# Technical English
# for
# Mechanical Engineering

“The Structure of Technical English”

by **A. J. Herbert**

# Contents

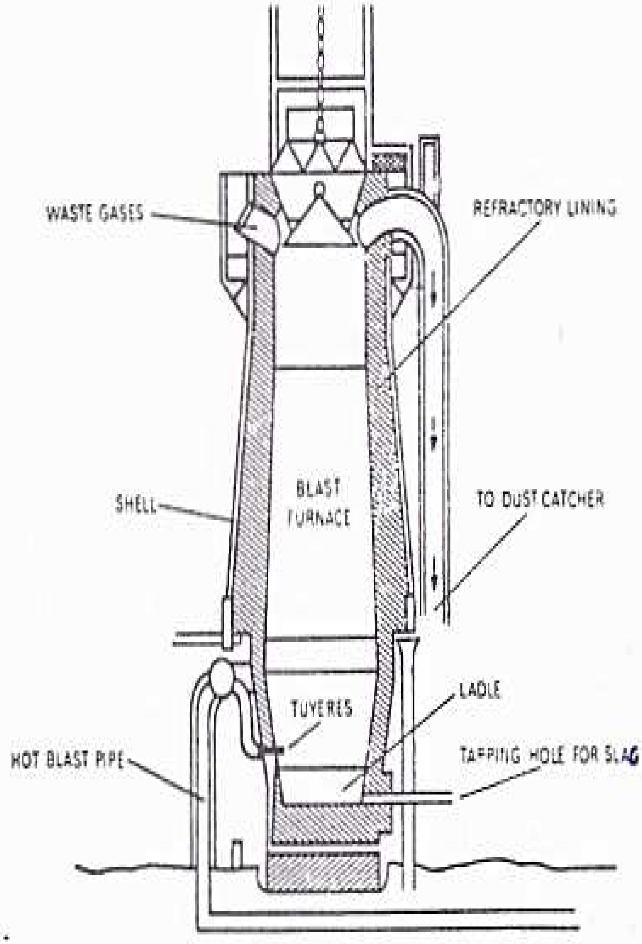
# Section 1: Iron and Steel

The earth contains a large number of metals which are useful to man. One of the most important of these is iron. Modern industry needs considerable quantities of this metal, either in the form of iron or in the form of steel. A certain number of non-ferrous metals, including aluminium and zinc, are also important, but even today the majority of our engineering products are of iron or steel. Moreover, iron possesses magnetic properties, which have made the development of electrical power possible .

The iron ore which we find in the earth is not pure. It contains some impurities which wemust remove by smelting. The process of smelting consists of heating the ore in a blast furnace with coke and limestone, and reducing it to metal. Blasts of hot air enter the furnacefrom the bottom and provide the oxygen which is necessary for the reduction of the ore. The orebecomes molten, and its oxides combine with carbonfrom the coke. The non-metallicconstituents of the ore combine with the limestone to form a liquid slag. This floats on top ofthe molten iron, and passes out of the furnace through a tap. The metal which remains is pig-iron.

We can melt this down again in another furnace - a cupola - with more coke and limestone, andtap it out into a ladle or directlyinto moulds. This is cast-iron. Cast-iron does not havethe strength of steel. It is brittleand may fracture under tension. But it possesses certain properties which make it very useful in the manufacture of machinery. In the molten state it isvery fluid,and therefore it is easy to cast it into intricate shapes. Also it is easy to machine it. Cast-iron contains small proportions of other substances. These non-metallic constituents of cast-iron include carbon, silicon and sulphur, and the presence of these substances affectsthe behaviour of the metal. Iron which contains a negligible quantity of carbon, for example wrought-iron, behaves differently from iron which contains a lot of carbon.

The carbon in cast-iron is present partly as free graphite and partly as a chemical combination of iron and carbon which we call cementite.This is a very hard substance,and itmakes the iron hard too. However, iron can only hold about $1\frac{1}{2}\%$ of cementite. Any carbon content above that percentage is present in the form of a flaky graphite.Steel contains no freegraphite, and its carbon content ranges from almost nothing to $1\frac{1}{2}\%$. We make wire and tubing from mild steel with a very low carbon content, and drills and cutting tools from highcarbon steel.



Cross-section of blast furnace

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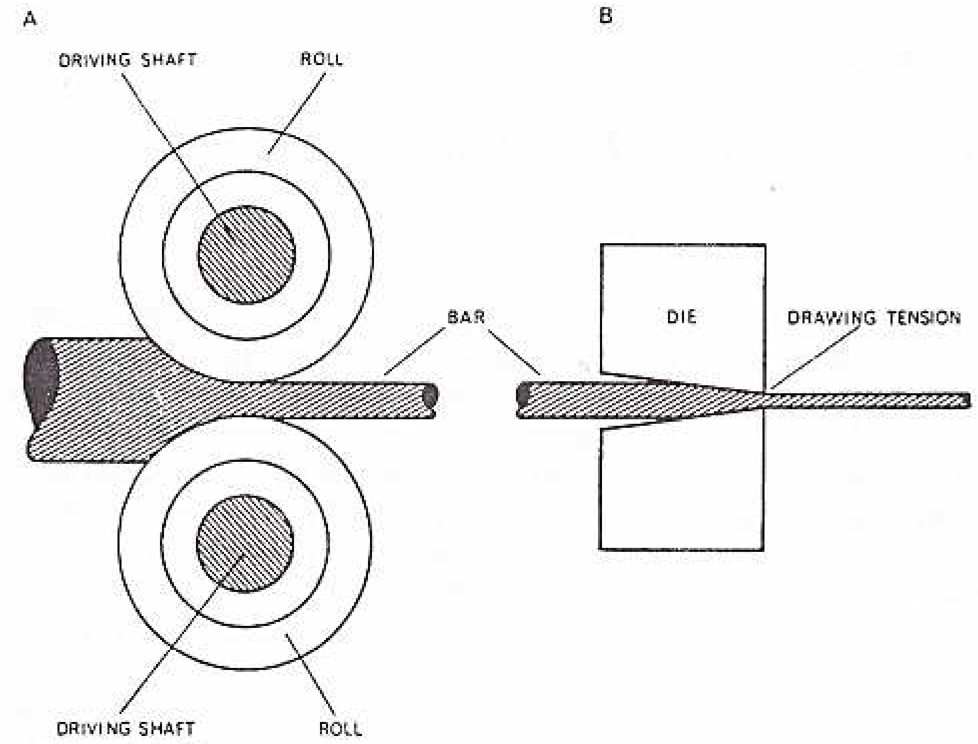
# Section 2: Heat Treatment of steel

We can alter the characteristics of steel in various ways. In the first place, steel which contains very little carbon will be milder than steel which contains a higher percentage of carbon, up tothe limit of about $1\frac{1}{2}$%. Secondly, we can heat the steel above a certain critical temperature, and then allow it to cool at different rates. At this critical temperature, changes begin to take place in the molecular structure of the metal. In theprocess known as annealing, we heatthe steel abovethe critical temperatureand permit it to cool very slowly. This causes themetal to become softer than before, and mucheasier to machine. Annealing has a secondadvantage. It helps to relieve any internal stresses which exist in the metal. These stresses are liable to occur through hammering orworking the metal, or through rapid cooling. Metal which we cause to cool rapidly contracts more rapidly on the outside than on the inside. Thisproduces unequal contractions, which may give rise to distortion or cracking. Metal which cools slowly is less liable to have these internal stresses than metal which cools quickly.

On the other hand, we can make steel harder by rapid cooling. We heat it up beyond thecritical temperature, and then quench it in water or some other liquid. The rapid temperature drop fixes the structural change in the steel which occurredat the critical temperature, and makes it very hard. But a bar of this hardened steel ismore liable to fracture than normal steel. We therefore heat it again to a temperature below the critical temperature, and cool itslowly. This treatment is called tempering. It helps to relieve the internal stresses, and makesthe steel less brittle than before. The propertiesof tempered steel enable us to use it in the manufacture of tools which need a fairly hard steel. High carbon steel is harder than tempered steel, but it is much more difficult to work.

These heat treatments take place during the various shaping operations. We can obtain barsand sheets of steel by rolling the metal through huge rolls in a rolling-mill. The roll pressures must be much greater for cold rolling than for hot rolling, but cold rolling enables the operators to produce rolls of great accuracy and uniformity, and with a better surface finish. Other shaping operations include drawing into wire, casting in moulds, and forging.



(A) Roller-mill with rolls
(B) Drawing-bench

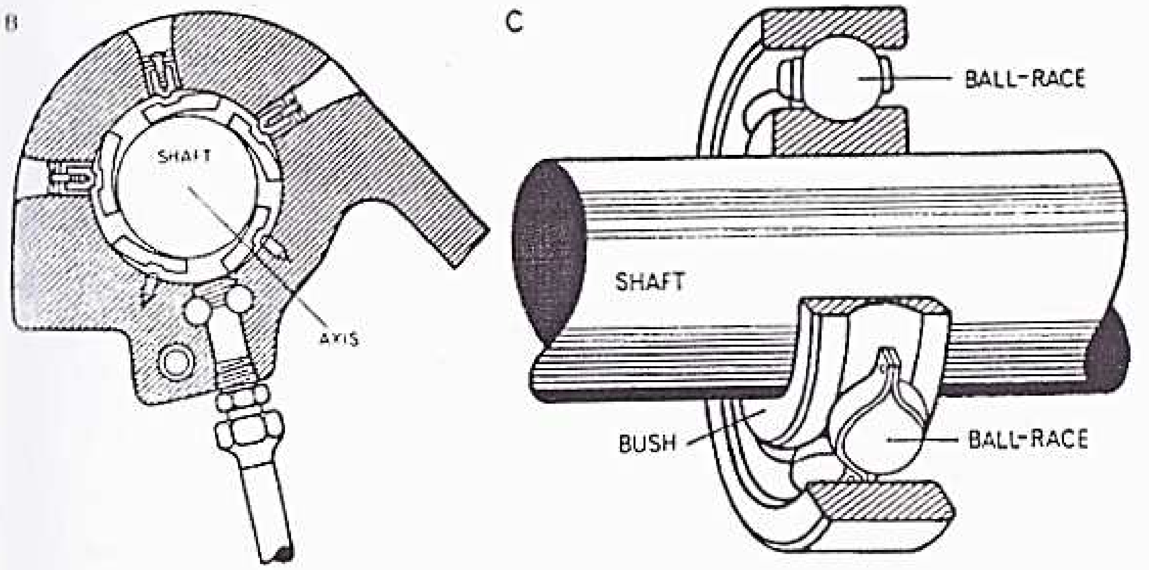
# Section 3: Lubrication of Bearings

The machine tools in a workshop sometimes have their own electric motors, or they may take the power they need from a motor which feeds several machines. The shafts which carry the power from the motor to the machines need some kind of support to keep them steady. Wecall these supports bearings. There are different types of bearings for different purposes. We can classify them according to whether they take the load on the shaft or the thrust along the axis of the shaft. The former type is known as a journal bearing, and the latter type as a thrust bearing.

The rotating shaft bears on a stationary bush or tube. We therefore have two metal surfaces in close contact with each other, and sliding over each other often at high speed. This will cause frictionand the bearing will become heated. So we have to protect the metal surfaces from overheating and damage. First of all, we avoid making the shaft and the bush of the same material. The shafting itself is generally of steel, but we use another metal such as cast-iron or bronze or white metal for the bush. At a certain temperature, the metal in the bush willseize or run, and thiswill prevent damage to the shaft. But of course it will not prevent overheating from occurring.

However, we can reduce the danger of overheating by lubrication. We have a thin film of oil between the two metallic surfaces to keep them apart. The internal friction of oil is muchless than the friction between two solids, and generates less heat. Lubrication also offers another advantage. A film of oil on the metal surfaces will prevent themfrom corroding by protecting them from the air.

The sort of lubricant which we use depends largely on the running speed of the bearing. We can use grease in low-speed bearings, but greaseoffers more resistanceto the turningmovement of the shaft. A lighter oil causes less friction, and so an oily lubricant is better for high-speed bearings. The rotation of the shaft carries the film of oil round the inside of thebearing and keeps the shaft from contact with the bush which houses it. We can feed the oilinto the bearing in several ways. Sometimes we allow it to drip down under the influence of gravity. More commonly, a pump or gun feeds it in under pressure. In motor-car and other engines, we half cover the bearing in an oil-bath, and oil splashes up into it.We can reduce the amount of frictioneven more with rolling bearings. The hardened steel balls in this type of bearing roll round in a finely-ground ball race, and make little more than point contact with the race.



(B) Journal bearing
(C) Roller bearing

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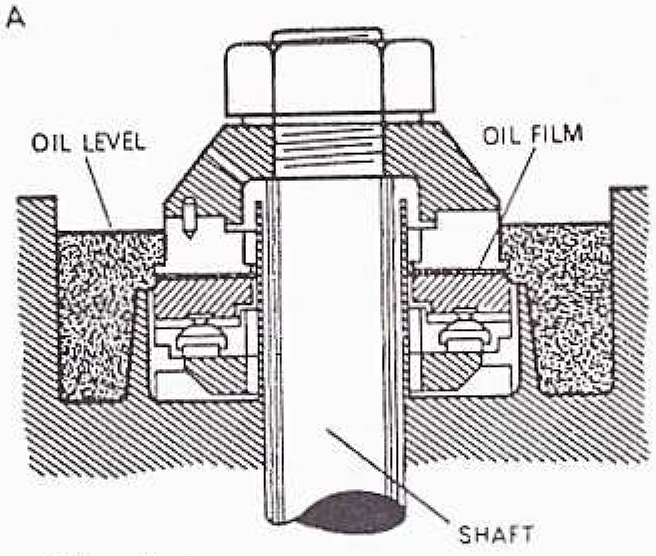


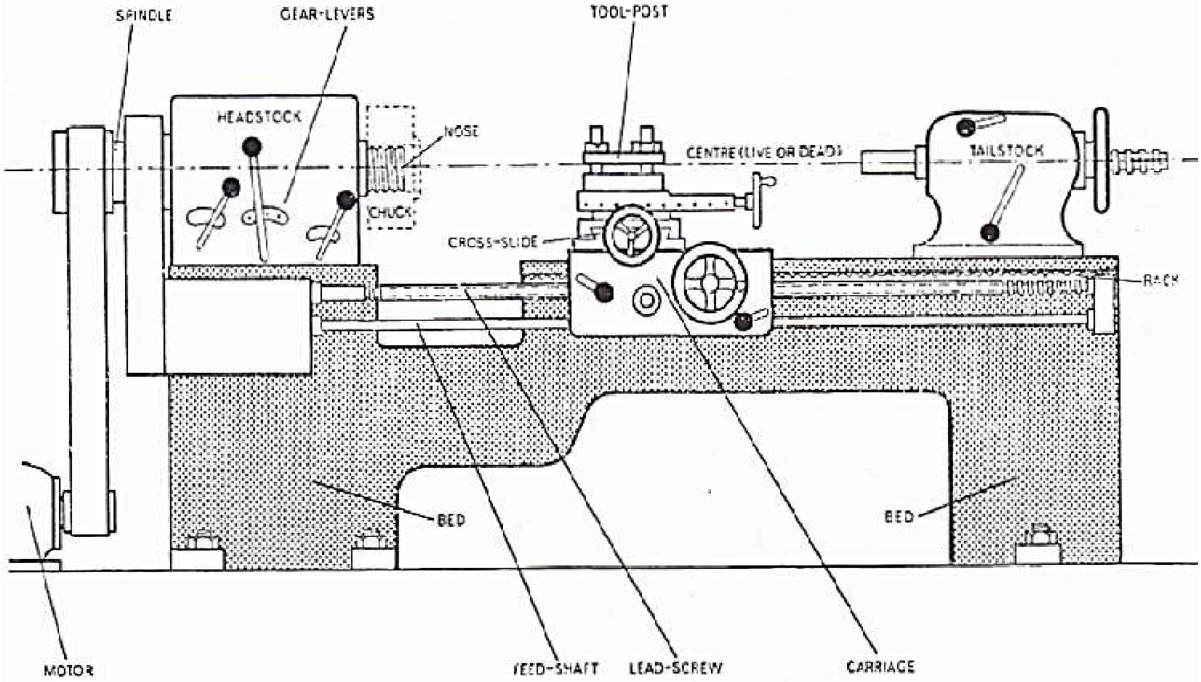
(A) Thrust bearing

# Section 4: The Lathe

The lathe is one of the most useful and versatile machines in the workshop, and is capable of carrying out a wide variety of machining operations. The main components of the lathe are the headstock and tailstock at opposite ends of a bed, and a tool-post between them which holdsthe cutting tool.The tool-post stands on a cross-slide which enables it to move sidewards across the saddle or carriage as well as along it, depending on the kind of job it is doing. Theordinary Centre lathe can accommodate only one tool at a time on the tool-post, but a turretlathe is capable of holding five or more tools on the revolving turret. The lathe bed must bevery solid to prevent the machine from bending or twisting under stress.

The headstock incorporates the driving and gear mechanism, and a spindle which holds theworkpiece and causes it to rotate at a speed which depends largelyon the diameter of the workpiece. A bar of large diameter should naturally rotate more slowly than a very thin barthe cutting speed of the tool is what matters. Tapered centres in the hollow nose of the spindleand of the tailstockhold the work firmly between them. A feed-shaft fromthe headstock drivesthe tool-post along the saddle, either forwards or backwards, at a fixed and uniformspeed. This enables the operator to make accurate cuts and to give the work a good finish.Gears between the spindle and the feed-shaft control the speed of rotation of the shaft, and therefore the forward or backward movement of the tool-post. The gear which the operator will select depends on the type of metalwhich he is cutting and the amount of metal he has to cut off. For a deep or roughing cut the forward movement of the tool should be less than fora finishing cut.

