4.5 BRAKING

Braking is very frequent in electric drives to stop a motor in a reasonably short time. For example, a plannar must quickly be stopped at the end of its stroke and sometimes must quickly be stopped at the end of its stroke and sometimes it is necessary to stop the motor in order to prevent accident. The essential of a good braking system should be

1) Reliable and quick in its action.

2) The braking force must be capable of being controlled.

3) Adequate means be provided for dissipating the stored energy that is kinetic energy
of the rotating parts.

1) In case of a fault in any part of the braking system the whole system must come to instantaneous rest or result in the application of the brakes.

There are two types of braking:

1) Mechanical braking:

The motor in this case is stopped due to friction between the moving part of the motor and the brake shoe that is stored energy is dissipated as heat by a brake shoe or brake lining which rubs against a brake shoe or brake lining which rubs against a brake drum.

2) Electric braking:

In this method of braking, the kinetic energy of the moving parts that is motor is converted into electrical energy which is consumed in a resistance as heat or alternatively it is returned to the supply source. During braking operation, a motor has to function as a generator. The motor can be held at stand still. In other words, the electric braking cannot hold the motor at rest. Thus, it becomes essential to provide mechanical brakes in addition to electric braking. Various types of electrical braking are:

a) Plugging

b) Rheostatic braking

c) Regenerative braking

PLUGGING

This is a simple method of electric braking and consists in reversing the connections of the armature of the motor so as to reverse its direction of rotation which will oppose the original direction of rotation of the motor and will bring it to zero speed when mechanical brakes can be applied. At the end of the braking period the supply to the motor is automatically cut off. This method of braking can be applied to the following motors.

1) DC motors

2) Induction motors

3) Synchronous motors

PLUGGING APPLIED TO DC MOTORS

To reverse a DC motors, it is necessary to reverse the connections of the armature while the connections of the field are kept the same. The direction of mmf remains the same even during braking periods.

Plugging applied to Series motors:

Total voltage of V+ Eb is available across the armature terminals which causes a current I to flow around the circuit. When Eb = V then the voltage across the armature is 2V and at the time of braking twice the normal voltage is applied to the resistance in series with the armature at this time in order to limit the current. While the motor is being braked, the current is still being drawn from the supply. This method requires energy from the supply for its action and not only the kinetic the motor is being wasted, but this energy is also being dissipated.

Speed and braking torque

Electric braking to torque

$$T_B \propto \Phi I$$

$$T_B = K\Phi I$$

where K is a constant

$$I = \frac{V + E_b}{R}$$

$$E_b = K_1 N\Phi$$

where, N is the speed; K_1 is a constant

$$I = \frac{V + K_1 N\Phi}{R}$$

$$T_B = K\Phi\left(\frac{V + K_1 N\Phi}{R}\right) = \left(\frac{K\Phi V}{R}\right) + \left(K\Phi\frac{K_1 N\Phi}{R}\right) = K_2\Phi + K_3\Phi^2 N$$

$$K_2 = \frac{KV}{R}$$

$$K_3 = \frac{KK_1}{R}$$

Apply the results obtained to the series motor, where, Φ α armature current (I_a)

Then Electric braking in series motor = $K_4 I_a + K_5 I_a^2$

In the case of shunt motor since flux is constant.

Electric braking torque:

Wherever there is a load on the machine the load will also exert braking torque due to it and then the total braking torque (T)

T = Electric braking torque + Load torque

PLUGGING APPLIED TO INDUCTION MOTORS

In the case of induction motor its speed can be reversed by inter changing any of the two stator phases which reverses the direction of rotation of motor field. Actually, at the time of braking when the induction motor is running at near synchronous speed. The point Q represents the torque at the instant of plugging one can notice that the torque increases gradually as one approaches the stand still speed. Different values of rotor resistance give rise to different shapes of speed torque curve in order to give any desired braking effect. The rotor current I_2 can be calculated during the braking period from the following relation.

$I_2 = sE_2/ \sqrt{[R_e^2 + (sX_2)^2]}$

where E_2 is the e.m.f. induced in rotor at standstill, R2 is the rotor resistance, X_2 is the standstill reactance of the rotor and s is the percentage slip

PLUGGING APPLIED TO SYNCHRONOUS MOTORS

Plugging can be applied to the synchronous motors, with the only difference that the field on the rotor will be rotating in opposite direction to that of the rotating field on the stator with the synchronous speed and the relative velocity between the two will be twice the synchronous speed.

