~~AC~~ A.C. Machines

- A.C. generators
  - Single phase
  - Two-phase
  - Three-phase
    - Synchronous generators
    - Asynchronous generators (Induction)
- A.C. motors
  - Single-phase
  - Two-phase
  - Three-phase
    - Synchronous motors
    - Asynch motors

Note:- (i) Two-phase A.C. machines although conceptually possible, are not very popular.

(ii) Synchronous machines run only at one speed. Asynchronous (induction) machines can have different speeds.

Basic A.C. Generators:-

(i) Regardless of size, all electrical generators, whether DC or AC, depend upon the principle of electromagnetic induction.

(ii) The emf is induced in:

(a) a Coil cutting through a magnetic field, or

(b) in a magnetic field cutting through a coil.

(iii) As long as there is relative motion b/w a conductor and a magnetic field, a voltage will be induced in a conductor.

(iv) That part of a generator that ~~for~~ produces the magnetic field ~~~~ is known as Field.

(v) That part of a generator in which the voltage is induced is known as Armature.

(vi) For a relative motion to take place between the conductor and the magnetic field, all generators must have two mechanical parts - a ~~Rotator~~ Rotor (Rotating part)
a Stator (Static part)

(vii) In a DC generator,
Armature = ~~Rotator~~ Rotor

(viii) In an AC generator (which is also known as ~~~~ Alternator)
either, (a) Armature = Stator
or (b) Armature = ~~Rotator~~ Rotor

Note:- For low voltages,
Armature = Rotor & Field = Stator

For high voltages,
Armature = Stator & Field = Rotor

Q. Magnetic induction occurs when there is relative motion ~~bet~~ between what & what?

Ans Conductor & magnetic field

Rotating - Armature Alternators :-

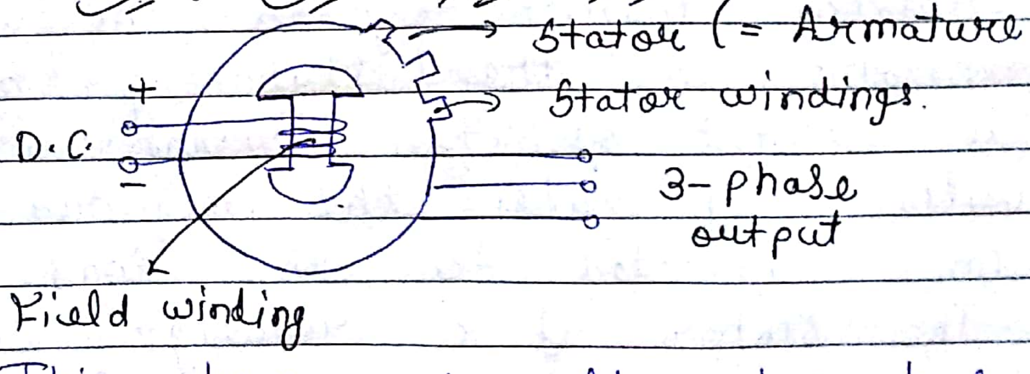
(i) Similar in construction to D.C. generators

(ii) In DC Generators, the emf generated in the armature windings is converted from AC to DC by means of the Commutator.

(iii) In the alternator, the generated AC is brought to the load unchanged by using Slip-rings.
So, Commutator is not used.

(iv) This type of AC generator is found only in low-power Applications. It is not easy to use this kind of generator to meet large-power demands.

Rotating - field Alternators :-



(i) This type of alternator has a stationary armature winding and a rotating field winding.

(ii) The advantage is that the generated voltage can be directly connected to the load with no rotating parts in between.

(iii) A rotating-armature type of alternator (already discussed) requires slip-rings and brushes to conduct the current from armature to load. The armature brushes, and slip-rings are difficult to insulate, and arc-overs and short-circuits can frequently occur. The rotating-armature construction is hence avoided for high-voltage alternators.

(iv) The high-voltage alternators are usually of rotating-field type. The voltage supplied to rotating field is low Voltage DC. The problem of high-voltage arc-over at the slip rings does not exist.

(v) The stationary armature, i.e. the stator of this type of alternators holds the windings that are cut by the rotating magnetic field. The voltage generated in the stationary armature is a result of the cutting action. This voltage generates the required AC power, once connected to the load.

(vi) The stator of a rotating-field alternator consists of a laminated iron core with the armature windings embedded in slots created around the periphery of the core.

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(vi) The core is mechanically secured (using bolts) to the stator frame (yoke)

Q Name the part of an alternator in which output voltage is generated.
Ans Armature

Q What are two basic types of alternators?
Ans "Rotating-Armature" type
and, "Rotating-field" type

Q What is the main advantage of "rotating-field" type of alternator?
Ans

The armature (stator) of a rotating-field type of alternator can be wounded to produce either a single-phase output, or a two-phase output, or a three phase output. Single-phase output is normally used for domestic low-power applications. Three-phase alternators are commonly used for industrial applications for power houses etc.

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★ Prime movers :-

(i) All generators, whether large or small or whether AC or DC, require a source of mechanical power to turn their rotors. This source of mechanical power is known as Prime Movers.

(ii) Prime Movers can be classified into two broad categories:
(a) High-speed prime movers
(b) Low-speed prime movers

(iii) Steam turbines & Gas turbines are two examples of high-speed prime movers

(iv) Internal Combustion (IC) engine is an example of low-speed prime movers.

(v) Hydroelectric turbine is another example of low-speed prime movers.

(vi) Wind turbine is another example of a low-speed prime movers.

★ Rotor Types:-

There are two types of rotors used in rotating-field types of alternators:
(a) Cylinderical Rotor, and
(b) Salient-pole Rotor

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Cylindrical Rotor → The rotor winding are arranged to form 2, 4, 6, 8 ... poles. This kind of construction is used for high-speed prime movers.

Salient-pole Rotor → has several separately-wound pole pieces, bolted to the frame of the rotor. Such rotors are used with low-speed prime movers.

★ Output frequency (In Alternator) :-

(i) The output frequency of the alternator voltage is given by -

$$f = \frac{NP}{120}$$

$f \rightarrow$ frequency [in Hz (or cycles/sec)]

P = Total number of poles on the ~~rotator~~ rotor.

