LINEAR INDUCTION MOTOR

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Why LIM ?

APPLICATION OF LINEAR ELECTRIC MOTORS

- Conveyor Systems , Material handling and storage
- People movers (Elevators) • Liquid metal pumping
- Machine tools operation • Operation of sliding doors

- Before the advent of linear motors, rotary motors with rotary to linear converters of some kind were used to produce linear motions.
- The most obvious advantage of a linear motor is that
- no gears and requires no mechanical rotary to linear converters.
- Thus compared with rotary motors with mechanical gears, and similar devices, the linear motor is robust and more reliable.

What is LIM

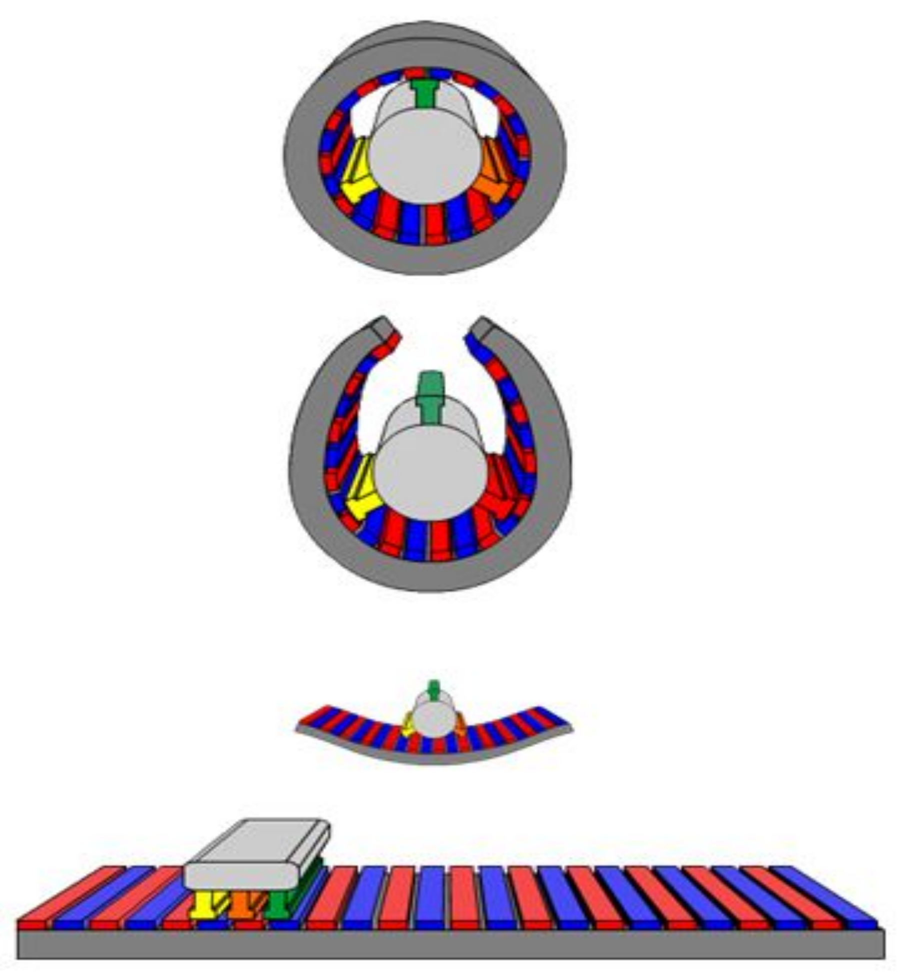
A Linear Induction Motor (or LIM) is a special type of induction motor used to achieve rectilinear motion rather than rotational motion as in the case of conventional motors

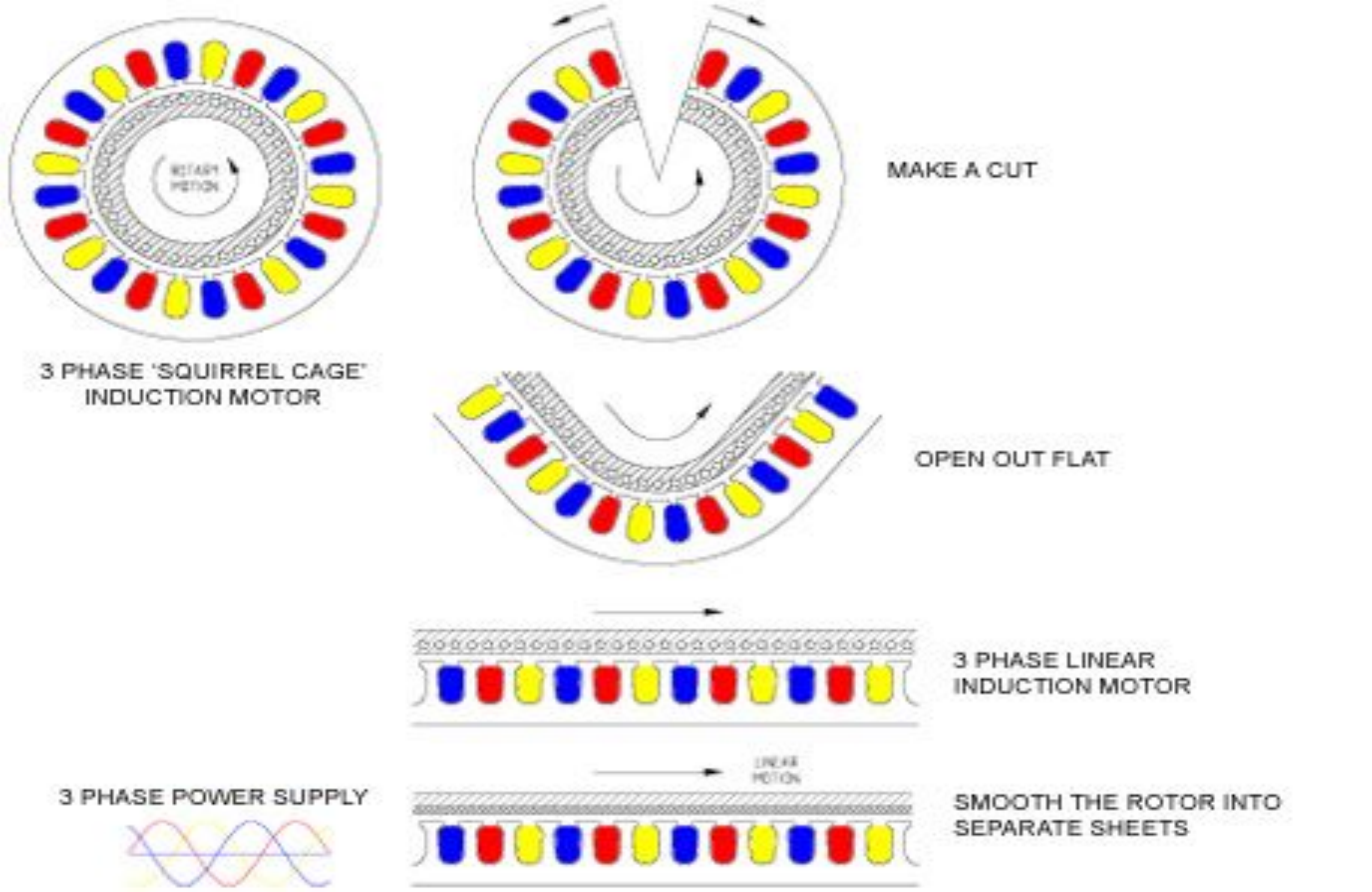
Linear induction motors are quite an engineering marvel, to convert a general motor for a special purpose with more or less similar working principle, thus enhancing its versatility of operation

The basic design and construction of a linear induction motor is similar to a three phase induction motor,

If we cut the stator of a polyphase induction motor and lay on a flat surface, it forms the primary of the linear induction motor system.

after cutting the rotor of the induction motor and making it flat, we get the secondary of the system.





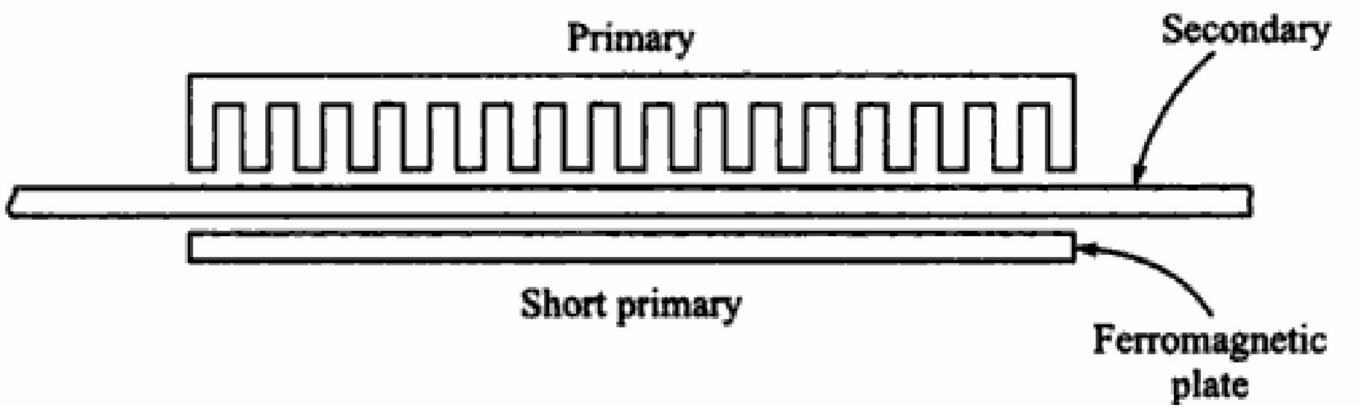
Construction of Linear Induction Motor

construction

- The three phase winding can be obtained by cutting the stator winding perpendicular to the paper and developing it as shown in the figure
- The secondary or rotor of the linear induction motor consists of plate of copper or aluminum
- A linear induction machine in its simplest form consists of a field system having a 3 phase distributed winding placed in slots as shown in the figure
- The field system may be single or double primary system. The secondary of this type of induction machine is normally a conducting plate made of either copper or aluminum in which interaction currents are induced.
- Depending upon the use, the linear induction machine can be one of the following three types

