MADHA
Expertise | Empathy | Excellence
ENGINEERING COLLEGE

Department of Mechanical Engineering

Lecture Notes

Subject Code : ME3591

Subject Name: DESIGN OF MACHINE ELEMENTS

Sem/Year : 05/III

Regulation : 2021

ME3591	**DESIGN OF MACHINE ELEMENTS**	**L**	**T**	**P**	**C**
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COURSE OBJECTIVES

1. To learn the various steps involved in the Design Process.
2. To Learn designing shafts and couplings for various applications.
3. To Learn the design of temporary and permanent Joints.
4. To Learn designing helical, leaf springs, flywheels, connecting rods and crank shafts for various applications.
5. To Learn designing and select sliding and rolling contact bearings, seals and gaskets.

(Use of PSG Design Data book is permitted)

UNIT – I FUNDAMENTAL CONCEPTS IN DESIGN 12

Introduction to the design process - factors influencing machine design, selection of materials based on mechanical properties - Preferred numbers- Direct, Bending and torsional loading- Modes of failure - Factor of safety – Combined loads – Principal stresses – Eccentric loading – curved beams – crane hook and 'C' frame- theories of failure – Design based on strength and stiffness – stress concentration – Fluctuating stresses – Endurance limit –Design for finite and infinite life under variable loading - Exposure to standards.

UNIT – II DESIGN OF SHAFTS AND COUPLINGS 12

Shafts and Axles - Design of solid and hollow shafts based on strength, rigidity and critical speed – Keys and splines – Rigid and flexible couplings.

UNIT – III DESIGN OF TEMPORARY AND PERMANENT JOINTS 12

Threaded fasteners - Bolted joints including eccentric loading, Knuckle joints, Cotter joints – Welded joints- Butt, Fillet and parallel transverse fillet welds – welded joints subjected to bending, torsional and eccentric loads, riveted joints for structures - theory of bonded joints.

UNIT – IV DESIGN OF ENERGY STORING ELEMENTS AND ENGINE COMPONENTS 12

Types of springs, design of helical and concentric springs–surge in springs, Design of laminated springs - rubber springs - Flywheels considering stresses in rims and arms for engines and punching machines-- Solid and Rimmed flywheels- connecting rods and crank shafts

UNIT – V DESIGN OF BEARINGS AND MISCELLANEOUS ELEMENTS 12

Sliding contact and rolling contact bearings - Hydrodynamic journal bearings, Sommerfeld Number, Raimondi & Boyd graphs, -- Selection of Rolling Contact bearings –Design of Seals and Gaskets.

TOTAL: 60 PERIODS

Unit-I Fundamental Concepts in Design

Introduction

The subject Machine Design is the creation of new and better machines and improving the existing ones. A new or better machine is one which is more economical in the overall cost of production and operation. The process of design is a long and time consuming one. From the study of existing ideas, a new idea has to be conceived. The idea is then studied keeping in mind its commercial success and given shape and form in the form of drawings. In the preparation of these drawings, care must be taken of the availability of resources in money, in men and in materials required for the successful completion of the new idea into an actual reality. In designing a machine component, it is necessary to have a good knowledge of many subjects such as Mathematics, Engineering Mechanics, Strength of Materials, Theory of Machines, Workshop Processes and Engineering Drawing.

Classifications of Machine Design

The machine design may be classified as follows:

1. ***Adaptive design.***

In most cases, the designer's work is concerned with adaptation of existing designs. This type of design needs no special knowledge or skill and can be attempted by designers of ordinary technical training. The designer only makes minor alternation or modification in the existing designs of the product.

2. ***Development design.***

This type of design needs considerable scientific training and design ability in order to modify the existing designs into a new idea by adopting a new material or different method of manufacture. In this case, though the designer starts from the existing design, but the final product may differ quite markedly from the original product.

3. ***New design.***

This type of design needs lot of research, technical ability and creative thinking. Only those designers who have personal qualities of a sufficiently high order can take up the work of a new design. The designs, depending upon the methods used, may be classified as follows:

(*a*) ***Rational design.*** This type of design depends upon mathematical formulae of principle of mechanics.

(*b*) ***Empirical design.*** This type of design depends upon empirical formulae based on the practice and past experience.

(*c*) ***Industrial design.*** This type of design depends upon the production aspects to manufacture any machine component in the industry.

(*d*) ***Optimum design.*** It is the best design for the given objective function under the specified constraints. It may be achieved by minimising the undesirable effects.

(*e*) ***System design.*** It is the design of any complex mechanical system like a motor car.

(*f*) ***Element design.*** It is the design of any element of the mechanical system like piston, crankshaft, connecting rod, etc.

(*g*) ***Computer aided design.*** This type of design depends upon the use of computer systems to assist in the creation, modification, analysis and optimisation of a design.

General Considerations in Machine Design

Following are the general considerations in designing a machine component:

1. ***Type of load and stresses caused by the load.*** The load, on a machine component, may act in several ways due to which the internal stresses are set up. The various types of load and stresses are discussed later.

2. ***Motion of the parts or kinematics of the machine.*** The successful operation of any machine depends largely upon the simplest arrangement of the parts which will give the motion required.

The motion of the parts may be:

(*a*) Rectilinear motion which includes unidirectional and reciprocating motions.
(*b*) Curvilinear motion which includes rotary, oscillatory and simple harmonic.
(*c*) Constant velocity.
(*d*) Constant or variable acceleration.

3. ***Selection of materials.*** It is essential that a designer should have a thorough knowledge of the properties of the materials and their behaviour under working conditions. Some of the important characteristics of materials are: strength, durability, flexibility, weight, resistance to heat and corrosion, ability to cast, welded or hardened, machinability, electrical conductivity, etc. The various types of engineering materials and their properties are discussed later.

4. ***Form and size of the parts.*** The form and size are based on judgment. The smallest practicable cross-section may be used, but it may be checked that the stresses induced in the designed cross-section are reasonably safe. In order to design any machine part for form and size, it is necessary to know the forces which the part must sustain. It is also important to anticipate any suddenly applied or impact load which may cause failure.

5. ***Frictional resistance and lubrication.*** There is always a loss of power due to frictional resistance and it should be noted that the friction of starting is higher than that of running friction. It is, therefore, essential that a careful attention must be given to the matter of lubrication of all surfaces which move in contact with others, whether in rotating, sliding, or rolling bearings.

6. ***Convenient and economical features.*** In designing, the operating features of the machine should be carefully studied. The starting, controlling and stopping levers should be located on the basis of convenient handling. The adjustment for wear must be provided employing the various take up devices and arranging them so that the alignment of parts is preserved. If parts are to be changed for different products or replaced on account of wear or breakage, easy access should be provided and the necessity of removing other parts to accomplish this should be avoided if possible. The economical operation of a machine which is to be used for production or for the processing of material should be studied, in order to learn whether it has the maximum capacity consistent with the production of good work.

7. ***Use of standard parts.*** The use of standard parts is closely related to cost, because the cost of standard or stock parts is only a fraction of the cost of similar parts made to order. The standard or stock parts should be used whenever possible; parts for which patterns are already in existence such as gears, pulleys and bearings and parts which may be selected from regular shop stock such as screws, nuts and pins. Bolts and studs should be as few as possible to avoid the delay caused by changing drills, reamers and taps and also to decrease the number of wrenches required.

8. ***Safety of operation.*** Some machines are dangerous to operate, especially those which are speeded up to insure production at a maximum rate. Therefore, any moving part of a machine which is within the zone of a worker is considered an accident hazard and may be the cause of an injury. It is, therefore, necessary that a designer should always provide safety devices for the safety of the operator. The safety appliances should in no way interfere with operation of the machine.

9. ***Workshop facilities.*** A design engineer should be familiar with the limitations of this employer’s workshop, in order to avoid the necessity of having work done in some other workshop. It is sometimes necessary to plan and supervise the workshop operations and to draft methods for casting, handling and machining special parts.

10. ***Number of machines to be manufactured.*** The number of articles or machines to be manufactured affects the design in a number of ways. The engineering and shop costs which are called fixed charges or overhead expenses are distributed over the number of articles to be manufactured. If only a few articles are to be made, extra expenses are not justified unless the machine is large or of some special design. An order calling for small number of the product will not permit any undue expense in the workshop processes, so that the designer should restrict his specification to standard parts as much as possible.

11. ***Cost of construction.*** The cost of construction of an article is the most important consideration involved in design. In some cases, it is quite possible that the high cost of an article may immediately bar it from further considerations. If an article has been invented and tests of handmade samples have shown that it has commercial value, it is then possible to justify the expenditure of a considerable sum of money in the design and development of automatic machines to produce the article, especially if it can be sold in large numbers. The aim of design engineer under all conditions should be to reduce the manufacturing cost to the minimum.

12. ***Assembling.*** Every machine or structure must be assembled as a unit before it can function. Large units must often be assembled in the shop, tested and then taken to be transported to their place of service. The final location of any machine is important and the design engineer must anticipate the exact location and the local facilities for erection.

General Procedure in Machine Design

In designing a machine component, there is no rigid rule. The problem may be attempted in several ways. However, the general procedure to solve a design problem is as follows:

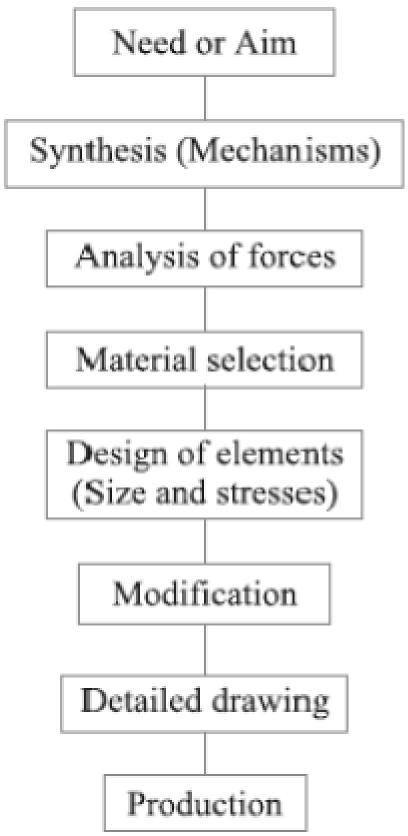


Fig.1. General Machine Design Procedure

1. ***Recognition of need.*** First of all, make a complete statement of the problem, indicating the need, aim or purpose for which the machine is to be designed.
2. ***Synthesis*** **(*Mechanisms*).** Select the
will give the desired motion.
3. ***Analysis of forces.*** Find the forces acting on each member of the machine and the energy transmitted by each member.
4. ***Material selection.*** Select the material best suited fo
5. ***Design of elements*** **(*Size and Stresses***

considering the force acting on the member and the permissible stresses for the material used. It should be kept in mind that each member limit.
6. ***Modification.*** Modify the size of the member to agree with the past experience and judgment to facilitate manufacture. The modification may also be necessary by consideration of manufacturing to reduce overall cost.
7. ***Detailed drawing.*** Draw the detailed drawing of each component and the assembly of the machine with complete specification for the manufacturing processes suggested.
8. ***Production.*** The component, as per the drawing, is manufactured in the workshop.
The flow chart for the general procedure in machine design is shown in Fig.
Note: When there are number of components in the market having the same qualities of efficiency, durability and cost, then the customer will naturally attract towards the most appealing product. The aesthetic and ergonomics are very important features which gives grace and lustre to product and dominates the market.