RHEOSTATIC BRAKING

In this method of braking, the motor is disconnected from the supply and run as generator driven by the remaining kinetic energy of the equipment that is the energy stored in motor and load which are to be braked.

The following drives can be braked by the rheostatic method:

1) DC motor
2) Induction motor
3) Synchronous motor

DC MOTORS

Shunt motor:

In this type of motor, the armature is simply disconnected from the supply and is connected to as resistance in series with it, the field; winding remains connect to the supply.

The braking can be adjusted suitably by varying the resistance in the armature circuit.

In the case of failure of the supply, there is no braking torque because of absence of the field.

Series motor:

In this case of the connections are made as shown is fig during braking operation.

The motor after disconnection from the supply in made to run as a DC series generator.

Braking torque and speed

$$\text{Braking current} = E_b/ R$$

$$= K_1\Phi N/R$$

$$\text{Electric braking torque} = KK_1\Phi 2N/R = K_2\Phi 2N$$

where, $K_2= KK_1/R$

In the case of a series motor the flux dependent upon the armature current

$$\text{Electric braking torque for series motor} = K_3I_a2N$$

While in the case of shunt motor since flux is constant

$$\text{Electric braking torque} = K_4N$$

INDUCTION MOTOR

In this case the stator is disconnected from the supply and is connected to DC supply which excites the windings thereby producing a DC field. The rotor is short-circuited across through resistance in each phase. When the short circuited rotor moves it outs the steady flux produced in the air gap due to DC current flowing in the stator produced in the air gap due to DC current flowing in the stator and an emf is induced in the rotor conductors Rheostatic braking in the synchronous motors is similar to the rheostatic braking in induction motors. In this case the stator is shorted across resistance in star or delta and the machine works like an alternator supplying the current to the resistance, there by dissipating in kinetic energy in the form of losses in the resistances.

REGENERATIVE BRAKING

In this type of braking, the motor is not disconnected from the supply but remains connected to it and its feeds back the braking energy or its kinetic energy to the supply system. This method is better than the first and second methods of braking since no energy is wasted and rather it is supplied back to the system. This method is applicable to following motors:

Shunt motor:

In a DC machine where energy will be taken from the supply or delivered to it depends upon the induced emf, if it in less than the line voltage the machine will operate as motor and if it is more than the line voltage, the machine will operate as generator. The emf induced in turn depends upon the speed and excitation that is when the field current or the speed is increased the induced emf exceeds the line voltage and the energy will be field into the system. This will quickly decrease the speed of the motor and will bring it to rest.

Series motor:

In this case, complications arise due to fact that the reversal of the current in the armature would cause a reversal of polarity of the series field. In the case of induction motors, the regenerative braking is inherent, since an induction motor act as a generator when running at speeds above synchronous speeds and it feeds power back to the supply system. No extra auxiliaries are needed for this purpose. This method is however very seldom used for braking but its application is very useful to lifts and hoists for holding a bending load at a speed only slightly above the synchronous speed.

Tramways:

The tramway is perhaps the cheapest type of transport available in very dense traffic. It receives power through a bow collector or a grooved wheel from an overhead conductor at about 600 V D.C., the running rail forming the return conductor. It is provided with at least two driving axles in order to secure necessary adhesion, start it from either end and use two motors with series- parallel control. Two drum-type controllers, one at each end used for controlling the tramcar. Though these controllers are connected in parallel, they have suitable interlocking arrangement to prevent their being used simultaneously. The main frame of the car body is made from high tensile steel. Aluminium is extensively used for bodywork. The under frame is of rolled steel sections. Seats are either in transverse direction or a combination of transverse and longitudinal arrangement is used. The equipment is similar to that used in railways but the output is considerably smaller and does not exceed 60 to 75 H.P. For normal service rheostatic and mechanical braking are employed. For mechanical braking, electro-mechanical drum brakes are used. Also, magnetic tracks brakes are used for giving better retardation.