Centres are notsuitable for every job on the lathe. The operator can replace them by various types of chucks, which hold the work betweenjaws, or by a front-plate, depending on the shape of the work and the particular cutting operation. He will use a chuck, for example, tohold a short piece of work, or work for drilling, boring or screw-cutting. A transverse movement of the tool-post across the saddle enables the tool to cut across the face of theworkpiece and give it a flat surface. For screw-cutting, the operator engages the lead-screw, a long screwed shaft which runs along in front of the bed and which rotates with thespindle. The lead-screw drives the tool-post forwardsalong the carriage at the correct speed, and this ensures that the threads on the screw are of exactly the right pitch. The operator can select different gear speeds, and this will alter the ratio of spindle and lead-screw speeds andtherefore alter the pitch of the threads. A reversing lever on the headstock enables him toreverse the movement of the carriage and so bring the tool back to its original position.



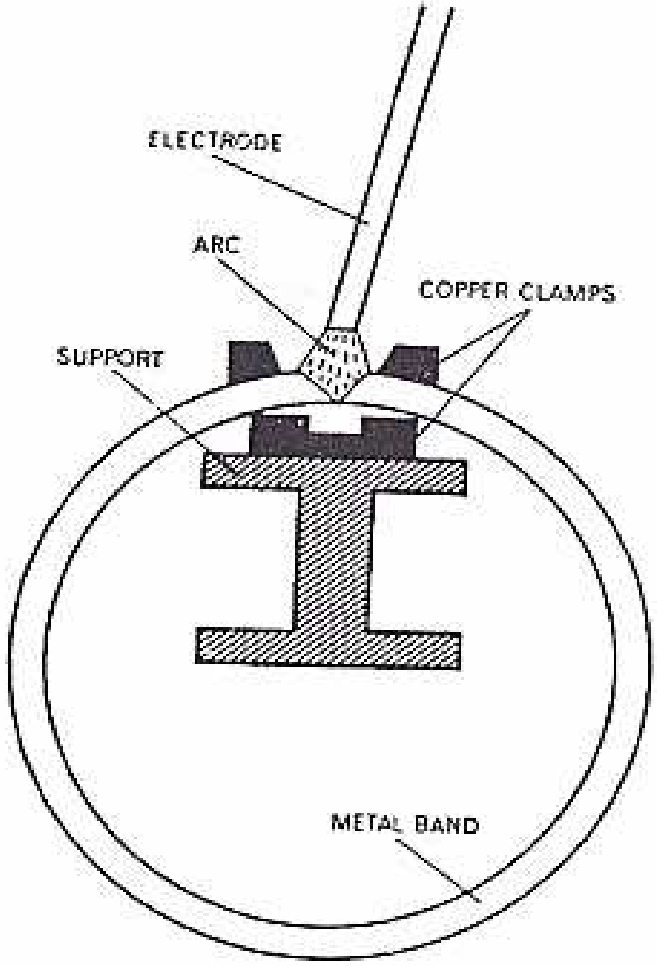
Centre lathe

# Section 5: Welding

There are a number of methods of joining metal articles together, depending on the type of metal and the strength of the joint which is required. Soldering gives a satisfactory joint forlight articles of steel, copper or brass, but the strength of a soldered joint is rather less than ajoint whichis brazed, riveted or welded. These methodsof joining metal arc normallyadopted forstrong permanent joints.

The simplest methodof weldingtwo piecesof metal together is known as pressure welding. The ends of metal are heated to a white heat - for iron, the welding temperature should be about 1300° C -in a flame. At this temperature the metalbecomes plastic. The ends are then pressed or hammered together, and the joint is smoothedoff. Care must be taken to ensure thatthe surfacesare thoroughly clean first, fordirt will weaken the weld. Moreover, the heating of iron or steel to a high temperature causes oxidation, and a film of oxide is formed on the heated surfaces. For this reason, a flux is applied to the heated metal. At welding heat, the flux melts, and the oxide particles are dissolved in it together with any other impurities which may be present. The metal surfaces are pressed together, and the flux is squeezed out from the centre of the weld. A number of different typesof weld may be used, but for fairly thick bars of metal, a vee-shaped weld should normally beemployed. It is rather stronger than the ordinary butt weld.

The heat forfusion welding is generated in several ways, depending on the sort of metal which is beingwelded and on its shape. An extremely hot flame can be produced from anoxy-acetylene torch. For certain welds an electric arc is used. In this method, an electriccurrent is passed across two electrodes, and the metal surfaces are placed between them. The electrodes are sometimes madeof carbon, but more frequently they are metallic. The work itself constitutes one ofthem and the other is an insulated filler rod. An arc is struck betweenthe two, and theheat whichis generated melts the metal at the weld. A different method isusually employed forwelding sheets or platesof metal together. This is known as spot welding. Two sheets or plates are placed together with a slight overlap, and acurrent ispassed between the electrodes. At welding temperature, a strong pressure is applied to the metal sheets, The oxide film, and any impurities which are trapped between the sheets, are squeezed out, and the weld is made.



Electric arc welding

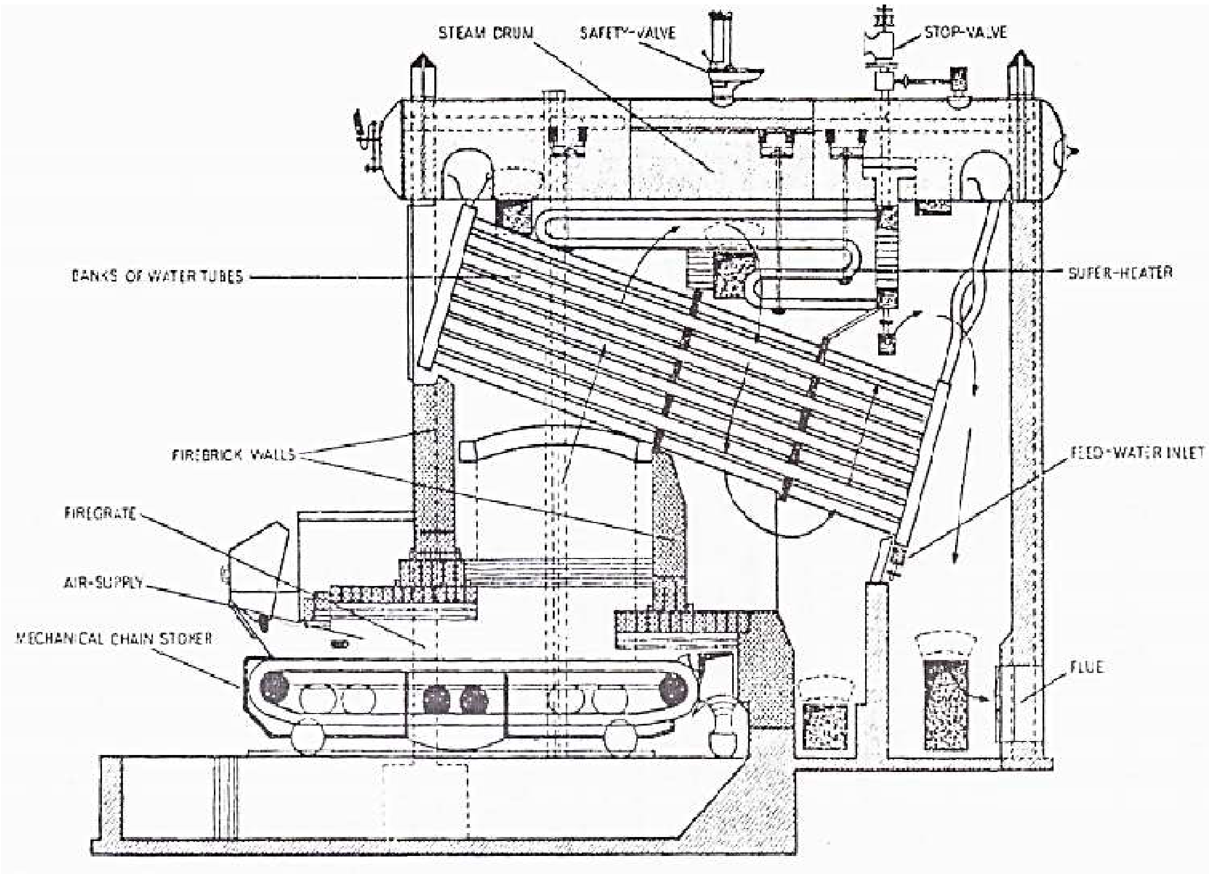
# Section 6: Steam Boilers

Large quantitiesof steam areused by modern industryin the generation of power. It is therefore necessary to design boilers which will produce high-pressure steam as efficiently aspossible. Modern boilers are frequently very large, and are sometimes capable of generating 300,000 lb.of steam per hour. To achieve this rateof steam production, the boilers should operate at very high temperatures. In some boilers, temperatures of over 1650° C may beattained. The fuelswhich arc burned in the furnace are selected for their high calorific value,and give the maximum amountof heat. They are often pulverised bycrushers outside thefurnace and forced in under pressure.

Modern boilers which employ solid fuels arc usually too large to be hand-stoked, and stoking is then carried out by mechanical stokers, which ensure that an adequate quantity of fuel is conveyed into the furnace at the proper speed. The air which is needed by the fuel forcombustion is blown across the fire grate by steam jets or fans. The amount of air which isallowed to enter is just more than sufficient for complete combustion of the fuel. An insufficient supplyof air willprevent complete combustion, but any air in excess of theminimum merely reduces the temperature of combustion. The hot gases which are produced by the combustion of the fuel are circulated round banks of water-tubes. These are inclined atan angle over the furnace, and connect the upper and lower steam drums. A large proportionof the heat is absorbed by the water in the boiler. The remainder may be used to heat up theincoming air-supply through an air-heater. The water and steam in the boiler should circulatefreely. The water and steam circuits are designed to allow the greatest possible fluid velocityto be attained, and rapid movement of the fluid is achieved by forced circulation. This assistsrapid heating and also prevents the formation of steam pockets in the tubes.

Loss of efficiencyin the boiler will be caused by the dissipation of heat through thewalls of thecombustion chamber. This heat loss can be considerably reduced by the use of firebricksround the walls of the chamber. This helps to insulate the chamber and to conserve the heat which is generated. However, at the temperatureswhich areattainable in modern boilers, the solid walls of the furnace are liable to be damaged by excessive heat. To avoidthis, they are often lined with water-tubes, and some of the heat of combustion is absorbed by the water.

The steam from the boiler is passed through a superheater and out past a stop-valve athigh pressure. A fresh supply of water is fed by pumps into the boiler to replace it. The feed-water should be pure, and free from dissolved salts which will cause deposits on the tubesand lead to overheating.



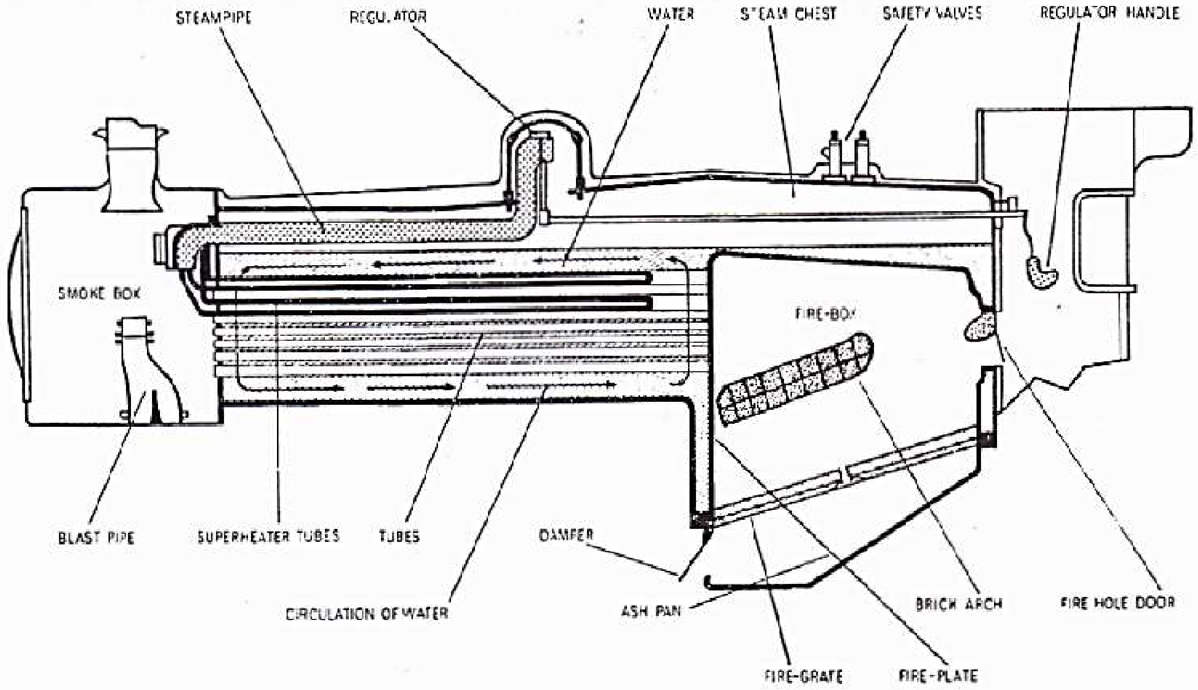
Cross-section of boiler with mechanical stoker

# Section 7: Steam Locomotives

From the date of the introduction of the steam locomotive about 130 years ago, there was a continuing increase in the size and weight of trains. This necessitated engines of greater andgreater power. In order to achieve this increase in power, much higher steam pressures were required. The modern steamlocomotive is capable of generatingsteam pressures often in excess of 300lb/in2, against the 50lb/in2 pressure of Stevenson's 'Rocket'. Normally thedemand for increased steam capacity is met by increasing the size of the boiler. However theboiler of a steam locomotive is strictly limited in size by the dimensions and load capacity ofthe railway track which it works on. It is therefore necessary to have a verylarge heating surface within the boiler.

There are two fire-boxes inside the boiler, an inner one and an outer one, which extenda long way forward. The inner fire-box is linked by tubes to the fire-plate at the front of the boiler. Practically the whole of theheating surface, which includes these fire-tubes, is surrounded by water. A high rate of evaporation in the boiler is essential, in order to generatethe large quantities of stain which are required. For this purpose a powerful draught of air isblown over the fire. The steam which is evolved ispassed through assuper-heater, which raises its temperature and makes it as dry as possible. Rapid evaporation at the heating surface tends to make the steam wet. The use of wet steam necessitates excessively high pressures in the cylinder.Super-heating the steam enables the requisite power to be obtained with considerably lower pressures.

The superheated steam is passed to the steam-chest which is attached to the cylinderFrom the steam-chest it is introduced into the cylinder at the appropriate moments throughports. These ports are opened and closed by slide valves, which are actuated by the rotation ofthe locomotive crankshaft. The steam is admitted under pressure to one side of the cylinder,and drives the piston forwards. The inlet port is then closed, and a second charge of steam isadmitted at the other side of the cylinder to drive the piston in the reverse direction. The exhaust steam from the first charge is driven out into the atmosphere through a blast pipe. Thisis done in order to increase the draught over the fire. The reciprocating action of the piston is changed into a rotational movement of the wheels by a connecting rod and crank.



Cross-section of steam locomotive

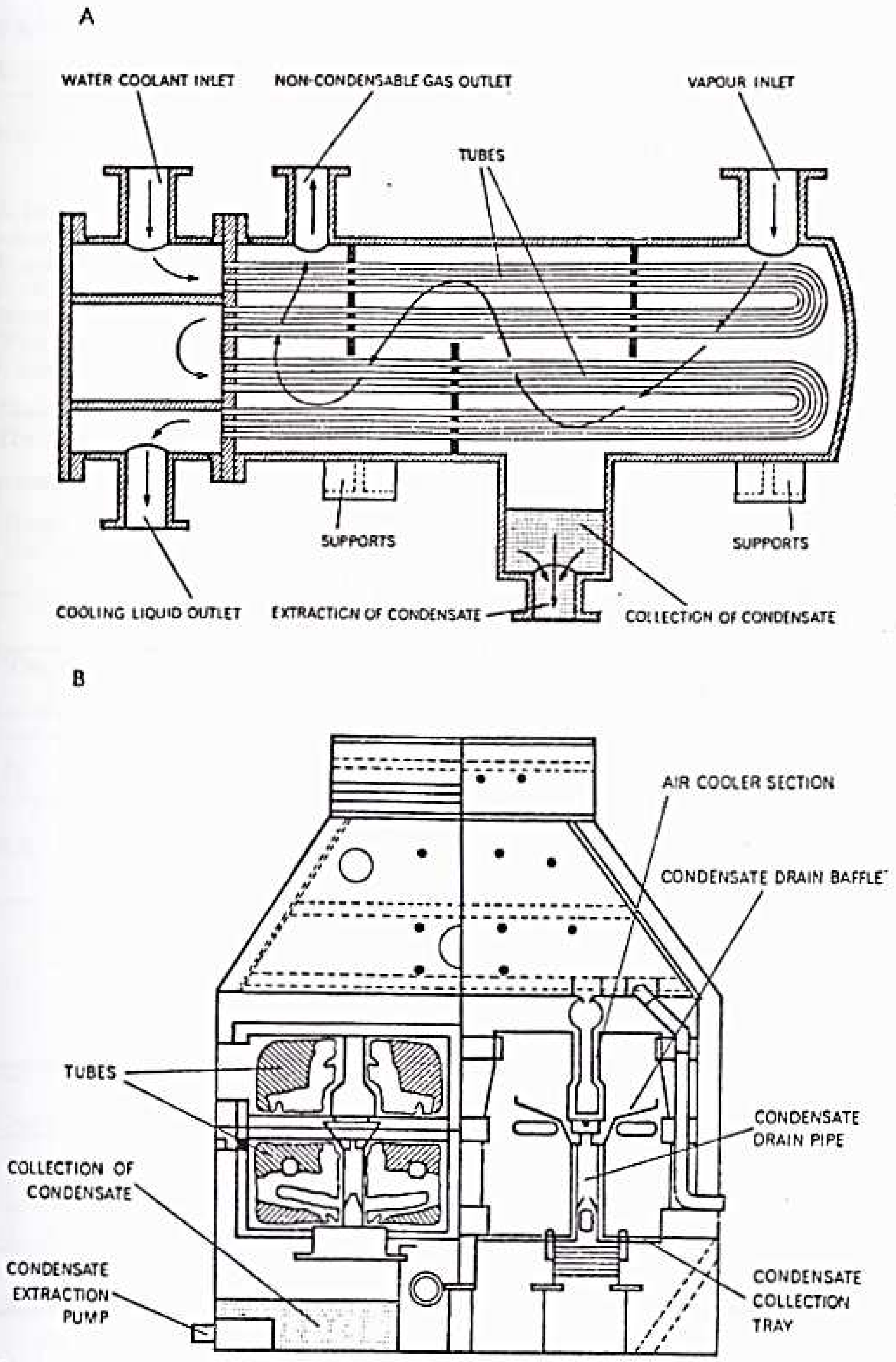
# Section 8: Condensation and Condensers

Steam which isadmitted to a cold engine cylinder is liable to be partiallycondensed bycontact with the cylinder walls. That part of the steam nearest to the walls is cooled and condenses as a film of water. The volume of steam in the cylinder is thereby considerably reduced, and more steam must be admitted in order that the pressure is sufficiently high todrive the piston along the cylinder. Condensation in a cylinder therefore raises the steamconsumption of theengine and thereby lowers its efficiency. It is therefore necessary todevise means of getting rid of this condensation as far as possible, and in modern reciprocating steam engines, condensation problems have been practically eliminated.

