Electrical Machine Design
Introduction
The magnetic flux in all electrical machines (generators, motors and transformers) plays an important role in converting or transferring the energy. Field or magnetizing winding of rotating machines produces the flux while armature winding supplies either electrical power or mechanical power. In case of transformers primary wing supplies the power demand of the secondary.

The basic design of an electrical machine involves the dimensioning of the magnetic circuit, electrical circuit, insulation system etc., and is carried out by applying analytical equations.

A designer is generally confronted with a number of problems for which there may not be one solution, but many solutions. A design should ensure that the products perform in accordance with the requirements at higher efficiency, lower weight of material for the desired output, lower temperature rise and lower cost. Also they are to be reliable and durable.

A practical designer must effect the design so that the stock (standard frames, punching etc.,) is adaptable to the requirements of the specification. The designer must also affect some sort of compromise between the ideal design and a design which comply with manufacturing conditions. A electrical designer must be familiar with the,

a. National and international standards
   - Indian Standard (IS), Bureau of Indian Standard (BIS), India
   - British Standard (BS), England
   - International Electrotechnical Commission (IEC)
   - NEMA (The National Electrical Manufacturers Association).

b. Specifications (that deals with machine ratings, performance requirements etc., of the consumer)
c. Cost of material and labour
d. Manufacturing constraints etc.

A designer can refer to Design Data Handbook (Electrical Machine Design Data Book, authored by A Shanmugasundaram and others, New Age International Publishers, Reprint 2007, or any other such handbooks) which is a source of design procedure, properties of materials, ranges of design parameters etc., and manufacturer’s brochure.

As the design involves a number of assumptions and constraints, final design values can be obtained only by iterative methods. Computer plays a vital role in arriving at the final values. By Finite Element Method (FEM), the effect of a single parameter on the dynamical performance of the machine can be studied. Furthermore, some tests, which are not even feasible in laboratory setup, can be virtually performed by Finite Element Method.

The design problems, that have been considered to solve in the latter chapters, are of different nature from the design worked out in detail in respect of any machine. However, these test
problems provide adequate elementary skills in design, which is an indication that a student has a fair knowledge to deal with the entire design.

**Factors for consideration 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,

1. **Magnetic circuit or the flux path:** Should establish required amount of flux using minimum mmf. The core losses should be less.
2. **Electric circuit or windings:** Should ensure required emf is induced with no complexity in winding arrangement. The copper losses should be less.
3. **Insulation:** Should ensure trouble free separation of machine parts operating at different potential and confine the current in the prescribed paths.
4. **Cooling system or ventilation:** Should ensure that the machine operates at the specified temperature.
5. **Machine parts:** Should be robust.

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. Conveniences 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.

Materials for Electrical Machines

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

Some of the properties of copper and aluminum are shown in the table-2.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Particulars</th>
<th>Copper</th>
<th>Aluminum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Resistivity at 20°C</td>
<td>0.0172 ohm / m/ mm²</td>
<td>0.0269 ohm / m/ mm²</td>
</tr>
<tr>
<td>2</td>
<td>Conductivity at 20°C</td>
<td>58.14 x 10⁶ S/m</td>
<td>37.2 x 10⁶ S/m</td>
</tr>
<tr>
<td>3</td>
<td>Density at 20°C</td>
<td>8933kg/m³</td>
<td>2689.9m³</td>
</tr>
<tr>
<td>4</td>
<td>Temperature coefficient (0-100°C)</td>
<td>0.393 % per °C</td>
<td>0.4 % per °C</td>
</tr>
<tr>
<td>5</td>
<td>Coefficient of linear expansion (0-100°C)</td>
<td>16.8x10⁻⁶ per °C</td>
<td>23.5x10⁻⁶ per °C</td>
</tr>
<tr>
<td>6</td>
<td>Tensile strength</td>
<td>25 to 40 kg / mm²</td>
<td>10 to 18 kg / mm²</td>
</tr>
<tr>
<td>7</td>
<td>Mechanical property</td>
<td>highly malleable and ductile</td>
<td>not highly malleable and ductile</td>
</tr>
<tr>
<td>8</td>
<td>Melting point</td>
<td>1083°C</td>
<td>660°C</td>
</tr>
<tr>
<td>9</td>
<td>Thermal conductivity (0-100°C)</td>
<td>599 W/m °C</td>
<td>238 W/m °C</td>
</tr>
<tr>
<td>10</td>
<td>Jointing</td>
<td>can be easily soldered</td>
<td>cannot be soldered easily</td>
</tr>
</tbody>
</table>
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 days 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 $\mu_r$.
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 Coercivity 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 / m$^3$).

