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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

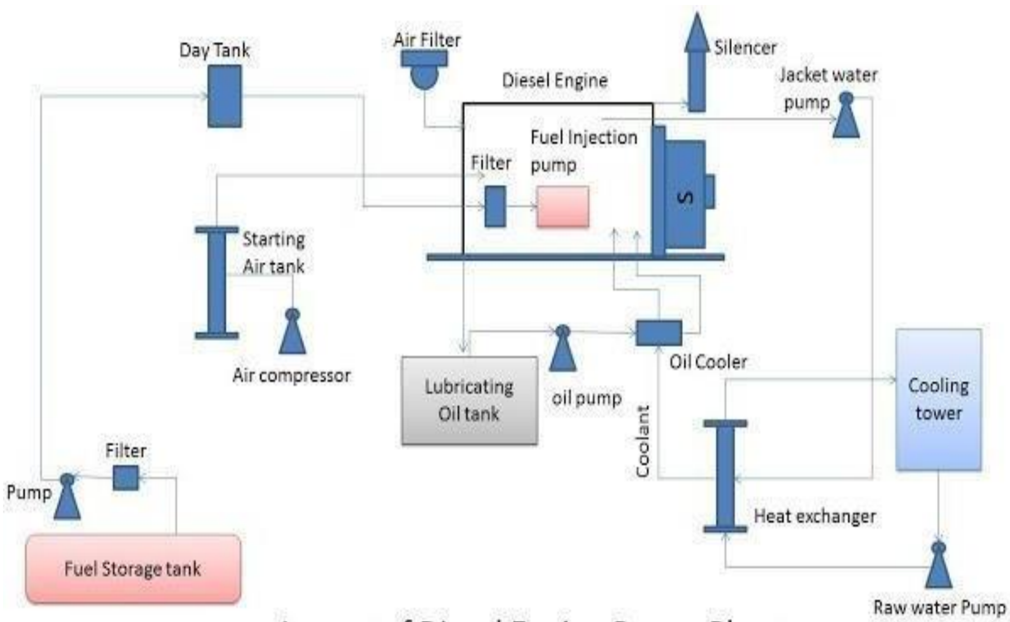
SEE1303-POWER GENERATION AND UTILIZATION

UNIT – I CONVENTIONAL POWER PLANTS

UNIT I - CONVENTIONAL POWER PLANTS

Layout and working of diesel, steam, low and high head power plants-pumped storage plants-principle of nuclear power generation - types and layouts of nuclear reactors- boiling water reactor- advanced gas cooled reactor- fast breeder reactor - reactor control - waste disposal.

Layout of diesel engine power plant:



Layout of Diesel Engine Power Plant

Diesel engine:

Diesel engines or compression ignition engines as they are called are generally classified as two stroke engine and four stroke engines. In diesel engine, air admitted into the cylinder is compressed, the compression ratio being 12 to 20. At the end of compression stroke, fuel is injected. It burns and the burning gases expand and do work on the position. The engine is directly coupled to the generator. The gases are then exhausted from the cylinder to atmosphere.

Engine starting system:

This includes air compressor and starting air tank. The function of this system is to start the engine from cold supplying compressed air.

Fuel system:

Pump draws diesel from storage tank and supplies it to the small day tank through the filter. Day tank supplies the daily fuel need of engine. The day tan is usually placed high so that diesel flowsto engine under gravity.Diesel is again filtered before being injected into the engine by the fuel injection pump. The fuel issupplied to the engine according to the load on the plant.

Air intake system:

Air filters are used to remove dust from the incoming air. Air filters may be dry type, which is made up of felt, wool or cloth. In oil bath type filters, the sir is swept over a bath of oil so thatdust particles get coated.

Exhaust system:

In the exhaust system, silencer (muffler) is provide to reduce the noise.

Engine cooling system:

The temperature of burning gases in the engine cylinder is the order of 1500 to 2000'C. to keep the temperature at the reasonable level, water is circulated inside the engine in water jackets which are passage around the cylinder, piston, combustion chamber etc. hot water leaving the jacket is sent to heat exchanger. Raw water is made to flow through the heat exchanger, where it takes up the heat of jacket water. It is then cooled in the cooling tower and recalculates again.

Engine lubrication system:

It includes lubricating oil tank, oil pump and cooler. Lubrication is essential to reduce friction and wear of engine parts such as cylinder walls and piston. Lubricating oil which gets heated due to friction of moving parts is cooled before recirculation. The cooling water used in the engine is used for cooling the lubricant also.

Advantages of diesel power plant:

1. Plant layout is simple. Hence it can be quickly installed and commissioned, while the erection and starting of a steam power plant or hydro-plant takes a fairly long time.

2. Quick starting and easy pick-up of loads are possible in a very short time.
3. Location of the plant is near the load center.
4. The load operation is easy and requires minimum labors.
5. Efficiency at part loads does not fall so much as that of a steam plant.
6. Fuel handling is easier and no problem of ash disposal exists.
7. The plant is smaller in size than steam power plant for same capacity.
8. Diesel plants operate at high overall efficiency than steam.

Applications of diesel power plant

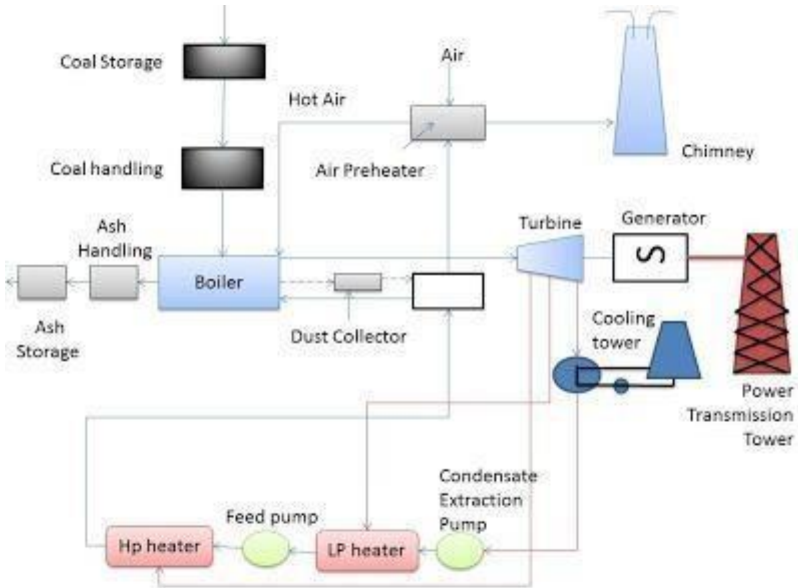
1. Diesel power plant's is in the range of 2 to 50 MW capacity. They are used ascentral station for small or medium power supplies.
2. They can be used as stand-by plants to hydro-electric power plants and steam powerplants for emergency services.
3. They can be used as peak load plants in combinations with thermal or hydro-plants.
4. They are quite suitable for mobile power generation and are widely used in transportation systems such as automobiles, railways, air planes and ships.
5. Now-a-days power cut has become a regular feature for industries. The onlysolution to tide over this difficulty is to install diesel generating sets.
6. Steam (Thermal) power Plant

A steam power plant, also known as thermal power plant, is using steam as working fluid. Steam is produced in a boiler using coal as fuel and is used to drive the prime mover, namely, the steam turbine. In the steam turbine, heat energy is converted into mechanical energy which is used for generating electric power. Generator is an electro- magnetic device which makes the power available in the form of electrical energy.

Layout of steam power plant:

The layout of the steam power plant is shown in figure below. It consists of four maincircuits. These are:

- Coal and ash circuit.
- Airand flue gas circuit
- Water and steam circuit and
- Cooling water circuit



Coal and ash circuit:

Coal from the storage yard is transferred to the boiler furnace by means of coal handling equipment like belt conveyor, bucket elevator, etc., ash resulting from the combustion of coal in the boiler furnace collects at the back of the boiler and is removedto the ash storage yard through the ash handling equipment.

Ash disposal :

The Indian coal contains 30% to 40% ash. A power plant of 100MW 20 to 25 tons of hot ash per hour. Hence sufficient space near the power plant is essential to dispose such large quantities of ash.

Air and flue gas circuit:

Air is taken from the atmosphere to the air pre heater. Air is heated in the air pre heaterby the heat of flue gas which is passing to the chimney. The hot air is supplied to the furnace of the boiler. The flue gases after combustion in the furnace, pass around the boiler tubes. The flue gases then passes through a dust collector, economizer and pre-heater before being exhausted to the atmosphere through the chimney. By this method the heat of the flue gases which would have been wasted otherwise is used effectively. Thus the overall efficiency of the plant is improved.

Air pollution:

The pollution of the surrounding atmosphere is caused by the emission of objectable gases and dust through the chimney. The air pollution and smoke cause nuisance to people surrounding the planet.

Feed water and steam circuit:

The steam generated in the boiler passes through super heater and is supplied to the steam turbine. Work is done by the expansion of steam in the turbine and the pressure of steam is reduced. The expanded steam then passes to the condenser, where it is condensed.The condensate leaving the condenser is first heated in a l.p. water heater by using the steam taken from the low pressure extraction point of the turbine. Again steam taken from the high pressure extraction point of the turbine is used for heating the feed water inthe H.P water heater. The hot feed water is passing through the economizer, where it is further heated by means of flue gases. The feed water which is sufficiently heated by thefeed water heaters and economizer is then fed into the boiler.

Cooling water circuit:

Abundant quantity of water is required for condensing the steam in the condenser. Water circulating through the condenser may be taken from various sources such as river or lake, provided adequate water supply is available from the river or lake throughout the year.
If adequate quantity of water is not available at the plant site, the hot water from the condenser is cooled in the cooling tower or cooling ponds and circulated again.

Advantages of thermal power plants:

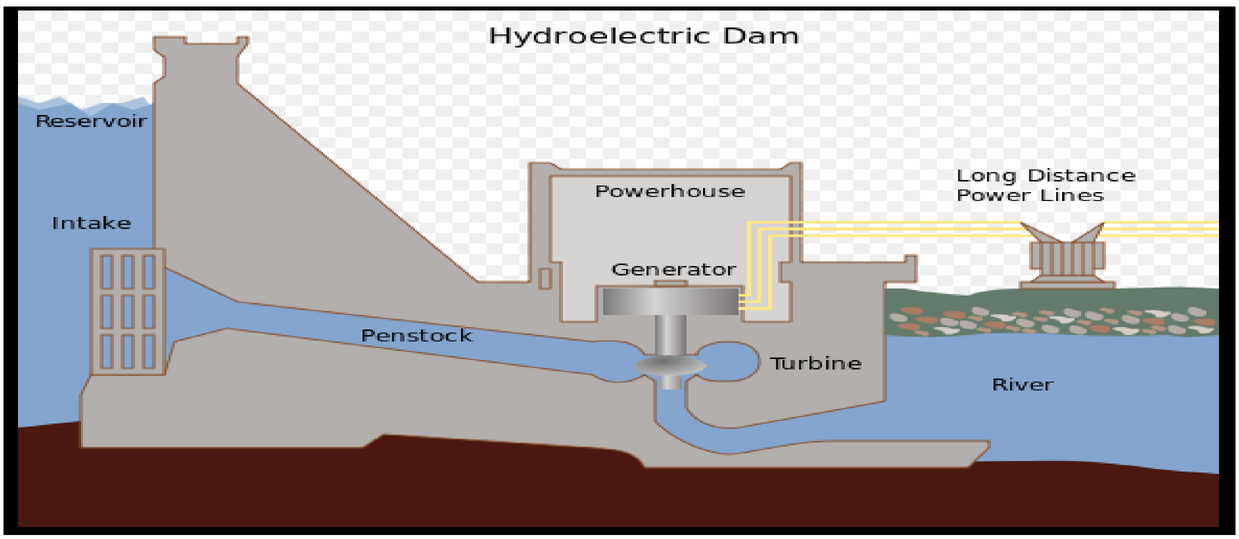
1. Initial cost is low compared with hydro-plant.
2. The power plant can be located near load center, so the transmission losses are

considerably reduced.

3. The generation of power is not dependent on the nature's mercy like hydro plant.
4. The construction and commissioning of thermal plant requires less period of timethan a hydro plant.

Hydro Electric Power Station

Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator. The power extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the head. A large pipe (the "penstock") delivers water from the reservoir to the turbine.



Pumped-storage

This method produces electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low electrical demand, the excess generation capacity is used to pump water into the higher reservoir. When the demand becomes greater, water is released back into the lower reservoir through a turbine. Pumped-storage schemes currently provide the most commercially important means of large-scale grid energy storage and improve the daily capacity factor of the generation system. Pumped storage is not an energy source, and appears as a negative number in listings.

Run-of-the-river

Run-of-the-river hydroelectric stations are those with small or no reservoir capacity, so that only the water coming from upstream is available for generation at that moment, and any oversupply must pass unused. A constant supply of water from a lake or existing reservoir upstream is a significant advantage in choosing sites for run-of-the- river. In the United States, run of the river hydropower could potentially provide 60,000 megawatts (80,000,000 hp) (about 13.7% of total use in 2011 if continuously available).

Tide

A tidal power station makes use of the daily rise and fall of ocean water due to tides; such sources are highly predictable, and if conditions permit construction of reservoirs, can also be dispatch able to generate power during high demand periods. Less common types of hydro schemes use water's kinetic energy or undammed sources such as undershot waterwheels. Tidal power is viable in a relatively small number of locations around the world.

Sizes, types and capacities of hydroelectric facilities

Large facilities

Large-scale hydroelectric power stations are more commonly seen as the largest power producing facilities in the world, with some hydroelectric facilities capable of generating more than double the installed capacities of the current largest nuclear power stations.

Small

Small hydro is the development of hydroelectric power on a scale serving a small community or industrial plant. The definition of a small hydro project varies but a generating capacity of up to 10 megawatts (MW) is generally accepted as the upper limit of what can be termed small hydro. This may be stretched to 25 MW and 30 MW in Canada and the United States. Small-scale hydroelectricity production grew by 28% during 2008 from 2005, raising the total world small- hydro capacity to 85 GW. Over 70% of this was in China (65 GW), followed by Japan (3.5 GW), the United States (3 GW), and India (2 GW).

Small hydro stations may be connected to conventional electrical distribution networks as a source of low-cost renewable energy. Alternatively, small hydro projects may be built in isolated areas that would be uneconomic to serve from a network, or in areas where there is no national electrical distribution network. Since small hydro projects usually have minimal reservoirs and civil construction work, they are seen as having a relatively low environmental impact compared to large hydro. This decreased environmental impact depends strongly on the balance between stream flow and power production.

Micro

Micro hydro is a term used for hydroelectric power installations that typically produce up to 100 kW of power. These installations can provide power to an isolated home or small community, or are sometimes connected to electric power networks. There are many of these installations around the world, particularly in developing nations as they can provide an economical source of energy without purchase of fuel. Micro hydro systems complement photovoltaic solar energy systems because in many areas, water flow, and thus available hydro power, is highest in the winter when solar energy is at a minimum.

Pico

Pico hydro is a term used for hydroelectric power generation of under 5 kW. It is useful in small, remote communities that require only a small amount of electricity. For example, to power one or two fluorescent light bulbs and a TV or radio for a few homes. Even smaller turbines of 200 - 300W may power a single home in a developing country with a drop of only 1 m (3 ft). A Pico- hydro setup is typically run-of-the-river, meaning that dams are not used, but rather pipes divert some of the flow, drop this down a gradient, and through the turbine before returning it to the stream.

Underground

An underground power station is generally used at large facilities and makes use of a large natural height difference between two waterways, such as a waterfall or mountain lake. An underground tunnel is constructed to take water from the high reservoir to the generating hall built in an underground cavern near the lowest point of the water tunnel and a horizontal tailrace taking water away to the lower outlet waterway.

Calculating available power

A simple formula for approximating electric power production at a hydroelectric station is: $P = \rho hrgk$, where

- P is Power in watts,
- ρ is the density of water (~1000 kg/m^3),
- h is height in meters,
- r is flow rate in cubic meters per second,
- g is acceleration due to gravity of 9.8 m/s^2,
- k is a coefficient of efficiency ranging from 0 to 1. Efficiency is often higher (that is, closer to 1) with larger and more modern turbines.

Advantages

Flexibility

Hydropower is a flexible source of electricity since stations can be ramped up and down very quickly to adapt to changing energy demands. Hydro turbines have a start-up time of the orderof a few minutes. It takes around 60 to 90 seconds to bring a unit from cold start-up to full load; this is much shorter than for gas turbines or steam plants. Power generation can also be decreased quickly when there is a surplus power generation. Hence the limited capacity of hydropower units is not generally used to produce base power except for vacating the flood pool or meeting downstream needs. Instead, it serves as backup for non-hydro generators.

Low power costs

The major advantage of hydroelectricity is elimination of the cost of fuel. The cost of operating a hydroelectric station is nearly immune to increases in the cost of fossil fuels such as oil, natural gas or coal, and no imports are needed. The average cost of electricity from a hydro station larger than 10 megawatts is 3 to 5 U.S. cents per kilowatt-hour. Hydroelectric stations have long economic lives, with some plants still in service after 50–100 years. Operating labor cost is also usually low, as plants are automated and have few personnel on site during normal operation.

Where a dam serves multiple purposes, a hydroelectric station may be added with relatively low construction cost, providing a useful revenue stream to offset the costs of dam operation. It has been calculated that the sale of electricity from the Three Gorges Dam will cover the construction costs after 5 to 8 years of full generation. Additionally, some data shows that in most countries large hydropower dams will be too costly and take too long to build to deliver a positive risk adjusted return, unless appropriate risk management measures are put in place.

Suitability for industrial applications

While many hydroelectric projects supply public electricity networks, some are created to serve specific industrial enterprises.

Reduced CO2 emissions

Since hydroelectric dams do not burn fossil fuels, they do not directly produce carbon dioxide. While some carbon dioxide is produced during manufacture and construction of the project, this is a tiny fraction of the operating emissions of equivalent fossil-fuel electricity generation. One measurement of greenhouse gas related and other externality comparison between energy sources can be found in the Extern project by the Paul Scherer Institute and the University of Stuttgart which was funded by the European Commission. According to that study, hydroelectricity produces the least amount of greenhouse gases and externality of any energy source. Coming in second place was wind, third was nuclear energy, and fourth was solar photovoltaic. The low greenhouse gas impact of hydroelectricity is found especially in temperate climates. The above study was for local energy in Europe; presumably similar conditions prevail in North America and Northern Asia, which all see a regular, natural freeze/thaw cycle (with associated seasonal plant decay and regrowth). Greater greenhouse gas emission impacts are found in the tropical regions because the reservoirs of power stations in tropical regions producea larger amount of methane than those in temperate areas.

Other uses of the reservoir

Reservoirs created by hydroelectric schemes often provide facilities for water sports, and become tourist attractions themselves. In some countries, aquaculture in reservoirs is common. Multi-use dams installed for irrigation support agriculture with a relativelyconstant water supply. Large hydro dams can control floods, which would otherwise affect people living downstream of the project.

Disadvantages

Ecosystem damage and loss of land

Large reservoirs associated with traditional hydroelectric power stations result in submersion of extensive areas upstream of the dams, sometimes destroying biologically rich and productive lowland and reverie valley forests, marshland and grasslands. The loss of land is often exacerbated by habitat fragmentation of surrounding areas caused by the reservoir.

Hydroelectric projects can be disruptive to surrounding aquatic ecosystems both upstream and downstream of the plant site. Generation of hydroelectric power changes the downstream river environment. Water exiting a turbine usually contains very little suspended sediment, which can lead to scouring of river beds and loss of riverbanks. Since turbine gates are often opened intermittently, rapid or even daily fluctuations in river flow are observed.

Siltation and flow shortage

When water flows it has the ability to transport particles heavier than itself downstream. This has a negative effect on dams and subsequently their power stations, particularly those on rivers or within catchment areas with high siltation. Siltation can fill a reservoir and reduce its capacity to control floods along with causing additional horizontal pressure on the upstream portion of the dam. Eventually, some reservoirs can become full of sediment and useless or over-top during a flood and fail. Changes in the amount of river flow will correlate with the amount of energy produced by a dam. Lower river flows will reduce the amount of live storage ina reservoir therefore reducing the amount of water that can be used for hydroelectricity. The result of diminished river flow can be power shortages in areas that depend heavily on hydroelectric power. The risk of flow shortage may increase as a result of climate change.

Relocation

Another disadvantage of hydroelectric dams is the need to relocate the people living where the reservoirs are planned. In 2000, the World Commission on Dams estimated that dams had physically displaced 40-80 million people worldwide.

Pumped storage plants

Pumped storage hydro power plant is a type of hydroelectric generation plant that stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation reservoir. It pumps water from lower reservoir to upper reservoir during off-peak period and generates electricity during peak periods. This is currently one of the most effective means of storing large amount of electrical energy. It helps in power generation load levelling.

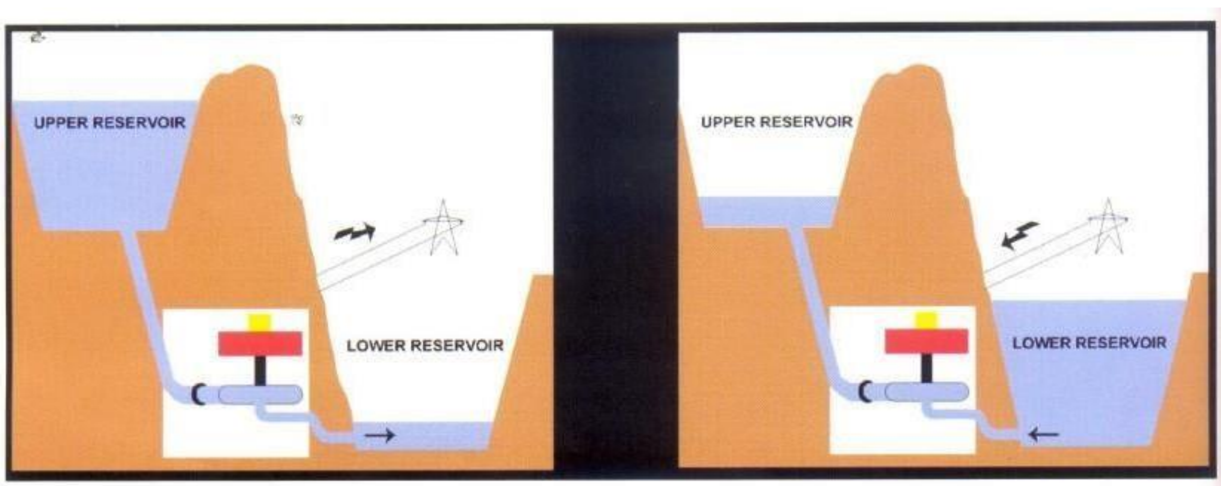
The basic principle of PSS is to store energy by pumping water from a low level reservoir downstream to power house (lower reservoir) into a high-level storage reservoir (upper reservoir) at times when the demand for power is low and then by utilizing the stored water of upper reservoir to generate hydroelectric power during the peak load periods.

The reservoir-based hydro power plant generally utilizes the water of the reservoir in a controlled manner to generate electricity and the water discharged from the turbine is passed to the tail trace from where it joins to the river. In a pumped storage scheme the water from the tail-trace is stored in a lower reservoir. During off-peak period, this water is pumped to the upper reservoir and during peak load hour this water is again used for power generation. Power for pumping is supplied either by an onsite conventional steam power plant or from remote

generating plant through electric grid. A separate pump can be installed to pump the water from the lower reservoir. Alternately, the turbine-generator set can be designed to operate as pump also so that during peak load hour it will function as power generating unit and during pumping it will act as a pump.
Generally, the later method is utilized in most of the pumped storage schemes.

In other words, the same machine which is reversible is used to generate power utilizing the potential energy of water stored in the upper reservoir during peak hours of demand and for pumping back water from the lower reservoir into the upper reservoir during off- peak hours utilizing surplus power from the grid. The water conductor path is same in both generating and pumping mode of operation.

When a reversible unit is rotated in one direction, it functions in the usual manner as turbine and generator. In the reverse direction, it operates as pump and motor. One crucial condition for installing pumped storage scheme is the availability of cheap off- peak power.



Advantages of pumped storage plants

The advantages of PSS are gives below

1.The net gain in energy for pumped storage scheme is negative depending on the efficiency of generator, turbine & pump due to the fact that some energy is lost while pumping & again during generation. But cost wise the company is not looser as peak- load energy is costlier then off-peak load. Hence the pumped storage schemes are economically advantageous because they convert low-value, low-cost, off-peak energy into high-value, high-cost, on –peak energy.

2. PSSs help in power generation load leveling. There are severe fluctuations in the daily power consumption patterns and it has become increasingly necessary to optimize the various types of power

3. Generation in order to achieve the most cost efficient supply of electricity. PSSs can make this possible by utilizing power from thermal and nuclear plants during off-peak hours to pump water from lower reservoir to upper reservoir and generate power during peak demand hours.

4. Although there are many methods of storing excess energy, it is the most attractive methodof storing large amount of energy.

5. It meets the peak demand of the system and improves system reliability. The availability of a pumped storage plant is much higher than of a thermal or nuclear plant.

6. Due to this, efficiency and economy of thermal power stations are improved. Thermal power plants cannot run at low loads efficiently. Pumped storage scheme consumes the off-peak power of thermal power plants making their operation economical.

7.Hydel power plants can be started and connected to the grid within 5 minutes where as thermal plant takes four to six hours. So to meet the peak load, pumped storage scheme is best suitable.

Principle of Nuclear Power Generation

Introduction

Nuclear power is universally controversial. Many would say that it is also universally needed. asan alternative or supplement to power generated by fossil fuels.

The combustion of fossil fuels produces carbon dioxide, now notorious for the threat of global warming. Nuclear power plants produce neither carbon dioxide nor oxides of sulfur and nitrogen, as does the burning of fossil fuels. Thus nuclear power reduces the global production of carbon dioxide and other pollutants, and helps to alleviate many of the pervasive problems of fossil fuel supply.

Petroleum is least available in regions of widest use; natural gas is, for the time being, plentiful and sought after by all; and widely abundant coal has come to be regarded as the great Satanof air pollution. Water power is important, but it offers limited possibility for growth. Solar energy, while promising, is far from being mainstay of the world's energy supply. Thus sources other than fossil fuels and nuclear power offer little hope to become major suppliers during our lifetimes. Nuclear power, in stasis for many years, may make a comeback.

Atoms and Molecules

Somewhat more than a hundred *elements* are known and are thought to be the building blocks ofeverything in the universe. The *atom* is the basic unit of structure for each element. An important connection between the microscopic world of the atom and the macroscopic world of experience is given by Avogadro's number. A gram-mole of any element has Avogadro's number (6.023 x 1023) of atoms.

The atom may be considered as consisting of a positively charged *nucleus* at itscenter and one or more negative charges around the nucleus called electrons that make the atom electrically neutral. The electron is the fundamental unit of negative charge. It may be viewed as a particle which is much smaller than the nucleus and which orbits around the nucleus as a planet orbits the sun, or it may be viewed as a diffuse electron cloud around the nucleus. Still another concept is that of a particle whose location isnot known but which is more likely to be in some places than others, its position being given by a probability distribution. We will not concern ourselves with therationales for these views. Thus atoms consist of nuclei surrounded by electrons. The sizes of atoms are conveniently measured in Angstroms (10-8 cm). The nucleus typically is of the order of10 .5 Angstroms. Thus the volume of the atom is largely due to the size of the outer electron's orbit or to the atom's electron cloud.

Molecules are collections of atoms held together by electromagnetic forces between the nuclei and the electrons. Atoms and molecules can exist in a variety of energy states associated with their electron distributions. These microscopic states and their macroscopic influences are dealt with theoretically in the fields of quantum mechanics and statistical thermodynamics. Molecules and atoms can interact with each other to form different molecules in ways that are controlled by their electron structures. These interactions, called *chemical reactions,* have little to do with the nucleus. The magnitudes of the energy associated with these chemical changes, while of great importance in thermal engineer-ing, are so small that they have no significant influence on the nuclei of the reacting atoms. Thus the nuclei may be thought of as merely going along for the ridewhen a chemical reaction occurs. An electrically neutral particle, however, can penetrate an atom's electromagnetic field and approach the nucleus, where it interacts via short range but powerful nuclear forces. Then the electrical forces holding the nucleus together may be overcome, resulting in changes in the nucleus. In these cases the inter atomic forces are largely irrelevant and are overpowered by nuclear events.

The Nucleus

The nucleus, for our purposes, may be thought of as being made up of integral numbers of protons and neutrons. The *proton* is a particle with a positive charge of the same magnitude as that of the electron, so that pairing a proton with an electron produces exact electrical neutrality. Thus protons account for the charge of the nucleus, and a like number of electrons ensures the electrical neutrality of the atom. Compared with the electron, the proton is a massive particle, having a mass which is about 1800 times the mass of the electron. Thus the hydrogen atom, which consists of one proton in the nucleus and a single electron in orbit around the nucleus, is electronically neutral and has a mass only slightly larger than that of the nucleus.

Atoms larger than the hydrogen atom have more than one proton in the nucleus and have one or more neutrons as well. A neutron, as the name suggests, is an electrically neutral particle with a mass only slightly larger than that of the proton. As components of the nucleus, protons and neutrons are called nucleons, and are thought of inter changeably with respect to mass because their masses differ so little from each other. The number of protons in an atom of an element is called the atomic number of the element. Thus hydrogen has an atomic number of 1. The atomic number of a given element is unique to that element. Thus we could identify the elements by their atomic numbers rather than by their names if we wished. Elements are ordered in the periodic table in part by their atomic numbers.

The mass number of an element is the number of nucleons in an atom of that element and is therefore the sum of the number of protons and neutrons in the nucleus. Atoms of a given element that have differing mass numbers are called *isotopes* of the element. A given isotope of an element is sometimes designated by a notation that includes the lament's chemical symbol, its mass number, and its atomic number. For example, the most common isotope of uranium is denoted as 92U238, where 92 is the atomic number of the element uranium and 238 is the sum of the number of protons and neutrons in the isotope nucleus. The isotopes are also sometimes simply identified by their name or symbol and mass number, such as U-235 or Uranium-235. Other significant examples are the isotopes of hydrogen, deuterium, 1H2, and tritium, 1H3, which have, respectively, one and two neutrons accompanying the proton. These isotopes are sometimes written 1D2 and 1T3 to reflect their commonly used names. The form of water, H2O, in which the isotope deuterium replaces hydrogen, is commonly called *heavy water*, D2O, because of the added mass of the extra neutron in each nucleus. It will be seen later that heavy water has characteristics that are advantageous in some nuclear processes.

Nuclear Reactions

Just as chemical fuels undergo chemical reactions that release energy, nuclei may also participate in energy-releasing nuclear reactions. When this happens atoms of erecting elements are converted to atoms of other elements, the sort of transmutation sought by the alchemists of the past.

Fission and Fusion

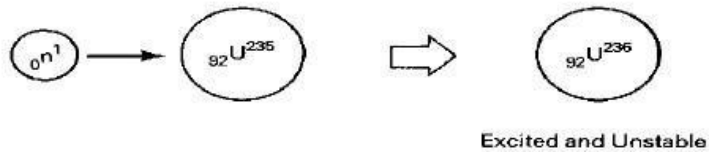
The process known as *nuclear fusion* occurs in nature in the stars, including our own sun. Since the Second World War, scientists have been attempting to achieve conditions for fusion in the laboratory. Because it can use heavy water from the sea as a fuel, *controlled thermonuclear fusion* offers the hope of vast quantities of power for many centuries in the future.

Fusion occurs when light atoms interact to form a heavier atom in reactions such as

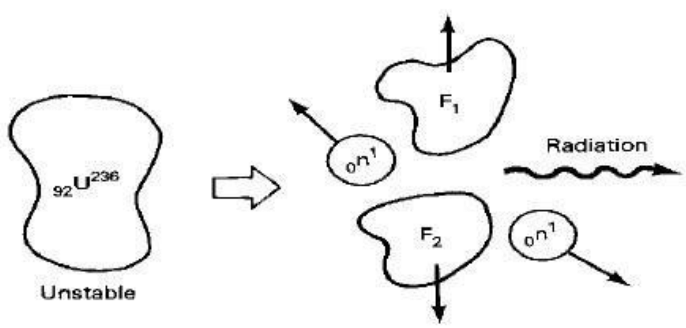
1D2 + 1D2 _ 2He3 + 0n1 + 3.2 MEV.

Here, two deuterium atoms collide to form helium-3 and a neutron while releasing 3.2 MEV of energy. Other fusion reactions exist that provide comparable amounts of energy. Using precise atomic masses measured with mass spectrometers, we can determine the differences of the masses of the reactants and products in this reaction. Application of the Einstein relation to the mass loss yields the same energy release (in this case 3.2 MEV) as is obtained by energy measurements. Thus the energy yield of known nuclear reactions may be determined with only mass measurements. For over fifty years, researchers have pursued the goal of achieving controlled Thermo nuclear fusion on a scale suited for commercial power production. Since there act ants are two positively charged nuclei, they must have high kinetic energies to overcome their mutual repulsion. These high energies imply a gaseous state with enormously high temperature, a condition known as a plasma. Because solid materials cannot exist at plasma conditions and plasmas would be cooled by the presence of solids, magnetic confinement of plasmas has been one approach to achieving thermonuclear plasma. Large experimental devices called Stellerators, Tokomaks, and mirror machines have been built to help solve the problems inherent in achieving large scale fusion reactions and in stably confining the associated thermonuclear plasma.

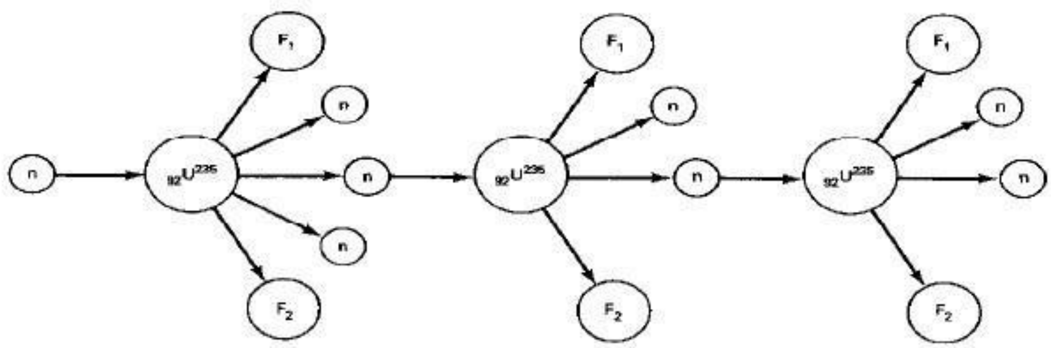
While progress continues, controlled thermonuclear fusion remains, and will likely continue, in the research stage for many years. It will therefore not be considered further here. Whereas nuclear fusion annihilates mass by forming larger atoms from light atoms; *fission* is a process of breaking massive atoms into two large, more-or-less equal-sized atoms, with an accompanying mass loss and energy release. While controlled fusion remains elusive, nuclear fission has beenproducing electrical power on a commercial scale for decades. The remainder of this chapter therefore deals with the fundamentals and commercial use of nuclear fission.



(a) Capture of a Neutron to form the Unstable Isotope, U-236.



(b) Creation of Fission Fragments from U-236.



Fundamentals of Nuclear Fission

Nuclear fission involves the breakup of certain massive elements resulting from collisions with neutrons. Uranium U-235, for instance, the isotope of uranium with 235nucleons, forms an highly excited isotope with 236 nucleons upon capture of a neutron,These excited U-236 atoms are unstable and break up into a variety of pairs of large atoms shortly after they are created. The many such fissions occurring in a reactor may be expressed as an average reaction:

92U235 + 0n1 _ 92U236_ *F*1 + *F*2 + 2.47 0n1 + 203 MEV

92U235 + 0n1 _ 92U236 _ 54Xe139 + 38Sr95 + 2 0n1 + energy

U-235 reactions exemplified by the Xe-Sr reaction create diverse fission fragments and small integral numbers of neutrons that average to 2.47 and release energies that average to 203 MEV. Over 80% of the 203 MEV of energy released by the average U- 235 fission reaction is the kinetic energy of the fission fragments associated with their large mass and high velocity. Because of their high energy, the fission fragments become ionized and ionize nearby atoms as they tear their way through surrounding materials. The fission fragments, however, travel only a very short distance, for interactions cause them to lose much of their energy to the surrounding solid. Thus most of the fission energy appears immediately as internal energy and therefore locally high temperature of the surrounding materials. It is, therefore, necessary that the fuel be cooled continuously to counter the *fission heat generation* to avoid temperature buildup and possible melting. The heated coolant is then provides the energy input for thermodynamic (usually steam) cycle.

As the fission fragments come to rest, their presence changes the character of the reactor materials. Non-fissionable material exists where fissionable and other atoms once resided. Intime these materials may decay radioactively, forming still different substances and releasing additional heat. But, importantly, they absorb neutrons without offering the possibility of fission. Thus the fission fragments are said to *poison* the reactor.

Nuclear Fuels

Uranium-235 is the only material that is both fissionable by thermal neutrons and found in nature in sufficient abundance for power production. Other *fissile fuels* are uranium-233 and plutonium-239 which are created from thorium-232 and uranium-238, respectively, by absorption of neutrons. Substances from which fissionable fuels are created, called *fertile fuels*, are transmuted into fissionable fuels in a reactor by extra neutrons not needed to sustain the fission chain reaction. Fertile fuel used in this way is said to have been *converted*. The resulting fissile materials may be processed to make new fuel elements when sufficient quantities have accumulated. Some of the converted material may be consumed directly by fissions during reactor operation. The composition of uranium ore is about 99.3% U-238 and 0.7% U-235. Because of the ore's small percentage of U-235, it is difficult to design a water-cooled, thermal reactor that uses natural uranium. Therefore the power reactors in the United States and most other parts of the world are thermal reactors that employ uranium enriched to between 2% and 5% U-235. Such reactors use ordinary (light) water for both cooling and moderation and are therefore commonly called light-water reactors.

Uranium enrichment is an expensive and difficult process because it involves separation of two isotopes of the same element, which rules out most chemical methods. Thus processes that rely on the small mass difference between U-235 andU-238 are usually used. The gaseous diffusion process involves conversion of uranium compound processed from the ore to gaseous uranium hexafluoride, UF6. The gaseous UF6 flows in hundreds of stages of diffusion through porous walls that eventually produce separate UF6 gas flows containing enriched and depleted uranium. The enriched UF6 then is processed to UO2 powder which is sintered into hard ceramic fuel pellets .The pellets are sealed in long cylindrical metal tubes for use in the reactor.

