## 1.3 MAGNETIC CIRCUIT CALCULATIONS

- The path of the magnetic flux is called a magnetic circuit.
- A magnetic circuit is analogous to an electric circuit. A review of laws of magnetic circuits is given below.

In an electric circuit Ohm’s law expresses a relationship between current, emf and resistance. While in a magnetic circuit, a similar relation exists relating flux, mmf and reluctance.

This relation is:

$$\text{flux}=\frac{\text{mmf}}{\text{relutane}}$$

$$\Phi=\frac{AT}{S}$$

$$\Phi = AT \times S$$

The reluctance of the magnetic material can be esusing the following equation.

$$\text{Reluctance}=\frac{\text{Length}}{\text{area x permeability}}$$

$$S=\frac{l}{A\mu}$$

**Table 1 Differences between electric and magnetic circuits**

| ELECTRIC CIRCUIT | MAGNETIC CIRCUIT |
|---|---|
| Current actually flows in the electric circuit. | Flux does not flow, but it is only assumed to flow. |
| When current flows, the energy is spend continuously. | Energy is needed only to create the flux but not to maintain it. |
| Resistance of the electric circuit is independent of current strength. | Reluctance of the magnetic circuit depends on total flux or flux density in the material. |

## Magnetic Curve (B-H Curve)

In magnetic materials, the magnetizing force required to establish a given flux density depends on the saturation of the material. If the material is not saturated, then a small increase in magnetizing force will result in a proportional increase in flux density. But when the material is saturated, a large increase in magnetizing force will result in a small increase in flux density. Therefore, the permeability of the magnetic material is not constant

In a non-magnetic material like air, copper, etc. there is no such phenomena of saturation. Hence the permeability of non-magnetic material is constant and the relation between B and H is linear. Therefore, the B-H curve will be straight line passing through origin.

In magnetic materials, the relation between the flux density B and the magnetizing force H is nonlinear. Hence, it is difficult to express the relation in terms of mathematical equation. Therefore, to calculate mmf per meter of flux path for a given flux density the B-H curve is employed.

The manufacturers of stamping or laminations for transformer, induction motor, ac machines etc will supply B-H curve. These curves are used to estimate magnetizing force and core loss for a given flux density or for a required flux density in any part of the machine.

By using digital computers, the analytic relations between B and H prove more convenient. Two of the most used mathematical relationships are given below.

$$B = \frac{aH}{1+bH} \qquad \textbf{(1)}$$

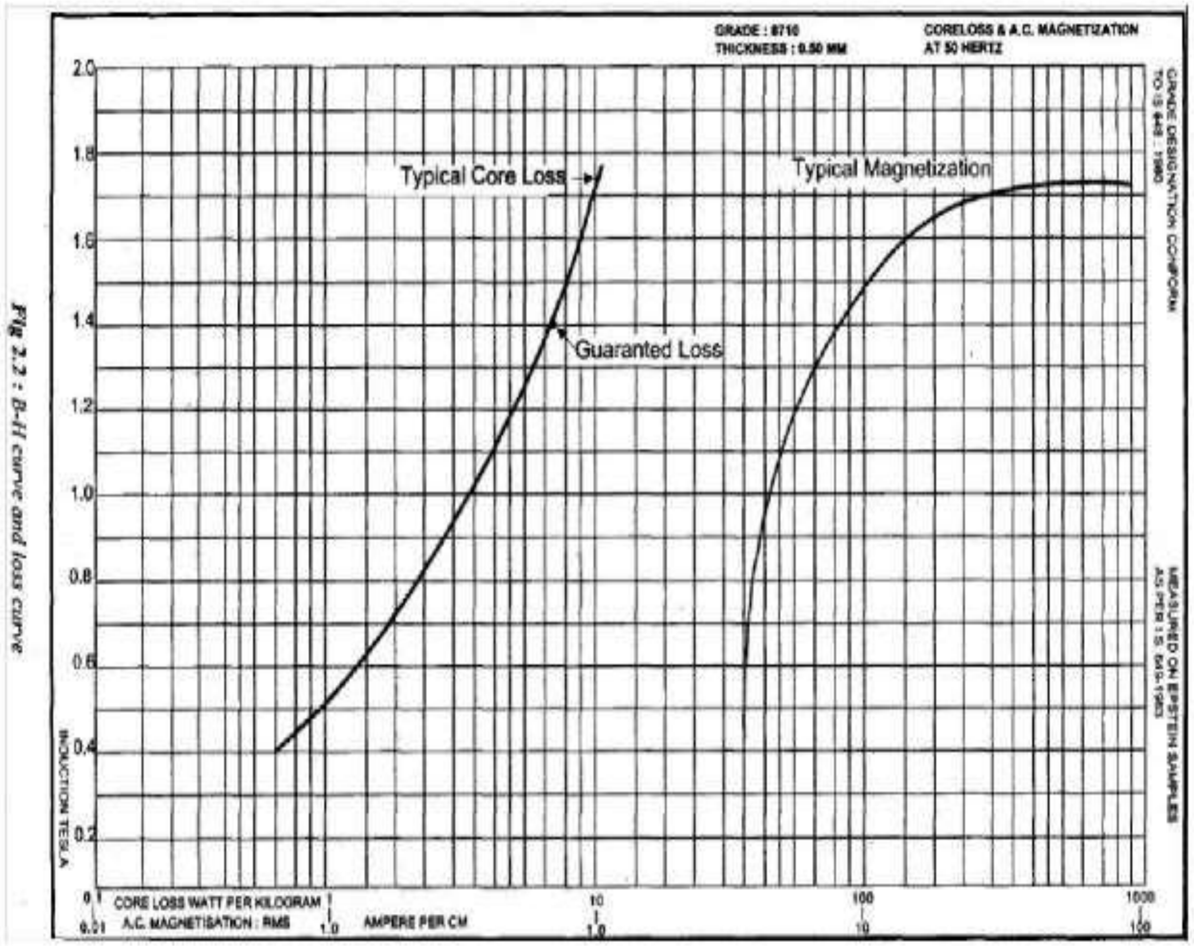


**Figure 1.3.1 B-H Curve**

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

## Magnetic Leakage

For magnetic circuit calculations, a term 'leakage co-efficient' is introduced in order to take into account the leakage flux. The value of this leakage co-efficient is defined as

$$\text{Leakage co-efficient, C} = \frac{\text{Useful Flux+Leakage Flux}}{\text{Useful Flux}}$$

## Types of Leakage Flux

The armature leakage fluxes affect most of the performance of rotating machines Hence the different types of armature leakage fluxes are discussed in this section. The different types of armature leakage fluxes are:

- Slot leakage flux
- Tooth top leakage flux
- Zigzag leakage flux
- Overhang leakage flux
- Harmonic or differential leakage flux
- Skew leakage flux
- Peripheral leakage flux

**Slot leakage flux**

The fluxes that cross the slot from one tooth to the next and returning through iron are called slot leakage flux. They link the conductors below them, as shown in fig.