Trolley-Bus:

Serious drawback of tramway is the lack of maneuverability in congested areas and noise; this is overcome by the trolley-bus drive. It is an electrically- operated pneumatic-tyred vehicle which needs no track in the roadway. It receives its power at 600 V D.C. from two overhead contact wires. A D.C compound motor of output of 50 to 100 kW is normally used. Speed control is obtained by field weakening method. Foot operated master controllers are used so that drive may have his hands free to steer the vehicle and apply hand brake. One pedal controls the starting, speed control and regenerative braking, if any and second pedal control rheostatic and compressed air brakes. Regenerative braking is usually not employed in trolley-bus drive because of difficulty of ensuring that supply system is always in a position to absorb the energy regenerated. The lighting system in the car is low-voltage D.C supplied from a motor- generator set connected in parallel with a battery. The vehicles are usually provided with secondary batteries so that the vehicles can be maneuvered in case of emergency. Since the body of the car is insulated from earth on account of the rubber-tyred wheels, it must be properly checked for adequate insulation resistance lest it leaks and causes electric shocks to the passengers while boarding and alighting from the bus. The insulation resistance is checked at the end of the day. Trolley – buses have more passenger carrying capacity, higher acceleration and braking retardation than oil-engine buses. These are, therefore, used for medium traffic density as obtained in inner suburbs. Oil engine buses, on the other hand, are used for outer suburbs and country side where there is low traffic density.

4.3 MECHANICS OF TRAIN MOVEMENT

TRAIN MOVEMENT

Speed-Time Curve

The curve drawn between speed and time is called the speed-time-curve and is given in figure 4.3.1. The speed-time curve gives complete information of the motion of the train. The curve gives the speed at various instants after the start of run directly. Slop of the curve at any point gives the acceleration at the corresponding instant or speed. The area covered by the curve, the time axis and the ordinates through the instants between which the time is taken, represents the distance covered in the corresponding time interval.

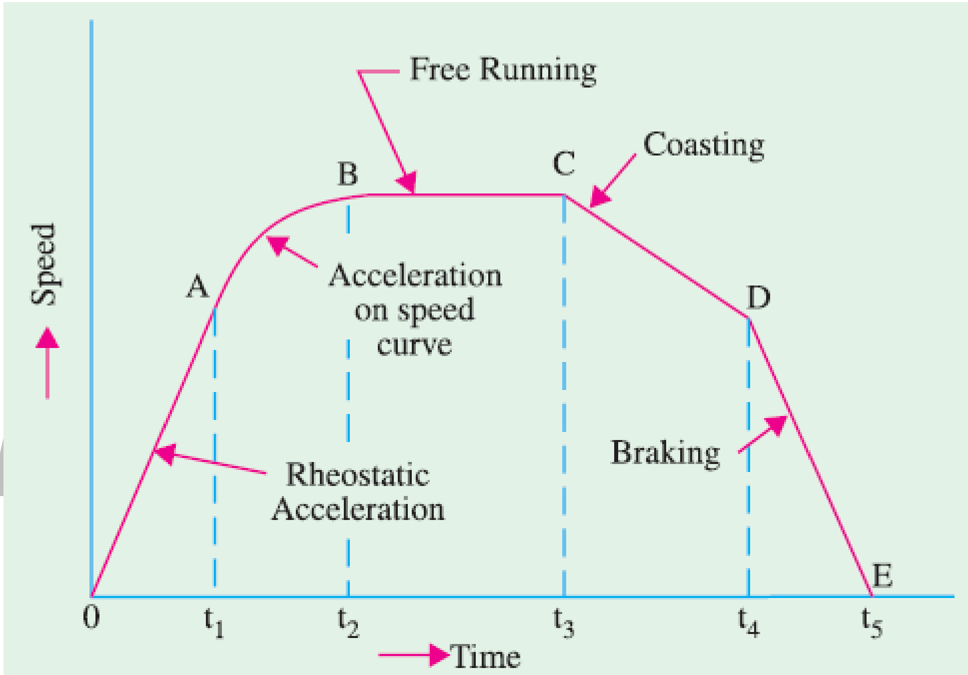

Figure 4.3.1 Driving mechanism of electric locomotives

[Source: "A Textbook of Electrical Energy" by B.L.Theraja, Page: 1711]

Speed-time curve mainly consists of

1) Initial acceleration

(a) Constant acceleration or acceleration while notching up and

(b)Speed curve running or acceleration on the speed curve

1. Acceleration period or Notching up period (0 to t_2):

From starting to the stage when locomotive attains maximum speed, the period is known as acceleration period, as the vehicle is constantly accelerated. This is represented by OA portion of the curve and time duration is t_1. During this period of run (0 to t_1), starting resistance is gradually cut so that the motor current is limited to a certain value and the voltage across the motor is gradually increased and the traction motor accelerates from rest. To cut the starting resistance, the starter handle has to be moved from one notch to another. Hence this period is called notching up period. The acceleration is almost uniform during this period. Now the torque decreases and speed increases according to the speed torque characteristics of the motor. Now the acceleration gradually decreases with the increase in speed and finally reaches the required torque for the movement of the train (at time t_2).