N = Speed of prime movers (in RPM)

e.g. For speed $(N) = 100$ RPM & $f = 50$ Hz

↳ $P = \frac{120 \times 50}{100} = 60$ → which requires large cyclinders to mount on.

By increasing speed (N), less 'P' is required.

↳ as in case of gas turbines, where speed can increase even 1500 RPM or so.

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Q1. What is the frequency of output Voltage of an alternator with 4 poles that is rotated at 3600 RPM.

Ans $$f = \frac{3600 \times 4}{120} = 120 \, HZ$$

★ Voltage regulation of an Alternator:-

$$= \frac{\text{No-load output Voltage} - \text{Full-load output Voltage}}{\text{Full-load output Voltage}} \times 100$$

Efficiency :-

$$= \frac{\text{Input Power} - \text{Loss}}{\text{Input Power}} \times 100$$

Losses :-

(i) Mechanical loss
(ii) Copper (Cu) loss in Rotor
(iii) Eddy Current plus Hysteresis
(iv) Gap loss
(v) Copper (Cu) loss in Stator

(i) For large alternators, special Cooling Techniques are necessary to keep the windings from getting too hot.

(ii) Periodic ~~maintainance~~ maintenance to, say remove accumulated dust from the inside of the alternator is a must.

☆ A.C. Motors :-

Advantages →

(i) Wide availability of AC power throughout the world.

(ii) In general, AC motors cost less than DC motors.

(iii) AC motors do not use commutators & brush. This eliminates sparking possibilities and reduces maintenance needs.

(iv) AC motors, especially the ~~synch~~ synchronous type, are well-suited to constant-speed applications.

Disadvantages →

(i) AC motors can't be made variable-speed to the external DC motors can be.

(ii) AC motors, in general, are not self-starting.

(iii) Lower starting torque, in many cases.

A.C. motors
- Synchronous (Constant-speed)
- Asynchronous (Inductors)
  - 3-phase
  - Single phase

Synchronous

$$\text{Speed } (N_S) = \frac{120f}{P} \quad \text{--- (1)}$$

A.C. motors
- Three-phase
- Single phase

Three-phase Synchronous Motor :-

(i) This kind of motor is similar ~~on~~ in construction to an alternator.

(ii) This kind of motor can generate thousands of horse-powers.

(iii) Three-phase input power to stator causes a rotating magnetic flux to be setup around the rotor.

(iv) The rotor is energized with DC, using an Exciter.

(v) The rotor tries to lock-in with the rotating flux caused by stator. This generates the necessary rotation.

(vi) The rotor needs an initial starting mechanism to get it going. However, once the rotor has attained the full speed (N_S) starting mechanism can be withdrawn.

(vii) This kind of motor helps in improving the power factor of AC input.

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Asynchronous Motor (Induction Motor):-

can be either three-phase type or single-phase type:

(i) This is the most commonly used AC motors
(ii) Its simple, rugged construction makes the motor an easy-to-build, easy-to-maintain, and highly-reliable option.
(iii) The rotor is not connected to an external DC generator.
(iv) The rotor is made-up of a laminated cylinder with slots in its surface.
(v) The windings in the rotor slots can be either Squirrel-cage type or Wound type
(vi) The most common is the squirrel-cage winding. The entire winding is made up of heavy Cu/Al bars connected together at each end by a metal ring made of Copper or brass.
(vii) Rotor finally settles down at a speed N somewhat lower than the speed N_S of the stator flux.

Percentage Slip :-

$$S = 100\left[\frac{N_S - N}{N_S}\right] \quad — (1)$$

$$\text{And, } N_S = \frac{120f}{P} \quad — (2)$$

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Q. A 3-phase, 4-pole, 50 Hz induction motor runs at 1460 RPM. Calculate the ~~paret~~ percentage slip.

Ans

$$N_S = \frac{120 \times 50}{4} = 1500 \text{ RPM}$$

$$N = 1460$$

$$\% S = \frac{1500 - 1460}{1500} \times 100$$

$$= \frac{4}{150} \times 100 \simeq 2.67\ \%$$

☆ Electric (al) heating:-

(i) Heat plays major role in everyday's life.
(ii) Heat and electricity are almost interchangable.
(iii) All modern heating requirements (room heating, immersion water heating, of metals, melting of metals, tempering, hardening, etc.) can be easily met with electric heating.
(iv) Besides using electricity, other methods for generating heat are using oil, using natural gas, etc.

Definition:-
Electrical heating is a process in which electrical energy is converted to heat.

Advantages:-
(i) Cleanliness:- Complete elimination of dust/ash reduces cleaning cost.
(ii) Absence of flue gas:- FLUE is a pipe or channel used for conveying exhaust gases from a fireplace, an oven, a furnace, a boiler, a steam generator, etc.

Flue gas is the gas existing to the atmosphere via a Flue. Quite often, the term "Flue-gas" also refers to the combustion or exhaust gas produced by power plants.

Since, electric heating is free of flue gas, there is no risk of contamination of atmosphere, or of the objects being heated.

(iii) Ease of Control :- Simple and accurate control of temperature can be provided either through manual control or through using fully-automatic devices. Temperature can be maintained either at a constant value or can be made to vary as per a pre-defined plan.

Further, any particular temperature or temperature-cycle can be accurately repeated at any time.

(iv) Low Attention & Low maintenance :- Electrical heating equipment generally requires less attention and lesser maintenance compared to alternative heating systems, substantial savings in labor cost can be achieved.

(v) Special heating requirements :- Special heating requirements such as uniform heating on only a portion of an object, are easier to achieve using electric heating.

(vi) Higher efficiency :- Electrically produced heat not go waste through Chimneys etc. Most of the heat produced is available to heat the material. [can be used at places required, ~~at~~ unlike oil & natural gas which needs to be carried first to the place of requirement]

(vii) Automatic Protection :- Automatic protection against over-heating, over-current, etc. is ~~nearly~~ easily achieved with electric heating.

(viii) Heating of non-conducting materials is generally achieved by only electric heating.

(ix) Better working conditions :- No irritating noises

(x) Less Floor area :- Less space requirement

Disadvantages :-
(i) Expensive (Cost per KWh)
(ii) Fire and shock related safety hazards.