This is effected by superheating the steam in the boiler and also by fitting steam jacketsRound the cylinder. These are fitted into the annular space between thecylinder and thecylinder liner, and are connected to thesteam supply. By raining the temperatureof thecylinder walls in this way, the outward flow of heat is greatly reduced.

Steam which is exhausted from the cylinder still has a considerable heat content, and inorder that this heat energy should not be wasted, the steam is condensed and passed back tothe boiler as hot feed water. Rapid condensation is accomplished by means of a condenser. In this condenser, a liquid coolant is circulated through banks of metal tubes. By flowing over these tubes, the steam is caused to transmit some of its heat to the liquid, and a rapid drop intemperature occurs. The steam condenses, and iscollected at the bottom of the condenser as condensate. By ensuring that there is no contact between the condensate and the coolant, a pure distilled water can be produced which is ideal for boiler feed water. This type of condenser is commonly used where pure water is not plentiful. The condensate is usually reheated, so that it may be circulated back to the boiler at an adequate temperature.

In other types of condensers, which are known as jet condensers, the steam is cooled byallowing it to mix intimately with jets of cold water which are injected into the condenser.Bythis means, rapid condensation takes place, and the mixture of condensate and coolant is withdrawn by means of an extraction pump. The water which is normally used as a coolantcannot usually be utilised in the boiler, and cannot therefore be re-circulated. It is eitherpumped up to a cooling tower or it gravitates into a cooling pond, and is stored for lateruse in the condenser.



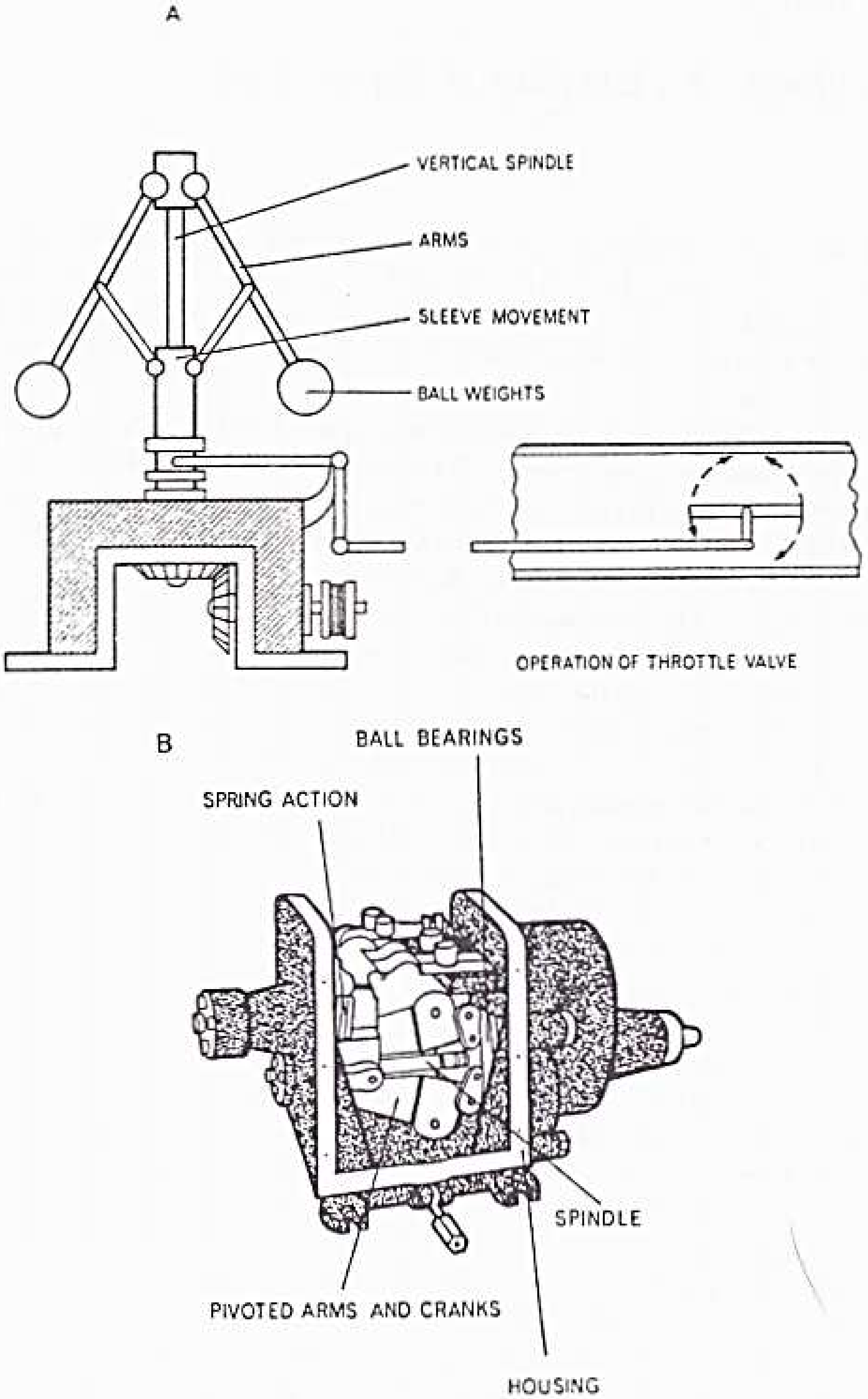
Cross-sections of (A) horizontal-process condenser
(B) steam surface condenser

# Section 9: Centrifugal Governors

Most engines in industrial use are rated to run at a constant speed, irrespective of the load theycarry. In order to keep the engine speed within the limits which it was designed for, a devicewhich is known as a governoris incorporated in the engine. Its function is to control therunning speed under all conditions of load.

The simplest form of governor consists of a pair of balls which are attached to a verticalshaft by means of arms. These balls act as weights. While they are stationary, they are acted on only by gravity. Now the vertical shaftis geared to the engine, and rotates with it. Whenthe engine starts, it causes the shaft to rotate, and this forces the rotating balls outwards underthe influence of centrifugal force. This movement of the balls at the end of their arms istransmitted to a sleeve which is free to slide up and down the shaft. As the engine increases speed, it rotates the shaft more quickly, and the weights rise further against the force of gravity. The sleeve also rises up the shaft, andwhen it rises beyond a certain point, it operatesa throttle valve lever, and so reduces the low of steam. The engine speed will then decrease,and as the sleeve slides down, it opens the throttle valve again. When the engine is running at constant speed, it produces a state of equilibrium in the governor, with the centrifugal force equal and opposite to the controlling force - that is, the weight of the governor and its gear.Governors which arerequired to work at very high engine speeds are normally weight-loaded. A weight is attached to the sleeve, and serves to prevent the sleeve from rising too far.

Both the simple and weight-loaded governors depend on gravity and must therefore be kept in a vertical position. This is often a disadvantage, and may be obviated by the use of aspring instead of a weight. The spring performs the same function as the weight, and keeps thesleeve depressed. It can be mounted in any position. By making simple adjustments to theloading on the spring, the governor speed caneasily be altered. The governor is mounted ina dome-shaped housing which contains the spring and the bell-crank levers, on which the rotating balls are pivoted. Ball bearings at the pivots and at the top of the spindle serve toreduce wear and friction. As the spindle rotates, it causes the weights to fly outwards, and thismovement about the pivotraises the sleeve against the pressure of the spring. Equilibrium isattained at a constant engine speed by the balancing of thecentrifugal force and the compressive load on the spring.



(A) Elementary governor principle
(B) Spring-loaded governor

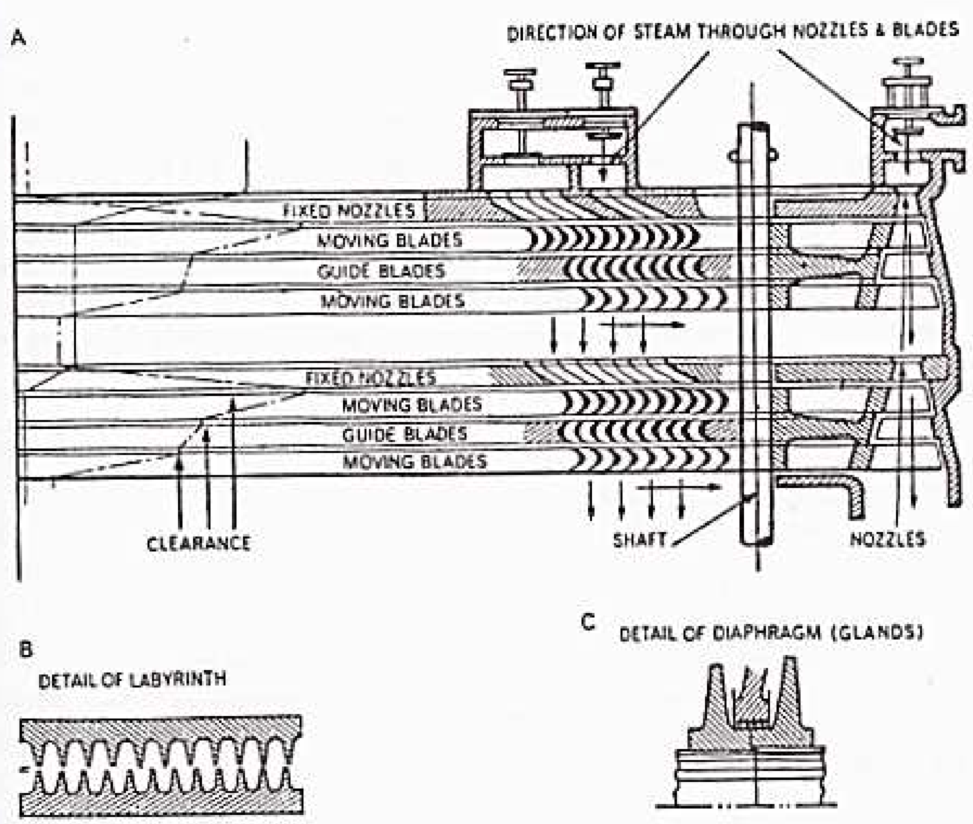
# Section 10: Impulse Turbines

In an impulse turbine steam is admitted through a nozzle and directed against one or morerows of blades. Prior to passing through this nozzle, the steam is at highpressure but low velocity. The nozzle normally consists of a convergent and divergent section. In the former, the steam suffers a dropin pressure, but itsvelocity is increased. The functionof thedivergent section is to reduce to a minimum the tendency of the fluid to turbulence,and thusto ensure that thefluid flow is as smooth as possible.

On emerging from the nozzle at its maximum velocity, the steam impinges on the rowof moving blades which project radially from the turbine shaft. In this axial-flow type of turbine, the steam flow is along the axis of rotation of the shaft, and therefore the blades radiate outwards from the shaft. On entering the blades, which are set at a definite angle tothe steam flow, the steam is deflected from its original path. In being deflected, it exerts animpulsive force on the blades, which causes them to rotate. While passing over the blades,the steam suffers a slight reduction in velocity through friction. In a simple turbine, it is then passed out into the atmosphere, or to a condenser, where it is condensed and led back to the boiler.

However, after leaving the blades of the turbine, the steam still possesses a considerablevelocity, and this may be utilised in another type of turbine by passing it through a series oftwo or more turbine wheels. This is known as velocity-compounding. On passing through thefirst row of moving blades, the steam encounters a row of stationary blades which deflect thesteam on to a second row of moving blades, and so on. Each time part of the kinetic energyof the steam is lost through friction, and therefore the velocity of the steam is progressivelyreduced. In order to compensate for this, the blades in each successive row are made progressively larger in cross-section, and their pitch is increased. In this way, a largerproportion of the kinetic energy of the steam can be utilised than in the simple turbine.

Another typeof turbine in common use is known as the pressure-compounded turbine. It incorporates several rows of blades, but each one is enclosed between diaphragms to form aseparate pressure stage. After passing through the first set of blades, the steam is directed through nozzles set in the succeeding diaphragm, and impinges on the following row of blades.



Cross-section of impulse turbine

# Section 11: The Petrol Engine

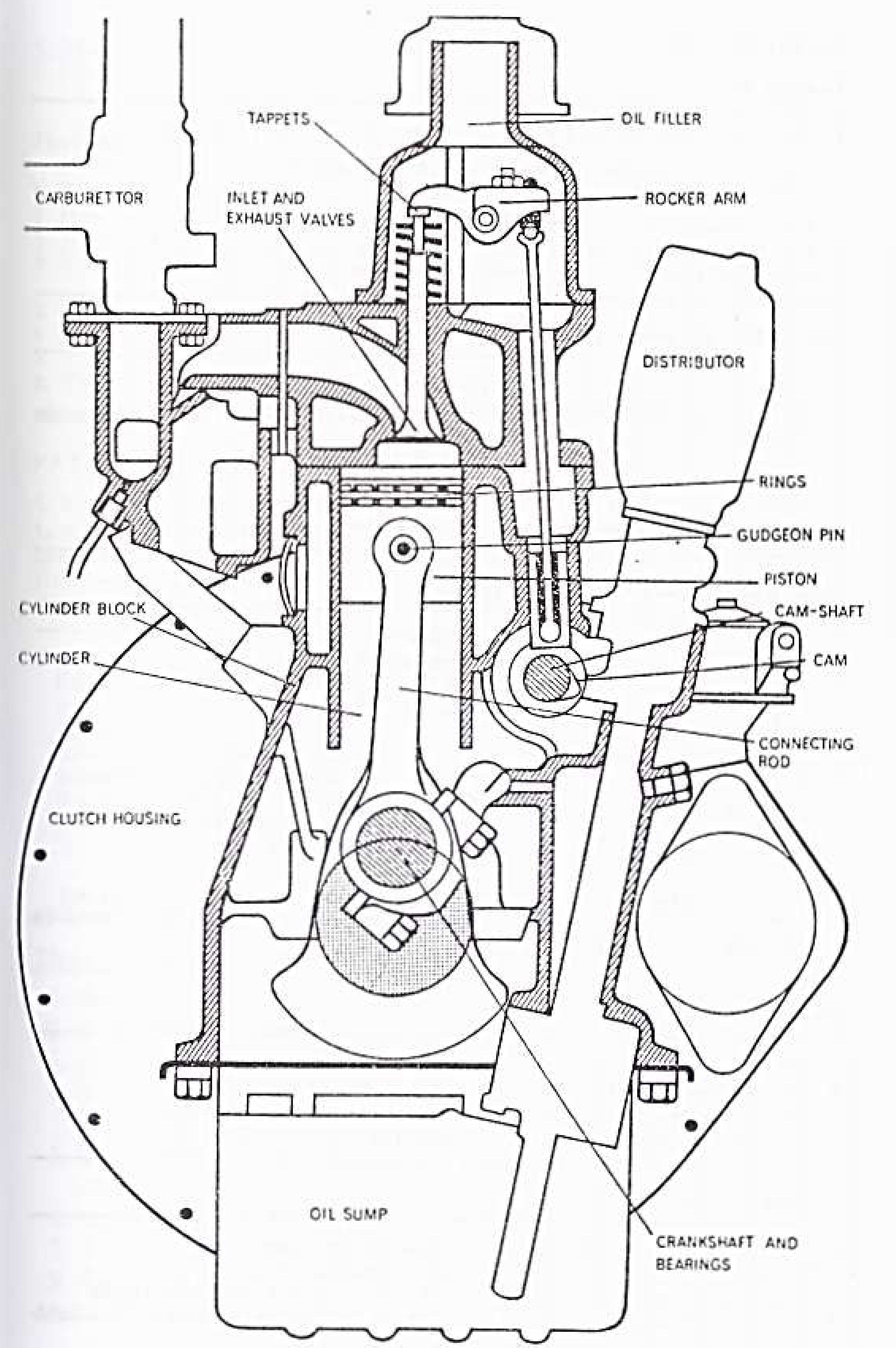
In the internal combustion engine, heat is generated by the combustion of an inflammable charge inside a cylinder, and the heat energy is immediately converted into mechanical energy. Some heavy internal combustion engines use a gas fuel or else Diesel oil, and the fuel/air mixture may be ignited either by a spark or by compression of the mixture. However, for small i.c. engines, such as those which are used in motor-cars, the charge is a mixture of petrol and air, and is ignited by a spark from the distributor.