Magnetic materials can broadly be classified as Diamagnetic, Paramagnetic, Ferromagnetic, Antiferromagnetic and Ferrimagnetic 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 steel, cobalt steel, alnico, hard ferrite etc.

**b) Soft magnetic materials** have small size hysteresis loop and a steep magnetization curve. Ex: 1) 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 (CRGOS) is costlier and superior to hot rolled. CRGO steel is generally used in transformers.

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) Perminvar (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 metre or more wide.

These alloys can be classified as iron rich based group and cobalt based group.

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum permeability $\mu \times 10^3$</th>
<th>Saturation magnetization in tesla</th>
<th>Coercivity A/m</th>
<th>Curie temperature $^\circ$C</th>
<th>Resistivity $\Omega$ m $\times 10^8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% Si grain oriented</td>
<td>90</td>
<td>2.0</td>
<td>6-7</td>
<td>745</td>
<td>48</td>
</tr>
<tr>
<td>2.5% Si grain non-oriented</td>
<td>8</td>
<td>2.0</td>
<td>40</td>
<td>745</td>
<td>44</td>
</tr>
<tr>
<td>&lt;0.5% Si grain non oriented</td>
<td>8</td>
<td>2.1</td>
<td>50-100</td>
<td>770</td>
<td>12</td>
</tr>
<tr>
<td>Low carbon iron</td>
<td>3-10</td>
<td>2.1</td>
<td>50-120</td>
<td>770</td>
<td>12</td>
</tr>
<tr>
<td>78% Ni and iron</td>
<td>250-400</td>
<td>0.8</td>
<td>1.0</td>
<td>350</td>
<td>40</td>
</tr>
<tr>
<td>50% Ni and iron</td>
<td>100</td>
<td>1.5-1.6</td>
<td>10</td>
<td>530</td>
<td>60</td>
</tr>
<tr>
<td>Iron based Amorphous</td>
<td>35-600</td>
<td>1.3-1.8</td>
<td>1.0-1.6</td>
<td>310-415</td>
<td>120-140</td>
</tr>
</tbody>
</table>
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 withstand 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 $10^{18} \, \Omega \text{cm}$)
7) Should not consume any power or should have a low dielectric loss angle $\delta$
8) Should withstand stresses due to centrifugal forces (as in rotating machines), electrodynamic 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 insulating material is sometimes used in a broader sense to designate also insulating liquids, gas and vacuum.

Solid: Used with field, armature, transformer windings etc. The examples are:

1) Fibrous or inorganic animal or plant origin, natural or synthetic paper, wood, card board, cotton, jute, silk etc., rayon, nylon, terelane, asbestos, fiber glass etc.,
2) Plastic or resins. Natural resins-lac, amber, shellac etc., Synthetic resins-phenol formaldehyde, melamine, polyesters, epoxy, silicon resins, bakelite, Teflon, PVC etc.
3) Rubber : natural rubber, synthetic rubber-butadiene, silicone rubber, hypalon, etc.,
4) Mineral : mica, marble, slate, talc chloride etc.,
5) Ceramic : porcelain, steatite, alumina etc.,
6) Glass : soda lime glass, silica glass, lead glass, borosilicate glass
7) Non-resinous : mineral waxes, asphalt, bitumen, chlorinated naphthalene, enamel etc.,

Liquid: Used in transformers, circuit breakers, reactors, rheostats, cables, capacitors etc., & for impregnation. The examples are:

1) Mineral oil (petroleum by product)
2) Synthetic oil askarels, pyranols etc.,
3) Varnish, French polish, lacquer epoxy resin etc.,
Gaseous: The examples are:
1) Air used in switches, air condensers, transmission and distribution lines etc.,
2) Nitrogen use in capacitors, HV gas pressure cables etc.,
3) Hydrogen though not used as a dielectric, generally used as a coolant
4) Inert gases neon, argon, mercury and sodium vapors generally used for neon sign lamps.
5) Halogens like fluorine, used under high pressure in cables

No insulating material in practice satisfies all the desirable properties. Therefore a material which satisfies most of the desirable properties must be selected.

