Introduction of Refrigeration

Refrigeration Literal meaning of refrigeration is the production of cold confinement relative to its surroundings. In this, temperature of the space under consideration is maintained at a temperature lower than the surrounding atmosphere. To achieve this, the mechanical device extracts heat from the space that has to be maintained at a lower temperature and rejects it to the surrounding atmosphere that is at a relatively higher temperature. Since the volume of the space which has to be maintained at a lower temperature is always much lower than the environment, the space under consideration experiences relatively higher change in temperature than the environment where it is rejected. The precise meaning of the refrigeration is thus the following: Refrigeration is a process of removal of heat from a space where it is unwanted and transferring the same to the surrounding environment where it makes little or no difference. To understand the above definition, let us consider two examples from the daily life.

Refrigerator

Refrigeration is the process of maintaining the temperature of a body below that of its surroundings. The working fluid used for this purpose is called Refrigerant the equipment used is called Refrigerator.
Refrigeration effect is an important term in refrigeration that defines the amount of cooling produced by a system. This cooling is obtained at the expense of some form of energy. The refrigerant is compressed to high pressure and high temperature in the compressor and it gets cooled in the condenser at constant pressure.

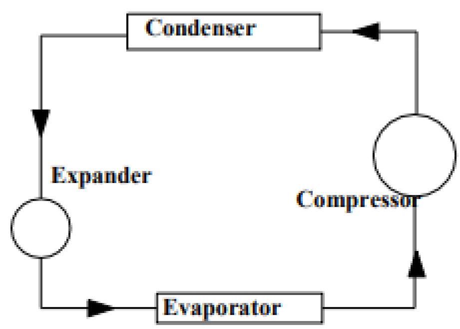


Figure 4.1- Basic Refrigeration Flow Diagram

A refrigeration system is a mechanical process or arrangement that is responsible for lowering the temperature between two points. For this process to take place, the thermodynamic properties of matter are involved, which are responsible for transferring thermal energy or heat between two points.

Working Principle of Refrigerator

Refrigerators work on the second law of thermodynamics. In the process of refrigeration, unwanted heat is taken from one place and discharged into another. The common refrigerator which we have in our homes, works on the principle of evaporation. A refrigerant is a substance used in a heat cycle to transfer heat from one area, and remove it to another. A refrigerant when passed through the food kept in the refrigerator, it absorbs heat from these items and transfers the absorbed heat to the surrounding with less temperature.

Vapour compression refrigeration cycle is followed for the refrigeration process. In this process, the Evaporator, Compressor, Condenser and expansion valves are connected to tubes made of copper or steel.

Evaporator tube is placed throughout the refrigerator, when heat is absorbed the liquid refrigerant absorbs the heat and then converts into vapour. The heat absorbed is passed to the external environment through the compressor from vapour state to liquid state. This process repeats when the heat is absorbed and passed through the expansion valve to the evaporator. This process helps to keep the refrigerator cool always.

The Components of Refrigerator

There are four components in the refrigerator system. They are:

1. Evaporator
2. Compressor
3. Condenser
4. Expansion valve

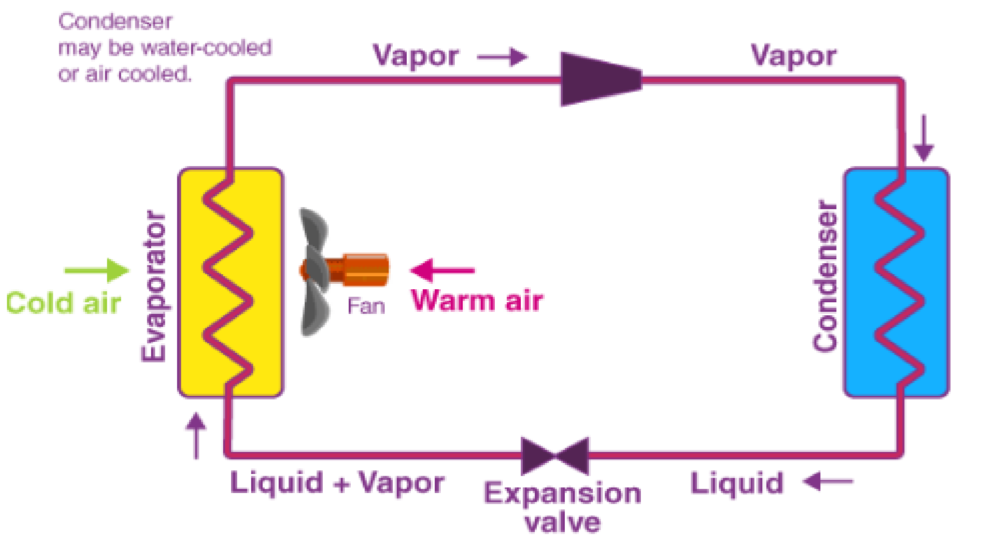


Figure 4.2

Evaporator: It is the main part of the refrigerator that helps to keep the device and things cool always. It features the tubes with high thermal conductivity that helps in absorbing the heat rejected by the fan or coil in the system.

Compressor: It compresses the low-pressure, low-temperature vapor into a high-temperature, high-pressure vapor. The refrigerant is passed from the evaporator and is compressed in a cylinder to generate a high-temperature, high-pressure gas.

Expansion valve helps to control the flow of refrigerant into the evaporator, or cooling coil. Expansion valve is also known as flow control valves. It is a sensitive small device that aids to sense the temperature change of the refrigerant.

Condenser: It comprises a set of tubes with external fins placed back of the refrigerator. This component helps to convert the gaseous refrigerant into liquid form.

Domestic Refrigerator

Internal Parts of the Domestic Refrigerator

The internal parts of the refrigerator are ones that carry out actual working of the refrigerator. Some of the internal parts are located at the back of the refrigerator, and some inside the main compartment of the refrigerator.

1) **Refrigerant**: The working substance used to make refrigeration is called the refrigerant. The refrigerant run through all the inner parts of the refrigerator. It is the refrigerant that carries out the cooling effect in the evaporator. It absorbs the heat from the body to be cooled in the evaporator (chillier or freezer) and throws it to the atmosphere via condenser. The refrigerant keeps on recalculating through all the inner parts of the refrigerator in cycle.
2) **Compressor:** The compressor is to be found at the rear of the refrigerator and in the bottom area. The compressor sucks the refrigerant from the evaporator and discharges it at high pressure and temperature. The compressor is driven by the electric motor and it is the major power intense devise of the refrigerator. In most of the refrigerator reciprocating and hermitically sealed compressor are used.
3) **Condenser:** In refrigerator air-cooled condenser is used since, the constriction of air-cooled condenser is very simple. The condenser is the thin coil of copper tubing situated at the back of the refrigerator. The refrigerant from the compressor come in the condenser where it is cooled by the atmospheric air thus losing heat absorbed by it in the evaporator and the compressor. To increase the heat transfer rate of the condenser, it is finned externally.
4) **Expansion valve or the capillary:** The refrigerant leave-taking the condenser enters the expansion devise, which is the capillary tube in case of the household refrigerators. The capillary is the thin copper tubing made up of number of turns of the copper coil. When the refrigerant is passed through the capillary its pressure and temperature drops down suddenly. And it is a constant enthalpy process.
5) **Evaporator or freezer:** The refrigerant at very low pressure and temperature enters the evaporator or the freezer. The evaporator is the heat exchanger made up of several turns of copper or aluminum tubing. In domestic refrigerators the plate types of evaporator is used as shown in the figure above. The refrigerant absorbs the heat from the substance to be cooled in the evaporator, gets evaporated and it then sucked by the compressor. This cycle keeps on repeating.

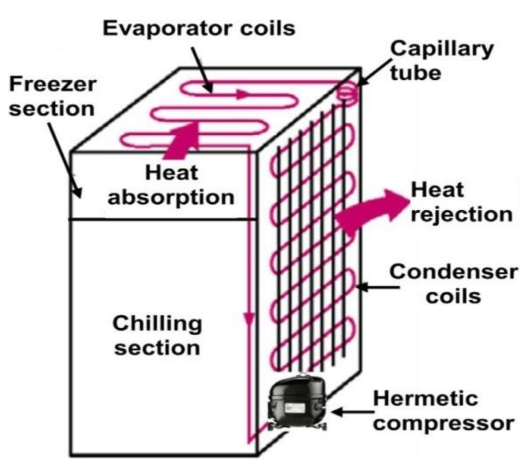


Figure 4.3-

6) **Temperature control devise or thermostat**: To control the temperature inside the refrigerator there is thermostat, whose sensor is connected to the evaporator. The thermostat setting can be done by the round knob inside the refrigerator compartment. When the set temperature is reached inside the refrigerator the thermostat stops the electric supply to the compressor and compressor stops and when the temperature falls below certain level it restarts the supply to the compressor.
7) **Defrost system:** The defrost system of the refrigerator helps removing the excess ice from the surface of the evaporator. The defrost system can be operated manually by the thermostat button or there is automatic

Air conditioner

Electric traction system

An **electric traction system** is the type of traction system that uses electrical energy for the movement of vehicle at any stage.