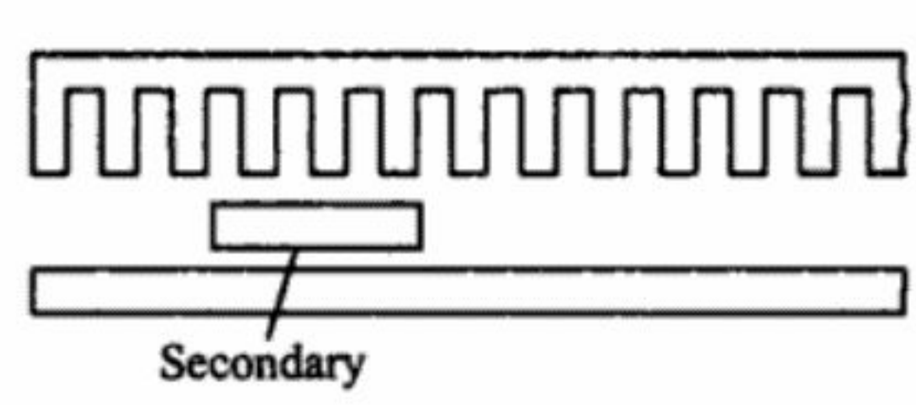
Short Primary-

- The primary is short and the secondary is long as shown in the figure This type is useful
- when the total distance to be travelled is large. In this type over heating of rotor is eliminated
- because of the continuous movement of the primary over cold part of the rotor, leaving behind the heated part. In this case primary moves and the secondary are stationary.



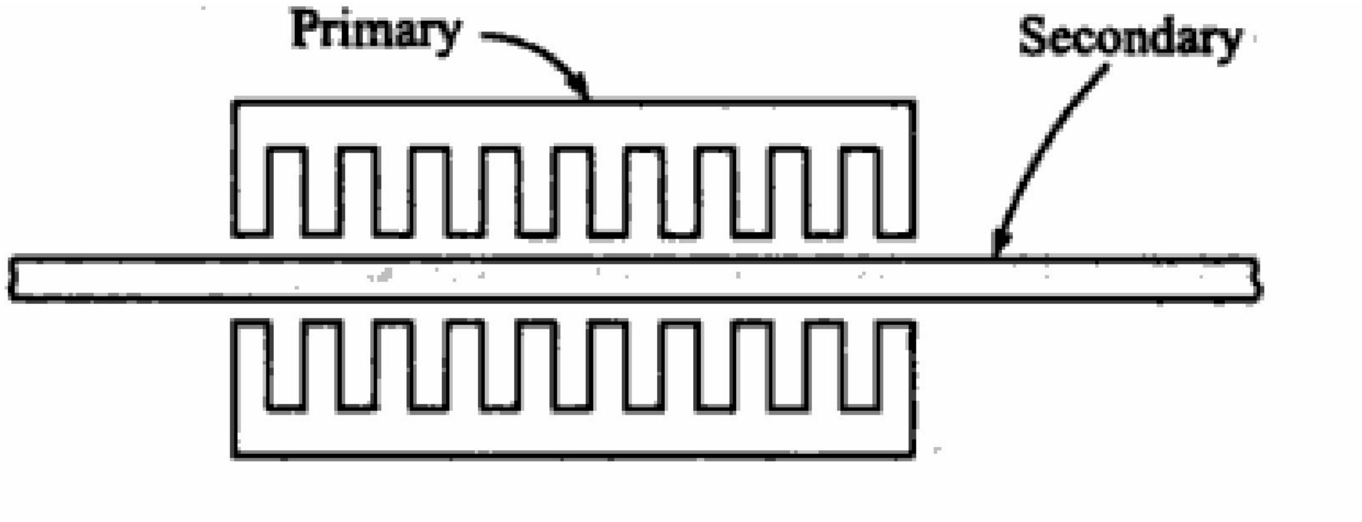
Short Secondary

- The secondary is short in comparison with primary as shown in the figure This type is useful
- when the travel is limited. It must be light. The long primary and short secondary has the following drawbacks:
- • Long primary is uneconomical as it requires a long three phase primary windings to be wound.
- • Only that part of the primary windings which are adjacent the secondary are effective at any one time.



Two Field Systems

- There are two field (Primary) systems, one on either side of the secondary as shown in the figure
- It is often used as it minimizes the leakage flux and avoids magnetic attraction between the
- moving parts and the reaction rail which exists in earlier two types

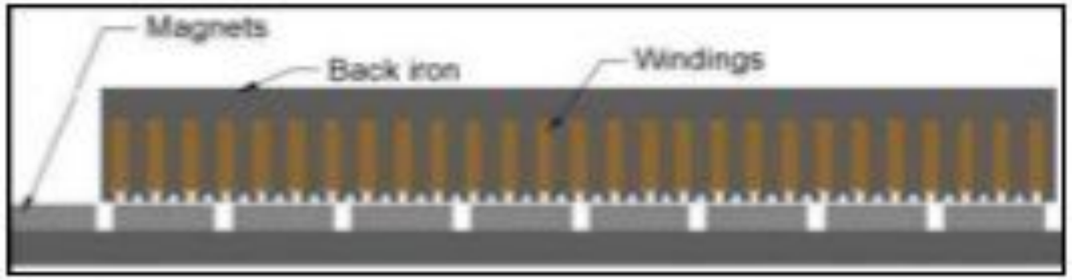


Two field system:

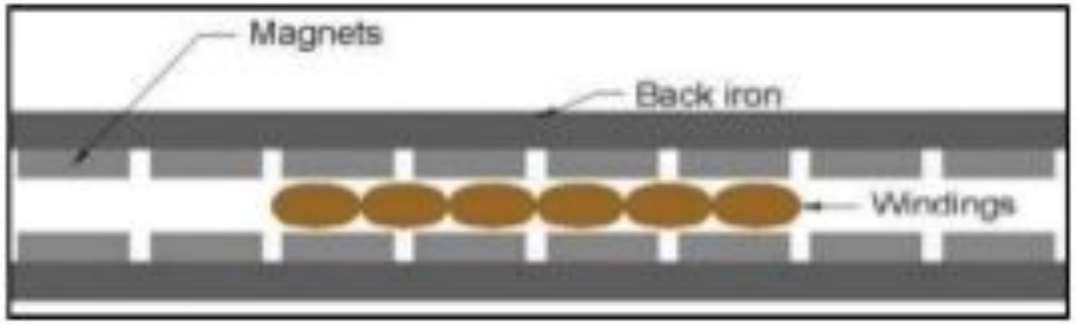
- Depending upon the particular requirements either member can be the stator, the other being the rotor
- The ferromagnetic plate, in a single primary system, is usually placed on the other side of the conducting plate to provide a path of low reluctance to the main flux.
- The ferromagnetic plate however gets attracted towards the primary when the field is energized. Consequently unequal gap length results on the two sides of the plate. Double primary system can be used to overcome this problem.
- The use of the motor decides which of the two primary and secondary will be shorter in length compared to the other. The primary is made shorter than secondary when the operating distance is large (Since winding a very long 3 phase primary is costly proposition) and the short secondary is used when the operating distance is limited.

TYPES OF LIM: ACCORDING TO CORE SHAPE

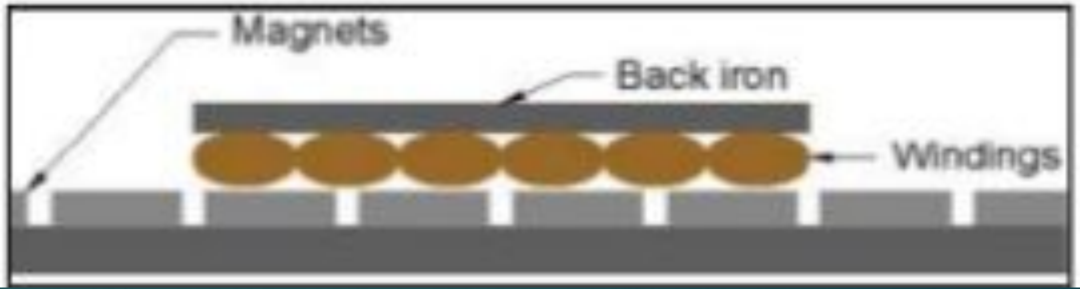
- Iron Core
  – Coils wound around teeth of laminations on forcer(LIM core).



- Ironless Core
  – Dual back iron separated by spacer
  – Coils held together with epoxy(resin for lamination).

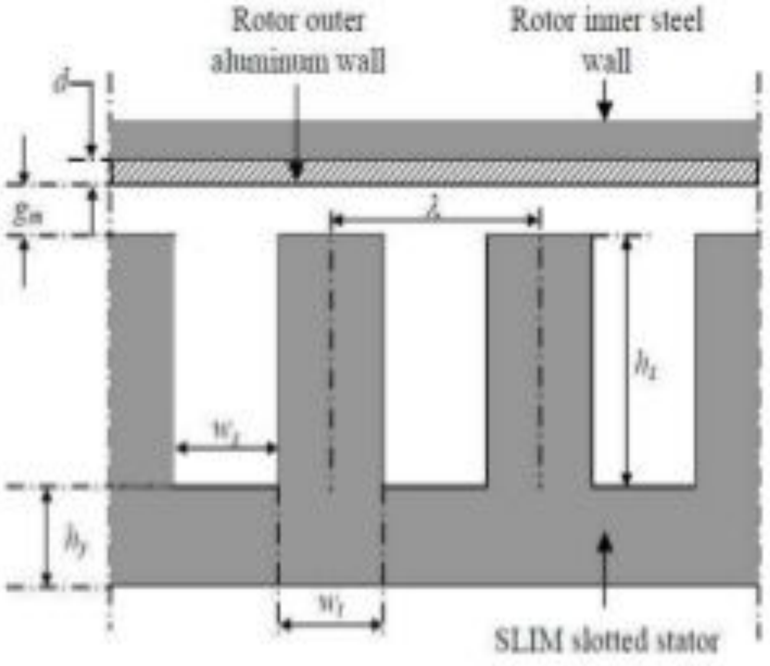


- Slot-less
  – Coil and back iron held together with epoxy.