Engineering materials and their properties

The knowledge of materials and their properties is of great significance for a design engineer. The machine elements should be made of such a material which has properties suitable for the conditions of operation. In addition to this, a design engineer must be familiar with the effects which the manufacturing processes and heat treatment have on the properties of the materials. Now, we shall discuss the commonly used engineering materials and their properties in Machine Design.

Classification of Engineering Materials

The engineering materials are mainly classified as:
1. Metals and their alloys, such as iron, steel, copper, aluminum, etc.
2. Non-metals, such as glass, rubber, plastic, etc.
The metals may be further classified as:
(a) Ferrous metals and (*b*) Non-ferrous metals.
The ****ferrous metals*** are those which have the iron as their main constituent, such as cast iron, wrought iron and steel.

The ***non-ferrous*** metals are those which have a metal other than iron as their main

constituent, such as copper, aluminum, brass, tin, zinc, etc.

Selection of Materials for Engineering Purposes

The selection of a proper material, for engineering purposes, is one of the most difficult problems for the designer. The best material is one which serves the desired objective at the minimum cost. The following factors should be considered while selecting the material:
1. Availability of the materials,
2. Suitability of the materials for the working conditions in service, and
3. The cost of the materials.
The important properties, which determine the utility of the material, are physical, chemical and mechanical properties. We shall now discuss the physical and mechanical properties of

the material in the following articles.

Physical Properties of Metals

The physical properties of the metals include luster, colour, size and shape, density, electric and thermal conductivity, and melting point. The following table shows the important physical properties of some pure metals.

Mechanical Properties of Metals

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness. We shall now discuss these properties as follows:

1. Strength. It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called stress.

2. Stiffness. It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. Elasticity. It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

4. Plasticity. It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. Ductility. It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminium, nickel, zinc, tin and lead.

6. Brittleness. It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads snap off without giving any sensible elongation. Cast iron is a brittle material.

7. Malleability. It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminium.

8. Toughness. It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed upto the point of fracture. This property is desirable in parts subjected to shock and impact loads.

9. Machinability. It is the property of a material which refers to a relative case with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel.

10. Resilience. It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

11. Creep. When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called **creep.** This property is considered in designing internal combustion engines, boilers and turbines.

12. Fatigue. When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as ***fatigue**. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

13. Hardness. It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal. The hardness is usually expressed in numbers which are dependent on the method of making the test. The hardness of a metal may be determined by the following tests:

(a) Brinell hardness test,
(b) Rockwell hardness test,
(c) Vickers hardness (also called Diamond Pyramid) test, and
(d) Shore scleroscope.

Steel

It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. Other elements *e.g*. silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to impart certain desired properties to it. Most of the steel produced now-a-days is ***plain carbon steel*** or simply ***carbon steel*.** A carbon steel is defined as a steel which has its properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese.

The plain carbon steels varying from 0.06% carbon to 1.5% carbon are divided into the following types depending upon the carbon content.

1. Dead mild steel — up to 0.15% carbon**2.** Low carbon or mild steel — 0.15% to 0.45% carbon
3. Medium carbon steel — 0.45% to 0.8% carbon
4. High carbon steel — 0.8% to 1.5% carbon

According to Indian standard *[IS: 1762 (Part-I)–1974], a new system of designating the steel is recommended. According to this standard, steels are designated on the following two basis: (*a*) On the basis of mechanical properties, and (*b*) On the basis of chemical composition. We shall now discuss, in detail, the designation of steel on the above two basis, in the following pages.

Steels Designated on the Basis of Mechanical Properties

These steels are carbon and low alloy steels where the main criterion in the selection and inspection of steel is the tensile strength or yield stress. According to Indian standard IS: 1570 (Part–I)- 1978 (Reaffirmed 1993), these steels are designated by a symbol ‘Fe’ or ‘Fe E’ depending on whether the steel has been specified on the basis of minimum tensile strength or yield strength, followed by the figure indicating the minimum tensile strength or yield stress in N/mm2. For example ‘Fe 290’ means a steel having minimum tensile strength of 290 N/mm2 and ‘Fe E 220’ means a steel having yield strength of 220 N/mm2.

Steels Designated on the Basis of Chemical Composition

According to Indian standard, IS : 1570 (Part II/Sec I)-1979 (Reaffirmed 1991), the carbon steels are designated in the following order :
(*a*) Figure indicating 100 times the average percentage of carbon content,
(*b*) Letter ‘C’, and
(*c*) Figure indicating 10 times the average percentage of manganese content. The figure after multiplying shall be rounded off to the nearest integer.
For example 20C8 means a carbon steel containing 0.15 to 0.25 per cent (0.2 per cent on average) carbon and 0.60 to 0.90 per cent (0.75 per cent rounded off to 0.8 per cent on an average) manganese.

Effect of Impurities on Steel

The following are the effects of impurities like silicon, sulphur, manganese and phosphorus on steel.

1. *Silicon*. The amount of silicon in the finished steel usually ranges from 0.05 to 0.30%. Silicon is added in low carbon steels to prevent them from becoming porous. It removes the gases and oxides, prevent blow holes and thereby makes the steel tougher and harder.
2. *Sulphur*. It occurs in steel either as iron sulphide or manganese sulphide. Iron sulphide because of its low melting point produces red shortness, whereas manganese sulphide does not affect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide.
3. *Manganese*. It serves as a valuable deoxidising and purifying agent in steel. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. When used in ordinary low carbon steels, manganese makes the metal ductile and of good bending qualities. In high speed steels, it is used to toughen the metal and to increase its critical temperature.
4. *Phosphorus*. It makes the steel brittle. It also produces cold shortness in steel. In low carbon steels, it raises the yield point and improves the resistance to atmospheric corrosion. The sum of carbon and phosphorus usually does not exceed 0.25%.

Manufacturing considerations in Machine design

Manufacturing Processes

The knowledge of manufacturing processes is of great importance for a design engineer. The following are the various manufacturing processes used in Mechanical Engineering.
1. *Primary shaping processes*. The processes used for the preliminary shaping of the machine component are known as primary shaping processes. The common operations used for this process are casting, forging, extruding, rolling, drawing, bending, shearing, spinning, powder metal forming, squeezing, etc.
2. *Machining processes*. The processes used for giving final shape to the machine component, according to planned dimensions are known as machining processes. The

common operations used for this process are turning, planning, shaping, drilling, boring, reaming, sawing, broaching, milling, grinding, hobbing, etc.

3. ***Surface finishing processes*****.** The processes used to provide a good surface finish for the machine component are known as surface finishing processes. The common operations used for this process are polishing, buffing, honing, lapping, abrasive belt grinding, barrel tumbling, electroplating, super finishing, sheradizing, etc.

4. ***Joining processes*****.** The processes used for joining machine components are known as joining processes. The common operations used for this process are welding, riveting, soldering, brazing, screw fastening, pressing, sintering, etc.

5. ***Processes effecting change in properties*****.** These processes are used to impart certain specific properties to the machine components so as to make them suitable for particular operations or uses. Such processes are heat treatment, hot-working, cold-working and shot peening.

Other considerations in Machine design

1. Workshop facilities.
2. Number of machines to be manufactured
3. Cost of construction

4. Assembling

Interchangeability

The term interchangeability is normally employed for the mass production of identical items within the prescribed limits of sizes. A little consideration will show that in order to maintain the sizes of the part within a close degree of accuracy, a lot of time is required. But even then there will be small variations. If the variations are within certain limits, all parts of equivalent size will be equally fit for operating in machines certain variations are recognized and allowed in the sizes of the mating parts to give the required fitting. This facilitates to select at random from a large number of parts for an assembly and results in a considerable saving I In order to control the size of finished part, with due allowance for error, for interchangeable parts is called ***limit system***

of two parts, the part which enters into the other, is known as cylindrical part) and the other in which one enters is called cylindrical part).

The term ***shaft*** also used to designate any external dimension of a part. The term diameter of a circular hole, but it is also used to designate any internal dimension

Important Terms used in Limit System

The following terms used in limit system (or interchangeable system) are important from the subject point of view:

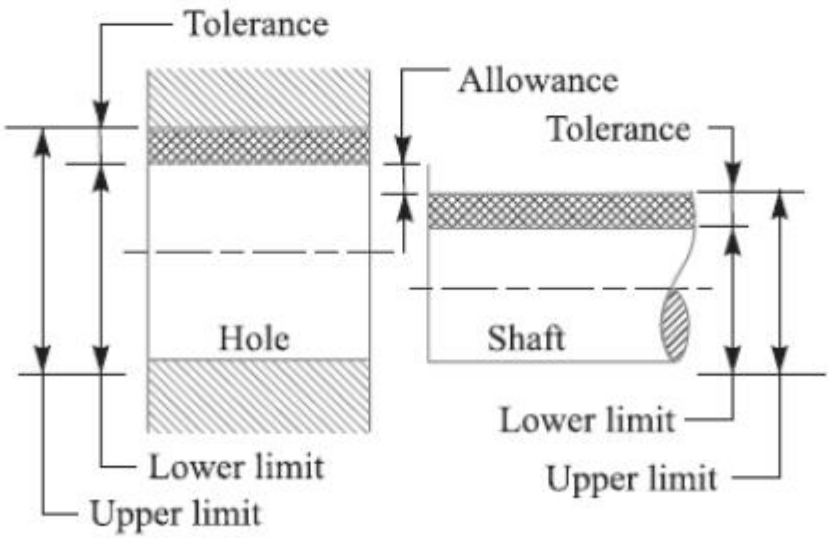


Fig. Limits of sizes.