The electric traction system is classified into two groups as −

1) Self-contained vehicles or locomotives (Ex. – battery-electric drive and diesel-electric drive)
2) Vehicles or locomotives which receive electric power from a distribution network or suitably placed substations (Ex. - railway electric locomotives, tramways and trolleybuses, etc.)

Here, we described different **types of electric traction systems** along with their advantages and disadvantages −

Straight Electric Traction System

In the straight electric traction system, either DC series motor or single phase AC series motor or three-phase induction motor is used for providing the required propelling torque. In this system, the electrical power is directly fed to the motor and the torque is generated.

Advantages of Straight Electric Traction System

The straight electric traction system possesses the following advantages −

Due to the absence of smoke, ash, etc. this system is clean and hence is suitable for underground railways.

1) This system provides high starting torque, high acceleration and retardation.
2) Straight electric traction system has high traffic holding capacity and flexibility in operation which is suitable for urban areas.
3) The starting time of straight electric traction system is quite less.
4) This system has high power to weight ratio.

Disadvantages of Straight Electric Traction System

The disadvantages of straight electric traction system include the following −

1) Due to the presence of overhead equipment, the capital cost is high.
2) Traction is tied to electric routes.
3) In this system, provision of negative booster is necessary.
4) It causes disturbance in neighboring communication lines.
5) Power failure of few minutes causes distortion in traffic.

I.C. Engine Electric Drive or Diesel-Electric Drive

In diesel-electric drive, a diesel engine (internal combustion engine) is used which is coupled to a DC generator. The speed of the diesel engine is maintained constant and this DC generator supplies power to the traction motors which are connected to the driving axels.

Advantages of Diesel Electric Drive

The advantages of the diesel electric drive are as follows −

1) Low capital cost due to the absence of overhead equipment.
2) It has high acceleration and retardation.
3) No requirement of modification in the existing tracks while converting from non-electric to diesel-electric traction.
4) This locomotive and train is a self-contained unit, therefore, it is not tied to any route.
5) The diesel electric drive can be put into service at any moment.
6) Overall efficiency of this system is high.

Disadvantages of Diesel-Electric Drive

The disadvantages of the diesel electric drive are given as follows −

- The diesel engine cannot be overloaded.
- This system has high running and maintenance costs.
- The life of a diesel engine is comparatively shorter.
- It is required to provide a separate cooling system for the diesel engine.
- The dead weight of this type of locomotive is more which requires more axels.
- In this type of traction system, the regenerative braking is not possible.

Advantages of Electric Traction

As compared to steam traction, electric traction has the following advantages:

1. **Cleanliness**. Since it does not produce any smoke or corrosive fumes, electric traction is most suited for underground and tube railways. Also, it causes no damage to the buildings and other apparatus due to the absence of smoke and flue gases.
2. **Maintenance Cost**. The maintenance cost of an electric locomotive is nearly 50% of that for a steam locomotive. Moreover, the maintenance time is also much less.
3. **Starting Time**. An electric locomotive can be started at a moment's notice whereas a steam locomotive requires about two hours heating up.
4. **High Starting Torque**. The motors used in electric traction have a very high starting torque. Hence, it is possible to achieve higher accelerations of 1.5 to 2.5 km/h/s as against 0.6 to 0.8 km/h/s in steam traction.
   As a result, we are able to get the following additional advantages:
   (i) high schedule speed

(ii) (ii) increased traffic handling capacity

(iii) less terminal space is required—a factor of great importance in urban areas.

(iv) **Braking**. It is possible to use regenerative braking in electric traction system. It leads to the following advantages :

   (i) about 80% of the energy taken from the supply during ascent is returned to it during descent.

   (ii) goods traffic on gradients becomes safer and speedier.