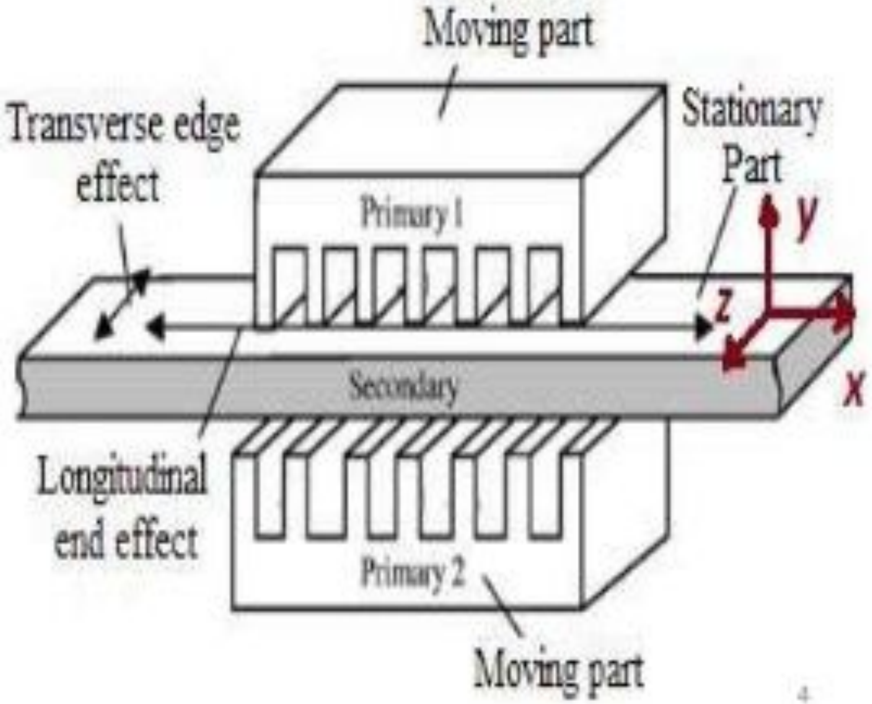


TYPES OF LIM

- SLIM



- DLIM

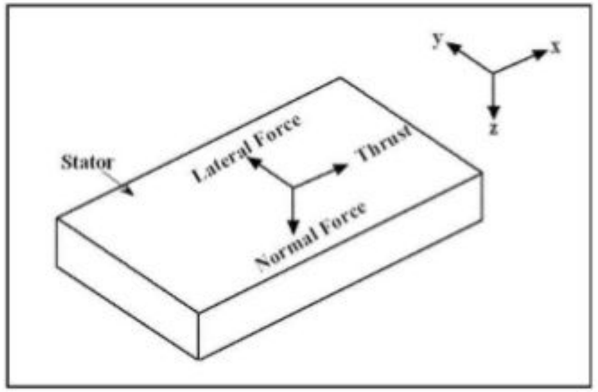


Forces in Linear Induction Motor

- The three main forces that are involved within the LIM
- Although some other forces are also involved in the operation, with less impact direct impact on the operational performance of the LIM

FORCES IN LIM

- NORMAL FORCE
- LATERAL FORCE
- THRUST FORCE



Normal Forces:

- the forces perpendicular to the thrust are normal forces.
- Explicitly, LIM experiences two types of normal forces, an attractive and a repulsive force.
- In the case of single sided linear induction motor (SLIM), the attraction force appears between the primary core and the back iron of the secondary increases the apparent weight of the “vehicle” eventually stressing the secondary mounting frame
- In double sided linear induction motor (DLIM), this force occurs between the two primaries independent of the position of reaction plate, producing stresses in the frame design.
- Two magnetized Iron surfaces experience this force. Repulsive force
- in SLIM appears between the currents in the primary and induced currents in the reaction plate. If the back iron of SLIM is not laminated then also repulsion force appears because of the induced currents in the back iron plate.

NORMAL FORCE DISTRIBUTION

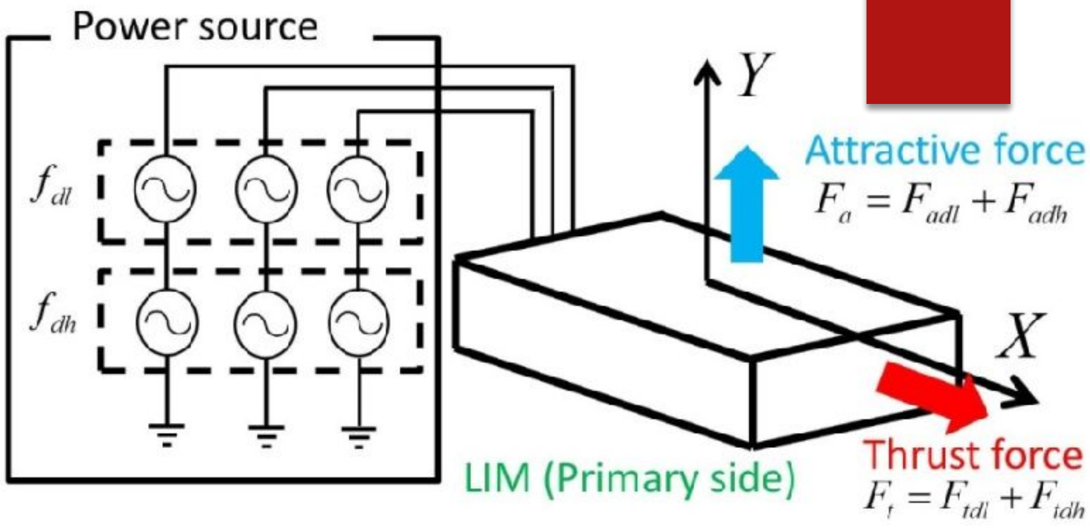
In SLIM configuration, due to the asymmetrical topology, there is a large net normal force between the primary and the secondary. During the synchronous speed of the machine, this force is attractive and its magnitude is reduced as the speed reduced.

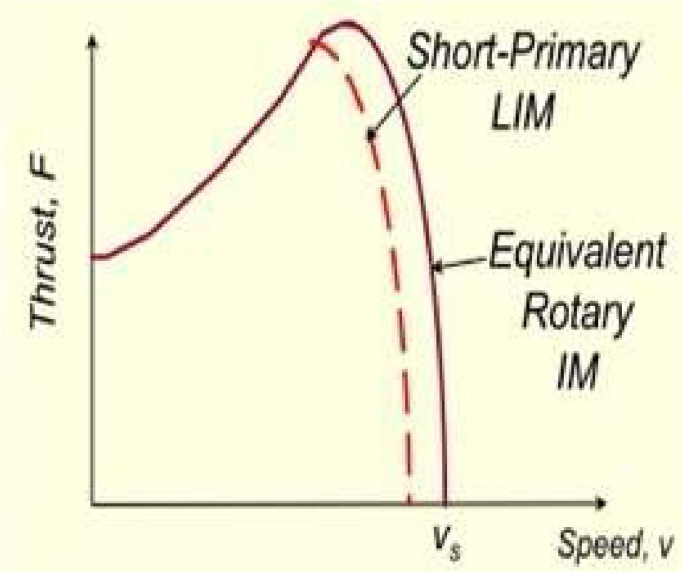
At certain other speeds, the force becomes repulsive, especially at high frequency operations.

In DLIM configuration, the resultant net force is zero at the reaction plate is centrally located between the two primaries. Thus the net normal force will occur only if the reaction plate (RP) is placed asymmetrically between the two primaries.

Thrust

- The LIM develops the thrust force proportional to the square of the applied voltage. This force is responsible for the linear motion of the LIM.
- This force reduces as slip reduced in a LIM. The speed-thrust curve of a LIM is drawn in Figure





Thrust

- Under normal operations, the LIM develops a thrust proportional to the square of the applied voltage, and this reduces as slip is reduced similarly to that of an induction motor with a high rotor resistance.
- the amount of thrust produced by a LIM is as follows:
- $F_s = P_o / V_c$
- where Po is the mechanical power transmitted to the rotor or the output power and Vc is the linear speed of the rotor.

Normal forces

- In a double-sided linear induction machine (DLIM) configuration,the reaction plate is centrally located between the two primary stators. The normal force between one stator and the reaction plate is ideally equal and opposite to that of the second stator and hence the resultant normal force is zero. Therefore, a net normal force will only occur if the reaction plate (secondary) is placed asymmetrically between the two stators. This force tends to center the reaction plate.
- In a SLIM configuration, there is a rather large net normal force between the primary and secondary because of the fundamental asymmetrical topology. At synchronous speed, the force is attractive and its magnitude is reduced as the speed is reduced. At certain speeds the force will become repulsive, especially at high-frequency operation.