When the mixture is ignited, the products of combustion expand down the cylinder, which is fitted with a reciprocating piston. The downward movement of the piston is converted into a rotational movement of the crank-shaft by means of a connecting rod. As the crankshaft rotates, the piston is driven upwards again, and the exhaust gases are expelled through the exhaust valve in the cylinder head. When the piston nears the top of this stroke, the inlet valve is opened and the exhaust valve closed. The piston then descends on the induction stroke, and draws a fresh charge into the cylinder. As the piston rises again on the compression stroke, the charge is compressed and ignited, and the cycle begins again. This is the four-stroke cycle which is in common use. An alternative cycle is the two-stroke cycle, which combines the exhaust and compression strokes into one.

The combustion of the mixture does not take place instantaneously. The spark is therefore timed to occur before the piston reaches top dead centre, otherwise maximum pressure would not be reached in time. By the time the piston is at top dead centre, combustion is well under way and the expansion of the gases is beginning. Once combustion starts, it should be carried through the mixture very rapidly, and this is assisted by making the clearance space above the piston as small as possible, and by careful design of the cylinder head. Rapid propagation of the flame through the compressed gas is also assisted by creating turbulence in the gas.

Most small i.c. engines in common use have four cylinders, which fire in a definite and regular sequence. This is necessary, otherwise the torque which the pistons impart to the crankshaft will be irregular and uneven. The torque is liable to be uneven in any case when the engine is running slowly, and a flywheel is fitted to the crankshaft to damp out these variations.

It is essential for the inlet and exhaust valves to open and close at exactly the appropriate moment in relation to the position of the piston. Therefore they are actuated by a cam-shaft running in phase with the crankshaft.



Cross-section of a petrol engine

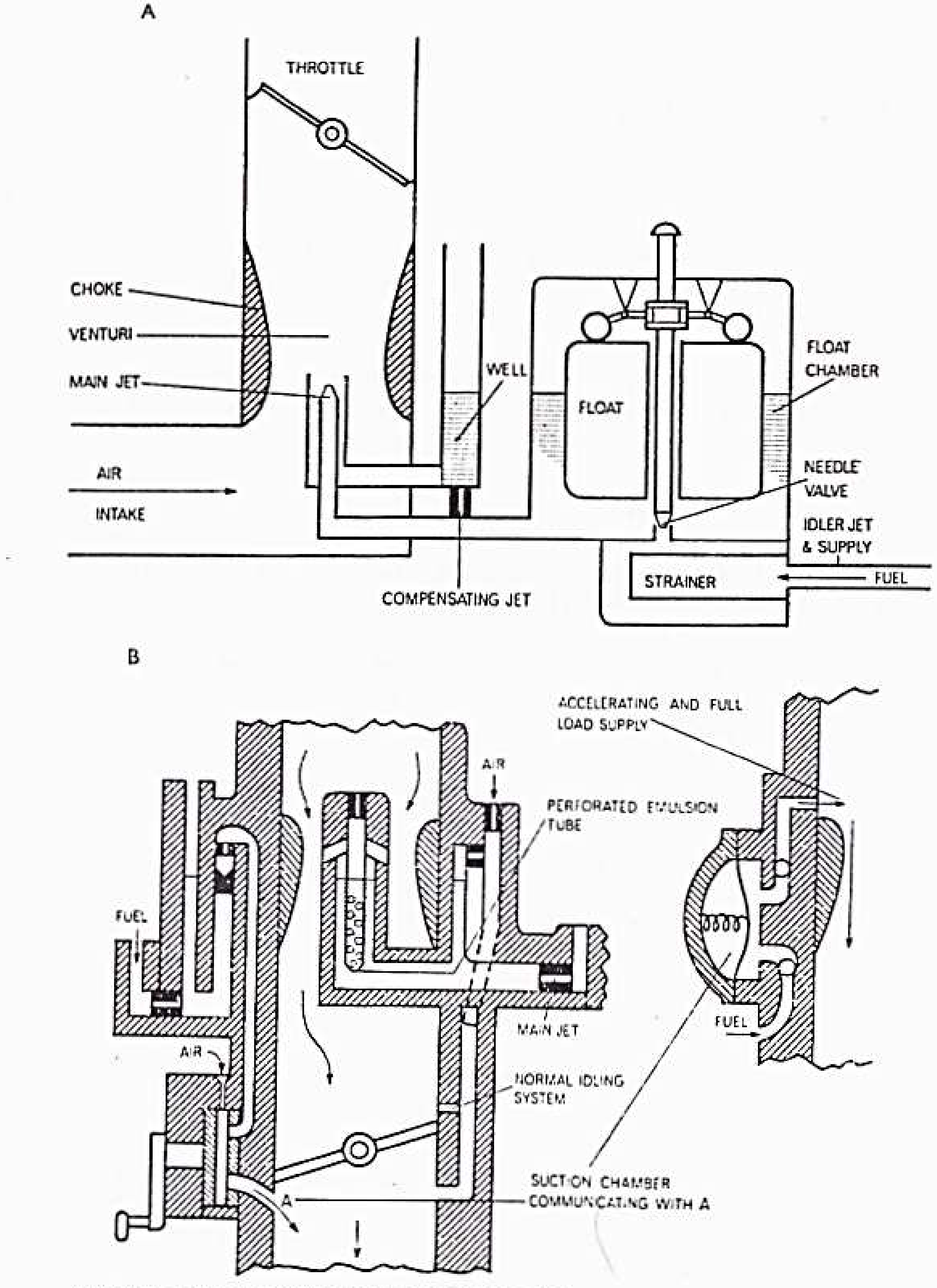
# Section 12: The Carburation System

Since it is essential to secure rapid and complete combustion in the cylinder of an internal combustion engine, the fuel and air mixture must be thoroughly mixed; and further, it must be in the correct proportions for all running conditions of the engine. This is accomplished by means of a device called a carburettor. In this carburettor, a stream of air blown over a jet mixes intimately with a spray of petrol drawn out of it. The jet is inserted into a choke or venturi in the intake manifold, and is supplied with petrol at atmospheric pressure.

During the suction stroke of the piston, the pressure in the intake manifold is below atmospheric, and air is induced through the intake and over the jet. As there is a further drop in pressure at the venturi, the pressure difference produced is large enough to draw petrol up out of the jet and atomise it. The level of the petrol in the jet is kept constant by the float and needle valve in the float chamber, which acts as a reservoir for the fuel. Above the venturi there is a throttle valve operated by the accelerator pedal, which controls the amount of mixture admitted to the cylinder.

However, this simple form of single-jet carburettor will not give correct mixture strength for all engine speeds. The chief difficulty encountered is that, at high running speeds, the amount of petrol taken up at the jet will increase faster than the increase in air-flow. Therefore a carburettor set to give correct mixtures at low speed will give a progressively richer mixture as the speed increases. To compensate for this, a second jet is provided, fed from a well open to the atmosphere and supplied with petrol from the float chamber. Owing to the fact that this compensating jet is larger than the main jet, it can supply petrol at a quicker rate than the main jet until the well is emptied. As the speed is increased, more and more of the petrol required is drawn from the main jet. The compensator jet can now supply only as much petrol as can pass through the small compensator orifice in the float chamber.

Another problem to be solved is that of starting. In order to obtain the rich mixture required for starting, the throttle must be almost closed. As the air velocity is then very low in the venturi, insufficient petrol is drawn out of the jet. This difficulty is overcome by the provision of an idler jet in the wall of the intake manifold near the throttle valve. This jet will only function when the throttle is nearly closed. When it is opened for faster running, the suction round the edge of the throttle decreases, and the idler automatically ceases to act.



(A) Early carburettor with simple compensating jet
(B) Downdraught carburettor

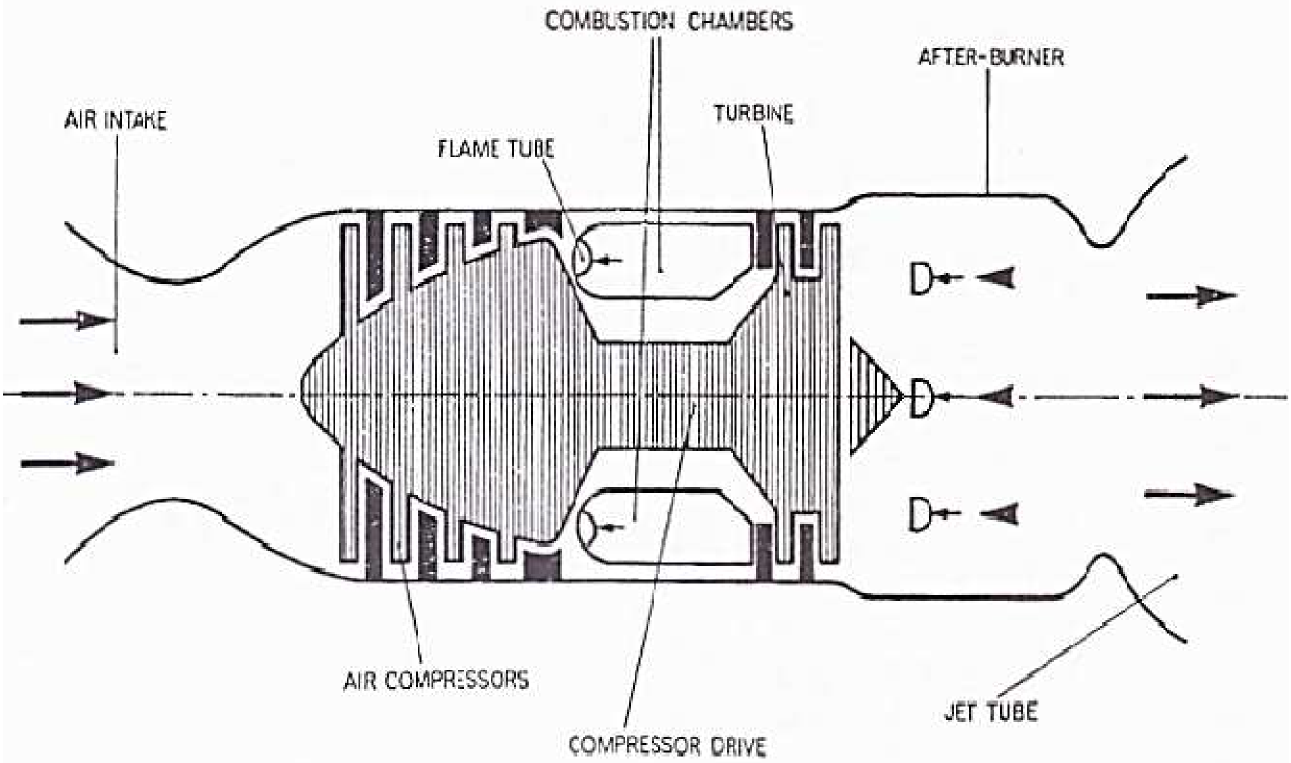
# Section 13: The Jet Engine

Jet engines with which most modern high-speed aircraft are equipped develop thrust on the same principle as the propellers of conventional aero-engines. In both, the propulsive force is derived from the reaction produced by a stream of air driven rearwards at high velocity. However, in jet-propulsion the air is directed rearwards in a jet from the engine itself. The earliest forms of jet propulsion, such as the pulsejet utilised in the Flying Bomb, were incapable of functioning at rest, in view of the absence of any means of air-compression. But the introduction of the turbo-jet overcame this problem, since the turbine developed sufficient power to drive a compressor.

Air enters the engine through a divergent inlet duct, in which its pressure raised to some extent. It then passes to a compressor, where it is compressed, and from which it is delivered to the combustion chambers. These are arranged radially round the axis of the turbine, into which the products of combustion pass on leaving the combustion chambers. A proportion of the power developed by these gases is utilised by the turbine to drive the air-compressor, and the residual energy provides the thrust where by the aircraft is propelled. Due to the expansion of the exhaust gases in the jet-pipe behind the turbine, their exit velocity is very high.

In each of the combustion chambers, there is a perforated flame-tube, into which kerosene is sprayed and ignited. Owing to the need to limit temperatures in the combustion chambers, a large volume of excess air is required. The air/fuel ratio necessary to reduce combustion temperatures to an acceptable level is about 60:1. However with this ratio of fuel to air, the mixture would lie difficult to ignite. Therefore only a small proportion of the compressed air is fed into the flame-tube, where it is ignited in a ratio of about 15:1. The remainder enters the flame-tube further down, or mixes with the products of combustion as they leave the tube. By virtue of this dilution of the hot gases with cooler air, the temperature at which they reach the turbine is reduced to about 850° C.

On entering the turbine, the gases pass through nozzles, by means of which they are directed through a ring of blades. These blades, the shape of which is determined by the need to reduce the torque to a minimum, rotate at high speed. Because of the tendency of fast-running blades to creep and change their shape, a special high-nickel alloy is used for them. After passing through the turbine, the gas expands down the jet-tube and is ejected into the atmosphere. Owing to the high proportion of unburnt oxygen in this efflux, after-burners are often provided in the jet-pipe, where by the hot gases are again ignited. This increases their velocity, and provides extra thrust for take-off.



ss-section of turbo-jet engine with after-burner

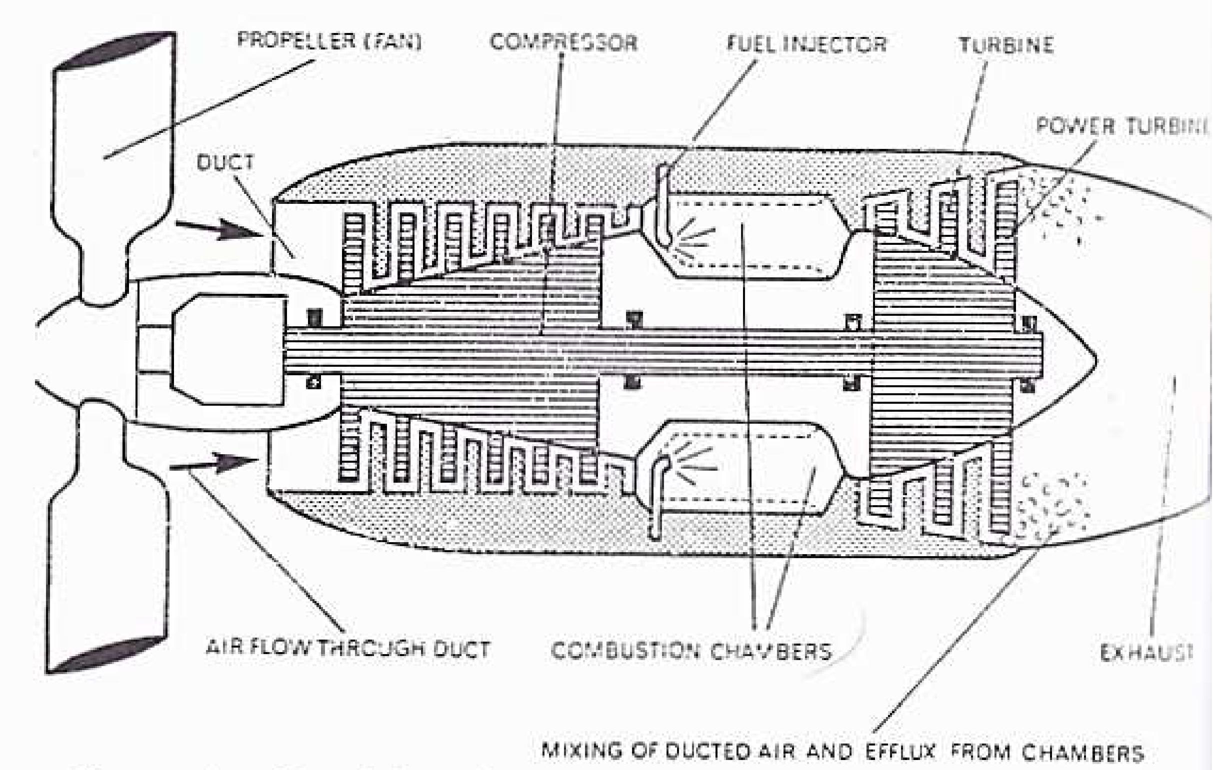
# Section 14: The Turbo-prop Engine

The efficiency of a turbo-jet engine varies with the speed and altitude at which it operates.Whilst it is very efficient at supersonic speeds and high altitudes, it is not suited to the low speeds involved in taking-off and landing. Under these conditions, thrust augmentors or after-burners are often required to boost the power, and this entails heavy fuel consumption and restricts the range of the aircraft. On the other hand, propeller-driven aircraft cannot attain speeds much in excess of 500 m.p.h., whereas at low speeds they have a much better performance.Since subsonic speeds are still acceptable for most civilian airliners, a type of engine known as the turbo-prop was developed, which combined some of the advantages of both jet and piston-driven engines.

In the turbo-jet, the turbine is required to develop enough power to drive the compressor only, whereas in the turbo-prop engine, it must supply power also for the propeller, to which it is coupled by means of reduction gearing. As the propeller rotates, it drives rearwards a much larger column of air than that which is expelled from the jet-tube of the turbo-jet, but at a much lower velocity. Consequently it is quieter than the turbo-jet, since the volume of noise produced by an aircraft engine increases with the velocity of the air column. Most airports are situated in or near large centres of population, with the result that any reduction in the noise level is a decided advantage. Furthermore, a large proportion of the energy of the products of combustion is needed to drive the compressor and the airscrew. As this proportion increases, so the amount of thrust developed in the jet-pipe diminishes. In consequence, the destructive blasts of hot gas which emanate from the jet-pipe of the turbo-jet while taxiing on runways or taking-off are greatly reduced.