   (iii) since mechanical brakes are used to a very small extent, maintenance of brake shoes, wheels, tyres and track rails is considerably reduced because of less wear and tear.

   (iv) Saving in High Grade Coal. Steam locomotives use costly high-grade coal which is not so abundant. But electric locomotives can be fed either from hydroelectric stations or pit-head thermal power stations which use cheap low-grade coal. In this way, high-grade coal can be saved for metallurgical purposes.

Lower Centre of Gravity. Since height of an electric locomotive is much less than that of a steam locomotive, its centre of gravity is comparatively low. This fact enables an electric locomotive to negotiate curves at higher speeds quite safely.

1. **Absence of Unbalanced Forces.** Electric traction has higher coefficient of adhesion since there are no unbalanced forces produced by reciprocating masses as is the case in steam traction. It not only reduces the weight/kW ratio of an electric locomotive but also improves its riding quality in addition to reducing the wear and tear of the track rails.

Disadvantages of Electric Traction

1. The most vital factor against electric traction is the initial high cost of laying out overhead electric supply system. Unless the traffic to be handled is heavy, electric traction becomes uneconomical.
2. Power failure for few minutes can cause traffic dislocation for hours.
3. Communication lines which usually run parallel to the power supply lines suffer from electrical interference. Hence, these communication lines have either to be removed away from the rail track or else underground cables have to be used for the purpose which makes the entire system still more expensive.
4. Electric traction can be used only on those routes which have been electrified. Obviously, this restriction does not apply to steam traction.
5. Provision of a negative booster is essential in the case of electric traction. By avoiding the flow of return currents through earth, it curtails corrosion of underground pipe work and interference with telegraph and telephone circuits.

Systems of Railway Electrification

Presently, following four types of track electrification systems are available:

1. Direct current system—600 V, 750 V, 1500 V, 3000 V

2. Single-phase ac system—15-25 kV, 2 16 3 , 25 and 50 Hz

3. Three-phase ac system—3000-3500 V at 2 16 3 Hz

4. Composite system—involving conversion of single-phase ac into 3-phase ac or dc

Direct Current System

Direct current at 600-750 V is universally employed for tramways in urban areas and for many suburban railways while 1500-3000 V dc is used for main line railways. The current collection is from third rail (or conductor rail) up to 750 V, where large currents are involved and from overhead wire for 1500 V and 3000 V, where small currents are involved. Since in majority of cases, track (or running) rails are used as the return conductor, only one conductor rail is required. Both of these contact systems are fed from substations which are spaced 3 to 5 km for heavy suburban traffic and 40-50 km for main lines operating at higher voltages of 1500 V to 3000 V. These sub-stations themselves receive power from 110/132 kV, 3-phase network (or grid). At these substations, this high-voltage 3-phase supply is converted into low-voltage 1-phase supply with the help of Scott connected or V-connected 3-phase transformers (Art. 31.9). Next, this low ac voltage is converted into the required dc voltage by using suitable rectifiers or converters (like rotary converter, mercury arc, metal or semiconductor rectifiers). These substations are usually automatic and are remote controlled.

The dc supply so obtained is fed via suitable contact system to the traction motors which are either dc series motors for electric locomotive or compound motors for tramway and trolley buses where regenerative braking is desired. It may be noted that for heavy suburban service, low voltage dc system is undoubtedly superior to 1-phase ac system due to the following reasons:

1. DC motors are better suited for frequent and rapid acceleration of heavy trains than ac motors.

2. DC train equipment is lighter, less costly and more efficient than similar ac equipment.

3. When operating under similar service conditions, dc train consumes less energy than a 1-phase ac train.

4. The conductor rail for dc distribution system is less costly, both initially and in maintenance than the high-voltage overhead ac distribution system.

5. DC system causes no electrical interference with overhead communication lines. The only disadvantage of dc system is the necessity of locating ac/dc conversion sub-stations at relatively short distances apart.