Lateral Forces

- Lateral Forces act in the Y-direction, perpendicular to the movement of the stator.
- Due to these forces, the system becomes unstable. Due to the asymmetric positioning of the stator, these forces are developed within the LIM. Small displacement results in avery small lateral force, that can also be negligible.
- In high frequency operations which is more than 50 Hz, these forces become the matter of concern

Cogging Forces

- During the no load condition, when currents are zero, the only force that exists is the force of attraction between the Iron-core of primary and magnets of the mover.
- This force is termed as ‘cogging force’ and occurs in both rotational and linear machines
- Cogging force and end effects can together influence the speed and position control, producing oscillations along the way. Therefore, it is important to reduce such forces which can be done by:
- Skewing of magnets or slots of the primary.
- Semi-closed slots or use of magnetic wedges in slot openings has also been found useful to suppress cogging force

Detent Forces

- The one of the major problem which occurs in linear machines is detent force.
- Which is a result of magnetic attraction between permanent magnets (PM) mounted on the translator and the stator teeth. It is the attractive force component that attempts to maintain the alignment between the stator teeth and the reaction plate with PMs .
- The ripples of the detent force produce both vibrations and noise, which are limiting factors for any machine. The detent force is summation of cogging force and end effect force as given:

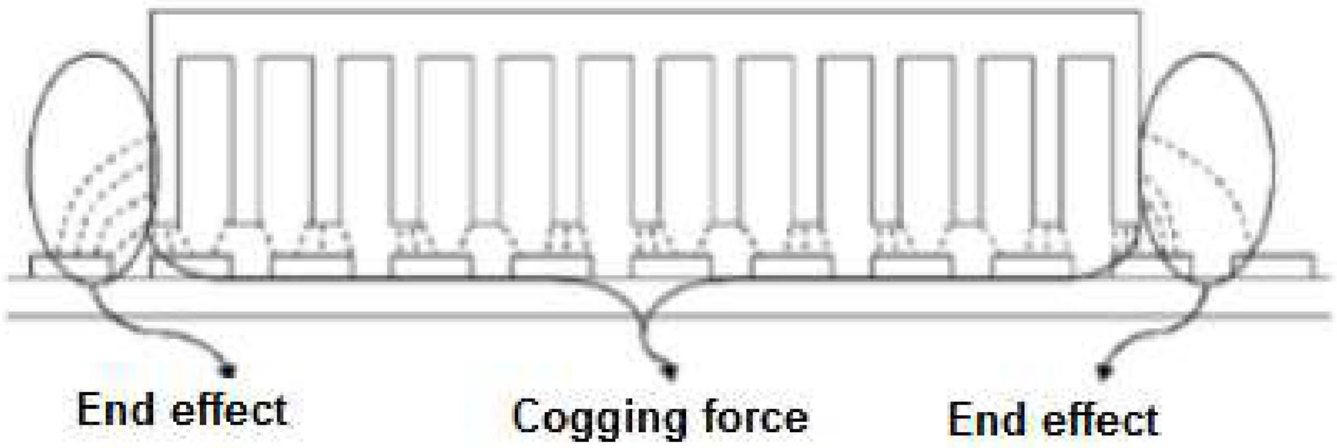
$$F_{\text{Detent}} = F_{\text{Cogging}} + F_{\text{End effect}}$$

Effects in LIM

- End effects are described as one of the biggest negative factors in high-speed LIM efficiency [6]. The fact that the LIM has an entry and an exit end, as opposed to a closed airgap common to a rotary induction motor, is the reason that LIM have this phenomenon. This causes discontinuities in the magnetic field producing part of the LIM or the conducting part of the LIM when using a short primary or short secondary LIM respectively.

Effects of Linear Induction Motor

- **End Effects**
- It is found that primary core and windings of linear induction motor has finite length called as the active length of the motor and due to this, LIM has two ends, the phenomenon so introduced is called as end effect



Static End Effect

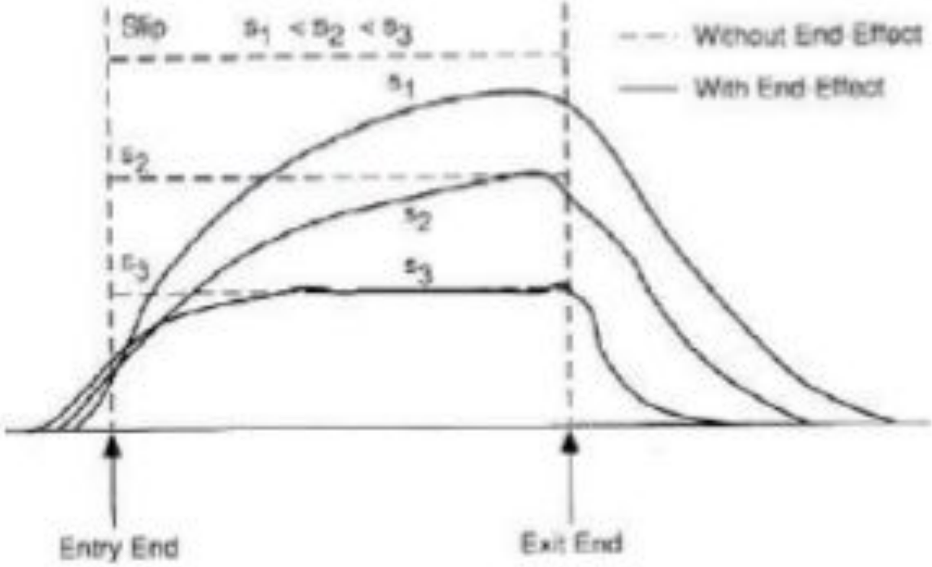
- Because of open ended construction of linear induction motor, it displays a peculiar effect known as end effect.
- This effect can be grouped into static end effect and dynamic end effect.
- In static end effect the mutual inductance of the phase windings are not equal to one another.
- This leads to asymmetric flux distribution in the air gap and gives rise to unequal induced voltages in the phase winding.

Dynamic End Effect:

- The dynamic end effect occurs due to the relative motion between primary and secondary. As the primary moves over the secondary at every instant, a new secondary conductor is coming under the leading edge of the primary, while one old secondary conductor is leaving the trailing edge of the primary.
- The conductor coming under the leading edge opposes the magnetic flux in the air gap, while the conductor leaving the trailing edge tries to maintain the flux. Therefore the flux distribution in the air gap is distorted.
- The flux is weaker in the leading edge region as compared to the trailing edge. It also leads to braking action especially at lower values of slip.

END EFFECT

1. Travelling magnetic field cannot join up on itself, and introduces end effects in LIM.
2. It produce a non-uniform flux density distribution along the length of the motor.
3. By increasing the number of poles, the end effects are reduced



- The end effects in a short secondary DSLIM are quite different from those experienced in a short primary DSLIM.
- in a short primary DSLIM, the field is travelling forward at the same speed as the vehicle, which in some high-speed transit applications is on the order of 200 miles per hour. At these high speeds, the magnetic field at the entry end of the primary shuttle is seriously degraded, and this degradation propagates backward into the primary shuttle as speed increases.
- If the primary is not long enough, the end effect can propagate through the entire primary shuttle, reducing the capacity for the vehicle to produce effective thrust.

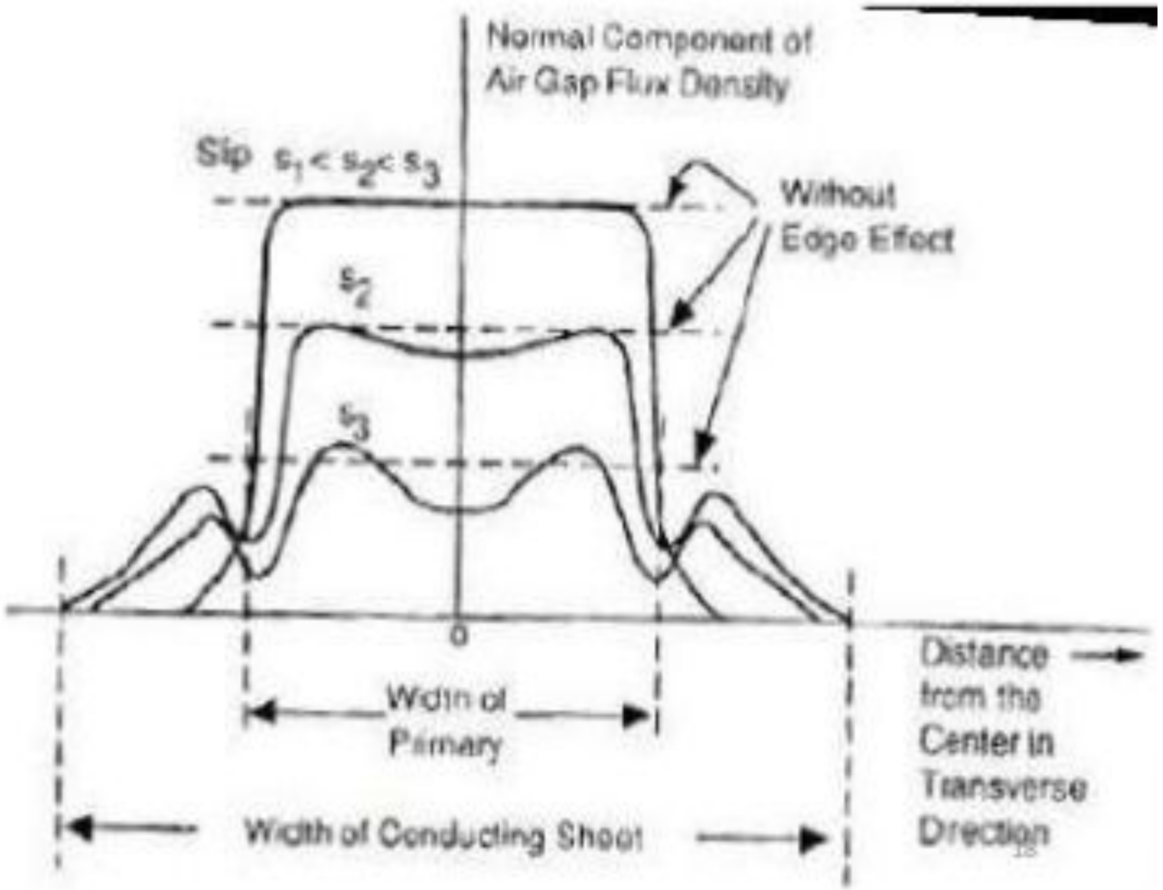
- In a short secondary DSLIM, the shuttle is now merely a conducting sheet of Aluminum or Copper, and the stationary primary produces a magnetic field that sweeps forward over the shuttle at a speed that is the difference between the speed of the applied field and the speed of the shuttle. This speed difference is known as the slip speed.
- Since it is desirable to operate any induction motor at low slip, it can be assumed that the slip speed of the short secondary DSLIM will be small compared to the actual shuttle speed at any point in time.
- Thus the short secondary DSLIM will have an end effect, but With proper selection of the secondary and proper attention to the slip that the machine is operating at, the end effect will have a much smaller effect than that in the short primary DSLIM.

Transverse Edge (Finite Width) Effects

- The primary and secondary of a LIM have finite lengths. In general, the secondary is wider than the primary. The consequences of this physical feature of a LIM are called transverse edge effects.
- These currents have a longitudinal component jx and a transverse component jz. The component jz is the source for these effects.
- The LIM having equal secondary and primary widths will show more transverse edge effects than having wide secondary.