1. Nominal size. It is the size of a part specified in the drawing
2. Basic size. It is the size of a part to which all limits of variation (
to arrive at final dimensioning of the mating parts. The nominal or basic size of a part is often the same.
3. Actual size. It is the actual measured dimension of the part. The difference between the basic size and the actual size should not exceed a certain limit; otherwise it will interfere with the interchangeability of the mating parts.
4. Limits of sizes. There are two e
shown in Fig. The largest permissible size for a dimension of the part is called
or **maximum limit,** whereas the smallest size of the part is known as
limit.
5. Allowance. It is the difference between the basic dimensions of the mating parts. The allowance may be **positive** or **negative**
allowance is **positive** and when the shaft size is greater than the hole size, then t
is **negative.**

(*a*) Unilateral tolerance. (*b*) Bilateral tolerance.

Fig. Method of assigning Tolerances

6. Tolerance. It is the difference between the upper limit and lower limit of a dimension. In

other words, it is the maximum permissible variation in a dimension. The tolerance may be **unilateral** or **bilateral.** When all the tolerance is allowed on one side of the nominal size, then it is said to be **unilateral system of tolerance**
used in industries as it permits changing the tolerance value while still retaining the same allowance or type of fit. When the tolerance is allowed on both sides of the nominal size,
, then it is said to be **bilateral system of tolerance**
limit and – 0.002 is the lower limit.
7. Tolerance zone. It is the zone between the maximum and minimum limit size.

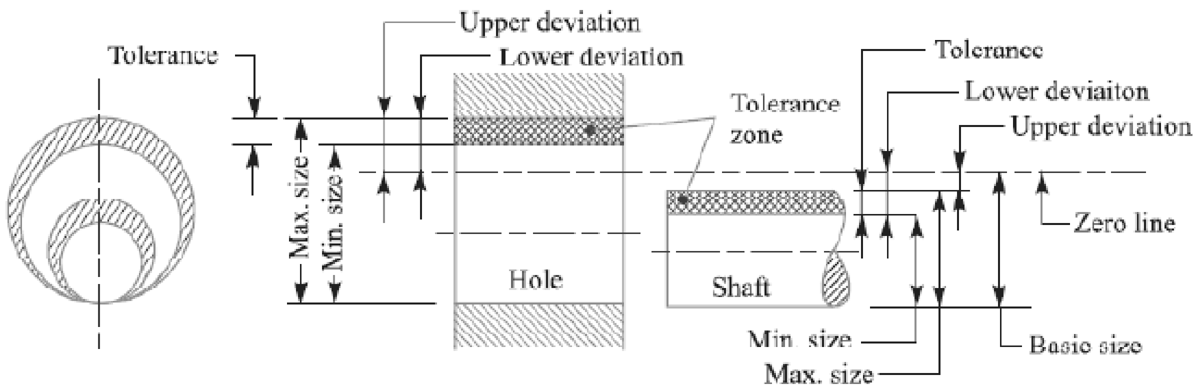


Fig. Tolerance Zone

8. Zero line. It is a straight line
from this line. The positive and negative deviations are shown above and below the zero line respectively.
9. Upper deviation. It is the algebraic difference between the maximum size and the basic size. The upper deviation of a hole is represented by a symbol
shaft, it is represented by es.
10. Lower deviation. It is the algebraic difference between t
size. The lower deviation of a hole is represented by a symbol
shaft, it is represented by ei.
11. Actual deviation. It is the algebraic difference between an actual size and the corresponding basic size.
12. Mean deviation. It is the arithmetical mean between the upper and lower deviations.

13. Fundamental deviation. It is one of the two deviations which are conventionally chosen to define the position of the tolerance zone in relation to zero l

Fits
The degree of tightness or looseness between the two mating parts is known as a
parts. The nature of fit is characterized by the presence and size of clearance and interference.
The ***clearance*** is the amount by which the actual size of the shaft is less than the actual size of the mating hole in an assembly as shown in Fig. 3.5 (
the difference between the sizes of the hole and the shaft before assemb
must be ***positive.***
The ***clearance*** is the amount by which the actual size of the shaft is less than the actual size

of the mating hole in an assembly. difference between the sizes of the hole and the shaft before assembly. The difference must be ***positive*.**

The ***interference*** is the amount by which the actual size of a shaft is larger than the actual finished size of the mating hole in an assembly line,

a). In other words, the clearance is the

b). In other words, theinterference is the arithmetical difference between the sizes of the hole and the shaft, before assembly. The difference must be ***negative*.**

Types of Fits

According to Indian standards, the fits are classified into the following three groups:

1. Clearance fit*.** In this type of fit, the size limits for mating parts are so selected that clearance between them always occur, as shown in Fig. (*a*). It may be noted that in a clearance fit, the tolerance zone of the hole is entirely above the tolerance zone of the shaft. In a clearance fit, the difference between the minimum size of the hole and the maximum size of the shaft is known as ***minimum clearance whereas the difference between the maximum size of the hole and minimum size of the shaft is called ***maximum clearance*** as shown in Fig. (*a*). The clearance fits may be slide fit, easy sliding fit, running fit, slack running fit and loose running fit.

2. *Interference fit*. In this type of fit, the size limits for the mating parts are so selected that interference between them always occur, as shown in Fig. (*b*). It may be noted that in an interference fit, the tolerance zone of the hole is entirely below the tolerance zone of the shaft. In an interference fit, the difference between the maximum size of the hole and the minimum size of the shaft is known as ***minimum interference,*** whereas the difference between the minimum size of the hole and the maximum size of the shaft is called ***maximum interference***.

The interference fits may be shrink fit, heavy drive fit and light drive fit.

3. *Transition fit*. In this type of fit, the size limits for the mating parts are so selected that either a clearance or interference may occur depending upon the actual size of the mating parts, It may be noted that in a transition fit, the tolerance zones of hole and shaft overlap. The transition fits may be force fit, tight fit and push fit.

Basis of Limit System

The following are two bases of limit system:

1. *Hole basis system*. When the hole is kept as a constant member (*i.e*. when the lower deviation of the hole is zero) and different fits are obtained by varying the shaft size, as shown in Fig. (*a*), then the limit system is said to be on a hole basis.

2. *Shaft basis system*. When the shaft is kept as a constant member (deviation of the shaft is zero) and different fits are obtained by varying the hole size, as shown in Fig.(*b*), Then the limit system is said to be on a shaft basis.

The hole basis and shaft basis system may also be shown as in Fig. with respect to the zero line. It may be noted that from the preferred. This is because the holes are usually produced and finished by standard tooling like drill, reamers, etc., whose size is not adjustable easily. On the other hand, the size of the shaft (which is to go into the hole) can be easily adjusted and is obtained by turning or grinding operations.

Stress

When some external system of forces or loads acts on a body, the internal forces (equal and opposite) are set up at various sections of the body, which resist the external forces. This internal force per unit area at any section of the body is known as ***unit stress*** or simply a ***stress***. It is denoted by a Greek letter sigma (σ). Mathematically,

$$\text{Stress, } \sigma = P/A$$

Where P = Force or load acting on a body, and

A = Cross-sectional area of the body.

In S.I. units, the stress is usually expressed in Pascal (Pa) such that 1 Pa = 1 N/m^2. In actual practice, we use bigger units of stress *i.e.* megapascal (MPa) and gigapascal (GPa), such that

$$1 \text{ MPa} = 1 \times 10^6 \text{ N/m}^2 = 1 \text{ N/mm}^2$$

And $$1 \text{ GPa} = 1 \times 10^9 \text{ N/m}^2 = 1 \text{ kN/mm}^2$$

Strain

When a system of forces or loads act on a body, it undergoes some deformation. This deformation per unit length is known as ***unit strain*** or simply a ***strain***. It is denoted by a Greek letter epsilon (ε). Mathematically,

Strain, $\varepsilon = \delta l / l$ or $\delta l = \varepsilon . l$

Where δl = Change in length of the body, and

l = Original length of the body.

Tensile Stress and Strain

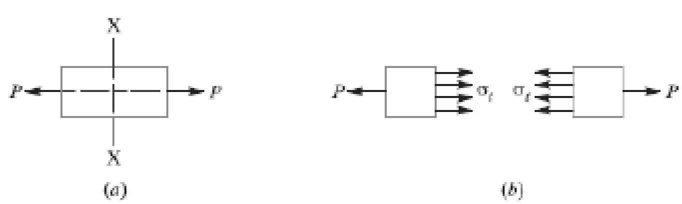


Fig. Tensile stress and strain

When a body is subjected to two equal and opposite axial pulls P (also called tensile load) as shown in Fig. (a), then the stress induced at any section of the body is known as ***tensile stress*** as shown in Fig. (*b*). A little consideration will show that due to the tensile load, there will be a decrease in cross-sectional area and an increase in length of the body. The ratio of the increase in length to the original length is known as ***tensile strain.***

Let P = Axial tensile force acting on the body,

A = Cross-sectional area of the body,

l = Original length, and

δl = Increase in length.

Then Tensile stress, $\sigma_t = P/A$

and tensile strain, $\varepsilon_t = \delta l / l$

Young's Modulus or Modulus of Elasticity

Hooke's law* states that when a material is loaded within elastic limit, the stress is directly proportional to strain, *i.e.*

$$\sigma \propto \varepsilon \qquad \text{or} \qquad \sigma = E.\varepsilon$$

$$E = \frac{\sigma}{\varepsilon} = \frac{P \times l}{A \times \delta l}$$

where E is a constant of proportionality known as ***Young's modulus*** or ***modulus of elasticity.*** In S.I. units, it is usually expressed in GPa *i.e.* GN/m^2 or kN/mm^2. It may be noted that Hooke's law holds good for tension as well as compression.

The following table shows the values of modulus of elasticity or Young's modulus (E) for the materials commonly used in engineering practice.

Values of E for the commonly used engineering materials.

Material	*Modulus of elasticity (E) in GPai.e. GN/m^2 for kN/mm^2*
Steel and Nickel	200 to 220
Wrought iron	190 to 200
Cast iron	100 to 160
Copper	90 to 110
Brass	80 to 90
Aluminium	60 to 80
Timber	10

Shear Stress and Strain

When a body is subjected to two equal and opposite forces acting tangentially across the resisting section, as a result of which the body tends to shear off the section, then the stress induced is called *shear stress.*

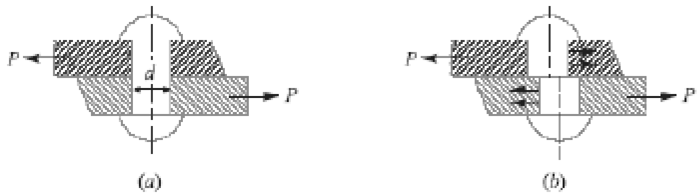


Fig. Single shearing of a riveted joint.