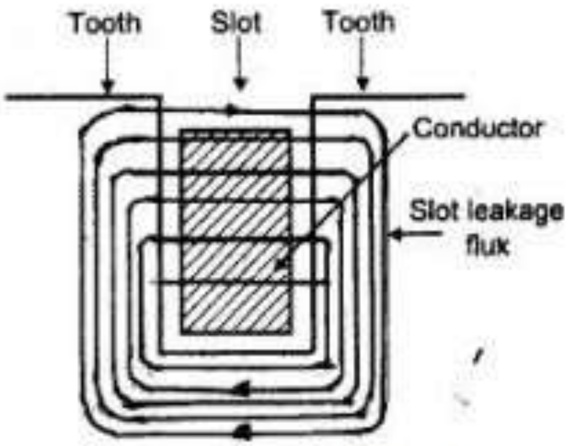


Fig. 3. Slot leakage flux

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

### Tooth top leakage flux

The flux flowing from top of the one tooth to the top of another tooth as shown in fig. 4 is called tooth top leakage flux. This leakage flux is considered only in machines having large air-gap length like DC machines and synchronous machines. Since in induction

**machines the air-gap length is very small the tooth top leakage flux is negligible**

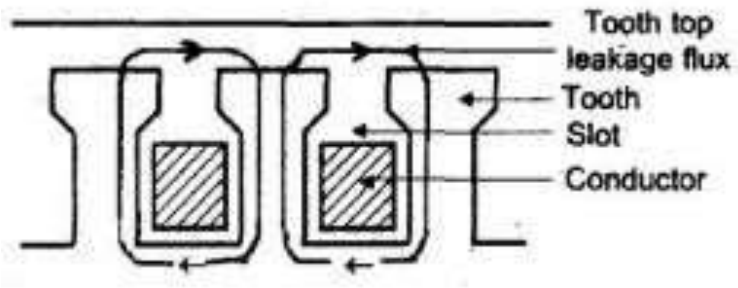


Fig. 4 Tooth top leakage flux

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

## Zigzag leakage flux

The flux passing from one tooth to another in a zigzag fashion across the air-gap as shown in fig. 5 is called zigzag leakage flux. The magnitude of this flux depends on the length of air-gap and the relative positions of the tips of rotor a stator tooth.

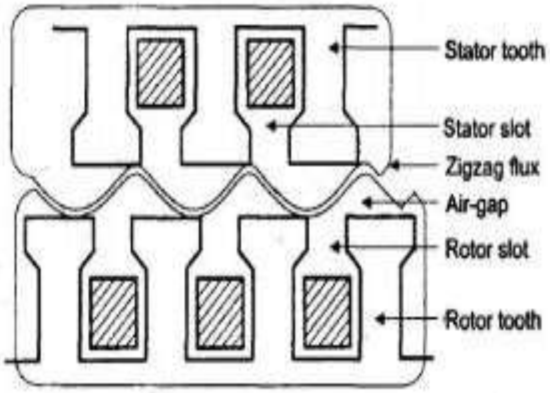


Fig. 5 Zigzag leakage flux

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

## Overhang leakage flux

The end connections (the conductor which connects the two sides of a coil) are called overhang. The fluxes produced by the overhang portion of the armature winding are called overhang leakage flux as shown in fig 6. It depends on the arrangement of overhang and the nearby metal parts (for eg. Core stiffness and end covers

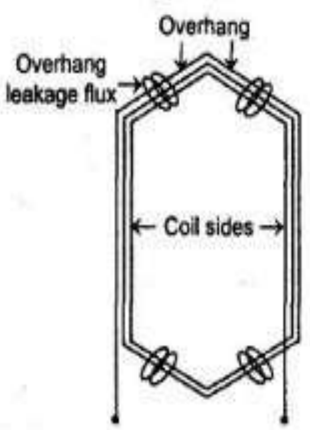


Fig. 6 Overhang leakage flux

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

### Harmonic (or Differential or Belt) leakage flux

The harmonic leakage flux is due to dissimilar mmf distribution in the stator and rotor. Actually the difference in the harmonic contents of stator and rotor mmfs produces harmonic leakage fluxes. In squirrel cage induction motor the rotor current is exactly balanced by stator current and so there is no harmonic leakage flux.

### Skew leakage flux

A twist provided in the rotor of induction motors to eliminate harmonic torques and noise is called skewing. The skewing reduces the mutual flux and thus creating a difference between total flux and mutual flux. This difference is accounted as skew leakage flux.

### Peripheral leakage flux

The fluxes flowing circumferentially round the air-gap without linking with any of the windings are called peripheral leakage flux. Usually this leakage flux is negligible in most of the machines.

## RELUCTANCE OF AIR-GAP IN MACHINES WITH SMOOTH ARMATURE

Let

L = length of core

$y_s$ = slot pitch

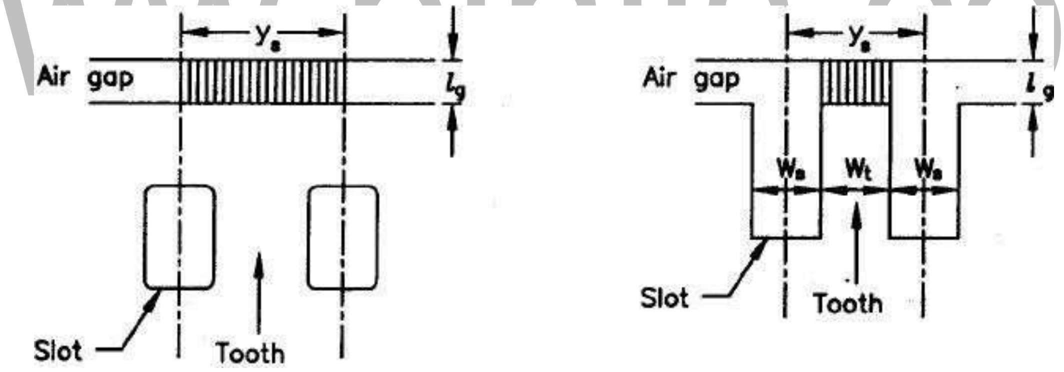
$W_t$ = width of tooth

$n_d$ = number of radial ducts

The iron surfaces around the air gap are not smooth and so the calculation of mmf for the air gap by ordinary methods gives wrong results. The problem is complicated by the fact that:

- One or both of the iron surfaces around the air gap may be slotted so that the flux tends to concentrate on the teeth rather than distributing itself uniformly over the air gap.
- There are radial ventilating ducts in the machine for cooling purposes which affect in a similar manner as above.
- In salient pole machines, the gap dimensions are not constant over whole of the pole pitch.

Consider the iron surfaces on the two sides of the air gap to be smooth as shown in fig. 7. The flux is



*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

If we confine our attention to only one slot pitch, the reluctance of air gap

$$\boxed{S_g = \frac{l}{\mu_o A} \quad \frac{l_g}{\mu_o L y}}$$

## RELUCTANCE OF AIR-GAP IN MACHINES WITH OPEN ARMATURE SLOTS

In armature with open and semi enclosed slots, the flux will flow through the teeth of the armature.

Hence the effective area of flux path is decreased, which results in increased reluctance of air gap.

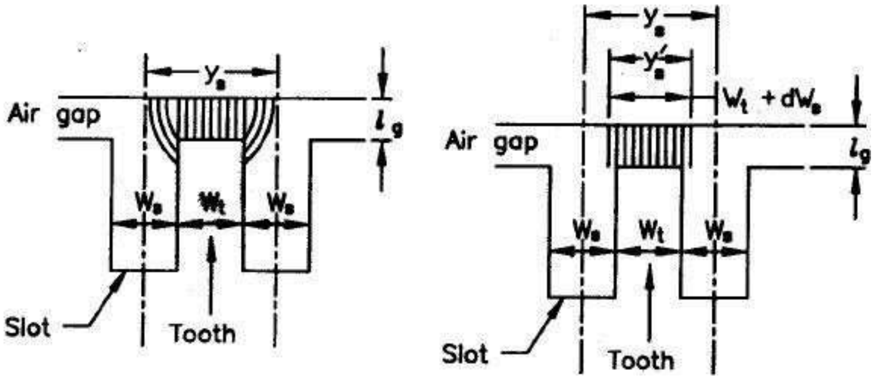
### Reluctance of air-gap neglecting fringing effect

Consider the armature with open type of slots as shown in fig. 8. Here the flux is only confined to the tooth width. Hence the area of cross-section of the air gap through which the flux passes is $L(y_s - w_s)$ or $Lw_t$ .

### Reluctance of air-gap including the effect of fringing

In armature with open slots the flux would fringe around the tooth and this fringing would increase the area of cross section of flux path.

Consider the open type slot of armature shown in fig. 9. Here the fringing of flux can be accounted by increasing the area of cross-section of flux path by $\delta w_s$ as shown in fig. 10.



*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-3.3]*

The reluctance in this case is more than that of a air-gap in smooth armature but lesser than that of the case where the whole flux is assumed to be confined over the tooth width.

A simple method to calculate reluctance in this case is to assume that the air gap flux is uniformly distributed over the whole of slot pitch expect for a fraction of slot width as shown in fig.(b). This fraction depends on the ratio of slot width to air gap length. Thus the flux of one slot is distributed over $W_t + \delta W_S$ .

Effective or contracted slot pitch

$$y' = W_t + \delta W_S$$

## 1.4 Design of Armature Windings

The different armature coils in a d.c. armature Winding must be connected in series with each other by means of end connections (back connection and front connection) in a manner so that the generated voltages of the respective coils will aid each other in the production of the terminal e.m.f. of the winding. Two basic methods of making these end connections are:

1. Simplex lap winding
2. Simplex wave winding

### 1. Simplex lap winding.

For a simplex lap winding, the commutator pitch $Y_C = 1$ and coil span $Y_S \simeq$ pole pitch. Thus the ends of any coil are brought out to adjacent commutator segments and the result of this method of connection is that all the coils of the armature .ire in sequence with the last coil connected to the first coil. Consequently, closed circuit winding results. This is illustrated in Fig. (1.21) where a part of the lap winding is shown. Only two coils are shown for simplicity. The name lap comes from the way in which successive coils overlap the preceding one.

### 2. Simplex wave winding

For a simplex wave winding, the commutator pitch $Y_C \simeq 2$ pole pitches and coil span = pole pitch. The result is that the coils under consecutive pole pairs will be joined together in series thereby adding together their e.m.f.s [See Fig. 1.22]. After passing once around the armature, the winding falls in a slot to the left or right of the starting point and thus connecting up another circuit. Continuing in this way, all the conductors will be connected in a single closed winding. This winding is called wave winding from the appearance (wavy) of the end connections.

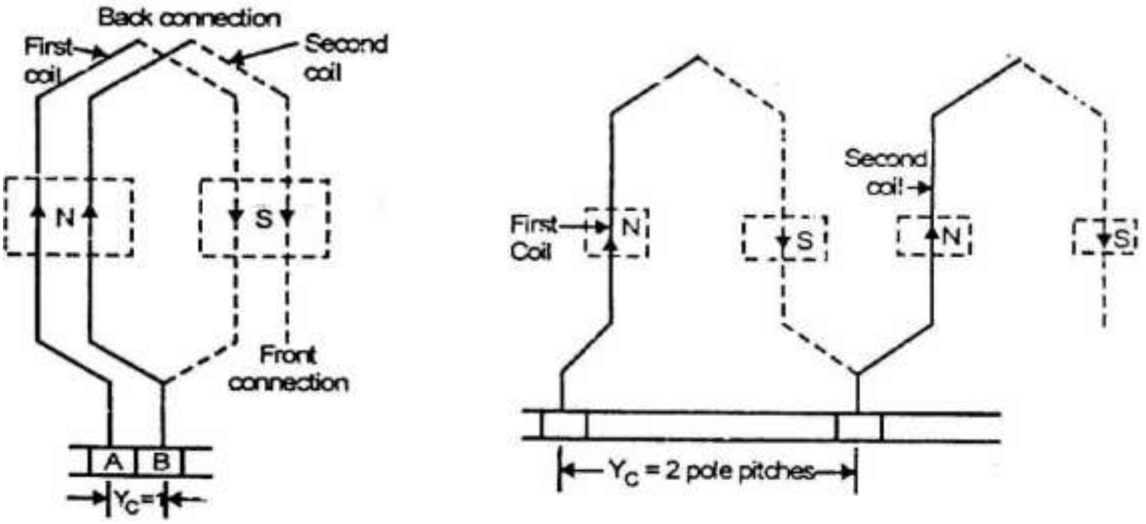


**Figure 1.4.1 a) lap winding b) wave winding**

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-7.5]*

### Armature Winding Terminology

Apart from the terms discussed earlier, the following terminology requires discussion:

### (i) Back Pitch ($Y_B$)

It is the distance measured in terms of armature conductors between the two sides of a coil at the back of the armature (See Fig. 1.23). It is denoted by $Y_B$ For example, if a coil is formed by connecting conductor 1 (upper conductor in a slot) to conductor 12 (bottom conductor in another slot) at the back of the armature, then back pitch is $Y_B = 12 - 1 = 11$ conductors.

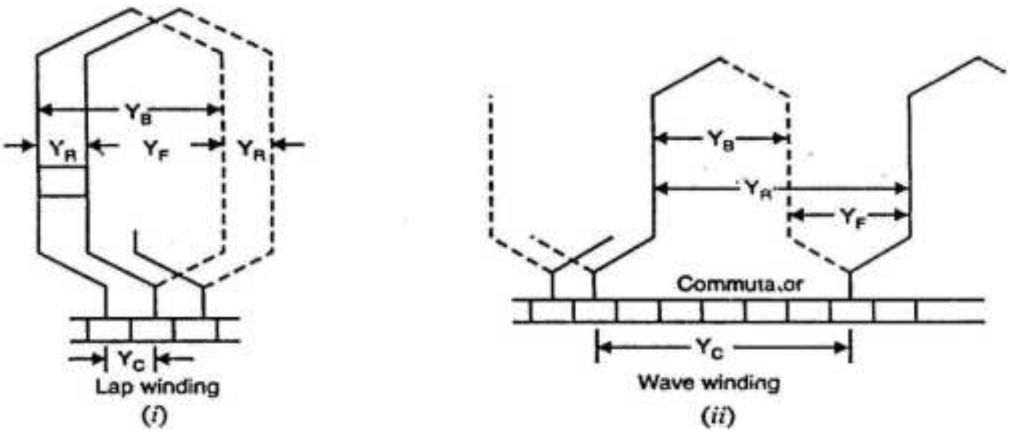


**Figure 1.4.2 a) lap winding b) wave winding**

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-7.5]*

### (i) Front Pitch ($Y_F$)

It is the distance measured in terms of armature conductors between the coil sides attached to any one commutator segment. It is denoted by $Y_F$ For example, if coil side 12 and coil side 3 are connected to the same commutator segment, then front pitch is $Y_F = 12 - 3 = 9$ conductors.

### (ii) Resultant Pitch (YR)

It is the distance (measured in terms of armature conductors) between the beginning of one coil and the beginning of the next coil to which it is connected. It is denoted by $Y_R$. Therefore, the resultant pitch is the algebraic sum of the back and front pitches.

### (iii) Commutator Pitch ($Y_C$)

It is the number of commutator segments spanned by each coil of the armature winding.

For simplex lap winding, $Y_C = 1$

For simplex wave winding, $Y_C \simeq 2$ pole pitches (segments)

### (iv) Progressive Winding

A progressive winding is one in which, as one traces through the winding, the connections to the commutator will progress around the machine in the same direction as is being traced along the path of each individual coil. Figure 1.4.3 shows progressive lap winding. Note that $Y_B > Y_F$ and $Y_C = +1$.

### (v) Retrogressive Winding

A retrogressive winding is one in which, as one traces through the winding, the connections to the commutator will progress around the machine in the opposite direction to that which is being traced along the path of each individual coil. Fig. (1.24) (ii) shows retrogressive lap winding. Note that $Y_F > Y_B$ and $Y_C = -1$. A retrogressive winding is seldom used because it requires more copper.

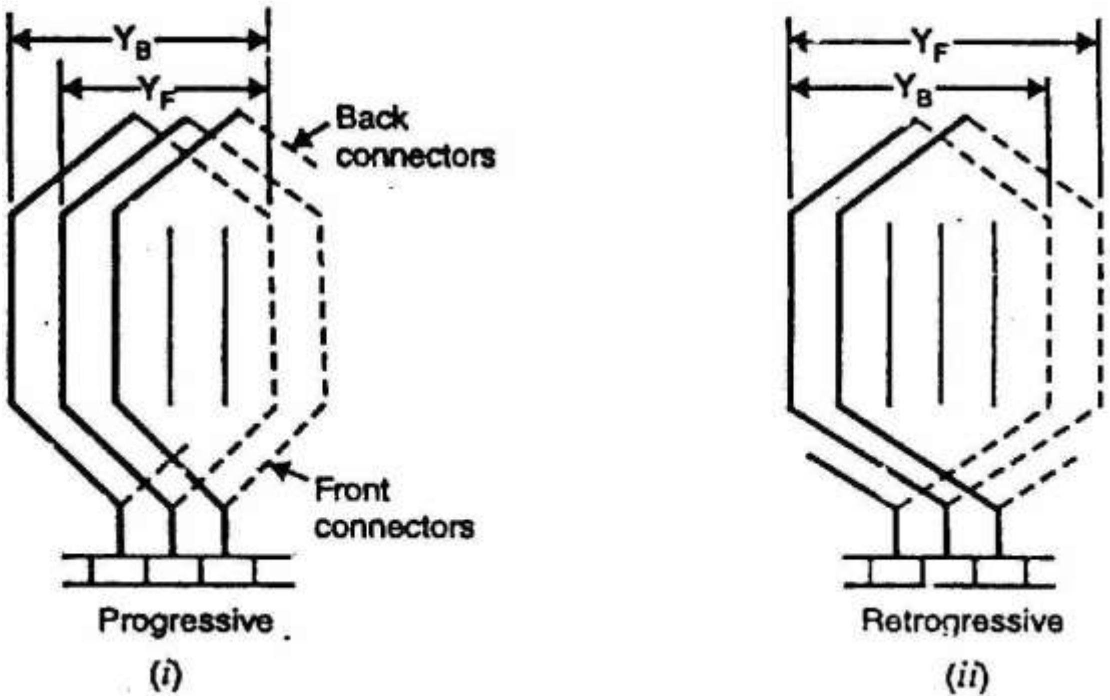


**Figure 1.4.3 a) Progressive lap winding b) Retrogressive lap winding**

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-7.6]*

### General Rules For D.C. Armature Windings

In the design of d.c. armature winding (lap or wave), the following rules may be followed:

(i) The back pitch ($Y_B$) as well as front pitch ($Y_F$) should be nearly equal to pole pitch. This will result in increased e.m.f. in the coils.