2. Free running period (t_2 to t_3):

During this period i.e. t_2 to t_3 the power supplied to the motor is at full voltage and speed of this period is constant, also during this period. Power drawn from the supply is constant. During this period the motor develops enough torque to overcome the friction and wind resistance and hence the locomotive runs at constant speed. This is shown by the portion AB of the curve.

3. Coasting (t_3 to t_4):

At the end of free running period supply to the motor is cut off and the train is allowed to run under its own kinetic energy. Due to train resistance speed of the train gradually decreases. The rate of decreasing of speed during this period is known as “coasting retardation”. When the locomotive is running at certain speed, if the motor is switch off, due to inertia the vehicle will continue to run, of course with little deceleration due to friction and windage.

4. Braking (t_4 to t_5):

At the end of coasting period the brakes are applied to bring the train to stop. During this period speed decreases rapidly and finally reduces to zero. The locomotive is retarded to stop it within short distance and at a particular spot. The shape of the curve will change depending upon the distance between consecutive stations. It is the curve drawn between speed of train in km/hour along y-axis and time in seconds along x-axis. The speed time curve gives complete information of the motion of the train. This curve gives the speed at various times after the start and run directly. The distance travelled by the train during a given interval of time can be obtained by determining the area between the curve and the time axis corresponding to this interval.

TYPES OF SERVICES

There are three types of electric traction services.

1. Main line service
2. Sub-urban service
3. Urban service

Speed – Time curve for suburban service

In this type of services, the distance between two successive stations is in the range of 1.5 km to 8 km. Figure represents speed-time curve for sub-urban service. Acceleration and braking retardation required are high. Free running period is not possible and coasting period will be comparatively longer than urban service.

Speed – Time curve for urban or city service

In city service the distance between the two stations is very short i.e., between 0.75 to 1 km. The time required for this run between the adjacent and retardation should be sufficient high. Fig shows the speed-time curve for urban or city service. It will be seen that there will be no free running period. The coasting period is also small.

MECHANICS OF TRAIN MOVEMENT

Essential driving mechanism of an electric locomotive is shown in figure 4.3.2.

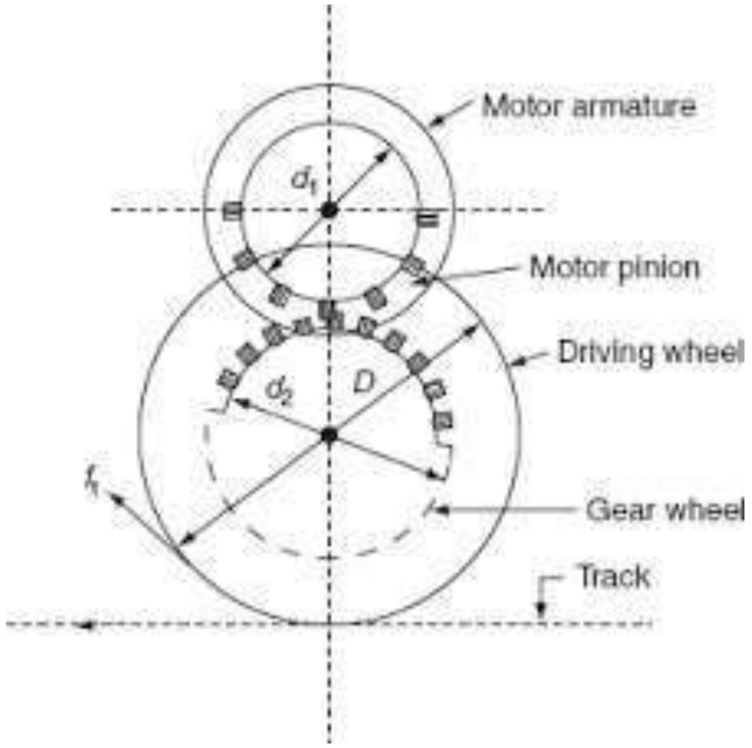

Figure 4.3.2 Driving mechanism of electric locomotives

[Source: "Generation and Utilization of Electrical Energy" by Sivanagaraju, Balasubba Reddy, Srilatha, Page: 499]

The electric locomotive consists of pinion and gear wheel meshed with the traction motor and the wheel of the locomotive. Here, the gear wheel transfers the tractive effort at the edge of the pinion to the driving wheel. The armature of the driving motor has a pinion diameter ‘d’ attached to it. The tractive effort at the edge of the pinion is transferred to the driving wheel by means of a gear wheel.