The corresponding strain is known as *shear strain* and it is measured by the angular deformation accompanying the shear stress. The shear stress and shear strain are denoted by the Greek letters tau (τ) and phi (φ) respectively. Mathematically,

$$\text{Shear stress, } \tau = \frac{\text{Tangential force}}{\text{Resisting area}}$$

Consider a body consisting of two plates connected by a rivet as shown in Fig. (*a*). In this case, the tangential force *P* tends to shear off the rivet at one cross-section as shown in Fig. (*b*). It may be noted that when the tangential force is resisted by one cross-section of the rivet (or when shearing takes place at one cross-section of the rivet), then the rivets are said to be in *single shear.* In such a case, the area resisting the shear off the rivet,

$$A = \frac{\pi}{4} \times d^2$$

And shear stress on the rivet cross-section

$$\tau = \frac{P}{A} = \frac{P}{\frac{\pi}{4} \times d^2} = \frac{4P}{\pi d^2}$$

Now let us consider two plates connected by the two cover plates as shown in Fig. *(a).* In this case, the tangential force *P* tends to shear off the rivet at two cross-sections as shown in Fig. (b). It may be noted that when the tangential force is resisted by two cross-sections of the rivet (or when the shearing takes place at Two cross-sections of the rivet), then the rivets are said to be in *double shear*. In such a case, the area resisting the shear off the rivet,

$$A = 2 \times \frac{\pi}{4} \times d^2 \qquad \text{(For double shear)}$$

and shear stress on the rivet cross-section.

$$\tau = \frac{P}{A} = \frac{P}{2 \times \frac{\pi}{4} \times d^2} = \frac{2P}{\pi d^2}$$

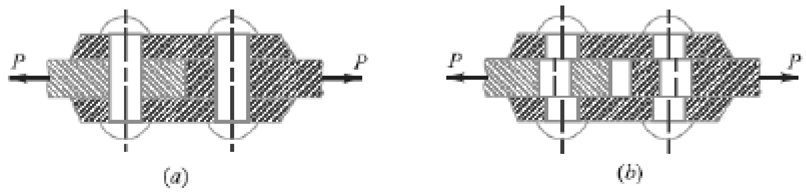


Fig. Double shearing of a riveted joint.

Notes:

1. All lap joints and single cover butt joints are in single shear, while the butt joints with double cover plates are in double shear.

2. In case of shear, the area involved is parallel to the external force applied.

3. When the holes are to be punched or drilled in the metal plates, then the tools used to perform the operations must overcome the ultimate shearing resistance of the material to be cut. If a hole of diameter '*d*' is to be punched in a metal plate of thickness '*t*', then the area to be sheared,

$$A = \pi d \times t$$

And the maximum shear resistance of the tool or the force required to punch a hole,

$$P = A \times \tau_u = \pi d \times t \times \tau_u$$

Where σ_u= Ultimate shear strength of the material of the plate.

Shear Modulus or Modulus of Rigidity

It has been found experimentally that within the elastic limit, the shear stress is directly proportional to shear strain. Mathematically

$$\tau \propto \phi \qquad \text{or} \quad \tau = C \cdot \phi \quad \text{or} \quad \tau / \phi = C$$

φ= Shear strain, and

C = Constant of proportionality, known as shear modulus or modulus of rigidity. It is also denoted by N or G.

The following table shows the values of modulus of rigidity (C) for the materials in every day use:

Values of C for the commonly used materials

Material	*Modulus of rigidity (C) in GPa i.e. GN/m² or kNmm²*
Steel	80 to 100
Wrought iron	80 to 90
Cast iron	40 to 50
Copper	30 to 50
Brass	30 to 50
Timber	10

Linear and Lateral Strain

Consider a circular bar of diameter d and length l, subjected to a tensile force P as shown in Fig. (a).

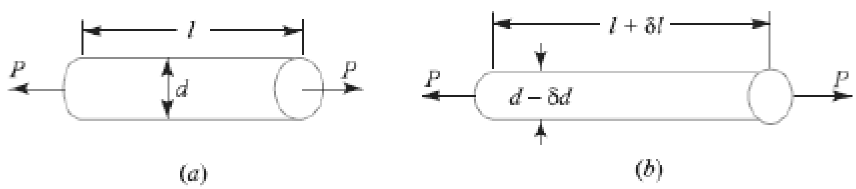


Fig. Linear and lateral strain.

A little consideration will show that due to tensile force, the length of the bar increases by an amount δl and the diameter decreases by an amount δd, as shown in Fig. (b). similarly, if the bar is subjected to a compressive force, the length of bar will decrease which will be followed by increase in diameter.

It is thus obvious, that every direct stress is accompanied by a strain in its own direction which is known as *linear strain* and an opposite kind of strain in every direction, at right angles to it, is known as *lateral strain.*

4.18 Poisson's Ratio

It has been found experimentally that when a body is stressed within elastic limit, the lateral strain bears a constant ratio to the linear strain, Mathematically,

$$\frac{\text{LateralStrain}}{\text{LinearStrain}} = \text{Constant}$$

This constant is known as **Poisson's ratio** and is denoted by $1/m$ or μ.

Following are the values of Poisson's ratio for some of the materials commonly used in engineering practice.

Values of Poisson's ratio for commonly used materials

S.No.	*Material*	*Poisson 's ratio (1/m or μ)*
1	**Steel**	0.25 **to** 0.33
2	Cast iron	0.23 **to** 0.27
3	Copper	0.31 to 0.34
4	Brass	0.32 **to** 0.42
5	Aluminium	0.32 to 0.36
6	Concrete	0.08 to 0.18
7	Rubber	0.45 to 0.50

Volumetric Strain

When a body is subjected to a system of forces, it undergoes some changes in its dimensions. In other words, the volume of the body is changed. The ratio of the change in volume to the original volume is known as ***volumetric strain.*** Mathematically, volumetric strain,

$$\varepsilon_v = \delta V / V$$

Where δV = Change in volume, and V = Original volume

Notes : 1. Volumetric strain of a rectangular body subjected to an axial force is given as

$$\varepsilon_v = \frac{\delta V}{V} - \varepsilon\left(1 - \frac{2}{m}\right), \text{ where } \varepsilon = \text{Linear strain.}$$

2. Volumetric strain of a rectangular body subjected to three mutually perpendicular forces is given by

$$\varepsilon_v = \varepsilon_x + \varepsilon_y + \varepsilon_z$$

where ε_x, ε_y and ε_z are the strains in the directions *x*-axis, *y*-axis and *z*-axis respectively.

Bulk Modulus

When a body is subjected to three mutually perpendicular stresses, of equal intensity, then the ratio of the direct stress to the corresponding volumetric strain is known as ***bulk modulus.*** It is usually denoted by *K*. Mathematically, bulk modulus,

$$K = \frac{\text{Direct stress}}{\text{Volumetric strain}} = \frac{\sigma}{\delta V / V}$$

Relation Between Bulk Modulus and Young's Modulus

The bulk modulus (*K*) and Young's modulus (*E*) are related by the following relation,

$$K = \frac{m.E}{3\,(m-2)} = \frac{E}{3\,(1-2\mu)}$$

Relation between Young's Modulus and Modulus of Rigidity

The Young's modulus (*E*) and modulus of rigidity (*G*) are related by the following relation,

$$G = \frac{m.E}{2\,(m+1)} = \frac{E}{2\,(1+\mu)}$$

Factor of Safety

It is defined, in general, as the **ratio of the maximum** stress **to the working** stress. Mathematically,

Factor of safety = Maximum stress/ Working or design stress

In case of ductile materials *e.g.* mild steel, where the yield point is clearly defined, the factor of safety is based upon the yield point stress. In such cases,

Factor of safety = Yield point stress/ Working or design stress

In case of brittle materials *e.g.* cast iron, the yield point is not well defined as for ductile materials. Therefore, the factor of safety for brittle materials is based on ultimate stress.

Factor of safety = Ultimate stress/ Working or design stress

This relation may also be used for ductile materials.

The above relations for factor of safety are for static loading.

Stresses due to Change in Temperature—Thermal Stresses

Whenever there is some increase or decrease in the temperature of a body, it causes the body to expand or contract. A little consideration will show that if the body is allowed to expand or contract freely, with the rise or fall of the temperature, no stresses are induced in the body. But, if the deformation of the body is prevented, some stresses are induced in the body. Such stresses are known as *thermal stresses.*

Let l = Original length of the body,

t = Rise or fall of temperature, and

α = Coefficient of thermal expansion,

δl Increase or decrease in length,

$$\delta l = l.\,\alpha.t$$

If the ends of the body are fixed to rigid supports, so that its expansion is prevented, then compressive strain induced in the body,

$$\varepsilon_c = \frac{\delta l}{l} = \frac{l.\alpha.t}{l} = \alpha.t$$

Thermal stress,

$$\sigma_{th} = \varepsilon_c.E = \alpha.t.E$$

1. When a body is composed of two or different materials having different coefficient of thermal expansions, then due to the rise in temperature, the material with higher coefficient of thermal expansion will be subjected to compressive stress whereas the material with low coefficient of expansion will be subjected to tensile stress.

2. When a thin tyre is shrunk on to a wheel of diameter D, its internal diameter d is a little less than the wheel diameter. When the type is heated, its circumference πd will increase to πD. In this condition, it is slipped on to the wheel. When it cools, it wants to return to its original circumference πd, but the wheel if it is assumed to be rigid, prevents it from doing so.

$$\text{Strain, } \varepsilon = \frac{\pi D - \pi d}{\pi d} = \frac{D - d}{d}$$

This strain is known as *circumferential* or *hoop strain.*

Therefore, Circumferential or hoop stress,

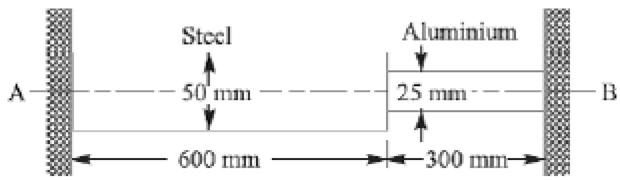
$$\sigma = E.\varepsilon = \frac{E\,(D-d)}{d}$$

Problem:

A composite bar made of aluminum and steel is held between the supports as shown in Fig. The bars are stress free at a temperature of 37°C. What will be the stress in the two bars when the temperature is 20°C, if (a) the supports are unyielding; and (b) the supports yield and come nearer to each other by 0.10 mm?

It can be assumed that the change of temperature is uniform all along the length of the bar.

Take Es = 210 GPa ; Ea = 74 GPa ; $\alpha_s = 11.7 \times 10^{-6}$ / °C ; and $\alpha_a = 23.4 \times 10^{-6}$ / °C.