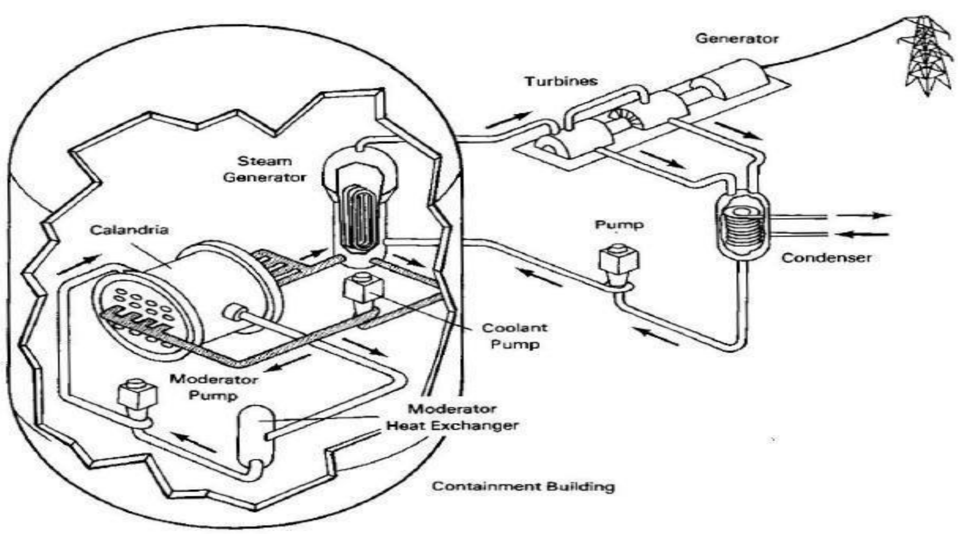
Newer enrichment processes currently available or under development includes: high speed centrifugal separation; which also relies on the uranium isotopic mass difference; a separation process that relies on differences in chemical reactivity between the isotopes; and laser enrichment, which relies on ionization of uranium by an intense light beam with subsequent chemical or physical separation of the ions.

The CANDU Reactor

The Canadian Deuterium Uranium, CANDU, reactor is a reactor of unique design that utilizes natural uranium as a fuel and heavy water as a moderator and coolant. These reactors produce a substantial saving due to the absence of fuel enrichment costs, but a large chemical plant is required to supply the quantities of heavy water required.

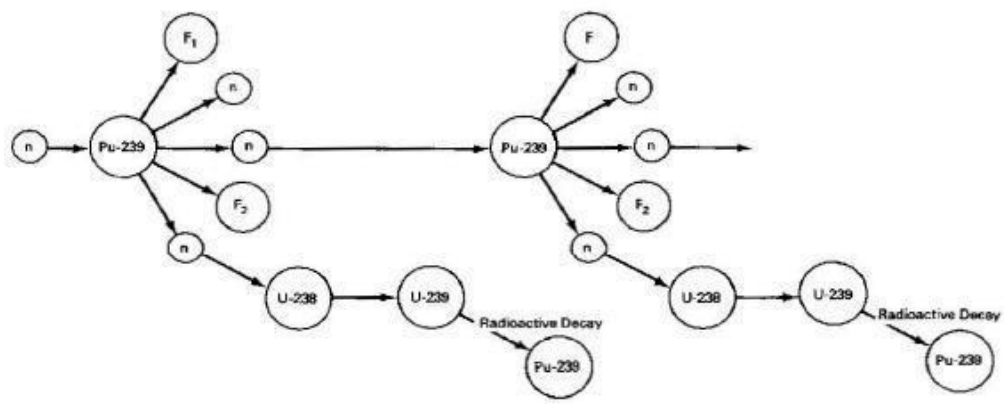
One of the important and unique features of the CANDU reactor is that, where as light-water reactors are shut down for refueling annually, CANDU reactors are refueled daily. The pressurized heavy-water-cooled fuel bundles are horizon-tally oriented in individual fuel channels inside the unpressurized "calandria,". Each bundle may be individually accessed, rearranged in the calandria, or replaced using special fuel handling equipment while the reactor is operating. Heavy water at atmospheric pressure in the calandria surrounds the fuel channels and moderates the reactor. Thus, in an emergency, the reactor can be shut down by draining the calandria to remove the moderator, thereby depriving the fuel of thermal neutrons. The pressurized heavy-water loop draws hot coolant from the fuel channels through headers to supply heat to steam generators as in a PWR. A light water loop passing through the steam generator in turn supplies steam to the turbine-feed water loop.

In the event of an emergency, escaping steam and radioactive materials would be drawn by vacuum into the structure. A coldwater spray would condense the steam to limit any pressure buildup. The thermal efficiency of a CANDU reactor plant is only about 29%, but the CANDU reactor uses a larger fraction of U-235 in uranium ore than other exactors and also makes better use of the U-238 to Pu-239 conversion process to extend fuel burn up.Moreover, statistics show that, among large reactors, CANDU reactors have outstanding reliability records, with annual capacity factors (the ratio of annual electrical energy output to maximum possible annual output) as high as 96% and cumulative capacity factors as high as 88%.



Fast Reactors

Reactors may be designed to fission with fast neutrons, but these fast reactors must be more compact than thermal reactors so that the fast neutrons may produce fissions quickly before they are absorbed or moderated by surrounding materials. They are designed with structural materials that are poor absorbers and moderators of neutrons, such as stainless steel. The coreof a fast reactor must contain a fissionable fuel of about 20% enrichment to compensate for the lowered probability of fashioning with high-energy neutrons. Because of their high fuel density, fast reactors have a high power density that poses a difficult cooling problem. One solution is the use of a liquid metal as coolant. Liquid metals such as sodium and potassium have excellentheat transfer characteristics and do not interfere significantly with neutron functions.



The choice of fuel used for thermal and fast reactors depends on the fuel’s fission Probability and the net number of neutrons produced per neutron absorbed. Cost- effective for thermal reactors is U-235, whereas Pu-239 is most suitable for fast reactors. In fashioning with fast neutrons, Pu-239 emits almost 20% more neutrons than does U-235. These additional neutrons are extremely important for making breeding practical, as will be discussed shortly. Because Pu-239 must be created from fertileU- 238, a plutonium reactor can use fuel processed from fuel produced in a uranium thermal reactor or in another plutonium reactor. This would occur in the core of a plutonium fast reactor and in a blanket of U-238 surrounding the core, where additional plutonium is created using neutrons that escape from the core.Note that each fission must produce a minimum of two neutrons for this reaction to continue. As a practical matter, more than two turns are required for complete replacement because of non- productive neutron captures' reactor that transmutes a fertile fuel to a fissionable fuel is called a *converter*. The *conversion* efficiency is the ratio of the number of new fissionable atoms produced to the number of atoms consumed in the fission.

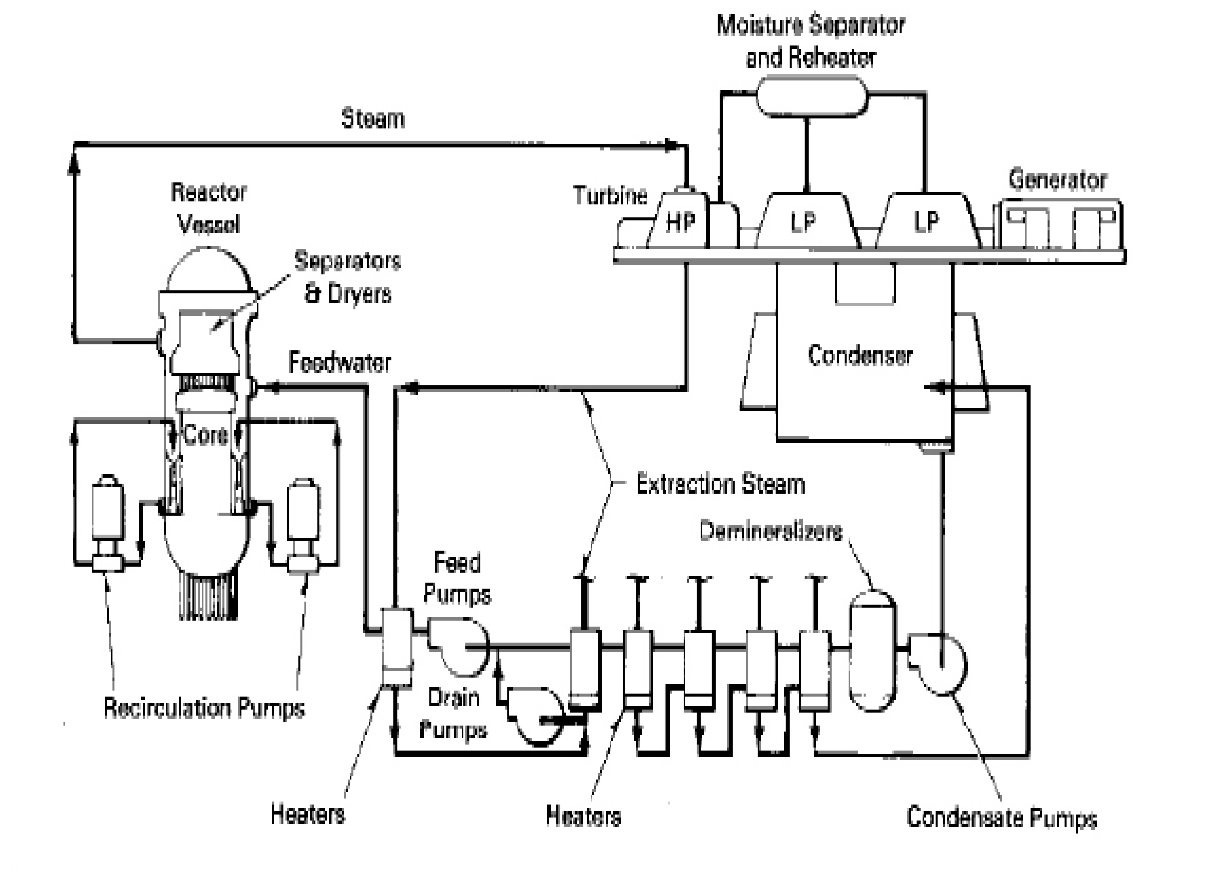
Power reactors active in the United States today are *light-water reactors*. They are designed so that the core is both moderated and cooled by highly purified water and therefore must use a fuel that fissions with thermal neutrons. Water has many advantages in thermal reactors. From a neutron point of view, H2O is an extremely efficient moderator. As we know from its extensive use in conventional power plants, water has excellent heat transfer characteristics, and the technologies of its use in steam power plants are well established. Water has disadvantages as well.

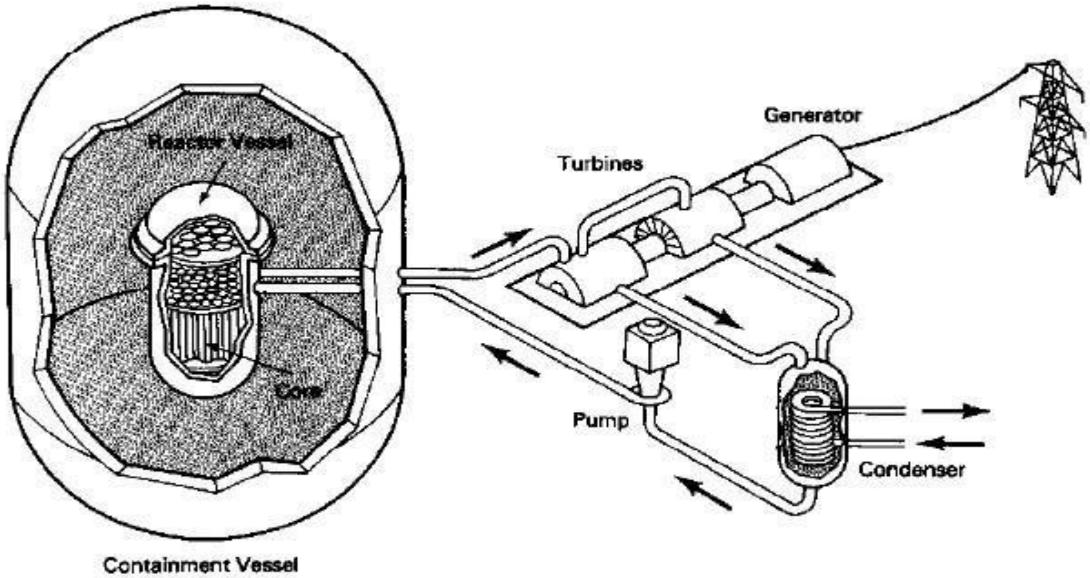
To maintain its excellent moderation and heat transfer capabilities, it must remain a liquid. Thus water reactors are currently limited to producing hot liquid or steam with little superheat. Moreover, boiling temperatures suited to an efficient plant require very high pressures, as in fossil fuel plants. Thus water-cooled reactor cores must be encased in pressure vessels that operate with high temperatures nearby. In addition, they must endure, for the design life of the plant, the severe environment resulting from the fission reactions.Finally, and perhaps most importantly, should reactor pressure integrity be lost while the reactor is operating, the liquid water will flash to steam, losing much of its heat transfer advantages. All of these factors contribute significantly to the challenges that an engineer faces in the thermal and mechanical design of light-water reactors.

There are two major types of light water reactors which are differentiated primarily by the thermodynamic conditions of the water used to cool uranium fuel elements in the reactor vessel.The boiling water reactor (BWR) operates at a pressure that allows boiling of the coolant water adjacent to the fuel elements. The water in the pressurized water reactor (PWR) is at about the same temperature as in the BWR but is at a higher pressure, so that the reactor coolant remains a liquid throughout the reactor coolant loop. In addition to their use in utility power reactors, PWRs are used in American nuclear submarines.

Boiling water reactor

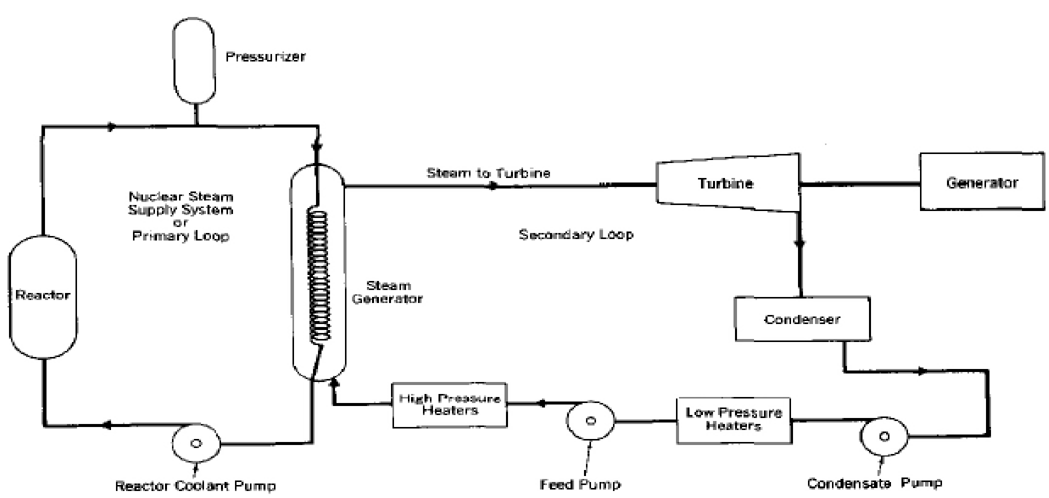
Water boils inside the reactor core, producing slightly radioactive steam that passes directly to the steam turbines. The radioactivity in the steam, however, has a half-life of only a few seconds. The carryover of radioactivity to the turbine-feed water system is virtually nonexistent, and experience has shown that components outside the reactor vessel (turbine, condensate pump, etc.) may be serviced essentially as in a fossil-fueled system. Some other reactor designs, such as the pressurized water reactor to be considered later, have an additional separate water loop, that isolates the turbine steam loop from the reactor coolant to provide further assurance that the turbine-feed water system components remain free of radioactivity.

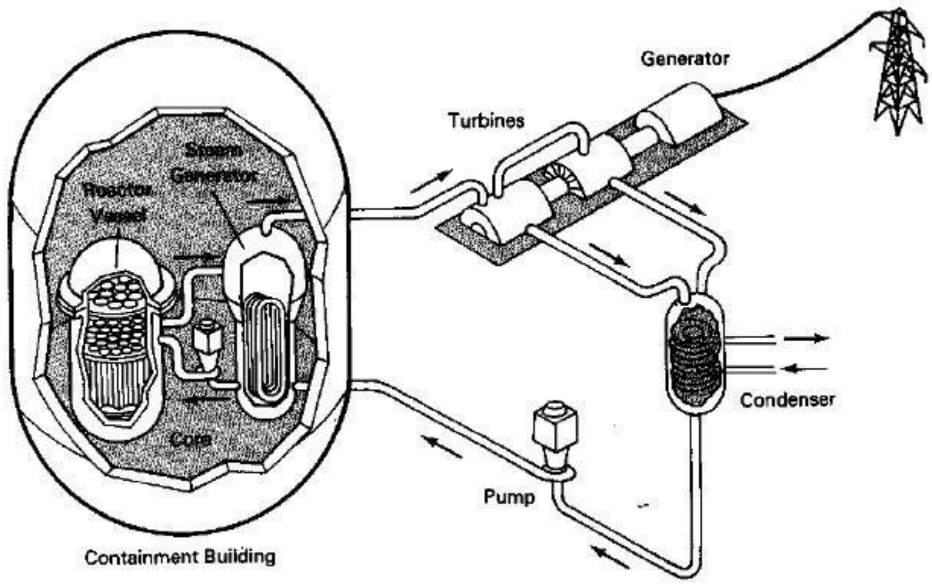




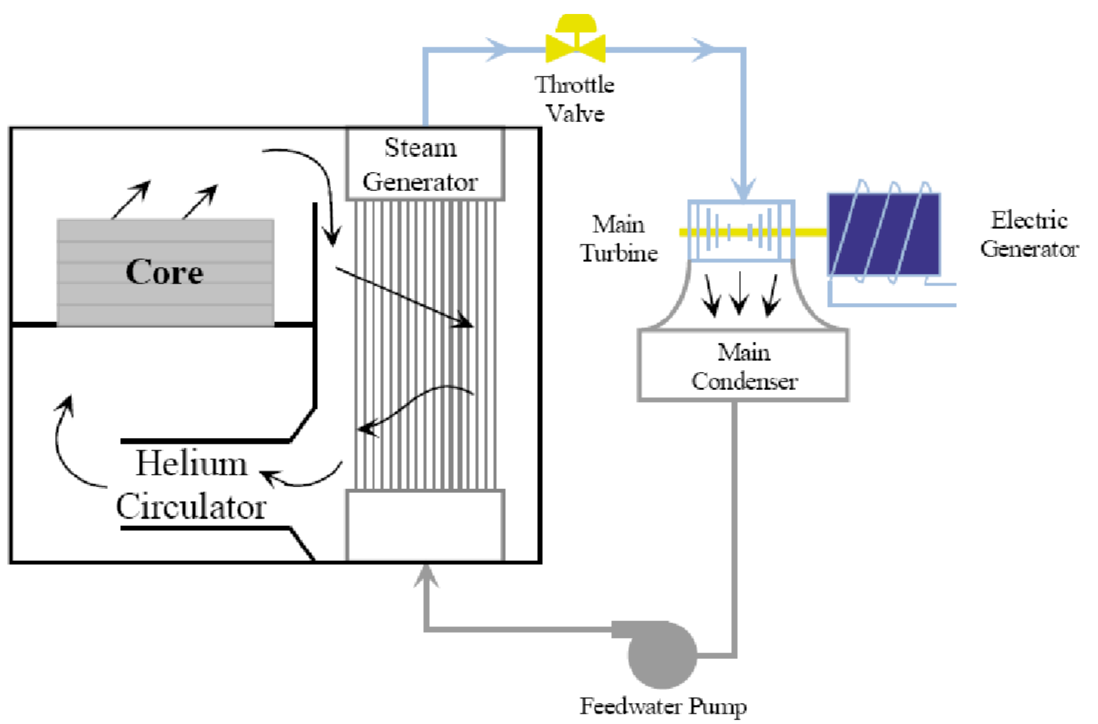
Pressurized Water Reactors

The pressurized water reactor, PWR, is currently the predominant reactor type in the world. It is a light-water reactor that uses slightly enriched U-235 as fuel. A major difference between BWRs and PWRs is that the pressure of the PWR coolant is above the saturation pressure (it is sub cooled liquid) through the entire cooling loop so that there is no possibility of bulk boiling in the core. Another difference is that control rods are at the top of the PWR and can drop by gravity into the reactor when necessary. The stairs and landings give some idea of the size of the equipment within the containment.





Advanced gas cooled reactor



In gas cooled reactor, gas is used as a coolant and graphite is used as a moderator.

Fast breeder reactor

The breeder reactor is of great importance because it would allow the use of the store of U-238 in uranium ore that remains as a by-product of the U-235enrichment process to provide fuel for current LWRs. This supply of U-238 has the potential to provide fuel for many years without further uranium mining. Fission ofU-235 is currently the only natural large-scale source of neutrons. The continued use of low-conversion- efficiency reactors could preclude the eventual use of much of the energy resource of the U-238 in uranium ore. One possibility for the design of a breeder reactor is a liquid-metal fast breeder reactor, LMFBR,which has the characteristics described briefly in the preceding section. The development of such a reactor involves careful design of its neutron economy and the development of a system of fuel reprocessing and nuclear waste storage. These topics will be considered in the next section.

Reactor control

A nuclear reactor is a system that contains and controls sustained nuclear chain reactions. Reactors are used for generating electricity, moving aircraft carriers and submarines, producing medical isotopes for imaging and cancer treatment, and for conducting research.

Fuel, made up of heavy atoms that split when they absorb neutrons, is placed into the reactor vessel (basically a large tank) along with a small neutron source. The neutrons start a chain reaction where each atom that splits releases more neutrons that cause other atoms to split. Each time an atom splits, it releases large amounts of energy in the form of heat. The heat is carried out of the reactor by coolant, which is most commonly just plain water. The coolant heats up and goes off to a turbine to spin a generator or drive shaft.

A nuclear reactor, formerly known as an atomic pile, is a device used to initiate and control a sustained nuclear chain reaction. Nuclear reactors are used at nuclear power plants for electricity generation and in propulsion of ships. Heat from nuclear fission is passed to a working fluid (water or gas), which runs through turbines. These either drive a ship's propellers or turn electrical generators. Nuclear generated steam in principle can be used for industrial process heat or for district heating. Some reactors are used to produce isotopes for medical and industrial use, or for production of weapons-grade plutonium. Some are run only for research.

Mechanism

A neutron is absorbed by the nucleus of a uranium-235 atom, which in turn splits into fast- moving lighter elements (fission products) and free neutrons. Though both reactors and nuclear weapons rely on nuclear chain-reactions, the rate of reactions in a reactor Occurs much more slowly than in a bomb. Just as conventional power-stations generate electricity by harnessing the thermal energy released from burning fossil fuels, nuclear reactors convert the energy released by controlled nuclear fission into thermal energy for further conversion to mechanical or electrical forms.

Fission

When a large fissile atomic nucleus such as uranium-235 or plutonium-239 absorbs a neutron, itmay undergo nuclear fission. The heavy nucleus splits into two or more lighter nuclei, (the fission products), releasing kinetic energy, gamma radiation, and free neutrons. A portion of these neutrons may later be absorbed by other fissile atoms and trigger further fission events, which release more neutrons, and so on. This is known as a nuclear chain reaction.

To control such a nuclear chain reaction, neutron poisons and neutron moderators can change the portion of neutrons that will go on to cause more fission. Nuclear reactors generally have automatic and manual systems to shut the fission reaction down if monitoring detects unsafe conditions.

Commonly-used moderators include regular (light) water (in 74.8% of the world's reactors), solidgraphite (20% of reactors) and heavy water (5% of reactors). Some experimental types of reactor have used beryllium, and hydrocarbons have been suggested as another possibility.

Heat generation

The reactor core generates heat in a number of ways:

- The kinetic energy of fission products is converted to thermal energy when these nuclei collide with nearby atoms.
- The reactor absorbs some of the gamma rays produced during fission and converts their energy into heat.
- Heat is produced by the radioactive decay of fission products and materials that have been activated by neutron absorption. This decay heat-source will remain for some time even after the reactor is shut down.

A kilogram of uranium-235 (U-235) converted via nuclear processes releases approximately three million times more energy than a kilogram of coal burned conventionally (7.2 × 1013 joulesper kilogram of uranium-235 versus 2.4 × 107 joules per kilogram of coal).

Cooling

A nuclear reactor coolant — usually water but sometimes a gas or a liquid metal (like liquid sodium) or molten salt — is circulated past the reactor core to absorb the heat that it generates. The heat is carried away from the reactor and is then used to generatesteam. Most reactor systems employ a cooling system that is physically separated from the water that will be boiled to produce pressurized steam for the turbines, like the pressurized water reactor. However, in some reactors the water for the steam turbines is boiled directly by the reactor core; for example the boiling water reactor.

Reactivity control

The power output of the reactor is adjusted by controlling how many neutrons are able to createmore fission. Control rods that are made of a neutron poison are used to absorb neutrons. Absorbing more neutrons in a control rod means that there are fewer neutrons available to cause fission, so pushing the control rod deeper into the reactor will reduce its power output, and extracting the control rod will increase it.

At the first level of control in all nuclear reactors, a process of delayed neutron emission by a number of neutron-rich fission isotopes is an important physical process. These delayed neutrons account for about 0.65% of the total neutrons produced in fission, with the remainder (termed "prompt neutrons") released immediately upon fission. The fission products which produce delayed neutrons have half lives for their decay by neutron emission that range from milliseconds to as long as several minutes, and so considerable time is required to determine exactly when a reactor reaches the critical point. Keeping the reactor in the zone of chain-reactivity where delayed neutrons are necessary to achieve a critical mass state allows mechanical devices or human operators to control a chain reaction in "real time"; otherwise the time between achievement of criticality and nuclear meltdown as a result of an exponential power surge from the normal nuclear chain reaction, would be too short to allow for intervention. This last stage, where delayed neutrons are no longer required to maintain criticality, is known as the prompt critical point. In some reactors, the coolant also acts as a neutron moderator. A moderator increases the power of the reactor by causing the fast neutrons that are released from fission to lose energy and become thermal neutrons. Thermal neutrons are more likely than fast neutrons to cause fission. If the coolant is a moderator, then temperature changes can affect the density of the coolant/moderator and therefore change power output. A higher temperature coolant would be less dense, and therefore a less effective moderator.

In other reactors the coolant acts as a poison by absorbing neutrons in the same way that the control rods do. In these reactors power output can be increased by heating the coolant, which makes it a less dense poison. Nuclear reactors generally have automatic and manual systemsto scram the reactor in an emergency shutdown. Most types of reactors are sensitive to a process variously known as xenon poisoning, or the iodine pit. The common fission product Xenon-135 produced in the fission process acts as a "neutron poison" that absorbs neutrons and therefore tends to shut the reactor down. Xenon-135 accumulation can be controlled by keeping power levels high enough to destroy it by neutron absorption as fast as it is produced. Reactors used in nuclear marine propulsion (especially nuclear submarines) often cannot be run at continuous power around the clock in the same way that land-based power reactors are normally run, andin addition often need to have a very long core life without refueling. For this reason many designs use highly enriched uranium but incorporate burnable neutron poison in the fuel rods.

Waste disposal

Radioactive Waste Management

- Nuclear power is the only large-scale energy-producing technology which takes full responsibility for all its wastes and fully costs this into the product.
- The amount of radioactive wastes is very small relative to wastes produced by fossil fuel electricity generation.
- Used nuclear fuel may be treated as a resource or simply as a waste.
- Nuclear wastes are neither particularly hazardous nor hard to manage relative to other toxic industrial wastes.
- Safe methods for the final disposal of high-level radioactive waste are technically proven;the international consensus is that this should be geological disposal.

All parts of the nuclear fuel cycle produce some radioactive waste (radiate) and the relativelymodest cost of managing and disposing of this is part of the electricity cost, *i.e.* it is internalized and paid for by the electricity consumers.

At each stage of the fuel cycle there are proven technologies to dispose of the radioactive wastes safely. For low- and intermediate-level wastes these are mostly being implemented. For high-level wastes some countries await the accumulation of enough of it to warrant building geological repositories; others, such as the USA, have encountered political delays.

Unlike other industrial wastes, the level of hazard of all nuclear waste – its radioactivity – diminishes with time. Each radionuclide contained in the waste has a half-life – the time taken for half of its atoms to decay and thus for it to lose half of its radioactivity. Radionuclide with long half-lives tend to be alpha and beta emitters – making their handling easier – while those with short half-lives tend to emit the more penetrating gamma rays. Eventually all radioactive wastes decay into non-radioactive elements. The more radioactive an isotope is, the faster it decays.

The main objective in managing and disposing of radioactive (or other) waste is to protect people and the environment. This means isolating or diluting the waste so that the rate or concentration of any radionuclide returned to the biosphere is harmless. To achieve this, practically all wastes are contained and managed – some clearly need deep and permanent burial. From nuclear power generation, none is allowed to cause harmful pollution.All toxic wastes need to be dealt with safely, not just radioactive wastes. In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes (the balance of which remains hazardous indefinitely).

Types of radioactive waste

Exempt waste & very low level waste

Exempt waste and very low level waste (VLLW) contains radioactive materials at a level whichis not considered harmful to people or the surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping *etc*) produced during rehabilitation or dismantling operations on nuclear industrial sites. Other industries, such as food processing, chemical, steel *etc* also produce VLLW as a result of the concentration of natural radioactivity present in certain minerals used in their manufacturing processes (see also information page on Naturally-Occurring Radioactive Materials). The waste is therefore disposed of with domestic refuse, although countries such as France are currently developing facilities to store VLLW in specifically designed VLLW disposal facilities.

Low-level waste

Low-level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, and filters *etc*, which contain small amounts of mostly short-lived radioactivity. It does not require shielding during handling and transport and issuitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. It comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste.

Intermediate-level waste

Intermediate-level waste (ILW) contains higher amounts of radioactivity and some requires shielding. It typically comprises resins, chemical sledges and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. It makes up some 7% of the volume and has 4% of the radioactivity of all radiate. By definition, its radioactive decay generates heat of less than about 2 kW/m3 so does not require heating to be taken into account in design of storage ordisposal facilities.

High-level waste

High-level waste (HLW) arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and Trans uremic elements generated in the reactor core. It is highly radioactive and hot due to decay heat, so requires cooling and shielding. It has thermal power above about 2 kW/m3 and can be considered as the 'ash' from 'burning' uranium. HLW accounts for over 95% of the total radioactivity produced in the process of electricity generation. There are two distinct kinds of HLW:

- Used fuel itself.
- Separated waste from reprocessing the used fuel (as described in section on Managing HLW from used fuel below).

HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclide to decrease to levels that are considered no longer hazardous for people and the surrounding environment. If generally short-lived fission products can be separated from long-lived actinides, this distinction becomes important in management and disposal of HLW.

HLW is a major focus of attention regarding nuclear power, and the industry has proposed that any option for the management of used nuclear fuel is sustainable if:

It covers all the steps of used fuel management until final disposal, in accordance with an acceptable, practical plan.

It proves to be feasible with an acceptable impact level by meeting defined key criteria. It includes a realistic and balanced financing plan.
It does not impose undue burdens on future generations.

Mining and milling

Traditional uranium mining generates fine sandy tailings, which contain virtually all the naturally occurring radioactive elements naturally found in uranium ore. These are collected in engineered tailings dams and finally covered with a layer of clay and rock to inhibit the leakage of radon gas and ensure long-term stability. In the short term, the tailings material is often covered with water. After a few months, the tailings material contains about 75% of the radioactivity of the original ore. Strictly speaking these are not classified as radioactive wastes.

Conversion, enrichment, fuel fabrication

Uranium oxide concentrate from mining, essentially 'yellowcake' (U_3O_8), is not significantly radioactive – barely more so than the granite used in buildings. It is refined then converted to uranium hexafluoride gas (UF_6). As a gas, it undergoes enrichment to increase the U-235 content from 0.7% to about 3.5%. It is then turned into a hard ceramic oxide (UO_2) for assembly as reactor fuel elements.

The main byproduct of enrichment is depleted uranium (DU), principally the U-238 isotope, which is stored either as UF6 or U3O8. About 1.2 million tones of DU is now stored. Some is used in applications where its extremely high density makes it valuable, such as the keels of yachts and military projectiles. It is also used (with reprocessed plutonium) for making mixed oxide fuel and to dilute highly-enriched uranium from dismantled weapons which are now being used for reactor fuel (see pages on Uranium and Depleted Uranium and Military Warheads as a Source of Nuclear Fuel).

Questions

Part – A

1. State the two main applications of a diesel power plant?
2. What type of turbine is used in the thermal station?
3. What is an economiser?
4. What are the equipments which are helpful in improving the efficiency of steam plants?
5. What is spillway and penstock in hydro station?
6. List out the factors to be considered in the selection of site for hydro-projects.
7. What is a pumped storage plant? What is its utility?
8. Name the parts of a nuclear plant.
9. How are nuclear reactors classified?
10. How are nuclear reactors controlled?
11. What is the necessity of moderator?
12. Give any two advantages of nuclear power plants.

Part-B

1. Draw the schematic diagram of a diesel power plant and explain each component.
2. a. Give the classification of hydro plants depending on the head of operation.

   b. Describe one type of hydro-plant with relevant diagram.
3. Draw the schematic diagram of a steam power station and explain each component.
4. a). Discuss the various types of turbines used in steam power generation.

b). Write short notes on pumped storage plant & discuss the economy of it.

5. Describe briefly the different types of nuclear reactors used for generating electricity commercially.

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SEE1303-POWER GENERATION AND UTILIZATION

UNIT – II ECONOMICS OF GENERATION

UNIT II-ECONOMICS OF GENERATION

Introduction-Definitions-Load Duration Curve-Number and size of Generator Units-Base Load and Peak Load Plants-Cost of Electrical Energy-Fixed cost-Running Cost of Energy-Tariff or Charge to Consumer.

Introduction

The function of a power station is to deliver power to a large number of consumers. However, the power demands of different consumers vary in accordance with their activities. The result of this variation in demand is that load on a power station is never constant, rather it varies from time to time. Most of the complexities of modern power plant operation arise from the inherent variability of the load demanded by the users. Unfortunately, electrical power cannot be stored and, therefore, the power station must produce power as and when demanded to meet the requirements of the consumers. On one hand, the power engineer would like that the alternators in the power station should run at their rated capacity for maximum efficiency and on the other hand, the demands of the consumers have wide variations. This makes the design of a power station highly complex. In this chapter, we shall focus our attention on the problems of variable load on power station.

Variable Load on Power Station

The load on a power station varies from time to time due to uncertain demands of the consumers and is known as variable load on the station.A power station is designed to meet the load requirements of the consumers.

An ideal load on the station, from stand point of equipment needed and operating routine, would be one of constant magnitude and steady duration. However, such a steady load on the station is never realised in actual practice. The consumers require their small or large block of power in accordance with the demands of their activities. Thus the load demand of one consumer at any time may be different from that of the other consumer. The result is that load on the power station varies from time to time.

Effects of variable load

The variable load on a power station introduces many perplexities in its operation. Some of the important effects of variable load on a power station are :

(i) Need of additional equipment.

The variable load on a power station necessitates to have additional equipment. By way of illustration, consider a steam power station. Air, coal and water are the raw materials for this plant. In order to produce variable power, the supply of these materials will be required to be varied correspondingly. For instance, if the power demand on the plant increases, it must be followed by the increased flow of coal, air and water to the boiler in order to meet the increased demand. Therefore, additional equipment has to be installed to accomplish this job. As a matter of fact, in a modern power plant, there is much equipment devoted entirely to adjust the rates of supply of raw materials in accordance with the power demand made on the plant.

(ii) Increase in production cost.

The variable load on the plant increases the cost of the production of electrical energy. An alternator operates at maximum efficiency near its rated capacity. If a single alternator is used, it will have poor efficiency during periods of light loads on the plant. Therefore, in actual practice, a number of alternators of different capacities are installed so that most of the alternators can be operated at nearly full load capacity. However, the use of a number of generating units increases the initial cost per kW of the plant capacity as well as floor area required. This leads to the increase in production cost of energy

Load Curves

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a load curve.

The load on a power station is never constant; it varies from time to time. These load variations during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t. time during the day. It is clear that load on the power station is varying, being maximum at 6 P.M. in this case. It may be seen that load curve indicates at a glance the general character of the load that is being imposed on the plant. Such a clear representation cannot be obtained from tabulated figures.

The monthly load curve can be obtained from the daily load curves of that month. For this purpose, average* values of power over a month at different times of the day are calculated and then plotted on the graph. The monthly load curve is generally used to fix the rates of energy. The yearly load curve is obtained by considering the monthly load curves of that particular year. The yearly load curve is generally used to determine the annual load factor.

Importance:

The daily load curves have attained a great importance in generation as they supply the following information readily :

1.The daily load curve shows the variations of load on the power station during different hours of the day.

2.The area under the daily load curve gives the number of units generated in the day. Units generated/day = Area (in kWh) under daily load curve.

3.The highest point on the daily load curve represents the maximum demand on the station on that day.

4.The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

Average load = Area (in kWh) under daily load curve / 24 hours

5.The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor.

Load factor = Average load / Max. demand = Average load * 24 / Max. demand * 24 = Area (in kWh) under daily load curve / Total area of rectangle in which the load curve is contained.

5.The load curve helps in selecting* the size and number of generating units.

6.The load curve helps in preparing the operation schedule** of the station.

Important Terms and Factors

The variable load problem has introduced the following terms and factors in power plant engineering:

(i) Connected load.

It is the sum of continuous ratings of all the equipments connected to supply system. A power station supplies load to thousands of consumers. Each consumer has certain equipment installed in his premises. The sum of the continuous ratings of all the equipments in the consumer's premises is the "connected load" of the consumer. For instance, if a consumer has connections of five 100-watt lamps and a power point of 500 watts, then connected load of the consumer is 5 × 100 + 500 = 1000 watts. The sum of the connected loads of all the consumers is the connected load to the power station.

(ii) Maximum demand :

It is the greatest demand of load on the power station during a given period. The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period (say a day) is the maximum demand. the maximum demand on the power station during the day is 6 MW and it occurs at 6 P.M. Maximum demand is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time. The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station. The station must be capable of meeting the maximum demand.

(iii) Demand factor.

It is the ratio of maximum demand on the power station to its connected load i.e.,

Demand factor = Maximum demand /Connected load

The value of demand factor is usually less than 1. It is expected because maximum demand on the power station is generally less than the connected load. If the maximum demand on the power station is 80 MW and the connected load is 100 MW,

then demand factor = 80/100 = 0·8.

The knowledge of demand factor is vital in determining the capacity of the plant equipment.

(iv) Average load.

The average of loads occurring on the power station in a given period (day or month or year) is known as average load or average demand.

Daily average load = No. of units (kWh) generated in a day / 24 hours

Monthly average load = No. of units (kWh) generated in a month / Number of hours in a month

Yearly average load = No. of units (kWh) generated in a year / 8760 hours

(v) Load factor.

The ratio of average load to the maximum demand during a given period is known as load factor i.e.,

Load factor = Average load / Max. demand

If the plant is in operation for T hours,

Units generated in T hours / Max. demand *T hours

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand. The load factor plays key role in determining the overall cost per unit generated. Higher the load factor of the power station, lesser* will be the cost per unit generated.