Torque developed by the motor,

$$T = F_p \times \frac{d_1}{2}, (Nm)$$

Tractive effort at the edge of the pinion,

$$F_p = \frac{2T}{d_1}, (N)$$

Tractive effort at the edge of the pinion transferred to the wheel of locomotive,

$$F_t = \eta F_p \times \frac{d_2}{D}, (N)$$

$$F = \frac{2\eta T}{D}\left(\frac{d_2}{d_1}\right) = \frac{2\eta T r}{D}, (N)$$

where, T is the torque exerted by the driving motor in Nm, d is the diameter of gear wheel in metres, D is the diameter of driving wheel in metres, η is the transmission efficiency and r is the gear ratio which is equal to d_2/d_1. For obtaining train motion without slipping tractive effort F should be less than or at the most equal to μW where μ the coefficient of adhesion between the wheel is and the track and W is the weight of the train on the driving axles (called the adhesive weight).

TRACTIVE EFFORT

The effective efforts required to run a train on track are:

- ➔ Tractive effort needed to provide acceleration, (F_a)
- ➔ Tractive effort needed to overcome the train resistance (F_r)
- ➔ Tractive effort needed to overcome gradients (F_g)

Tractive effort required for acceleration (F_a):

$$Force = mass \times acceleration$$

$$F = ma$$

$$Mass\ of\ train,\ m = 1000\ Wkg$$

$$Acceleration = \alpha, \left(\frac{km}{hr \cdot sec}\right) = \alpha \times \frac{1000}{3600}, \left(\frac{m}{s^2}\right) = 0.2778\alpha, \left(\frac{m}{s^2}\right)$$

Tractive effort required for linear acceleration,

$$F_a = 1000W \times 0.2778\alpha = 277.8W\alpha, (N)$$

When a train is accelerated in a linear direction, its rotating parts like the wheels and armature of motors have to be accelerated in an angular direction. Therefore, the accelerating mass of the train is greater than the dead mass of the train. The accelerating weight (W_e) is much higher (about 8-15%) than the dead weight (W) of the train.

Tractive effort required for linear and angular acceleration,

$$F_a = 277.8W_e\alpha, (N)$$

Tractive effort required to overcome the train resistance (F_r):

While moving, the train has to overcome the opposing force due to the surface friction and wind resistance. The train resistance depends upon various factors such as shape, size, condition of track etc.

Tractive effort required to overcome the train resistance,

$$F_r = W \times r, (N)$$

where W – dead weight of the train in ton, r is the specific train resistance in N/ton of the dead weight.

Tractive effort required to overcome gradients (F_g):

Consider that an electric train is moving upwards on a slope. The dead mass of the train along the slope will tend to bring it downward. To overcome this effect of gravity, tractive effort is required in opposite direction.

Tractive effort to overcome the effect of gravity,

$$F_g = \pm Mg \sin\theta = \pm 1000Wg \sin\theta, (N)$$

where, g is the acceleration due to gravity = 9.81 m/sec^2, θ is the angle of slope.

$$F_g = \pm 1000W \times 9.81 \sin\theta, (N)$$

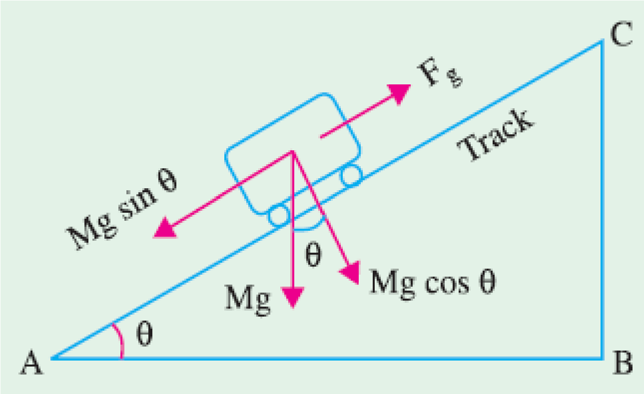

Figure 4.3.3 Train moving on up-gradient

[Source: "Generation and Utilization of Electrical Energy" by Sivanagaraju, Balasubba Reddy, Srilatha, Page: 501]