Solution. Given : $t_1 = 37°C$; $t_2 = 20°C$; $E_s = 210$ GPa $= 210 \times 10^9$ N/m² ; $E_a = 74$ GPa $= 74 \times 10^9$ N/m² ; $\alpha_s = 11.7 \times 10^{-6}$/ °C ; $\alpha_a = 23.4 \times 10^{-6}$/ °C , $d_s = 50$ mm = 0.05 m ; $d_a = 25$ mm = 0.025 m ; $l_s = 600$ mm = 0.6 m ; $l_a = 300$ mm = 0.3 m

Let us assume that the right support at *B* is removed and the bar is allowed to contract freely due to the fall in temperature. We know that the fall in temperature,

$$t = t_1 - t_2 = 37 - 20 = 17°C$$

∴ Contraction in steel bar

$$= \alpha_s \,.\, l_s \,.\, t = 11.7 \times 10^{-6} \times 600 \times 17 = 0.12 \text{ mm}$$

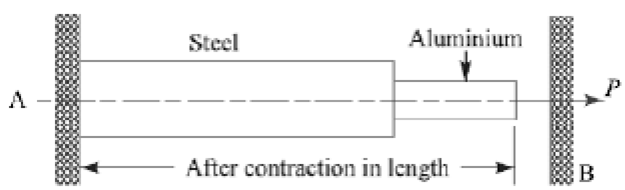
and contraction in aluminium bar

$$= \alpha_a \,.\, l_a \,.\, t = 23.4 \times 10^{-6} \times 300 \times 17 = 0.12 \text{ mm}$$

$$\text{Total contraction } = 0.12 + 0.12 = 0.24 \text{ mm} = 0.24 \times 10^{-3} \text{ m}$$

It may be noted that even after this contraction (*i.e.* 0.24 mm) in length, the bar is still stress free as the right hand end was assumed free.

Let an axial force *P* is applied to the right end till this end is brought in contact with the right and support at *B*, as shown in Fig.



We know that cross-sectional area of the steel bar,

$$A_s = \frac{\pi}{4}(d_s)^2 = \frac{\pi}{4}(0.05)^2 = 1.964 \times 10^{-3} \text{ m}^2$$

and cross-sectional area of the aluminium bar,

$$A_a = \frac{\pi}{4}(d_a)^2 = \frac{\pi}{4}(0.025)^2 = 0.491 \times 10^{-3} \text{ m}^2$$

We know that elongation of the steel bar,

$$\delta l_s = \frac{P \times l_s}{A_s \times E_s} = \frac{P \times 0.6}{1.964 \times 10^{-3} \times 210 \times 10^9} = \frac{0.6P}{412.44 \times 10^6} \text{ m}$$
$$= 1.455 \times 10^{-9} P \text{ m}$$

and elongation of the aluminium bar,

$$\delta l_a = \frac{P \times l_a}{A_a \times E_a} = \frac{P \times 0.3}{0.491 \times 10^{-3} \times 74 \times 10^9} = \frac{0.3P}{36.334 \times 10^6} \text{ m}$$

$$= 8.257 \times 10^{-9} P \text{ m}$$

∴ Total elongation, $\delta l = \delta l_s + \delta l_a$

$$= 1.455 \times 10^{-9} P + 8.257 \times 10^{-9} P = 9.712 \times 10^{-9} P \text{ m}$$

Let σ_s = Stress in the steel bar, and

σ_a = Stress in the aluminium bar.

(a) When the supports are unyielding

When the supports are unyielding, the total contraction is equated to the total elongation, *i.e.*

$$0.24 \times 10^{-3} = 9.712 \times 10^{-9} P \quad \text{or} \quad P = 24\,712 \text{ N}$$

∴ Stress in the steel bar,

$$\sigma_s = P/A_s = 24\,712 / (1.964 \times 10^{-3}) = 12\,582 \times 10^3 \text{ N/m}^2$$
$$= 12.582 \text{ MPa} \quad \textbf{Ans.}$$

and stress in the aluminium bar,

$$\sigma_a = P/A_a = 24\,712 / (0.491 \times 10^{-3}) = 50\,328 \times 10^3 \text{ N/m}^2$$
$$= 50.328 \text{ MPa} \quad \textbf{Ans.}$$

(b) When the supports yield by 0.1 mm

When the supports yield and come nearer to each other by 0.10 mm, the net contraction in length

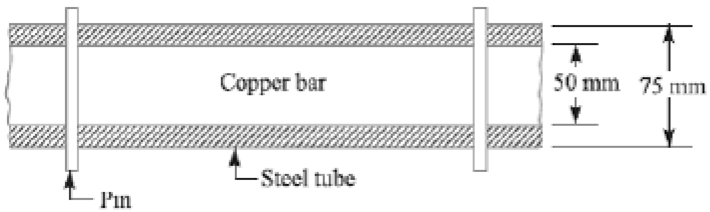
$$= 0.24 - 0.1 = 0.14 \text{ mm} = 0.14 \times 10^{-3} \text{ m}$$

Problem:

A copper bar 50 mm in diameter is placed within a steel tube 75 mm external diameter and 50 mm internal diameter of exactly the same length. The two pieces are rigidly fixed together by two pins 18 mm in diameter, one at each end passing through the bar and tube. Calculate the stress induced in the copper bar, steel tube and pins if the temperature of the combination is raised by 50°C. Take E_s = 210 GN/m^2 ; E_c = 105 GN/m^2 ; $\alpha_s = 11.5 \times 10^{-6}$/°C and $\alpha_c = 17 \times 10^{-6}$/°C.

Solution. Given: d_c = 50 mm ; d_{se} = 75 mm ; d_{si} = 50 mm ; d_p = 18 mm = 0.018 m ; t = 50°C; E_s = 210 GN/m^2 = 210 × 10^9 N/m^2 ; E_c = 105 GN/m^2 = 105 × 10^9 N/m^2 ; $\alpha_s = 11.5 \times 10^{-6}$/°C ; $\alpha_c = 17 \times 10^{-6}$/°C

The copper bar in a steel tube is shown in Fig. 4.18.



We know that cross-sectional area of the copper bar,

$$A_c = \frac{\pi}{4}(d_c)^2 = \frac{\pi}{4}(50)^2 = 1964 \text{ mm}^2 = 1964 \times 10^{-6} \text{ m}^2$$

and cross-sectional area of the steel tube,

$$A_s = \frac{\pi}{4}\left[(d_{se})^2 - (d_{si})^2\right] = \frac{\pi}{4}\left[(75)^2 - (50)^2\right] = 2455 \text{ mm}^2$$

$$= 2455 \times 10^{-6} \text{ m}^2$$

Let l = Length of the copper bar and steel tube.

We know that free expansion of copper bar

$$= \alpha_c \,.\, l \,.\, t = 17 \times 10^{-6} \times l \times 50 = 850 \times 10^{-6}\, l$$

and free expansion of steel tube

$$= \alpha_s \,.\, l \,.\, t = 11.5 \times 10^{-6} \times l \times 50 = 575 \times 10^{-6}\, l$$

∴ Difference in free expansion

$$= 850 \times 10^{-6}\, l - 575 \times 10^{-6}\, l = 275 \times 10^{-6}\, l \qquad ...(i)$$

Since the free expansion of the copper bar is more than the free expansion of the steel tube, therefore the copper bar is subjected to a compressive stress, while the steel tube is subjected to a tensile stress. Let a compressive force P newton on the copper bar opposes the extra expansion of the copper bar and an equal tensile force P on the steel tube pulls the steel tube so that the net effect of reduction in length of copper bar and the increase in length of steel tube equalizes the difference in free expansion of the two.

Therefore, Reduction in length of copper bar due to force P

$$= \frac{P \,.\, l}{A_c \,.\, E_c}$$

$$= \frac{P.l}{1964 \times 10^{-6} \times 105 \times 10^{9}} = \frac{P.l}{206.22 \times 10^{6}} \text{ m}$$

and increase in length of steel bar due to force P

$$= \frac{P.l}{A_s . E_s} = \frac{P.l}{2455 \times 10^{-6} \times 210 \times 10^{9}} = \frac{P.l}{515.55 \times 10^{6}} \text{ m}$$

$$\therefore \text{Net effect in length} = \frac{P.l}{206.22 \times 10^{6}} + \frac{P.l}{515.55 \times 10^{6}}$$

$$= 4.85 \times 10^{-9} P.l + 1.94 \times 10^{-9} P.l = 6.79 \times 10^{-9} P.l$$

Equating this net effect in length to the difference in free expansion, we have

$$6.79 \times 10^{-9} P.l = 275 \times 10^{-6} l \quad \text{or} \quad P = 40\,500 \text{ N}$$

Stress induced in the copper bar, steel tube and pins

We know that stress induced in the copper bar,

$$\sigma_c = P / A_c = 40\,500 / (1964 \times 10^{-6}) = 20.62 \times 10^{6} \text{ N/m}^2 = 20.62 \text{ MPa} \textbf{ Ans.}$$

Stress induced in the steel tube,

$$\sigma_s = P / A_s = 40\,500 / (2455 \times 10^{-6}) = 16.5 \times 10^{6} \text{ N / m}^2 = 16.5 \text{ MPa} \textbf{ Ans.}$$

and shear stress induced in the pins,

$$\tau_p = \frac{P}{2\,A_p} = \frac{40\,500}{2 \times \frac{\pi}{4} (0.018)^2} = 79.57 \times 10^{6} \text{ N/m}^2 = 79.57 \text{ MPa} \textbf{ Ans.}$$

...($\because$ The pin is in double shear)

Where T = Torque transmitted in N-m, and

ω = Angular speed in rad/s.

Problem:

A shaft is transmitting 100 kW at 160 r.p.m. Find a suitable diameter for the shaft, if the maximum torque transmitted exceeds the mean by 25%. Take maximum allowable shear stress as 70 MPa.

Solution. Given : $P = 100$ kW $= 100 \times 10^3$ W ; $N = 160$ r.p.m ; $T_{max} = 1.25\ T_{mean}$; $\tau = 70$ MPa $= 70$ N/mm^2

Let T_{mean} = Mean torque transmitted by the shaft in N m, and

d = Diameter of the shaft in mm.