EDGE EFFECT

1. The figure shows a dip at the centre due to the edge effect, and the dip is more obvious at higher slips.
2. The edge effect will increase the secondary resistivity.



- Transverse edge effects are the result of eddy currents produced as a consequence of the applied magnetic field .These eddy currents are a natural result of the application of the time-varying magnetic field across the secondary, which in turn generates a magnetic field to satisfy Faraday's Law.
- The components of the induced currents that flow in the x-direction serve to increase the effective resistance of the secondary. An increase in the effective resistance of the secondary in turn increases the magnetic time constant, which exacerbates end effects, as well as increases resistive heating losses.

- In summary, the main consequences of transverse edge effects appear in the forms of:
- an increase in secondary resistivity
- a tendency toward lateral instability
- a distortion of air gap fields, and
- a deterioration of the LIM performance, due to the first three factors.

Effects

- Saturation Effect In the linear induction motor, back iron material is made of Steel or Iron. So, at certain transient conditions saturation appears which has to be pre-determined for performance evaluation. The saturation level is governed by the depth of field penetration in Iron. This can be determined and controlled with help of saturation coefficient, which is the ratio of back iron reluctance to the sum of the conductor and the airgap reluctances
- Dolphin Effect An asymmetric airgap magnetic flux density at the end parts of a linear motor produces an unbalanced normal force, due to which, the airgap tends to increase at the entry and decrease at the exit part. This is called the “Dolphin Effect.”

- the force of attraction and the force of repulsion are not uniformly distributed, therefore primary experiences a drag 18 in addition to normal forces called Dolphin Effect, due to which the entry end airgap becomes non-uniform at the ends of LIM, which is found very prominent in high speed double sided linear induction motor (DLIM)

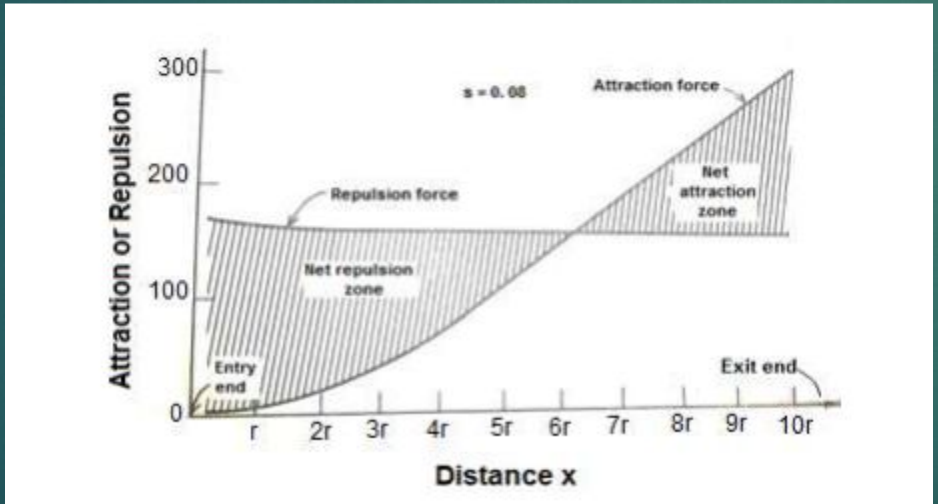


Figure 1.13 Forces graph of LIM [9]

Goodness Factor

- The concept of the realistic goodness factor is important for the study of LIM.
- It is a convenient measure for assessing the quality of LIM.
- This factor takes into account the airgap leakage, the reaction plate skin effect, and transverse edge effects.
- It is shown that the end effect can be expressed as a function of this factor, the slip and the number of poles. The Goodness factor is a useful index in the preliminary design of linear induction motors [9].
- Mathematically, it can be written as:

$$G = \omega\sigma\mu/g\beta^2$$

- Where, = El ular velocity, σ = Electrical conductivity of mover = Magnetic permeability, g = Length of airgap = Face constant rad. / mt.

Working Principle of Linear Induction Motor

- When the primary of a LIM gets excited by a balanced three-phase power supply
- flux starts traveling along the entire length of the primary
- This linearly traveling magnetic field is equivalent to the rotating magnetic field in the stator of a three phase induction motor
- Electric current gets induced in the conductors of the secondary due to the relative motion between the traveling flux and the conductors.
- Then the induced current interacts with the traveling flux wave to produce linear force or thrust.

PRINCIPAL OF WORKING

- “Whenever a relative motion occurs between the field and short circuited conductors currents are induced in them which results in electro-magnetic forces   under the influence of these forces, according to Lenz’s law the conductors try to move in such a way as to eliminate the induced currents
- When a three phase primary winding of the motor is energized from a balanced three phase source, a magnetic field moving in a straight line from one end to other at a linear synchronous speed Vs is produced. The linear synchronous speed Vs is given as

$$Vs=2f\tau$$

DERIVATION OF POWER IN LIM

- Where f is the supply frequency and τ is the pole pitch in meters. The interaction of magnetic fields with the current induced in the secondary exerts a thrust on the secondary to move in the same direction if the primary is held stationary. Alternatively if the secondary is stationary and the primary is free to move, the primary moves in the direction opposite to that of the magnetic field. The relative speed of the stator and rotor is

$$Vr=Vs(1-s)$$

- Where s is the slip and the relative speed between the moving field and the secondary is sVs. The slip is therefore given by
  - S=(Vs-Vr)/vs

- The linear force is given by the equation shown below.

$$F = \frac{\text{air gap power}}{\text{linear synchronous velocity } (v_s)}$$

The air gap power Pg is given by

$$Pg = 3I_2^2(\frac{r_2}{s})$$

And developed power Pr is given by

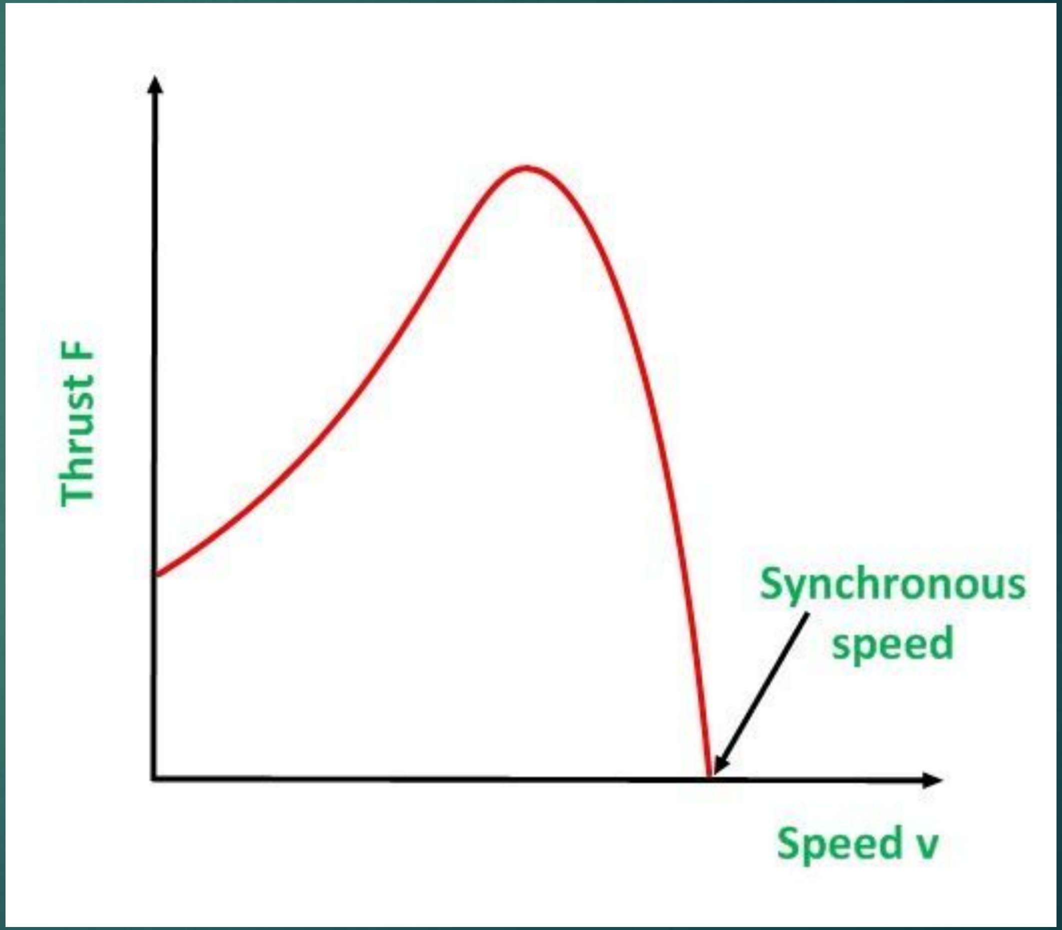
$$Pr = (1 - s)Pg$$

The developed thrust Fm is therefore given by

$$Fm = \frac{Pg}{Vs} = 3I_2^2(\frac{r_2}{sVs})$$

Speed Thirst characteristics

- The speed thrust characteristics of a linear induction motor is shown in the figure ,It is similar to the speed torque characteristics of a three phase conventional induction motor.
- The speed of the linear induction motor decreases rapidly with the increasing thrust.
- For this reason the linear induction motor often operate at low slip, resulting a relatively low efficiency.



The air gap for a typical LIM machine is 2mm, variations up to ±20% are considered acceptable. The effect of the air gap on thrust and current line is shown in (Figure 4.5).