In railway practice, the gradient is expressed in terms of rise or fall in every 100 m of track and it is denoted by G %. From figure 4.3.3, we get,

$$Gradient, G = \sin\theta = \frac{BC}{AC} = \frac{Elevation}{distance\ along\ the\ track}$$

$$\%G = 100 \sin\theta$$

$$F_g = \pm 1000 W \times 9.81 \times \frac{G}{100} = \pm 98.1 W G, (N)$$

Positive sign is to be used for up-gradient and negative sign for down-gradient.

The total tractive effort required for the propulsion of train,

$$F_t = F_a + F_r \pm F_g$$

$$F_t = 277.8 W_e \alpha + W r \pm 98.1 W G, (N)$$

4.1 MERITS OF ELECTRIC TRACTION

The locomotive in which the driving or tractive force is obtained from electric motors is called Electric traction. Electric traction has many advantages as compared to other non-electrical systems of traction including steam traction.

Electric traction is used in:

i) Electric trains
ii) Trolley buses
iii) Tram cars
iv) Diesel-electric vehicles etc.

Traction systems

All traction systems, broadly speaking, can be classified as follows:

1. Non-electric traction systems:

These systems do not use electrical energy at some stage or the other. Examples: Steam engine drive used in railways at some stage or the other. These are further sub-divided into the following two groups:

a) Self-contained vehicles or locomotives

Examples:

i) Battery-electric drive
ii) Diesel-electric drive

b) Vehicles which receive electric power from a distribution network or suitably placed sub-stations.

Examples:

i) Railway electric locomotive fed from overhead AC supply
ii) Tramways and trolley buses supplied with DC supply

Here power is applied to the vehicle from an overhead wire suspended above the track.

2. Electric traction systems

Electric traction systems may be broadly categorized as those operating on:

1. Alternating current supply
2. Direct current supply

In general, the following electric traction systems exist:

a. AC 3 phase 3.7 kV system

b. AC single phase 15/16 kV - 161/25 Hz

c. AC single phase 20/25 kV - 50/60 Hz

d. DC 600 V

e. DC 1200 V

f. DC 1.5 kV

g. DC 3 kV

Advantages:

Electrical transmission is applied to high power units and has following advantages:

i. It has smooth starting without shocks.
ii. Full driving torque is available from standstill.
iii. Engine can be run at its most suitable speed range. This given higher efficiency range.
iv. Characteristics of traction motor and generator are so chosen that the speed of the traction unit automatically adjusts according to the load and gradient so as to maintain constant output and not to overload the diesel engine.
v. Electrical transmission docs not only work as torque converter but also works as reversion gear.

REQUIREMENTS OF ELECTRIC TRACTION SYSTEM

The following are some of the important requirements of the driving equipment used for traction purposes:

a. High adhesion coefficient, so that high tractive effort at the start is possible to have rapid acceleration.
b. The locomotive or train unit should be self-contained so that it can run on any route.
c. Minimum wear on the track.
d. It should be possible to overload the equipment for short periods.
e. The equipment required should be minimum, of high efficiency and low initial and maintenance cost.
f. It should be pollution free.
g. Speed control should be easy.
h. Braking should be such that minimum wear is caused on the brake shoes, and if possible, the energy should be regenerated and returned to the supply during braking period.

4.6 RECENT TRENDS IN ELECTRIC TRACTION

Magnetic levitation, **maglev** or **magnetic suspension** is a method by which an object is suspended with no support other than magnetic fields. Magnetic pressure is used to counteract the effects of the gravitational and any other accelerations. Earnshaw's theorem proves that using only static ferromagnetism it is impossible to stably levitate against gravity, but servomechanisms, the use of diamagnetic materials, super conduction, or systems involving eddy currents permit this to occur. In some cases, the lifting force is provided by magnetic support bearing little load that provides stability. This is termed levitation, but there is a mechanical **pseudo-levitation**. Magnetic levitation is used for maglev trains, magnetic bearings and for product display purposes.