We know that the power transmitted (P),

$$100 \times 10^3 = \frac{2\ \pi\ N\ .\ T_{mean}}{60} = \frac{2\pi \times 160 \times T_{mean}}{60} = 16.76\ T_{mean}$$

$$\therefore \quad T_{mean} = 100 \times 10^3/16.76 = 5966.6 \text{ N-m}$$

and maximum torque transmitted,

$$T_{max} = 1.25 \times 5966.6 = 7458 \text{ N-m} = 7458 \times 10^3 \text{ N-mm}$$

We know that maximum torque (T_{max}),

$$7458 \times 10^3 = \frac{\pi}{16} \times \tau \times d^3 = \frac{\pi}{16} \times 70 \times d^3 = 13.75\ d^3$$

$$\therefore \quad d^3 = 7458 \times 10^3/13.75 = 542.4 \times 10^3 \text{ or } d = 81.5 \text{ mm } \textbf{Ans.}$$

Bending Stress

In engineering practice, the machine parts of structural members may be subjected to static or dynamic loads which cause bending stress in the sections besides other types of stresses such as tensile, compressive and shearing stresses. Consider a straight beam subjected to a bending moment M as shown in Fig.

The following assumptions are usually made while deriving the bending formula.

1. The material of the beam is perfectly homogeneous (*i.e.* of the same material throughout) and isotropic (*i.e.* of equal elastic properties in all directions).

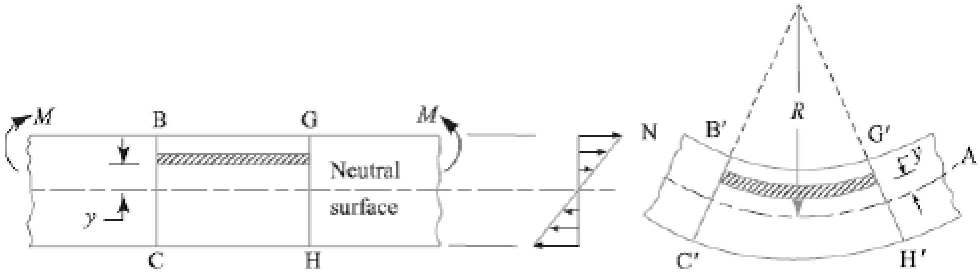
2. The material of the beam obeys Hooke's law.

3. The transverse sections (*i.e.* BC or GH) which were plane before bending remain plane after bending also.

4. Each layer of the beam is free to expand or contract, independently, of the layer, above or below it.

5. The Young's modulus (E) is the same in tension and compression.

6. The loads are applied in the plane of bending.



A little consideration will show that when a beam is subjected to the bending moment, the fibres on the upper side of the beam will be shortened due to compression and those on the lower side will be elongated due to tension. It may be seen that somewhere between the top and bottom fibres there is a surface at which the fibres are neither shortened nor lengthened. Such a surface is called ***neutral surface***. The intersection of the neutral surface with any normal cross-section of the beam is known *as* ***neutral axis***. The stress distribution of a beam is shown in Fig. The bending equation is given by

$$\frac{M}{I} = \frac{\sigma}{y} - \frac{E}{R}$$

Where M = Bending moment acting at the given section,

σ = Bending stress,

I = Moment of inertia of the cross-section about the neutral axis,

y = Distance from the neutral axis to the extreme fibre,

E = Young's modulus of the material of the beam, and

R = Radius of curvature of the beam.

From the above equation, the bending stress is given by

$$\upsilon = y \times \frac{E}{R}$$

Since E and R are constant, therefore within elastic limit, the stress at any point is directly proportional to y, *i.e.* the distance of the point from the neutral axis.

Also from the above equation, the bending stress,

$$\sigma = \frac{M}{I} \times y = \frac{M}{I / y} = \frac{M}{Z}$$

The ratio I/y is known as ***section modulus*** and is denoted by Z.

Notes: 1. the neutral axis of a section always passes through its centroid.

2. In case of symmetrical sections such as circular, square or rectangular, the neutral axis passes through its geometrical centre and the distance of extreme fibre from the neutral axis is $y = d / 2$, where d is the diameter in case of circular section or depth in case of square or rectangular section.

3. In case of unsymmetrical sections such as L-section or T-section, the neutral axis does not pass through its geometrical centre. In such cases, first of all the centroid of the section is calculated and then the distance of the extreme fibres for both lower and upper side of the section is obtained. Out of these two values, the bigger value is used in bending equation.

Problem:

A beam of uniform rectangular cross-section is fixed at one end and carries an electric motor weighing 400 N at a distance of 300 mm from the fixed end. The maximum bending stress in the beam is 40 MPa. Find the width and depth of the beam, if depth is twice that of width.

Solution. Given: $W = 400$ N ; $L = 300$ mm ; $\sigma_b = 40$ MPa $= 40$ N/mm^2 ; $h = 2b$

The beam is shown in Fig. 5.7.

Let b = Width of the beam in mm, and

h = Depth of the beam in mm.

∴ Section modulus,

$$Z = \frac{b \cdot h^2}{6} = \frac{b\,(2b)^2}{6} = \frac{2\,b^3}{3} \text{ mm}^3$$

Maximum bending moment (at the fixed end),

$$M = WL = 400 \times 300 = 120 \times 10^3 \text{ N mm}$$

We know that bending stress (σ_b),

$$40 = \frac{M}{Z} = \frac{120 \times 10^3 \times 3}{2\,b^3} = \frac{180 \times 10^3}{b^3}$$

∴ $b^3 = 180 \times 10^3/40 = 4.5 \times 10^3$ or $b = 16.5$ mm **Ans.**

and $h = 2b = 2 \times 16.5 = 33$ mm **Ans.**

Principal Stresses and Principal Planes

In the previous chapter, we have discussed about the direct tensile and compressive stress as well as simple shear. Also we have always referred the stress in a plane which is at right angles to the line of action of the force. But it has been observed that at any point in a strained material, there are three planes, mutually perpendicular to each other which carry direct stresses only and no shear stress. It may be noted that out of these three direct stresses, one will be maximum and the other will be minimum. These perpendicular planes which have no shear stress are known as *principal planes* and the direct stresses along these planes are known as *principal stresses*. The planes on which the maximum shear stress act are known as planes of maximum shear.

Determination of Principal Stresses for a Member Subjected to Bi-axial Stress

When a member is subjected to bi-axial stress (*i.e.* direct stress in two mutually perpendicular planes accompanied by a simple shear stress), then the normal and shear stresses are obtained as discussed below:

Consider a rectangular body *ABCD* of uniform cross-sectional area and unit thickness subjected to normal stresses σ_1 and σ_2 as shown in Fig. (*a*). In addition to these normal stresses, a shear stress τ also acts. It has been shown in books on '*Strength of Materials*' that the normal stress across any oblique section such as *EF* inclined at an angle θ with the direction of σ_2, as shown in Fig. (*a*), is given by

$$\sigma_t = \frac{\sigma_1 + \sigma_2}{2} + \frac{\sigma_1 + \sigma_2}{2} \cos 2\theta + \tau \sin 2\theta \qquad ...(i)$$

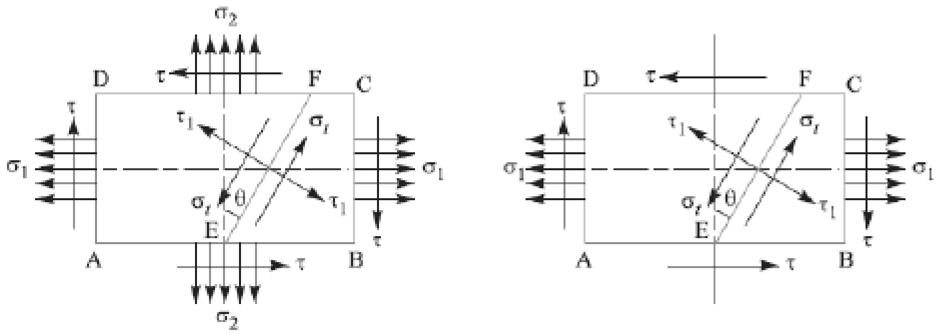
And tangential stress (*i.e.* shear stress) across the section *EF*,

$$\tau_1 = \frac{1}{2} (\sigma_1 - \sigma_2) \sin 2\theta - \tau \cos 2\theta \qquad ...(ii)$$

Since the planes of maximum and minimum normal stress (*i.e.* principal planes) have no shear stress, therefore the inclination of principal planes is obtained by equating $\tau_1 = 0$ in the above equation (*ii*), *i.e.*

$$\frac{1}{2} (\sigma_1 - \sigma_2) \sin 2\theta - \tau \cos 2\theta = 0$$

$$\tan 2\theta = \frac{2\tau}{\sigma_1 - \sigma_2} \qquad ...(iii)$$



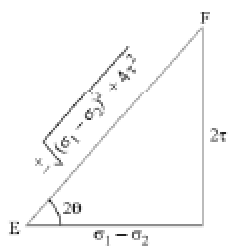
(*a*) Direct stress in two mutually prependicular planes accompanied by a simple shear stress.

(*b*) Direct stress in one plane accompanied by a simple shear stress.

Fig. Principal stresses for a member subjected to bi-axial stress

We know that there are two principal planes at right angles to each other. Let θ_1 and θ_2 be the inclinations of these planes with the normal cross-section. From the following Fig., we find that

$$\sin 2\theta = \pm \frac{2\tau}{\sqrt{(\sigma_1 - \sigma_2)^2 + 4\tau^2}}$$



$$\therefore \qquad \sin 2\theta_1 = + \frac{2\tau}{\sqrt{(\sigma_1 - \sigma_2)^2 + 4\tau^2}}$$

$$\text{and} \qquad \sin 2\theta_2 = - \frac{2\tau}{\sqrt{(\sigma_1 - \sigma_2)^2 + 4\tau^2}}$$

$$\text{Also} \qquad \cos 2\theta = \pm \frac{\sigma_1 - \sigma_2}{\sqrt{(\sigma_1 - \sigma_2)^2 + 4\tau^2}}$$

$$\therefore \qquad \cos 2\theta_1 = + \frac{\sigma_1 - \sigma_2}{\sqrt{(\sigma_1 - \sigma_2)^2 + 4\tau^2}}$$

$$\text{and} \qquad \cos 2\theta_2 = - \frac{\sigma_1 - \sigma_2}{\sqrt{(\sigma_1 - \sigma_2)^2 + 4\tau^2}}$$

The maximum and minimum principal stresses may now be obtained by substituting the values of sin 2θ and cos 2θ in equation (*i*).