The main disadvantage of the turbo-prop engine is of course the limitation imposed on speed by the airscrew, as a result of which it is likely to become obsolete on all except short-haul aircraft.

A more recent development in jet propulsion is the ducted-fan jet, in which the turbine drives a multi-bladed fan enclosed in a duct. A certain proportion of the air which enters the engine by-passes the compressor and combustion chambers, and is impelled by the fan down the outside of the duct, so that it is expelled at considerable velocity from the rear of the engine. It amplifies the mass of hot exhaust gases, and thus serves to augment the thrust derived from them. Consequent on the more moderate speed of this ducted air, the noise level is kept reasonably low. In addition, this type of engine performs well both below and above the speed of sound, whereas the other types of engine are efficient only at certain speeds.



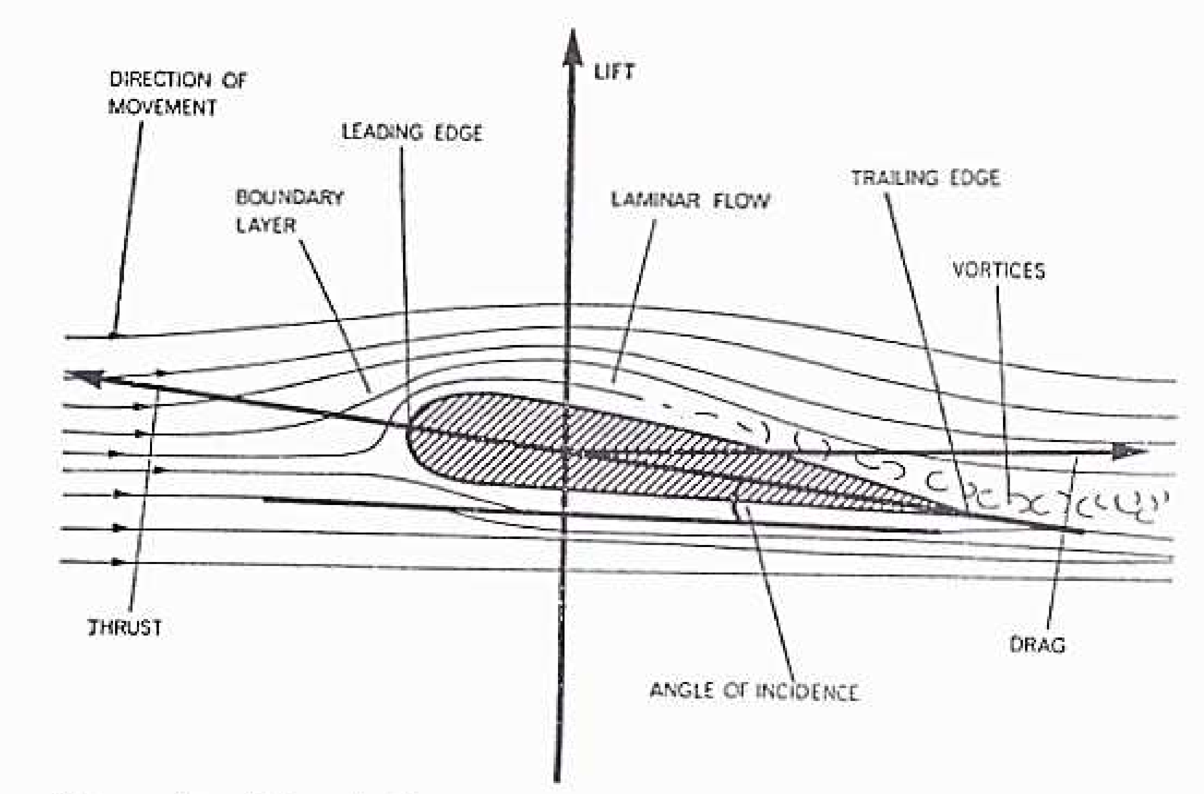
Cross-section of ducted fan engine

# Section 15: Aerofoils

Apart from the fuselage and the engines, the most important parts of an aircraft are the surfaces known as aerofoils. These include the rudder, elevators and ailerons, whose function is to control the aircraft in flight; and the wings which provide the lift necessary to overcome the weight of the aircraft and lift it through the air. A substantial horizontal thrust, provided by the jet or the propeller, drives the aircraft through the surrounding air, while the wing deflects downwards the mass of air flowing on to it. This produces a reactive force acting in the opposite direction, which lifts the wing upwards. Without some means of horizontal propulsion, no lift can be produced by the wing. Modern aircraft are so heavy that the wings must develop a very large lift force in order to sustain the aircraft.

The design of the wings is therefore very important, and various factors have to be considered. Wind-tunnels reproducing flight conditions are used to examine the behaviour of air flowing over different types of wings at different speeds. The lift produced by a wing will depend on, among other factors, the wing area, its profile, and the angle of incidence - that is, the angle at which the wing is inclined to the direction of motion. Air flowing over the top of the aerofoil should flow smoothly and without turbulence. This laminar flow is achieved by streamlining the profile and by making the skin of the aerofoil smooth. As a result, the air-flow will follow the contour of the wing, except for a narrow boundary layer of stationary air on its surface. However, above a certain angle of incidence, which varies with the type of wing, the air-flow is liable to break up and become so turbulent as to destroy the low-pressure region above the wing. This causes such a rapid loss of lift that the aircraft may stall. To counteract this, slots are sometimes fitted to the leading edge of the wing, guiding the air-flow more steadily over the aerofoil. Since low speeds are essential for landing, extendable flaps are also fitted to the trailing edge. These extend the effective area of the wing, and thus prevent the aircraft from stalling.

The force exerted by the deflected column of air beneath the wing has a vertical component called lift, and a horizontal component called drag. Drag in its various forms represents a loss of the energy available to provide lift, but it always accompanies lift. It can never be entirely eliminated, since the wing itself offers resistance to the air through which it moves. A laminar flow over the wing, reducing drag to a minimum, is the optimum condition. But around the wing-tips and on the trailing edge, some turbulence is inevitable. The air, flowing through a region of higher pressure under the wing, swirls up at these edges into a region of low pressure above the wing and produces a vortex, which may be so violent as to produce vapour trails at the wing-tips.



Cross-section of aircraft wing

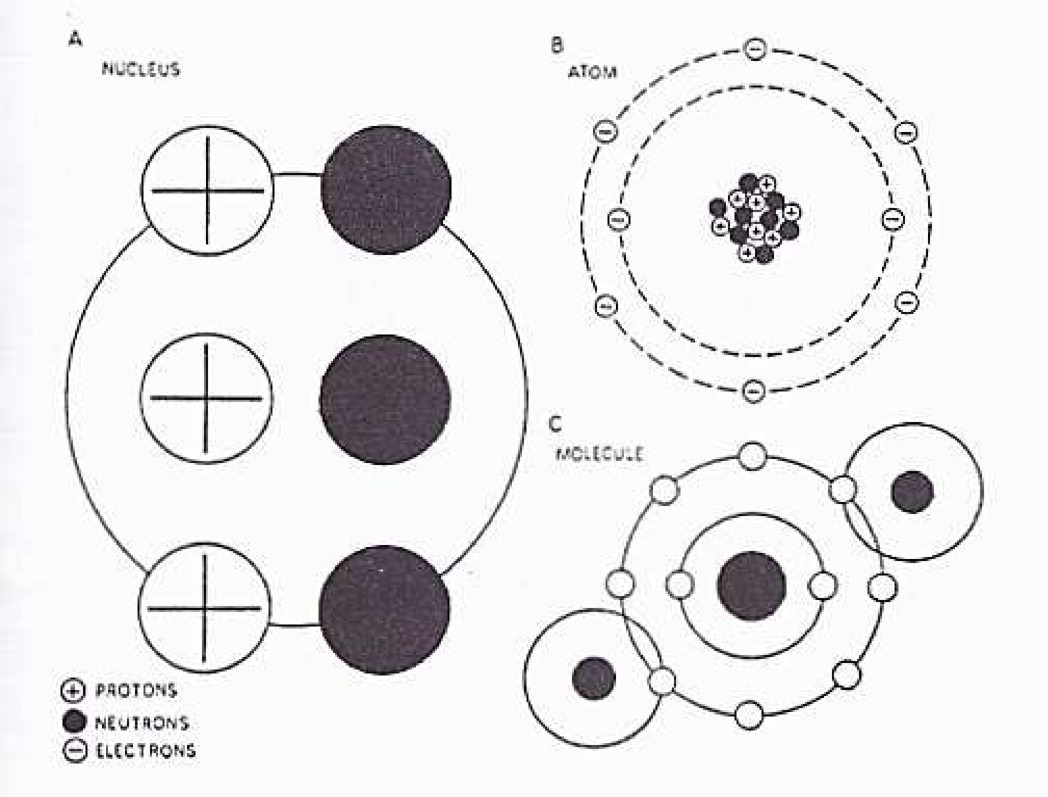
# Section 16: Radioactivity

Atomic nuclei consist of combinations of protons, or positively-charged particles, and neutrons, or uncharged particles. The number of protons and neutrons in each element can vary, but only certain combinations are stable. For example, calcium-48, having 20 protons and 28 neutrons, is a stable isotope of calcium. But if there is an excess or deficiency of neutrons in any combination, the isotope will be unstable. A nucleus is more likely to be unstable if it is a heavy one - that is, if it contains a large number of protons and neutrons. Unstable nuclei attempt to achieve stability by emitting some form of radiation, until they transform themselves into stable isotopes.

There are radioactive isotopes of every element, either those existing in nature or else those activated artificially by bombardment of stable nuclei with nuclear particles such as protons, alpha-particles or neutrons. However, a particle will not be absorbed by the target nucleus unless its velocity corresponds with one of the energy levels of the nucleus. Heavy nuclei, having more energy levels than light nuclei, are more likely to affect capture of a particle a fact which helps to explain the importance of uranium, thorium and other very heavy atoms in nuclear research.

Since the neutron is uncharged, it is not affected by the charged electrons and protons of the target atom, and is therefore more likely to be captured than any other particle, provided that it is in resonance with an energy level of the nucleus. In the event of neutron capture, the mass number of the nucleus will be raised, and it will thus become unstable and radioactive. As radiation continues, the level of radioactivity falls exponentially, and the time taken for it to reach half its original value is known as the half-life of the isotope, which may vary from a fraction of a second to millions of years. Isotopes with long half-lives have many uses in medicine and industry, but they must be handled and disposed of with great care, in case they cause radiation damage.

Neutron bombardment of the very heavy uranium atoms may have a quite different result. It may cause the nucleus of the fissile U-235 atom to split into two parts. This nuclear fission releases large quantities of energy which finally takes the form of heat energy, and at the same time other neutrons are ejected from the nucleus. The fission fragments are highly radioactive, and will contaminate the fissile uranium if they are not removed periodically. A number of these fission products, such as Caesium-137, are very useful as irradiation sources, and it is now possible to separate out the desired isotope from the spent fuel.


A
NUCLEUS
B
ATOM
C
MOLECULE
⊕ PROTONS
● NEUTRONS
⊖ ELECTRONS

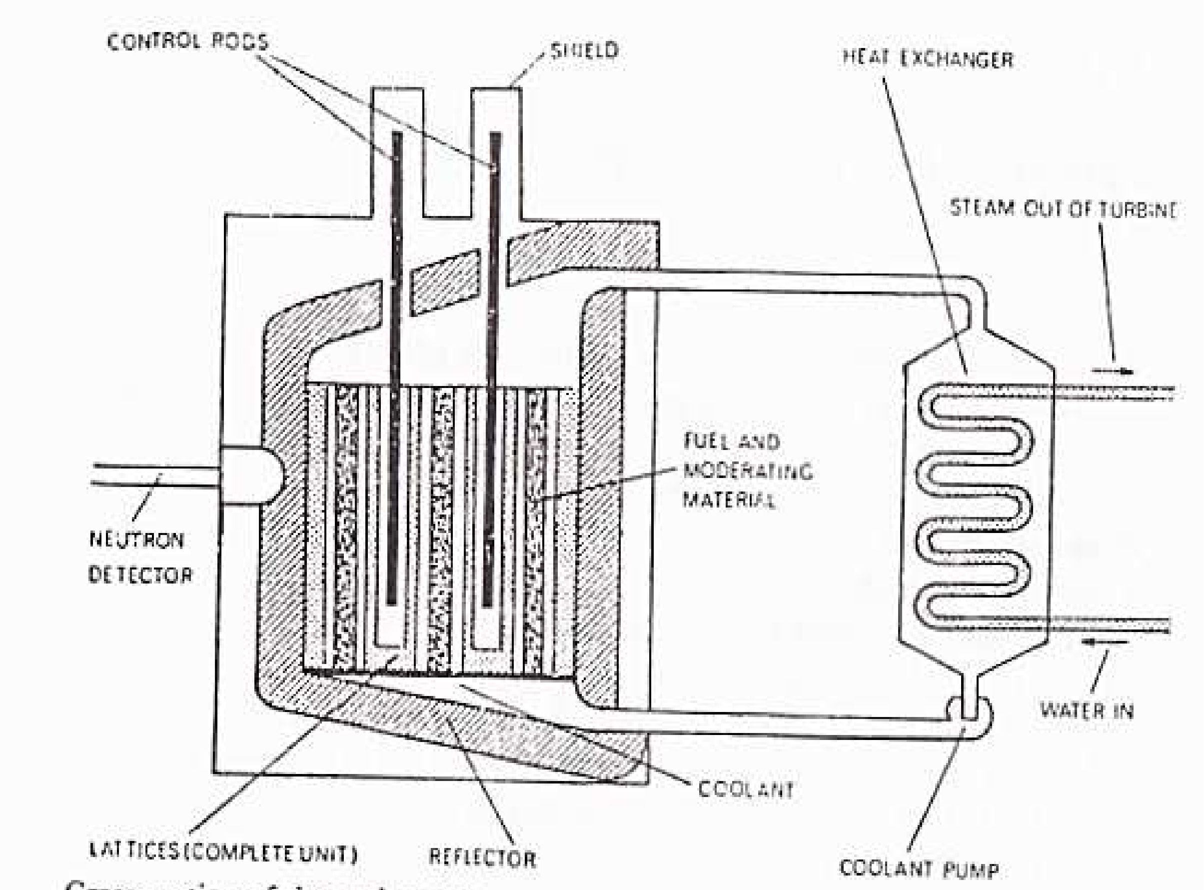
# Section 17: Chain Reaction

When fission occurs, an average of 2-5 neutrons are emitted from the nucleus. If the fission process can be so arranged that one of these liberated neutrons is captured by another U-235 nucleus to produce another fission, then the reaction will become self-sustaining.

When emitted, neutrons travel at a high velocity, and it is known that such fast neutrons have little chance of being captured by the fissile uranium. However, if slowed down to thermal speeds, their probability of capture is greatly increased. In the normal thermal reactor, the uranium is surrounded by a large mass of moderating material. The liberated neutrons collide repeatedly with the light atoms of the moderator in such a way that they lose much of their energy and eventually become thermalised. The moderator may be either a liquid such as heavy water, or a solid such as graphite. Both these substances are of low atomic weight and have low neutron absorption cross-sections. With the graphite moderator, the uranium which is generally in the form of rods is inserted into channels cut out of the graphite. These channels are so arranged as to form a lattice structure, the object of which is to reduce neutron escape to a minimum. Provided that a sufficient mass of uranium is disposed in a number of rods through the moderator, a high enough proportion of the emitted neutrons will find their way to fissile nuclei to produce a chain reaction. The minimum quantity of uranium required to initiate the chain reaction is called the critical mass.

Once irradiated, the uranium fuel elements tend to lose strength and become wrinkled. It is therefore necessary to encase them in a can or cladding of some material such as aluminium or magnesium. These cans are designed so that they not only support the uranium inside, but also contain the highly radioactive fission products, and prevent reaction taking place between the fuel and the coolant.

A chain reaction can be initiated by inserting more and more fuel elements into the reactor core until the critical mass is attained. It can be terminated by withdrawing the rods. Once started, the chain reaction must be controlled in such a way that a steady neutron flux rate, and thus a steady production of heat energy, is maintained. The simplest method of control is by inserting control rods of cadmium, or some similar material with a very high neutron absorption cross-section, into the moderator. The purpose of the control rods is to absorb the neutrons emanating from a fissioned nucleus. It therefore there is an increase in the neutron flux rate in the reactor, more control rods can be inserted until the reaction rate is stabilised again; that is, until the multiplication factor is exactly 1.