(ii) Both pitches ($Y_B$ and $Y_F$) should be odd. This will permit all end connections (back as well as front connection) between a conductor at the top of a slot and one at the bottom of a slot.

(iii) The number of commutator segments is equal to the number of slots or coils (or half the number of conductors).

No. of commutator segments = No. of slots = No. of coils

It is because each coil has two ends and two coil connections are joined at each commutator segment

(iv) The winding must close upon itself i.e. it should be a closed circuit winding.

## Relations between Pitches for Simplex Lap Winding

In a simplex lap winding, the various pitches should have the following relation:

(i) The back and front pitches are odd and are of opposite signs. They differ numerically by 2,

$Y_B = Y_B = Y_F \pm 2$

$Y_B = Y_F + 2$ for progressive winding

$Y_B = Y_F - 2$ for retrogressive winding

(ii) Both $Y_B$ and $Y_F$ should be nearly equal to pole pitch.

(iii) Average pitch $= (Y_B + Y_F)/2$. It equals pole pitch (= Z/P).

(iv) Commutator pitch, $Y_C = \pm 1$

$Y_C = +1$ for progressive winding

$Y_C = -1$ for retrogressive winding

(v) The resultant pitch ($Y_B$) is even, being the arithmetical difference of two odd numbers viz., $Y_B$ and $Y_F$.

**Developed diagram**

Developed diagram is obtained by imagining the cylindrical surface of the armature to be cut by an axial plane and then flattened out. (i) shows the developed diagram of the winding. Note that full lines represent the top coil sides (or conductors) and dotted lines represent the bottom coil sides (or conductors).

The winding goes from commutator segment 1 by conductor 1 across the back to conductor 12 and at the front to commutator segment 2, thus forming a coil. Then from commutator segment 2, through conductors 3 and 14 back to commutator segment 3 and so on till the winding returns to commutator segment 1 after using all the 40 conductors.

**Position and number of brushes**

We now turn to find the position and the number of brushes required. The brushes, like field poles, remain fixed in space as the commutator and winding revolve. It is very important that brushes are in correct position relative to the field poles. The arrowhead marked “rotation” in Fig. (1.25) (i) shows the direction of motion of the conductors. By right-hand rule, the direction of e.m.f. in each conductor will be as shown.

In order to find the position of brushes, the ring diagram shown in Fig. (1.25) (ii) is quite helpful. A positive brush will be placed on that commutator segment where the currents in the coils are meeting to flow out of the segment. A negative brush will be placed on that commutator segment where the currents in the coils are meeting to flow in. Referring to Fig. (1.25) (i), there are four brushes—two positive and two negative. Therefore, we arrive at a very important conclusion that in a simplex lap winding, the number of brushes is equal to the number of poles. If the brushes of the same polarity are connected together, then all the armature conductors are connected in four parallel paths; each path containing an equal number of conductors in series.

Since segments 6 and 16 are connected together through positive brushes and segments 11 and 1 are connected together through negative brushes, there are four parallel paths, each containing 10 conductors in series. Therefore, in a simplex lap winding, the number of parallel paths is equal to the number of poles.