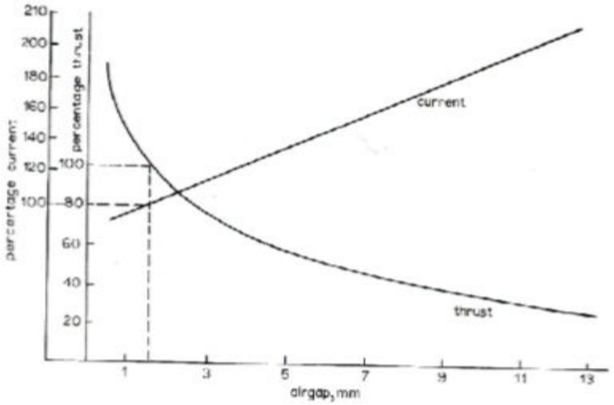


Figure 4.6 Air gap on thrust and current characteristics

The amount of thrust produced by a LIM is as follows

$$F = \frac{P_r}{V_s} \tag{4.3}$$

Where

F=thrust [N],

P_r=power transmitted to the rotor [W],

V_s=linear synchronous speed [m/s]

The equivalent circuit of the LIM shown in figure 3.2.5 is exactly the same as of a conventional 3-phase rotary machine. The power output is as follows:

$$\text{Power output} = 3(I'_1)^2 \frac{R'_r}{s}(1-s) \quad \text{Watt} \tag{4.4}$$

The main forces involved with the LIM are thrust, normal and lateral (Figure 4.4). Thrust is what this thesis is interested in, and its relationship with the other adjustable parameters. The normal force is perpendicular to the stator in the z-direction. Lateral forces are side forces that are undesirable, due to orientation of the stator.

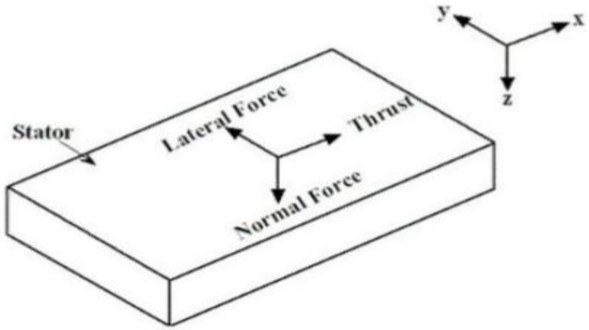


Figure 4.4 Forces

4.3.1 Thrust:-

Under normal operations, the LIM develops a thrust proportional to the square of the applied voltage (Figure 4.4), and this reduces as the slip is reduced similarly to that of an induction motor with a high rotor resistance [3].

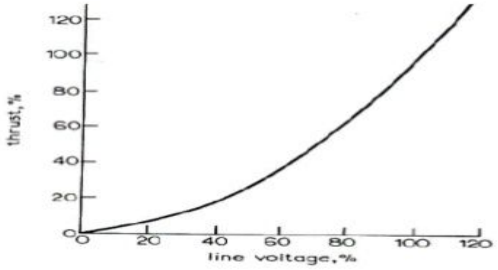
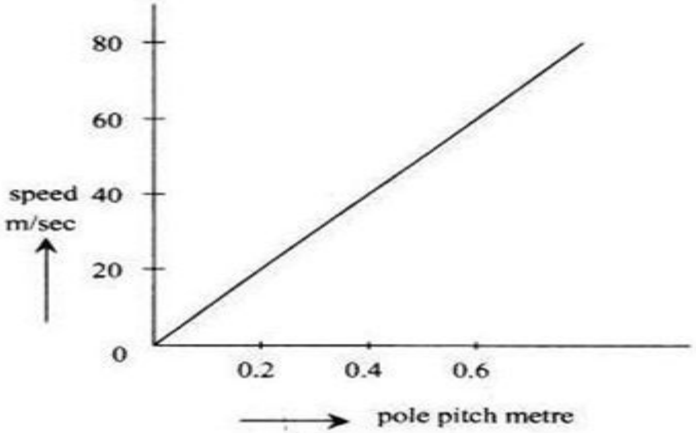
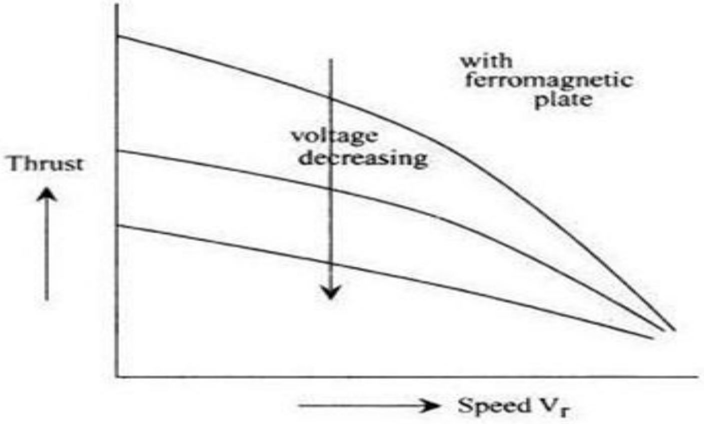


Figure 4.5 Thrust line voltage characteristics

Linear Induction Motor - Characteristics

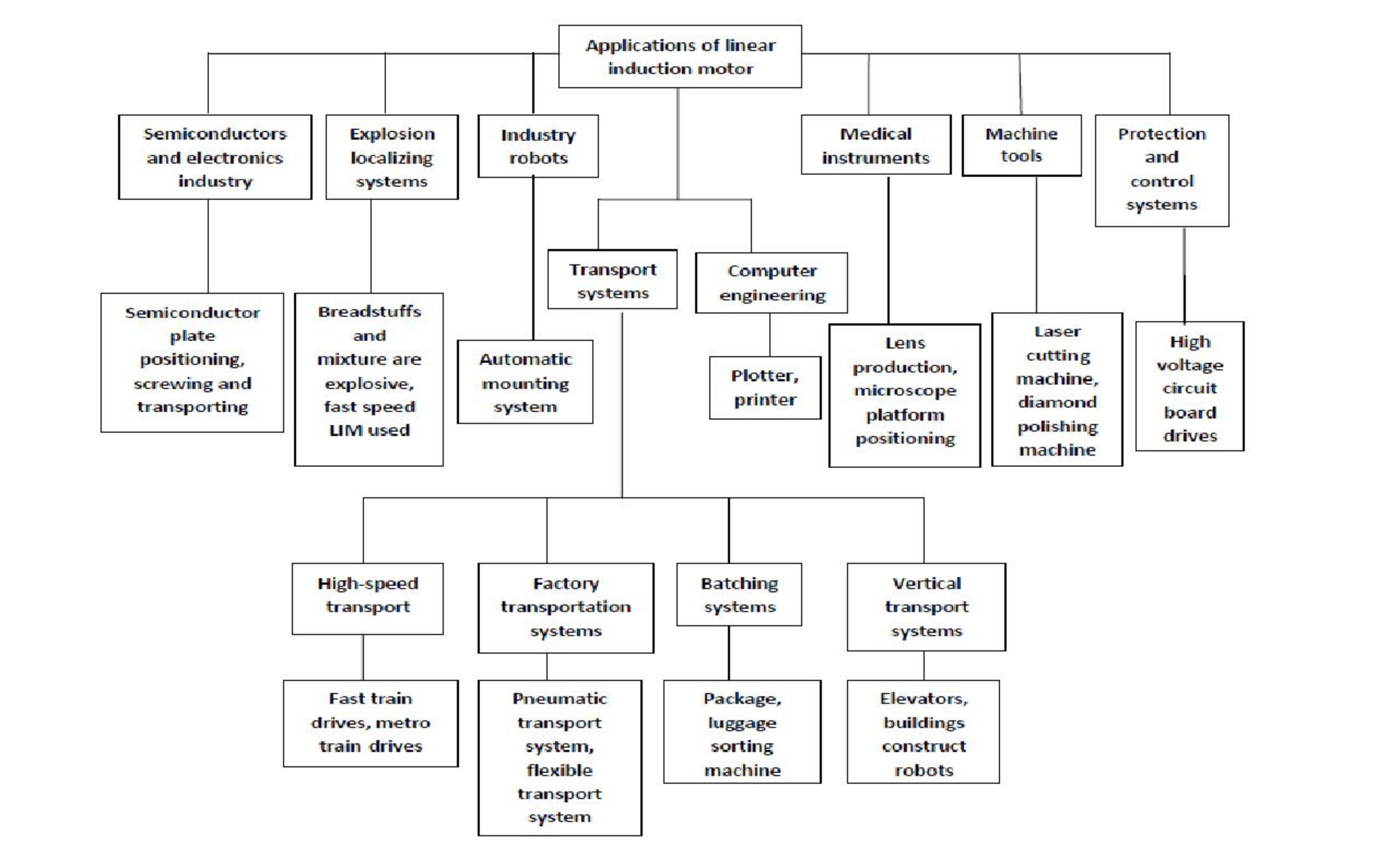


(a) Speed Vs Pole pitch characterestic



(b) effect of supply voltage variation

APPLICATION OF LIM



Merits

- Direct electromagnetic thrust propulsion without mechanical transmission or wheel adhesion limitation for propulsion
- Ruggedness; very low maintenance costs
- Easy topological adaptation to direct linear motion applications
- Precision linear positioning as no backlash with any mechanical transmission
- Separate cooling of primary and secondary
- All advanced drive technologies for RIMs may be applied without changes to LIMs