(vi) Diversity factor.

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e.,

Diversity factor = Sum of individual max. demands / Max. demand on power station

A power station supplies load to various types of consumers whose maximum demands generally do not occur at the same time. Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers. Obviously, diversity† factor will always be greater than 1. The greater the diversity factor, the lesser‡ is the cost of generation of power.

(vii) Plant capacity factor.

It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e.,

Plant capacity factor = Actual energy produced / Max. energy that could have been produced

= Average demand / Plant capacity

Thus if the considered period is one year,

Annual plant capacity factor = Annual kWh output / Plant capacity* 8760

The plant capacity factor is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future. Therefore, the installed capacity of the plant is always somewhat greater than the maximum demand on the plant.

Reserve capacity = Plant capacity − Max. demand

It is interesting to note that difference between load factor and plant capacity factor is an indication of reserve capacity. If the maximum demand on the plant is equal to the plant capacity, then load factor and plant capacity factor will have the same value. In such a case, the plant will have no reserve capacity.

(viii) Plant use factor.

It is ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation i.e.

Plant use factor = Station output in kWh / Plant capacity * Hours of use

Units Generated per Annum

It is often required to find the kWh generated per annum from maximum demand and load factor. The procedure is as follows :

Load factor = Average load / Max. demand

∴ Average load = Max. demand × L.F.

Units generated/annum = Average load (in kW) × Hours in a year

= Max. demand (in kW) × L.F. × 8760

Load Duration Curve

When the load elements of a load curve are arranged in the order of descending magnitudes, the curve thus obtained is called a load duration curve.

The following points may be noted about load duration curve :

(i) The load duration curve gives the data in a more presentable form. In other words, it readily shows the number of hours during which the given load has prevailed.

(ii) The area under the load duration curve is equal to that of the corresponding load curve. Obviously, area under daily load duration curve (in kWh) will give the units generated on that day.

(iii) The load duration curve can be extended to include any period of time. By laying out the abscissa from 0 hour to 8760 hours, the variation and distribution of demand for an entire year can be summarised in one curve. The curve thus obtained is called the annual load duration curve.

Types of Loads

A device which taps electrical energy from the electric power system is called a load on the system. The load may be resistive (e.g., electric lamp), inductive (e.g., induction motor), capacitive or some combination of them. The various types of loads on the power system are :

(i) Domestic load.

Domestic load consists of lights, fans, refrigerators, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (i.e., 24 hours) e.g., lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

(ii) Commercial load.

Commercial load consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of airconditioners and space heaters.

(iii) Industrial load.

Industrial load consists of load demand by industries. The magnitude of industrial load depends upon the type of industry. Thus small scale industry requires load upto 25 kW, medium scale industry between 25kW and 100 kW and large-scale industry requires load above 500 kW. Industrial loads are generally not weather dependent.

(iv) Municipal load.

Municipal load consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric motors. Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

(v) Irrigation load.

This type of load is the electric power needed for pumps driven by motors to supply water to fields. Generally this type of load is supplied for 12 hours during night.

(vi) Traction load.

This type of load includes tram cars, trolley buses, railways etc. This class of load has wide variation. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

2.1. The maximum demand on a power station is 100 MW. If the annual load factor is 40% , calculate the total energy generated in a year.

Solution.

Energy generated/year = Max. demand × L.F. × Hours in a year

$= (100 \times 10^3) \times (0{\cdot}4) \times (24 \times 365)$ kWh $= 3504 \times 10^5$ kWh

2.2. A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being $61{\cdot}5 \times 10^6$ per annum. Calculate (i) the demand factor and (ii) load factor.

Solution.

Demand factor = Max. demand / Connected load = 20 / 43 = 0·465

Average demand = Units generated / annum Hours in a year = 7020 kW

∴ Load factor = Average demand / Max. demand = 0·351 or 35·1%

Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature. It is clear that load on the power station varies from time to time. However, a close look at the load curve reveals that load on the power station can be considered in two parts, namely;

(i) Base load (ii) Peak load

(i) Base load.

The unvarying load which occurs almost the whole day on the station is known as base load. it is clear that 20 MW of load has to be supplied by the station at all times of day and night i.e. throughout 24 hours. Therefore, 20 MW is the base load of the station. As base load on the station is almost of constant nature, therefore, it can be suitably supplied (as discussed in the next Article) without facing the problems of variable load.

(ii) Peak load.

The various peak demands of load over and above the base load of the station is known as peak load. it is clear that there are peak demands of load excluding base load. These peak demands of the station generally form a small part of the total load and may occur throughout the day.

Economics of Power Generation

The art of determining the per unit (i.e., one kWh) cost of production of electrical energy is known as economics of power generation.

The economics of power generation has assumed a great importance in this fast developing power plant engineering. A consumer will use electric power only if it is supplied at reasonable rate. Therefore, power engineers have to find convenient methods to produce electric power as cheap as possible so that consumers are tempted to use electrical methods. Before passing on to the subject further, it is desirable that the readers get themselves acquainted with the following terms much used in the economics of power generation :

(i) Interest.

The cost of use of money is known as interest. A power station is constructed by investing a huge capital. This money is generally borrowed from banks or other financial institutions and the supply company has to pay the annual interest on this amount. Even if company has spent out of its reserve funds, the interest must be still allowed for, since this amount could have earned interest if deposited in a bank. Therefore, while calculating the cost of production of electrical energy, the interest payable on the capital investment must be included. The rate of interest depends upon market position and other factors, and may vary from 4% to 8% per annum.

(ii) Depreciation.

The decrease in the value of the power plant equipment and building due to constant use is known as depreciation. If the power station equipment were to last for ever, then interest on the capital investment would have been the only charge to be made. However, in actual practice, every power station has a useful life ranging from fifty to sixty years. From the time the power station is installed, its equipment steadily deteriorates due to wear and tear so that there is a gradual reduction in the value of the plant. This reduction in the value of plant every year is known as annual depreciation. Due to depreciation, the plant has to be replaced by the new one after its useful life. Therefore, suitable amount must be set aside every year so that by the time the plant retires, the collected amount by way of depreciation equals the cost of replacement. It becomes obvious that while determining the cost of production, annual depreciation charges must be included.

Cost of Electrical Energy

The total cost of electrical energy generated can be divided into three parts, namely ; (i) Fixed cost ; (ii) Semi-fixed cost ; (iii) Running or operating cost.

(i) Fixed cost.

It is the cost which is independent of maximum demand and units generated. The fixed cost is due to the annual cost of central organisation, interest on capital cost of land and salaries of high officials. The annual expenditure on the central organisation and salaries of high officials is fixed since it has to be met whether the plant has high or low maximum demand or it generates less or more units. Further, the capital investment on the land is fixed and hence the amount of interest is also fixed.

(ii) Semi-fixed cost.

It is the cost which depends upon maximum demand but is independent of units generated. The semi-fixed cost is directly proportional to the maximum demand on power station and is on account of annual interest and depreciation on capital investment of building and equipment, taxes, salaries of management and clerical staff. The maximum demand on the power station determines its size and cost of installation. The greater the maximum demand on a power station, the greater is its size and cost of installation. Further, the taxes and clerical staff depend upon the size of the plant and hence upon maximum demand.

(iii) Running cost.

It is the cost which depends only upon the number of units generated. The running cost is on account of annual cost of fuel, lubricating oil, maintenance, repairs and salaries of operating staff. Since these charges depend upon the energy output, the running cost is directly proportional to the number of units generated by the station. In other words, if the power station generates more units, it will have higher running cost and vice-versa.

Methods of Determining Depreciation

There is reduction in the value of the equipment and other property of the plant every year due to depreciation. Therefore, a suitable amount (known as depreciation charge) must be set aside annually so that by the time the life span of the plant is over, the collected amount equals the cost of replacement of the plant. The following are the commonly used methods for determining the annual depreciation charge : (i) Straight line method ; (ii) Diminishing value method ; (iii) Sinking fund method.

(i) Straight line method.

In this method, a constant depreciation charge is made every year on the basis of total depreciation and the useful life of the property. Obviously, annual depreciation charge will be equal to the total depreciation divided by the useful life of the property. Thus, if the initial cost of equipment is Rs 1,00,000 and its scrap value is Rs 10,000 after a useful life of 20 years, then,

Annual depreciation charge = Total depreciation / Useful life = 100 000 -10 000 / 20

= Rs 4,500

In general, the annual depreciation charge on the straight line method may be expressed as

Annual depreciation charge = P-S / n

where

P = Initial cost of equipment

n = Useful life of equipment in years

S = Scrap or salvage value after the useful life of the plant.

The straight line method is extremely simple and is easy to apply as the annual depreciation charge can be readily calculated from the total depreciation and useful life of the equipment. It is clear that initial value P of the equipment reduces uniformly, through depreciation, to the scrap value S in the useful life of the equipment. The depreciation curve (PA) follows a straight line path, indicating constant annual depreciation charge. However, this method suffers from two defects. Firstly, the assumption of constant depreciation charge every year is not correct. Secondly, it does not account for the interest which may be drawn during accumulation.

(ii) Diminishing value method.

In this method, depreciation charge is made every year at a fixed rate on the diminished value of the equipment. In other words, depreciation charge is first applied to the initial cost of equipment and then to its diminished value. As an example, suppose the initial cost of equipment is Rs 10,000 and its scrap value after the useful life is zero. If the annual rate of depreciation is 10%, then depreciation charge for the first year will be 0·1 × 10,000 = Rs 1,000. The value of the equipment is diminished by Rs 1,000 and becomes Rs 9,000. For the second year, the depreciation charge will be made on the diminished value (i.e. Rs 9,000) and becomes 0·1 × 9,000 = Rs 900. The value of the equipment now becomes 9000 − 900 = Rs 8100. For the third year, the depreciation charge will be 0·1 × 8100 = Rs 810 and so on.

(iii) Sinking fund method.

In this method, a fixed depreciation charge is made every year and interest compounded on it annually. The constant depreciation charge is such that total of annual instalments plus the interest accumulations equal to the cost of replacement of equipment after its useful life.

2.3. A transformer costing Rs 90,000 has a useful life of 20 years. Determine the annual depreciation charge using straight line method. Assume the salvage value of the equipment to be Rs 10,000.

Solution :

Initial cost of transformer, P = Rs 90,000

Useful life, n = 20 years

Salvage value, S = Rs 10,000

Using straight line method,

Annual depreciation charge = P – S / n − = Rs 90 000 -10 000 /20 = Rs 4000

Importance of High Load Factor

The load factor plays a vital role in determining the cost of energy. Some important advantages of high load factor are listed below :

(i) Reduces cost per unit generated :

A high load factor reduces the overall cost per unit generated. The higher the load factor, the lower is the generation cost. It is because higher load factor means that for a given maximum demand, the number of units generated is more. This reduces the cost of generation.

(ii) Reduces variable load problems :

A high load factor reduces the variable load problems on the power station. A higher load factor means comparatively less variations in the load demands at various times. This avoids the frequent use of regulating devices installed to meet the variable load on the station.

TARIFF

The rate at which the electrical energy is supplied to the consumers.

Types of Consumers

1. Domestic Consumers
2. Commercial Consumers
3. Industrial Consumers
4. Agricultural Consumers

Factors Affecting the Electricity Tariffs

The following factors are taken into accounts to decide the electricity tariff:

Types of Load – The load is mainly classified into three types, i.e., domestic, commercial, or industrial. The industrial consumers use more energy for a longer time than domestic consumers, and hence the tariff for the industrial consumers is more than the domestic consumers. The tariff of the electric energy varies according to their requirement.

Maximum demand – The cost of the electrical energy supplied by a generating station depends on the installed capacity of the plant and kWh generated. Increased in maximum capacity increased the installed capacity of the generating station.

The time at which load is required – The time at which the maximum load required is also essential for the electricity tariff. If the maximum demand coincides with the maximum demand of the consumer, then the additional plant is required. And if the maximum demand of the consumers occurs during off-peak hours, the load factor is improved, and no extra plant capacity is needed. Thus, the overall cost per kWh generated is reduced.

The power factor of the load – The power factor plays a major role in the plant economics. The low power factor increases the load current which increases the losses in the system. Thus, the regulation becomes poor. For improving the power factor, the power factor correction equipment is installed at the generating station. Thus, the cost of the generation increases.

The amount of energy used – The cost of electrical energy is reduced by using large amounts of energy for longer periods.

Objectives of tariff

Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items :

(i) Recovery of cost of producing electrical energy at the power station.
(ii) Recovery of cost on the capital investment in transmission and distribution systems.
(iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.
(iv) A suitable profit on the capital investment.

Desirable Characteristics of a Tariff

A tariff must have the following desirable characteristics:

(i) **Proper return :** The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

(ii) **Fairness :** The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy.

Similarly, a consumer whose load conditions do not deviate much from the ideal (i.e., nonvariable) should be charged at a lower* rate than the one whose load conditions change appreciably from the ideal.

(iii) **Simplicity :** The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) **Reasonable profit :** The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. Therefore, the investment is relatively safe due to non-competition in the market. This calls for the profit to be restricted to 8% or so per annum.

(v) **Attractive :** The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy. Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

Types of Electricity Tariff

Some of the most important types of tariff are as follows;

1. Flat Demand Rate tariff
2. Straight-line Meter rate tariff
3. Block meter Rate tariff
4. Two-part tariff
5. Power factor tariff
6. Seasonal rate tariff
7. Peak load tariff
8. Three-part tariff

The different types of tariffs are explained below in details

1. **Flat demand rate tariff** – The flat demand rate tariff is expressed by the equation C = Ax. In this type of tariff, the bill of the power consumption depends only on the maximum demand of the load. The generation of the bill is independent of the normal energy consumption. This type of tariff is used on the street light, sign lighting, irrigation, etc., where the working hours of the equipment are unknown. The metering system is not used for calculating such type of tariffs.

2. **Straight-line meter rate tariff –** This type of tariff is given by the equation C = By. The generation of the bills depends on the energy consumption of the load. Thus, different types of bills are generated by the consumers.
   The charges for different types of consumption depends on the load and diversity factors of the load. For example, the tariff for small devices is less as compared to the power loads. Hence different meters are used for measuring the power consumption.

3. **Block meter rate tariff –** In this type of tariff, the energy consumption is distinguished into blocks. The per unit tariff of the individual block is fixed. The price of the block is arranged in the decreasing order. The first block has the highest cost, and it goes on decreasing accordingly.
   The price and the energy consumption are divided into three blocks. The first few units of energy at a certain rate, the next at a slightly lower rate and the remaining unit at a very lower rate.

4. **Two-part tariff –** In such type of tariff, the total bill is divided into two parts. The first one is the fixed charge and the second is the running charge. The fixed charge is because of the maximum demand and the second charge depends on the energy consumption by the load.

   $$C = Ax + By$$

   $$C = A(kW) + B(kWh)$$

   The factor A and B may be constant and vary according to some sliding.

5. **Power factor tariff** – The tariff, which depends on the power factor of the load is known as the power factor tariff. The power factor tariff is mainly classified into two types.

a. kVA maximum demand tariff – This is also a two-part tariff.

The low power factor increases the KVA rating of the load.

$$Total\ charges = A(kVA) + B(kWh)$$

b. kWh and kVarh tariff – The bill is calculated by the sum of the kVarh and Kwh rating of the load.

$$Total\ charges = A_1(kWh) + B_1(kVArh)$$

The kVarh is inversely proportional to the power factor of the load.

c. Sliding Scale or Average power factor tariff – In Average power factor tariff, the particular value of the power factor is taken as reference. If the power factor at the consumer end is low, then the consumer has to pay the additional charges. Similarly, if the power factor of the load is above from the reference value, then the discount will be given to the consumer.

6. **Seasonal rate tariff** – Such type of tariff measures the high price in kWh used by the consumer in one complete year. It is also known as the on peak season tariff. If the low consumption occurs in the year, then it called the off-peak season tariffs.

7. **Peak-load tariff** – Such type of tariff is similar to peak load tariffs. The only difference is that the seasonal tariff measures the peak hour of the year and the peak tariff calculates it for the day. If the power consumption is high, then it is known as the on-peak tariff, and for low power consumption, it is called off-peak load tariffs.

   The peak load and seasonal tariffs both are used for reducing the idle or standby capacity of the load.

8. **Three-part tariff** – The three-part tariff is in the form of,and it is applied to the big consumer. The total bill of the consumer has three parts, namely, fixed charge D, semi-fixed charge Ax and running charge By.

$$C = Ax + By + D$$

where, C – total charge for a period (say one month)

x – maximum demand during the period (kW or kVA)

y – Total energy consumed during te period (kW or kVA)

A – cost per kW or kVa of maximum demand.

B – cost per kWh of energy consumed.

D – fixed charge during each billing period.

2.4 A Consumer has a M.D of 80Kw at 0.45 load factor. If the tariff is Rs. 750/ Kw of M.D plus Rs. 1.10 /Kwh, Determine the Overall cost/Kwh.

Solution:

Load Factor = Average load / M.D

Annual Avg Demand = 0.45 * 80 * 24 * 365 = 315360 Kwh

Tariff = Rs. 750 * 80 + 1.10 * 315360 = Rs. 406896

Overall cost/ Kwh = 406896 / 315360 = Rs.1.29.

2.5 An Industrial consumer has a M.D of 150Kw at a L.F of 0.65. The tariff is Rs. 900/KVA of M.D/ year + Rs. 1.30/Kwh of energy consumed. If the average P.F is 0.82 lagging, calculate the total energy consumed / year & the total yearly electricity bill.

Solution:

Max KVA demand = Max Kw Demand / P.F = 150 / 0.82 = 1.82.9268 KVA

Annual energy consumption = L.F * M.D * 8760 = 0.65 * 150 * 8760 = 854100 Kwh

Annual Electricity bill = Rs.[900 * 182.9268 + 1.30 * 854100] = Rs.1274964

2.6 An industrial consumer has a M.D of 100Kw. Two alternative tariffs are available.

a) A fixed charge of Rs. 800 / Kw of M.D / year plus a running charge of Rs.1.30 / kwh of energy consumed.

b) A flat rate of Rs.1.83 / Kwh Which tariff is economical if the factory runs for 3600 hrs/year with a L.F of 0.8?

Solution:

Avg demand = M.D * L.F = 100 * 0.8 =80Kw

Annual energy consumption = Avg demand * working hrs / year = 80 * 3600 = 288000Kwh

Annual bill with first tariff = Rs. (800 * 100 + 1.3 * 288000) = Rs. 454400

Annual bill with second tariff = Rs. 1.83 * 288000 = Rs. 527040

Since the annual bill with two part tariff is lower than that with flat rate tariff, the two part tariff is economical.

2.7 The following tariffs are offered to a consumer:

a) Rs.500 per year plus Rs.0.90 /Kwh

b) Rs. 1.43 for the first 100 units/month & Rs.1.63 for next 100 units & Rs. 1.83 for all the additional units.

Find the energy consumed / year for which the charges due to both tariffs become equal.

Solution:

Let x be the number of units consumed

Annual charges due to first tariff

C1 = Rs. (500+0.90 * x)

Annual charges due to second tariff

C2= Rs. (1.43 * 100) + Rs. (1.63 * 100) + Rs. ((1.83) (x-200) = Rs.(1.83x – 60)

If C1=c2

500+0.90 * x = 1.83x – 60

X = 560 / 0.93 = 6.02 Kwh

2.8 Determine the generation cost / Kwh from the following data:

Installed Capacity = 500Mw

Capital cost = Rs. 35000 / Kw

Interest & Depreciation = 12%

Fuel Consumption = 0.85 Kg / Kwh

Fuel cost = Rs.800/1000 Kg

Other Operating costs = 25% of fuel cost

Peak load = 475 Mw

Load Factor = 0.82

Solution:

Average load = M.D * L.F = 475 * 0.82 = 389.5Mw

Energy Generated / year = Avg .load in Kw * No. of hrs / year = $389.5 * 10^3 * 8760$

Total Investment = Rs. $(500 * 10^3) * 35000$ = Rs. $1.75 * 10^{10}$

Annual interest and depreciation, C_{ID} = Rs.12/100 * $1.75 * 10^{10}$ = Rs.$2.1 * 10^9$

Fuel consumption / year = $0.85 * 389.5 * 10^3 * 8760$

Annual fuel cost, C_{AF} = Rs. 800/1000 * $0.85 * 389.5 * 10^3 * 8760$ = Rs. $2.32017 * 10^9$

Other operating cost / year , C_{AC} = 25% of fuel cost = 25/100 * C_{AF} = 0.25 CAF

Annual plant cost, C_{PC} = annual fixed cost + annual operating costs

$$= C_{ID} + C_{AF} + 0.25 * C_{AF} = \text{Rs. } (2.1 * 10^9 + 1.25 * 2.32017 * 10^9)$$

$$= \text{Rs. } 5.00021 * 10^9$$

Generation cost / Kwh = C_{PC} / energy generated / year

$$= 5.00021 * 10^9 / 389.5 * 10^3 * 8760 = \text{Rs. } 1.47$$

2.9 Calculate the minimum two part tariff to be charged from the consumers of a supply has the following data:Generating cost / Kwh is 50 paise. Generating cost /Kw of M.D is Rs. 100. Total energy generated / year is 40,000Mwh. L.F of the station is 50%. Annual charges for distribution are Rs. 2,00,000. Diversity Factor for the distribution network is 1.25. Total loss between the station & consumer is 10%.

Solution:

M.D = $40000 * 10^3 / (0.5 * 365 * 24)$ = 9132.42Kw

Diversity factor = sum of Max Demands / M.D

Sum of all individual M.D = 1.25 * 9132.42 = 11,415.531 Kw

10% is lost = 11415.53 * 0.1 = 1141.55

Consumer M.D = 11415.53 – 1141.55 = 10273.98 Kw

Fixed charges = Rs. 100 * 9132.42 + 200000 = Rs. 1.113 * 10^6

Fixed charges / K.w of M.D = Rs. 1.113 * 10^6 / 10273.98 = Rs.108.33 / Kw

Two part tariff = Rs. 0.5/Kwh * Kwh + Rs. 108.33 /Kw of M.D * Kw

QUESTIONS

PART A

1. Discuss the terms demand factor and load factor.
2. Express the formula for the cost of electrical energy.
3. Discuss about power factor tariff.
4. Survey the load curve for 24 hours.
5. Categorize the cost of electrical energy.
6. List the different methods of depreciation cost.

PART B

1. Explain the various methods of accumulating the depreciation amount.
2. A domestic lighting installation having 15, 60 W lamps is operated as follows :

   5 lamps from 6 pm till 8 pm

   10 lamps from 8 pm till 10 pm

   6 lamps from 10 pm till 12 pm

   a.Determine the connected load, the maximum demand, demand factor and daily load factor

   b.Also determine the improved load factor if a 2 KW immersion heater is used fron 1 pm till 5 pm and a 2KW heater from 8 pm till 11pm.

3. There are four consumers of electricity having different load requirements at different times. Consumer1 has a maximum demand of 2 KW at 9 pm a demand of 1.6 KW at 8 pm and a daily load factor of 15%. Consumer2 has a maximum demand of 2 KW at 12 noon, a load of 1 KW at 8 pm and an average load of 500W. Consumer3 has a maximum demand of 8 KW at 5pm, a load of 5 KW at 8 pm and daily load factor of 25%. Consumer4 has an average load of 1 KW and his maximum demand is 4 KW at 8 pm. Determine

(i) The diversity factor

(ii) The load factor and average load of each consumer

(iii) The average load and load factor of the combined load Elaborate various resistances welding process.

4. Discuss the various methods of electrical tariff used in practice.

REFERENCE BOOKS

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2. Uppal.S.L. “Electrical Power”, Khanna Publishers, 9th Edition, 2001.
3. Leonard L.Grigsby, ”Electric power generation, transmission and Distribution”, CRC Press, Taylor and Francis Group, 2012.
4. S.Sivanagaraju, M.Balasubba Reddy and D.Srilatha, ”Electric Energy-Generation, Utilization and Conservation” Pearson, 2012.

SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SEE1303-POWER GENERATION AND UTILIZATION

UNIT – III ILLUMINATION

UNIT III-ILLUMINATION

Nature of radiation - definition-laws-lighting calculations-polar curves-Rousseau construction-design of Illumination Systems-Flood Lighting and Calculations-Street Lighting-Classification of Light Sources- Incandescent lamps- gas discharge lamps- sodium vapour, mercury vapour, Fluorescent Lamps and LED lamps.

ILLUMINATION

Illumination is a branch of engineering that deals with planning the lighting systems of new buildings and outdoor areas (as streets, parking lots) and the study and correction of old lighting installations

NATURE OF RADIATION

The usual method of producing artificial light consists in raising a solid body or vapour to incandescence by applying heat to it. It is found that as the body is gradually heated above room temperature, it begins to radiate energy in the surrounding medium in the form of electromagnetic waves of various wavelengths. The *nature* of this radiant energy depends on the temperature of the hot body. Thus, when the temperature is low, radiated energy is in the form of heat waves only but when a certain temperature is reached, light waves are also radiated out in addition to heat waves and the body becomes luminous. Further increase in temperature produces an increase in the amount of both kinds of radiations but the colour of light or visible radiation changes from bright red to orange, to yellow and then finally, if the temperature is high enough, to white. As temperature is increased, the wavelength of the visible radiation goes on becoming shorter. It should be noted that heat waves are identical to light waves except that they are of longer wavelength and hence produce no impression on the retina. Obviously, from the point of view of light emission, heat energy represents so much wasted energy.

1 A.U=10^{-8}cm=10^{-10}m

Hence, the wave-length of red light becomes λr = 7800 × 10-10 m or 7800 A.U. and λv = 3900×10-10 m or 3900 A.U. The sensation of colour is due to the difference in the wavelengths and hence frequencies of the light radiations.

DEFINITIONS

Plane Angle

A Plane angle is subtended ata appoint and is enclosed by two straight lines lying in the same plane.A Plane angle is expressed in terms of degrees or radian.

Solid angle

A concept which frequently is used for illumination calculation is the solid angle and is explained as follows:

Consider an area A which is part of a sphere of radius r (Fig. 3.1). Let us find the solid angle ω subtended by this area at the centre C of the sphere. For this purpose, let point C be joined to every point on the edges of the area A. Then, the angle enclosed by the cone at point C gives the solid angle. Its value is

$$\omega = \frac{A}{r^2} \text{ steradian} \qquad \text{..(1)}$$

The unit of solid angle is ***steradian*** (sr). If, in the above equation, $A = r2$, then ω= 1 steradian. Hence, steradian is defined as the angle subtended at the centre of a sphere by a part of its surface having an area equal to (radius).

Candela

It is the unit of luminous intensity of a source. It is defined as 1/60th of the luminous intensity per cm2 of a black body radiator at the temperature of solidification of platinum (2045°K). A source of one candela (*cd*) emits one lumen per steradian. Hence, total flux emitted by it all round is

Luminous Flux (F or)

It is the light energy radiated out per second from the body in the form of luminous light waves. Since, it is a rate of flow of energy, it is a sort of *power* unit. Unit of luminous flux is *lumen* (lm). It is defined as the ***flux contained per unit solid angle of a source of one candela or standard candle***

(Fig. 3.1). Approximate relation between lumen and electric unit of power *i.e.* watt is givenas

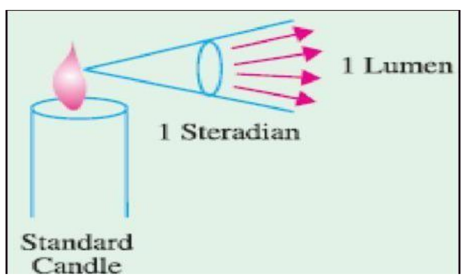


Fig.3.1

Lumen

One lumen is defined as the luminous flux emitted bya source of one candle power in a unit solid angle

Lumen+candle power of source x solid angle

Lumen-hour

It is the quantity of light delivered in one hour by a flux of one lumen.

Luminous Intensity (I) or Candle-power of a point source in any particular direction is givenby the ***luminous flux radiated out per unit solid angle in that direction***. In other words, it is solid angular flux density of a source in a specified direction.

If flux is measured in lumens and solid angle in steradian, then its unit is lumen/steradian (lm/sr) or candela (*cd*).

If a source has an average luminous intensity of *I* lm/sr (or *I* candela), then total flux radiated byit all around Φ S.

Generally, the luminous intensity or candle power of a source is different in different directions. The average candle-power of a source is the average value of its candle power in all directions.

Obviously, it is given by total flux (in lm) emitted in all directions in all planes divided by 4 . Thisaverage candle-power is also known as ***mean spherical candle- power*** (M.S.C.P.).

$$\text{M.S.C.P.} = \frac{\text{total flux in lumens}}{4\pi} \qquad (2)$$

If the average is taken over a hemisphere (instead of sphere), then this average candle poweris known as ***mean hemispherical candle-power*** (M.H.S.C.P.).
It is given by the total flux emitted in a hemisphere (usually the lower one) divided by the solid angle subtended at the point source by the hemisphere.

$$\text{M.H.S.C.P.} = \frac{\text{flux emitted in a hemisphere}}{2\pi} \qquad (3)$$

Lux

One meter candle or lux is defined as the illumination produced by a uniform souce of one CP on the inner surface of a sphere of radius one meter.

Reduction Factor of a source is given by the ratio, *f* = M.S.C.P./M.H.C.P. where M.H.C.P. is the mean horizontal candle power. It is also referred to as spherical reductionfactor.

Illuminance or Illumination (E)

When the luminous flux falls on a surface, it is said to be illuminated. Theillumination of a surface is measured by the normal luminous flux per unit area.

Transmittance (T) of an Illuminated Diffuse Reflecting Surface

It is defined as the ratio of the total luminous flux transmitted by it to the total flux incident on it.
The relation between luminous exitance (*M*) of a surface transmitting light and illuminance
(E) on the other side of it is

M=TE or M=T/E .... (4)

Reflection Ratio or Coefficient of Reflection or Reflectance It is givenby
Luminous flux refiected from a small area of the surface to the total flux incident upon it.

Specific Output or Efficiency of a lamp is the ratio of luminous flux to the power intake.Its unit is lumen/watt (lm/W). Following relations should be taken note of :

(*a*) $$\frac{\text{lumen}}{\text{watt}} = \frac{4\pi \times \text{M.S.C.P.}}{\text{watt}}$$

or $$\frac{\text{lm}}{\text{W}} = \frac{4\pi}{\text{watt/M.S.C.P.}}$$

(*b*) since $f = \text{M.S.C.P./M.H.C.P.}$ $\quad \therefore \quad \text{lm/W} = \dfrac{4\pi f}{\text{watt/M.S.C.P.}}$

(*c*) Obviously, $\text{watts/M.S.C.P.} = \dfrac{4\pi}{\text{1m/W}} = \dfrac{\text{watt/M.H.C.P.}}{f}$

(*d*) Also $\text{watts/M.H.C.P.} = \dfrac{4\pi f}{\text{1m/W}} = f \times \text{watts/M.S.C.P.}$

Specific Consumption. It is defined as the ratio of the power input to the averagecandlepower. It is expressed in terms of watts per average candle or watts/M.S.C.P.
The summary of the above quantities along with their units and symbol is given in Table

Name of Qty	*Unit*	*Symbols*
Luminous Flux	Lumen	*F* or Φ
Luminous Intensity (candle-power)	Candela	*I*
Illumination or Illuminance	lm/m^2 or lux	*E*
Luminance or Brightness	cd/m^2	*L* or *B*
Luminous Exitance	lm/m^2	*M*

Table 3.1 Calculation of Luminance (L) of a Diffuse Reflecting Surface

The luminance (or brightness) of a surface largely depends on the character of the surface, if itis itself not the emitter. In the case of a polished surface, the luminance depends on the angle of viewing. But if the surface is matt and diffusion is good, then the luminance or brightness is practically independent of the angle of viewing. However, the reflectance of the surface reduces the brightness proportionately. In Fig. 3.4 is shown a perfectly diffusing surface of small area *A*. Suppose that at point *M* on a hemisphere with centre *O* and radius *R*, the illuminance is *L* cd/m2.

LAWS OF ILLUMINATION

The illumination on a surface depends upon the luminous intensity, distance between the source and surface and the direction of rays of light. It is governed by following laws :

1. Inverse square law

2. Lambert‟s cosine law

The Inverse Square Law

As a surface that is illuminated by a light source moves away from the light source, the surface appears dimmer. In fact, it becomes dimmer much faster than it moves away from the source. The inverse square law, which quantifies this effect, relates illumi-nance (Ev) and intensity (Iv) as follows:

Ev = Iv/d2 -- (5)

Where d = the distance from the light source.

For example, if the illuminance on a surface is 40 lux (lm/m2) at a distance of 0.5 meters from the light source, the illuminance decreases to 10 lux at a distance of 1 meter, as shown in the following figure.

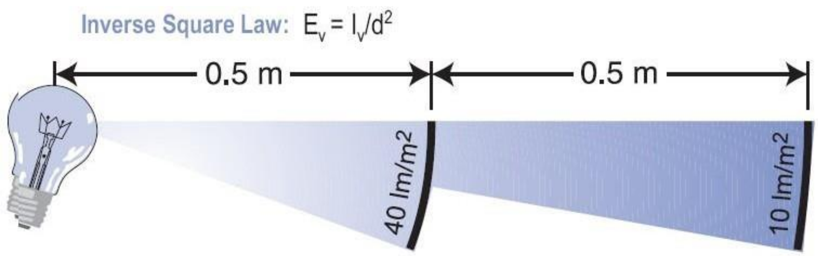


Fig 3.2

Note: the inverse square law can only be used in cases where the light source approximates a point source. For lambertian light sources (Lambertian Emission and Reflection”), a useful guideline to use for illuminance measurements is the “five times rule”: the distance from the measurement point to the light source should be greater than five times the largest dimension of the source for an accurate measurement. However, the five times rule does not work for a strongly directional light source.

Lambert’s Cosine Law

Lambert‟s cosine law states that the illuminance falling on any surface depends on the cosine of the light‟s angle of incidence, θ.

Eθ = Ecosθ --(6)

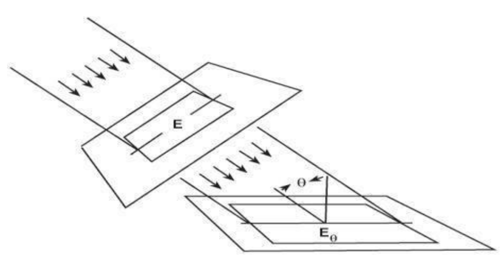


Fig 3.3

Lambertian Emission and Reflection A lambertian surface reflects or emits equal (isotropic) luminance in every direction. For example, an evenly illuminated diffuse flat surface such as a piece of paper is approximately lambertian, because the reflected light is the same in every direction from which you can see the surface of the paper.However, it does not have isotropic intensity, because the intensity varies according to the cosine law. Figure 4.3 shows a lambertian reflection from a surface. Notice that the reflec- tion follows the cosine law — the amount of reflected energy in a particular direction (the intensity) is proportional to the cosine of the reflected angle. Remember that luminance is intensity per unit area. Because both intensity and apparent area follow the cosine law, they remain in proportion to each other as the viewing angle changes. Therefore, luminance remains constant while luminous intensity does not. To compare illuminance and luminance on a lambertian surface, consider the following example: a surface with a luminance of 1 lm/m2/sr radiates a total of πA lumens, where A is the area of the surface, into a hemisphere (which is 2π steradians). The illuminance of the surface is equal to the total luminous flux divided by the total area — π lux/m2. In other words, if you were to illuminate a perfectly diffuse reflect- ing surface with 3.1416 lm/m2, its luminance would be 1 lm/m2/sr.

LIGHTING CALCULATIONS

A well-designed lighting scheme is one which

(i) Provides adequate illumination
(ii) Avoids glare and hard shadows
(iii) provides sufficiently uniform distribution of light all over the working plane. Before explaining the method of determining the number, size and proper arrangement of lamps in order to produce a given uniform illumination over a certain area, let us first considerthe following two factors which are of importance in such calculations.

Utilization Factor or Coefficient of Utilization (η)

It is the ratio of the lumens actually received by a particular surface to the total lumens emitted bya luminous source.

$$\eta = \frac{\text{lumens actually received on working plane}}{\text{lumens emitted by the light source}} \quad \text{.............(7)}$$

The value of this factor varies widely and depends on the following factors :

1.the typeof lighting system, whether direct or indirect etc.

2.the type and mounting height of the fittings 3.thecolour and surface of walls and ceilings and

4. to some extent on the shape and dimensions of the room.

For example, for direct lighting, the value of η varies between 0.4 and 0.6 and mainly depends on the shape of the room and the type and mounting height of fittings but very little on the colour of walls and ceiling. For indirect lighting, its value lies between 0.1 and 0.35 and the effect of walls and ceiling, from which light is reflected on the working plane, is much greater. Exact determination of the value of utilization factor is complicated especially in small rooms where light undergoes multiple reflections. Since the light leaving the lamp in different directions is subjected to different degrees of absorption, the initial polar curve of distribution has also to be taken into account. Even though manufacturers of lighting fittings supply tables giving utilization factors for each type of fitting underspecified conditions yet, since such tables apply only to the fittings for which they have been compiled a good deal of judgment is necessary while using them.

Depreciation Factor (p)

This factor allows for the fact that effective candle power of all lamps or luminous sources deteriorates owing to blackening and/or accumulation of dust or dirt on the globes and reflectors etc. Similarly, walls and ceilings etc., also do not reflect as much light as when they are clean. The value of this factor may be taken as 1/1.3 if the lamp fittings are likely to be cleaned regularly or 1/1.5 if there is much dust etc.

$$p = \frac{\text{illumination under actual condtions}}{\text{illumination when everything is perfectly clean}}$$ ....-(8)

Since illumination is specified in lm/m^2, the area in square metre multiplied by the illuminationrequired in lm/m^2gives the total useful luminous flux that must reach the working plane. Taking into consideration the utilization and depreciation or maintenance factors, the expression for the grosslumens required is

Total lumens, $$\Phi = \frac{E \times A}{\eta \times p}$$ ....-(9)

Where E = desired illumination in lm/m^2 ;

A= area of working plane to be illuminated in m^2 p=depreciation or maintenance factor ;

η= utilization factor.

The size of the lamp depends on the number of fittings which, if uniform distribution is required, should not be far apart. The actual spacing and arrangement is governed by space/height values and by the layout of ceiling beams or columns. Greater the height, wider thespacing that may be used, although the larger will be the unit required. Having settled the number of units required, the lumens per unit may be found from (total lumens/number ofunits) from which the size of lamp can be calculated.

Example 1.

A room 8 m× 12 m is lighted by 15 lamps to a fairly uniform illumination of 100 lm/m^2. Calculate the utilization coefficient of the room given that the output of each lamp is1600 lumens.

Solution.

Lumens emitted by the lamps = 15×1600 = 24,000 lm

Lumens received by the working plane of the room = 8×12×100 = 9600 lmUtilization

coefficient = 9600/24,000 =0.4 or 40%.

Example 2.