Single-Phase Low-frequency AC System

In this system, ac voltages from 11 to 15 kV at 2 3 16 or 25 Hz are used. If supply is from a generating station exclusively meant for the traction system, there is no difficulty in getting the electric supply of 2 3 16 or 25 Hz. If, however, electric supply is taken from the high voltage transmission lines at 50 Hz, then in addition to step-down transformer, the substation is provided with a frequency converter. The frequency converter equipment consists of a 3-phase synchronous motor which drives a I-phase alternator having or 25 Hz frequency. The 15 kV 2 3 16 or 25 Hz supply is fed to the electric locomotors via a single over-head wire (running rail providing the return path). A step-down transformer carried by the locomotive reduces the 15-kV voltage to 300-400 V for feeding the ac series motors. Speed regulation of ac series motors is achieved by applying variable voltage from the tapped secondary of the above transformer. Low-frequency ac supply is used because apart from improving the commutation properties of ac motors, it increases their efficiency and power factor. Moreover, at low frequency, line reactance is less so that line impedance drop and hence line voltage drop is reduced. Because of this reduced line drop, it is feasible to space the substations 50 to 80 km apart. Another advantage of employing low frequency is that it reduces telephonic interference.

Three-phase Low-frequency AC System

It uses 3-phase induction motors which work on a 3.3 kV, 2 3 16 Hz supply. Sub-stations receive power at a very high voltage from 3-phase transmission lines at the usual industrial frequency of 50 Hz. This high voltage is stepped down to 3.3 kV by transformers whereas frequency is reduced from 50 Hz to 2 3 16 Hz by frequency converters installed at the sub-stations. Obviously, this system employs two overhead contact wires, the track rail forming the third phase (of course, this leads to insulation difficulties at the junctions). Induction motors used in the system are quite simple and robust and give trouble-free operation. They possess the merits of high efficiency and of operating as a generator when driven at speeds above the synchronous speed. Hence, they have the property of automatic regenerative braking during the descent on gradients. However, it may be noted that despite all its advantages, this system has not found much favor and has, in fact, become obsolete because of its certain inherent limitations given below:

1. The overhead contact wire system becomes complicated at crossings and junctions.

2. constant-speed characteristics of induction motors are not suitable for traction work.

3. Induction motors have speed/torque characteristics similar to dc shunt motors. Hence, they are not suitable for parallel operation because, even with little difference in rotational speeds caused by unequal diameters of the wheels, motors will becomes loaded very unevenly.

Single-phase AC to DC System

This system combines the advantages of high-voltage ac distribution at industrial frequency with the dc series motors traction. It employs overhead 25-kV, 50-Hz supply which is stepped down by the transformer installed in the locomotive itself. The low-voltage ac supply is then converted into dc supply by the rectifier which is also carried on the locomotive. This dc supply is finally fed to dc series traction motor fitted between the wheels. The system of traction employing 25-kV, 50-Hz, 1-phase ac supply has been adopted for all future track electrification in India. 43.15. Advantages of 25-kV, 50-Hz AC System Advantages of this system of track electrification over other systems particularly the dc system are as under:

1. Light Overhead Catenaries Since voltage is high (25 kV), line current for a given traction demand is less. Hence, cross-section of the overhead conductors is reduced. Since these small-sized conductors are light, supporting structures and foundations are also light and simple. Of course, high voltage needs higher insulation which increases the cost of overhead equipment (OHE) but the reduction in the size of conductors has an overriding effect.

2. Less Number of Substations Since in the 25-kV system, line current is less, line voltage drop which is mainly due to the resistance of the line is correspondingly less. It improves the voltage regulation of the line which fact makes larger spacing of 50-80 km between sub-stations possible as against 5-15 km with 1500 V dc system and 15-30 km with 3000 V dc system. Since the required number of substations along the track is considerably reduced, it leads to substantial saving in the capital expenditure on track electrification.

3. Flexibility in the Location of Substations Larger spacing of substations leads to greater flexibility in the selection of site for their proper location. These substations can be located near the national high-voltage grid which, in our country, fortunately runs close to the main railway routes. The substations are fed from this grid thereby saving the railway administration lot of expenditure for erecting special transmission lines for their substations. On the other hand, in view of closer spacing of dc substations and their far away location, railway administration has to erect its own transmission lines for taking feed from the national grid to the substations which consequently increases the initial cost of electrification.