Mechanical constraint (pseudo-levitation):

With a small amount of mechanical constraint for stability, pseudo-levitation is relatively straightforwardly achieved. If two magnets are mechanically constrained along a single vertical axis, for example, and arranged to repel each other strongly, this will act to levitate one of the magnets above the other. Another geometry is where the magnets are attracted, but constrained from touching by a tensile member, such as a string or cable. Another example is the Zippe-type centrifuge where a cylinder is suspended under an attractive magnet, and stabilized by a needle bearing from below.

Diamagnetism:

Diamagnetism is the property of an object which causes it to create a magnetic field in opposition to an externally applied magnetic field, thus causing a repulsive effect. Specifically, an external magnetic field alters the orbital velocity of electrons around their nuclei, thus changing the magnetic dipole moment. According to Lenz's law, this opposes the external field. Diamagnets are materials with a magnetic permeability less than $\mu 0$ (a relative permeability less than 1). Consequently, diamagnetism is a form of magnetism that is only exhibited by a substance in the presence of an externally applied magnetic field. It is generally quite a weak effect in most materials, although superconductors exhibit a strong effect. Diamagnetic materials cause lines of magnetic flux to curve away from the material, and superconductors can exclude them completely (except for a very thin layer at the surface).

Direct diamagnetic levitation:

A substance that is diamagnetic repels a magnetic field. All materials have diamagnetic properties, but the effect is very weak, and is usually overcome by the object's paramagnetic or ferromagnetic properties, which act in the opposite manner. Any material in which the diamagnetic component is strongest will be repelled by a magnet. Earnshaw's theorem does not apply to diamagnets. These behave in the opposite manner to normal magnets owing to their relative permeability of $\mu_r < 1$ (i.e. negative magnetic susceptibility). Diamagnetic levitation can be used to levitate very light pieces of pyrolytic graphite or bismuth above a moderately strong permanent magnet. As water is predominantly diamagnetic, this technique has been used to levitate water droplets and even live animals, such as a grasshopper, frog and a mouse. However, the magnetic fields required for this are very high, typically in the range of 16 teslas, and therefore create significant problems if ferromagnetic materials are nearby. The modern trend is towards the use of d.c motors (both separately excited and d.c series motors) equipped with thyristor control. The operating voltages are 600V or 1,000V. Braking employed are mechanical, rheostatic and regenerative, Thyristorised converters provide accurate control and fast response. Main advantages of thyristor control are the absence of bulky on load tap changer and electromagnetic devices, saving of energy, notch less control, increase in pulling ability of the motive power, and minimum wear and tear because of absence of conventional moving parts in the motor control circuits. In electric traction, it is desirable that the train accelerates and decelerates at a constant rate for the comfort of the passengers. Using thyristors, this objective can be met in the following way: When the speed goes down during breaking the generator voltage decreases. For a particular braking torque, a particular armature current is required. This is achieved by increasing the field excitation to a relatively high value. If, however, the generator voltage exceeds the supply voltage, in dynamic braking, this increase is permissible as the armature is not connected to the supply and the energy of the generator can be dissipated in the braking resistors, external resistances in series with the armature are connected in case of regenerative braking to absorb the voltage difference between the armature voltage and supply voltage. With this, of course, part of the generated power is wasted in the external resistors and the efficiency of the overall system is decreased. Various methods of speed control and electric braking employing thyristors have already been studied in power electronic subjects. In addition to ordinary phase control methods, **cycle selection methods** of control of SCR for varying the voltage applied to the traction motors are also employed. In this method the required average voltage is obtained by accepting or rejecting a certain numbers of complete half cycles. In practice, at the start only one half out of eight is accepted and as the speed builds up, it is gradually raised to 2/8, 3/8 and finally 8/18 for full power operation. This method is advantageous due to low frequency harmonics, low rate of rise of current, better power factor etc. In **chopper control** of traction motors, at start, the *'on'* period of pulse is kept very short which lengthens during the period of controlled acceleration. Thus, the average voltage applied across the traction motors is gradually increased keeping the mean value of the input current close to the desired value. Figure shows a typical thyristorised dc traction system supplying a group of four separately excited motors. The armatures are supplied from half controlled bridge converters. However, it is desirable to feed the field windings through fully controlled bridge converters so as to reduce the ripple in the field current. Low ripple in the field current ensures low iron losses in the machines. However, if regenerative braking is required then the armature should be supplied from fully controlled bridges. Freewheeling diodes are connected as illustrated to ensure good waveform of armature current. The armatures are connected in series – parallel arrangement to ensure good

starting and running characteristics. It is seen that armatures are supplied by three bridges connected in series. For starting first only bridge A is triggered and firing angle is advanced as speed builds up. When bridge A is fully conducting (i.e. when $\alpha=0$), bridge B is triggered and then bridge C is triggered. During starting field currents are set to maximum to provide high starting torque. The use of three bridges ensures better power factor than would be possible with a single bridge.