The illumination in a drawing office 30 m× 10 m is to have a value of 250 luxand is to be provided by a number of 300-W filament lamps. If the coefficient of utilization is 0.4 and the depreciation factor 0.9, determine the number of lamps required. The luminous efficiency of each lamp is 14 lm/W.

Solution.

Φ= EA / η p ; E = 250 lm/m2, A= 30×10 = 300 m^2;η= 0.4, p= 0.9

∴ Φ=250×300/0.4×0.9 = 208,333 lm

Flux emitted/lamp = 300×14 = 4200 lm; No. of lamps reqd.= 208,333/4200 =50.

Example 3 *A drawing hall in an engineering college is to be provided with a lighting installation. The hall is 30 m × 20 m × 8 m (high). The mounting height is 5 m and the required level of illumination is 144 lm/m². Using metal filament lamps, estimate the size and number of single lamp luminaries and also draw their spacing layout. Assume :*

Utilization coefficient = 0.6; maintenance factor = 0.75; space/height ratio = 1

lumens/watt for 300-W lamp = 13 lumens/watt for 500-W lamp = 16.

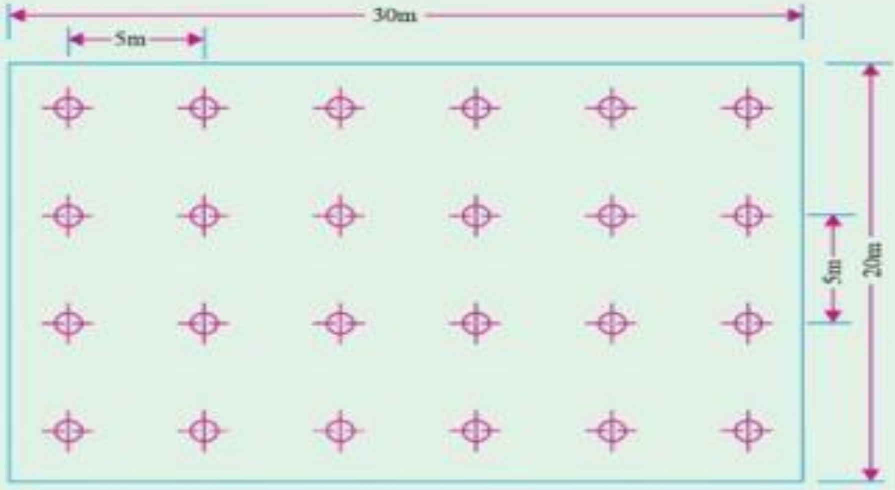


Fig. 49.40

Solution. Flux is given by $\Phi = EA/\eta p = 30 \times 20 \times 144/0.6 \times 0.75 = 192{,}000$ lm

Lumen output per 500-W lamp = $500 \times 16 = 8{,}000$

$\therefore$ No. of 500-W lamps required $= 192{,}000/8000 =$ **24**

Similarly, No. of 300-W lamps required = 192,000/3900 = **49**

The 300-W lamps cannot be used because their number cannot be arranged in a hall of 30 m × 20 m with a space/height ratio of unity. However, 500-W lamps can be arranged in 4 rows of 6 lamps each

Example 4 *Estimate the number and wattage of lamps which would be required to illuminate a workshop space 60 × 15 metres by means of lamps mounted 5 metres above the working plane. The average illumination required is about 100 lux.*

Coefficient of utilization = 0.4 ; Luminous efficiency = 16 lm/W.

Assume a spacing/height ratio of unity and a candle power depreciation of 20%.

(Utilization of Electrical Energy, Madras Univ.)

Solution. Luminous flux is given by $\Phi = \dfrac{EA}{\eta p} = \dfrac{100 \times (60 \times 15)}{0.4 \times 1/1.2} = 27 \times 10^4$ lm

Total wattage reqd. $= 27 \times 10^4/16 =$ **17,000 W**

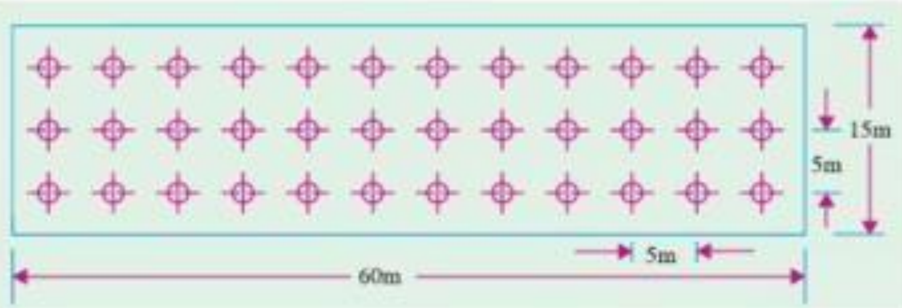


Fig. 49.41

For a space/height ratio of unity, only three lamps can be mounted along the width of the room. Similarly, 12 lamps can be arranged along the length of the room. Total number of lamps required is $12 \times 3 =$ **36**. Wattage of each lamp is = 17,000/36 = 472 W. We will take the nearest standard lamp of **500 W**. These thirty-six lamps will be arranged

Example 5 *A drawing hall 40 m × 25 m × 6 high is to be illuminated with metal-filament gas-filled lamps to an average illumination of 90 lm/m^2 on a working plane 1 metre above the floor. Estimate suitable number, size and mounting height of lamps. Sketch the spacing layout.*

Assume coefficient of utilization of 0.5, depreciation factor of 1.2 and spacing/height ratio of 1.2

Size of lamps	*200 W*	*300 W*	*500 W*
Luminous efficiency (in lm/W)	*16*	*18*	*20*

(Elect. Technology, Bombay Univ.)

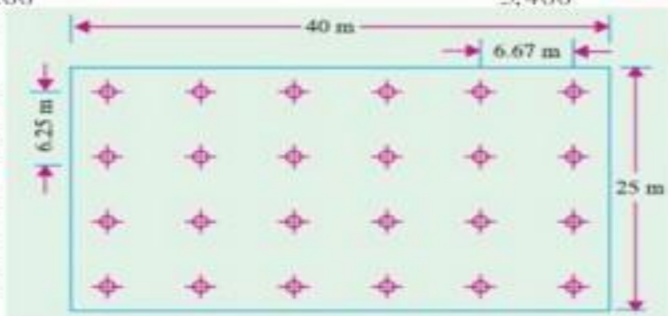
Solution. Total flux required is $\Phi = \dfrac{40 \times 25 \times 90}{0.5 \times 1/1.2} = 216{,}000$ lm

Lumen output of each 200-W lamp is 3200 lm, of 300-W lamp is 5,400 lm and of 500-W lamp is 10,000 lm.

No. of 200-W lamps reqd. $= \dfrac{216{,}000}{3{,}200} =$ **67**; No. of 300-W lamps reqd. $= \dfrac{216{,}000}{5{,}400} =$ **40**

No. of 500-W lamps reqd. = 216,000/ 10,000 = **22**

With a spacing/height ratio of 1.2, it is impossible to arrange both 200-W and 300-W lamps. Hence, the choice falls on 500-W lamp. If instead of the calculated 22, we take 24 lamps of 500 wattage, they can be arranged in four rows each having six lamps as shown in Fig. 49.42. Spacing along the length of the hall is 40/6 = 6.67 m and that along the width is 25/4 = 6.25 m.



Since mounting height of the lamps is 5 m above the working plane, it gives a space/height ratio of 6.7/5 = 1.5 along the length and 6.25/5 = 1.4 along the width of the hall.

Example 6 *A school classroom, 7 m × 10 m × 4 m high is to be illuminated to 135 lm/m^2 on the working plane. If the coefficient of utilization is 0.45 and the sources give 13 lumens per watt, work out the total wattage required, assuming a depreciation factor of 0.8. Sketch roughly the plan of the room, showing suitable positions for fittings, giving reasons for the positions chosen.*

Solution. Total flux required is $\Phi = EA/\eta p$

Now $E = 135$ lm/m^2;

$A = 7 \times 10 = 70$ m^2;

$\eta = 0.45$; $p = 0.8$

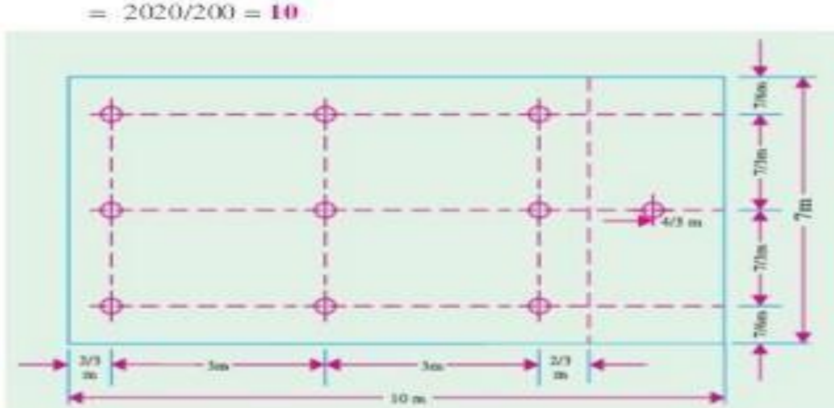
$F = 135 \times 7 \times 10/0.45 \times 0.8 = 26{,}250$ lm

Total wattage reqd. $= 26{,}250/13 =$ **2020 W**

Taking into consideration the dimensions of the room, light fitting of 200 W would be utilized.

No. of fittings required $= 2020/200 =$ **10**

As shown in Fig. 49.43, the back row of fittings has been located 2/3 m from the rear wall so as to *(i)* provide adequate illumination on the rear desk and *(ii)* to minimise glare from paper because light would be incident practically over the shoulders of the students. The two side fittings help eliminate shadows while writing. One fitting has been provided at the chalk board end of the classroom for the benefit of the teacher. The fittings should be of general diffusing pendant type at a height of 3 m from the floor.



LIGHTING SCHEMES

Different lighting schemes may be classified as

(i) direct lighting(ii) indirect lighting and ***(iii)***semi-direct lighting ***(iv)***semi-indirect lighting and ***(v)***general diffusing systems.

(*i*)Direct Lighting

As the name indicates, in the form of lighting, the light from the source falls directly on the objector the surface to be illuminated (Fig. 49.35). With the help of shades and globes and reflectors of various types as discussed in Art. 49.11, most of the light is directed in the lower hemisphere and also the brilliant source of light is kept out of the direct line of vision. Direct illumination by lamps in suitable reflectors can be supplemented by standard or bracket lamps on desk or by additional pendant fittings over counters.

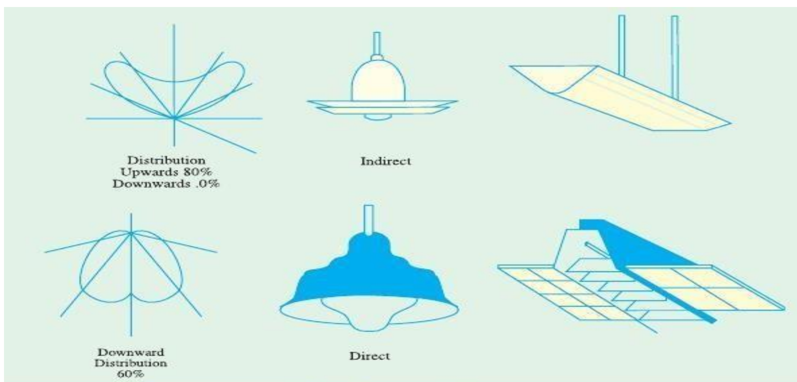


Fig 3.4

The fundamental point worth remembering is planning any lighting installation is that sufficient and sufficiently uniform lighting is to be provided at the working or reading plane. For this purpose, lamps of suitable size have to be so located and furnished with such fittings as to give correct degree and distribution of illumination at the required place. Moreover, it is importantto keep the lamps and fittings clean otherwise the decrease in effective illumination due to dirty bulbs or reflectors may amount to 15 to 25% in offices and domestic lighting and more in industrial areas as a result of a few weeks neglect. Direct lighting, though most efficient, is liable to cause glare and hard shadows.

(ii) Indirect Lighting

In this form of lighting, light does not reach the surface directly from the source but indirectly by diffuse reflection (Fig. 49.36). The lamps are either placed behind a cornice or in suspended ***opaque*** bowls. In both cases, a silvered reflector which is corrugated for eliminating striations isplaced beneath the lamp.

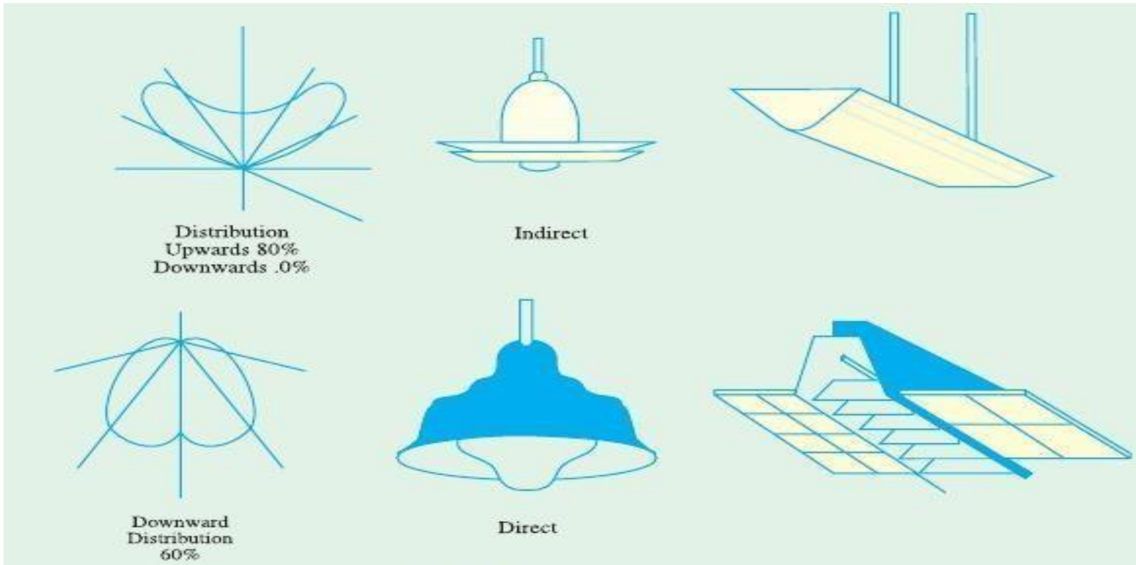


Fig 3.5

In this way, maximum light is thrown upwards on the ceiling from which it is distributed all over the room by diffuse reflection. Even gradation of light on the ceiling is secured by careful adjustment of the position and the number of lamps. In the cornice and bowl system of lighting, bowl fittings are generally suspended about three-fourths the height of the room and in the case of cornice lighting, a frieze of curved profile aids in throwing the light out into the room to be illuminated. Since in indirect lighting whole of the light on the working plane is received by diffusereflection, it is important to keep the fittings clean. One of the main characteristics of indirect lighting is that it provides shadowless illumination which is very useful for drawing offices, composing rooms and in workshops especially where large machines and other obstructions would cast troublesome shadows if direct lighting were used. However, many people find purely indirect lighting flat and monotonous and even depressive

Most of the users demand 50 to 100% more light at their working plane by indirect lighting than with direct lighting. However, for appreciating relief, a certain proportion of direct lighting is essential.

(iii) Semi-direct System

This system utilizes luminaries which send most of the light downwards directly on the working plane but a considerable amount reaches the ceilings and walls also The division is usually 30% upwards and 45% downwards. Such a system is best suited to rooms with high ceilings where a high level of uniformly-distributed illumination is desirable. Glare in such units is avoided by using diffusing globes which not only improve the brightness towards the eyelevel but improve the efficiency of the system with reference to the working plane.

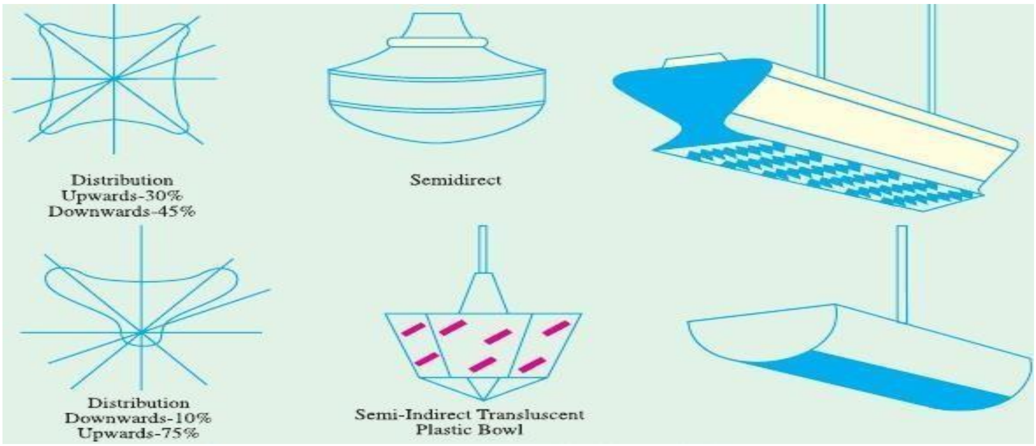


Fig 3.6

(iv) Semi-indirect Lighting

In this system which is, in fact, a compromise between the first two systems, the light is partly received by diffuse reflection and partly direct from the source (Fig. 49.38). Such a system, therefore, eliminates the objections of indirect lighting mentioned above. Instead of using opaque bowls with reflectors, translucent bowls without reflector are used. Most of the light is, as before, directed upwards to the ceiling for diffuse reflection and the rest reaches the working plane directly except for some absorption by the bowl.

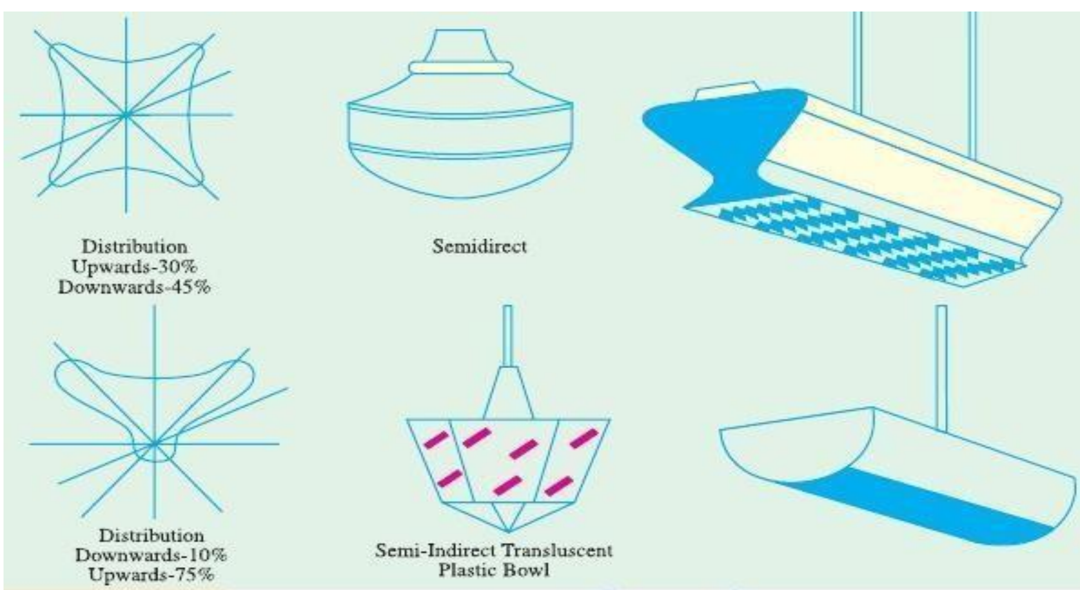


Fig 3.7

(v) General Diffusing System

In this system, luminaries are employed which have almost equal light distributiondownwards and upwards as shown

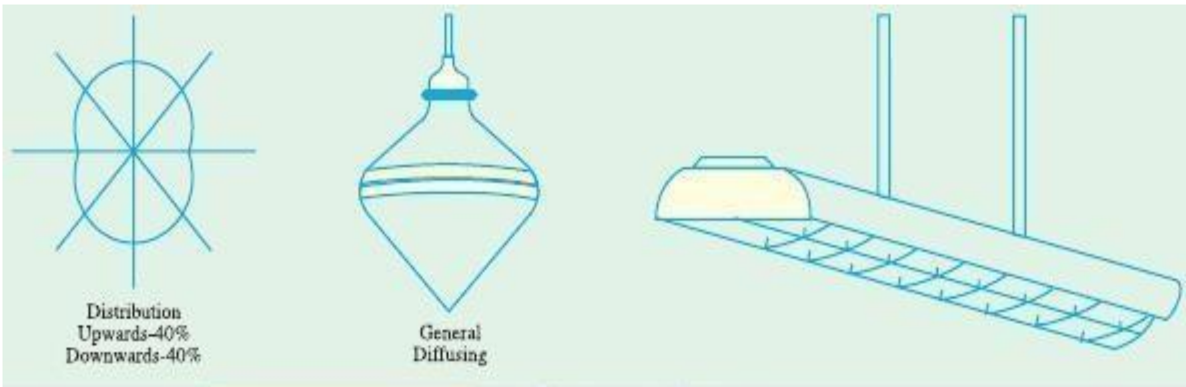


Fig 3.8

ARTIFICIAL SOURCES OF LIGHT

The different methods of producing light by electricity may, in a board sense, be divided into three groups.

1. By temperature incandescence. In this method, an electric current is passed through a filament of thin wire placed in vacuum or an inert gas. The current generates enough heat to raise the temperature of the filament to luminosity. Incandescent tungsten filament lamps are examples of this type and since their output depends on the temperature of their filaments, they are known as temperature radiators.
2. By establishing an arc between two carbon electrodes. The source of light, in their case, is the incandescent electrode.
3. Discharge Lamps. In these lamps, gas or vapour is made luminous by an electric discharge through them. The colour and intensity of light i.e. candle-power emitted depends on the nature of the gas or vapour only. It should be particularly noted that these discharge lamps are luminescent light lamps and do not depend on temperature for higher efficiencies. In this respect, they differ radically from incandescent lamps whose efficiency is dependent on temperature. Mercury vapour lamp, sodium-vapour lamp, neon-gas lamp and fluorescent lamps are examples of light sources based on discharge through gases and vapours.

FLOOD LIGHTING

It means „flooding" of large surfaces with the help of light from powerful projectors. Flooding is employed for the following purposes :

1. For aesthetic purposes as for enhancing the beauty of a building by night *i.e.* flood lighting

of ancient monuments, religious buildings on important festive occasions etc.

2.For advertising purposes *i.e.* flood lighting, huge hoardings and commercial buildings.

3.For industrial and commercial purposes as in the case of railway yards, sports stadiums and quarries etc.

Usually, floodlight projectors having suitable reflectors fitted with standard 250-, 500-, or 1,000- watt gas-filled tungsten lamps, are employed. One of the two typical flood light installations often used is as shown in Fig*a*). The projector is kept 15 m to 30 m away from the surface to be floodlighted and provides approximately parallel beam having beam spread of 25°to 30°. Fig.

(b) shows the case whenthe projector cannot be located away from the building. In that case, an asymmetric reflector is used which directs more intense light towards the top of the building.

The total luminous flux required to flood light a building can be found from the relation,

$$\Phi = EA/\eta \times p \text{ --------------------------------(10)}$$

However, in the case of flood-lighting, one more factor has to be taken into account. That factor is known as waste-light factor (*W*). It is so because when several projectors are used, there is bound to be a certain amount of overlap and also because some light would fall beyond the edges of the area to be illuminated. These two factors are taken into account by multiplying the theoretical value of the flux required by a waste-light factor which has a value of nearly 1.2 for regular surfaces and about 1.5for irregular objects like statues etc. Hence, the formula for calculation of total flux required for floodlighting purposes is

$$\Phi = EAW/\eta\rho \text{ ---(11)}$$

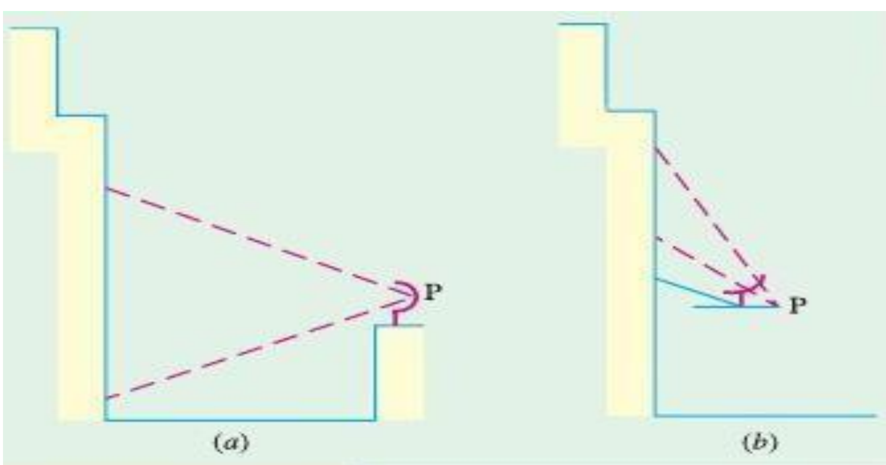


Fig 3.9

STREET LIGHTING

The major purposes of street lighting are

To promote the community and convenience in the street at night through adequatevisibility
To promote the community value of a street
To increase the attractiveness of the street

In a well-lighted street objects are shown up in silhouette by the background of the road surface. An object is shown up in silhouette when the general level of brightness of all or a substantial part of it is lower than the brightness of its back ground. The method of discernment predominates in the observation of distant objects on lighted streets and highways where the object itself may possess relatively low average brightness in the direction of the observer whereas the street possess a relatively high background brightness.
For proper illumination of streets, the main requirements for the light distribution from the lamps are:
1.The lamps should give a peak of intensity at a sufficiently high angle to make best use of the reflecting properties of the surface of the road.
2.The intensities below the peak should gradually become smaller in order that the luminance of the road close to the lamp-post should not be so great as to cause a patchy appearance.
3.The reduction in intensity above the peak should be sharp in order to reduce glare.

Incandescent Lamps

An incandescent lamp essentially consists of a fine wire of a high-resistance metal placed in an evacuated glass bulb and heated to luminosity by the passage of current through it. Such lamps were * It indicates the divergence of a beam and may be defined as the angle within which the minimum illumination on a surface normal to the axis of the beam is 1/10th of the maximum produced commercially for the first time by Edison in 1879.

His early lamps had filaments of carbonized paper which were, later on, replaced by carbonized bamboo. They had the disadvantage of negative temperature coefficient of resistivity. In 1905, the metallized carbon-filament lamps were put in the market whose filaments had a positive temperature coefficient of resistivity (like metals). Such lamps gave 4 lm/W. At approximately the same time, osmium lamps were manufactured which had filaments made of osmium which is very rare and expensive metal. Such lamps had a very fair maintenance of candle-power during their useful life and an averae efficiency of 5 lm/W. However, osmium filaments were found to be very fragile.

In 1906 tantalum lamps having filaments of tantalum were produced which had an initial efficiency of 5 lm/watt. All these lamps were superseded by tungsten lamps which were commercially produced in about 1937 or so. The superiority of tungsten lies mainly in its ability to withstand a high operating temperature without undue vaporisation of the filament. The

necessity of high working temperature is due to the fact that the amount of visible radiation increases with temperature and so does the radiant efficiency of the luminous source. The melting temperature of tungsten is 3655°K whereas that of osmium is 2972°K and that of tantalum is 3172°K. Actually, carbon has a higher melting point than tungsten but its operating temperature is limited to about 2073°K because of rapid vaporization beyond this temperature.
In fact, the ideal material for the filament of incandescent lamps is one which has the following properties :

1. A high melting and hence operating temperature

2. A low vapour pressure

3. A high specific resistance and a low temperature coefficient

4. Ductility and

5. Sufficient mechanical strength to withstand vibrations. Since tungsten possesses practically all the above mentioned qualities, it is used in almost all modern incandescent lamps. The earlier lamps had a square-cage type filament supported from a central glass stem enclosed in an evacuated glass bulb.

The object of vacuum was two fold :

i.to prevent oxidation and

ii.to minimize loss of heat by convection and the consequent lowering of filament temperature. However, vacuum favoured the evaporation of the filament with the resulting blackening of the lamp so that the operating temperature had to be kept as low as 2670º K with serious loss in luminous efficiency

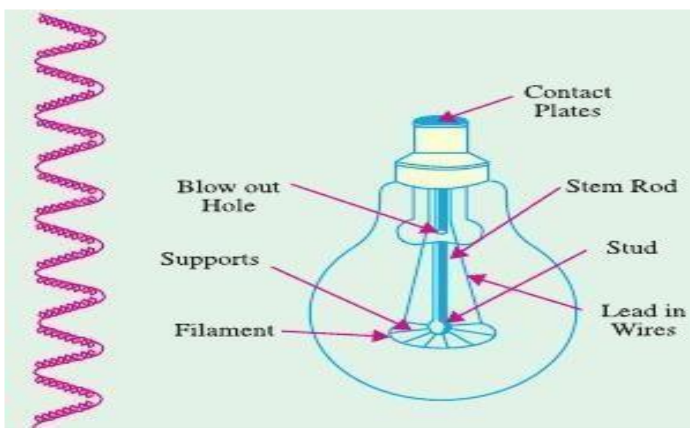


Fig 3.10

It was, later on, found that this difficulty could be solved to a great extent by inserting a chemically inert gas like nitrogen or argon. The presence of these gases within the glass bulb decreased the evaporation of the filament and so lengthened its life. The filament could now be run at a relatively higher temperature and hence higher luminous efficiency could be realized. In practice, it was found that an admixture of 85% argon and about 15 percent nitrogen gave the best results. However, introduction of gas led to another difficulty i.e. loss of heat due to convection which offsets the additional increase in efficiency. However, it was found that for securing greater efficiency, a concentrated filament having a tightly-wound helical construction was necessary. Such a coiled filament was less exposed to circulating gases, its turns supplying heat to each other and further the filament was mechanically stronger. The latest improvementis that the coiled filament is itself coiled, resulting in _coiled-coil,, filament Fig. 3.10

(a) which leads to further concentrating the heat, reducing the effective exposure to gasesand allows higher temperature operation, thus giving greater efficiency.
The construction of a modern coiled coil gas-filled filament lamp is shown

(b) The lamp has a _wreath,, filament i.e. a coiled filament arranged in the form of a wreathon radial supports

Discharge Lamps

In all discharge lamps, an electric current is passed through a gas or vapour which renders illuminous. The elements most commonly used in this process of producing light by gaseous conduction are neon, mercury and sodium vapours.
The colours (. wavelength) of light produced depends on the nature of gas or vapour. For example, the neon discharge yields orange-red light of nearly 6,500A.U. which is very popular for advertising signs and other spectacular effects. The pressure used in neon tubes is usually from 3 to 20 mm of Hg. Mercury-vapour light is always bluish green and deficient in red rays, whereas sodium vapour light is orange-yellow.
Discharge lamps are of two types. The first type consists of those lamps in which the colour of light is the same as produced by the discharge through the gas or vapour. To this group belong the neon gas lamps, mercury vapour (M.V.) and sodium vapour lamps. The other type consists of vapour lamps which use the phenomenon of fluorescence. In their case, the discharge through the vapour produces ultra-violet waves which cause fluorescence in certain materials known as phosphors. The radiations from the mercury discharge (especially 2537 A° line) impinge on these phosphors which absorb them and then re-radiate them at longer wave-lengths of visible spectrum. The inside of the fluorescent lamp is coated with these phosphors for this purpose. Different phosphors have different exciting ranges of frequency and give lights of different colours as shown in table

Table 3.2 Lights of Different Colours

Phosphor	Lamp Colour	Exciting range A°	Emitted wavelenght A°
Calcium Tangstate	Blue	2200 - 3000	4400
Zinc Silicate	Green	2200 - 2960	5250
Cadmium Borate	Pink	2200 - 3600	6150
Cadmium Silicate	Yellow-pink	2200 - 3200	5950

Sodium Vapour Lamp

One type of low-pressure sodium-vapour lamp along with its circuit connection is shownin Fig. 3.11. It consists of an inner U-tube A made of a special sodium-vapour-resisting glass. It houses the two electrodes and contains sodium together with the small amount of neon- gas at a pressure of about 10 mm of mercury and one percent of argon whose main function istoreduce the initial ionizing potential. The discharge is first started in the neon gas (which gives out redish color).After a few minutes, the heat of discharge through the neon gas becomes sufficient to vaporise sodium and then discharge passes through the sodium vapour. In this way, the lamp starts its normal operation emitting its characteristic yellow light.

The tungsten-coated electrodes are connected across auto-transformer T having a relatively high leakage reactance. The open-circuit voltage of this transformer is about 450 V which is sufficient to initiate a discharge through the neon gas. The leakage reactance is used not only for starting the current but also for limiting its value to safe limit. The electric discharge or arc strikes immediately after the supply is switched on whether the lamp is hot or cold. The normal burning position of the lamp is horizontal although two smaller sizes of lamp may be burnt vertically. The lamp is surrounded by an outer glass envelope B which servesto reduce the loss of heat from the inner discharge tube A. In this way, B helps to maintain the necessary high temperature needed for the operation of a sodium vapour lamp irrespective of draughts. The capacitor C is meant for improving the power factor of the circuit.

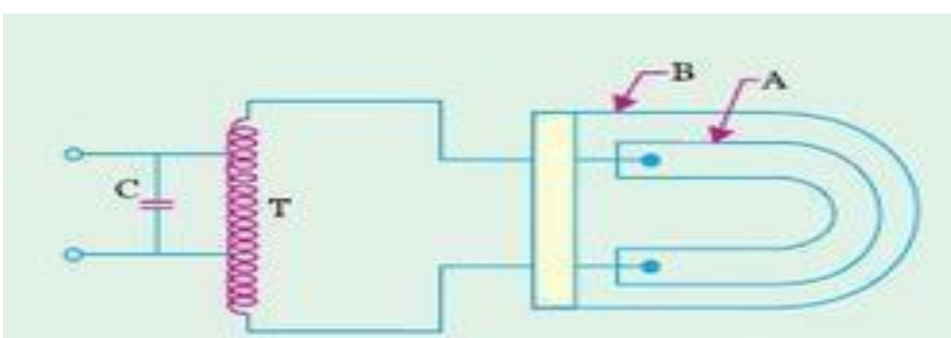


Fig 3.11

The light emitted by such lamps consists entirely of yellow colour. Solid objects illuminated by sodium-vapour lamp, therefore, present a picture in monochrome appearing as various shades of yellow or black.

Mercury Vapour Lamp

Like sodium-vapour lamp, this lamp is also classified as electric discharge lamp in which light is produced by gaseous conduction. Such a lamp usually consists of two bulbs — an arc-tube containing the electric discharge and an outer bulb which protects the arc-tube from changes in temperature. The inner tube or arc tube A is made of quartz (or hard glass)the outer bulb B of hard glass. As shown in Fig. 3.12, the arc tube contains a small amount of mercury and argon gas and houses three electrodes D, E and S. The main electrodes are D and E whereas S is the auxiliary starting electrode. S is connected through a high resistance R (about 50 kΩ) to the main electrode situated at the outer end of the tube. The main electrodes consist of tungsten coils with electron- emitting coating or elements of thorium metal.

When the supply is switched on, initial discharge for the few seconds is established in the argon gas between D and S and then in the argon between D and E . The heat produced due to this discharge through the gas is sufficient to vaporise mercury. Consequently, pressure inside A increases to about one or two atmospheres and the
p.d. across D and E grows from about 20 to 150 V, the operation taking about 5-7 minutes. During this time, discharge is established through the mercury vapours which emit greenish-blue light.

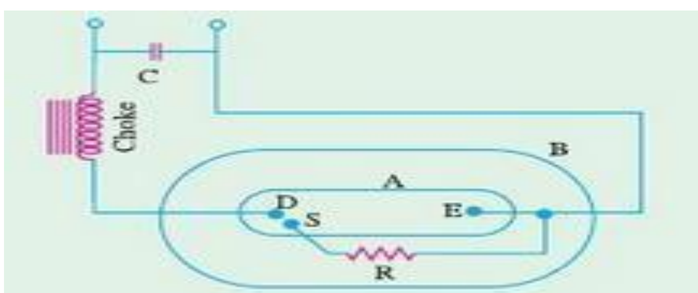


Fig 3.12

The choke serves to limit the current drawn by the discharge tube A to a safe limit and capacitorC helps to improve the power factor of the circuit. True colour rendition is not possible with mercury vapour lamps since there is complete absence of red-light from their radiations. Consequently, red objects appear black, all blues appear mercury-spectrum blue and all greens the mercury-spectrum green with the result that colour valuesare distorted.

Correction for colour distortion can be achieved by

1.Using incandescent lamps (which are rich in red light) in combination with the mercury lamps.

2.Using colour-corrected mercury lamps which have an inside phosphor coat to add red colour to the mercury spectrum. Stroboscopic (Flickering) effect in mercury vapour lamps is caused by the 100 on and off arc strikes when the lamps are used on the 50-Hz supply. The effect may be minimized by

1. Using two lamps on lead-lag transformer
2. Using three lamps on separated phases of a 3-phase supply and3.Using incandescent lamps in combination with mercury lamps.

In the last few years, there has been tremendous improvement in the construction and operation of mercury-vapour lamps, which has increased their usefulness and boosted their application for all types of industrial lighting, floodlighting and street lighting etc. As compared to an incandescent lamp, a mercury-vapour lamp is (a) smaller in size (b) has 5 to 10 times longeroperating life and(c) has 3 times higher efficiency
i.e.3 times more light output for given electrical wattage input. Typicalmercury-vapour lamp

applications are :

1.High-bay industrial lighting — where high level illumination is required and colourrendition isnot important.
2.Flood-lighting and street-lighting
3.Photochemical applications — where ultra-violet output is useful as in chlorination, watersterilization and photocopying etc.
4.For a wide range of inspection techniques by ultra-violet activation of fluorescent and phos-phorescent dyes and pigments.
5.Sun-tan lamps — for utilizing the spectrum lines in the erythemal region of ultra-violetenergyfor producing sun-tan.

POLAR CURVES

The Luminous flux obtained by a source can be determined from the intensity distribution curve. The luminous intensity or candle power of any practical lamp is not uniform in all directions due to its unsymmetrical shape. The distribution light is given by polar curves. If the actual luminous intensity of a source in various directions be plotted to scale along lines radiating from the centre of the source at corresponding angles, we obtain the polar curve of thecandle power. Suppose we construct a figure consisting of large number of spokes radiating out from a point —the length of each spoke representing to some scale the candle power or luminous intensity of the source in that particular direction. If now we join the ends of these spokes by some suitable material, say, by linen cloth, then we get a surface whose shape will represent to scale the three dimensional candle power distribution of the source placed atthe centre. In the ideal case of a point source having equal distribution in all directions, the surface would be spherical. It would be realized that it is difficult to give a graphic representationof such a 3-dimensional model in a plane surface. Therefore, as with engineering drawings, it is usual to draw only one or more elevations and a plan of sections through the centre of the source. Elevations represent c.p. distribution in the ***vertical*** plane and the plans represent c.p. distribution in ***horizontal*** plane. The number of elevations required to give a complete idea of the c.p. distribution of the source in all directions depends upon the shape of the plan *i.e.* on the horizontal distribution. If the distribution is uniform in every horizontal plane *i.e.* if the polar curve of horizontal distributionis a circle, then only one vertical curve is sufficient to give full idea of the space distribution.