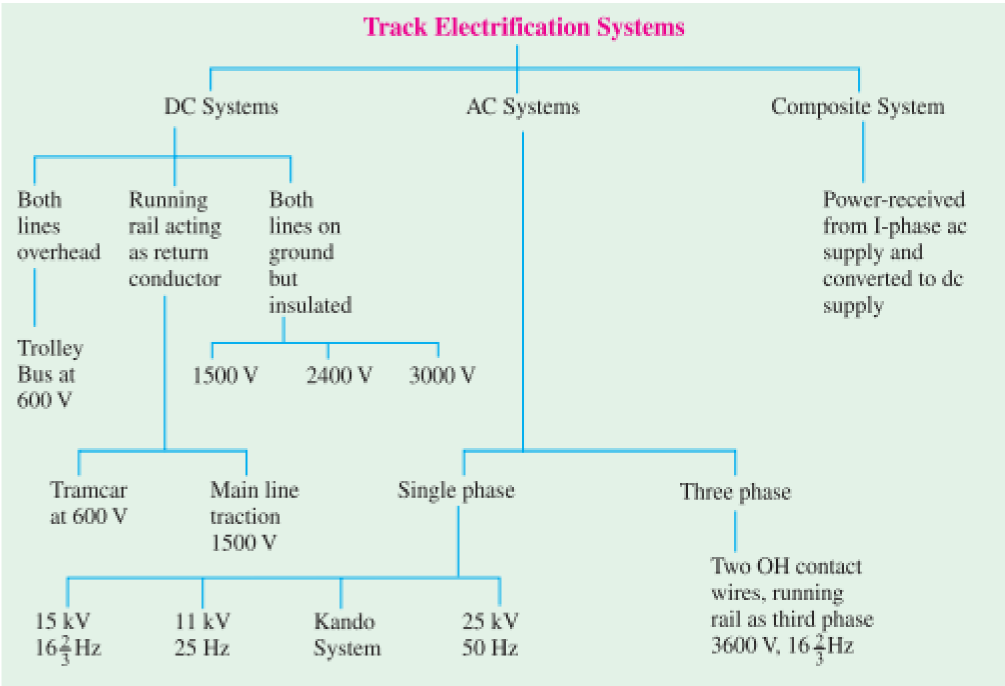
4. Simplicity of Substation Design In ac systems, the substations are simple in design and layout because they do not have to install and maintain rotary converters or rectifiers as in dc systems. They only consist of static transformers along with their associated switchgear and take their power directly from the high-voltage national grid running over the length and breadth of our country. Since such sub-stations are remotely controlled, they have few attending personnel or even may be unattended.

5. Lower Cost of Fixed Installations The cost of fixed installations is much less for 25 kV ac system as compared to dc system. In fact, cost is in ascending order for 25 kV ac, 3000 V dc and 1500 V dc systems. Consequently, traffic densities for which these systems are economical are also in the ascending order.

Disadvantages of 25-kV AC System

1. Single-phase ac system produces both current and voltage unbalancing effect on the supply.

2. It produces interference in telecommunication circuits. Fortunately, it is possible at least to minimize both these undesirable effects.



Types of Railway Services

There are three types of passenger services offered by the railways:

1. City or Urban Service. In this case, there are frequent stops, the distance between stops being nearly 1 km or less. Hence, high acceleration and retardation are essential to achieve moderately high schedule speed between the stations.
2. Suburban Service. In this case, the distance between stops averages from 3 to 5 km over a distance of 25 to 30 km from the city terminus. Here, also, high rates of acceleration and retardation are necessary.
3. Main Line Service. It involves operation over long routes where stops are infrequent. Here, operating speed is high and accelerating and braking periods are relatively unimportant. On goods traffic side also, there are three types of services (i) main-line freight service (ii) local or pick-up freight service and (iii) shunting service.

Train Movement

The movement of trains and their energy consumption can be conveniently studied by means of speed/time and speed/distance curves. As their names indicate, former gives speed of the train at various times after the start of the run and the later gives speed at various distances from the starting point. Out of the two, speed/time curve is more important because

1. its slope gives acceleration or retardation as the case may be.

2. area between it and the horizontal (i.e. time) axis represents the distance travelled.

3. energy required for propulsion can be calculated if resistance to the motion of train is known.

Typical Speed/Time Curve

Typical speed/time curve for electric trains operating on passenger services. It may be divided into the following five parts :

1. Constant Acceleration Period (0 to t1) It is also called notching-up or starting period because during this period, starting resistance of the motors is gradually cut out so that the motor current (and hence, tractive effort) is maintained nearly constant which produces constant acceleration alternatively called ‘rheostatic acceleration’ or ‘acceleration while notching’.
2.