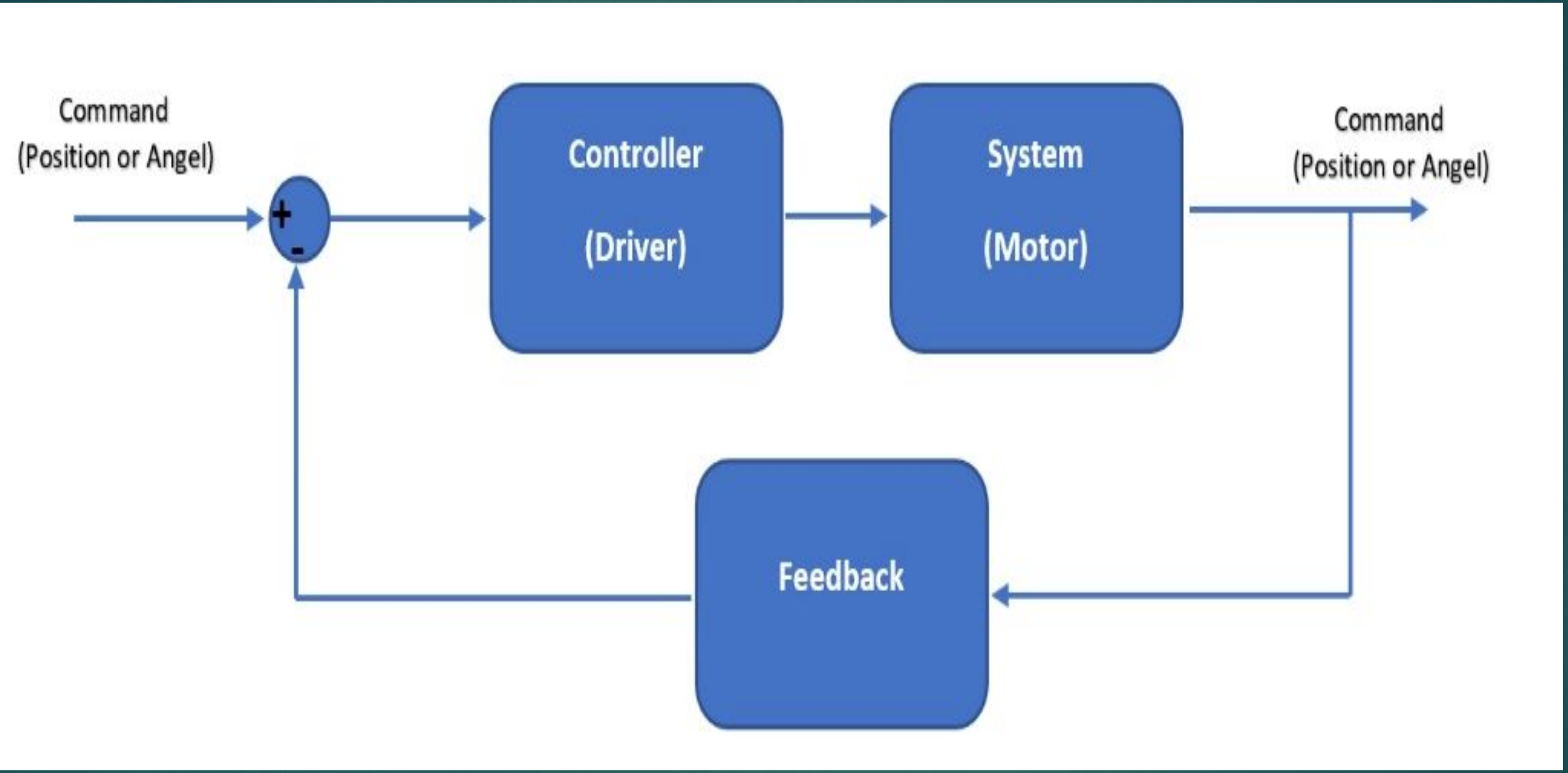
Demerits

- Due to the large airgap to pole pitch ratios the power factor and efficiency tend to be lower than with RIM. However, the efficiency is to be compared with the combined efficiency of rotary motor and mechanical transmission counterpart. Larger mechanical clearance is required for medium and high speeds. The Aluminium sheet (if any) in the secondary contributes an additional magnetic airgap.
- Efficiency and power factor are further reduced by longitudinal end effects. Fortunately, these effects are notable only in high speed, low pole count LIMs and they may be somewhat limited by pertinent design measures.

- https://youtu.be/Yvfz51moMaQ
- https://youtu.be/0_QBl6-_jJU
- https://youtu.be/IGX6_B_AbmQ
- Working of LIM
- https://youtu.be/WvSKbjsPRIg
- By professor in1971
- https://youtu.be/oWiYsRi2Dss
- https://youtu.be/uf_Z57gAJTc

Servo Motor

- Servo motor is part of a motion control system that produces motion in response to a command.
- To do the job, there should be a closed loop control system.
- This simple closed loop control system consists of
- an actuator which here is an electric motor,
- a sensor to measure controlling parameters,
- and a controller to generate suitable commands to achieve the desired output.
- So in order to understand servos better, let’s take a look at a simple diagram of a closed loop control system.


Command
(Position or Angel)
+
-
Controller
(Driver)
System
(Motor)
Command
(Position or Angel)
Feedback

Servo mechanism :

- A negative feedback closed loop control system receives an input signal as the command.
- If the actual value of the system output differs from the value declared by the command, it means the system has an error.
- This command in a servo mechanism can be a specific angle that must be obtained.
- The amount of the error is calculated and then fed to the controller which is often a sophisticated PID.
- Then the system starts reacting to the command which is generated by the PID.
- Here we can say the motor's shaft starts rotating.
- Meanwhile, The output of the system is measured and the change in motor shaft angle is continuously measured by a sensor.

Sensor (Encoder)

- Encoder : (Sensor) Every closed-loop feedback system needs a sensor in order to measure the controlling parameter.
- In a servo system, the output is the position or speed of the servo’s shaft.
- The Encoder measures the angular change and sends it back to the driver and controller.
- So the system controller can monitor the output status and issue the corresponding command based on that.
- Some of the servo motors available in the market are mostly self-contained which has an integrated circuitry to receive commands and also an integrated feedback system that is used to determine the angular position of its shaft.
- For example, SG90 is a micro servo that contains a driver motor and encoder.
- Two main types of servo motors which are AC servo motor and DC servo motor.

Types of Servo Motors

- DC SERVO MOTOR
- This servo type uses a dc motor as their moving part.
- One of the most important advantages of DC motors compared to other types of motor is their motion control simplicity.
- DC motors are mostly of permanent magnet type which is cheap and easy to use.
- There are two major types of DC motors which are called
- Brushed and Brushless DC motors.

- Brushed DC Motors

- Brushless DC Motors
- Brushless dc motor is the other type of dc motor and as its name implies, it has no brushes. In this type, the commutation is done by electronic circuitry. This circuit consists mainly of transistors, Mosfets, IGBTs, … as switches, and a hall effect sensor. So, unlike the brushed type, this one can't be connected directly to a dc power supply and needs a driver.
- The stator is made of the permanent magnet material. The rotor magnetic field is made by powering the stator coils through the driver. These two magnetic fields create the torque needed to rotate the rotor.
- Brushless dc motors (BLDCs) are more expensive, but more reliable and less noisy compared to brushed dc motors and are preferred where more reliability and less maintenance is desired.
- .

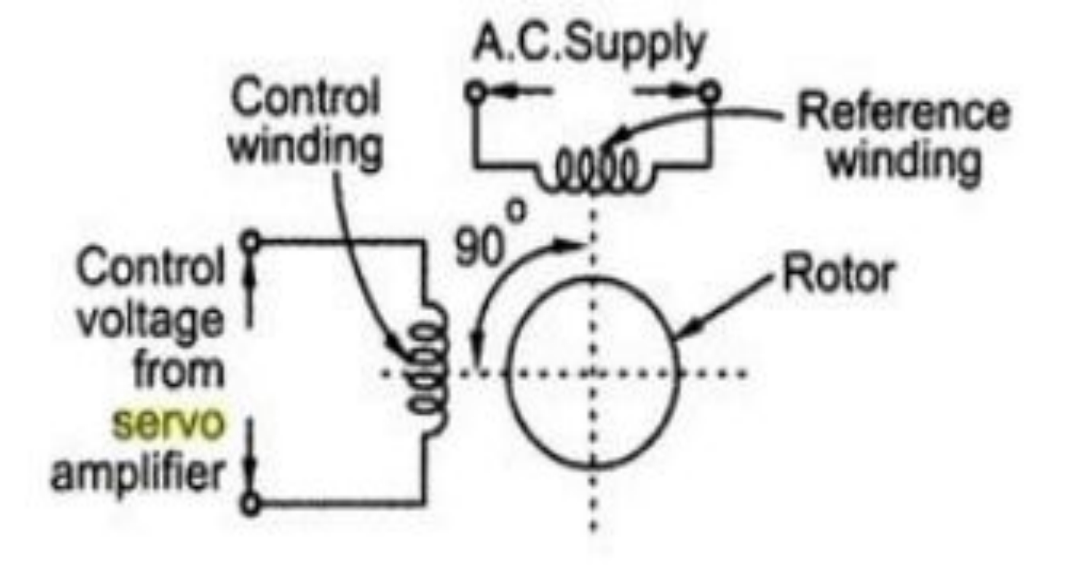
- AC SERVO MOTOR
- AC motors are another type of electromotors. This type of motor is powered by either a single or three phase ac current. AC servo motors have two types which are called asynchronous ac motors and synchronous ac motors. This type of electric motor is more reliable and more rigid than dc motors and are available in higher powers. The rotation speed of ac motors is determined by the input frequency.

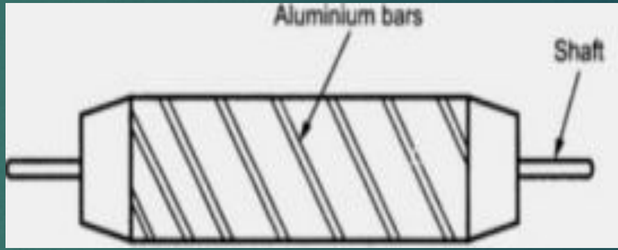
	DC		AC	
Aspect	BH	BL	ASYNC	SYNC
Technology	Old	New	Medium	Medium
Durability	Low	High	High	High
Shaft control	Easier	Easier	Harder	Harder
Power range	Low	Low	High	Medium
Maintenance	High	Low	Very Low	Low
Noise	High	Low	Low	Low
Cost	$$	$$$	$$	$$$

Types of Servo motor

- A DC motor with servomechanism is referred as DC servo motor.
- A AC motor with servomechanism is referred as AC servo motor.
- AC servo-motors are generally preferred for low power use.
- •For high-power use DC servomotors are preferred because they operate more efficiently in high-power than AC servo-motors.
- There are various types of DC servomotors which are
- Armature and field controlled DC Servomotor Series motors;
- Split series motors;
- Shunt control motor;
- Permanent magnet shunt motor

- AC Servomotor
- • Basically two phase induction motor
- • Output power – fraction of watts to few hundred of watts
- • Operating frequency is 50 Hz to 400 Hz
- AC servomotor – Stator & Rotor
- • Stator – 2 windings; displaced by 900
- • Main/fixed/reference winding – constant voltage supply
- • Control winding – variable voltage from servo amplifier –
- 900 out of phase with main winding voltage –
- rotating magnetic field •
- Reduce loading on amplifier –
- control winding input impedance is increased – tuning capacitor in parallel to control winding
- • Rotor • Squirrel cage rotor