(Fig 3.12) are shown two polar curves of c.p. distribution in a vertical plane. Curve 1 is for Vacuum type tungsten lamp with zig-zag filament whereas curve 2 is for gas filled tungstenlamp with filament arranged as a horizontal ring.

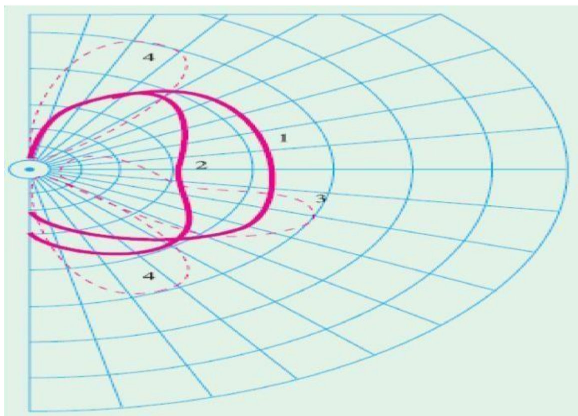


Fig 3.13

If the polar curve is symmetrical about the vertical axis as in the figures given below, then it is sufficient to give only the polar curve within one semicircle in order to completely define the distribution of c.p. as shown in Fig.(3.12). The curves 1 and 2 are as in Fig. (3.12), curves 3 isfor d.c. open arc with plain carbons and curve 4 is for a.c. arc with plain carbons. However, if thesource and/or reflector are not symmetrical about vertical axis, it is impossible to represent the space distribution of c.p. by a single polar diagram and even polar diagrams for two planes at right angles to each other give no definite idea as to the distribution in the intermediate planes.

Consider a filament lamp with a helmet-type reflector whose axis is inclined and cross-section elliptical—such reflectors are widely used for lighting shop windows. Fig. (3.13) represents the distribution of luminous intensity of such source and its reflector in two planes at right angles to each other. The importance of considering the polar curves in different planes when the c.p. distribution in asymmetrical is even more strikingly depicted by the polar curves in *YY* plane and *XX* plane of a lamp with a special type of reflector designed for street lighting purposesFig(3.14)

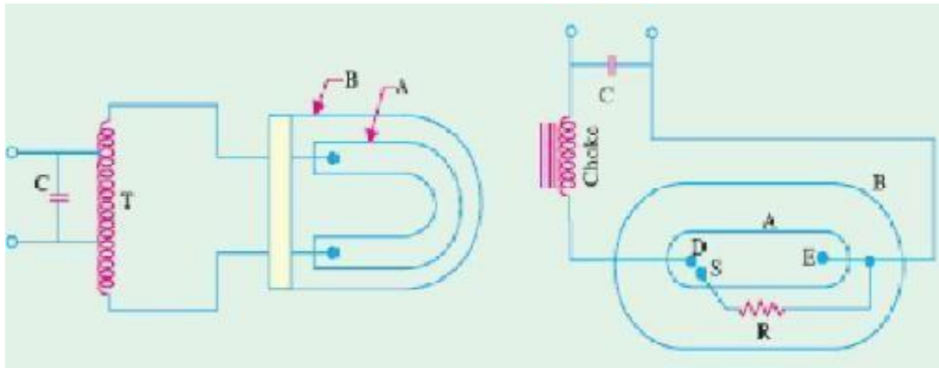


Fig 3.14

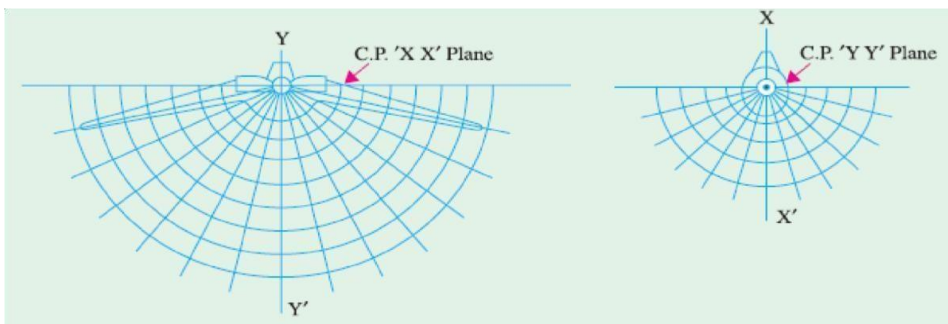


Fig 3.15

It would be realized from above that the polar distribution of light from any source can be given any desired form by using reflectors and/or refractors of appropriate shape.

ROUSSEAU'S CONSTRUCTION

Only half of the vertical polar curve is shown in the figure (Fig. 3.16 &3.17) since it is symmetrical about the vertical axis. With *O* is the centre and radius *OR* equal to the maximum radius of the polar curve, a semi-circle *LRM* is drawn. A convenient number of points on this semi-circle (say 10° points) are projected onto any vertical plane as shown. For example, points *a*,*b*,*c* etc. are projected to *d*,*e*,*f* and so on. From point *d*, the horizontal line *dg* is drawn equal to the intercept *OA* of the polar diagram on the radius *oa*. Similarly, *eh* = *OB, fk* = *OC* and so on. The points *g, h, k* etc., define the Rousseau figure. The average width *w* of this figure represents the M.S.C.P. to the same scale as that of the candle powers in the polar curve. The average width is obtained by dividing the Rousseau area by the base of the Rousseau figure *i.e.* length lm which is the projection of the semi-circle *LM* on the vertical axis. The area may be determined by Simpson,,s rule or by using a planimeter

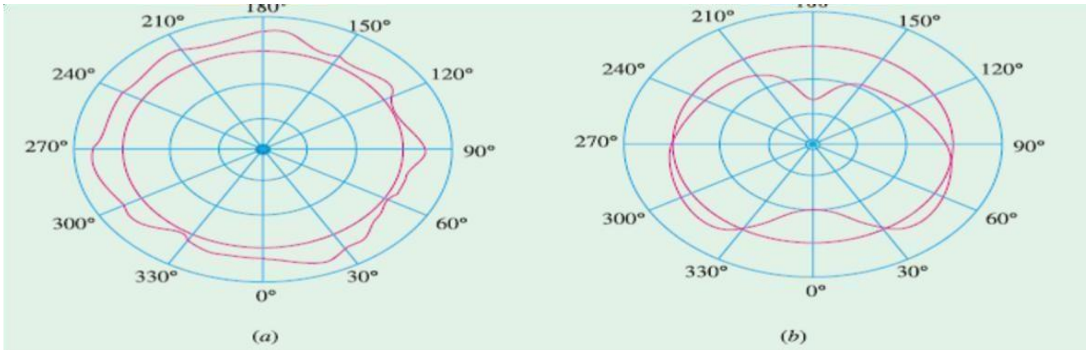


Fig 3.16

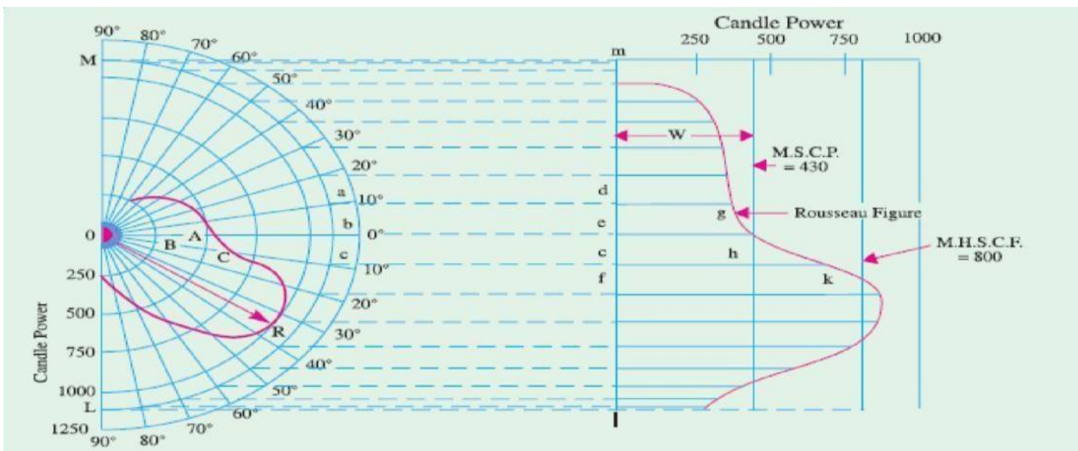


Fig 3.17

$$\therefore \qquad \text{M.S.C.P.} = \frac{\text{area of Rousseau figure}}{\text{length of the base}}$$ ....-(12)

As explained earlier, the M.H.C.P. of an incandescent lamp can be easily obtained by mounting the lamp with its axis vertical and taking photometer readings in the horizontal plane while the lamp is rotated about its axis in steps of 10° or so. A definite ratio exists between the M.H.C.P. and M.S.C.P. of each particular type of filament. M.S.C.P. of a lamp can be found by multiplying

M.H.C.P. by a factor known as spherical reduction factor which, as defined earlier, is For the

particular lamp considered, $f = 430/80 = 0.54$ (approx.)----------------------- (13)

$$\text{Spherical reduction factor} \quad f = \frac{\text{M.S.C.P.}}{\text{M.H.C.P.}} \qquad \therefore \quad \text{M.S.C.P.} = f \times \text{M.H.C.P.}$$

LEDs (Light-Emitting Diodes)

LEDs are solid-state semiconductor devices that convert electrical energy directly into light. LEDs can be extremely small and durable; some LEDs can provide much longer lamp life thanother sources. Figure 3.18 shows several typical LEDs. The plastic encapsulant and the lead frame occupy most of the volume. The light-generating chip is quite small (typically a cuboid with one side equal to 0.25 mm). Light is generated inside the chip, a solid crystal material, when current flows across the junctions of different materials. The composition of the materials determines the wavelength and therefore the color of light.

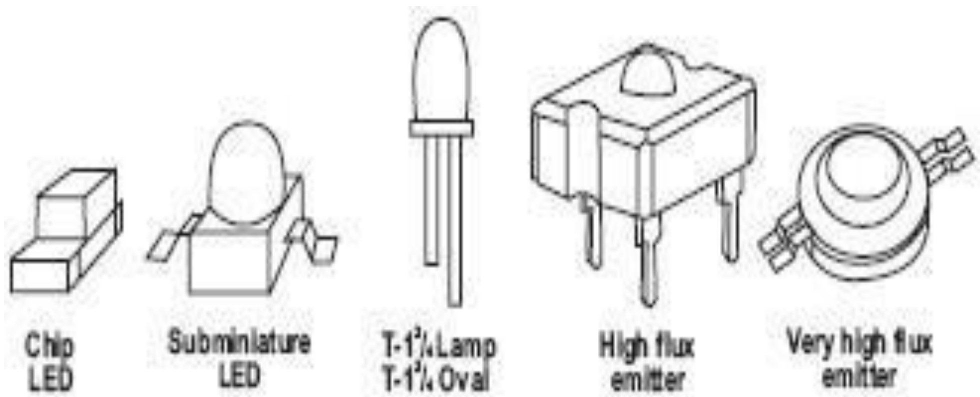


Fig 3.18

Fluorescent Lamp

A fluorescent lamp, or fluorescent tube, is a low-pressure mercury-vapor gas-discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapor, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow. A fluorescent lamp converts electrical energy into useful light much more efficiently than incandescent lamps. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt, several times the efficacy of incandescent bulbs with comparable light output.

Fluorescent lamp fixtures are more costly than incandescent lamps because they require a ballast to regulate the current through the lamp, but the lower energy cost typically offsets the higher initial cost. Compact fluorescent lamps are now available in the same popular sizes as incandescents and are used as an energy-saving alternative in homes.

A fluorescent lamp tube is filled with a gas containing low-pressure mercury vapor and argon, xenon, neon, or krypton. The pressure inside the lamp is around 0.3% of atmospheric pressure. The inner surface of the lamp is coated with a fluorescent (and often slightly phosphorescent) coating made of varying blends of metallic and rare-earth phosphor salts. The lamp's electrodes are typically made of coiled tungsten and usually referred to as cathodes because of their prime function of emitting electrons. For this, they are coated with a mixture of barium, strontium and calcium oxides chosen to have a low thermionic emission temperature.Fluorescent lamp tubes are typically straight and range in length from about 100 millimeters (3.9 in) for miniature lamps, to 2.43 meters (8.0 ft) for high-output lamps. Some lamps have the tube bent into a circle, used for table lamps or other places where a more

compact light source is desired. Larger U- shaped lamps are used to provide the same amount of light in a more compact area, and are used for special architectural purposes. Compact fluorescent lamps have several small-diameter tubes joined in a bundle of two, four, or six, or a small diameter tube coiled into a helix, to provide a high amount of light output in little volume.
Light-emitting phosphors are applied as a paint-like coating to the inside of the tube. The organic solvents are allowed to evaporate, then the tube is heated to nearly the melting point of glass to drive offremaining organic compounds and fuse the coating to the lamp tube. Careful control of the grain size of the suspended phosphors is necessary; large grains, 35 micrometers or larger, lead to weak grainy coatings, whereas too many small particles 1 or 2 micrometers or smaller leads to poor light maintenance and efficiency. Most phosphors perform best with a particle size around 10 micrometers. The coating must be thick enough to capture all the ultraviolet light produced by the mercury arc, but not so thick that the phosphor coating absorbs too much visible light. The first phosphors were synthetic versions of naturally occurring fluorescent minerals, with small amounts of metals added as activators. Later other compounds were discovered, allowing differing colors of lamps to be made.

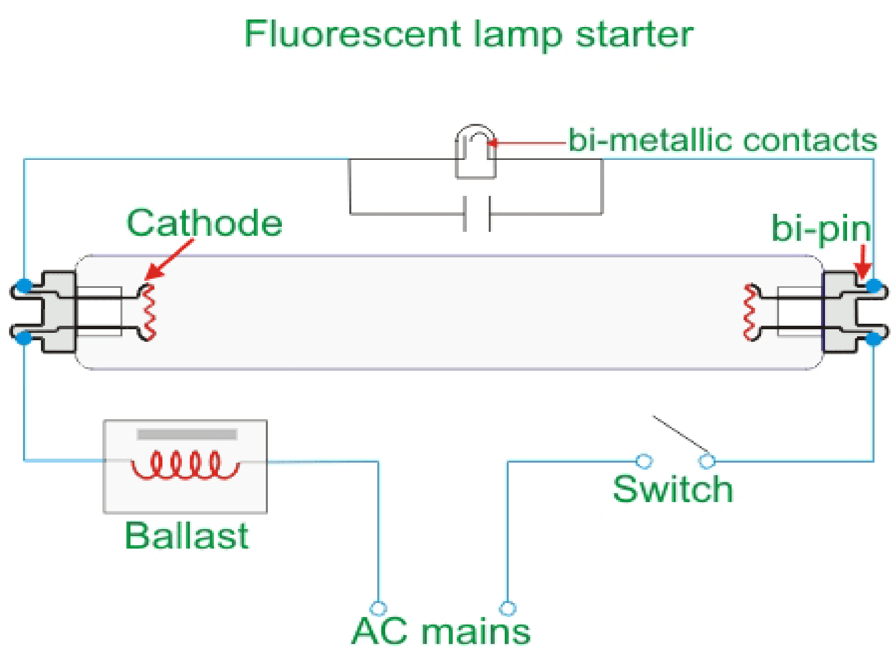


Fig 3.19

Applications

Fluorescent lamps come in many shapes and sizes. The compact fluorescent lamp (CFL) is becoming more popular. Many compact fluorescent lamps integrate the auxiliary electronics into the base of the lamp, allowing them to fit into a regular light bulb socket.
In US residences, fluorescent lamps are mostly found in kitchens, basements, or garages, but schools and businesses find the cost savings of fluorescent lamps to be significant and rarely use

incandescent lights. Tax incentives and building codes result in higher use in places such as California. In other countries, residential use of fluorescent lighting varies depending on the price of energy, financial and environmental concerns of the local population, and acceptability of the light output. In East and Southeast Asia it is very rare to see incandescent bulbs in buildings anywhere.

Some countries are encouraging the phase-out of incandescent light bulbs and substitution of incandescent lamps with fluorescent lamps or other types of energy-efficient lamps.In addition to general lighting, special fluorescent lights are often used in stage lighting for film and video production. They are cooler than traditional halogen light sources, and use high-frequency ballasts to prevent video flickering and high color-rendition index lamps to approximate daylight color temperatures.

Advantages

Luminous efficacy

Fluorescent lamps convert more of the input power to visible light than incandescent lamps, though as of 2013 LEDs are sometimes even more efficient and are more rapidly increasing in efficiency. A typical 100 watt tungsten filament incandescent lamp may convert only 5% of its power input to visible white light (400–700 nm wavelength), whereas typical fluorescent lamps convert about 22% of the power input to visible white light.

The efficacy of fluorescent tubes ranges from about 16 lumens per watt for a 4 watt tube with an ordinary ballast to over 100 lumens per watt with a modern electronic ballast, commonly averaging 50 to 67 lm/W overall. Most compact fluorescents above 13 watts with integral electronic ballasts achieve about 60 lm/W. Lamps are rated by lumens after 100 hours of operation. For a given fluorescent tube, a high-frequency electronic ballast gives about a 10% efficacy improvement over an inductive ballast. It is necessary to include the ballast loss when evaluating the efficacy of a fluorescent lamp system; this can be about 25% of the lamp power with magnetic ballasts, and around 10% with electronic ballasts.

Life

Typically a fluorescent lamp will last 10 to 20 times as long as an equivalent incandescent lamp when operated several hours at a time. Under standard test conditions general lighting lamps have 9,000 hours or longer service life.

The higher initial cost of a fluorescent lamp compared with an incandescent lamp is usually more than compensated for by lower energy consumption over its life.

A few manufacturers are producing T8 lamps with 90,000 hour lamp lives, rivalling the life of LED lamps.

Lower luminance

Compared with an incandescent lamp, a fluorescent tube is a more diffuse and physically larger light source. In suitably designed lamps, light can be more evenly distributed without point source of glare such as seen from an undiffused incandescent filament; the lamp is large compared to the typical distance between lamp and illuminated surfaces.

Lower heat

Fluorescent lamps give off about one-fifth the heat of equivalent incandescent lamps. This greatly reduces the size, cost, and energy consumption devoted to air conditioning for office buildings that would typically have many lights and few windows.

Questions

Part – A

1. Define space –height ratio.
2. State different lighting schemes.
3. Define i) Solid angle ii) Luminous intensity.
4. Define the terms,Lumen,Candle power.
5. Define i) Angstrom ii) Luminous flux
6. List out the requirements of good lighting?
7. What are the advantages of fluorescents lighting over plain mercury dischargelighting?
8. Why tungsten is selected as the filament material & on what factors its life depends?
9. What are the advantages & disadvantages of sodium & high pressure mercury lightingover that of filaments lamp?

Part – B

1. Explain the working of high-pressure mercury vapour lamp with neat sketch.
2. Explain with the help of diagram, how the MSCP can be found from a vertical polar curve by Rousseau's construction.
3. Explain with a neat diagram, the principle and operation of sodium vapour Lamp.
4. Draw the schematic diagram of low-pressure mercury vapour lamp & explain the operation of thelamp.
5. Draw the schematic diagram of sodium vapour lamp.
6. The illumination in a drawing office 30 m× 10 m is to have a value of 250 lux and is to be provided by a number of 300-W filament lamps. If the coefficient of utilization is 0.4 and the depreciation factor 0.9, determine the number of lamps required. The luminous efficiency of each lamp is 14 lm/W.
7. Explain the schematic diagram of Fluorescent Lamp.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SEE1303-POWER GENERATION AND UTILIZATION

UNIT – IV
HEATING AND WELDING

UNIT IV HEATING AND WELDING

Introduction - methods of heating - design of heating element- resistance, inductance, arc furnaces- high freq. dielectric heating- welding - types- resistance, arc welding- construction and its characteristics.

4.1. Introduction

Electric heating is any process in which electrical energy is converted to heat. Common applications include space heating, cooking, water heating and industrial processes. An electric heater is an electrical device that converts electric current to heat. The heating element inside every electric heater is an electrical resistor, and works on the principle of Joule heating: an electric current passing through a resistor will convert that electrical energy into heat energy. Most modern electric heating devices use nichrome wire as the active element; the heating element, depicted on the right, uses nichrome wire supported by ceramic insulators.

Alternatively, a heat pump uses an electric motor to drive a refrigeration cycle, that draws heat energy from a source such as the ground or outside air and directs that heat into the space to be warmed. Some systems can be reversed so that the interior space is cooled and the warm air is discharged outside or into the ground. Heat pumps can deliver three or four units of heating energy for every unit of electricity purchased, with the amount of heating energy delivered being a function of equipment efficiency as well as the temperature difference between the ground (or outdoor air) and the building interior.

30 kW resistance heating coils

4.1.1. Space heating

Space heating is used to warm the interiors of buildings. Electric space heating is useful in places where air-handling is difficult, such as in laboratories. Several methods of electric space heating are used.

4.1.2. Radiant heaters

Electric radiant heating uses heating elements that reach a high temperature. The element is usually packaged inside a glass envelope resembling a light bulb and with a reflector to direct the energy output away from the body of the heater. The element emits infrared radiation that travels through air or space until it hits an absorbing surface, where it is partially converted to heat and partially reflected. This heat directly warms people and objects in the room, rather than warming the air. This style of heater is particularly useful in areas through which unheated air flows. They are also ideal for basements and garages where spot heating is desired. More generally, they are an excellent choice for task-specific heating. Radiant heaters operate silently and present the greatest potential danger of ignition of nearby furnishings due to the focused intensity of their output and lack of overheat protection. In the United Kingdom, these appliances are sometimes called electric fires, because they were originally used to replace open fires.

The active medium of the heater depicted at the right is a coil of nichrome resistance wire inside a fused silica tube, open to the atmosphere at the ends, although models exist where the fused silica is sealed at the ends and the resistance alloy is not nichrome.

4.1.3. Convection heaters

In a convection heater, the heating element heats the air in contact with it by thermal conduction. Hot air is less dense than cool air, so it rises due to buoyancy, allowing more cool air to flow in to take its place. This sets up a convection current of hot air that rises from the heater, heats up the surrounding space, cools and then repeats the cycle. These heaters are sometimes filled with oil. They are ideally suited for heating a closed space. They operate silently and have a lower risk of ignition hazard if they make unintended contact with furnishings compared to radiant electric heaters.

4.1.4. Fan heaters

A fan heater, also called a forced convection heater, is a variety of convection heater that includes an electric fan to speed up the airflow. They operate with considerable noise caused by the fan. They have a moderate risk of ignition hazard if they make unintended contact with furnishings. Their advantage is that they are more compact than heaters that use natural convection.

4.1.5. Storage heating

A storage heating system takes advantage of cheaper electricity prices, sold during low demand periods such as overnight. The storage heater stores heat in clay bricks, then releases it during the day when required. Newer storage heaters are able to be used with various tariffs. Alongside new designs the use of a thermostat or sensor has improved the efficiency of the storage heater. A thermostat or sensor is able to read the temperature of the room, and change the output of the heater accordingly. Water can also be used as a heat-storage medium.

4.1.6. Domestic electrical under floor heating

An electric under floor heating system has heating cables embedded in the floor. Current flows through a conductive heating material, supplied either directly from the line voltage (120 or 240 volts) or at low voltage from a transformer. The heated cables warm the flooring until it reaches the right temperature set by the floor thermostat. The flooring then heats the adjacent air, which circulates, heating other objects in the room (tables, chairs, people) by convection. As it rises, the heated air will warm the room and all its contents up to the ceiling. This form of heating gives the most consistent room temperature from floor to ceiling compared to any other heating system. A variation of this principle uses tubes filled with circulating hot water.

4.1.7.Lighting system

In large office towers, the lighting system is integrated with the heating and ventilation system. Waste heat from fluorescent lamps is captured in the return air of the heating system; in large buildings a substantial part of the annual heating energy is supplied by the lighting system. However, this waste heat becomes a liability when using air conditioning.

4.1.8.Heat pumps

A heat pump uses an electrically driven compressor to operate a refrigeration cycle that extracts heat energy from outdoor air, the ground or ground water, and moves that heat to the space to be warmed. A liquid contained within the evaporator section of the heat pump boils at low pressure, absorbing heat energy from the outdoor air or the ground. The vapor is then compressed by a compressor and piped into a condenser coil within the building to be heated. The heat from the hot dense gas is absorbed by the air in the building (and sometimes also used for domestic hot water) causing the hot working fluid to condense back into a liquid. From there the high pressure fluid is passed back to the evaporator section where it expands through an orifice and into the evaporator section, completing the cycle. In the summer months, the cycle can be reversed to move heat out of the conditioned space and to the outside air.

Heat pumps may obtain low-grade heat from the outdoor air in mild climates. In areas with average winter temperatures well below freezing, ground source heat pumps are more efficient than air source heat pumps because they can extract residual solar heat stored in the ground at warmer temperatures than is available from cold air. According to the US EPA, geothermal heat pumps can reduce energy consumption up to 44% compared with air source heat pumps and up to 72% compared with electric resistance heating. The high purchase price of a heat pump vs resistance heaters may be offset when air conditioning is also needed.

4.1.9.Liquid heating

4.1.9.1.Immersion heater

Small domestic immersion heater, 500 W

An immersion heater has an electrical resistance heating element encased in a tube and directly placed in the water (or other fluid) to be heated. The immersion heater may be placed in an insulated hot water tank. A temperature sensor within the tank triggers a thermostat to control the temperature of the water. Small portable immersion heaters may not have a control thermostat, since they are intended to be used only briefly and under control of an operator.

4.1.9.2.Domestic immersion heaters

Domestic immersion heaters, usually rated at 3 kilowatts and on a 1.5" British Standard Pipe screw plug in the UK, run on the normal domestic electricity supply, but consumers may also take advantage of a cheaper, off-peak electricity tariff such as. In a typical off-peak installation, a lower immersion heater is connected to the separately switched off-peak heating circuit and an upper heater is connected to the normal circuit via its own switch. The consumer then has the option to top-up the available hot water supply at any time, rather than waiting for the cheaper supply to turn on (typically after midnight). A poorly insulated hot water cylinder will increase running costs because a consumer must pay for electricity used to replace lost heat.

Electric shower and tank less heaters also use an immersion heater (shielded or naked) that is turned on with the flow of water. A group of separate heaters can be switched in order to offer different heating levels. Electric showers and tank less heaters usually use from 3 to 7.5 kilowatts. Irish-American comedian Des Bishop talks about his first encounter with a domestic immersion heater in one of his comedy routines.

4.1.9.3.Industrial immersion heaters

Industrial immersion heaters can be either screwed or flanged. Screwed industrial immersion heaters, in the UK usually on a 2.25" British Standard Pipe are usually only rated up to approximately 24 kW, with 6 kW being considered the very top end that can be accommodated safely on a single phase supply. Flanged immersion heaters (such as those used in electric steam boilers) can be rated at up to 2000 kilowatts, or more, and require a three-phase supply.

Electrical immersion heaters may heat water immediately adjacent to the heating element high enough to promote the formation of scale, commonly calcium carbonate, in hard water areas. This accumulates on the element, and over time, as the element expands and contracts through its heating cycle, the scale cracks off and drops to the bottom of the tank, progressively filling up the tank. This reduces the tank's capacity and, where the immersion heater is secondary to the heating of the water by a coil fed from a gas or oil-fired boiler, can reduce the efficiency of the primary heating source by covering that other coil and in turn reducing its efficiency. Regular flushing-out of accumulated sediment can reduce this problem.

Such problems can be avoided at the design stage, by maximizing the amount of hot element in the liquid, thus reducing the watts density. This reduces the working temperature of the surface of the element, reducing the buildup of lime scale.

4.1.9.4.Direct electric heat exchangers (DEHE)

The direct electric heat exchangers (DEHE) uses heating elements inserted into the "shell side" medium directly to provide the heating effect. Virtually all of the electric heat generated by the electric circulation heater is transferred into the medium, thus an electric heater is nearly 100 percent efficient. Direct electric heat exchangers or "circulation heaters" are used to heat liquids and gases in industrial processes.

4.2.Methods of heating

4.2.1.Electric heating

Methods of converting electric energy to heat energy by resisting the free flow of electric current. Electric heating has several advantages: it can be precisely controlled to allow a uniformity of temperature within very narrow limits; it is cleaner than other methods of heating because it does not involve any combustion; it is considered safe because it is protected from overloading by automatic breakers; it is quick to use and to adjust; and it is relatively quiet. For these reasons, electric heat is widely chosen for industrial, commercial, and residential use.

Resistance heaters produce heat by passing an electric current through a resistance—a coil, wire, or other obstacle which impedes current and causes it to give off heat. Heaters of this kind have an inherent efficiency of 100% in converting electric energy into heat. Devices such as electric ranges, ovens, hot-water heaters, sterilizers, stills, baths, furnaces, and space heaters are part of the long list of resistance heating equipment.

Dielectric heaters use currents of high frequency which generate heat by dielectric hysteresis (loss) within the body of a nominally non conducting material. These heaters are used to warm to a moderate temperature certain materials that have low thermal conducting properties; for example, to soften plastics, to dry textiles, and to work with other materials like rubber and wood.

Induction heaters produce heat by means of a periodically varying electromagnetic field within the body of a nominally conducting material. This method of heating is sometimes called eddy-current heating and is used to achieve temperatures below the melting point of metal. For instance, induction heating is used to temper steel, to heat metals for forging, to heat the metal elements inside glass bulbs, and to make glass-to-metal joints.

Electric-arc heating is really a form of resistance heating in which a bridge of vapor and gas carries an electric current between electrodes. The arc has the property of resistance. Electric-arc heating is used mainly to melt hard metals, alloys, and some ceramic metals.

Electricity is one choice for heating houses, but with only a 35% efficiency rate, electricity has been a less attractive option than the direct use of gas and oil for heating homes. Common electric heating systems in houses are central heating employing an electric furnace with forced air circulation; central heating employing an electric furnace with forced water circulation; central heating using radiant cables; electrical duct heaters; space (strip) heaters which use radiation and natural convection for heat transfer; and portable space heaters.

4.2.2.Resistance heating

The generation of heat by electric conductors carrying current. The degree of heating for a given current is proportional to the electrical resistance of the conductor. If the resistance is high, a large amount of heat is generated, and the material is used as a resistor rather than as a conductor.

In addition to having high resistivity, heating elements must be able to withstand high temperatures without deteriorating or sagging. Other desirable characteristics are low temperature coefficient of resistance, low cost, formability, and availability of materials. Most commercial resistance alloys contain chromium or aluminum or both, since a protective coating of chrome oxide or aluminum oxide forms on the surface upon heating and inhibits or retards further oxidation.

Since heat is transmitted by radiation, convection, or conduction or combinations of these, the form of element is designed for the major mode of transmission. The simplest form is the helix, using a round wire resistor, with the pitch of the helix approximately three wire diameters. This form is adapted to radiation and convection and is generally used for room or air heating. It is also used in industrial furnaces, utilizing forced convection up to about 1200°F (650°C). Such helixes are stretched over grooved high-alumina refractory insulators and are otherwise open and unrestricted.

The electrical resistance of molten salts between immersed electrodes can be used to generate heat. Limiting temperatures are dependent on decomposition or vaporization temperatures of the salt, Parts to be heated are immersed in the salt. Heating is rapid and, since there is no exposure to air, oxidation is largely prevented. Disadvantages are the personnel hazards and discomfort of working close to molten salts.

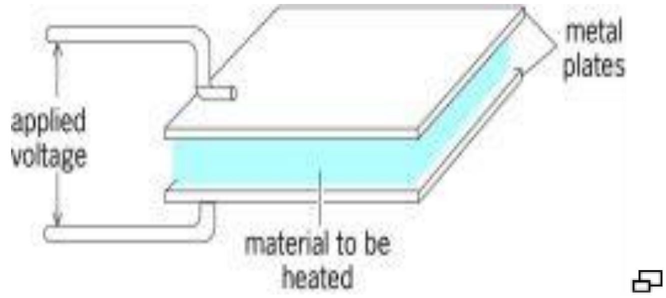
A major application of resistance heating is in electric home appliances, including electric ranges, clothes dryers, water heaters, coffee percolators, portable radiant heaters, and hair dryers. Resistance heating also has application in home or space heating.

If the resistor is located in a thermally insulated chamber, most of the heat generated is conserved and can be applied to a wide variety of heating processes. Such insulated chambers are called ovens or furnaces, depending on the temperature range and use. The term oven is generally applied to units which operate up to approximately 800°F (430°C). Typical uses are for baking or roasting foods, drying paints and organic enamels, baking foundry cores, and low-temperature treatments of metals. The term furnace generally applies to units operating above 1200°F (650°C). Typical uses of furnaces are for heat treatment or melting of metals, for verification and glazing of ceramic wares, for annealing of glass, and for roasting and claiming of ores.

4.2.3.Dielectric heating

The heating of a nominally electrical insulating material due to its own electrical (dielectric) losses, when the material is placed in a varying electrostatic field.

The material to be heated is placed between two electrodes (which act as capacitor plates) and forms the dielectric component of a capacitor (see illustration). The electrodes are connected to a high-voltage source of 2-90-MHz power, produced by a high-frequency vacuum-tube oscillator.



The resultant heat is generated within the material, and in homogeneous materials is uniform throughout. Dielectric heating is a rapid method of heating and is not limited by the relatively slow rate of heat diffusion present in conventional heating by external surface contact or by radiant heating.

This technique is widely employed industrially for preheating in the molding of plastics, for quick heating of thermosetting glues in cabinet and furniture making, for accelerated jelling and drying of foam rubber, in foundry core baking, and for drying of paper and textile products. Its advantages over conventional methods are the speed and uniformity of heating, which offset the higher equipment costs. Because of the absence of high thermal gradients, an improved end-product quality is usually obtained.

4.2.4.Induction heating

The heating of a nominally electrical conducting material by eddy currents induced by a varying electromagnetic field. The principle of the induction heating process is similar to that of a transformer. In the illustration, the inductor coil can be considered the primary winding of a transformer, with the work piece as a single-turn secondary. When an alternating current flows in the primary coil, secondary currents will be induced in the work piece. These induced currents are called eddy currents. The current flowing in the work piece can be considered as the summation of all of the eddy currents.

In the design of conventional electrical apparatus, the losses due to induced eddy currents are minimized because they reduce the overall efficiency. However, in induction heating, their maximum effect is desired. Therefore close spacing is used between the inductor coil and the work piece, and high coil currents are used to obtain the maximum induced eddy currents and therefore high heating rates.

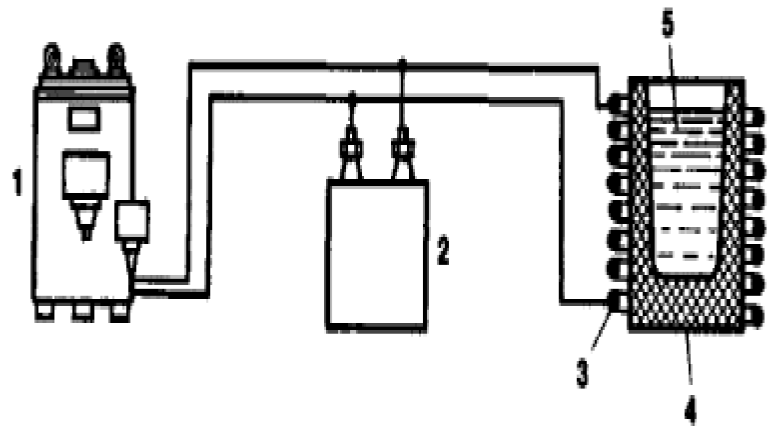
Induction heating is widely employed in the metalworking industry for a variety of industrial processes. While carbon steel is by far the most common material heated, induction heating is also used with many other conducting materials such as various grades of stainless steel, aluminum, brass, copper, nickel, and titanium products.

The advantages of induction heating over the conventional processes (like fossil furnace or salt-bath heating) are the following: (1) Heating is induced directly into the material. It is therefore an extremely rapid method of heating. It is not limited by the relative slow rate of heat diffusion in conventional processes using surface-contact or radiant heating methods. (2) Because of skin effect, the heating is localized and the heated area is easily controlled by the shape and size of the inductor coil. (3) Induction heating is easily controllable, resulting in uniform high quality of the product. (4) It lends itself to automation, in-line processing, and automatic-process cycle control. (5) Startup time is short, and standby losses are low or nonexistent. (6) Working conditions are better because of the absence of noise, fumes, and radiated heat.

Induction heating is characterized by the non uniform release of power in the object being heated. Eighty-six percent of the power is released in the surface layer (the so-called penetration). The penetration of the current Δ (in meters) where ρ is the specific electrical resistivity in ohms • m, μ, is the relative magnetic permeability, and f is the frequency in hertz (Hz).

Low-frequency (50 Hz), medium-frequency (up to 10 kHz) and high-frequency (over 10 kHz) currents are used in induction heating to generate an alternating electromagnetic field. Mechanical and static converters, as well as tube oscillators, are used to supply medium- or high-frequency current to induction heaters.

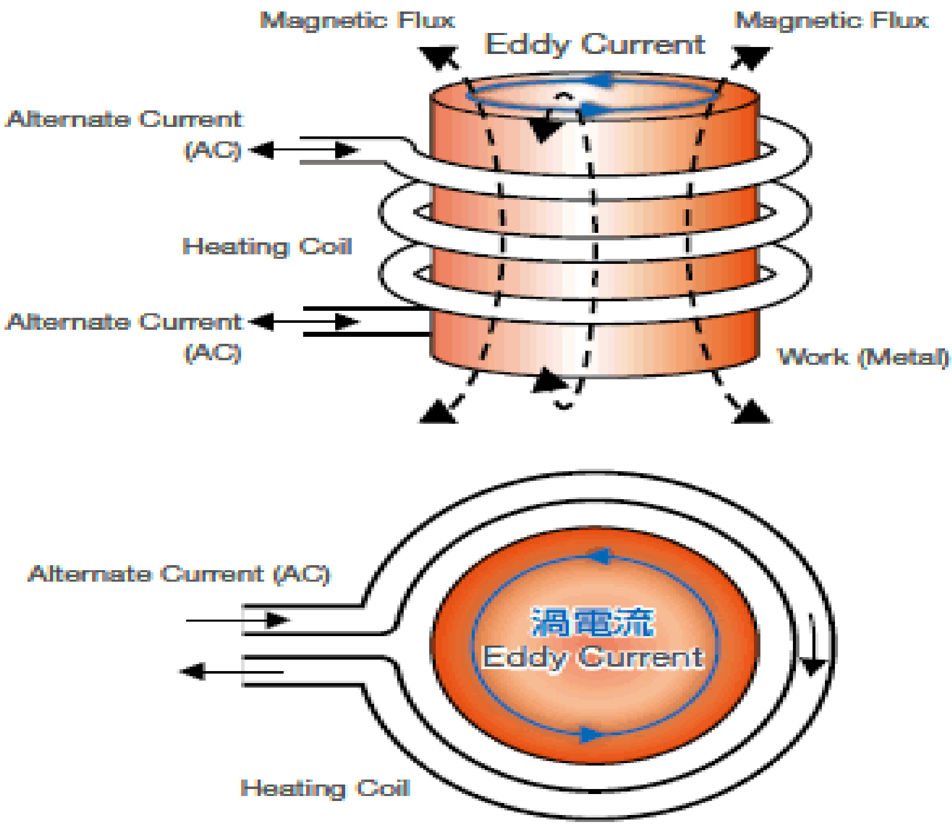
Induction heating is most widely used in the melting of metals, zone melting, and heating for pressure shaping. Induction heating is the most advanced contactless method of transmitting electrical energy to the object being heated, converting electrical energy directly into thermal energy.



