Physics Investigatory project

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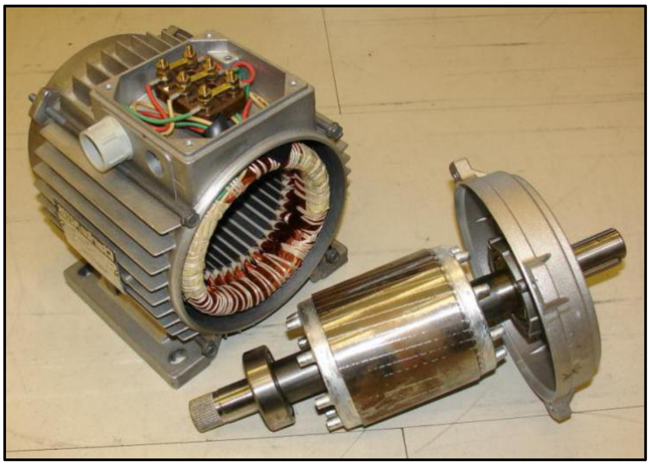
INTRODUCTION

1. Basics :

- Electric motor is an device that converts electrical energy into mechanical energy. Electromagnetic induction (EMI) is the basic principle of an electric motor.
- A motor functions in a manner opposite to that of the generator (using current to produce motion rather than motion to produce current.)

2. Induction motor :

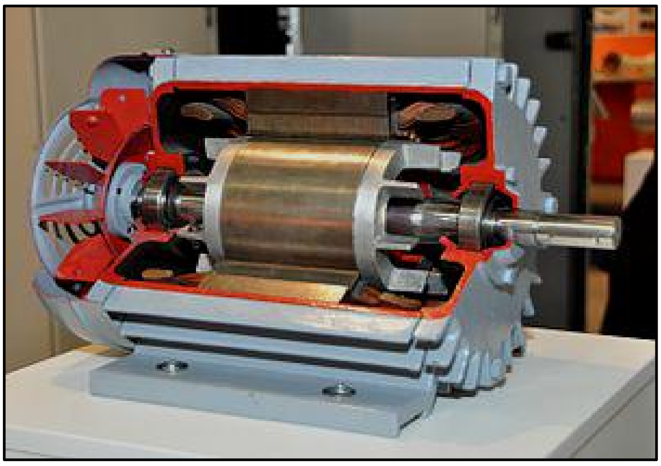
- Induction motor is an AC electric motor in which the electric current in the rotor, needed to produce torque, is obtained by electromagnetic induction from the rotating magnetic field produced around the stator winding.
- The current sets up a torque which therein helps the rotor to rotate. The rotor is further connected to other components ; useful rotational kinetic energy.
- A wonderful application of the Faraday's law of EMI.
- Utilised mainly in the industrial sector and household appliances.