★ Modes of Heat Transfer :-

The transmission of heat energy from one body to another (because of the temperature gradient between two bodies) takes place by using any of the following methods:

(i) Conduction
(ii) Convection
(iii) Radiation

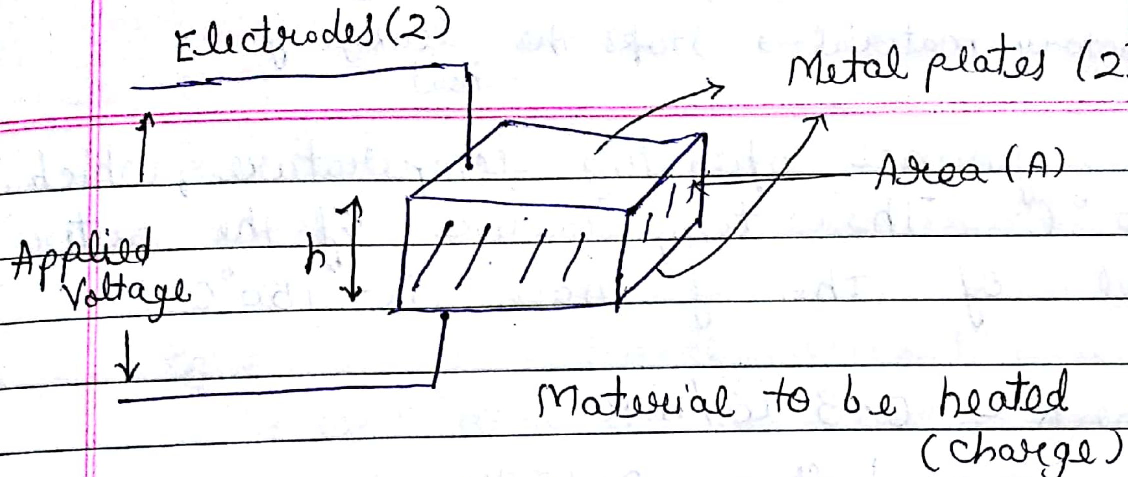
(i) Thermal Conduction :- In this mode, the heat transfers from one part of substance to another without movement in molecules of the substance.

(ii) Thermal Convection :- The heat transfer takes place from one part of a fluid substance to another due to the actual motion of molecules.

(iii) Thermal Radiation :- The heat transfer occurs without heating the medium in b/w the substances.

★ Conduction :-

Consider a solid material of cross-section A (in m^2) and thickness 'h' (in m) as shown below:



If T_1 and T_2 are the temperatures (in (Kelvin) of the two sides of the slab, then the heat conducted b/w the two opposite faces in time 't' (measured in seconds) is given by Fourier's law of heat conduction

$$H = \frac{KA(T_1 - T_2)\, t}{h} \quad \text{— ①}$$

This is an approx. description of reality.

K = Thermal Conductivity of the material (measured in W/mK) Kelvin watt meter

~~H → Joule-sec or~~
[H → watt-sec or Joule]

Q. Determine the rate of heat transfer by conduction per unit area, for a furnance wall made of fire clay. Furnance wall thickness is half a foot. Thermal conductivity of the furnance wall clay is 0.3 W/mK. The furnace wall ~~temperating~~ temperature can be taken to be the same

Below 1000 °F → Oven
Above 1000 °F → Furnace
Referactory material → stops the leakage of heat.

as furnace operating temperature, which is 650 °C. The temperature of the outer wall of the furnace is 150°C.

Ans

$K = 0.3 \text{ W/mK}$

$h = \frac{1}{2} \text{ ft} = 0.1524 \text{ m}$

$A = 1 \text{ m}^2$, $t = 1 \text{ sec.}$

$T_1 - T_2 = 650 - 150 = 500 \text{ K}$

So, $H = \frac{0.3 \times (500) \times 1}{0.1524}$

$H \simeq 1000 \text{ W/m}^2$

★ Convection :-

For vertical heating surfaces in air, natural convection takes place according to the following approximate eqn:

$$H \simeq 3.875 \, (T_1 - T_2)^{1.25} \quad \text{— (2)}$$

★ Radiation :-

The Stephen's law of radiation may be written as follows:

$$H \simeq \eta \varepsilon \left\{ 5.72 \times 10^4 \left[\left(\frac{T_1}{1000}\right)^4 - \left(\frac{T_2}{1000}\right)^4 \right] \right\} \quad \text{— (3)}$$

T_1 = Temp. of the radiating surface (Kelvin)
T_2 = Temp. of the absorbing surface (Kelvin)

ε = Emissivity of the radiating surface
η = Radiating Efficiency

η = 1 for single element
= 0.5 to 0.8 for several elements side by side

ε = 1 for Black body (Ideal case)
= 0.9 for resistance heating elements.