4.2.5. Principle of High-frequency Induction Heater Unit

Induction heater units incorporate high frequency generators for non-contact heating of metal using electromagnetic induction.

When AC is applied to a coil surrounding the work (metal), a magnetic field is generated by the current flowing in the coil, and induced loss (hysteresis loss) is generated causing a heat. At the same time, in the magnetic field which alternates with the AC, a spiral current (eddy current) is generated by the electromagnetic induction. This eddy current generates Joule heating, and a heat loss of the electromagnetic energy (eddy-current loss) will be caused. High frequency induction heating equipment performs heating by utilizing the two heating principle, namely hysteresis loss and eddy-current loss.



4.2.6. Arc heating

The matter may be solid, liquid, or gaseous. When the heating is direct, the material to be heated is one electrode; for indirect heating, the heat is transferred from the arc by conduction, convection, or radiation.

At atmospheric pressure, the arc behaves much like a resistor operating at temperatures of the order of thousands of kelvins. The energy source is extremely concentrated and can reach many millions of watts per cubic meter. Almost all materials can be melted quickly under these conditions, and chemical reactions can be carried out under oxidizing, neutral, or reducing conditions.

In a direct-arc furnace, the arc strikes directly between the graphite electrodes and the charge being melted. These furnaces are used in steelmaking, foundries, ferroalloy production, and some nonferrous metallurgical applications. Although an extremely large number of furnace types are available, they are all essentially the same. They consist of a containment vessel with a refractory lining, a removable roof for charging, electrodes to supply the energy for melting and reaction, openings and a mechanism for pouring the product, a power supply, and controls. The required accessory components include water-cooling circuits, gas cleaning and extraction equipment, cranes for charging the furnace, and ladles to remove the product. Because the electrodes are consumed by volatilization and reaction, a mechanism must be provided to feed them continuously through the electrode holders.

In submerged-arc furnaces, the arcs are below the solid feed and sometimes below the molten product. Submerged-arc furnaces differ from those used in steelmaking in that raw materials are fed continuously around the electrodes and the product and slag are tapped off intermittently. The furnace vessel is usually stationary. Submerged-arc furnaces are often used for carbothermic reductions (for example, to make ferroalloys), and the gases formed by the reduction reaction percolate up through the charge, preheating and sometimes pre reducing it. Because of this, the energy efficiency of this type of furnace is high. The passage of the exhaust gas through the burden also filters it and thus reduces air-pollution control costs.

Although carbon arcs are plasmas, common usage of the term plasma torch suggests the injection of gas into or around the arc. This gas may be inert, neutral, oxidizing, or reducing, depending on the application and the electrodes used. Plasma torches are available at powers ranging from a few kilowatts to over 10 MW; usually they use direct-current electricity and water-cooled metallic electrodes.

Direct-current carbon arc furnaces operate on the basis that a direct-current arc is more stable than its alternating-current counterpart, and can, therefore, be run at lower current and higher voltage by increasing the arc length. This reduces both the electrode diameter and the electrode consumption compared to alternating-current operation at similar powers. Tests have also shown that injecting gas through a hole drilled through the center of the electrode further increases stability and reduces wear. Powdered ore and reluctant may be injected with this gas, reducing the need for agglomerating the arc furnace feed.In most cases, direct-current carbon arc furnaces have one carbon electrode, with the product forming the second electrode. The current is usually removed from the furnace through a bottom constructed of electrically conducting material. Several direct-current plasma furnaces with powers ranging from 1 to 45 MW are in operation.

4.2.7. Disadvantages of Electric Heating

With space heaters, we can't easily provide central filtration, humidification or cooling . However, this is also true of boilers and radiant heating, for example, no matter which fuel is used to generate the heat. Electric furnaces , of course, do have the opportunity to provide central filtration, humidification and cooling. Some people would suggest that the electrical hazard of shock and fire caused by electricity is an issue. However, since this is already an issue in homes because of the electrical distribution system, most people do not feel that this adds considerably to the hazard of the house. Electric heat requires a larger electrical service than normal. There is a cost associated with this.

4.3.Welding

4.3.1. Introduction to Welding

A weld is made when separate pieces of material to be joined combine and form one piece when heated to a temperature high enough to cause softening or melting. Filler material is typically added to strengthen the joint. Welding is a dependable, efficient and economic method for permanently joining similar metals. In other words, you can weld steel to steel or aluminum to aluminum, but you cannot weld steel to aluminum using traditional welding processes. Welding is used extensively in all sectors or manufacturing, from earth moving equipment to the aerospace industry.

4.3.2. Welding Processes

The most popular processes are shielded metal arc welding (SMAW), gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW).

All of these methods employ an electric power supply to create an arc which melts the base metal(s) to form a molten pool. The filler wire is then either added automatically (GMAW) or manually (SMAW & GTAW) and the molten pool is allowed to cool.

Finally, all of these methods use some type of flux or gas to create an inert environment in which the molten pool can solidify without oxidizing.

4.3.3.Electric resistance welding

where heat to form the weld is generated by the electrical resistance of material combined with the time and the force used to hold the materials together during welding. Some factors influencing heat or welding temperatures are the proportions of the work pieces, the metal coating or the lack of coating, the electrode materials, electrode geometry, electrode pressing force, electrical current and length of welding time. Small pools of molten metal are formed at the point of most electrical resistance (the connecting or "faying" surfaces) as an electrical current (100–100,000 A) is passed through the metal. In general, resistance welding methods are efficient and cause little pollution, but their applications are limited to relatively thin materials and the equipment cost can be high (although in production situations the cost per weld may be low)

4.3.4.Spot welding

Spot welding is a resistance welding method used to join two or more overlapping metal sheets, studs, projections, electrical wiring hangers, some heat exchanger fins, and some tubing. Usually power sources and welding equipment are sized to the specific thickness and material being welded together. The thickness is limited by the output of the welding power source and thus the equipment range due to the current required for each application. Care is taken to eliminate contaminants between the faying surfaces. Usually, two copper electrodes are simultaneously used to clamp the metal sheets together and to pass current through the sheets. When the current is passed through the electrodes to the sheets, heat is generated due to the higher electrical resistance where the surfaces contact each other. As the electrical resistance of the material causes a heat buildup in the work pieces between the copper electrodes, the rising temperature causes a rising resistance, and results in a molten pool contained most of the time between the electrodes. As the heat dissipates throughout the work piece in less than a second (resistance welding time is generally programmed as a quantity of AC cycles or milliseconds) the molten or plastic state grows to meet the welding tips. When the current is stopped the copper tips cool the spot weld, causing the metal to solidify under pressure. The water cooled copper electrodes remove the surface heat quickly, accelerating the solidification of the metal, since copper is an excellent conductor. Resistance spot welding typically employs electrical power in the form of direct current, alternating current, medium frequency half-wave direct current, or high-frequency half wave direct current.

If excessive heat is applied or applied too quickly, or if the force between the base materials is too low, or the coating is too thick or too conductive, then the molten area may extend to the exterior of the work pieces, escaping the containment force of the electrodes (often up to 30,000 psi). This burst of molten metal is called expulsion, and when this occurs the metal will be thinner and have less strength than a weld with no expulsion. The common method of checking a weld's quality is a peel test. An alternative test is the restrained tensile test, which is much more difficult to perform, and requires calibrated equipment. Because both tests are destructive in nature (resulting in the loss of salable material), non-destructive methods such as ultrasound evaluation are in various states of early adoption by many OEMs.

The advantages of the method include efficient energy use, limited work piece deformation, high production rates, easy automation, and no required filler materials. When high strength in shear is needed, spot welding is used in preference to more costly mechanical fastening, such as riveting. While the shear strength of each weld is high, the fact that the weld spots do not form a continuous seam means that the overall strength is often significantly lower than with other welding methods, limiting the usefulness of the process. It is used extensively in the automotive industry— cars can have several thousand spot welds. A specialized process, called shot welding, can be used to spot weld stainless steel.

There are three basic types of resistance welding bonds: solid state, fusion, and reflow braze. In a solid state bond, also called a thermo-compression bond, dissimilar materials with dissimilar grain structure, e.g. molybdenum to tungsten, are joined using a very short heating time, high weld energy, and high force. There is little melting and minimum grain growth, but a definite bond and grain interface. Thus the materials actually bond while still in the solid state. The bonded materials typically exhibit excellent shear and tensile strength, but poor peel strength. In a fusion bond, either similar or dissimilar materials with similar grain structures are heated to the melting point (liquid state) of both. The subsequent cooling and combination of the materials forms a “nugget” alloy of the two materials with larger grain growth. Typically, high weld energies at either short or long weld times, depending on physical characteristics, are used to produce fusion bonds. The bonded materials usually exhibit excellent tensile, peel and shear strengths. In a reflow braze bond, a resistance heating of a low temperature brazing material, such as gold or solder, is used to join either dissimilar materials or widely varied thick/thin material combinations. The brazing material must “wet” to each part and possess a lower melting point than the two work pieces. The resultant bond has definite interfaces with minimum grain growth. Typically the process requires a longer (2 to 100 ms) heating time at low weld energy. The resultant bond exhibits excellent tensile strength, but poor peel and shear strength.

4.3.5.Seam welding

Resistance seam welding is a process that produces a weld at the faying surfaces of two similar metals. The seam may be a butt joint or an overlap joint and is usually an automated process. It differs from butt welding in that butt welding typically welds the entire joint at once and seam welding forms the weld progressively, starting at one end. Like spot welding, seam welding relies on two electrodes, usually made from copper, to apply pressure and current. The electrodes are disc shaped and rotate as the material passes between them. This allows the electrodes to stay in constant contact with the material to make long continuous welds. The electrodes may also move or assist the movement of the material.

A transformer supplies energy to the weld joint in the form of low voltage, high current AC power. The joint of the work piece has high electrical resistance relative to the rest of the circuit and is heated to its melting point by the current. The semi-molten surfaces are pressed together by the welding pressure that creates a fusion bond, resulting in a uniformly welded structure. Most seam welders use water cooling through the electrode, transformer and controller assemblies due to the heat generated. Seam welding produces an extremely durable weld because the joint is forged due to the heat and pressure applied. A properly welded joint formed by resistance welding is typically stronger than the material from which it is formed.

A common use of seam welding is during the manufacture of round or rectangular steel tubing. Seam welding has been used to manufacture steel beverage cans but is no longer used for this as modern beverage cans are seamless aluminum.

There are two modes for seam welding: Intermittent and continuous. In intermittent seam welding, the wheels advance to the desired and stop to make each weld. This process continues until the desired length of the weld is reached. In continuous seam welding, the wheels continue to roll as each weld is made.

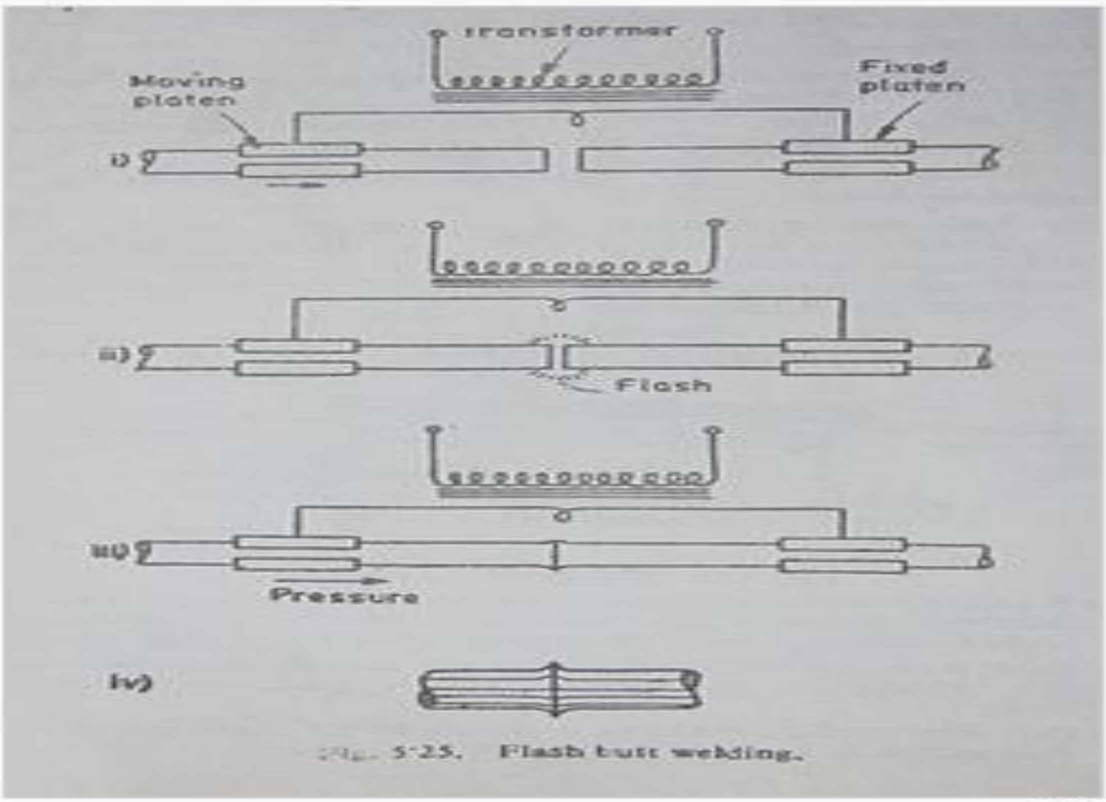
4.3.6.Low-frequency Electric resistance welding

Electric resistance welded (ERW) pipe is manufactured by cold-forming a sheet of steel into a cylindrical shape. Current is then passed between the two edges of the steel to heat the steel to a point at which the edges are forced together to form a bond without the use of welding filler material. Initially this manufacturing process used low frequency A.C. current to heat the edges.

Over time, the welds of low frequency ERW pipe was found to be susceptible to selective seam corrosion, hook cracks, and inadequate bonding of the seams, so low frequency ERW is no longer used to manufacture pipe. The high frequency process is still being used to manufacture pipe for use in new pipeline construction.

4.3.7.Flash welding

The pieces of metal to be welded are set apart at a predetermined distance based on material thickness, material composition, and desired properties of the finished weld. Current is applied to the metal, and the gap between the two pieces creates resistance and produces the arc required to melt the metal. Once the pieces of metal reach the proper temperature, they are pressed together, effectively forging them together.



Flash Butt welding drawing

4.3.7.1 Applications

According to the Journal of Materials Processing, the railroad industry is using flash welding to join sections of mainline rail together. This mainline rail is also known as continuously welded rail (CWR) and is much smoother than mechanically joined rail because there are no gaps between the sections of rail. This smoother rail reduces the wear on the rails themselves, effectively reducing the frequency of inspections and maintenance. In other countries, continuously welded rail is used on high-speed rail lines because of its smoothness. A study published in Materials Science and Design proved that flash welding is also beneficial in the railroad industry because it allows dissimilar metals and non ferrous metals to be joined. This allows crossings, which are generally composed of high manganese steel, to be effectively welded to the carbon steel rail with the use of a stainless steel insert, while keeping the desired mechanical properties of both the rail and the crossing intact. The ability of this single process to weld many different metals with simple parameter adjustments makes it very versatile. Materials and Design discusses the use of flash welding in the metal building industry to increase the length of the angle iron used to fabricate joists.

4.3.8.Spot welding

Resistance spot welding (RSW) is a process in which contacting metal surfaces are joined by the heat obtained from resistance to electric current.

Work-pieces are held together under pressure exerted by electrodes. Typically the sheets are in the 0.5 to 3 mm (0.020 to 0.118 in) thickness range. The process uses two shaped copper alloy electrodes to concentrate welding current into a small "spot" and to simultaneously clamp the sheets together. Forcing a large current through the spot will melt the metal and form the weld. The attractive feature of spot welding is that a lot of energy can be delivered to the spot in a very short time (approximately 10–100 milliseconds).That permits the welding to occur without excessive heating of the remainder of the sheet.

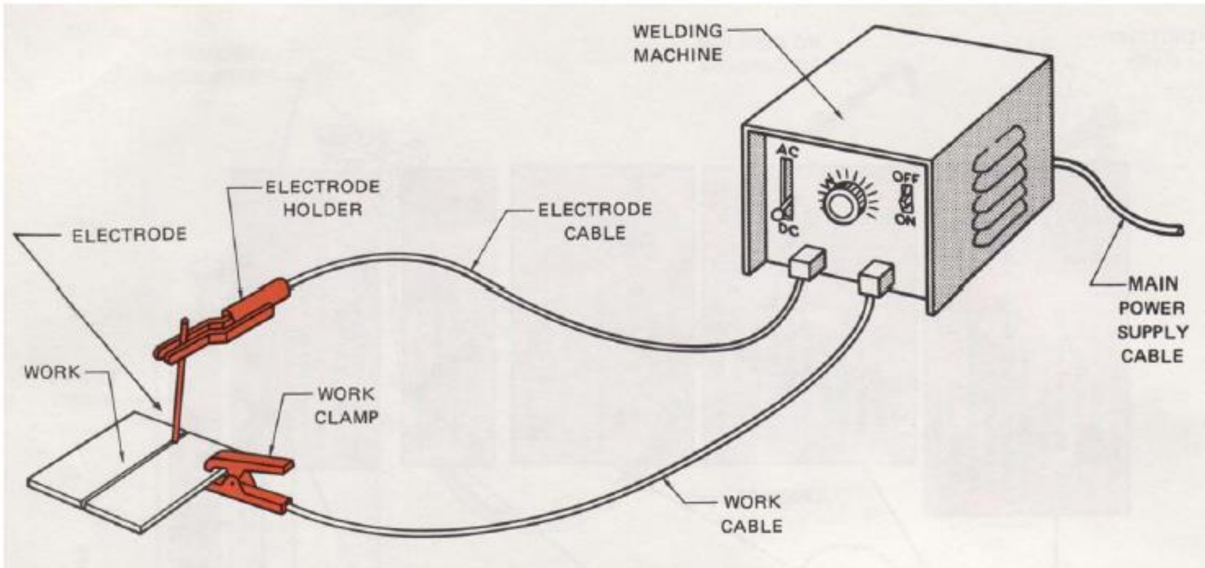
The amount of heat (energy) delivered to the spot is determined by the resistance between the electrodes and the magnitude and duration of the current. The amount of energy is chosen to match the sheet's material properties, its thickness, and type of electrodes. Applying too little energy will not melt the metal or will make a poor weld. Applying too much energy will melt too much metal, eject molten material, and make a hole rather than a weld. Another feature of spot welding is that the energy delivered to the spot can be controlled to produce reliable welds.

Projection welding is a modification of spot welding. In this process, the weld is localized by means of raised sections, or projections, on one or both of the work pieces to be joined. Heat is concentrated at the projections, which permits the welding of heavier sections or the closer spacing of welds. The projections can also serve as a means of positioning the work pieces. Projection welding is often used to weld studs, nuts, and other screw machine parts to metal plate. It is also frequently used to join crossed wires and bars. This is another high-production process, and multiple projection welds can be arranged by suitable designing and jigging.

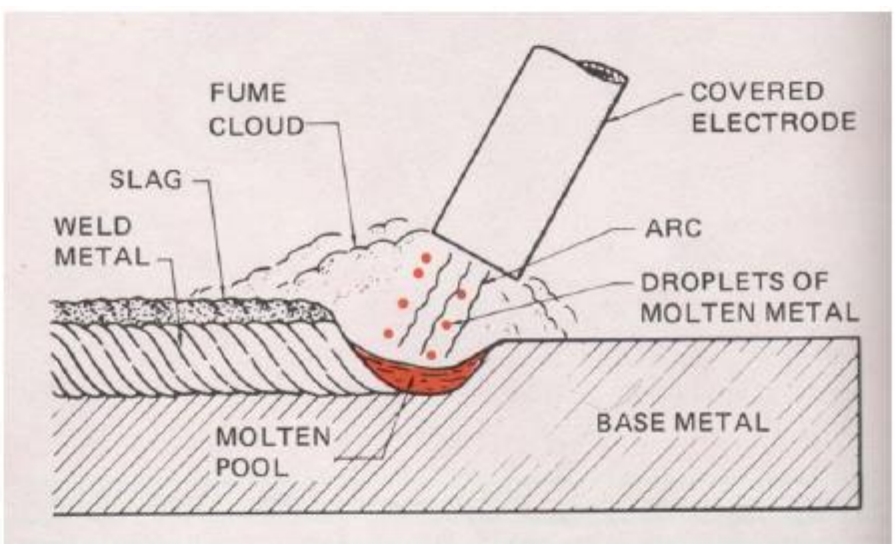
4.3.9.Arc welding

Arc welding is a type of welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is usually protected by some type of shielding gas, vapor, or slag. Arc welding processes may be manual, semi-automatic, or fully automated. First developed in the late part of the 19th century, arc welding became commercially important in shipbuilding during the Second World War. Today it remains an important process for the fabrication of steel structures and vehicles.

4.3.9.1.Shielded Metal Arc Welding (SMAW)



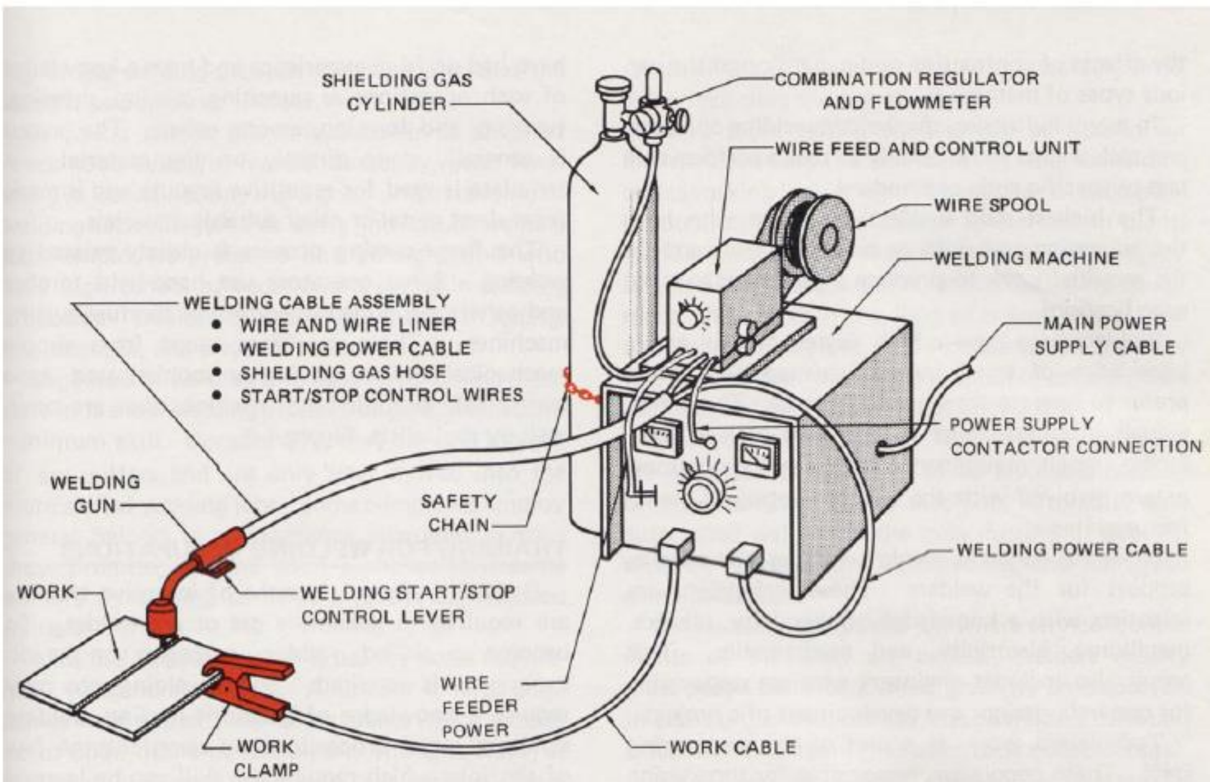
SMAW is a welding process that uses a flux covered metal electrode to carry an electrical current. The current forms an arc that jumps a gap from the end of the electrode to the work. The electric arc creates enough heat to melt both the electrode and the base material(s). Molten metal from the electrode travels across the arc to the molten pool of base metal where they mix together. As the arc moves away, the mixture of molten metals solidifies and becomes one piece. The molten pool of metal is surrounded and protected by a fume cloud and a covering of slag produced as the coating of the electrode burns or vaporizes. Due to the appearance of the electrodes, SMAW is commonly known as 'stick' welding.



SMAW is one of the oldest and most popular methods of joining metal. Moderate quality welds can be made at low speed with good uniformity. SMAW is used primarily because of its low cost, flexibility, portability and versatility. Both the equipment and electrodes are low in cost and very simple. SMAW is very flexible in terms of the material thicknesses that can be welded (materials from 1/16" thick to several inches thick can be welded with the same machine and different settings). It is a very portable process because all that's required is a portable power supply (i.e. generator). Finally, it's quite versatile because it can weld many different types of metals, including cast iron, steel, nickel & aluminum.

Some of the biggest drawbacks to SMAW are (1) that it produces a lot of smoke & sparks, (2) there is a lot of post-weld cleanup needed if the welded areas are to look presentable, (3) it is a fairly slow welding process and (4) it requires a lot of operator skill to produce consistent quality welds.

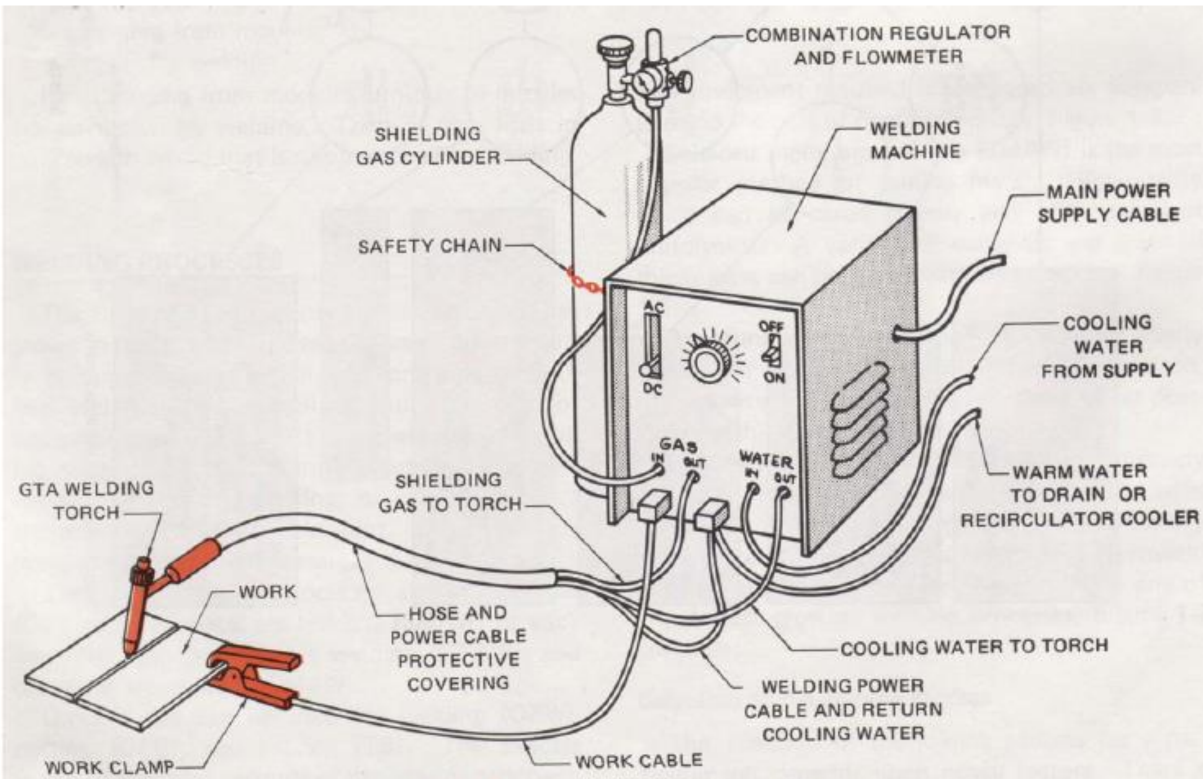
4.3.9.2.Gas Metal Arc Welding (GMAW)



In the GMAW process, an arc is established between a continuous wire electrode (which is always being consumed) and the base metal. Under the correct conditions, the wire is fed at a constant rate to the arc, matching the rate at which the arc melts it. The filler metal is the thin wire that's fed automatically into the pool where it melts. Since molten metal is sensitive to oxygen in the air, good shielding with oxygen-free gases is required. This shielding gas provides a stable, inert environment to protect the weld pool as it solidifies. Consequently, GMAW is commonly known as MIG (metal inert gas) welding. Since fluxes are not used (like SMAW), the welds produced are sound, free of contaminants, and as corrosion-resistant as the parent metal. The filler material is usually the same composition (or alloy) as the base metal.

GMAW is extremely fast and economical. This process is easily used for welding on thin-gauge metal as well as on heavy plate. It is most commonly performed on steel (and its alloys), aluminum and magnesium, but can be used with other metals as well. It also requires a lower level of operator skill than the other two methods of electric arc welding discussed in these notes. The high welding rate and reduced post-weld cleanup are making GMAW the fastest growing welding process.

4.3.9.3.Gas Tungsten Arc Welding (GTAW)



In the GTAW process, an arc is established between a tungsten electrode and the base metal(s). Under the correct conditions, the electrode does not melt, although the work does at the point where the arc contacts and produces a weld pool. The filler metal is thin wire that's fed manually into the pool where it melts. Since tungsten is sensitive to oxygen in the air, good shielding with oxygen-free gas is required. The same inert gas provides a stable, inert environment to protect the weld pool as it solidifies. Consequently, GTAW is commonly known as TIG (tungsten inert gas) welding. Because fluxes are not used (like SMAW), the welds produced are sound, free of contaminants and slags, and as corrosion-resistant as the parent metal.

Tungsten's extremely high melting temperature and good electrical conductivity make it the best choice for a non-consumable electrode. The arc temperature is typically around 11,000° F. Typical shielding gasses are Ar, He, N, or a mixture of the two. As with GMAW, the filler material usually is the same composition as the base metal.

GTAW is easily performed on a variety of materials, from steel and its alloys to aluminum, magnesium, copper, brass, nickel, titanium, etc. Virtually any metal that is conductive lends itself to being welded using GTAW. Its clean, high-quality welds often require little or no post-weld finishing. This method produces the finest, strongest welds out of all the welding processes. However, it's also one of the slower methods of arc welding.

4.4.Selection of the welding process

The selection of the joining process for a particular job depends upon many factors. There is no one specific rule governing the type of welding process to be selected for a certain job. A few of the factors that must be considered when choosing a welding process are:
Availability of equipment
Repetitiveness of the operation
Quality requirements (base metal penetration, consistency, etc.)
Location of work
Materials to be joined
Appearance of the finished product
Size of the parts to be joined
Time available for work
Skill experience of workers
Cost of materials
Code or specification requirements

4.4.1. Welding power supply

A welding power supply is a device that provides an electric current to perform welding. Welding usually requires high current (over 80 amperes) and it can need above 12,000 amperes in spot welding. Low current can also be used; welding two razor blades together at 5 amps with gas tungsten arc welding is a good example. A welding power supply can be as simple as a car battery and as sophisticated as a high-frequency inverter using IGBT technology, with computer control to assist in the welding process.

4.4.2. Classification

Welding machines are usually classified as constant current (CC) or constant voltage (CV); a constant current machine varies its output voltage to maintain a steady current while a constant voltage machine will fluctuate its output current to maintain a set voltage. Shielded metal arc welding and gas tungsten arc welding will use a constant current source and gas metal arc welding and flux-cored arc welding typically use constant voltage sources but constant current is also possible with a voltage sensing wire feeder.

The nature of the CV machine is required by gas metal arc welding and flux-cored arc welding because the welder is not able to control the arc length manually. If a welder attempted to use a CV machine to weld with shielded metal arc welding the small fluctuations in the arc distance would cause wide fluctuations in the machine's output. With a CC machine the welder can count on a fixed number of amps reaching the material to be welded regardless of the arc distance but too much distance will cause poor welding.

4.4.3. Power supply designs

The welding power supplies most commonly seen can be categorized within the following types:

4.4.4. Transformer

A transformer-style welding power supply converts the moderate voltage and moderate current electricity from the utility mains (typically 230 or 115 VAC) into a high current and low voltage supply, typically between 17 to 45 (open-circuit) volts and 55 to 590 amperes. A rectifier converts the AC into DC on more expensive machines.

This design typically allows the welder to select the output current by variously moving a primary winding closer or farther from a secondary winding, moving a magnetic shunt in and out of the core of the transformer, using a series saturating reactor with a variable saturating technique in series with the secondary current output, or by simply permitting the welder to select the output voltage from a set of taps on the transformer's secondary winding. These transformer style machines are typically the least expensive.

The trade off for the reduced expense is that pure transformer designs are often bulky and massive because they operate at the utility mains frequency of 50 or 60 Hz. Such low frequency transformers must have a high magnetizing inductance to avoid wasteful shunt currents. The transformer may also have significant leakage inductance for short circuit protection in the event of a welding rod becoming stuck to the work piece. The leakage inductance may be variable so the operator can set the output current.

4.4.5. Generator and alternator

Welding power supplies may also use generators or alternators to convert mechanical energy into electrical energy. Modern designs are usually driven by an internal combustion engine but older machines may use an electric motor to drive an alternator or generator. In this configuration the utility power is converted first into mechanical energy then back into electrical energy to achieve the step-down effect similar to a transformer. Because the output of the generator can be direct current, or even a higher frequency ac current, these older machines can produce DC from AC without any need for rectifiers of any type, or can also be used for implementing formerly-used variations on so-called heli arc (most often now called TIG) welders, where the need for a higher frequency add-on module box is avoided by the alternator simply producing higher frequency ac current directly.

4.4.6. Inverter

Since the advent of high-power semiconductors such as the insulated gate bipolar transistor (IGBT), it is now possible to build a switched-mode power supply capable of coping with the high loads of arc welding. These designs are known as inverter welding units. They generally first rectify the utility AC power to DC; then they switch (invert) the DC power into a step down transformer to produce the desired welding voltage or current. The switching frequency is typically 10 kHz or higher. Although the high switching frequency requires sophisticated components and circuits, it drastically reduces the bulk of the step down transformer, as the mass of magnetic components (transformers and inductors) that is required for achieving a given power level goes down rapidly as the operating (switching) frequency is increased. The inverter circuitry can also provide features such as power control and overload protection. The high

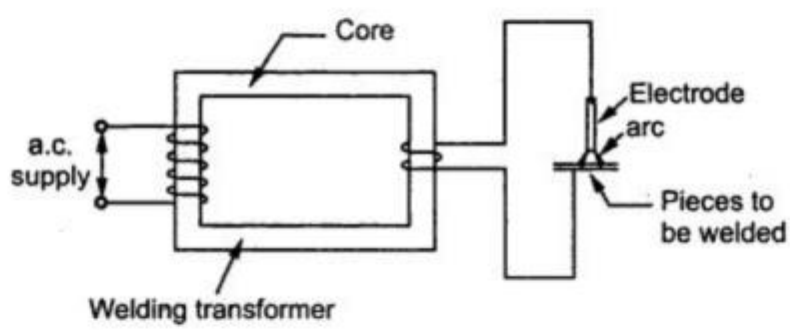
frequency inverter-based welding machines are typically more efficient and provide better control of variable functional parameters than non-inverter welding machines.
The IGBTs in an inverter based machine are controlled by a microcontroller, so the electrical characteristics of the welding power can be changed by software in real time, even on a cycle by cycle basis, rather than making changes slowly over hundreds if not thousands of cycles. Typically, the controller software will implement features such as pulsing the welding current, providing variable ratios and current densities through a welding cycle, enabling swept or stepped variable frequencies, and providing timing as needed for implementing automatic spot-welding; all of these features would be prohibitively expensive to design into a transformer-based machine, but require only program memory space in a software-controlled inverter machine. Similarly, it is possible to add new features to a software-controlled inverter machine if needed, through a software update, rather than through having to buy a more modern welder.

4.4.7. Other types

Additional types of welders also exist, besides the types using transformers, motor/generator, and inverters. For example, laser welders also exist, and they require an entirely different type of welding power supply design that does not fall into any of the types of welding power supplies discussed previously. Likewise, spot welders require a different type of welding power supply, typically containing elaborate timing circuits and large capacitor banks that are not commonly found with any other types of welding power supplies.

4.4.7.1. Welding Transformers

Most of the power supplies available now are a.c. Therefore a transformer for welding is most commonly used as compared to motor-generator set. Moreover motor-generator set has to be kept in the running position continuously during the weld is made.



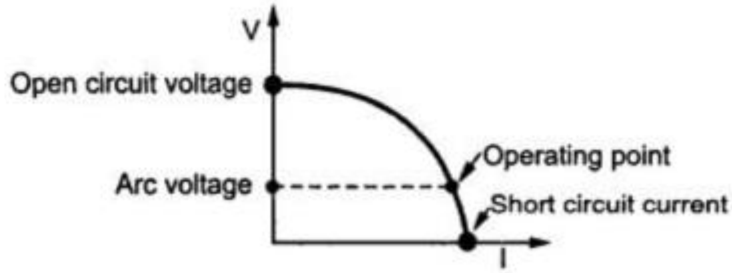
Welding transformer is a transformer having thin primary winding with large number of turns. While the secondary is having more area of cross-section and with less number of turns. This ensures very high current and less voltage in the secondary.

One end of the secondary is connected to welding electrode and another end is connected to the pieces to be welded. Due to the contact resistance between the electrode and pieces to be welded, when a very high current flows, I^2R heat is produced. This heat is very large. Due to this heat, a tip of the electrode melts and fills the gap between the two pieces.

A winding used for the welding transformer is highly reactive or a separate reactor may be added in series with the secondary winding.

4.4.7.2.V-I Characteristics

Volt ampere characteristics for a welding transformer is as shown in the Fig.