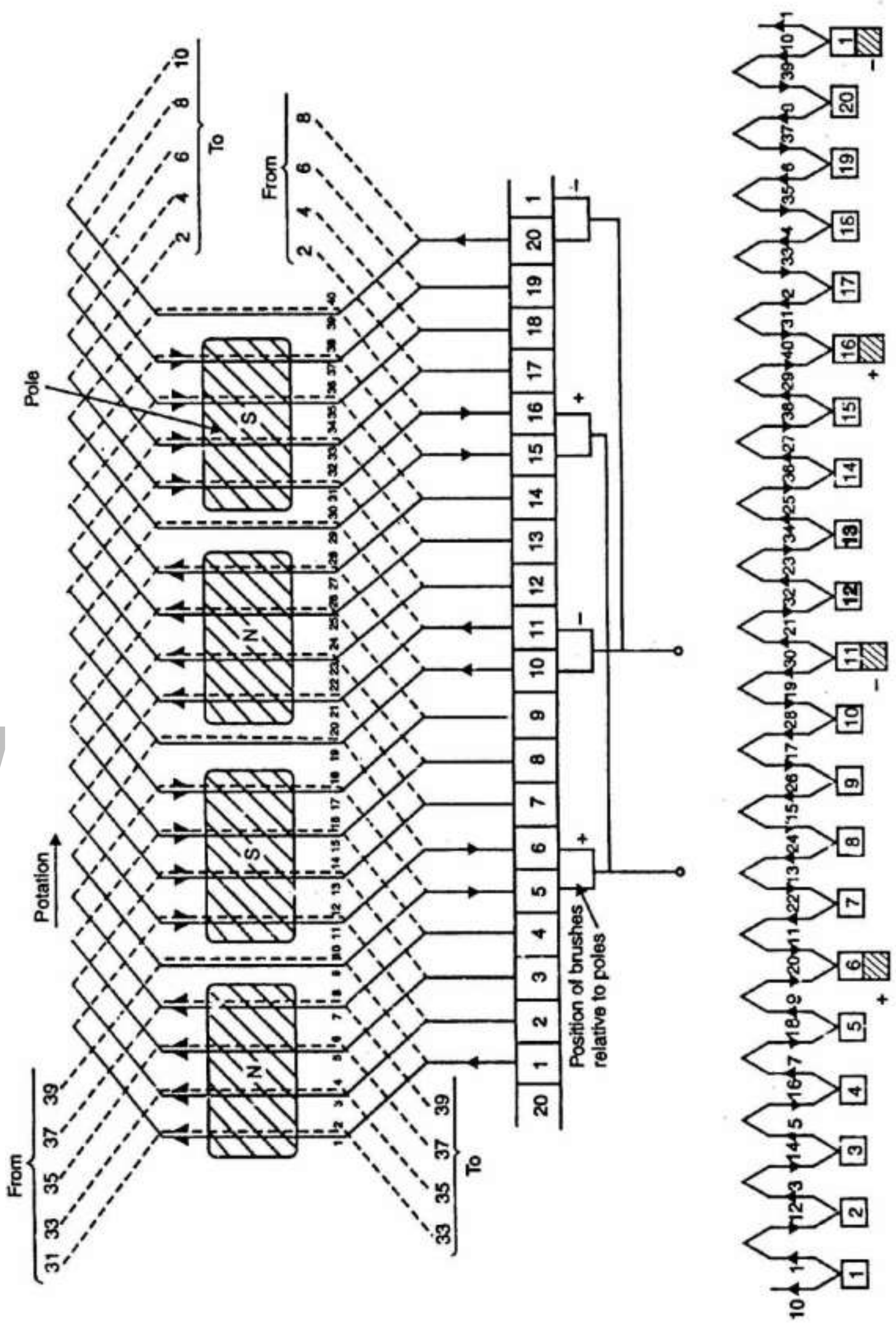


**Figure 1.4.4 Sequence diagram for winding**

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-7.15]*

## Simplex Wave Winding

The essential difference between a lap winding and a wave winding is in the commutator connections. In a simplex lap winding, the coils approximately pole pitch apart are connected in series and the commutator pitch $Y_C = \pm 1$ segment. As a result, the coil voltages add. In a simplex wave winding, the coils approximately pole pitch apart are connected in series and the commutator pitch $Y_C \simeq 2$ pole pitches (segments). Thus in a wave winding, successive coils "wave" forward under successive poles instead of "lapping" back on themselves as in the lap winding.

The simplex wave winding must not close after it passes once around the armature but it must connect to a commutator segment adjacent to the first and the next coil must be adjacent to the first as indicated. This is repeated each time around until connections are made to all the commutator segments and all the slots are occupied after which the winding automatically returns to the starting point. If, after passing once around the armature, the winding connects to a segment to the left of the starting point, the winding is retrogressive. If it connects to a segment to the right of the starting point, it is progressive. This type of winding is called wave winding because it passes around the armature in a wave-like form.

### Developed diagram

Fig. (1.30) (i) shows the developed diagram for the winding. Note that full lines represent the top coil sides (or conductors) and dotted lines represent the bottom coil sides (or conductors). The two conductors which lie in the same slot are drawn nearer to each other than to those in the other slots.

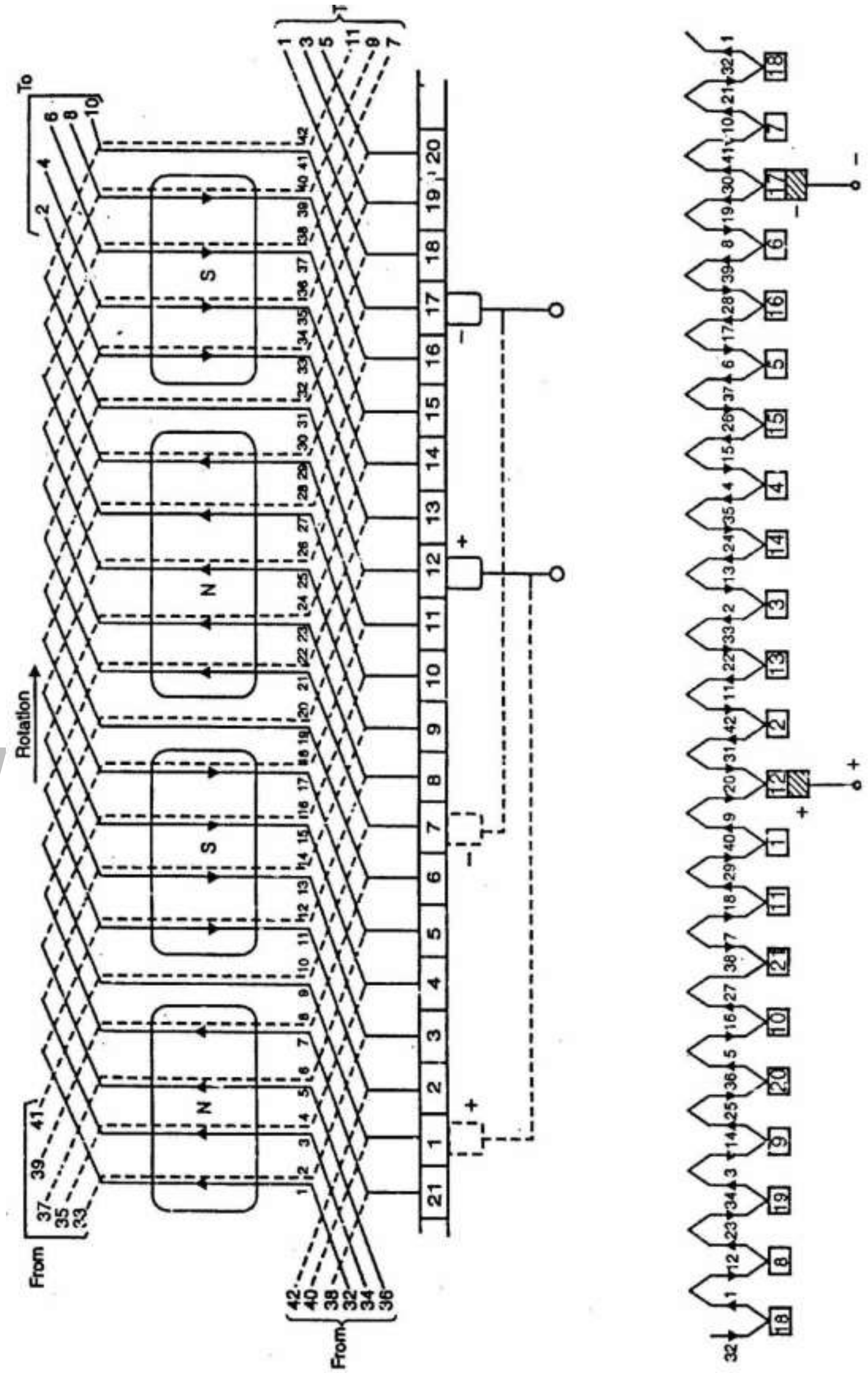


Figure 1.4.5 Sequence diagram for winding

*[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-7.15]*

## 1.1 Major considerations in Electrical Machine Design

The basic components of all electromagnetic apparatus are the field and armature windings supported by dielectric or insulation, cooling system and mechanical parts. Therefore, the factors for consideration in the design are,

**Magnetic circuit or the flux path:**

Should establish required amount of flux using minimum MMF. The core losses should be less.