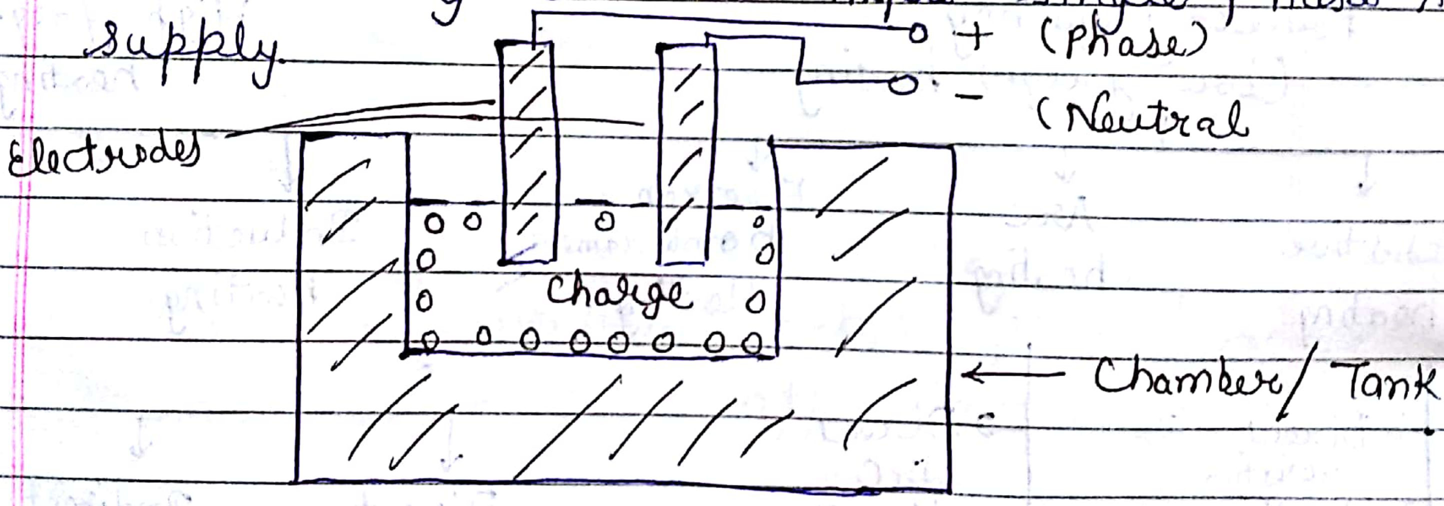
Methods of Electric Heating

- Power-frequency (Low freq.) heating
  - Resistive heating
    - Direct resistive heating
    - Indirect resistive heating
    - Infra-red (IR)
  - Arc heating
    - Direct ArC Heating
    - Indirect ArC Heating
  - Electron Bombardment Heating
- High freq. heating
  - Induction heating
    - Direct induction heating
    - Indirect induction heating
  - Dielectric heating

* Resistive Heating :-

(i) Based on I^2R loss
(ii) when a current is passed through a resistive material, heat is produced.

(a) Direct Resistive Heating →
(i) Electrodes are immersed in the material (also known as Charge) to be heated.
(ii) The electrodes are connected to either DC or AC supply.
(iii) Two electrodes are sufficient if we are using DC or ~~simple~~ single-phase AC supply.

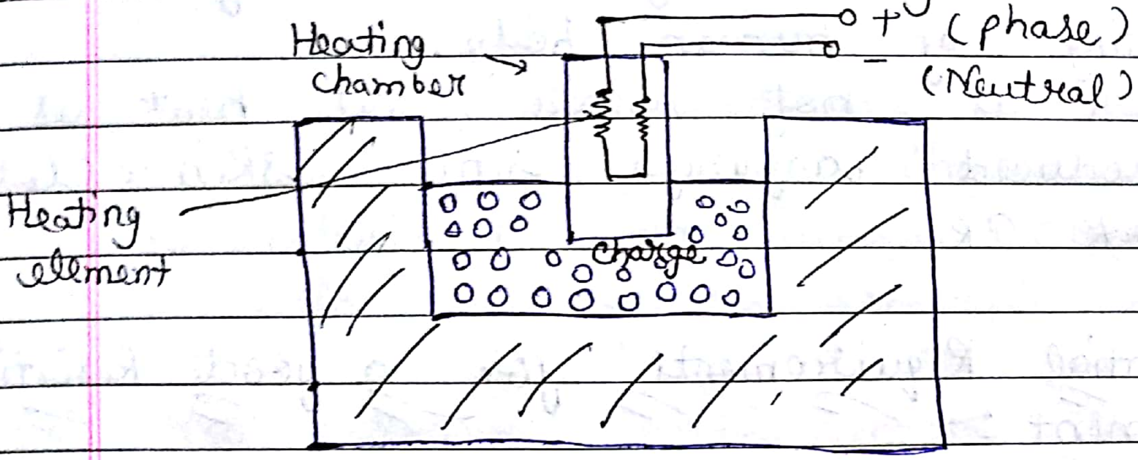


(iv) When metal pieces are to be heated, the powder of a highly-resistive material is sprinkled over the surface of the pieces to avoid direct short-circuit.
(v) This method is quite efficient (low losses)

(vi) Automatic temperature control is not easy to achieve.

Note:- In Indirect resistive heating → Current is not passing through the material (or, charge) but it can still get hot.
∴ Thermal shock ✓ Electrical shock ✗

(b) Indirect resistive heating →



Tank

(i) A heating chamber, heated by resistive elements connected to AC/DC supply is immersed in the material to be heated.
(ii) Heating chamber transfers heat to the material indirectly by radiation or convection.
(iii) Less ~~affective~~ efficient method.
(iv) Automatic temperature control is easier to achieve.

e.g. Gyser

(c) Infra-red Heating:-

(i) This is a fairly-recent development in the field of electrical heating.
(ii) These systems operate in the far infrared (IR) spectrum, producing sun-like heat tuned b/w 9 μm & 14 μm wavelength range.

(iii) 9 μm - 14 μm range ensures safe & healthy heating of human body.
(iv) IR is not visible but heat is produced anyways since skin + clothes absorb IR.

★ Essential Requirements for a good Resistive element :-

1. High Specific resistance (ρ)

$$R = \rho \frac{L}{A}$$

High ρ ensures that, for a given amount of produced heat, the element length (L) is minimized.

2. High melting point helps the element in withstanding high tolerance.

3. Low temp. - coefficient of Resistance → For accurate temperature control, the variation of element's resistance with operating temperature should be very low.

4. Free from oxidation → The element material should not be oxidized when subjected to high temperature. The formation of ~~oxiside~~ oxidized layers shortens

the life of the element.

5. High Mechanical Strength → The material should have high mechanical strength under normal conditions as well as under expected vibrations.