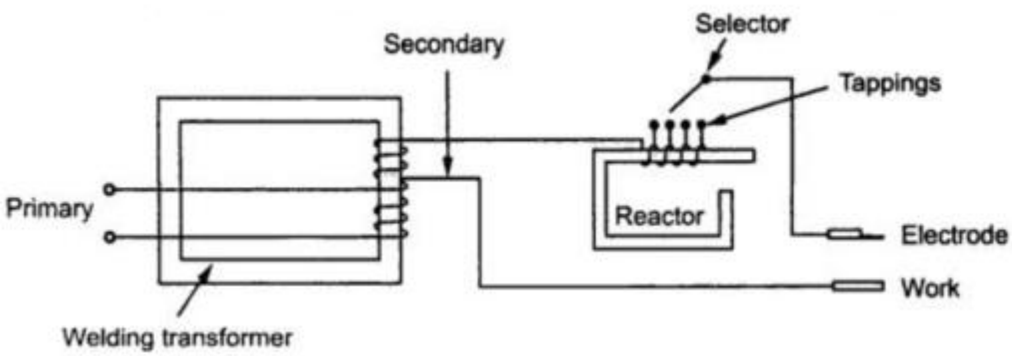


Volt ampere characteristics for a welding transformer

4.4.7.3.Reactors used with with Welding Transformer

The welding transformer can be used with various reactors for control of arc. The various methods of such control are :

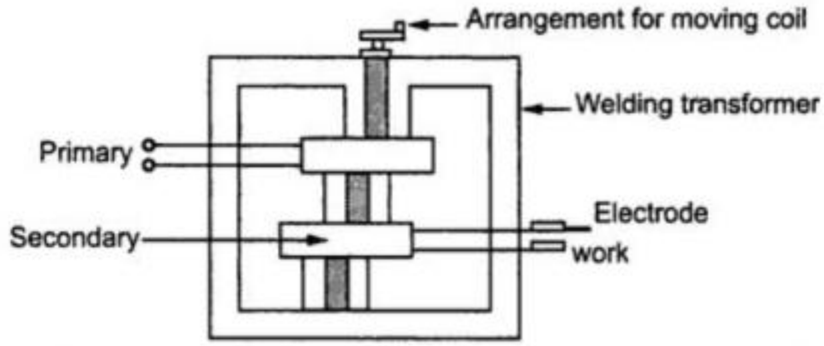
i) Tapped Reactor : In this, output current is regulated by taps on the reactor. This has limited number of current settings.



Tapped reactor

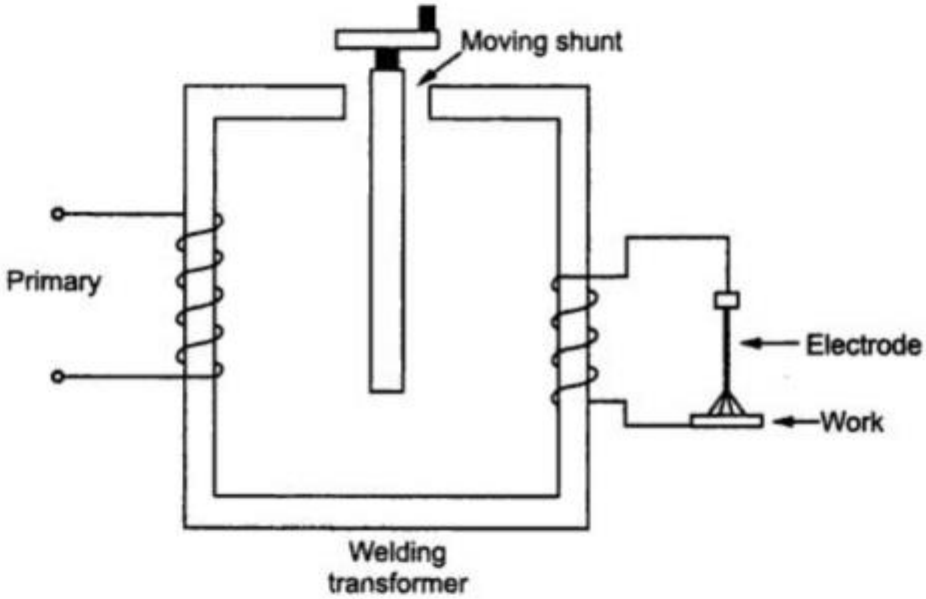
ii) Moving Coil Reactor :

In this method, the relative distance between primary and the secondary is adjusted. When the distance between the coils is large the current obtained is less.



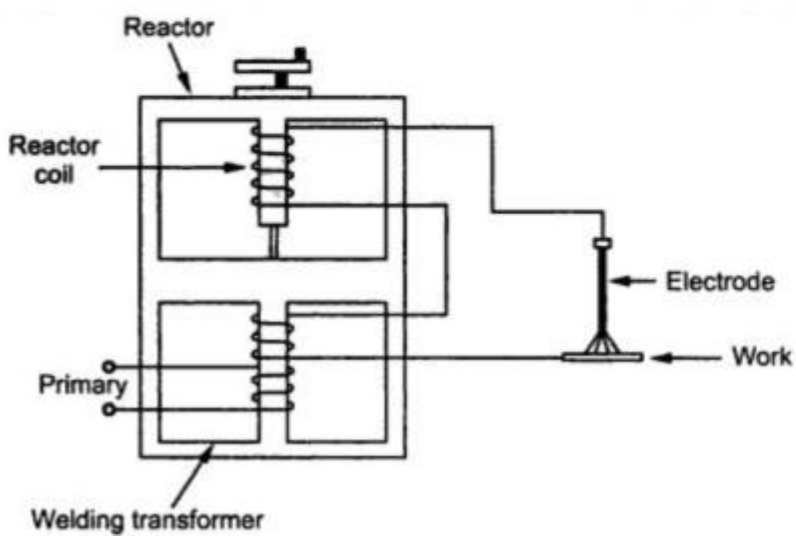
Moving coil reactor

iii) Magnetic Shunt Reactor : In this method, position of central magnetic shunt can be adjusted. This adjusts the shunted flux and hence output current gets changed.



Magnetic shunt reactor

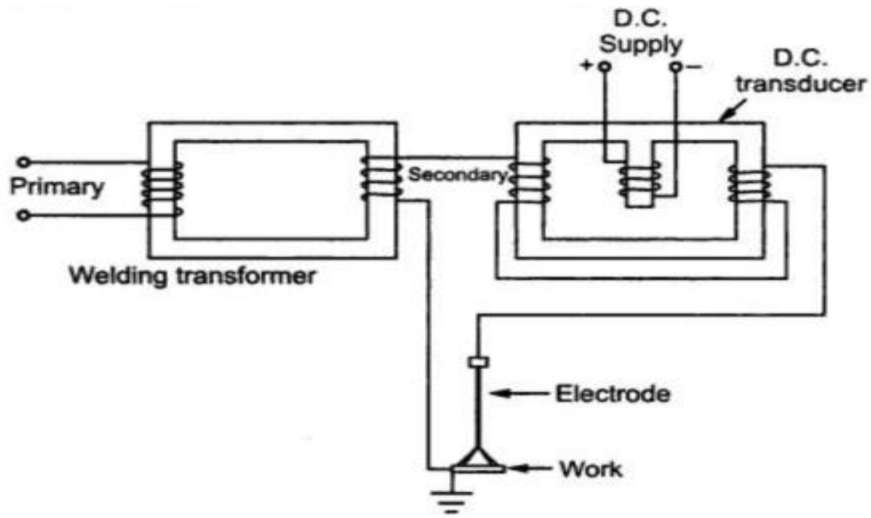
iv) Continuously Variable Reactor : The height of the reactor is continuously varied in this method. Greater the core insertion greater is the reactance and less is the output current.



Continuously variable reactor

v) Saturable Reactor :

The reactance of the reactor is adjusted by changing the value of d.c. excitation obtained from d.c. controlled transducer. More the d.c. currents, reactor approaches to saturation. This changes the reactance of reactor and hence changing the current.



Saturation reactor

QUESTIONS

PART A

1. List out the requirements for a good heating element.
2. Discuss the principle of arc furnace?
3. Distinguish between core type and coreless type induction furnaces.
4. Compare direct arc & indirect arc furnaces.
5. Discuss the principle of induction heating.
6. List out the advantages of coreless induction furnace.
7. Compare induction & dielectric heating.

PART B

1. Outline dielectric heating and explain its application in industry & domestic areas.
2. Explain the core type (AJAX-WYATT) induction furnace and state its application.
3. Discuss with neat sketch, the various methods of electrical arc welding.
4. Elaborate various resistances welding process.
5. With neat sketch, develop the construction, principle of operation, application & control methods of direct & indirect arc furnaces.
6. Explain butt & spot welding with a neat sketch.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SEE1303-POWER GENERATION AND UTILIZATION

UNIT – V ELECTRIC TRACTION

UNIT V - ELECTRIC TRACTION

Introduction - requirements of an ideal traction Train Movement-Speed-Time Curve-mechanics of train movement - tractive effort calculations- Power and energy output from driving axles-Traction motors and its Characteristics-Traction motor control-Current collection systems.

INTRODUCTION

Electric traction means using the electric power for traction system (i.e. for railways, trams, trolleys etc). Electric traction means use of the electricity for all the above machines. Basically dc motors are used for electric traction systems.

Electric traction has many advantages as compared to other non-electrical systems of traction including steam traction.

TRACTION SYSTEMS

Broadly speaking, all traction systems may be classified into two categories

Non-electric traction systems

They do not involve the use of electrical energy at ***any stage***. Examples are: steam enginedrive used in railways and internal-combustion-engine drive used for road transport.

Electric traction systems

They involve the use of electric energy at some stage or the other. They may be further subdivided intotwo groups

1.First group consists of self-contained vehicles or locomotives. Examplesare : battery-electric drive and diesel-electric drive etc.
2.Second group consists of vehicles which receive electric power from a distribution network fed at suitable points from either central power stations or suitably-spaced sub- stations.

Examples are : railway electric locomotive fed from overhead ac supply and tramwaysandtrolley buses supplied with dc supply.

Direct Steam Engine Drive

Though losing ground gradually due to various reasons, steam locomotive is still the most widely adopted means of propulsion for railway work. Invariably, the reciprocating engineis employed because

1.It is inherently simple.
2.Connection between its cylinders and the driving wheels is simple.
3.Its speed can be controlled very easily.

However, the steam locomotive suffers from the following disadvantages:

1. Since it is difficult to install a condenser on a locomotive, the steam engine runs non-condensing and, therefore, has a very low thermal efficiency of about 6-8 percent.

2. It has strictly limited overload capacity.

3. It is available for hauling work for about 60% of its working days, the remaining 40% beingspent in preparing for service, in maintenance and overhaul.

Diesel-electric Drive

It is a self-contained motive power unit which employs a diesel engine for direct drive of a dc generator. This generator supplies current to traction motors which are geared to the driving axles. In India, diesel locomotives were introduced in 1945 for shunting service on broad guage (BG) sections and in 1956 for high-speed main-line operations on metre-guage (MG) sections. It was only in 1958 that Indian Railways went in for extensive main-line dieselisation.

Diesel-electric traction has the following advantages:

1.No modification of existing tracks is required while converting from steam to diesel- electric traction.

2.It provides greater tractive effort as compared to steam engine which results in higherstarting acceleration.

3.It is available for hauling for about 90% of its working days.

4.Diesel-electric locomotive is more efficient than a steam locomotive (though less efficient than an electric locomotive).

Disadvantages

1.For same power, diesel-electric locomotive is costlier than either the steam or electric locomotive.

2.Overload capacity is limited because diesel engine is a constant-kW output prime mover.

3.Life of a diesel engine is comparatively shorter.

4.Diesel-electric locomotive is heavier than plain electric locomotive because it carries the main engine, generator and traction motors etc.

5.Regenerative braking cannot be employed though rheostatic braking can be.

Battery-electric Drive

In this case, the vehicle carries secondary batteries which supply current to dc motors used for driving the vehicle. Such a drive is well-suited for shunting in railway yards, for traction in mines, for local delivery of goods in large towns and large industrial plants. They have low maintenance cost and are free from smoke. However, the scope of such vehicles is limited because of the small capacity of the batteries and the necessity of charging them frequently.

REQUIREMENTS OF AN IDEAL TRACTION

The requirements of an ideal traction system are

1. The locomotive should be self-contained and able to run on any route braking should be such that minimum wear is caused on the brake shoes if possible the braking energy should be regenerated and returned to the supply.
2. Speed control should be easy.
3. The wear on the track should be the minimum.
4. The starting tractive effort should be high so as to have rapid acceleration.
5. There should be no interference to the communication lines running along the lines.
6. It should be Pollution free.
7. Low initial and maintenance costs.

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 to heat 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

5. 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.

6.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.

7.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 theentire 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, 16 23, 25 and 50 Hz

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

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

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 is shown in Fig. 1.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. **Acceleration on Speed Curve(T1 to t2)**

This acceleration commences after the starting resistance has been all cut out at point *t*1 and full supply voltage has been applied to the motors. During this period, the motor current and torque decrease as train speed increases. Hence, acceleration gradually ***decreases*** till torque developed by motors exactly balances that due to resistance to the train motion. The shape of the portion *AB* of the speed/time curve depends primarily on the torque/speed characteristics of the traction motors.

3. **Free-running Period (t2 to t3)**

The train continues to run at the speed reached at point *t*2. It is represented by portion *BC* in Fig. 1and is a constant-speed period which occurs on level tracks.

4. **Coasting (t3 to t4)**

Power to the motors is cut off at point *t*3 so that the train runs under its momentum, the speed gradually falling due to friction, wind age etc. (portion *CD*). During this period, retardation remains practically constant. Coasting is desirable because it utilizes some of the kinetic energy of the train which would, otherwise, be wasted during braking. Hence, it helps to reduce the energy consumption of the train.

5. **Braking (t4 to t5)**

At point t4, brakes are applied and the train is brought to rest at point *t*5.
It may be noted that coasting and braking are governed by train resistance and allowable retardation respectively.

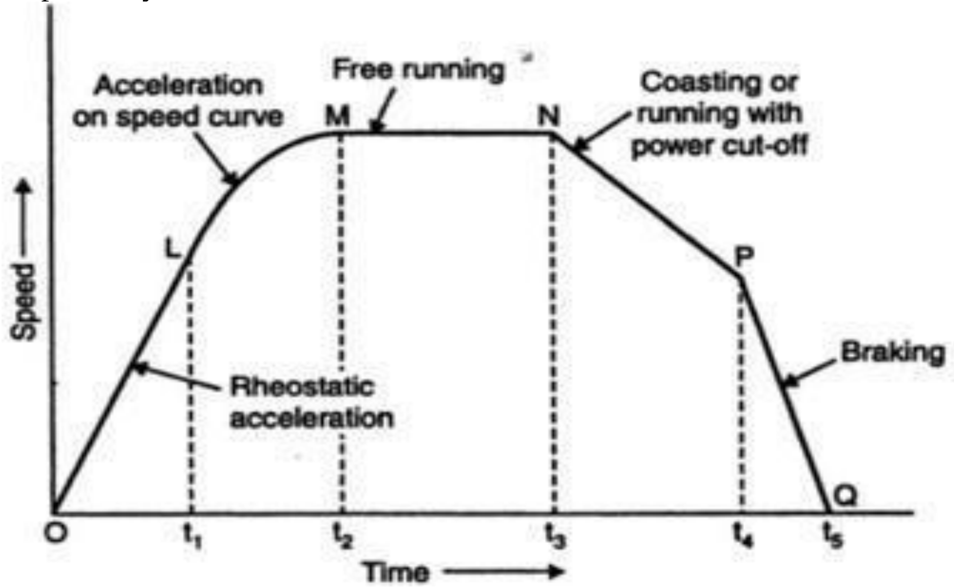


FIG 1 SPEED-TIME CURVES

SPEED/TIME CURVES FOR DIFFERENT SERVICES

Fig. 2 (*a*) is representative of city service where relative values of acceleration and retardationare high in order to achieve moderately high average speed between stops. Due to short Distances between stops, there is no possibility of free-running period though a short coasting period is included to save on energy consumption.

In suburban services [Fig. 2 (*b*)], again there is no free-running period but there is comparatively ***longer*** coasting period because of longer distances between stops. In this case also, relatively high values of acceleration and retardation are required in order to make the service as attractive as Possible.

For main-line service [Fig. 2 (c)], there are long periods of free-running at high speeds. The accelerating and retardation periods are relatively unimportant.

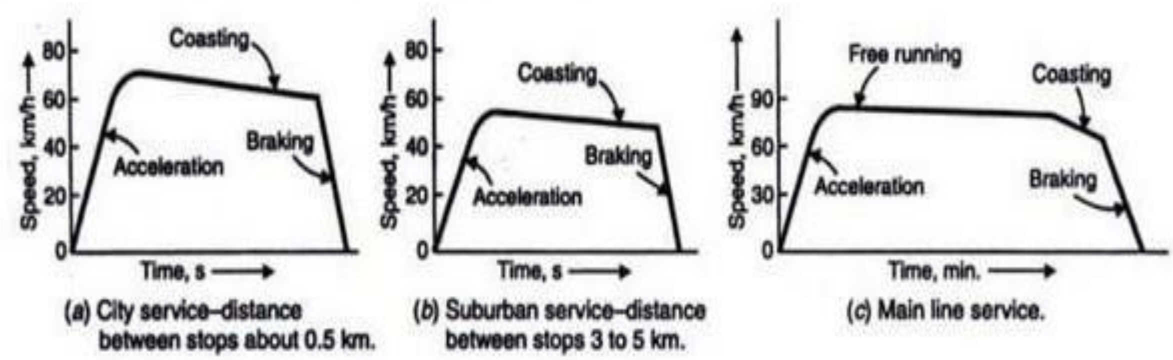


FIG 2 DIFFETENT SPEED-TIME CURVES

SIMPLIFIED SPEED/TIME CURVE

For the purpose of comparative performance for a given service, the actual speed/time curve of Fig. 1 is replaced by a simplified speed/time curve which does not involve the knowledge of motor characteristics. Such a curve has simple geometric shape so that simple mathematics can be used to find the relation between acceleration, retardation, average speed and distance etc. The simple curve would be fairly accurate provided it

(i) retains the same acceleration and retardation and (ii) has The same area as the actual speed/time curve. The simplified speed/time curve can have either of the two shapes:

(i) trapezoidal shape OABC of Fig. 3 where speed-curve running and coasting periods of the actual speed/time curve have been replaced by a constant speed period.

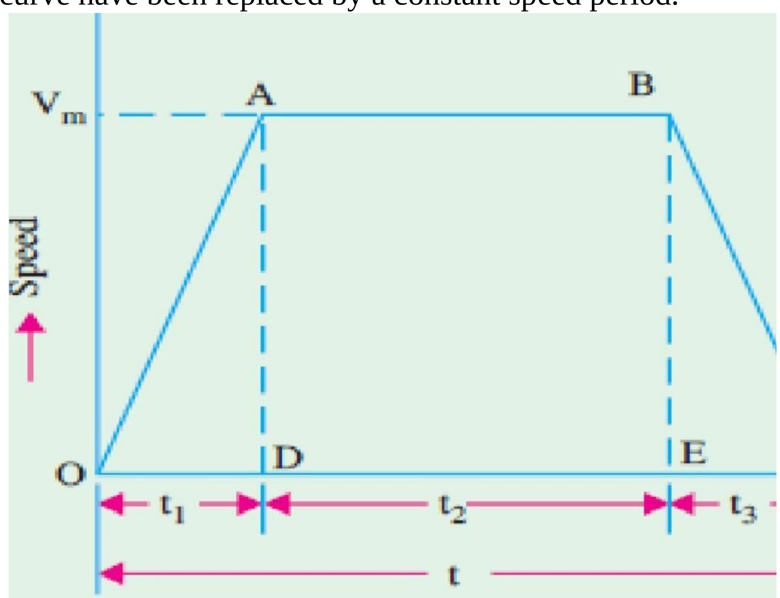


FIG 3 Trapezoidal Speed-time curve

RELATIONSHIP BETWEEN PRINCIPAL QUANTITIES IN TRAPEZOIDAL DIAGRAM

As seen from Fig. 3

α = *Vm* /*t*1 or *t*1 = *Vm* /α β

= *Vm* /*t*3 or *t*3 = *Vm* /β

As we know, total distance *D* between the two stops is given by the area of trapezium

OABC.

therefore *D* = area *OABC*

= area *OAD* + area *ABED* + area *BCE*

$$= \frac{1}{2} V_m t_1 + V_m[t - (t_1 + t_3)] + \frac{1}{2} V_m t_3$$

$$= V_m \left[\frac{t_1}{2} + t - t_1 - t_3 + \frac{t_3}{2}\right]$$

$$= V_m \left[t - \frac{1}{2}(t_1 + t_3)\right]$$

$$= V_m \left[t - \frac{V_m}{2}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right)\right]$$

Let, $K = \frac{1}{2}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right)$. Substituting this value of K in the above equation, we get

$$D = V_m (t - KV_m)$$

or $$KV_m^2 - V_m t + D = 0 \qquad \ldots(i)$$

$$\therefore \quad V_m = \frac{t \pm \sqrt{t^2 - 4KD}}{2K}$$

Rejecting the positive sign which gives impracticable value, we get

$$V_m = \frac{t \pm \sqrt{t^2 - 4KD}}{2K}$$

From Eq. (*i*) above, we get

$$KV_m^2 = V_m t - D \qquad \text{or} \qquad K = \frac{t}{V_m} - \frac{D}{V_m^2} = \frac{D}{V_m^2}\left(V_m \cdot \frac{t}{D} - 1\right)$$

Now, $V_a = \dfrac{D}{t}$ $\qquad \therefore \qquad K = \dfrac{D}{V_m^2}\left(\dfrac{V_m}{V_a} - 1\right)$

Obviously, if V_m, V_a and D are given, then value of K and hence of α and β can be found

(ii) Quadrilateral shape *OABC* where the same two periods are replaced by the extensions of initial constant acceleration and coasting periods. It is found that trapezoidal diagram *OA*1*B*1*C* gives simpler relationships between the principal quantities involved in train movement and also gives closer approximation of actual energy consumed during ***main-line service on level track***. On the other hand, quadrilateral diagram approximates more closely to the actual conditions in ***city and*** suburban services.

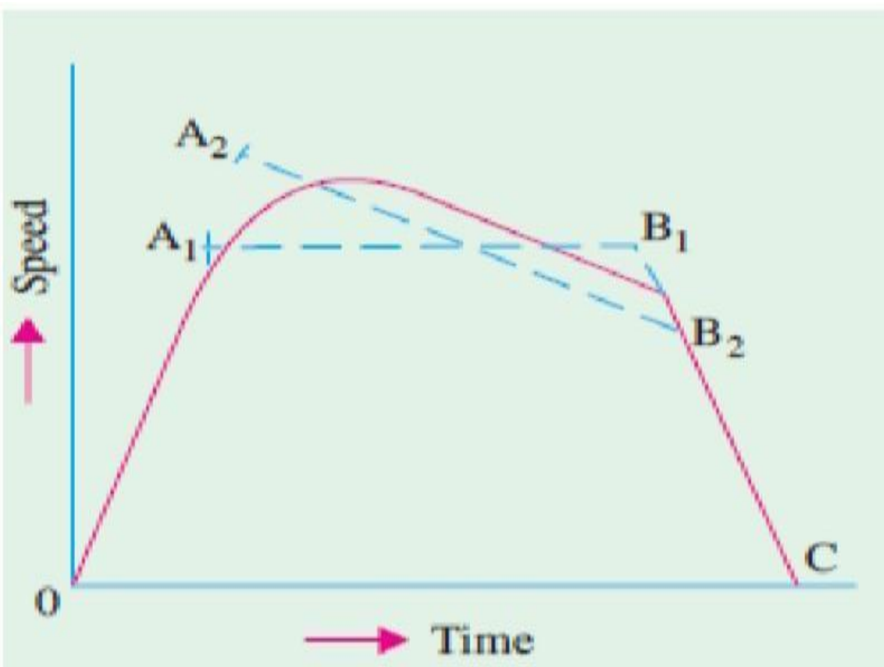


Fig 4 Quadrilateral Speed/Time Curve

RELATIONSHIP BETWEEN PRINCIPAL QUANTITIES IN QUADRILATERAL DIAGRAM

As before,

$$
\begin{aligned}
t_1 &= V_1/\alpha,\ t_2 = (V_2 - V_1)/\beta_c \text{ and } t_3 = V_2/\beta \\
D &= \text{area } OABC \\
&= \text{area } OAD + \text{area } ABED + \text{area } BCE \\
&= \frac{1}{2}V_1 t_1 + t_2\left(\frac{V_1 + V_2}{2}\right) + \frac{1}{2}V_2 t_3 \\
&= \frac{1}{2}V_1(t_1 + t_2) + \frac{1}{2}V_2(t_2 + t_3) \\
&= \frac{1}{2}V_1(t - t_3) + \frac{1}{2}V_2(t - t_1) \\
&= \frac{1}{2}t(V_1 + V_2) - \frac{V_1 t_1}{2} - \frac{V_1 t_3}{2} \\
&= \frac{1}{2}t(V_1 + V_2) - \frac{1}{2}V_1 V_2\left(\frac{1}{\alpha} + \frac{1}{\beta}\right) \\
&= \frac{1}{2}t(V_1 + V_2) - KV_1 V_2
\end{aligned}
$$

where $\quad K = \frac{1}{2}\left(\frac{1}{\alpha} + \frac{1}{\beta}\right) = \frac{\alpha + \beta}{2\alpha\beta}$ Also, $\beta_c = \frac{(V_1 - V_2)}{t_2}$

$$
\begin{aligned}
\therefore \quad V_2 &= V_1 - \beta_c t_2 = V_1 - \beta_c(t - t_1 - t_3) \\
&= V_1 - \beta_c\left(t - \frac{V_1}{\alpha} - \frac{V_2}{\beta}\right) = V_1\beta_c\left(t - \frac{V_1}{\alpha}\right) + \beta_c\frac{V_2}{\beta}
\end{aligned}
$$

or $\quad V_2\left(1 - \frac{\beta_c}{\beta}\right) = V_1 - \beta_c\left(t - \frac{V_1}{\alpha}\right) \qquad \therefore\ V_2 = \frac{V_1 - \beta_c(t - V_1/\alpha)}{(1 - \beta_c/\beta)}$

TRACTIVE EFFORT FOR PROPULSION OF TARIN

The **tractive effort** is *defined as the effective force necessary to propel the train at the wheels of locomotive.*

The tractive effort (F_t) required for train propulsion is given by :

$$F_t = F_a + F_r \qquad \text{...For } \textit{Level track} \text{ ;} \quad \text{... 1}$$

$$F_t = F_a \pm F_g + F_r \qquad \text{... When } \textit{gradients are involved} \quad \text{... 2}$$

[+ *sign* for *ascending gradient*, and – *sign* for *descending gradient*]

where, F_a = Force required for giving linear acceleration to the train,

F_g = Force required to overcome the gravitational effect, and

F_r = Force required to overcome resistance to the motion of train.

1. **Value of F_a.** If M is the dead or stationary mass of the train and α is the linear acceleration, then

$$F_a = M\alpha \qquad \text{... 3}$$

Owing to the fact that a train has rotating parts likes wheels, axles, motor armatures and gearing etc., its *effective* or *accelerating* mass M_e is more (about 8-15 percent) than its stationary mass. These parts need to be given angular acceleration at the same time as the whole train is accelerated in linear direction. Hence,

$$F_a = M_e \cdot \alpha \qquad \text{... 4}$$

- If M_e is in kg and α in m/s^2, then $F_a = m.\alpha$ newton ... 5
- If M_e is in tonne and α in km/h/s, then converting them in absolute units, we have

$$F_a = (1000\, M_e) \times \left(\frac{1000}{3600}\right)\alpha = 277.8\, \alpha\, M_e \text{ newton} \qquad \text{... 6}$$

2. **Value of F_g :**

$$F_g = W \sin\theta = M_g \sin\theta \qquad \text{... 7}$$

$$\text{Now gradient} = \sin\theta = \frac{\text{Elevation } (BC)}{\text{Distance along truck } (AC)}$$

% gradient $G = 100 \sin\theta$

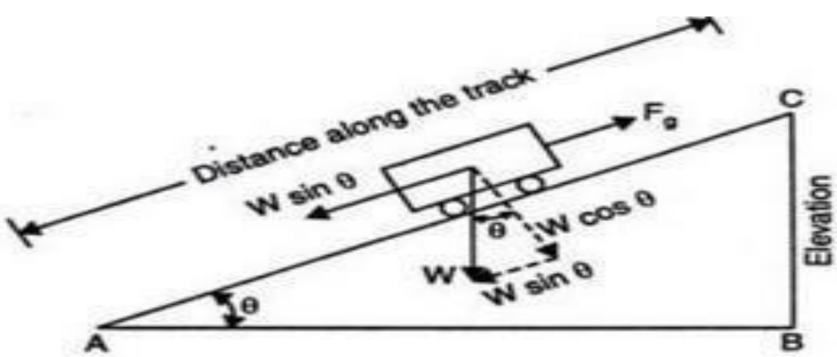


Fig 5

Substituting the value of sin θ in eqn. 7 we get

$$F_g = \frac{Mg.G}{100} \quad \text{... 8}$$

- When M is in kg, $F_g = 0.098\,MG$ ... 9
- When M is in tonne, then

$$F_g = 0.098\,(1000\,M)G = 98\,MG \text{ newton} \quad \text{...10}$$

3. Value of F_r :

Train resistance consists of all the forces which resist the motion of a train. It consists of the following :

(*i*) ***Mechanical resistance :***

(*a*) *Internal resistance.* It comprises friction at journals, axles, guides and buffers etc.

(*b*) *External resistance.* It consists of friction between wheels and rails and flange friction etc.

— Mechanical resistance is *almost independent of train speed but depends on its weight.*

(*ii*) ***Wind resistance.*** The wind resistance varies *directly as the square of the train speed.*

If r is '*specific resistance*' of the train *i.e., resistance offered per unit mass of the train, then*

$$F_r = M.r \quad \text{.. 11}$$

or,

$$E = F_t \times \frac{1}{2} V_m t_1 + F_t' \times V_m t_2 \quad \text{... 12}$$

where, F_t = The tractive effort during acceleration periods (It consists of all the three components given in Art. 7.6), and

$F_t' = (98\,MG + Mr)$ provided there is an ascending gradient.

SPECIFIC ENERGY OUTPUT

It is the energy output of the driving wheel expressed in watt-hour (Wh) per tonne-km (*t*-km) of the train. It can be found by first converting the energy output into Wh and then dividing it by the mass of the train in route distance in km.

Hence, unit of specific energy output generally used in railway work is : Wh/tonne-km (Wh/t-km).

EVALUATION OF SPECIFIC ENERGY OUTPUT

We will first calculate the total energy output of the driving axles and then divide it by train mass in tonne and route length in km to find the specific energy output. It will be presumed that :

(i) there is a gradient of G throughout the run and

(ii) power remains ON upto the end of free run in the case of trapezoidal curve and up to the accelerating period in the case of quadrilateral curve

Now, output of the driving axles is used for the following purposes :

1. for accelerating the train
2. for overcoming the gradient
3. for overcoming train resistance.

(i) *Energy required to accelerate the train* (E_a) :

From trapezoidal diagram of Fig. 7.4, we have

$$E_a = F_a \times \text{Distance } OAD$$

$$= 277.8\, \alpha M_e \times \frac{1}{2} V_m t_1 \text{ joules}$$

$$= 277.8\, \alpha M_e \times \frac{1}{2} V_m \times \frac{V_m}{\alpha} \text{ joules} \qquad \left(\because\ t_1 = \frac{V_m}{\alpha}\right)$$

$$= 277.8\, \alpha M_e \times \left[\frac{1}{2} \times \frac{V_m \times 1000}{3600} \times \frac{V_m}{\alpha}\right] \text{joules}$$

It may be noted that since V_m in km/h. it has been converted into m/s by multiplying it with the conversion factor of $\left(\frac{1000}{3600}\right)$. In the case of $\frac{V_m}{\alpha}$, conversion factor for V_m and α being the same, they cancel out.

Since $1 \text{ Wh} = 3600 \text{ J}$,

$$\therefore \qquad E_a = 277.8\, \alpha M_e \left[\frac{1}{2} \times \frac{V_m \times 1000}{3600} \times \frac{V_m}{\alpha}\right] \times \frac{1}{3600} \text{ Wh}$$

or,

$$E_a = 0.01072\, V_m^2 M_e\, Wh \qquad \ldots 13$$

(ii) *Energy required to overcome gradient* (E_g) :

$$E_g = F_g \times D' \qquad \ldots 14$$

Where D' is the total distance over which power remains ON.

Hence, limiting value of train speed $= 23.11 \times \frac{3600}{1000} = \mathbf{83.2 \text{ km/h.}}$

ENERGY CONSUMPTION

It equals the total energy input to the traction motors from the supply. It is usually expressed in Wh which equals 3600 J. It can be found by dividing the energy output of the driving wheels with the combined efficiency of transmission gear and motor.

$$\therefore \quad \text{energy consumption} = \frac{\text{output of driving axles}}{\eta_{motor} \times \eta_{gear}}$$

SPECIFIC ENERGY CONSUMPTION

It is the energy consumed (in Wh) per tonne mass of the train per km length of the run. Specificenergy consumption,

$$E_{spc} = \frac{\text{total energy consumed in Wh}}{\text{train mass in tonne} \times \text{run length in km}} = \frac{\text{specific energy output}}{\eta}$$

where η = overall efficiency of transmission gear and motor = $\eta_{gear} \times \eta_{motor}$

As seen from Art. 43.41, specific energy consumption is

$$E_{spc} = \left(0.01072 \cdot \frac{V_m^2}{\eta D} \cdot \frac{M_e}{M} + 27.25 \frac{G}{\eta} \cdot \frac{D'}{D} + 0.2778 \frac{r}{\eta} \cdot \frac{D'}{D}\right) \text{Wh/t-km}$$

If no gradient is involved, then specific enrgy consumption is

$$E_{spc} = \left(0.01072 \cdot \frac{V_m^2}{\eta D} \cdot \frac{M_e}{M} + 0.2778 \frac{r}{\eta} \cdot \frac{D'}{D}\right) \text{Wh/t-km}$$

The specific energy consumption of a train running at a given schedule speed is influenced by **1.** Distance between stops **2.** Acceleration **3.** Retardation **4.** Maximum speed **5.** Type of train and equipment **6.** Track configuration.

Adhesive Weight

It is given by the total weight carried on the driving wheels. Its value is *Wa* = *x W*, where *W* is dead weight and *x* is a fraction varying from 0.6 to 0.8.

Coefficient of Adhesion

Adhesion between two bodies is due to interlocking of the irregularities of their surfaces in contact. The adhesive weight of a train is ***equal to the total weight to be carried on the driving.***

wheels. It is less than the dead weight by about 20 to 40%.

If $\quad x = \dfrac{\text{adhesive weight, } W_a}{\text{dead weight } W}$, then, $\quad W_a = x\,W$

Let, $\quad F_t$ = tractive effort to slip the wheels

or

= maximum tractive effort possible without wheel slip

Coefficient of adhesion, $\quad \mu_a = F_t / W_a$

$\therefore \quad F_t = \mu_a W_a = \mu_a xW = \mu_a x\,Mg$

If M is in tonne, then

$$F_t = 1000 \times 9.8\, x\, \mu_a M = 9800\, \mu_a\, x\, M \text{ newton}$$

It has been found that tractive effort can be increased by increasing the motor torque but onlyUp to a certain point. Beyond this point, any increase in motor torque does not increase the tractive effortbut merely causes the driving wheels to slip. It is seen from the above relation that for increasing *Ft*, it is not enough to increase the kW rating of the traction motors alone but the weight on the driving wheels has also to be increased.

Adhesion also plays an important role in braking. If braking effort exceeds the adhesive weightof the vehicle, skidding takes place.

MECHANISM OF TRAIN MOVEMENT

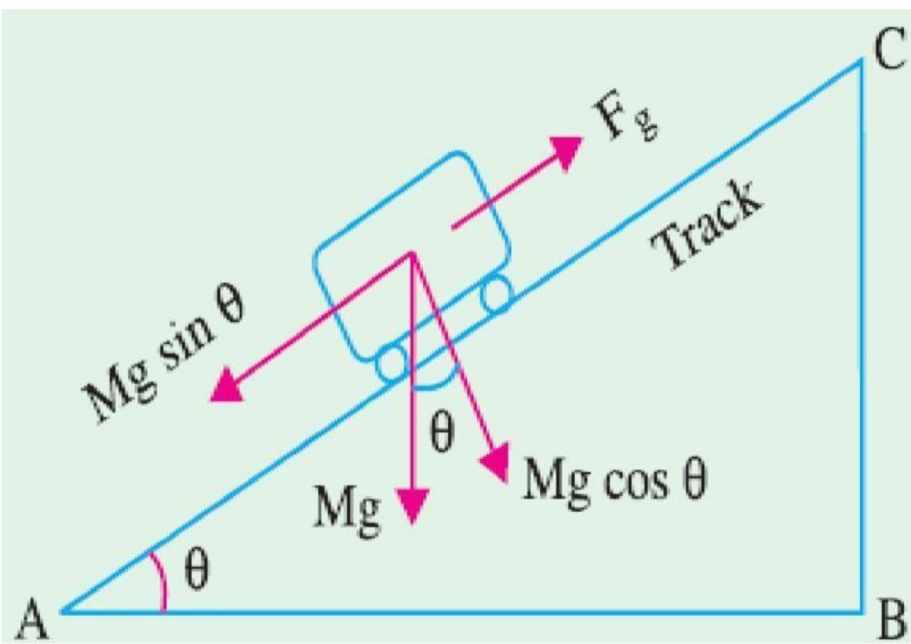


Fig 6 Mechanism of Train movement

The essentials of driving mechanism in an electric vehicle are illustrated in Fig.6. The armature of the driving motor has a pinion which meshes with the gear wheel keyed to the axle of the driving wheel. In this way, motor torque is transferred to the wheel through the gear.

Let, T = torque exerted by the motor

$F1$ = tractive effort at the pinion Ft
= tractive effort at the wheel γ =gear ratio
Here, $d1$, $d2$ = diameters of the pinion and gear wheel respectively
D = diameter of the driving wheel
η = efficiency of power transmission from the motor to driving axle Now, T =
$F1 \times d1/2$ or $F1 = 2T/d1$
Tractive effort transferred to the driving wheel is

$$F_t = \eta F_1 \left(\frac{d_2}{D}\right) = \eta \cdot \frac{2T}{d_1}\left(\frac{d_2}{D}\right) = \eta T \left(\frac{2}{D}\right)\left(\frac{d_2}{d_1}\right) = 2\gamma\eta \frac{T}{D}$$

For obtaining motion of the train without slipping, $Ft \leq \mu a\ Wa$ where μa is the coefficient ofadhesion and Wa is the adhesive weight.