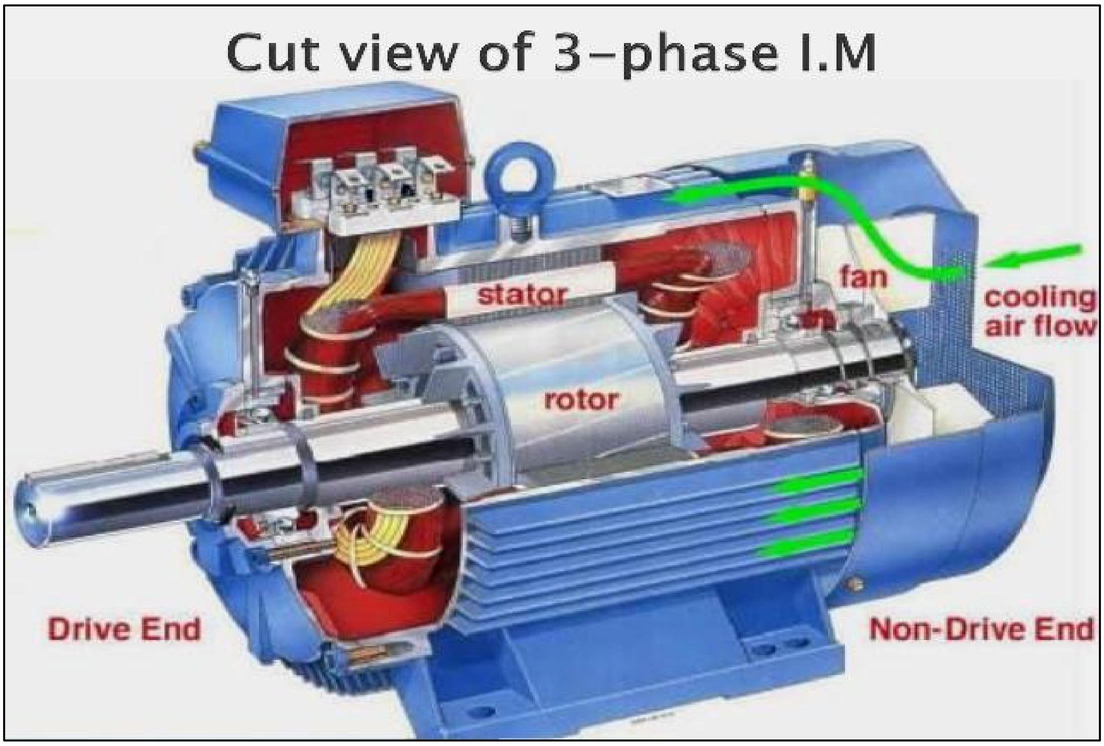


3 PHASE INDUCTION MOTOR :

- ✓ **STATOR (LEFT)**
- ✓ **ROTOR (RIGHT)**

CUTWAY VIEW THROUGH STATOR OF INDUCTION MOTOR.





THEORY

❖ Electromagnetic induction :

- The phenomenon of production of induced EMF and hence induced current in a circuit due to the change of magnetic flux linked with that closed circuit.
- Faraday's popular experiments of electromagnetic induction-- between magnets and closed coils/loops -- lead to the conclusion that **relative motion between coil and magnets produces an induced EMF and thus, an induced current in the circuit.**
- Faraday drew conclusions and formulated two laws.

❖ Faraday's Laws of Electromagnetic induction :

1. Whenever the magnetic flux linked with a closed coil changes, an EMF is induced in it which lasts only so long as the change in flux is taking place.
2. The magnitude of induced EMF is equal to the rate of change of magnetic flux linked with the the closed circuit.

$$\boxed{EMF = -\frac{d\Phi}{dt}}$$

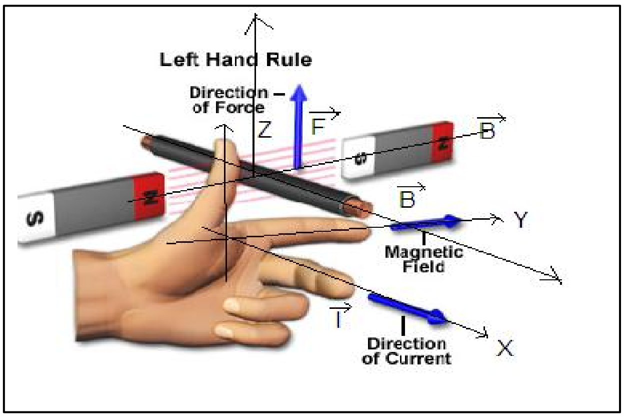
❖ Force on a current carrying conductor :

- When a wire carrying an electric current is placed in a magnetic field, each of the moving charges, which comprise the current, experiences the Lorentz force.
- The Lorentz force experienced by all electrons together create a macroscopic force on the wire. The following equation results, in the case of a straight, stationary wire:

$$\boxed{\mathbf{F} = I\boldsymbol{\ell} \times \mathbf{B}}$$

- where $\boldsymbol{\ell}$ is a vector whose magnitude is the length of wire, and whose direction is along the wire, aligned with the direction of conventional current flow I.
- If the wire is not straight but curved, the force on it can be computed by :

$$\boxed{\mathbf{F} = I\int \mathrm{d}\boldsymbol{\ell} \times \mathbf{B}}$$



The direction of force is given by Fleming's Left hand rule as shown

❖ Torque acting on a current carrying loop placed in a magnetic field :

- When a current travels in a loop that is exposed to a magnetic field, the field exerts a torque on the loop.
- The forces acting upon the loop are equal and opposite, they both act to rotate the loop in the same direction.
- Torque experienced is independent of the loop's shape. But,the torque depends on area of the loop.

$$\boxed{\tau = NIAB\sin\theta}$$

- This principle is commonly used in motors, in which the loop is connected to a shaft that rotates as a result of the torque.

- Thus, the electrical energy from the current is converted to mechanical energy as the loop and shaft rotate, and this mechanical energy is then used to power another device .