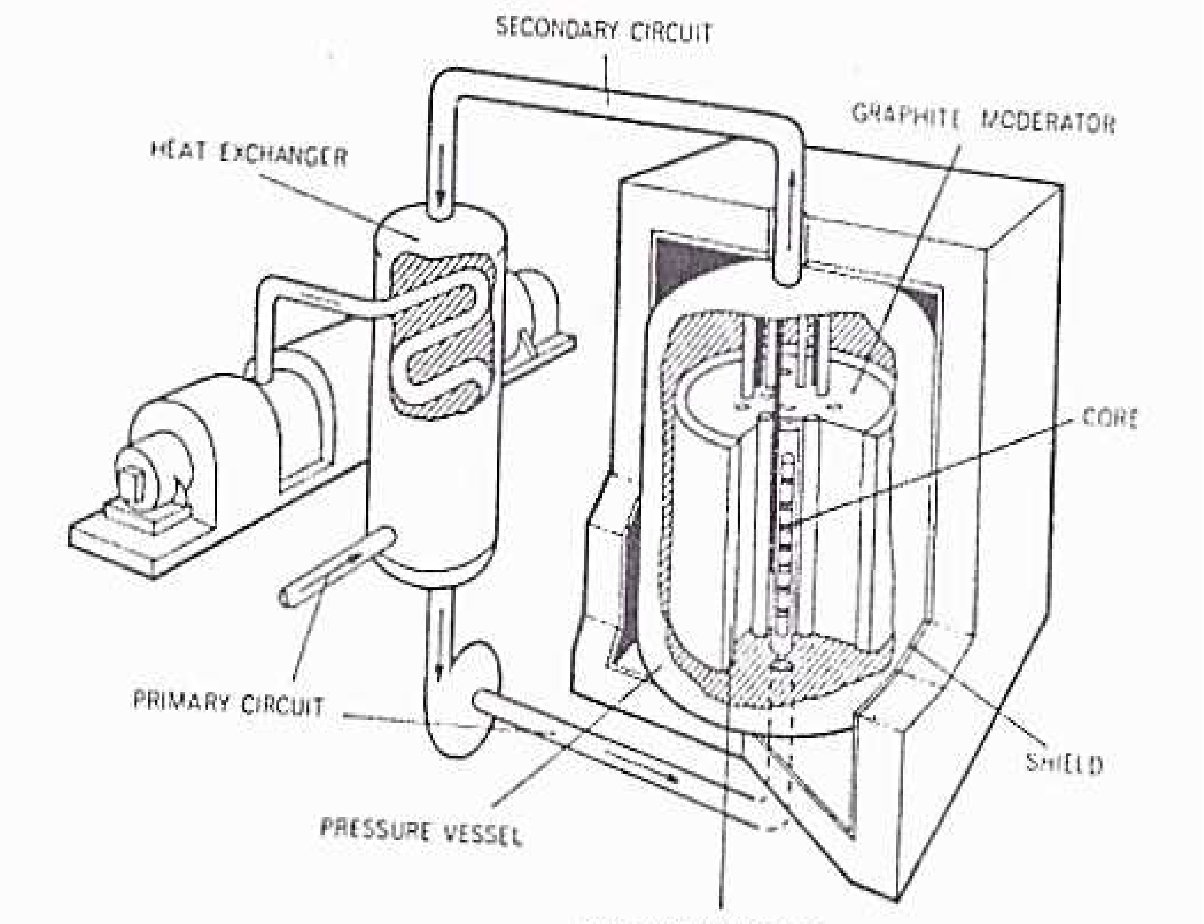
Cross-section of thermal reactor

# Section 18: Reactor Cooling System

Various types of reactor have been designed and constructed for a number of different purposes, such as the production of fissile material, the production of radio-isotopes, and the generation of electrical power. In the case of reactors designed to produce power, it is essential to devise some method of transferring the heat generated in the reactor core to a heat engine, where it can be converted into electrical power. It is in any case necessary to provide some efficient cooling system, so that the temperatures in the core should not exceed the safe limit of about 600° C.

The cooling system adopted in a reactor depends on whether the moderator is liquid or solid. In the case of a liquid-moderated reactor, the moderator itself acts as a coolant, and can be circulated out of the core and through a heat exchanger. But in cases where the moderator is a solid (normally graphite), a separate cooling system must be provided. The coolant is circulated through the annular spaces between the fuel elements and the moderator, absorbing heat as it passes, and the heat so absorbed is conveyed out of the core to the heat exchanger. Very large quantities of heat are generated by fission, and in order that these may be rapidly dissipated, a large volume of coolant is required. It is therefore frequently pressurised, especially where a gaseous coolant is used, to increase its density. A number of different coolants have been employed, including water, carbon dioxide and liquid metals. It is essential that the fluid so used should have good heat-removal properties, and also a low neutron absorption. To pump such a large quantity of coolant through the core, large pumps are needed, and the power supply for these pumps is taken from the power output of the reactor. Since the power thus consumed diminishes the total useful output of the reactor, it should be kept as low as possible.

Coolant which has been passed through the reactor will be in some degree contaminated by radiation, and cannot therefore be allowed to come into contact with the turbo-generators. The coolant is circulated in a closed primary circuit, and its heat content is transferred to a secondary circuit through a heat exchanger. In some reactors a liquid-metal coolant is used, and it is likely to become heavily irradiated. In such cases, both the primary circuit and the heat exchanger are therefore included within the biological shield. The working fluid in the secondary circuit is fed into turbo-generators, where its energy is converted into electrical power. Reactors have recently been built which are capable of generating up to several hundred megawatts.



Reactor cooling system

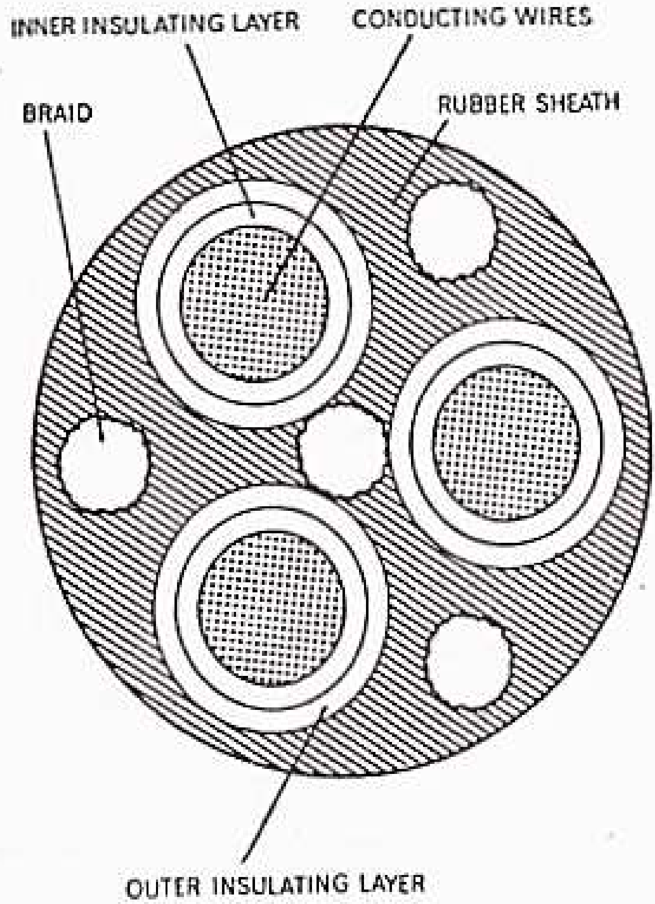
# Section 19: Conductors and Conductivity

It is usual to consider electric current as a flow of electrons from one point to another through a medium, or even through a vacuum. If the electron flow takes place in a vacuum, as in the case of electronic valves, the electrons will travel at considerable speeds, since little resistance is offered by the medium, and fewer impacts will occur between the electrons. If the medium is a solid in which case the electrons are more tightly packed - the electron flow will be slower.

All substances may be classified electrically as conductors or insulators, according to the degree of resistance which the medium offers to the flow of current. Most liquids, particularly solutions in liquids, are good conductors. Most gases at normal temperature and pressure are good insulators, but gases maintained at low pressure in a sealed tube allow a flow of current to take place as a result of ionisation of the gas molecules. Solids vary greatly in resistance, some being very good conductors, while others are so resistant that they are referred to as insulators. Electric current is normally transmitted along annealed copper wire.

The resistance of any material to the flow of current is affected by a number of factors, such as the length and cross-section of the conductor, and by its resistivity, which is a specific property of the material at a specific temperature. The temperature therefore also has some effect on the resistance of a material: in most cases, an increase in temperature causes an increase in resistance. With certain metals, such as copper or iron, the change in resistance which attends on changes in temperature is relatively large - a fact which is utilised in the resistance thermometer, in which it is possible to measure temperature changes, as in the windings of an electric motor, for instance, by the change in resistance.

Some materials have a very high resistance, and as such they can be used as insulators to prevent the leakage of current. Among these materials are asbestos, celluloid, porcelain, cotton and rubber, and recently a number of new materials have been developed, including synthetic textiles such as nylon, and synthetic resins such as vinyl resins. The resistivity of most insulators decreases with an increase in temperature, for which reason the temperatures in insulated conductors must be kept reasonably low. A breakdown of insulation may occur under the application of very high voltages, and it is necessary to know the dielectric strength of any insulating material. Some materials, such as cotton, which is often used as insulation, are liable to absorb moisture, and this will adversely affect their insulating properties. Rubber, which is a standard insulating material, is liable to deteriorate under sunlight, and it is therefore advisable to protect it with some weatherproof material.



Cross-section of electric cable

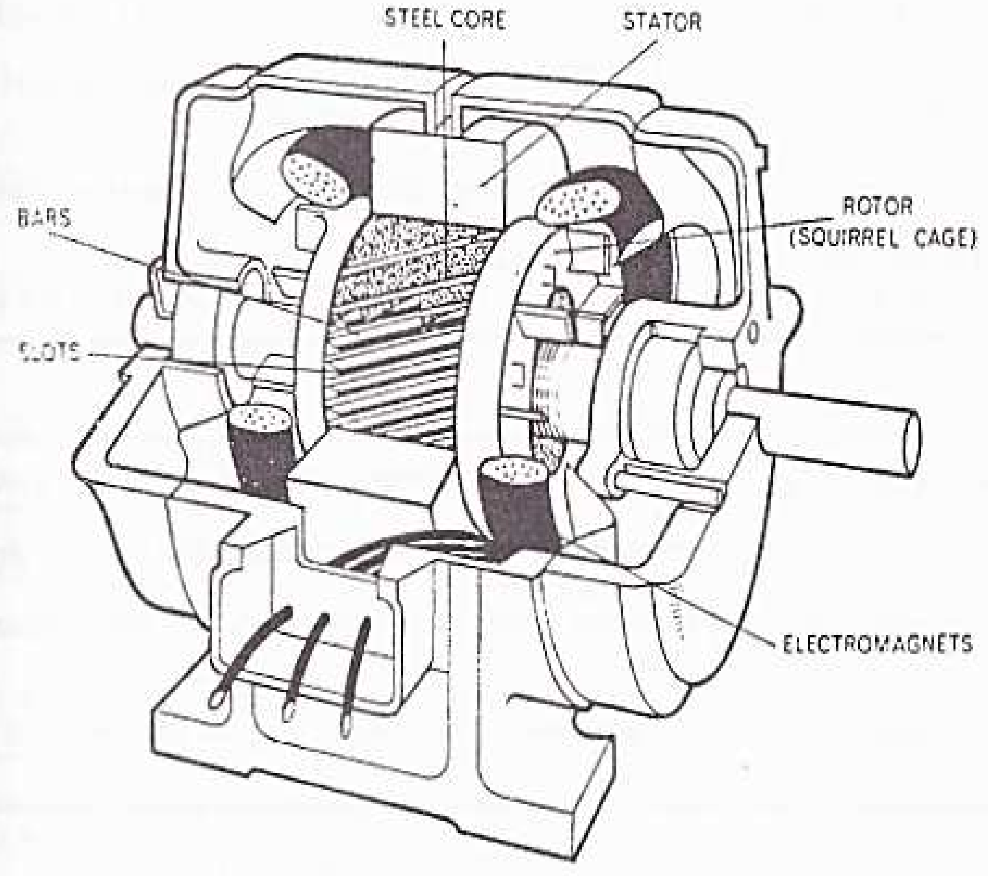
# Section 20: Induction Motors

In almost every respect an a.c. motor is similar in construction to a d.c. motor. The essential difference lies in the fact that a d.c. motor requires a commutator to maintain moving contact between the rotating armature and the source of power. It will be appreciated that the necessity of providing a commutator with its carbon brushes complicates the construction of the motor, and limits its capacity. Furthermore, with an a.c. motor it is possible to have the windings on the stator and to rotate the magnetic field, rather than have a stationary magnetic field and place the windings on the rotating armature, as is the case with a d.c. motor. It is obvious that this simplifies the problem of insulating the windings.

The commonest form of a.c. motor is the polyphase induction motor. As its name suggests, the current in the rotor is derived not from an external power supply, as in the d.c. motor, but is induced by a moving magnetic field in the air-gap between the rotor and the stator. Excitation of the stator winding by a three phase current causes a rotating magnetic field, as each of the electromagnets in turn reaches its maximum strength. And this rotating magnetic field between the stator and the rotor induces a voltage in the rotor conductors.

It has been proved that induced voltage causes a current to flow in opposition to the force producing it. It follows therefore that the rotor will revolve in the same direction as the rotation of the magnetic field, so that the relative motion between the two is lessened. Now the rotating field will rotate at the synchronous speed of the supply - that is, the frequency multiplied by 60 and divided by the number of electromagnets in the winding. Since the speed of the rotor will always be less than the speed of the rotating magnetic field, a torque will be exerted on it. It should be noted that the slip, which is the difference in speeds of the two expressed as a percentage, will never be zero, or no current would be induced in the rotor. When the motor is put on load, the rotor speed will decrease temporarily, thus increasing the percentage slip. The result of this, however, is to increase the induced current and therefore the torque. It will be seen therefore that, as the load increases, the speed is only reduced by a fairly small amount.

For small motors, a squirrel-cage rotor is used, as shown in the diagram. It consists of a number of identical bars of copper or aluminium sunk into slots in a laminated steel core. It is cheap to produce, but has the disadvantage of a low starting torque and a lack of control of speed. In the case of large motors, it is desirable that there should be an adequate starting torque and some control over speed. For large motors therefore, a phase-wound rotor is used, with the windings connected at one end to each other and at the other end to slip-rings, thus enabling the resistance of the rotor to be varied at will, providing a greater starting torque, and some speed control.



Squirrel-cage induction motor

# Section 21: Electrolysis

Many substances, when dissolved in water, undergo dissociation – that is, some of the molecules are broken down into charged particles or ions. For example, common salt dissolved in water partially dissociates into positively-charged sodium ions,and negatively-charged chlorine ions. The degree of dissociation which takes place varies with different substances, and also with the degree of dilution.

When an electric current is passed between two electrodes immersed in such a solution, the charged - ions move towards the anode, while the + charged ions are drawnto the cathode.Assuming that the electrolyte is a copper sulphate solution and the electrodes are of copper, then the sulphate ions will be attracted to the anode,where they unite with the copper of the plate to form new copper sulphate, while the metallic copper ions are deposited on the cathode as pure copper.Assuming that the process goes on long enough, the anode will gradually betaken into solution, and the cathode will increase in size through continuing deposition of copper.If there were no losses in this process, the whole of the energy supplied would be used informing pure metal on the cathode.But in practice deposits of gas round the electrodes reduce the electrolytic activity slightly, and would interfere more seriously with it if some chemical agent were not introduced to combat it.

Where both electrodes areof thesame material, the potentials developed will be equal and opposite. But if dissimilar metals are used, the potentials will differ, and an electromotive force is set up. The cell may then be used as a sourceof electric energy. In primary cells, energy is produced only until the anode is consumed. Secondary cells, or accumulators, however, unlike the primary cells, can be recharged by passing a reversed current through them.

The principle of cathodic deposition, as it is called, has many industrial applications. It is employed, for instance, in the production of pure metals, such as aluminium or sodium, by using a fused ore of the metal as the electrolyte.Another application is in the process known as electro-plating, in which a thin surface of some metal such as chromium or tin is deposited on a metallic base so that it adheres firmly to the base. Electro-forming, as distinct from electro-plating, involves growing metal on to a base in such a way that the base can subsequently be melted out or removed, leaving only the electro- formed deposit. Assuming that all the factors involved, such as temperature andcurrent density, can be closely controlled, a surface of theexact shape and thickness required can be produced. Supposing it was desired to produce certain components of very complicated shape. If this were done by normal machining processes, it would be very costly and difficult to makewithin the required tolerances. But bymaking a cast of the component to be produced, and metallising it so that it acts as a cathode, a deposit of exactly the correct shape and dimensions can be grown on to it.