QUANTITIES INVOLVED IN TRACTION MECHANICS

Following principal quantities are involved in train movement:
D = distance between stops
M = dead mass of the train
Me = effective mass of the train
W = dead weight of the train We = effective weight of the train α = acceleration during starting period β= retardation during coasting β = retardation during braking
Va = average speed
Vm = maximum (or crest) speed.
t = total time for the run $t1$ = time of acceleration $t2$ = time of freerunning = $t - (t1 + t3)$ $t3$ = time of braking
Ft = tractive effort
T = torque

ELECTRIC BRAKING

When a motor is in moving state, it has some kinetic energy stored in it. If you have to stop the motor, then you have to remove or dissipate this energy(commonly called brake energy).

A running motor may be brought to rest quickly by either mechanical braking or **electrical braking**. The mechanical braking is applied by means of mechanical break shoes. Hence the smoothness of mechanical braking is dependent on the surface and physical condition of brakes. Smooth **braking of a motor** can be achieved by **electric braking**.

The **electric braking of a** DC motor is of three types, (i) Rheostatic or dynamic braking,
(ii) Plugging or reverse current braking and (iii) **Regenerative beaking**.

REGENERATIVE BRAKING

Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This baking method is called regenerative baking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

PLUGGING

Another type of braking is **Plugging type braking**. In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases. During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.

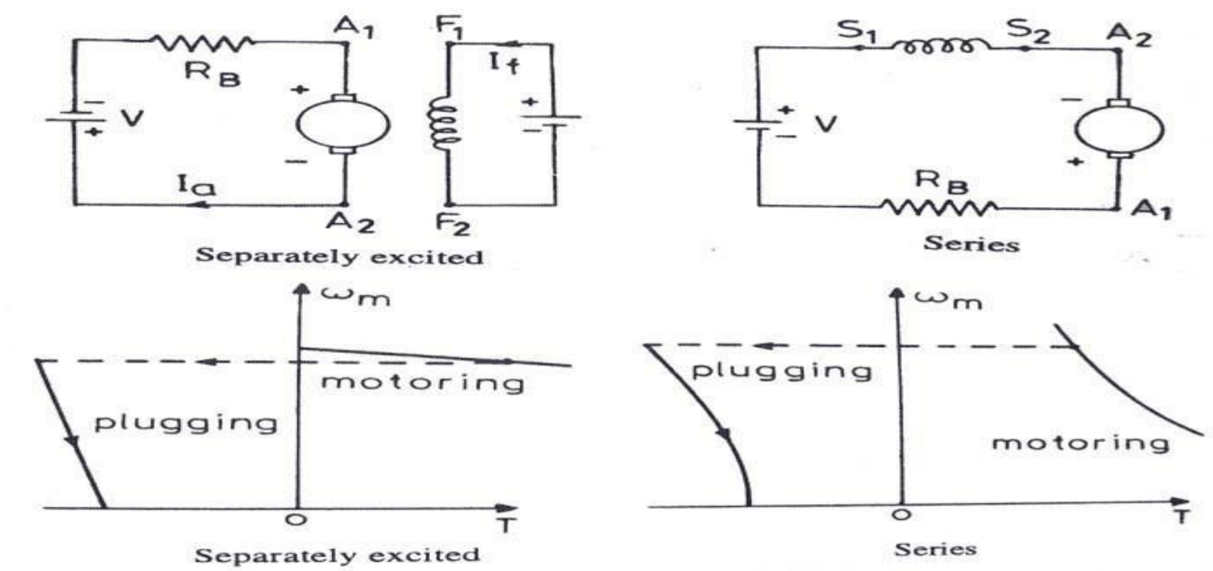


Fig 7 Plugging

DYNAMIC BRAKING

Another method of reversing the direction of torque and braking the motor is **dynamic braking**. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self –excited generator. When the motor works as a generator the flow of the current and torque reverses. During braking to maintain the steady torque sectional resistances are cut out one by one.

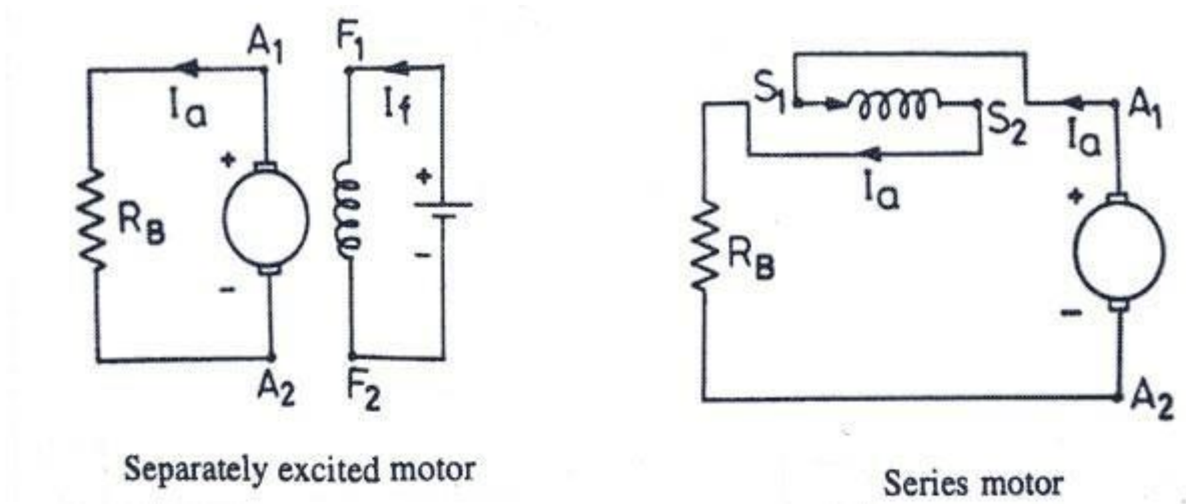


FIG 8 DYNAMIC BRAKING

SERIES PARALLEL TRANSITIONCONTROL OF D.C. MOTORS

The starting current of motor is limited to its normal rated current by starter during starting. At the instant of switching on the motor, back e.m.f. $Eb = 0$ therefore Supply voltage = $V = IR$ + Voltage drop across *Rs*.At any other instant during starting

$V = IR$ + Voltage across $Rs + Eb$

At the end of accelerating period, when total *Rs* is cut-off $V = Eb + IR$

If *T* is the time in sec. for starting and neglecting *IR* drop, total energy supplied = *V.I.T.* watt-sec

From Fig. 9 (*b*) Energy wasted in *Rs* = Area of triangle $ABC \times I = ½. T.V.I.$ watt - sec. = ½ *VIT* watt - sec. But total energy supplied = *V.I.T* watt - sec.Therefore Half the energy is wasted in starting

Therefore ηstarting = 50%

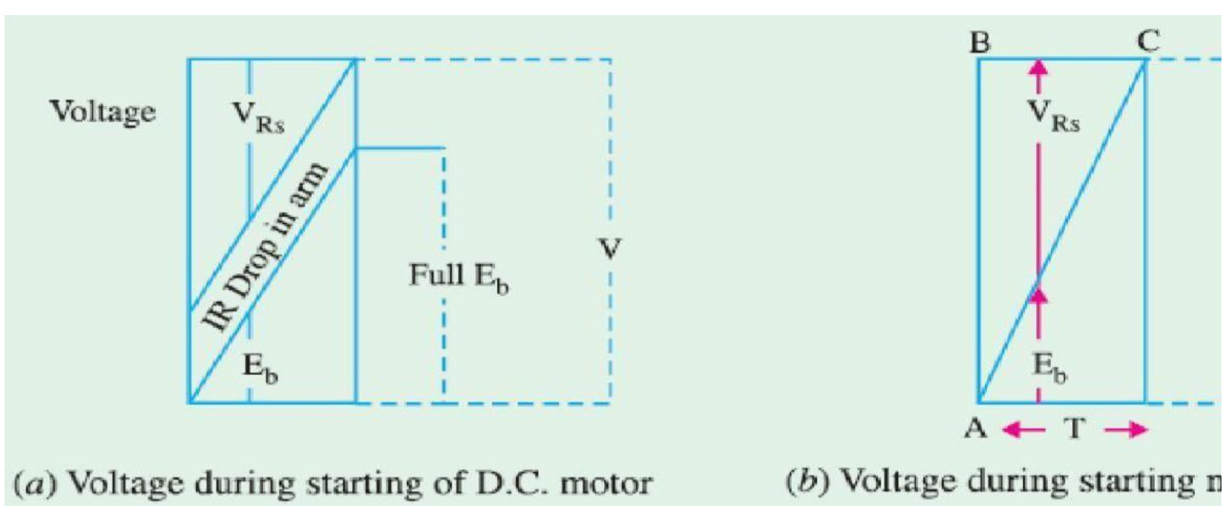


FIG 9 **SERIES - PARALLEL STARTING**

With a 2 motor equipment ½ the normal voltage will be applied to each motor at starting as shown in Fig. 10 (*a*) (Series connection) and they will run up to approximate ½ speed, at which instant they are switched on to parallel and full voltage is applied to each motor. *Rs* is gradually cut out, with motors in series connection and then reinserted when the motors are connected in parallel, and again gradually cut-out.

In traction work, 2 or more similar motors are employed. Consider 2 series motors started by series parallel method, which results in saving of energy.

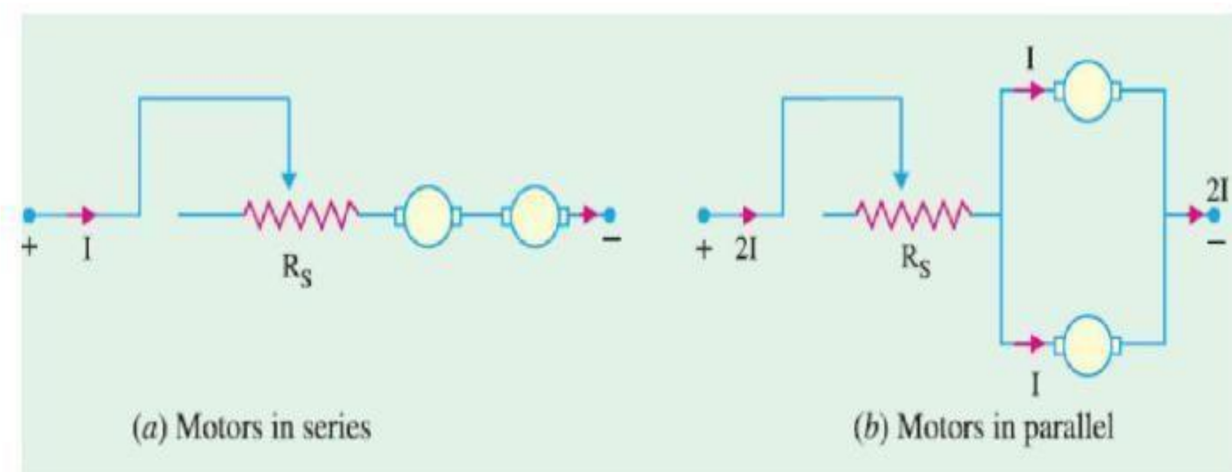


FIG 10 Series Parallel Starting

(a) Series operation.

The 2 motors, are started in series with the help of *Rs*. The current during starting is limited to normal rated current ‗*I*' per motor. During series operation, current ‗*I*' is drawn from supply. At the instant of starting *OA* = *AB* = *IR* drop in each motor. *OK* = Supply voltage ‗*V*'. The back e.m.fs. of 2 motors jointly develop along *OM* as shown in Fig.
(*a*). At point. *E*, supply voltage *V* = Back e.m.fs of 2 motors + *IR* drops of 2 motor. Any point on the line *BC* represents the sum of Back e.m.fs. of 2 motors + *IR* drops of 2 motors + Voltage across resistance *Rs* of 2 motors *OE* = time taken for series running.

At pt ‗*E*' at the end of series running period, each motor has developed a back e.m.f.=2*V* − *IREL* = *ED* — *LD*

(b) Parallel operation.

The motors are switched on in parallel at the instant ‗*E*', with *Rs* reinserted as shown in Fig. 10 (*b*). Current drawn is 2*I* from supply. Back e.m.f. across each motor = *EL*. So the back e.m.f. now develops along *LG*. At point ‗*H*' when the motors are in full parallel, (*Rs* = 0 and both the motors are running at rated speed) Supply voltage = *V* = *HF* = *HG* + *GF*= Normal Back e.m.f. of each motor + *IR* drop in each motor.

To find ts, tp and η of starting

The values of time *ts* during which the motors remain in seriesand *tp* during which they are in parallel can be determined from Fig.11(*a*), (*b*). From Fig.11(*a*), triangles *OLE* and *OGH* are

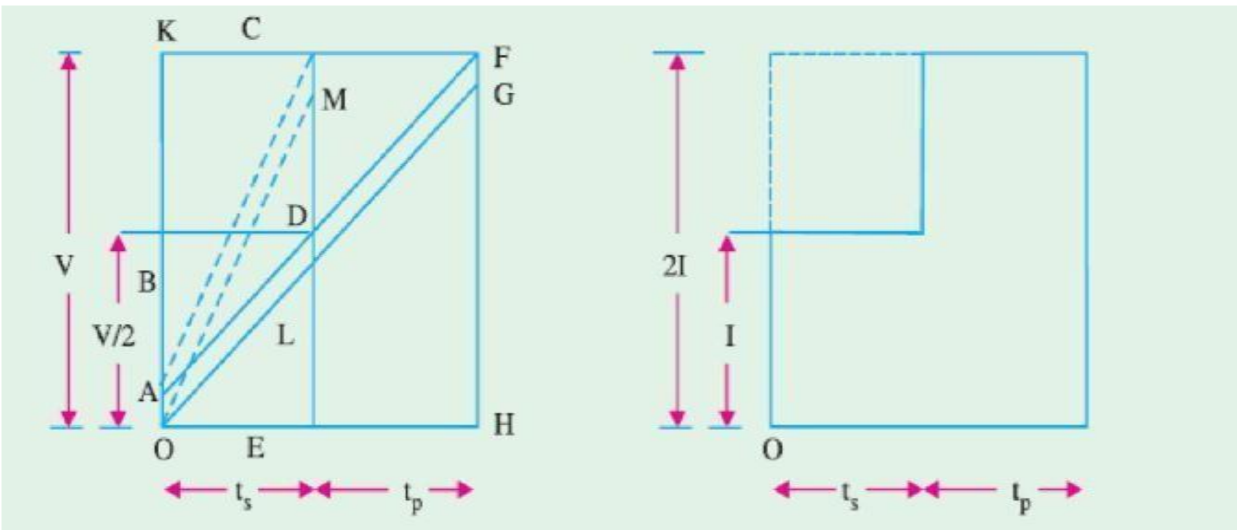
$$\therefore \quad \frac{OE}{OH} = \frac{LE}{GH} \quad \therefore \frac{t_s}{T} = \frac{DE - DL}{FH - FG} = \frac{V/2 - IR}{V - IR}$$

$$\therefore \quad t_s = \frac{1}{2}\left(\frac{V - 2IR}{V - IR}\right)T$$

$$t_p = T - t_s = T - \left\{\frac{1}{2}\left(\frac{V - 2IR}{V - IR}\right)T\right\}$$

$$t_p = T\left\{1 - \frac{1}{2}\left(\frac{V - 2IR}{V - IR}\right)T\right\}$$

similar



(*a*) Voltage built-up in series-parallel starting (*b*) Variation of current in series-parallel starting

FIG 11 Series Parallel operation

total energy supplied = *I V t* + 2 *I V t* (Series) (Parallel) = 3 *V I t*

$$\therefore \eta \text{ of starting} = \frac{3VIt - VIt}{3VIt} = \frac{2}{3} = 66.6\%$$

$\therefore$ η is increased by 16.66% as compared to pervious case. If there are 4 motors then $\eta_{starting}$ = 73%. So there is saving of energy lost in R_s, during starting period as compared with starting by both motors in parallel.

Series Parallel Control by Shunt Transition Method

The various stages involved in this method of series – parallel control are shown in Fig.

In steps 1, 2, 3, 4 the motors are in series and are accelerated by cutting out the *Rs* in steps. In step 4, motors are in full series. During transition from series to parallel, *Rs* is reinserted in circuit– step 5. One of the motors is bypassed -step 6 and disconnected from main circuit — step 7. It is then connected in parallel with other motor-step 8, giving 1st parallel position. *Rs* is again cut-out in steps completely and the motors are placed in full parallel.

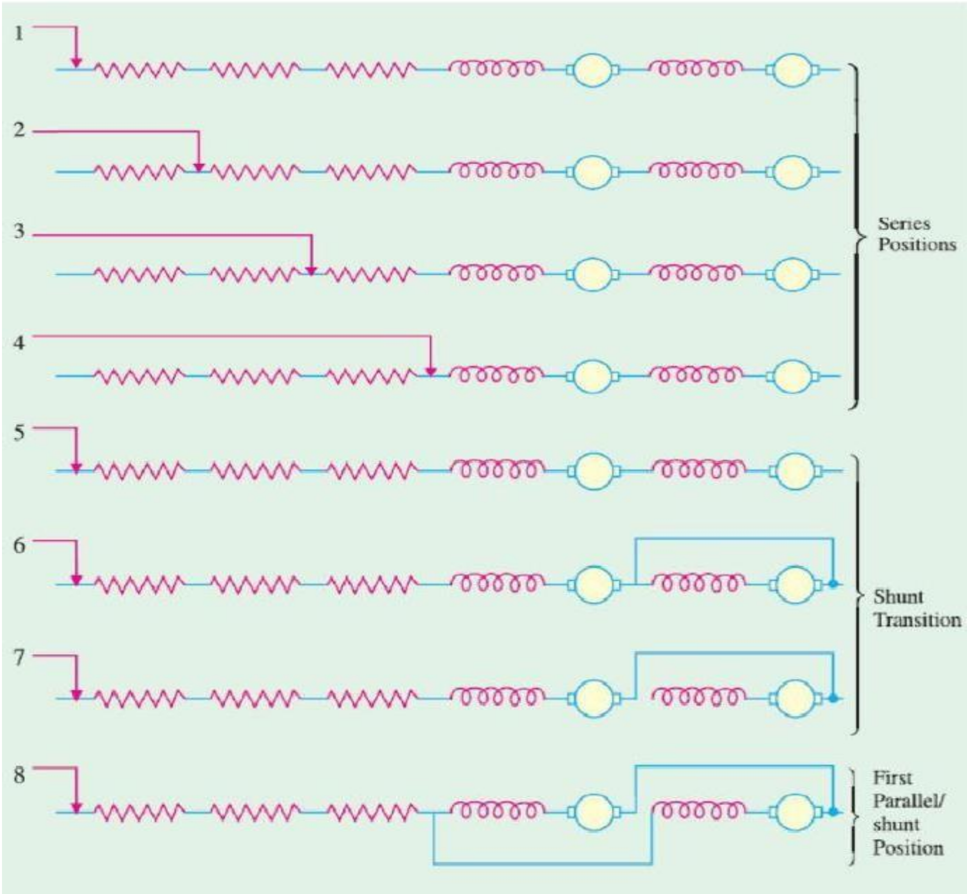


FIG 12 Series Parallel Shunt Operation

The main difficulty with series parallel control is to obtain a satisfactory method of transition fromseries to parallel without interrupting the torque or allowing any heavy rushes of current. In shunt transition method, one motor is short circuited and the total torque is reduced by about 50% during transition period, causing a noticeable jerk in the motion of vehicle. The Bridge transition is more complicated, but the resistances which are connected in parallel with or_bridged' across the motors are of such a value that current through the motors is not altered in magnitude and the total torque is therefore held constant and hence it is normally used for railways. So in this method it is seen that, both motors remain in circuit through-out the transition. Thusthe jerks will not be experienced if this method is employed.

SERIES PARALLEL CONTROL BY BRIDGE TRANSITION

(a) At starting, motors are in series with *Rs i.e.* link *P* in position = *AA′*

(b) Motors in full series with link *P* in position = *BBRs* in the circuit)
The motor and *Rs* are connected in the form of Wheatstone Bridge. Initially motors are in series with full *Rs* as shown in Fig. 13. *A* and *A*' heads are moved in direction of arrow heads. In position BB'motors are in full series as shown in fig 14, with no *Rs* present in the circuit.

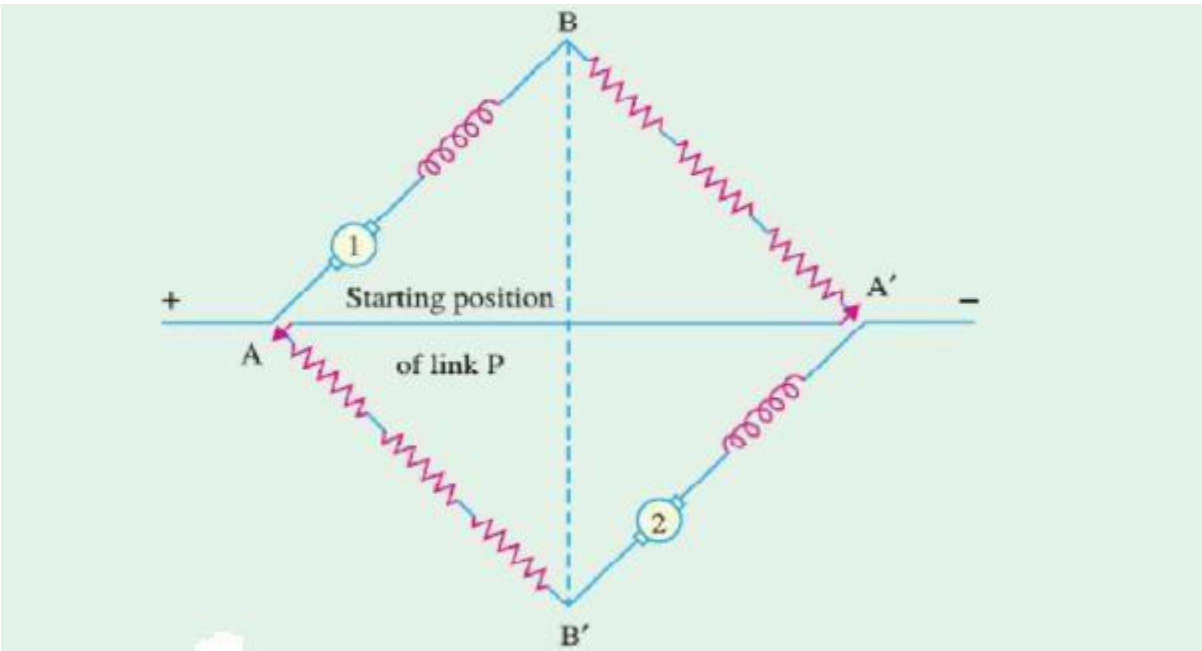


FIG 13 Series Parallel Bridge operation(a)

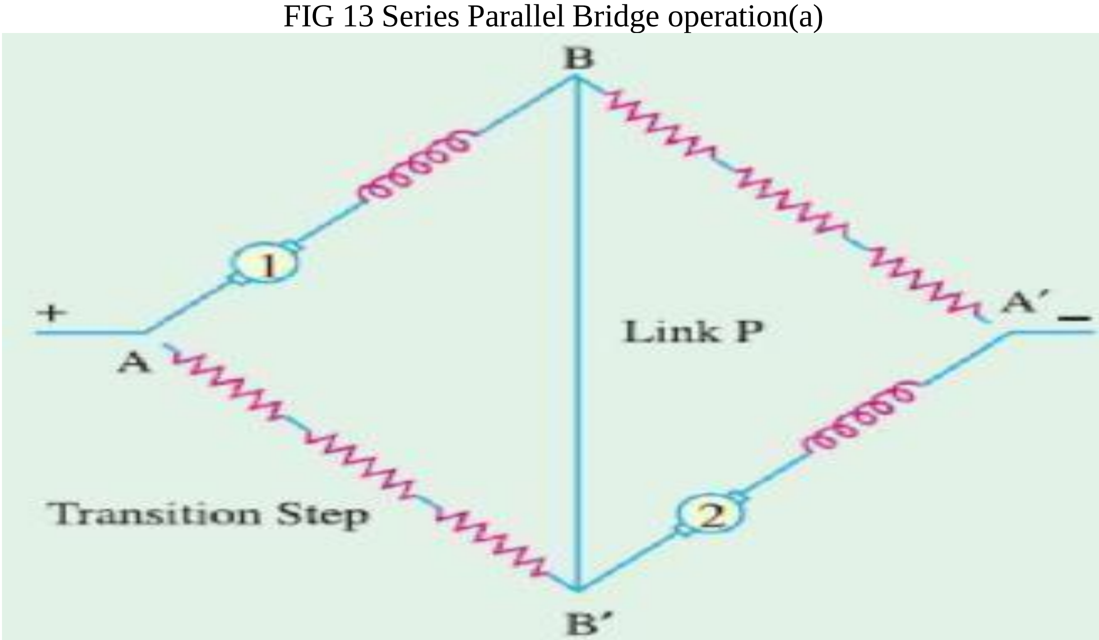


FIG 14 Series Parallel Bridge operation(b)

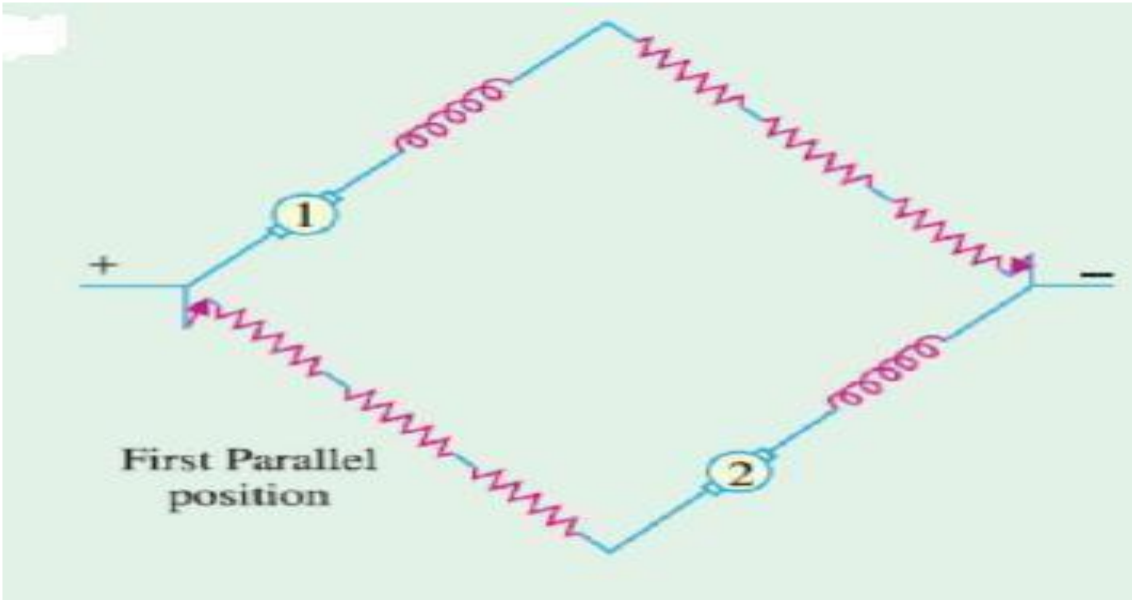


FIG 15 Series Parallel Bridge operation(c)

In transition step the *Rs* is reinserted.In Ist parallel step, link *P* is removed and motors are connected in parallel with full *Rs* as shown in Fig. 15. Advantage of this method is that the normal acceleration torque is available from both the motors, through - out starting period. Therefore acceleration is smoother, without any jerks, which is very much desirable for traction motors.

THE TRAMWAYS

It is the most economical means of transport for very dense traffic in the congested streets of large cities. It receives power through a bow collector or a grooved wheel from an overhead conductor at about 600 V dc, the running rail forming the return conductor. It is provided with at least two driving axles in order to **(*i*)** secure necessary adhesion **(*ii*)** start it from either end and (iii) use two motors with series-parallel control. Two drum- type controllers, one at each end, areused for controlling the tramcar. Though these controllers are connected in parallel, they have suitable interlocking arrangement meant to prevent their being used simultaneously.

Tramcars are being replaced by trolley-buses and internal-combustion-engine omnibuses becauseof the following reasons :

1. Tramcars lack flexibility of operation in congested areas.

2. The track constitutes a source of danger to other road users.

THE TROLLEYBUS

It is an electrically-operated pneumatic-tyred vehicle which needs ***no track in the roadway***. It receives its power at 600 V dc from two overhead contact wires. Since adhesion between a rubber tyred wheel and ground is sufficiently high, only a single driving axle and, hence, a single motor is used. The trolleybus can manoeuvre through traffic a metre or two on each side of the centre line of the trolley wires

Overhead Equipment (OHE)

Broadly speaking, there are two systems of current collection by a traction unit :

(i) third rail system and **(ii)** overhead wire system.

It has been found that current collection from overhead wire is far superior to that from the third rail. Moreover, insulation of third rail at high voltage becomes an impracticable proposition and endangers the safety of the working personnel.

The simplest type of OHE consists of a single contact wire of hard drawn copper or silicon-bronze supported either by bracket or an overhead span. To facilitate connection to the supports, the wire is grooved as shown in Fig.16. Because there is appreciable sag of the wire between supports, it limits the speed of the traction unit to about 30 km/h. Hence, single contact wire system is suitable for tramways and in complicated yards and terminal stations where speeds are low and simplicity of layout is desirable.

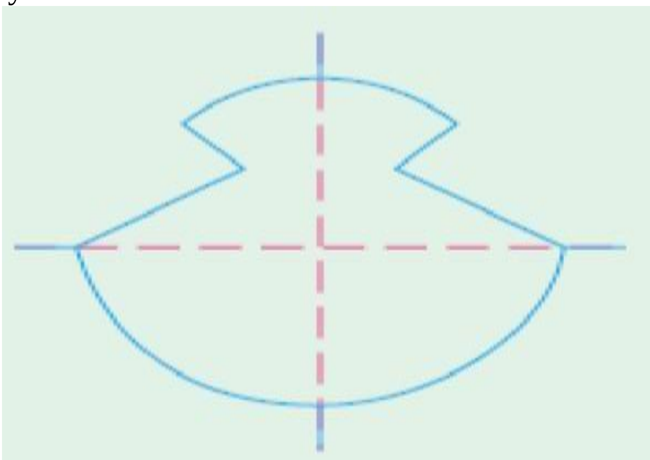


FIG 16 TrolleyBus

For collection of current by high-speed trains, the contact (or trolley) wire has to be kept level without any abrupt changes in its height between the supporting structures. It can be done by using the single catenary system which consists of one catenary or messenger wire of steel with high sag and the trolley (or contact) wire supported from messenger wire by means of droppers clipped to both wires as shown in Fig. 17.

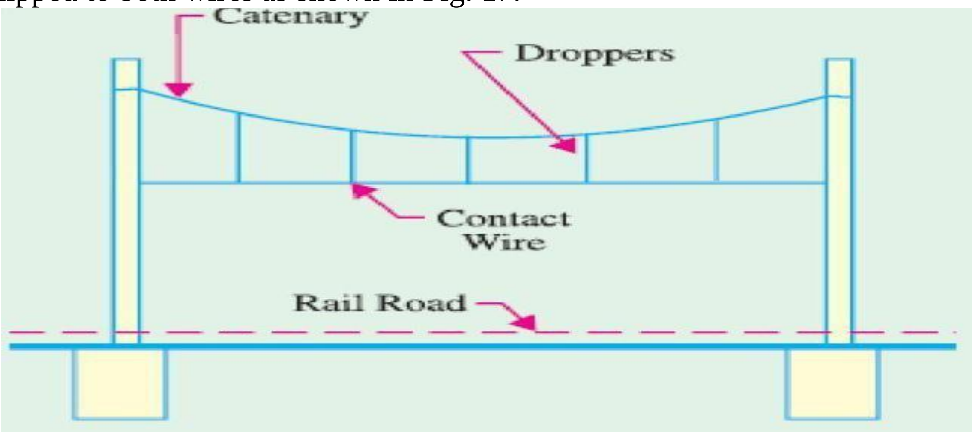


FIG 17 OHE

Collector Gear for OHE

The most essential requirement of a collector is that it should keep continuous contact with trolley wire at all speeds. Three types of gear are in common use :

1.Trolley collector 2. Bow collector and 3. Pantograph collector.

To ensure even pressure on OHE, the gear equipment must, be flexible in order to follow variations in the sag of the contact wire. Also, reasonable precautions must be taken to prevent the collector from leaving the overhead wire at points and crossings.

The Trolley Collector

This collector is employed on tramways and trolley buses and is mounted on the roof of the vehicle. Contact with the OH wire is made by means of either a grooved wheel or a sliding shoe carried at the end of a light trolley pole attached to the top of the vehicle and held in contact with OH wire by means of a spring. The pole is hinged to a swivelling base so that it may be reversed for reverse running thereby making it unnecessary for the trolley wire to be accurately maintained above the centre of the track. Trolley collectors always operate in the trailing position. The trolley collector is suitable for low speeds up to 32 km/h beyond which there is a risk of its jumping off the OH contact wire particularly at points and crossing.

The Bow Collector It can be used for higher speeds. As shown in Fig. 18, it consists of two roof mounted trolley poles at the ends of which is placed a light metal strip (or bow) about one metre long for currentcollection. The collection strip is purposely made of soft material (copper, aluminium or carbon) in order that most of the wear may occur on it rather than on the trolley wire. The bow collector also operates in the trailing position. Hence, it requires provision of either duplicate bows or an arrangement for reversing the bow for running in the reverse direction. Bow collector is not suitable for railway work where speeds up to 120 km/h and currents up to 3000 A are encountered. It is so because the inertia of the bow collector is too high to ensure satisfactory current collection.

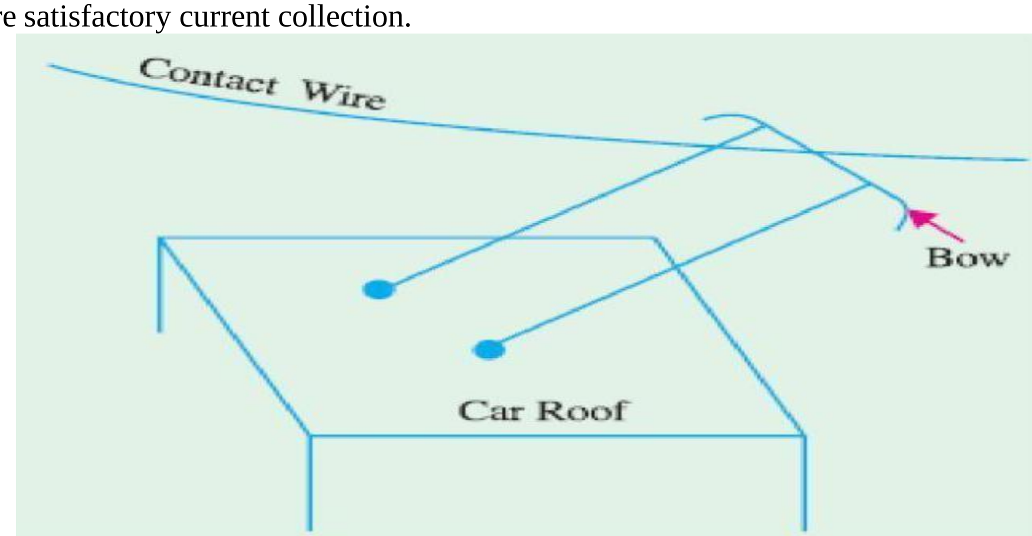


FIG 18 Bow Collector

The Pantograph Collector

Its function is to maintain link between overhead contact wire and power circuit of the electric locomotive at different speeds under all wind conditions and stiffness of OHE. It means that positive pressure has to be maintained at all times to avoid loss of contact and sparking but the pressure must be as low as possible in order to minimize wear of OH contact wire. A diamond ‘type single-pan pantograph is shown in Fig. 43.5. It consists of a pentagonal framework of high-tensile alloy-steel tubing. The contact portion consists of a pressed steel pan fitted with renewable copper wearing strips which are forced against the OH contact wire by the upward action of pantograph springs. The pantograph can be raised or lowered from cabin by air cylinders.

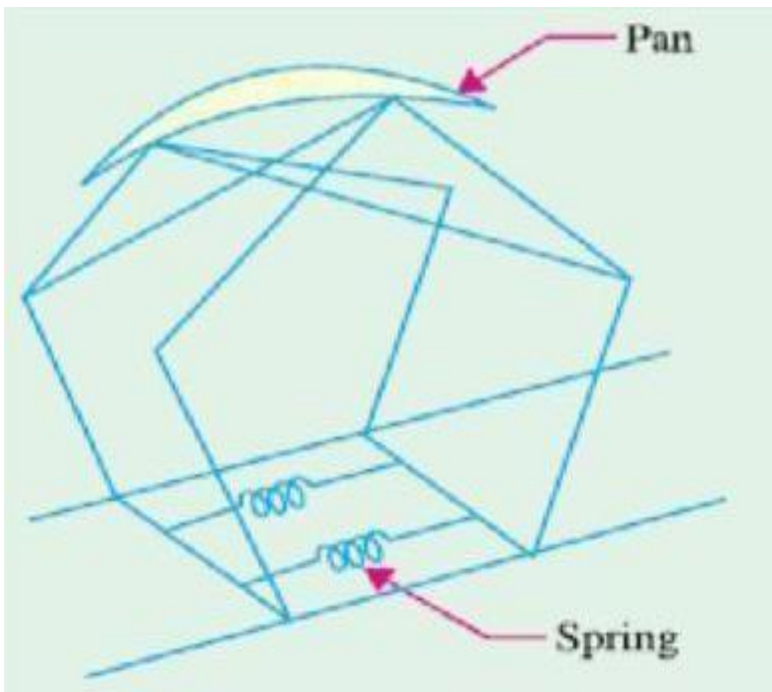


FIG 19 Pantograph Collector

Questions

Part A

1. What is trolley bus?
2. Write the advantages of electric traction.
3. What are the factors to be considered while selecting a motor for a given service?
4. Why do series motors are preferred for DC traction.
5. Draw the speed –time curve of an electric train for mainline service.
6. What is meant by electric braking?
7. Name the various system of traction.
8. What are tramways?

Part-B

1. Write short notes on

   A) Tractive effort b). Specific energy consumption
2. A train is required to run between two stations 1.6 Km apart at an average speed of 43 Kmph.The run is to be made to a simplified quadrilateral speed time curve. If the maximum speed is to be limited to 64 Kmph. Acceleration to 2 Kmphps & coasting & braking retardation to 0.16 and 32 Kmphps respectively, determine the duration of acceleration, coasting and braking periods.
3. Explain three methods of electric braking employed in traction; bring out their merits & Demerits.
4. Discuss the ‘bridge’ transition and ‘shunt’ transition methods used during starting of traction motors. Compare their performance & state their applications.
5. Explain the requirements of ideal traction and show which drive satisfies almost all the requirements?
6. Derive expression for

   i) Tractive effort for propulsion of a train on level track

   ii) Tractive effort for propulsion of a train up & down a gradient.

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