6. Non-corrosive
7. Economical

Commonly used materials :- Alloys of Nickel & Chromium

* Approximate energy consumption of Resistive ovens :-

(i) Baking Bread : 50-100 Kwh / tonne

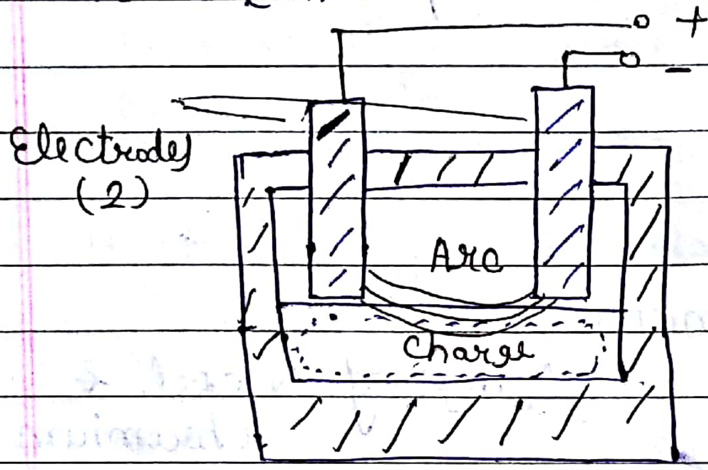
(ii) Annealing Copper : 100-200 Kwh/tonne

(iii) Carburizing : 250-500 Kwh/tonne

(iv) Vitreous Channeling of Sheet Steel : 400-700 Kwh/tonne

✶ Direct Arc Furnace :-

(i) When supply is given to two electrodes, arcs are established across them. Current directly passes through the material to be heated (known as 'charge')



Chamber

Advantages of direct Arc furnace →

(i) The stirring action is inherent and charge does not need to be externally - stirred.

(ii) Lower losses

(iii) Costlier than resistive heating.

(iv) Simple and easy to control

✶ Indirect Arc Furnace :-

(i) Arc strikes between two electrodes by bringing the electrodes momentarily together and then withdrawing them.

(ii) The heat developed by arc is transferred to the charge via radiation.
(iii) This kind of furnace needs to be rocked continuously.
(iv) The electrodes are contained in a heating chamber. Heating chamber gets hot and indirectly transfers heat to charge.
(v) Lower effeciency

☆ Electron-bombartment Heating:-

(i) Free electrons in ~~vacum~~ ~~vaccum~~ vacuum can be influenced by electric and magnetic field (as happens in a CRO) to produce a high-energy beam.
(ii) If the beam is made to collide with a material, it transfers most of its energy to the material.
(iii) Very fast local heating can be obtained.
(iv) used mostly in semiconductor industry.

✯ High-frequency Heating :-

(i) The main difference b/w power-frequency and high-frequency heating is that in the power-frequency methods, the heat is transferred via either conduction, or convection, or radiation, but in high-frequency methods the electromagnetic energy is directly converted to heat energy inside the material to be heated.

(ii) High-frequency heating can be applied to two types of materials, namely, electrical conductors and insulators. Insulators are also called Dielectric.

(iii) The heat of conductors (Copper, Ferrous materials, etc.) is known as Induction heating.

(iv) The heating of dielectrics is known as Dielectric heating.

(v) The heat transfer rate in the conventional power-frequency methods is quite low (nearly 0.5 to 20 W/cm^2)
The heat transfer rate in the high-frequency methods is quite high ($\sim 100\ W/cm^2$)

(vi) High-frequency heating is well-suited to high-speed production.

☆ Induction heating:-

(i) This method is based on the principle on which transformers work, namely Induction

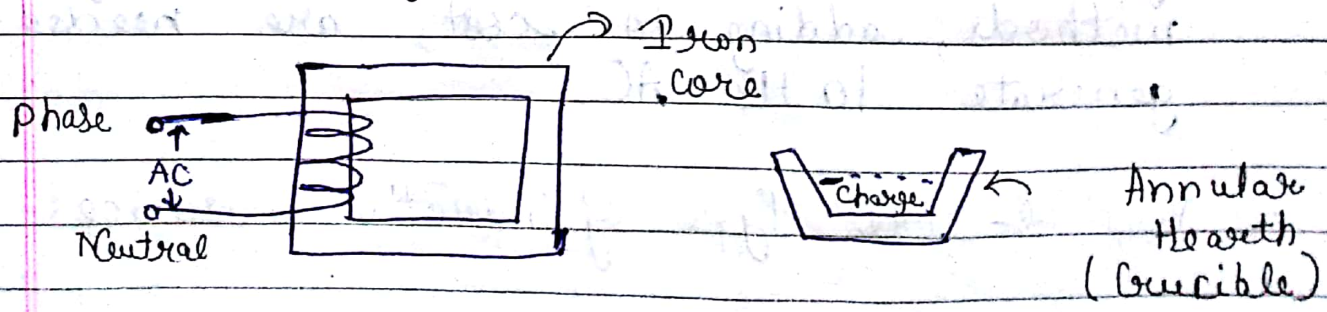
(ii) There is a primary winding through which an AC current is passed. This winding is also knows as coil.

(iii) The flux produced by coil ~~...~~ links with the metal to be heated. The metal to be heated (i.e. Charge) acts as the secondary windings.

Induction Furnaces

- Core Type
  - Direct Core
  - Vertical Core
  - Indirect Core
- Coreless Type

Direct-Core type Induction Furnace



(i) The direct-core type of Induction Furnace, in essence, is a transformer in which the charge to be heated forms the secondary circuit and is magnetically coupled to the primary through the iron core.

(ii) The furnace consists of a circular hearth in the form of a Trough which contains the charge to be melted.

(iii) The Coupling is weak.

(iv) If current ~~excceds~~ density exceeds about $500\ A/cm^2$, electromagnetic forces in the molten metal become high enough to cause repulsion among molecules. This is known as Pinching effect

(v) Pinching leads to intermittent secondary circuit (because of formation of bubbles and voids in the molten metal). This undesirable phenomenon is negligible if we operate the furnace with about 10 Hz supply. Special methods, adding to cost, are needed to generate 10 Hz AC.

Vertical-core Type of induction Furnace :-

(i) This furnace is an improvement over the

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Direct - core type Induction Furnace.

(ii) This furnace is also known as Ajax Wyatt Induction Furnace.

(iii) Core is made vertical which minimizes the pinching effect even when the AC supply has higher frequency.

(iv) Efficiency is higher.

(v) Accurate temperature Control is possible.

