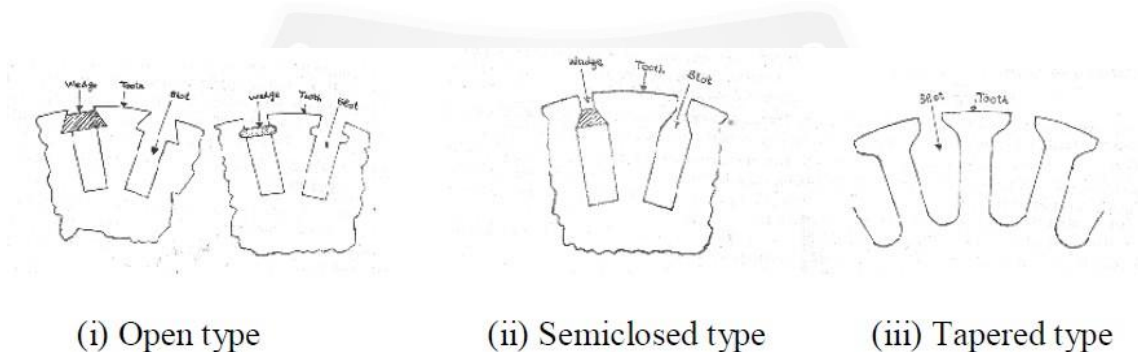## 5.4 ARMATURE DESIGN

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 $T_{ph} = E_{ph}\, /\, 4.44\, f\Phi K_w$

       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.
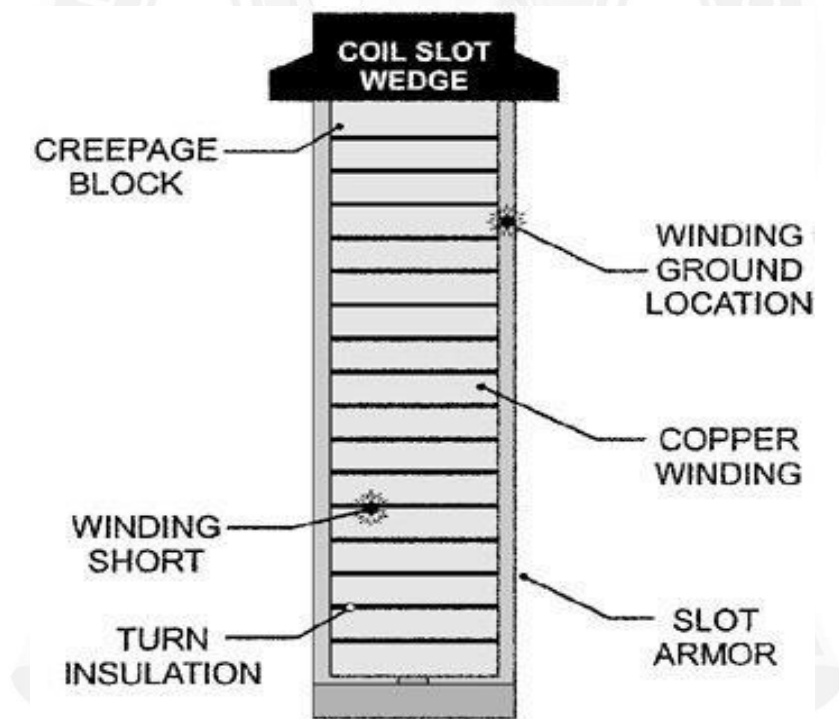

Figure 5.4.2 Single turn bar coil

[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.
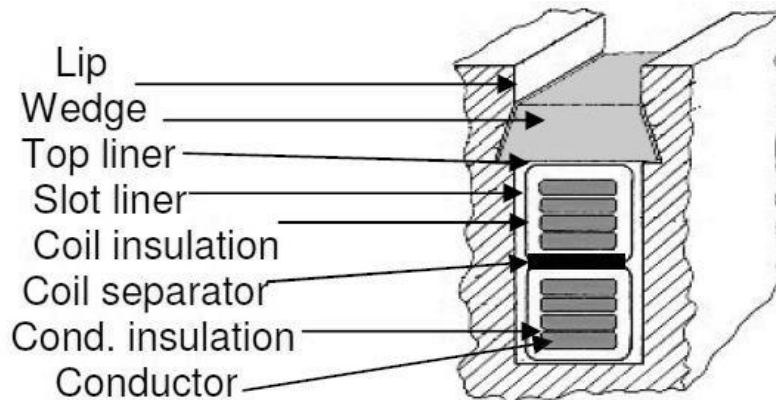
Figure 5.4.3 Multi - turn coils.

[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.

(iv)   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.

$$lmt = 2l + 2.5 \ p + 5 \ kV + 15 \ cm.$$