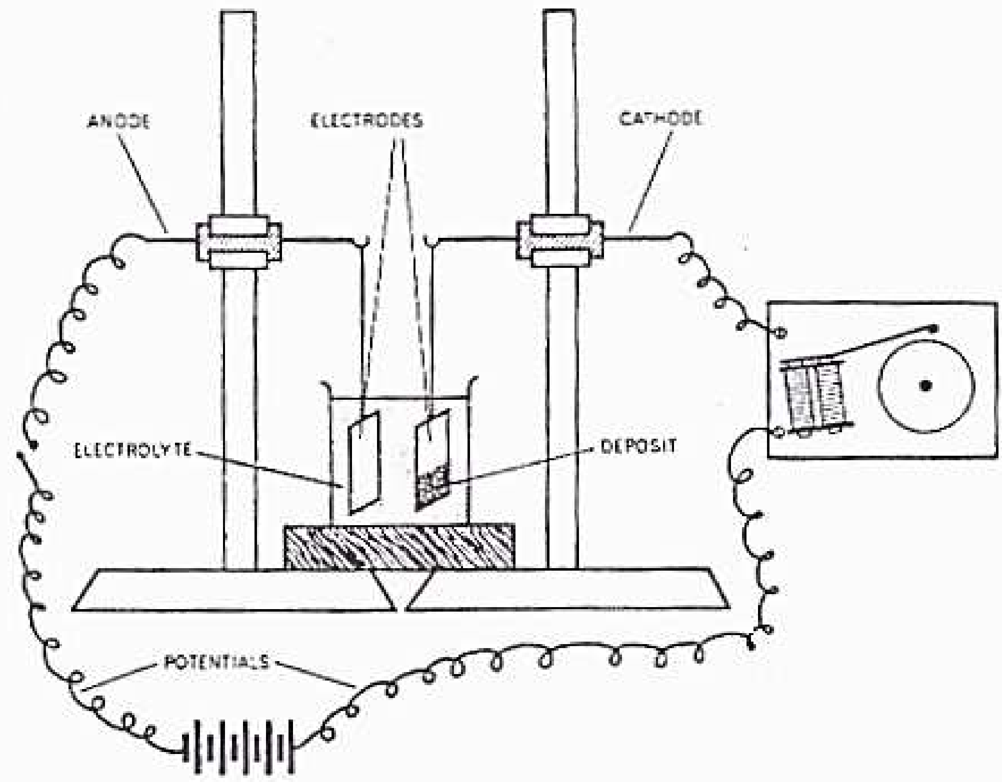


Illustration of electro-plating

# Section 22: Liquid Flow and Metering

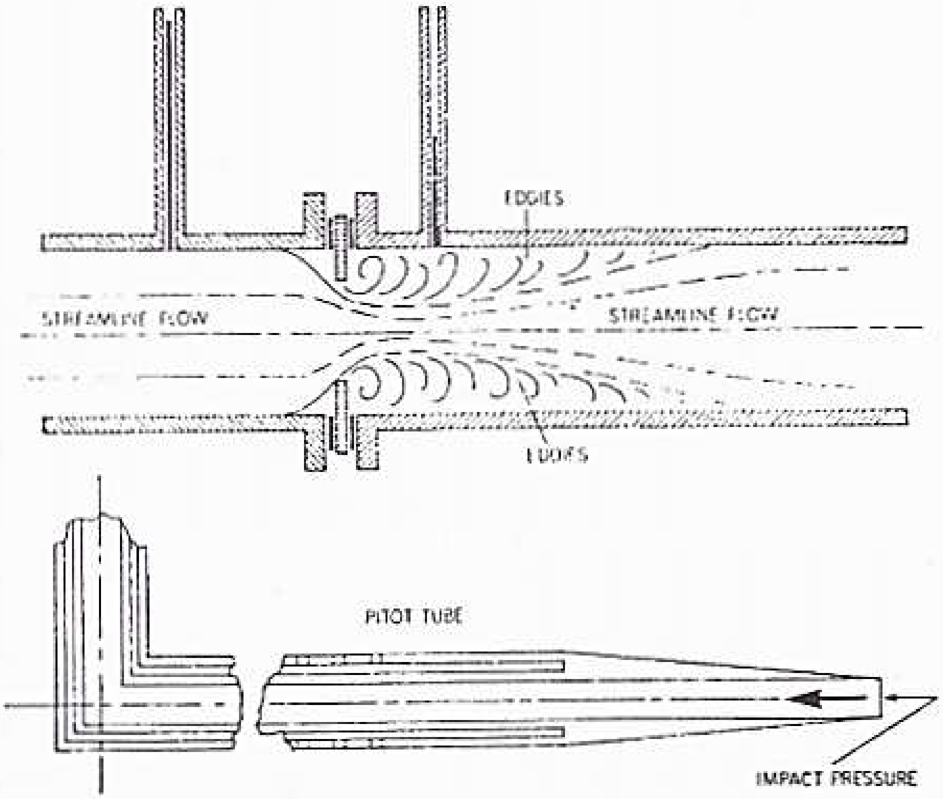
The behaviour of a fluid flowing through a pipe is affected by a number of factors, including the viscosity of the fluid and the speed at which it is pumped. Below a certain critical velocity, the flow is streamline, but when the velocity is increased beyond this value, the fluid becomes unstable and the smooth flow will eventually break up, eddies being formed which give rise to turbulence and loss of kinetic energy. The velocity at which this occurs varies both with the internal diameter of the pipe and with its surface characteristics. Small roughnesses on the pipe walls do not materially affect the flow, since they do not protrude beyond the laminar sub-layer at the pipe wall. But if the roughness is such that it projects into the main stream, then the turbulence in this region will be increased, more of the kinetic energy of the fluid being dissipated as heat.

Liquids flowing through pipes are subject to loss of head due to frictional forces at the surface of the pipe. The fluid flow close to the pipe walls is retarded by contact with them, this drag being transmitted through the viscous fluid, so that a velocity gradient exists at right angles to the flow. Thus it is not possible to measure the rate of flow by a single velocity measurement, and a number of readings should be taken at radial intervals through the flow.

An accurate estimation of the probable loss of head in a pipe is important, since it will determine the horse-power required to ensure discharge at the required rate and pressure. It is theoretically possible to calculate the frictional pressure drop in a given length of pipe of a given diameter and roughness from the following data: the rate of flow of the fluid, its viscosity and its density. Additional allowances, however, have to be made for losses due to the presence of sharp bends or elbows in the pipe, provided they are such as to impede the normal flow to any appreciable extent.

The rate of flow at any section of a pipe can be measured by a variety of metering devices, the commonest being those in which the fluid is either retarded or accelerated at the measuring point, the pressure difference being then measured. In a pitot-tube, a small filament of the fluid is brought to rest in a small-bore tube, the impact pressure being measured against the static pressure of the fluid in an outer tube. In other instruments, the stream is accelerated through a Venturi or nozzle. Its kinetic energy is thereby increased, and the rate of flow can again be determined from the pressure difference involved.

Flow meters, like valves, are liable to be a source of friction, and their design should be such that they obstruct the fluid flow as little as possible.



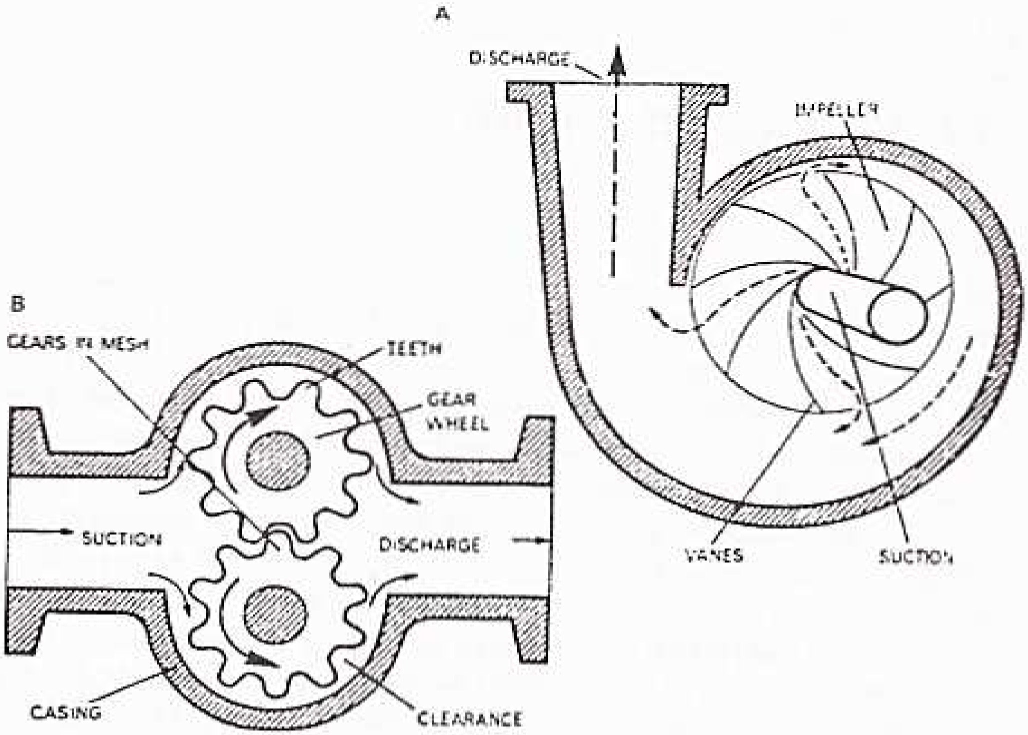
The flow of liquid through pipes

# Section 23: Liquid Pumps

A wide variety of liquids are now being used in chemical plants, and these usually have to be pumped through pipelines. In choosing the type of pump most suitable for any specific operation, a number of problems have to be taken into account. In the first place the quantity of liquid, and the pressure at which it is required to be pumped, must be considered. Neglecting all other considerations, the reciprocating pump is ideal for pumping small quantities of liquid at high pressure, the amount of fluid delivered depending on the volumetric displacement of the pistons. The delivery however is rather uneven - a defect which can only be remedied by compounding a number of cylinders, thus making the machine rather large and expensive.

The viscosity of the liquid is another factor which must be taken into account, in that it largely determines the frictional losses which will occur. Rotary-type pumps are widely used in the handling of highly viscous liquids. They differ from reciprocating pumps in that they deliver an even flow of liquid, but they are unsuitable for pumping liquids of low viscosity, which tend to leak past the tips of the gear teeth. They are mainly used for the pumping of oils and similar liquids of high viscosity, which are less liable to leakage and which moreover provide the necessary lubrication for the moving parts of the pump, thus obviating the need for a separate lubricant. A further consideration involved in the choice of pump is whether or not the liquid is corrosive or contains solid particles in suspension. In such cases, precautions have to be taken to avoid damage to the mechanism. With regard to suspensions, the clearances in the pump must be large enough to permit the particles to pass, and from this point of view, the rotary pump is not suitable, clearances necessarily being small to reduce leakage. The centrifugal type of pump is more commonly used when suspensions are present, since various types of impeller can be fitted, thus enabling the pump to handle a wide variety of liquids, including those with suspensions.

The centrifugal pump is compact and requires little maintenance. But it suffers from a certain disadvantage, in that there are considerable friction losses in the entry and discharge passages of the impeller, and further losses due to turbulence in the impeller itself. The pump consists essentially of one or more impellers rotating in the centre of a casing. This impeller contains a number of vanes so designed that the fluid entering the pump is carried round by the vanes at a speed depending on their speed of rotation. It is then discharged into a delivery chamber with a high kinetic energy imparted by the action of the vanes. This energy is then converted into pressure energy, thus adding to the large pressure difference between the suction and delivery sides of the pump. Excessive speed of rotation of the impeller is liable to cause the pressure on the suction side to fall so low that the liquid will vaporise, thus causing damage to the impeller.



(A) Centrifugal pump
(B) Gear pump

# Section 24: Petroleum

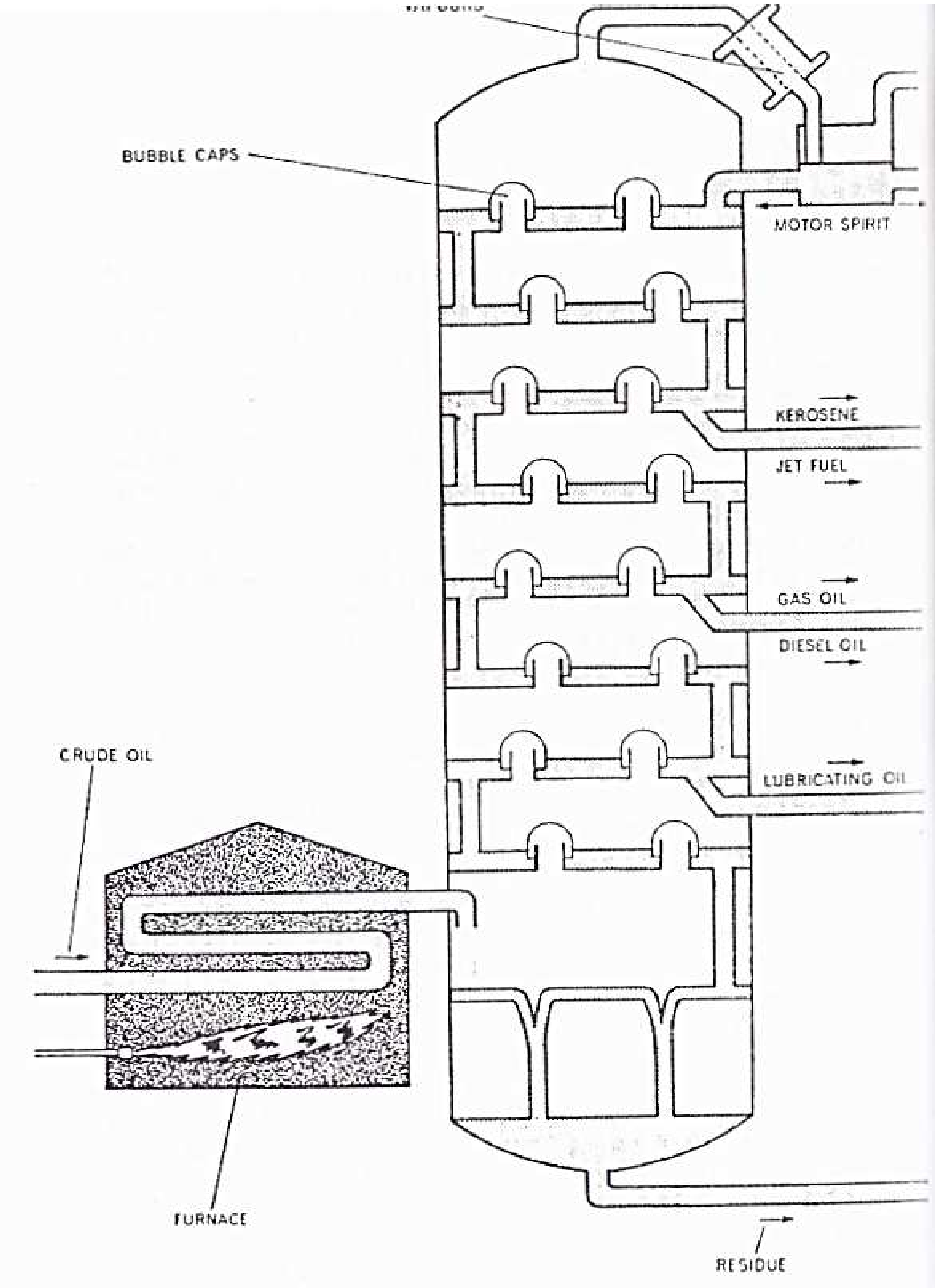
Petroleum is the largest source of liquid fuel, and, in spite of attempts to develop synthetic fuels, and the continued use of solid fuels, world consumption of petroleum products is about four times greater now than in 1940.

Crude petroleum oil from different oilfields is never exactly identical in composition. Although all petroleum is composed essentially of a number of hydrocarbons, they are present in varying proportions in each deposit, and the properties of each deposit have to be evaluated. Samples are subjected to a series of tests in the laboratory, the object of which is largely to determine the correct processing methods to be adopted in each case.

Petroleum is not normally used today in the crude state. The mixture of oils of which it is composed must be separated out into a number of products such as petrol, aviation spirit, kerosene, diesel oils and lubricants, all of which have special purposes. The main method of separation used in refineries is fractional distillation, although further processing is normally required to produce marketable petroleum products. The different hydrocarbons present in petroleum have different boiling temperatures, and the fractions can therefore be isolated according to their boiling temperatures. Petrol, for instance, is a mixture of the lower-boiling hydrocarbons, with boiling temperatures ranging from 100° to 400° C. Diesel oils on the other hand have boiling temperatures of upwards of 400° C.

Distillation was originally carried out in batch-stills and, although this is still done for special purposes, the development of the pipe-still has revolutionised refinery processes, since it allows continuous vaporisation and rectification of the fractions. The pipe-still consists of a brick-lined furnace, in which is fitted a battery of tubes, through which the crude oil is pumped. The oil is heated, and partial vaporisation occurs. The oil then enters the fractionating tower, where it is distilled by coming into contact with condensed vapour whichhas previously been evolved from the still. Fractions of different boiling ranges are drawn off at different points in the tower, or, in some plants, in a series of towers, each one distilling successively heavier fractions.

The heavier distillates, such as gas oil, undergo various other processes, of which the most important is known as cracking. In this process, they are heated to a temperature of about 550° C, as a result of which the heavier molecules are broken up, lighter oils such as petrol being produced. Catalytic cracking, in which silicon compounds are used as catalysts to aid the process of decomposition, gives higher octane petrols. These are widely used as motor-car fuels, since the high octane value reduces the tendency of the fuel to detonation.



Cross-section of oil distillery

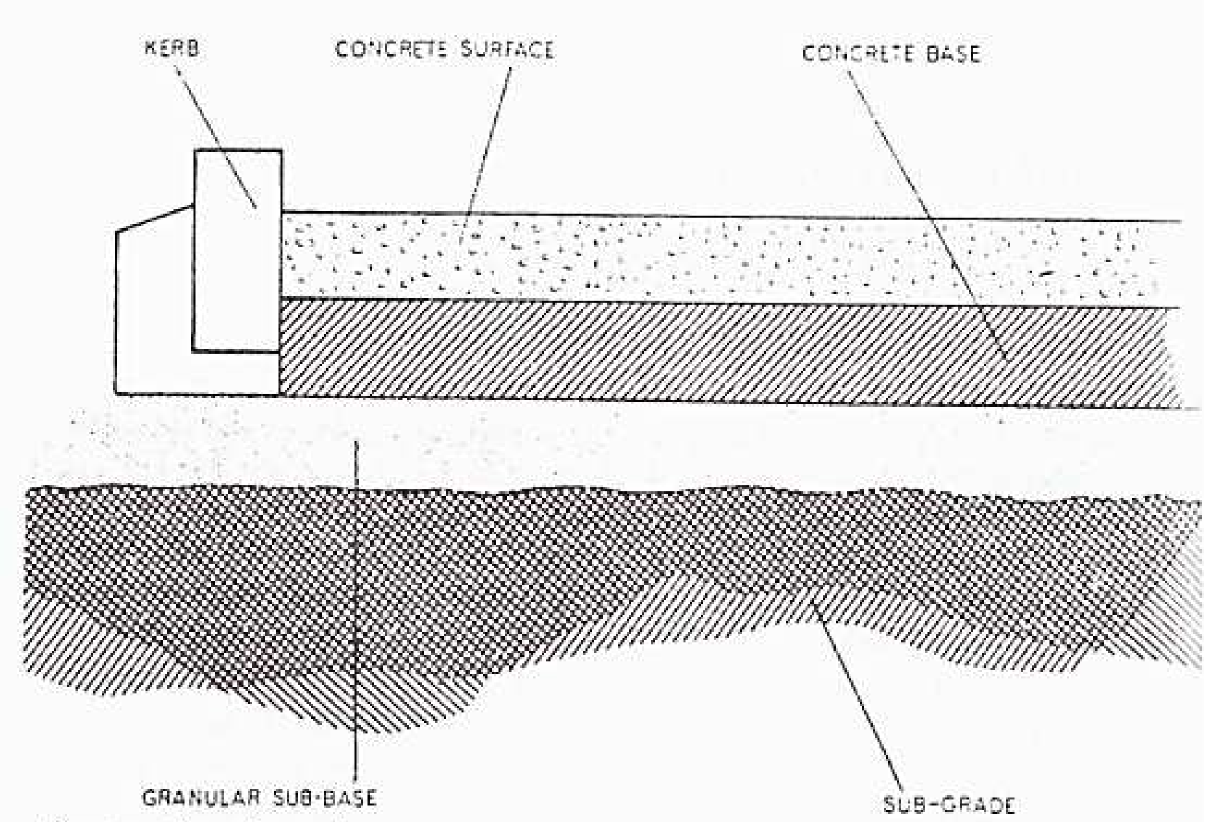
# Section 25: Road Foundations

In planning a road, extensile preliminary surveys must be carried out to determine the precise line of the road, and to work out how much earth will require to be moved and what quantities of surfacing material will be needed.