CONSTRUCTION

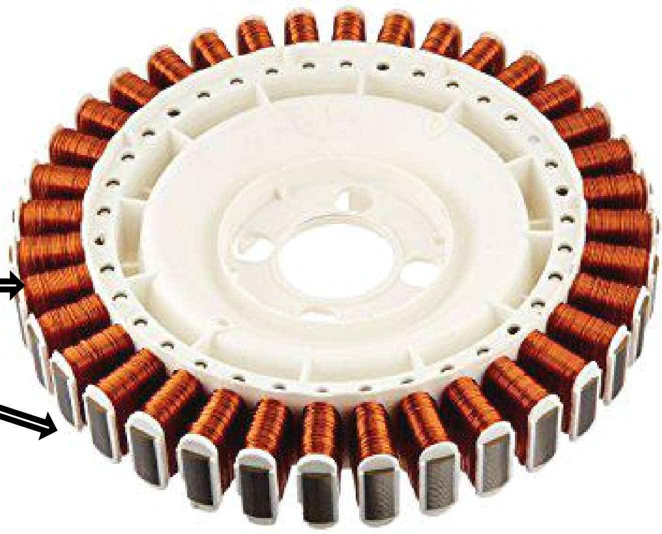
Here, we shall deal with the essentials of a 3-phase induction motor.

The components of an induction motor are :

✓ Stator :

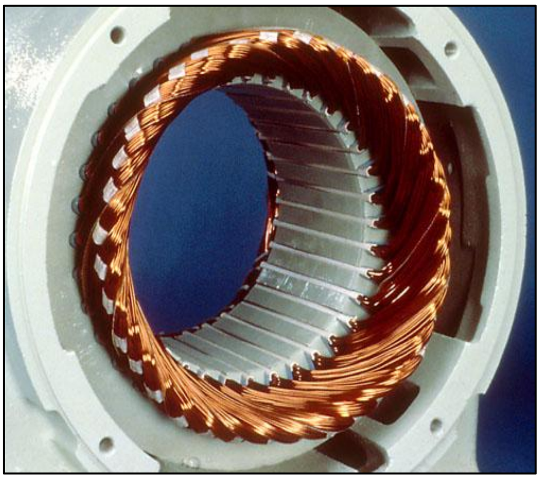
- The stator is the **stationary portion** of the motor that delivers a rotating magnetic field to interact with the rotor.
- The stator is made up of **various stampings with slots** to carry **three phase individual windings** which overlap one another and are offset by an electrical angle of **120°.**

STAMPINGS WITH SLOTS



- It is wound for a **distinct number of poles.** One or more copper windings make up a "pole" within the stator, and there is always an even number of poles within a motor.

  The electric **current alternates through the poles,** resulting in a rotating magnetic field.