So, Maximum principal (or normal) stress,

$$\sigma_{t1} = \frac{\sigma_1 + \sigma_2}{2} + \frac{1}{2}\sqrt{(\sigma_1 - \sigma_2)^2 + 4\,\tau^2} \quad \ldots(iv)$$

And minimum principal (or normal) stress,

$$\sigma_{t2} = \frac{\sigma_1 + \sigma_2}{2} - \frac{1}{2}\sqrt{(\sigma_1 - \sigma_2)^2 + 4\,\tau^2} \quad \ldots(v)$$

The planes of maximum shear stress are at right angles to each other and are inclined at 45° to the principal planes. The maximum shear stress is given by ***one-half the algebraic difference between the principal stresses,*** *i.e.*

$$\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sqrt{(\sigma_1 - \sigma_2)^2 + 4\,\tau^2} \quad \ldots(vi)$$

Notes: 1. when a member is subjected to direct stress in one plane accompanied by a simple shear stress, then the principal stresses are obtained by substituting $\sigma_2 = 0$ in equation (*iv*), (*v*) and (*vi*).

$$\sigma_{t1} = \frac{\sigma_1}{2} + \frac{1}{2}\left[\sqrt{(\sigma_1)^2 + 4\,\tau^2}\right]$$

$$\sigma_{t2} = \frac{\sigma_1}{2} - \frac{1}{2}\left[\sqrt{(\sigma_1)^2 + 4\,\tau^2}\right]$$

$$\tau_{max} = \frac{1}{2}\left[\sqrt{(\sigma_1)^2 + 4\,\tau^2}\right]$$

2. In the above expression of $\sigma t2$, the value of $\frac{1}{2}\left[\sqrt{(\sigma_1)^2 + 4\,\tau^2}\right]$ is more than $\sigma_1/2$ Therefore the nature of σ_{t2} will be opposite to that of σ_{t1}, *i.e.* if σ_{t1} is tensile then σ_{t2} will be compressive and *vice-versa*.

Application of Principal Stresses in Designing Machine Members

There are many cases in practice, in which machine members are subjected to combined stresses due to simultaneous action of either tensile or compressive stresses combined with shear stresses. In many shafts such as propeller shafts, C-frames etc., there are direct tensile or compressive stresses due to the external force and shear stress due to torsion, which acts normal to direct tensile or compressive stresses. The shafts like crank shafts, are subjected simultaneously to torsion and bending. In such cases, the maximum principal stresses, due to the combination of tensile or compressive stresses with shear stresses may be obtained. The results obtained in the previous article may be written as follows:

1. Maximum tensile stress,

$$\sigma_{t(max)} = \frac{\sigma_t}{2} + \frac{1}{2}\left[\sqrt{(\sigma_t)^2 + 4\,\tau^2}\right]$$

2. Maximum compressive stress,

$$\sigma_{c(max)} = \frac{\sigma_c}{2} + \frac{1}{2}\left[\sqrt{(\sigma_c)^2 + 4\,\tau^2}\right]$$

3. Maximum shear stress,

$$\tau_{max} = \frac{1}{2}\left[\sqrt{(\sigma_t)^2 + 4\,\tau^2}\right]$$

Where σ_t = Tensile stress due to direct load and bending,

σ_c = Compressive stress, and

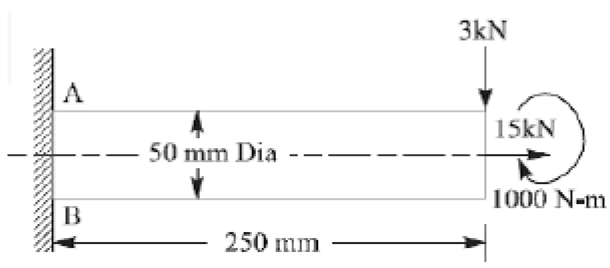
τ = Shear stress due to torsion.

Notes: 1. When $\tau = 0$ as in the case of thin cylindrical shell subjected in internal fluid pressure, then $\sigma_{tmax} = \sigma_t$

2. When the shaft is subjected to an axial load (*P*) in addition to bending and twisting moments as in the propeller shafts of ship and shafts for driving worm gears, then the stress due to axial load must be added to the bending stress (σ_b). This will give the resultant tensile stress or compressive stress (σ_t or σ_c) depending upon the type of axial load (*i.e.* pull or push).

Problem:

A shaft, as shown in Fig., is subjected to a bending load of 3 kN, pure torque of 1000 N-m and an axial pulling force of 15 kN. Calculate the stresses at A and B.



Solution. Given : $W = 3$ kN $= 3000$ N ; $T = 1000$ N-m $= 1 \times 10^6$ N-mm ; $P = 15$ kN $= 15 \times 10^3$ N ; $d = 50$ mm; $x = 250$ mm

We know that cross-sectional area of the shaft,

$$A = \frac{\pi}{4} \times d^2$$

$$= \frac{\pi}{4} (50)^2 = 1964 \text{ mm}^2$$

$\therefore$ Tensile stress due to axial pulling at points A and B,

$$\sigma_o = \frac{P}{A} = \frac{15 \times 10^3}{1964} = 7.64 \text{ N/mm}^2 = 7.64 \text{ MPa}$$

Bending moment at points A and B,

$$M = W.x = 3000 \times 250 = 750 \times 10^3 \text{ N-mm}$$

Section modulus for the shaft,

$$Z = \frac{\pi}{32} \times d^3 = \frac{\pi}{32} (50)^3$$

$$= 12.27 \times 10^3 \text{ mm}^3$$

$\therefore$ Bending stress at points A and B,

$$\sigma_b = \frac{M}{Z} = \frac{750 \times 10^3}{12.27 \times 10^3}$$

$$= 61.1 \text{ N/mm}^2 = 61.1 \text{ MPa}$$

This bending stress is tensile at point A and compressive at point B.

$\therefore$ Resultant tensile stress at point A,

$$\sigma_A = \sigma_b + \sigma_o = 61.1 + 7.64$$
$$= 68.74 \text{ MPa}$$

and resultant compressive stress at point B,

$$\sigma_B = \sigma_b - \sigma_o = 61.1 - 7.64 = 53.46 \text{ MPa}$$

We know that the shear stress at points A and B due to the torque transmitted,

$$\tau = \frac{16\,T}{\pi\,d^3} = \frac{16 \times 1 \times 10^6}{\pi\,(50)^3} = 40.74 \text{ N/mm}^2 = 40.74 \text{ MPa} \qquad \ldots\left(\because\ T = \frac{\pi}{16} \times \tau \times d^3\right)$$

Stresses at point A

We know that maximum principal (or normal) stress at point *A*,

$$\sigma_{A(max)} = \frac{\sigma_A}{2} + \frac{1}{2}\left[\sqrt{(\sigma_A)^2 + 4\,\tau^2}\right]$$

$$= \frac{68.74}{2} + \frac{1}{2}\left[\sqrt{(68.74)^2 + 4\,(40.74)^2}\right]$$

$= 34.37 + 53.3 = 87.67$ MPa (tensile) **Ans.**

Minimum principal (or normal) stress at point *A*,

$$\sigma_{A(min)} = \frac{\sigma_A}{2} - \frac{1}{2}\left[\sqrt{(\sigma_A)^2 + 4\,\tau^2}\right] = 34.37 - 53.3 = -18.93 \text{ MPa}$$

$= 18.93$ MPa (compressive) **Ans.**

and maximum shear stress at point *A*,

$$\tau_{A(max)} = \frac{1}{2}\left[\sqrt{(\sigma_A)^2 + 4\,\tau^2}\right] = \frac{1}{2}\left[\sqrt{(68.74)^2 + 4\,(40.74)^2}\right]$$

$= 53.3$ MPa **Ans.**

Stresses at point B

We know that maximum principal (or normal) stress at point *B*,

$$\sigma_{B(max)} = \frac{\sigma_B}{2} + \frac{1}{2}\left[\sqrt{(\sigma_B)^2 + 4\,\tau^2}\right]$$

$$= \frac{53.46}{2} + \frac{1}{2}\left[\sqrt{(53.46)^2 + 4\,(40.74)^2}\right]$$

$= 26.73 + 48.73 = 75.46$ MPa (compressive) **Ans.**

Minimum principal (or normal) stress at point *B*,

$$\sigma_{B(min)} = \frac{\sigma_B}{2} - \frac{1}{2}\left[\sqrt{(\sigma_B)^2 + 4\tau^2}\right]$$

$= 26.73 - 48.73 = -22$ MPa

$= 22$ MPa (tensile) **Ans.**

and maximum shear stress at point *B*,

$$\tau_{B(max)} = \frac{1}{2}\left[\sqrt{(\sigma_B)^2 + 4\,\tau^2}\right] = \frac{1}{2}\left[\sqrt{(53.46)^2 + 4\,(40.74)^2}\right]$$

$= 48.73$ MPa **Ans.**

A 50 mm diameter shaft is made from carbon steel having ultimate tensile strength of 630 MPa. It is subjected to a torque which fluctuates between 2000 N-m to – 800 N-m. Using Soderberg method, calculate the factor of safety. Assume suitable values for any other data needed.

Solution. Given : $d = 50$ mm ; $\sigma_u = 630$ MPa $= 630$ N/mm^2 ; $T_{max} = 2000$ N-m ; $T_{min} = -800$ N-m

We know that the mean or average torque,

$$T_m = \frac{T_{max} + T_{min}}{2} = \frac{2000 + (-800)}{2} = 600 \text{ N-m} = 600 \times 10^3 \text{ N-mm}$$

∴ Mean or average shear stress,

$$\tau_m = \frac{16\, T_m}{\pi d^3} = \frac{16 \times 600 \times 10^3}{\pi (50)^3} = 24.4 \text{ N/mm}^2 \qquad \ldots \left(\because T = \frac{\pi}{16} \times \tau \times d^3 \right)$$

Variable torque,

$$T_v = \frac{T_{max} - T_{min}}{2} = \frac{2000 - (-800)}{2} = 1400 \text{ N-m} = 1400 \times 10^3 \text{ N-mm}$$

$$\therefore \text{ Variable shear stress, } \tau_v = \frac{16\, T_v}{\pi d^3} = \frac{16 \times 1400 \times 10^3}{\pi (50)^3} = 57 \text{ N/mm}^2$$

Since the endurance limit in reversed bending (σ_e) is taken as one-half the ultimate tensile strength (*i.e.* $\sigma_e = 0.5\,\sigma_u$) and the endurance limit in shear (τ_e) is taken as $0.55\,\sigma_e$, therefore

$$\tau_e = 0.55\,\sigma_e = 0.55 \times 0.5\,\sigma_u = 0.275\,\sigma_u$$
$$= 0.275 \times 630 = 173.25 \text{ N/mm}^2$$

Assume the yield stress (σ_y) for carbon steel in reversed bending as 510 N/mm^2, surface finish factor (K_{sur}) as 0.87, size factor (K_{sz}) as 0.85 and fatigue stress concentration factor (K_{fs}) as 1

Since the yield stress in shear (τ_y) for shear loading is taken as one-half the yield stress in reversed bending (σ_y), therefore

$$\tau_y = 0.5\,\sigma_y = 0.5 \times 510 = 255 \text{ N/mm}^2$$

Let $\quad F.S.$ = Factor of safety.