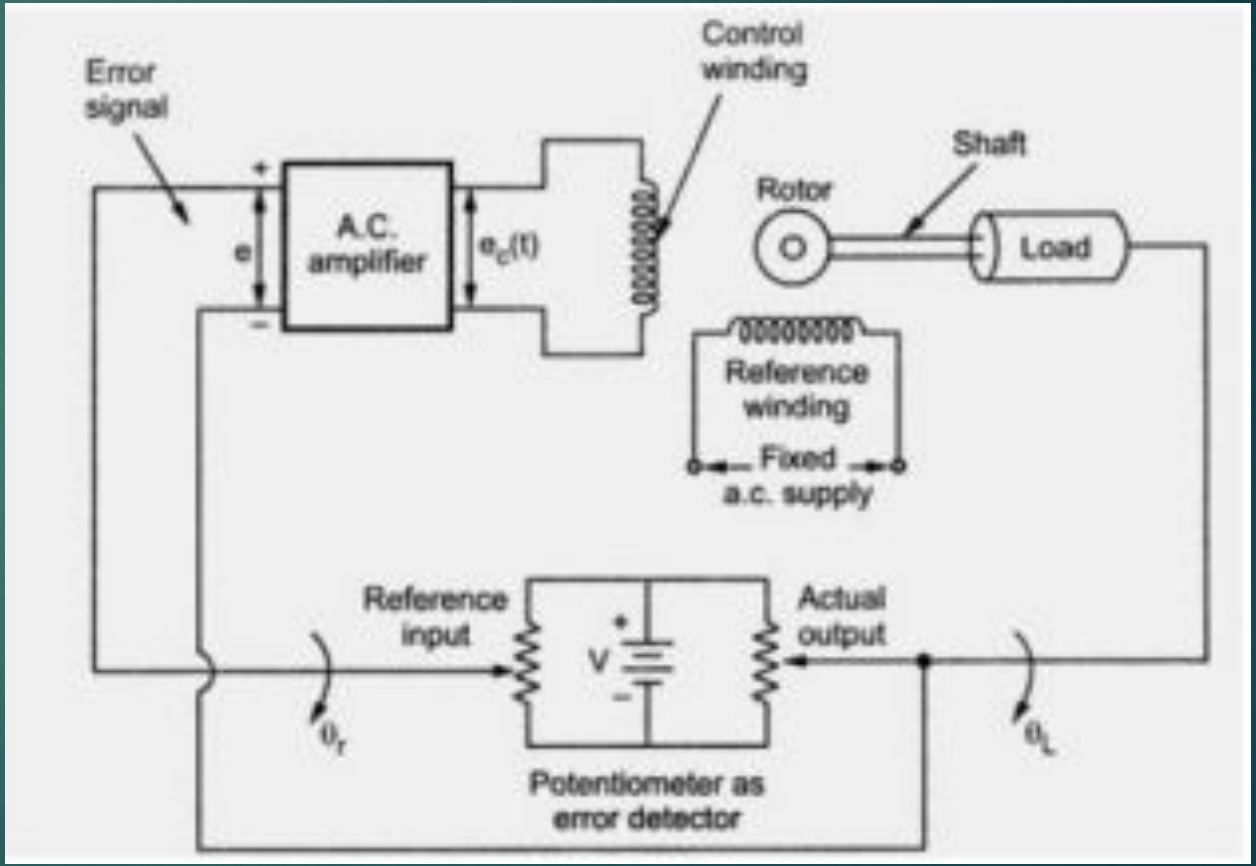

A.C.Supply
Control winding
Reference winding
90°
Control voltage from servo amplifier
Rotor


Aluminium bars
Shaft

- Features (Adv.) of A.C. Servomotor
- ▪ Light in weight for quick response.
- ▪ Robust in construction.
- ▪ It is reliable and its operation is stable in nature.
- Smooth and noise free operation.
- ▪ Large torque to weight ratio.
- ▪ Large resistance to reactance ratio.
- ▪ No brushes or slip rings are required. Hence maintenance free.
- ▪ Driving circuits are simple to design.
- ▪ The negative slope of the torque-slip characteristics adds more friction improving the damping. This improves the stability of the motor. This features is called internal electric damping of two phase AC servomotor.

AC Servomotor Application

- The other applications of a.c. servomotors.
- ▪ Instrument servos
- ▪ Process controllers ▪
- Robotics
- ▪ Self-balancing recorders
- ▪ Machine tools



Comparison between AC servomotor and DC servomotor

A.C Servomotor	D.C. Servomotor
1) Low power output of about 0.5 W to 100 W.	1) Deliver high power output
2) Efficiency is less about 5 to 20 %.	2) High Efficiency.
3) Due to absence of commutator maintenance is less.	3) Frequent maintenance required due to commutator.
4) Stability problems are less.	4) More problems of stability.
5) No radio frequency noise.	5) Brushes produce radio frequency noise.
6) Relatively stable and smooth operation.	6) Noisy operation.
7) A.C. amplifier used have no drift.	7) Amplifiers used have a drift.

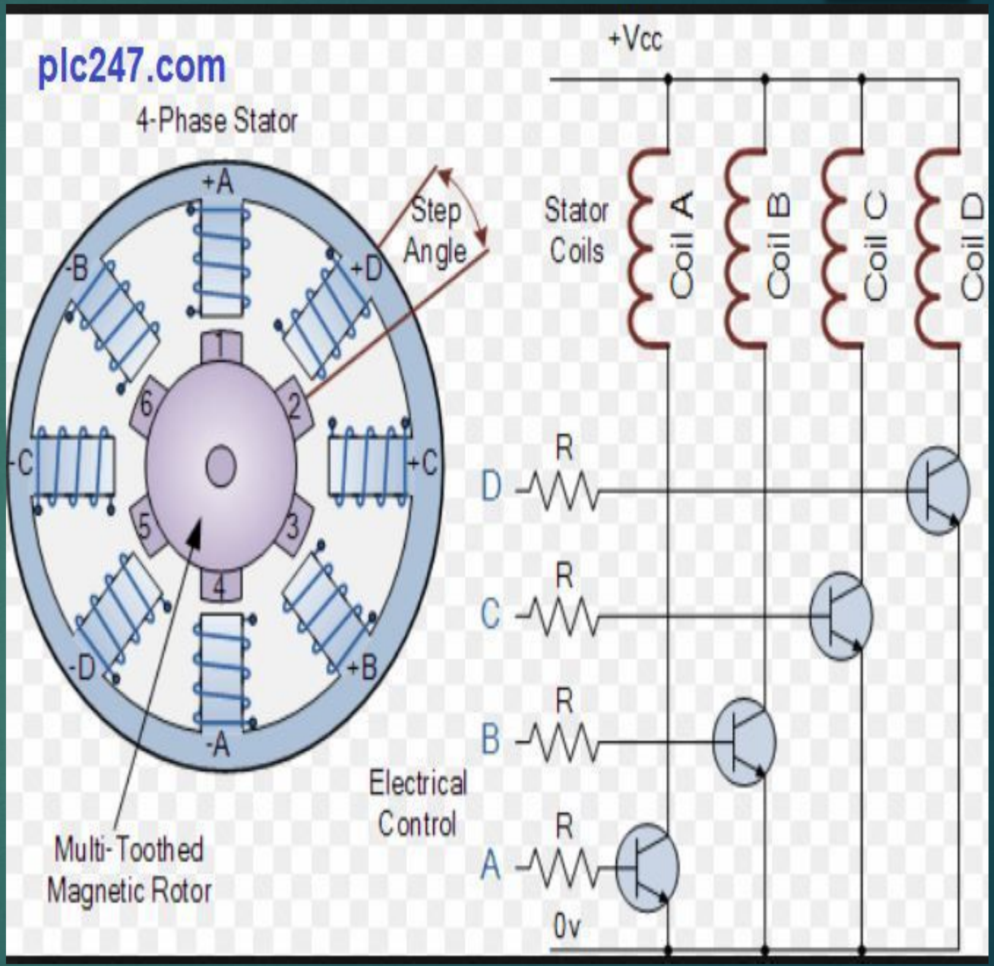
STEPPER MOTORS

- • A stepper motor is a "pulse-driven" motor that changes the angular position of the rotor in "steps"
- A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements.
- The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence.
- The motors rotation has several direct relationships to these applied input pulses.

The stepper motor uses the theory of operation for magnets to make the motor shaft turn a precise distance when a pulse of electricity is provided.

The stator has eight poles, and the rotor has six poles. The rotor will require 24 pulses of electricity to move the 24 steps to make one complete revolution.

Another way to say this is that the rotor will move precisely 15° for each pulse of electricity that the motor receives.



- The stepper motor is a digital actuator whose input is in the form of digital signals and whose output is in the form of discrete angular rotation.
- The angular rotation is dependent on the number of input pulses the motor is suitable for controlling the position by controlling the number of input pulses.
- Thus they are identically suited for open position and speed control.
- Types of Stepper Motor :
  - Permanent Magnet Stepper motor
  - Variable reluctance stepper motor
  - Hybrid stepper motor

Operation of Stepper Motor

- Stepper motors operate differently from DC brush motors.
- It rotate when voltage is applied to their terminals.
- Stepper motors effectively have multiple toothed electromagnets arranged around a central gear-shaped piece of iron.
- The electromagnets are energized by an external control circuit.
- To make the motor shaft turn, first one electromagnet is given power
- It makes the gear's teeth magnetically attracted to the electromagnet's teeth.
- The point when the gear's teeth are thus aligned to the first electromagnet, they are slightly offset from the next electromagnet.
- When the next electromagnet is turned ON and the first is turned OFF.
- The gear rotates slightly to align with the next one and from there the process is repeated.

- Each of those slight rotations is called a step, with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise. Stepper motor doesn’t rotate continuously, they rotate in steps. There are 4 coils with 90o angle between each other fixed on the stator. The stepper motor connections are determined by the way the coils are interconnected.
- https://youtu.be/eyqwLiowZiU