Classification of insulating materials based on thermal consideration

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).

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

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) = 130°C.

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 200°C 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 °C rise in temperature. The present day trend is to design the machine using class F insulation for class B temperature rise.
Chapter 2 DESIGN OF DC MACHINES

Details to be specified while ordering a DC machine or consumer’s specification

1. Output : kW (for generators), kW or Hp (for motors)
2. Voltage : V volt
3. Speed : N rpm
4. Rating : Continuous or Short time
5. Temperature rise: \(\theta\)°C for an ambient temperature of 40°C
6. Cooling : Natural or forced cooling
7. Type: Generator or motor, separately excited or self-excited-shunt, series, or compound, if compound type of connection – long or short shunt, type of compounding – cumulative or differential, degree of compounding – over, under or level. With or without inter poles, with or without compensating windings, with or without equalizer rings in case of lap winding.
8. Voltage regulation (in case of generators) : Range and method
9. Speed control (in case of motors) : Range and method of control
10. Efficiency: must be as far as possible high (As the efficiency increases, cost of the machine also increases).
11. Type of enclosure: based on the field of application – totally enclosed, screen protected, drip proof, flame proof, etc.,
12. Size of the machine etc.,

Size of the DC machine
The size of the DC machine depends on the main or leading dimensions of the machine viz., diameter of the armature D and armature core length L. As the output increases, the main dimensions of the machine D and L also increases.
OUTPUT EQUATION

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
- \( I_a \): armature current
- \( \phi \): 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 = \( E \, I_a \times 10^{-3} \)

\[
= \frac{\phi \, Z \, N \, P}{60 \, A} \times I_a \times 10^{-3}
\]

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

The term \( P\phi \) 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,
\[ B_{av} = \frac{P\phi}{\pi DL} \text{ Wb/m}^2 \text{ or tesla denoted by } T \]

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

The term \((I_a Z/A)\) 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,

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

Therefore \[ I_a Z/A = q \pi D \] ............ (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 \[ D^2 L = \frac{kW}{1.64 \times 10^4 B_{av} q N} \text{ m}^3 \]

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

**Effect of higher value of \(q\)**

Note: Since armature current \(I_a\) and number of parallel paths \(A\) are constants and armature diameter \(D\) must be as less as possible or \(D\) must be a fixed minimum value, the number of armature conductors increases as \[ q = \frac{I_a Z}{A \pi D} \] increases.

a. As \(q\) increases, number of conductors increases, resistance increases, \(I^2R\) loss increases and therefore the temperature of the machine increases. Temperature is a limiting factor of any equipment or machine.

b. As \(q\) increases, number of conductors increases, conductors/slot increases, quantity of insulation in the slot increases, heat dissipation reduces, temperature increases, losses increases and efficiency of the machine reduces.

c. As \(q\) increases, number of conductors increases, armature ampere-turns per pole \[ AT_a / \text{pole} = (I_a Z / 2 A P) \] increases, flux produced by the armature increases, and therefore the effect of armature reaction increases. In order to overcome the effect of
armature reaction, field mmf has to be increased. This calls for additional copper and increases the cost and size of the machine.

d. As q increases, number of conductors and turns increases, reactance voltage proportional to (turns)$^2$ increases. This leads to sparking commutation.

**Effect of higher value of B\textsubscript{av}**

a. As B\textsubscript{av} increases, core loss increases, efficiency reduces.
b. As B\textsubscript{av} increases, degree of saturation increases, mmf required for the magnetic circuit increases. This calls for additional copper and increases the cost of the machine.