4.2 SUPPLY SYSTEMS

Mainly, there are three supply systems for Electric traction:

- ➔ The direct current system -
- ➔ The single-phase AC system operating at low frequency 162/3 Hz or 25 Hz and at normal frequency 50 Hz
- ➔ The three phase AC system

Direct current system:

The transformation and high voltage generation of dc is very inconvenient to the dc supply used is at normally 600 V and this voltage is almost universal for use in urban and suburban railways. For direct current equipment, the series motor is universally employed as its speed-torque characteristics are best suited to traction requirements. Generally, two or more motors are used in single equipment and these are coupled in series or in parallel to give the different running speeds required. The motors are initially connected in series with starting rheostats across the contact line and rails, the rheostats are then cut out in steps, keeping roughly constant current until the motors are running in full series. After this the motors are rearranged in parallel, again with rheostats, the rheostats are cut out in steps, leaving the motors in full parallel. The power input remains approximately constant during the series notching, then jumps to twice this value during the parallel notching. Thus a 4-motor unit will have three economical speeds when the motors are running in series, series-parallel connections. The rheostats are operated electro magnetically or electro-pneumatically.

AC single phase system:

In this supply is taken from a single overhead conductor with the running rails. A pantograph collector is used for this purpose. The supply is transferred to primary of the transformer through on oil circuit breaker. The secondary of the transformer is connected to the motor through switchgear connected to suitable tapping on the secondary winding of the transformer. The switching equipment may be mechanically operated tapping switch or remote-controlled contractor of group switches. The switching connections are arranged in two groups usually connected to the ends of a double choke coil which lies between the collections to adjacent tapping points on the transformer. Thus, the coil acts as a preventive coil to enable tapping change to be made without short circuiting sections of the transformer winding and without the necessity of opening the main circuit.

AC three phase system:

In case of 3-phase system, energy can be drawn directly from the existing 3-phase electric network or by using transformer substation in case the network is operating at higher voltage. This system, therefore, has high efficiency as no converting equipment is involved. Here, two trolly wires per track are required and are connected between two phases of the supply. The induction motor is used as the drive which is robust in construction and cheap in first cost. It has high efficiency and it acts as an induction generator when runs at a speed more than its synchronous speed, thus during regenerative braking by changing the number of poles (increase) the synchronous speed can be reduced and hence power can be pumped back into the supply system. Since, it is a constant speed motor, which can be used to limit the speed of the train to a definite value. Three phase main line railways operate at a voltage between 3300 and 3600 and a frequency of 162/3 Hz. Low starting torque, high starting current and constant speed characteristics of induction motors are some reasons why 3-phase systems could not become popular for traction purposes.

4.4 TRACTION MOTORS AND CONTROL

TRACTION MOTORS

The motor for electric traction has to operate under different conditions which are arduous than those in most industrial applications and a special type of motor known as traction motor has been developed which incorporates the following features:

Electric features:

High starting torque

Series speed-torque characteristics

Simple speed control

Possibility of dynamic/regenerative braking

Good commutation under rapid fluctuations of supply voltage

Mechanical features:

Robustness

Ability to withstand continuous vibrations

Minimum weight and overall dimensions

Protection against dirt and dust

No type of motor completely fulfills all these requirements. Motors, which have been found satisfactory are DC series motor for DC systems and AC series motor for AC systems. Also, AC three phase motors can be used.

TRACTION MOTOR CONTROL

The control of traction motors for starting and for smooth acceleration is very much essential to avoid damage to the motors. The control equipment is provided for manual and automatic operation. Usually a master controller is used for the purpose.

1) D.C series motor control or plain rheostat control
2) Series –Parallel control
    i. Open circuit transition
    ii. Shunt transition control
    iii. Bridge transition control
3) Metadyne control
4) Multiple Unit control