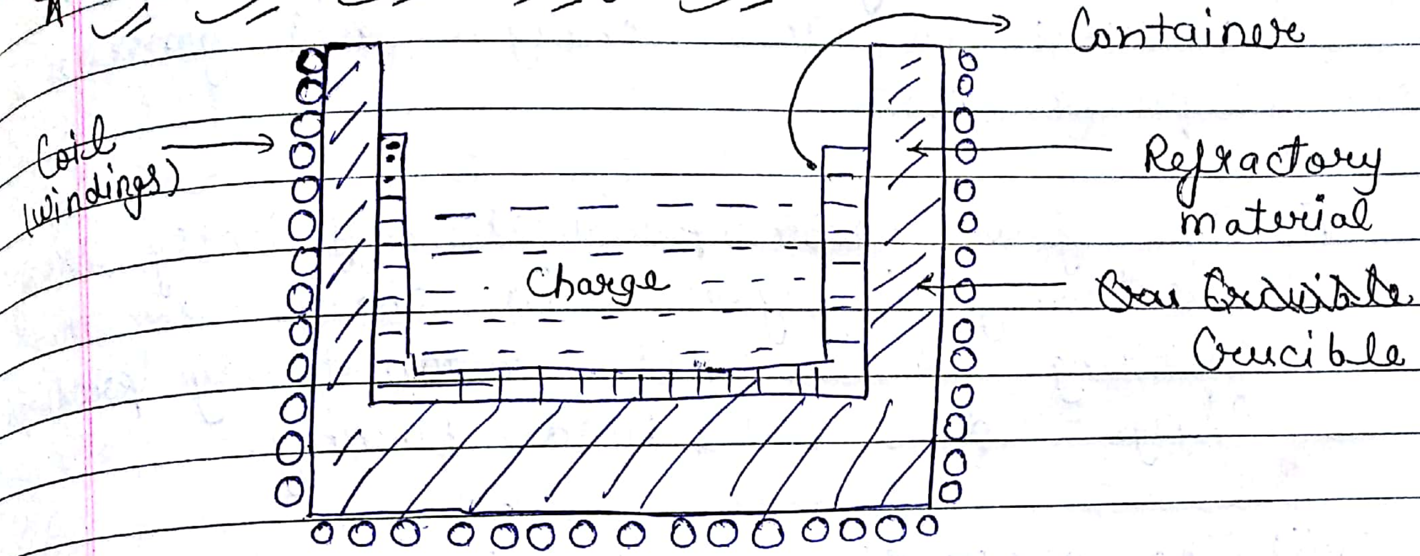
Indirect - Core Type Induction Furnace:-

(i) The heat produced in the secondary is transmitted to charge via Radiation.

(ii) used for providing heat treatment to metals.

(iii) wide variation of temperature Control is possible.

★ Coreless induction furnace :-



(i) This kind of furnace does not have the core. The heat is developed in the charge through eddy currents generated in the charge.

(ii) The furnace consists of a refractory or ceramic crucible cylindrical in shape and enclosed within a coil that forms the primary winding.

(iii) The furnace also contains a conducting or non-conducting container that ~~cost~~ acts as secondary.

(iv) If the container is made-up of non-conducting material, the material to be heated (charge) should have conducting properties.

(v) The primary winding is excited by an AC source. The flux thus set up, induces eddy currents in the charge. This generates the required heat.

(vi) The flux also produces sufficiently strong electromagnetic forces in charge so that stirring action is automatically produced. Charge does not need Rocking.

(vii) The generated power is given by-

$$W_e = K B_m^2 f$$

$K \rightarrow$ constant of proportionality

$f \rightarrow$ frequency of AC supply

$B_m \rightarrow$ Maximum flux density (in Wb/m^2 or Tesla)

(viii) Because there is no core, B_m will be low. Hence, 'f' needs to be sufficiently high.

(ix) Because of high 'f', primary sees higher loss and hence, higher temperature. cooling is necessary.

(x) Primary may use hollow copper tubes through which cold water is circulated.

Advantages :-

(i) Ease of Control
(ii) Less time needed to reach melting temperature
(iii) Inherent stirring Action
(iv) Less cost for building the system & maintaining it.
(v) Any crucible shape can be used
(vi) Suitable for intermittent operation.

★ Dielectric Heating :-

(i) For heating non-metallic materials such as wood, plastic, or ceramics, we make use of "dielectric loss" which occurs in materials when they are subjected to an AC supply.

(ii) The material is placed between two metallic electrodes across which an AC Voltage is applied.

(iii) Frequencies between 10 MHz and 50 MHz, and voltage as high as 20 KV, are needed to generate an adequate amount of heat.

(iv) Dielectric materials have poor thermal conductivity. However, the heat is produced in the material itself.

(v) Dielectric heating is much faster than, say, oven heating since no heat transfer is involved.

(vi) Equipment is costly, thus this method is used only when absolutely necessary.

★ Advantages of Dielectric Heating :-

(i) Uniform Heating
(ii) Lower Running Cost
(iii) Non- conducting materials can be heated.
(iv) Easy Control
(v) Faster Heating
(vi) ~~Inflammation~~ Inflammable materials (e.g. plastics) can be safely heated.

Disadvantages :-

The only disadvantage is high initial cost required to set up the system.

★ Typical Applications of dielectric heating :-

(i) Bonding of laminated wood
(ii) Bonding of plastic materials
(iii) Dehydration of food, tobacco, etc.
(iv) Sterilization of cereals.
(v) Electronic Sewing
(vi) Removal of moisture from oil.
(vii) Heating of tissues of bones in human body

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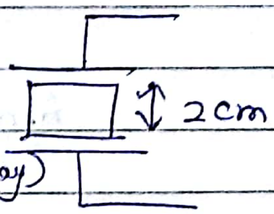
(needed in many medical procedures), etc.

Q. A wooden board of dimensions 30cm X 20cm X 2cm is to be heated from 25°C to 175°C in 10 minutes by dielectric heating using 30 MHz supply. Wood parameters are : Specific heat = 0.35 Cal/gm°C,
Density = 0.5 gm/cc,
Dielectric constant = 5, and
Power factor = 0.05

Determine the Voltage needed across the specimen and the current drawn during heating.
[Assume that loss of heat energy by radiation etc. is 5%]

Sol.