It is clear that there is no advantage gained by selecting higher values of q and B\textsubscript{av}. If the values selected are less, then D$^2$L will be large or the size of the machine will unnecessarily be high. Hence optimum value of q and B\textsubscript{av} must be selected.

In general q lies between 15000 and 50000 ampere-conductors/m. Lesser values are used in low capacity, low speed and high voltage machines.

In general B\textsubscript{av} lies between 0.45 and 0.75 T.

**SEPARATION OF D$^2$L PRODUCT**

Knowing the values of kW and N and assuming the values of q and B\textsubscript{av}, a value for $D^2L = \frac{kW}{1.64 \times 10^{-4} \times B_{av} q N}$ can be calculated.

Let it be 0.1 m$^3$.

Since the above expression has two unknowns namely D and L, another expression relating D and L must be known to find out the values of D and L.

Usually a value for the ratio armature core length L to pole pitch is assumed to separate D$^2$L product. The pole pitch $\tau$ refers to the circumferential distance corresponding one pole at diameter D. In practice $L/\tau$ lies between 0.55 and 1.1.

Therefore $L = (0.55 \text{ to } 1.1) \times \frac{\pi D}{P}$

If $L/\tau = 1.0$ and $P = 4$, then $L = 1.0 \times \frac{\pi D}{4} = 1.0 \times \frac{\pi D}{P} = 0.785D$.

Therefore $D^2 \times 0.785D = 0.1$ or $D = 0.5m$. Thus $L = 0.785 \times 0.5 = 0.395m$.

Note: The D$^2$L product can also be separated by assuming a value for the peripheral velocity of the armature.
LIMITATIONS OF D AND L

As the diameter of the armature increases, the peripheral velocity of the armature \( v = \frac{\pi DN}{60} \) m/s, centrifugal force and its effects increase. Therefore the machine must be mechanically made robust to withstand the effect of centrifugal force. This increases the cost of the machine. In general for normal construction, peripheral velocity should not be greater than 30 m/s as far as possible.

To prevent arcing between commutator segments, voltage between the commutator segments should not be greater than about 20V on open circuit. If a single turn coil is used then the voltage/conductor \( e = B_{av} L v \) should not be more than 10V.

\( B_{av} \) – Average value of flux density in the air gap in tesla, \( L \) – Length of the conductor or gross armature core length in metre and \( v \) – Peripheral velocity of armature in m/s).

Therefore, armature core length \( L = \frac{e}{B_{av} v} \) should not be greater than \( 10 / (0.75 \times 30) = 0.44 \) m for normal design.

**Ventilating ducts and net iron length of armature core**

To keep down the temperature rise of the machine parts, the core is provided with both radial and axial ventilating ducts. Radical ducts are created by providing vent or duct spacers in between core packets of width 5-7 cm. Width of the radial duct lies between 0.8 and 1.0 cm in practice.

\[
\text{It is clear from the figure that the net core length } L = (L - n_v b_v)
\]

\( n_v \) – number of ventilating ducts and \( b_v \) – width of the ventilating duct.

Since the core is laminated to reduce the eddy current loss and flux takes the least reluctance path, flux confines to the iron only. Therefore the length over which the flux passes is not \( L \) or \( (L - n_v b_v) \) but less than that. Generally the thickness of insulation on the laminated core will be
around 10% of the gross core length. Therefore the net iron length will be 0.9 times the net core length or net iron length, 

\[ L_i = K_i (L - n_v b_v) \]

where \( K_i \) is called the iron or stacking factor and is approximately 0.9 in practice.

**Estimation of number of ventilating ducts**

Determine the number of ducts if the length of armature core is 35 cm.

Since the width of the core packet lies between 5 and 7 cm, let the width of the core packet be 6 cm. Therefore number of core packets is equal to \( 35 / 6 \) or 6 say. Six core packets lead to 5 ducts. If the width of the duct is assumed to be 1.0 cm, then the net core length will be \( (35 - 1 \times 5) = 30 \) cm and each core packet after revision will be \( 30 / 6 = 5 \) cm in width.

**CHOICE OF NUMBER OF POLES**

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

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

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.