**Electric circuit or windings:**

Should ensure required EMF is induced with no complexity in winding arrangement. The copper losses should be less.

**Insulation:**

Should ensure trouble free separation of machine parts operating at different potential and confine the current in the prescribed paths.

**Cooling system or ventilation:**

Should ensure that the machine operates at the specified temperature.

**Machine parts:**

The art of successful design lies not only in resolving the conflict for space between iron, copper, insulation and coolant but also in optimization of cost of manufacturing, and operating and maintenance charges.

The factors, apart from the above, that requires consideration are

a. Limitation in design (saturation, current density, insulation, temperature rise etc.,)

b. Customer's needs

c. National and international standards

d. Convenience in production line and transportation

e. Maintenance and repairs

f. Environmental conditions etc.

**Limitations in design:**

The materials used for the machine and others such as cooling etc., imposes a limitation in design. The limitations stem from saturation of iron, current density in conductors, temperature, insulation, mechanical properties, efficiency, power factor etc.

- **a. Saturation:** Higher flux density reduces the volume of iron but drives the iron to operate beyond knee of the magnetization curve or in the region of saturation. Saturation of iron poses a limitation on account of increased core loss and excessive excitation required to establish a desired value of flux. It also introduces harmonics.
- **b. Current density:** Higher current density reduces the volume of copper but increases the losses and temperature.
- **c. Temperature:** poses a limitation on account of possible damage to insulation and other materials.
- **d. Insulation**: (which is both mechanically and electrically weak): poses a limitation on account of breakdown by excessive voltage gradient, mechanical forces or heat.
- **e. Mechanical strength:** of the materials poses a limitation particularly in case of large and high speed machines.
- **f. High efficiency**: and high power factor poses a limitation on account of higher capital cost. (A low value of efficiency and power factor on the other hand results in a high maintenance cost).
- **g. Mechanical Commutation**: in dc motors or generators leads to poor commutation.

Apart from the above factors Consumer, manufacturer or standard specifications may pose a limitation.

## 1.2 Materials for Electrical apparatus

The main material characteristics of relevance to electrical machines are those associated with conductors for electric circuit, the insulation system necessary to isolate the circuits, and with the specialized steels and permanent magnets used for the magnetic circuit.

### Conducting materials:

Commonly used conducting materials are copper and aluminum. Some of the desirable properties a good conductor should possess are listed below.

1. Low value of resistivity or high conductivity
2. Low value of temperature coefficient of resistance
3. High tensile strength
4. High melting point
5. High resistance to corrosion
6. Allow brazing, soldering or welding so that the joints are reliable
7. Highly malleable and ductile
8. Durable and cheap by cost

For the same resistance and length, cross-sectional area of aluminum is 61% larger than that of the copper conductor and almost 50% lighter than copper. Though the aluminum reduces the cost of small capacity transformers, it increases the size and cost of large capacity transformers. Aluminum is being much used now a day’s only because copper is expensive and not easily available. Aluminum is almost 50% cheaper than Copper and not much superior to copper.

### Magnetic materials:

The magnetic properties of a magnetic material depend on the orientation of the crystals of the material and decide the size of the machine or equipment for a given rating, excitation required, efficiency of operation etc.

The some of the properties that a good magnetic material should possess are listed below.

1. Low reluctance or should be highly permeable or should have a high value of relative permeability μr.
2. High saturation induction (to minimize weight and volume of iron parts)
3. High electrical resistivity so that the eddy EMF and the hence eddy current loss is less
4. Narrow hysteresis loop or low Coercively so that hysteresis loss is less and efficiency of operation is high
5. A high curie point. (Above Curie point or temperature the material loses the magnetic property or becomes paramagnetic, that is effectively non-magnetic)
6. Should have a high value of energy product (expressed in joules / m3).

Magnetic materials can broadly be classified as Diamagnetic, Paramagnetic, Ferromagnetic, Antiferromagnetic and Ferromagnetic materials. Only ferromagnetic materials have properties that are well suitable for electrical machines. Ferromagnetic properties are confined almost entirely to iron, nickel and cobalt and their alloys. The only exceptions are some alloys of manganese and some of the rare earth elements.

The relative permeability $\mu_r$ of ferromagnetic material is far greater than 1.0. When ferromagnetic materials are subjected to the magnetic field, the dipoles align themselves in the direction of the applied field and get strongly magnetized.

Further the Ferromagnetic materials can be classified as Hard or Permanent Magnetic materials and Soft Magnetic materials.

a) Hard or permanent magnetic materials have large size hysteresis loop (obviously hysteresis loss is more) and gradually rising magnetization curve. Ex: carbon steel, tungsten steal, cobalt steel, alnico, hard ferrite etc.

b) Soft magnetic materials have small size hysteresis loop and a steep magnetization curve. Ex: i) cast iron, cast steel, rolled steel, forged steel etc., (in the solid form). Generally used for yokes poles of dc machines, rotors of turbo alternator etc., where steady or dc flux is involved. ii) Silicon steel (Iron + 0.3 to 4.5% silicon) in the laminated form. Addition of silicon in proper percentage eliminates ageing & reduce core loss. Low silicon content steel or dynamo grade steel is used in rotating electrical machines and are operated at high flux density. High content silicon steel (4 to 5% silicon) or transformer grade steel (or high resistance steel) is used in transformers. Further sheet steel may be hot or cold rolled. Cold rolled grain oriented steel

c) Special purpose Alloys: Nickel iron alloys have high permeability and addition of molybdenum or chromium leads to improved magnetic material. Nickel with iron in different proportion leads to
    (i) High nickel permalloy (iron +molybdenum +copper or chromium), used in current transformers, magnetic amplifiers etc.,
    (ii) Low nickel Permalloy (iron +silicon +chromium or manganese), used in transformers, induction coils, chokes etc.
    (iii) Perminvor (iron +nickel +cobalt)
    (iv) Pemendur (iron +cobalt +vanadium), used for microphones, oscilloscopes, etc.
    (v) Mumetal (Copper + iron)

d) Amorphous alloys (often called metallic glasses): Amorphous alloys are produced by rapid solidification of the alloy at cooling rates of about a million degrees centigrade per second. The alloys solidify with a glass-like atomic structure which is non-crystalline frozen liquid. The rapid cooling is achieved by causing the molten alloy to flow through an orifice onto a rapidly rotating water cooled drum. This can produce sheets as thin as 10μm and a meter or more wide.

