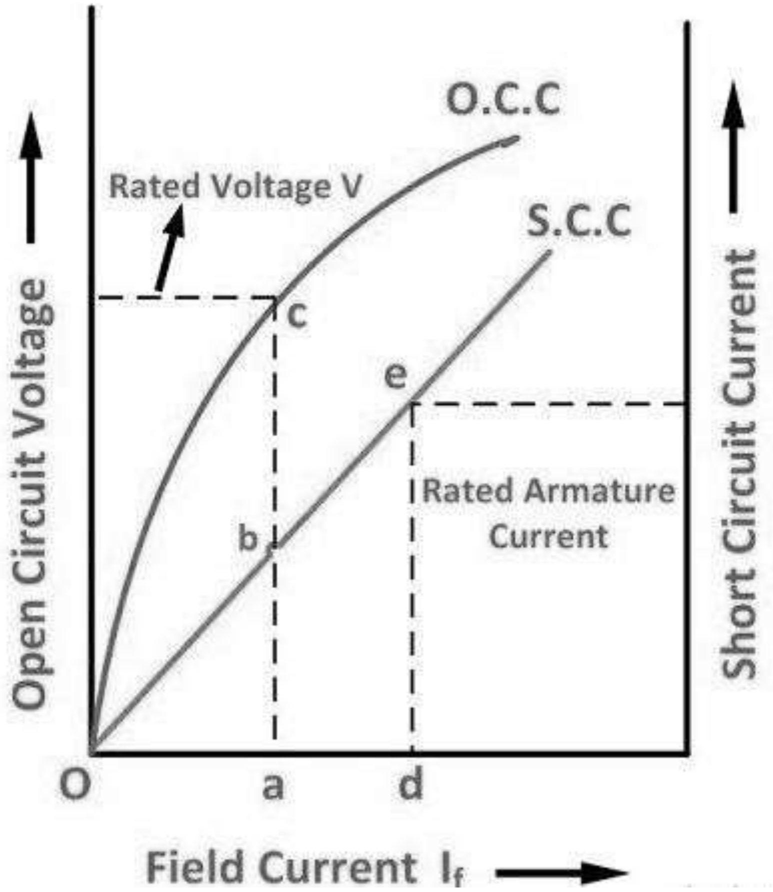


Figure 5.3.1 O.C.C and S.C.C

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-11.18]

The short circuit ratio can be calculated from the open-circuit characteristic (O.C.C) at rated speed and the short circuit characteristic (S.C.C) of a three-phase synchronous machine as shown in the figure below:

$$\text{SCR} = \frac{\text{If required to procuce O.C Voltage}}{\text{If required to produce S.C current}}$$

$$\text{SCR} = \text{OA/OD}$$

Since the triangles Oab and Ode are similar. Therefore,

$$\text{SCR} = \text{OA/OD} = \text{AB/DE}$$

The direct axis synchronous reactance Xd is defined as the ratio of open-circuit voltage for a given field current to the armature short circuit current for the same field current.

For the field current equal to Oa, the direct axis synchronous reactance in ohms is given by the equation shown below:

$$X_d = \frac{AC}{AB}$$

The per-unit value of Xd is given as:

$$X_{d(p.u)} = \frac{Xd}{\text{Base Impedance}}$$

But, the base impedance is:

$$\text{Base Impedance} = \frac{\text{Per phase rated voltage}}{\text{Per phase armature rated current}}$$

$$\text{Base Impedance} = \frac{AC}{DE}$$

Therefore,

$$X_{d(p.u)} = \frac{DE}{AB}$$

Therefore,

$$SCR = \frac{1}{Xd}$$

Significance of SCR

- If the value of SCR is low,

1. The synchronous reactance will be high and the regulation of machine will be poor.
2. Poor stability limit
3. The length of air gap will less. Hence less field copper. So expensive field winding.

- If the value of SCR is high,

  The machine will have a higher stability limit, low voltage regulation, a high value short circuit current, a larger air gap and hence expensive field system.

Values of SCR

1. Cylindrical (or) Turbo alternator - 0.5 to 0.8 average 0.6
2. Water wheel alternator - 0.9 to 1.0 or even 2
3. Synchronous condenser - 0.4