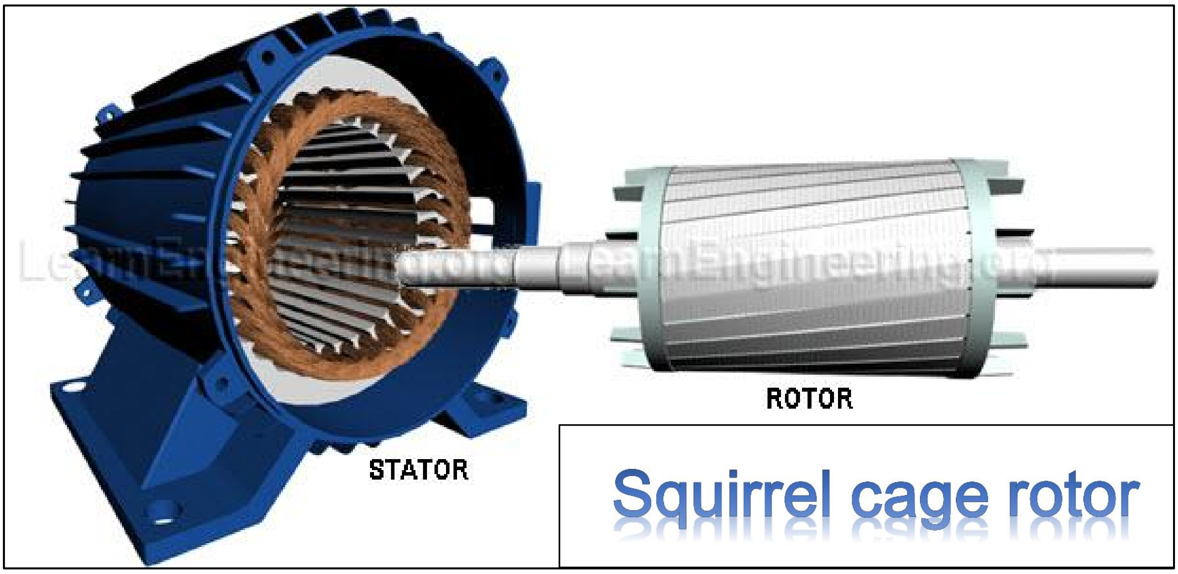


✓ Rotor :

- The rotor is the **rotating part of the electromagnetic circuit**. It is the central component of the motor, and is fixed to the shaft.
- The rotor comprises of a **cylindrical laminated core** with axially placed **parallel slots** for carrying the conductors. Each slot carries a **copper, aluminium,** or alloy bar.

- The slots are not exactly made parallel to the axis of the shaft but are **slotted a little skewed** because this arrangement **reduces magnetic humming noise** & can avoid stalling of motor.

- These conductors are attached at each end to a circular fixture. This configuration is called a **"squirrel cage rotor"** because of its appearance.



- The **magnetic field** generated by the stator **induces a current in the rotor**, which then **creates its own magnetic field**.
  The interaction of the magnetic fields in the stator and rotor results in a **mechanical torque** of the rotor.

- So, rotor voltage is induced in the rotor windings rather than being physically connected by wires.

✓ Shaft :

- The motor shaft is fixed within the rotor, and rotates with it. The shaft extends outside of the motor casing, and allows a connection to an outside system to transmit the rotational power. The shaft is sized to the amount of torque the motor puts out to avoid breaking the shaft.

✓ Bearings :

- The rotor shaft is held in place by bearings at either end of the motor casing. The bearings minimize the friction of the shaft connection to the casing, increasing the efficiency of the motor.

✓ Casing :

- The casing of the induction motor contains all of the motor components, provides electrical connections and allows for ventilation of the motor parts to reduce heat build-up.

  The casing design often includes fins to assist with heat dissipation.

WORKING

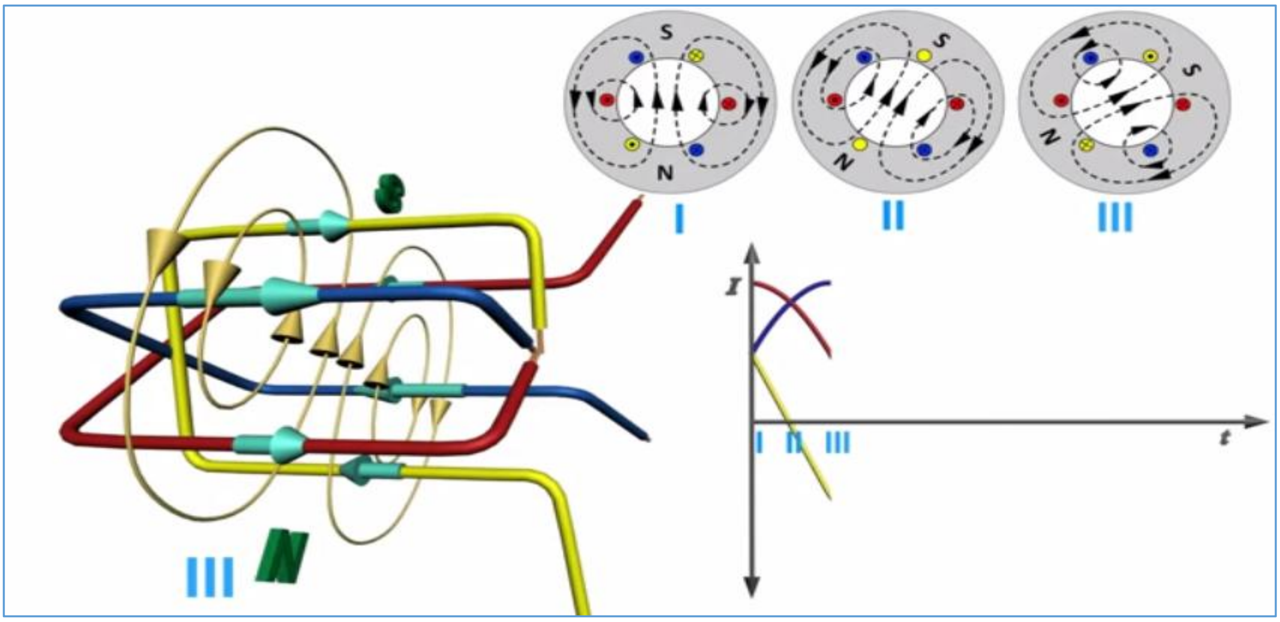
- When the induction motor is plugged in, an **electric current flows** through the **3 pairs of coils** wound on the slots of the stator. Whenever a current passes through a coil, it produces a magnetic field around it. Hence the 3 pairs of coils acts as **electromagnets**.