A second purpose of the surveys will be to take samples of the different soils encountered at different depths by boring, in order to decide whether they are suitable for use or whether they must be replaced by imported fill. This is of great importance, since various types of soil have properties which result in low bearing capacities. Failures in road surfaces arc usually attributable to insufficient preparation and compaction of the sub-grade - that is, the soil on which the surface of the road is laid. Certain soils, such as clay or peat, are unstable, either because they are largely impermeable and hence difficult to drain or because they cannot be properly compacted. It is sometimes possible to stabilise some soils with cement, but in most cases it will be necessary to excavate the soil to a considerate depth and to replace it by a suitable granular soil. The most stable sub-grade soils are gravel or sand, both being readily compaction and easy to drain. It is often unnecessary to excavate these soils to a depth of more than three or four inches, and, if sufficient supplies are available they can be used as filling material, particularly on embankments, where the soil must be capable of a high degree of compaction.

The stability of a soil is largely dependent on an unchanging moisture content, and to assist this, adequate drainage is necessary, although in the case of heavy clays no form of drainage is very effective.

Mechanical excavation is carried out by a variety of machines, including the shovel and drag-line excavator. The choice of plant used will depend on how deep a cut is required and also on how accessible the cut is. After the soil has been excavated to the appropriate depth and filled, it is compacted by a roller until it is firm. Following this, it is common practice to lay a sub-base over the sub-grade soil in order to strengthen it, and to ensure that the traffic load shall be distributed as widely as possible over the foundations. The sub base is normally composed of granular material with good drainage characteristics, and will vary in depth according to the nature of the sub-grade, and also according to what thickness of concrete is to be laid above it. It is essential that the sub-base should be compacted to a uniform density, since the density of a soil is closely related to its bearing capacity. The compacted soil is then covered cither with a sealing coat of tar, or with rolls of waterproof paper, the object of which is to prevent liquid cement from the concrete base from seeping into it, thus weakening the lower layers of the concrete and increasing the moisture content of the base.



Construction of a road

# Section 26: Rigid Pavements

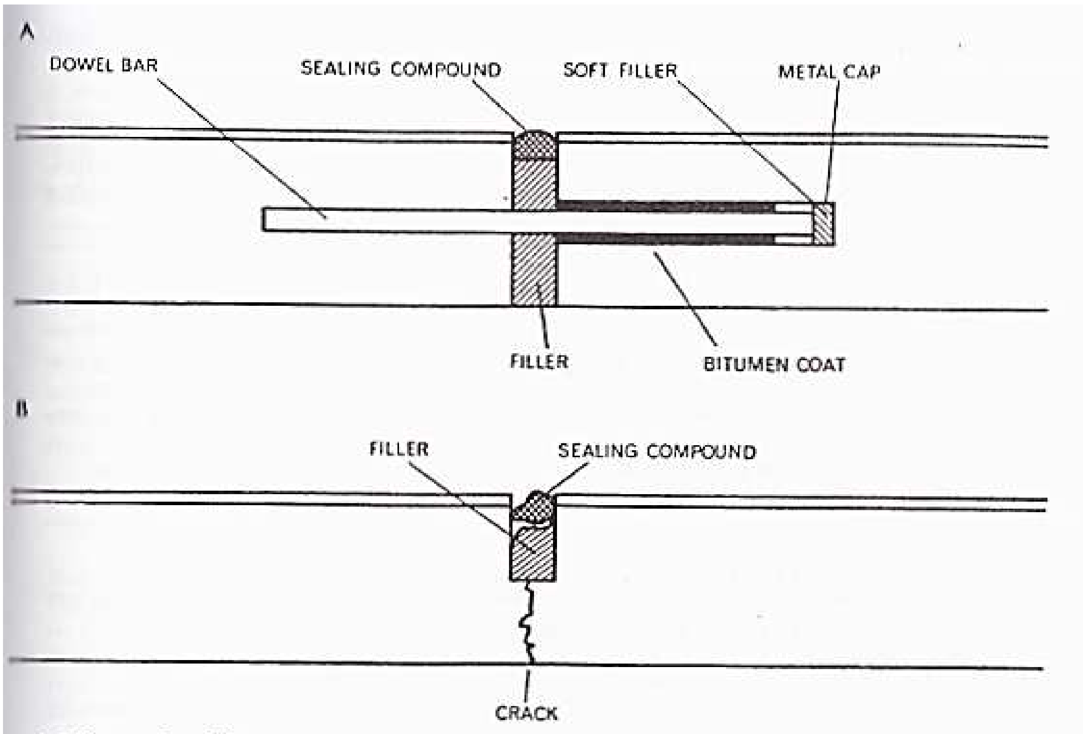
When a vehicle passes over a road, its weight is transmitted through the wheels on to the pavement beneath it. The function of the rigid pavement, as opposed to the flexible tarred pavement, is to distribute the dynamic stresses, and any additional stresses which may be superimposed on them through the sub-grade. The maximum stresses occur at the corners and edges of the concrete slabs, and they are therefore sometimes thickened to counteract this. The thickness of the concrete base varies considerably, according to the nature of the sub-grade and the anticipated traffic density, being sometimes as much as 14 inches on motorways. On such major roads, where the total width greatly exceeds 15 feet, it is impracticable to lay the concrete in a single slab, and the slabs are normally laid in strips with interlocking joints.

The cement for the concrete is mixed with fine aggregate, or sand, and coarse aggregate, which may be gravel or crushed stones accurately graded in one or more sizes. The mix varies in its proportions, a 1:2: 4 mix being fairly common, although in some cases a lean concrete one part of cement to about 10 or 14 parts of aggregate may be used in accordance with the specifications. The mixing is carried out in a batching plant, and water is added to make the cement workable.

Concrete is laid between steel forms, the purpose of the formwork being to retain the concrete in place until it has hardened. The forms may also act as rails on which the vibrating plant can be moved along the roadway. Pavements which are more than seven or eight inches thick are best laid in layers to ensure adequate compaction. Where reinforcement is used, it is most conveniently placed between the layers. It is now common practice to reinforce pavements with steel mesh or with rods. This ensures that any cracking which does occur will be prevented from opening out. The steel is subject to corrosion, and it is normally specified that it should be covered by at least two inches of concrete.

The length of each slab is governed by the need to provide expansion joints, and this will depend partly on the season in which the concrete was laid and partly on the thickness of it. Expansion joints may be spaced at regular intervals of up to 200 feet, and may require a gap of as much as ¾ inch between slabs. Since these joints must be watertight to prevent rainwater from draining down into the sub-grade, they are filled with some resilient material such as cork, and sealed with a sealing compound. Any tendency of the slab to warp or move relative to the next slab is resisted by the use of dowel-bars embedded in the slabs, or by grooving the joints. Contraction joints are perhaps even more important, and aim to control the effects of contraction of the concrete by providing planes of weakness at certain regular intervals along the pavement.

Once the surface has been laid, it is compacted by tamping, or by some form of vibrator, and then it is cured. The object of curing is to prevent the concrete from drying out too quickly, and this is achieved by covering the wet concrete with waterproof paper or polythene, or alternatively by spraying on a liquid resin which insulates it from the air.



(A) Expansion joint
(B) Contraction joint

# Section 27: Piles for Foundations

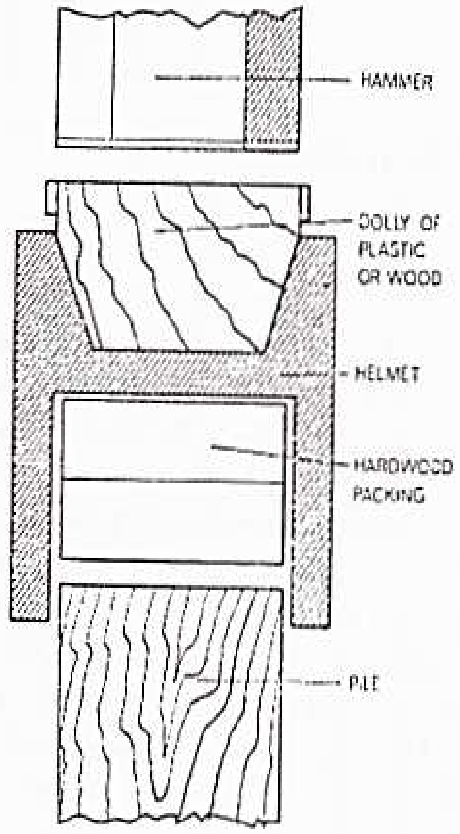
When the foundations of a building have to be carried to a considerable depth to provide adequate support for it and to ensure that no undue settlement will occur, it is normal practice to use piles of concrete or steel. Piled foundations are particularly applicable to structures which are to be built over water or on mud, such as wharves and jetties, but also to large concrete structures which impose a very heavy load on their foundations, thereby rendering them liable to total or differential settlement. The carrying capacity of the piles may be due to the frictional resistance of the ground against the sides of the piles, in cases where the strength of the ground does not materially increase with depth; or to the strong bearing layer to which the point of the piles reach, in which case they transmit the load from the soft strata above to the bearing stratum.

The majority of piles are installed by being driven into the ground and displacing the soil through which they pass. Certain soils, however, are difficult to displace by this method, clay being one example, and for this and other reasons an alternative method is adopted, in which the soil is cored out and the hole is then filled with compacted concrete. Such piles are known as in situ piles, since they are actually cast in the position in which they are required.

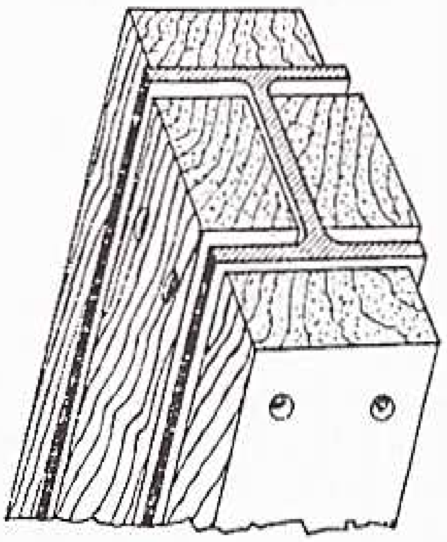
In the case of driven piles, a mechanical pile-driver is required, to hold the pile firmly while it is being driven into the ground by blows from a hammer moving up and down the frame. The frame in some machines can be adjusted so that the pile is driven either vertically downwards or at the required rake.

The amount of penetration with each blow will vary with the force of the impact and the resistance of the ground. The piles are liable to be damaged by the repeated blows of a hammer which may weigh as much as eight tons, and the heads must therefore be protected by a helmet of cast steel, packed with hardwood or some similar material.

Steel piles, commonly in the form of H-beams, have a greater strength weight ratio than concrete piles, and are capable of being driven through hard material with less risk of damage. Extra lengths may be butt-welded on to the driven sections to increase their length. Where concrete piles are used, they are pre-cast except for those cast in situ, and this involves difficult handling and transportation problems, since they are very heavy and may be as much as 100 feet in length. Partly for this reason, driven concrete piles usually require reinforcement, whereas for the in situ piles this is not normally essential, as they are subject to no handling stresses and are not hammered into the ground. When the pile has been driven to the required depth, the reinforcement bars must be exposed at the top by breaking out the concrete, and they are then tied in to the rest of the foundations.



Pile-driver with hammer



WOOD LAGGING ON H PILES

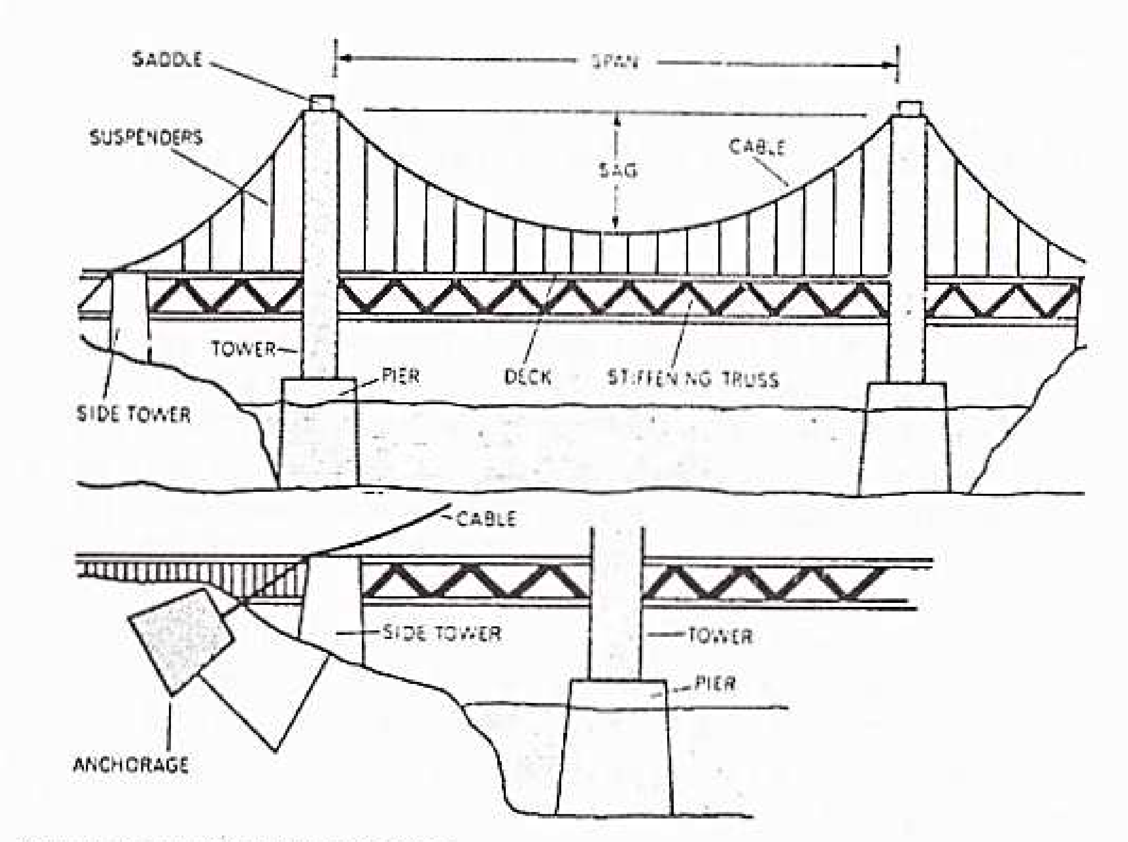
# Section 28: Suspension Bridges

Suspension bridges are frequently constructed in preference to other types of bridge, especially where relatively light traffic has to be carried over long spans, since they are more economical in material and are extremely strong. There are in existence suspension bridges with main spans of more than 3000 feet, the entire weight of the deck being supported from above by cables (usually only two or four in number) suspended between two towers at either side of the river.

The cables are composed of thousands of wires, made of high-tensile steel, which are galvanised to resist corrosion. Two or three hundred of these wires, each of about 0-19 inch in diameter, are clamped together to form a single strand, and the whole cable may consist of a considerable number of such strands compacted and bound together with wire. In constructing the cable, two distinct methods may be adopted. The wires may cither be twisted into strands, the strands then sometimes being twisted round a central strand to form the completed cable, or they may be spun parallel to each other, and clamped together at intervals. This latter method obviously involves a much longer spinning operation, since each wire or small group of wires must be spun and adjusted to the correct sag individually, whereas the strands of twisted wire can be erected as units, provided that they are not so heavy as to be unmanageable. However, on bridges with very long spans, there are certain advantages in the parallel wire method of spinning the cable.

The cables are normally made continuous through the tops of the towers, down through side towers, where these exist, and thence into the anchorage. They bear on specially constructed saddles on the towers, which are shaped to accommodate them, the saddles being either fixed so that the cables may slide over them, or mounted on rollers so that they move with any movement of the cables. In view of the enormous pull exerted by the heavy cables, their ends must be secured in firm anchorages, and unless they can be embedded in sound natural rock, constructions of masonry or concrete must be provided strong enough to withstand the severe pressures put upon them. The cable strands are normally looped round strand-shoes, which are in turn connected by chains to an anchor-plate embedded in the base of the anchorage.

At intervals along the main span, cast-steel cable-bands are attached to the cables, gripping them firmly and excluding moisture from them, and from these bands suspenders of wire-rope or chains hang down. Since these suspenders have to take the weight of the deck to which they are attached, they must have a high tensile strength. One advantage of using the braced-chain suspenders is that they largely dispense with the need for a system of stiffening, being themselves rigid. This stiffening is necessary to resist deformations of the deck of the bridge due to moving traffic loads and also to resist lateral pressures from wind. In the case of wire-rope suspenders, the stiffening must be provided by trusses constructed at the level of the deck, the depth of the truss varying with the length of the span.



Suspension bridge and anchorage