**Insulating materials:**

To avoid any electrical activity between parts at different potentials, insulation is used.

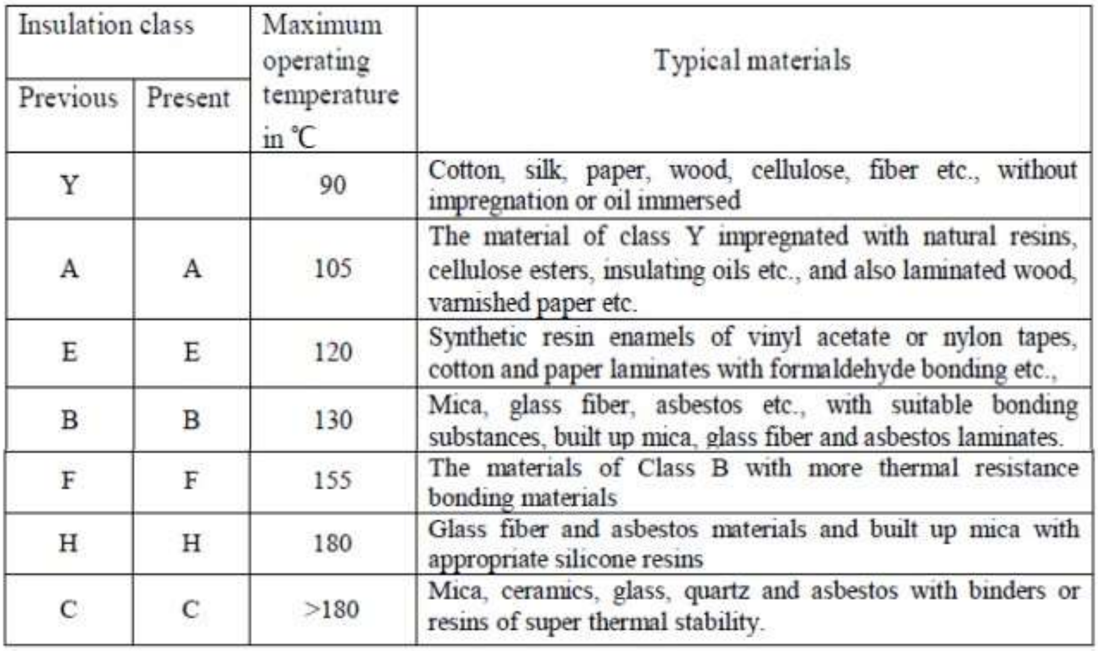
An ideal insulating material should possess the following properties.

1. Should have high dielectric strength.
2. Should with stand high temperature.
3. Should have good thermal conductivity
4. Should not undergo thermal oxidation
5. Should not deteriorate due to higher temperature and repeated heat cycle
6. Should have high value of resistivity (like 1018 Ωcm)

7. Should not consume any power or should have a low dielectric loss angle δ
8. Should withstand stresses due to centrifugal forces (as in rotating machines), electro dynamic or mechanical forces (as in transformers)
9. Should withstand vibration, abrasion, bending 10) Should not absorb moisture 11) Should be flexible and cheap 12) Liquid insulators should not evaporate or volatilize.

Insulating materials can be classified as Solid, Liquid and Gas, and vacuum. The term insulting material is sometimes used in a broader sense to designate also insulating liquids, gas and vacuum.

Classification of insulating materials based on thermal consideration



| Insulation class | | Maximum operating temperature in ℃ | Typical materials |
|---|---|---|---|
| Previous | Present | | |
| Y | | 90 | Cotton, silk, paper, wood, cellulose, fiber etc., without impregnation or oil immersed |
| A | A | 105 | The material of class Y impregnated with natural resins, cellulose esters, insulating oils etc., and also laminated wood, varnished paper etc. |
| E | E | 120 | Synthetic resin enamels of vinyl acetate or nylon tapes, cotton and paper laminates with formaldehyde bonding etc., |
| B | B | 130 | Mica, glass fiber, asbestos etc., with suitable bonding substances, built up mica, glass fiber and asbestos laminates. |
| F | F | 155 | The materials of Class B with more thermal resistance bonding materials |
| H | H | 180 | Glass fiber and asbestos materials and built up mica with appropriate silicone resins |
| C | C | >180 | Mica, ceramics, glass, quartz and asbestos with binders or resins of super thermal stability. |

The insulation system (also called insulation class) for wires used in generators, motors transformers and other wire-wound electrical components is divided into different classes according the temperature that they can safely withstand.As per Indian Standard (Thermal evaluation and classification of Electrical Insulation, IS.No.1271,1985, first revision) and other international standard insulation is classified by letter grades A, E, B, F, H (previous Y, A, E, B, F, H, C).

The maximum operating temperature is the temperature the insulation can reach during operation and is the sum of standardized ambient temperature i.e. 40 degree centigrade, permissible temperature rise and allowance tolerance for hot spot in winding.

For example, the maximum temperature of class B insulation is (ambient temperature 40+ allowable temperature rise 80 + hot spot tolerance 10) = 130ºC.

Insulation is the weakest element against heat and is a critical factor in deciding the life of electrical equipment. The maximum operating temperatures prescribed for different class of insulation are for a healthy lifetime of 20,000 hours. The height temperature permitted for the machine parts is usually about 2000C at the maximum. Exceeding the maximum operating temperature will affect the life of the insulation. As a rule of thumb, the lifetime of the winding insulation will be reduced by half for every 10 ºC rise in temperature. The present day trend is to design the machine using class F insulation for class B temperature rise.