- **Rotor** is a solid cylinder present inside the stator. It has a series of **highly conducting Aluminium rods embedded** in its surface. The stator's electromagnets (three pairs of coils) **must induce a current** in these rods of rotor by its motion.

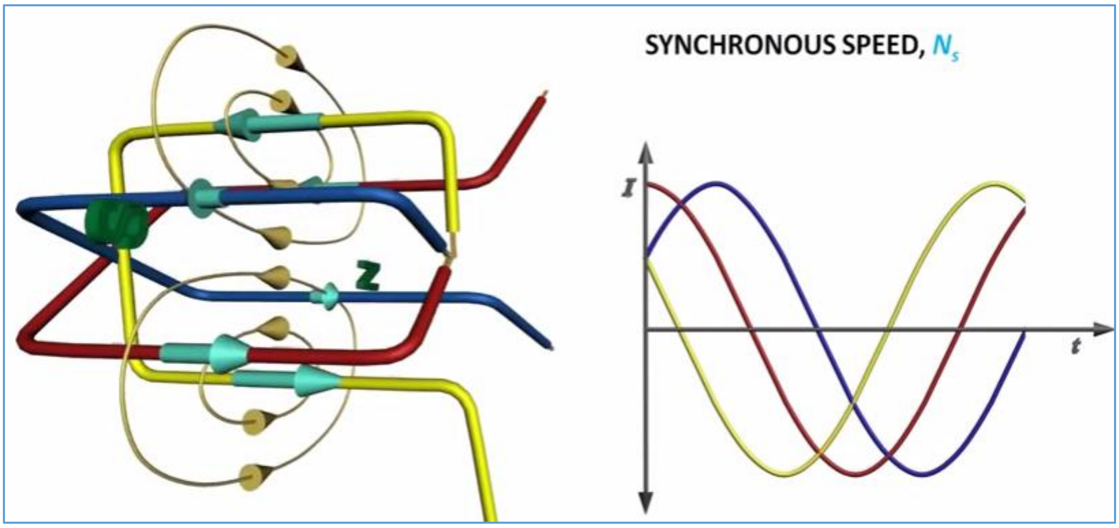
- But the remarkable thing is **stator is stationary** and the coils do not move. This is where the brilliance and simplicity of induction motor comes into play.**The stator simulates motion**.

- The coils only become electromagnets when electricity flows through them. **The electric current does not pass through all the three coils at the same time.** The stator **switches** the electric current between the three coils, one after the other, thereby creating magnets one after the other.

- Hence, the three current carrying coils create a **simulation of one pair of magnets** spinning around the stator at **1800 rpm.**



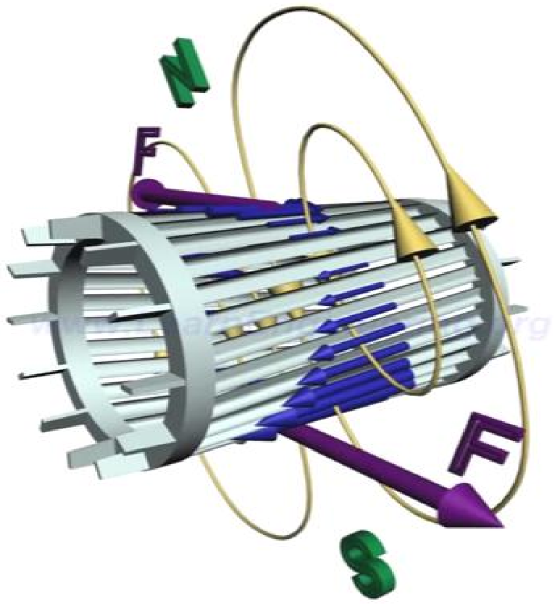
Uniform magnetic field produced by 3 phase windings at different instants of time (above)



Electric current vs. time graph for a 3 phase induction motor (above)

- From these figures, it is clear that the magnetic field of 3 phase AC current is of uniform strength. The rotating magnetic field causes a change in magnetic flux linked with rotor coils, an EMF is induced in the coil by Faraday’s laws of induction. The EMF causes a current flow in the loop.