Capacitance $C = \frac{\epsilon_0 \epsilon A}{t}$ (in Faraday)



Electrical heating

ϵ_0 = Permittivity of free-space
$= 8.854 \times 10^{-12}$ F/m

$A = 0.3 \times 0.2 = 0.6\ m^2$
$t = 0.02\ m$ = Thickness b/w plates
(Or, Thickness of board)

Reactance offered by board to the supply is –

$$X_C = \frac{1}{2\pi f C}\ \Omega$$

Once X_C is known, and if assume that supply Voltage is 'V' volts (R.M.S. Value)

Then, Magnitude of Current in board $(I) = \frac{V}{X_C}$

The Total power consumed by the board
$(P) = V I \cos\phi$
$= \frac{V^2}{X_C} \cos\phi$ $[\cos\phi = 0.05]$

Thermal heating → Volume of the board $= 1200 \times 10^{-6}\ m^3$
$= 1200 cc$
Mass of board $=$ Volume × density
$= 1200 \times 0.5 = 600\ gm = 0.6\ kg$

Amount of heat energy ~~supplied~~ = Mass × Specific heat × (Temp. diff)
$= 600 \times 0.35 \times (175 - 25)$
$= 90000 \times 0.35$
$= 31500$ Cal
$= 31.5$ K-Cal

1 KWh = 860 K-Cal

Heat (in KWh) $= \frac{31.5}{860}$ KWh $= 36.6 \times 10^{-3}$ KWh

↳ Taking in account the losses (5%) by radiation
Heat required $= \frac{36.6 \times 10^{-3}}{0.95} = 38.5 \times 10^{-3}$ KWh

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$P_{heat} \times t = 38.5 \times 10^{-3}$ KWh

$\Rightarrow P_{heat} = \frac{38.5 \times 10^{-3}}{10/60}$ KW

$\simeq 231$ Watts

Now, $\underset{\text{power}}{\text{Electrical}} = \underset{\text{power}}{\text{Thermal}}$

$\Rightarrow \frac{V^2}{X_C} \cos\phi = 231$

$\Rightarrow V \simeq 430$ ~~Watts~~ Volts

And, $I = \frac{V}{X_C} \Rightarrow I \simeq 10.76$ Amp.

Mechatronics

Drives:- Drives are mechanisms used for motion control in the various parts of a Mechatronic system.

Drives can be either:

(a) Mechanical drives

(b) Electrical drives

Sensor:- converts a physical phenomenon into electrical signals.

Actuator:- does the opposite of Sensors.

Electrical Signal → physical Phenomenon

Sensors + Actuators → Transducers

MTBF → Minimum time between Failures

↳ Quality factor for various devices

Electric Drives :-

★ The mechanism employed ~~mor~~ for motion control in an electromechanical system is called a Drive. If the prime-mover (source of all motions in the system) is an AC motor, or a DC motor, then the Drive is called electric drive.

Main Components in an electric drive

- Motor
- Power Modulator
- Source
- Control unit
- Sensors

Electric Motors can be either AC type or DC type

DC motors :-

Separately excited OR Self-excited

Self-excited:
- Series wound
- Shunt wound
- Compound wound

AC motors :- (i) Synchronous Motors
(ii) Induction Motors

AC motors:
- Single-Phase
- Three-phase

Power Modulators :-

Power Modulators are the devices that alter the nature of supply Voltage (or both) to control devices.

Power modulators can be of three main types :

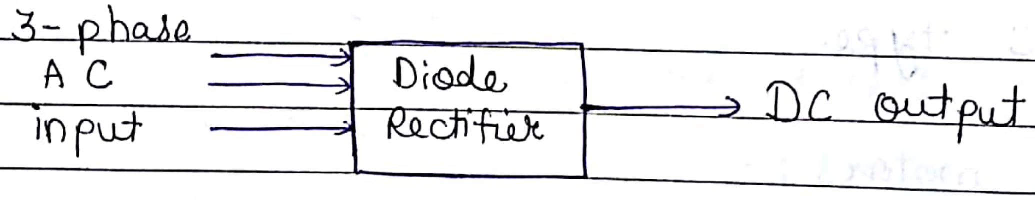
(i) Converters [AC to DC converters, AC regulators, DC to DC converters, Inverters, cycloconverters, etc.]

(ii) Variable Impedance Circuit

(iii) Switching circuits

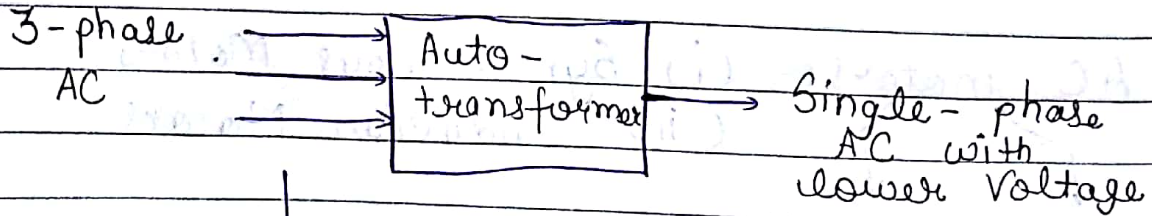
(i) Converters →

(a) AC to DC converters :-



↳ Input can be single-phase too.