- So, a current carrying loop is situated in a magnetic field. It experiences magnetic Lorentz Forces of equal magnitude in opposite direction i.e. a TORQUE which gives rise to the rotation of the rotor.



Torque on “squirrel cage rotor” created by interaction of magnetic fields of stator and rotor.

- The torque thereby helps the rotor to rotate. The motor is connected to other components to ensure that useful work is obtained. Insulated iron core lamina are packed inside rotor to ensure eddy current losses are minimal.

❖ WHY ASYNCHRONOUS?

This motor is also called as asynchronous motor because it runs at a speed less than its synchronous speed.

Synchronous speed is the speed of rotation of the magnetic field in a rotary machine and it depends upon the frequency and number poles of the machine. **An induction motor always runs at a speed less than synchronous speed.**

- **REASON:**

If $N_S = N_{Rotor}$

(N_{Rotor} = speed of rotor)
(N_S = speed of synchronous motor)

- Assume the rotor speed and synchronous speed to be equal. Then the **rotating rotor** will always experience **constant magnetic field.** Thus, **no change in magnetic flux.** Hence **no induced EMF** and **no current**. So, **torque is zero** causing rotor to slow down gradually.

- But as the rotor slows down, it experiences a changing magnetic field. So, a current will be induced and torque is non-zero causing rotor to speed up. **Therefore, $N_{rotor} < N_s$. Speed of rotor is always slightly less than synchronous speed. The difference $N_s - N_{rotor}$ = slip speed.**

APPLICATIONS:

❖ Industrial motors are used in a variety of areas because:

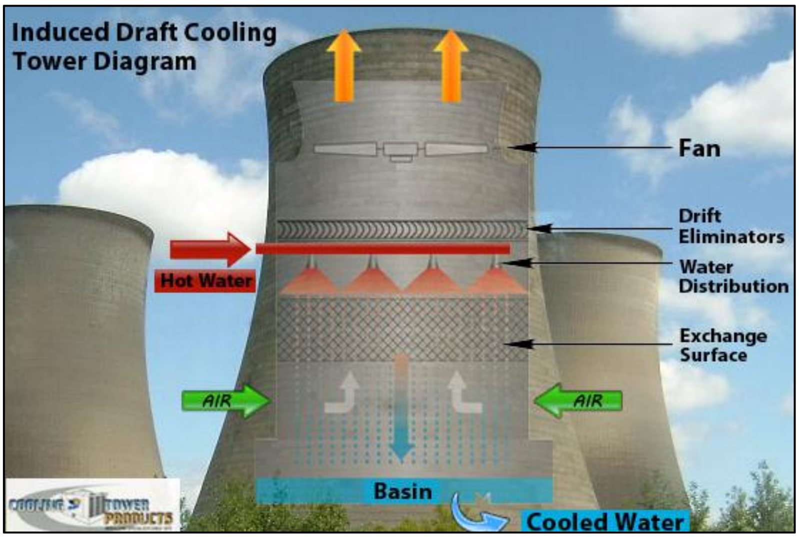
- Cheaper, rugged, economical and reliable.
- Induction motors do not require any additional power source.
- No mechanical parts in motor; easier to maintain compared to other alternatives.
- Creates a powerful rotation with the help of magnets only.

❖ Induction motors drive:

Heavy-duty Saws

Conveyor belts

Industrial and chemical pumps



Cooling Towers

Process Machinery

CONCLUSION

- The Induction Motor is a special type of electric motor. The three phase AC induction motor is the most common type.

- The electric current in the rotor, needed to produce torque, is obtained by electromagnetic induction from the rotating magnetic field produced around the stator winding.

- The rotating magnetic field is a simulation effect created by current flowing in 3 wires at three different phases around the stator.

- So, a current carrying loop is situated in a magnetic field. It experiences magnetic Lorentz Forces of equal magnitude in opposite direction i.e. a torque which gives rise to the rotation of the rotor.

- The rotor rotates and is connected via ball bearings, gears etc. to other parts of the machine where rotation is necessary.

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