(b) AC regulators :-

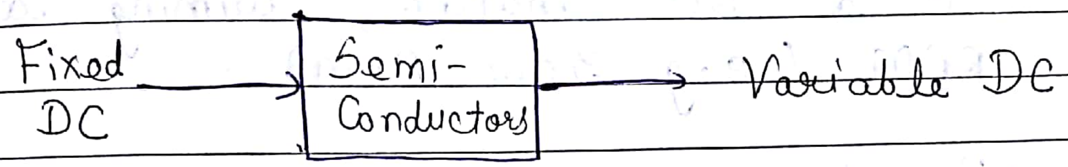


↳ Input can be single-phase

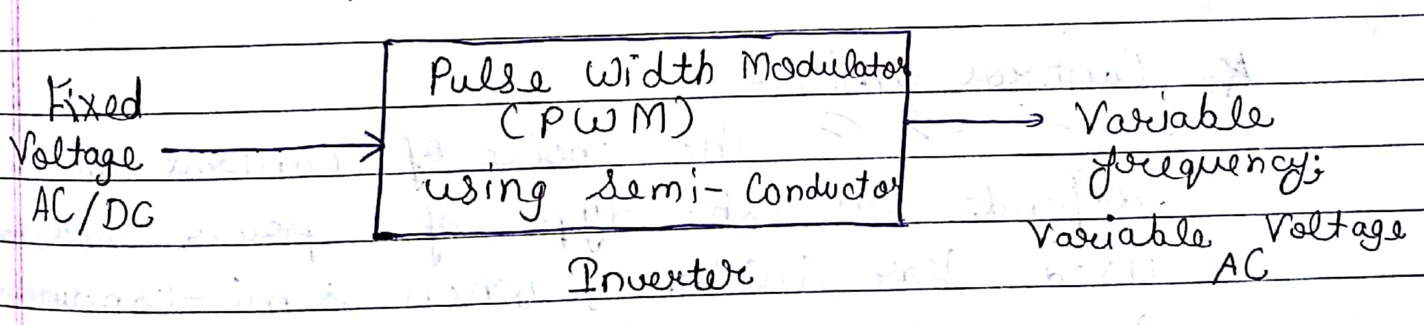
↳ Output & input Voltages are generally not same.

(c) DC to DC converters :-
(also known as Choppers)

These are used to get a variable DC voltage from a fixed DC voltage. Semi-conductors ~~like~~ devices like MOSFET (Metal oxide Semi-conductor field effect transistor) are used.



(d) Inverters :- generate (from a fixed AC voltage input) a variable AC output voltage.



(e) Cycloconverters :- convert the fixed-frequency, fixed voltage AC input into variable-frequency, variable voltage AC output.

(ii) Variable impedence circuits :-
control speed by varying the resistance or impedence of the circuit.

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(iii) Switching circuits :- These are used for running the motor smoothly; can also be used to protect the motor during faults.

★ Source :-

(i) may be either an AC motor, or a DC motor, running at a fixed RPM (e.g. 3000 RPM)

(ii) AC motors of low/medium power rating can be driven by using 440V supply. Motors with higher power ratings will need 3.3 KV, 6.6 KV & 11KV etc.

★ Control unit :-

The choice of control unit depends on the type of power modulator used. For instance, when semi-conductor converters are used, then the control unit consists of "firing circuits", when are driven by microprocessors.

★ Advantages of Electrical Drives :-

(i) Available in wide ranges of torque, speed & power.

(ii) Flexible control characteristics (Electronic Braking, Electronic Starting, etc.)

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(iii) can operate in all the four quadrants of speed - Torque plane.
(iv) Do not pollute the environment.
(v) can be started instantly
(vi) can be loaded Immediately.

Classification of Electric Drives :-

(a) Group drive
(b) Individual drive
(c) Multimotor drive

(a) Group drive :-

(i) only one single electric motor is used. Other machines are operated by means of line shaft from that single motor.

(ii) The entire operation is done ~~via~~ using energy transmitted via the line shaft. Hence, this kind of drive is also known as Line Shaft Drive.

(iii) The line shaft is fitted with a belt and multi-stepped pulleys which drive the working equipment with variations in speed.

(iv) Due to a Group drive's whole system-dividing nature, the power rating of the motor is quite high.

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(v) Group drives is normally used when a switchover ~~switch over~~ from engine drive to electric motor is expected, because only one motor will have to be purchased.

(vi) Groups drives are more ~~econom~~ economical, especially in case of large factories.

(vii) Group drives have simpler operation than multi-motor drives.

Advantages

(viii) Lower Reliability
(ix) Wear & tear in line shaft.
(x) All shafts rotate even if not needed.

disadvantages

(b) Individual drive :-
(i) We use a separate motor for each individual equipment.

(ii) Typical applications of Individual drives are Cranes, Lathes, Drilling Machines, etc.

(iii) Higher Reliability.
(iv) Higher Safety

Advantages

~~(c) Multi-motor Drives :-~~
(c) Multimotor Drives :-
(i) Each motor is used to different parts in a single equipment.

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(ii) Typical applications → metal cutting Machine tools, Paper marking machines, Really Rolling Mills, etc.

(iii) Improved reliability

(iv) Quite costly

Group drive	Individual drive	Multi-motor drive
(i) Single motor for all equipments.	Separate motor for each individual equipment	Separate motor for different parts in a single equipment.
(ii) Less Reliable	High Reliability	High Reliability
(iii) No automation	Automation	Automation
(iv) System is simple.	System is complex	System is highly complex
(v) Low Cost	High Cost	Highest Cost

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* Factors governing the selection of electric motors:-

(i) Nature of electric supply (AC or DC)

(ii) Type of Drive (group drive, individual drive & multi-motor drive)

(iii) Nature of load
↳ (constant torque, Variable torque Constant speed, Variable speed)

(iv) Electrical Characteristics:-
Starting torque, Speed Control, Braking torque, etc.

(v) Mechanical considerations:-
Type of Enclosure, Type of Bearings, Type of Transmission, Noise level, Heating / Cooling Requirements, etc.

(vi) Service Capacity & Rating:-
(a) Continuous load cycle, Intermittent load cycle, Variable Load cycle
(b) Overload ~~Cycle~~ Capacity

(vii) Appearance

(viii) Cost:- Capital Initial Cost, Operating Cost & Maintenance Cost

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* DC motors versus AC motors :-

(i) DC motors are not as widely used as AC motors since extra equipment is needed to convert AC into DC.

(ii) DC motors have commutators that are prone to issues like sparking, arc-over, brush wear and tear, presence of moisture & destructive fumes around the motor, etc.

(iii) However, in many applications like excavators, steel mills, cranes, etc., accurate and wide-ranging speed control is necessary. This is possible with only DC motors.

(iv) Single-phase AC motors are used only for low-power applications.

(v) Three-phase AC motors can be used for very high power ratings, but three-phase supply would be needed.

* Industries using Motors :-

(i) Textile Industry → (a) Ginning → It separates seeds from cotton

(b) Spinning → production of continuous yarn of sufficient strength

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(c) Weaving → Before the yarn is woven, it is made into a unifor layer.

For these multi-operations, Squirrel Cage Induction Motor is used.
↓ which is cost-effective
(Though, weaving action isn't performed effectively by this motor)

(ii) Rolling mills

For cranes, multi-motors are used.

(iii) Cement plant → Induction motors are used, generally.