We know that according to Soderberg's formula,

$$\frac{1}{F.S.} = \frac{\tau_m}{\tau_y} + \frac{\tau_v \times K_{fs}}{\tau_e \times K_{sur} \times K_{sz}} = \frac{24.4}{255} + \frac{57 \times 1}{173.25 \times 0.87 \times 0.85}$$
$$= 0.096 + 0.445 = 0.541$$

$$\therefore \quad F.S. = 1 / 0.541 = 1.85 \quad \textbf{Ans.}$$

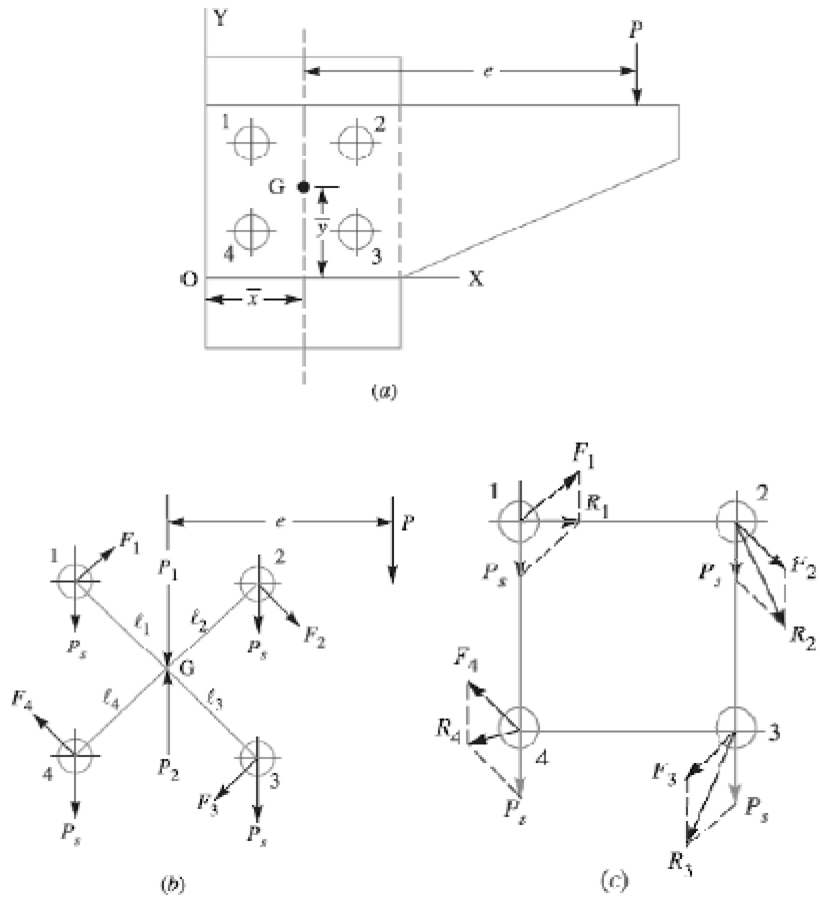


Fig. 1. Eccentric loaded riveted joint.

2. Introduce two forces *P*1 and *P*2 at the centre of gravity '*G*' of the rivet system. These forces are equal and opposite to *P* as shown in Fig.(*b*).

3. Assuming that all the rivets are of the same size, the effect of $P_1 = P$ is to produce direct shear load on each rivet of equal magnitude. Therefore, direct shear load on each rivet,

$$P_s = \frac{P}{n}, \text{acting parallel to the load P,}$$

4. The effect of $P_2 = P$ is to produce a turning moment of magnitude $P \times e$ which tends to rotate the joint about the centre of gravity '*G*' of the rivet system in a clockwise direction. Due to the turning moment, secondary shear load on each rivet is produced. In order to find the secondary shear load, the following two assumptions are made:

(*a*) The secondary shear load is proportional to the radial distance of the rivet under consideration from the centre of gravity of the rivet system.

(*b*) The direction of secondary shear load is perpendicular to the line joining the centre of the rivet to the centre of gravity of the rivet system..

Let F_1, F=, F_3 ... = Secondary shear loads on the rivets 1, 2, 3...etc.

F_1, F_2, F_3 ... = Radial distance of the rivets 1, 2, 3 ...etc. from the centre of gravity '*G*' of the rivet system.

∴ From assumption (*a*), $F_1 \propto l_1$; $F_2 \propto l_2$ and so on

or $$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \ldots$$

$$F_2 = F_1 \times \frac{l_2}{l_1}, \text{ and } F_3 = F_1 \times \frac{l_3}{l_1}$$

We know that the sum of the external turning moment due to the eccentric load and of internal resisting moment of the rivets must be equal to zero.

$$\therefore P.e = F_1.l_1 + F_2.l_2 + F_3.l_3 + \ldots$$

$$= F_1 l_1 + F_1 \times \frac{l_2}{l_1} \times l_2 + F_1 \times \frac{l_3}{l_1} \times l_3 + \ldots$$

$$= \frac{F_1}{l_1}\left[(l_1)^2 + (l_2)^2 + (l_3)^2 + \ldots\right]$$

From the above expression, the value of F_1 may be calculated and hence F_2 and F_3 etc. are known. The direction of these forces are at right angles to the lines joining the centre of rivet to the centre of gravity of the rivet system, as shown in Fig. 1(*b*), and should produce the moment in the same direction (*i.e.* clockwise or anticlockwise) about the centre of gravity, as the turning moment ($P \times e$).

5. The primary (or direct) and secondary shear load may be added vectorially to determine the resultant shear load (*R*) on each rivet as shown in Fig.1 (*c*). It may also be obtained by using the relation

$$R = \sqrt{(P_s)^2 + F_2 + 2Ps \times F \times \cos\theta}$$

Where θ = Angle between the primary or direct shear load (P_s)

And secondary shear load (F).

When the secondary shear load on each rivet is equal, then the heavily loaded rivet will be one in which the included angle between the direct shear load and secondary shear load is minimum. The maximum loaded rivet becomes the critical one for determining the strength of the riveted joint. Knowing the permissible shear stress (τ), the diameter of the rivet hole may be obtained by using the relation,

$$\text{Maximum resultant shear load } (R) = \frac{\pi}{4} \times d^2 \times \tau$$

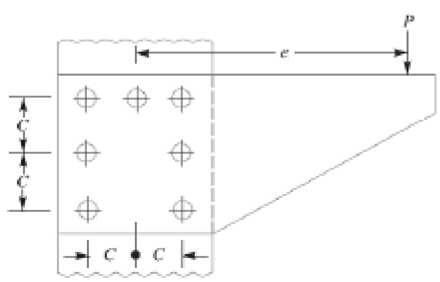
From DDB, the standard diameter of the rivet hole (d) and the rivet diameter may be specified

Notes : 1. In the solution of a problem, the primary and shear loads may be laid off approximately to scale and generally the rivet having the maximum resultant shear load will be apparent by inspection. The values of the load for that rivet may then be calculated.

2. When the thickness of the plate is given, then the diameter of the rivet hole may be checked against crushing.

3. When the eccentric load P is inclined at some angle, then the same procedure as discussed above may be followed to find the size of rivet.

Problem: An eccentrically loaded lap riveted joint is to be designed for a steel bracket as shown in Fig. 2. The bracket plate is 25 mm thick. All rivets are to be of the same size. Load on the bracket, P = 50 kN ; rivet spacing, C = 100 mm; load arm, e = 400 mm. Permissible shear stress is 65 MPa and crushing stress is 120 MPa. Determine the size of the rivets to be used for the joint.



Solution. Given: t = 25 mm ; P = 50 kN = 50 × 103 N ; e = 400 mm ; n = 7 ; τ= 65 MPa = 65 N/mm$_2$; □c = 120 MPa = 120 N/mm^2.

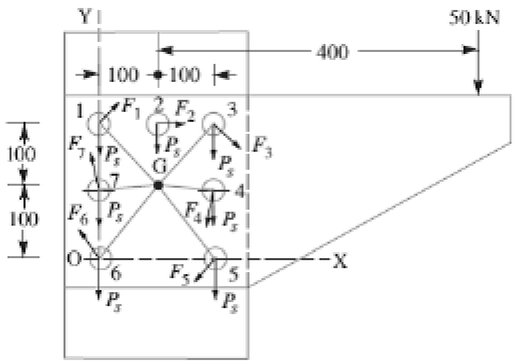


Fig.2

First of all, let us find the centre of gravity (G) of the rivet system.

Let $\bar{x}$ = Distance of centre of gravity from OY,

$\bar{y}$ = Distance of centre of gravity from OX,

$x_1, x_2, x_3...$ = Distances of centre of gravity of each rivet from OY, and

$y_1, y_2, y_3...$ = Distances of centre of gravity of each rivet from OX.

We know that

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7}{n}$$

$$= \frac{100 + 200 + 200 + 200}{7} = 100 \text{ mm} \qquad ...(\because x_1 = x_6 = x_7 = 0)$$

$$\bar{y} = \frac{y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7}{n}$$

$$= \frac{200 + 200 + 200 + 100 + 100}{7} = 114.3 \text{ mm} \quad ...(\because y_5 = y_6 = 0)$$

The centre of gravity (G) of the rivet system lies at a distance of 100 mm from OY and 114.3 mm from OX, as shown in Fig. 2.

We know that direct shear load on each rivet,

Unit-II Design of shafts and coupling

Shafts:

A shaft is a rotating machine element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. In order to transfer the power from one shaft to another, the various members such as pulleys, gears etc., are mounted on it. These members along with the forces exerted upon them causes the shaft to bending.

In other words, we may say that a shaft is used for the transmission of torque and bending moment. The various members are mounted on the shaft by means of keys or splines. The shafts are usually cylindrical, but may be square or cross-shaped in section. They are solid in cross-section but sometimes hollow shafts are also used. An ***axle***, though similar in shape to the shaft, is a stationary machine element and is used for the transmission of bending moment only. It simply acts as a support for some rotating body such as hoisting drum, a car wheel or a rope sheave. A ***spindle*** is a short shaft that imparts motion either to a cutting tool (*e.g.* drill press spindles) or to a work piece (*e.g.* lathe spindles).

Types of Shafts

The following two types of shafts are important from the subject point of view:

1. ***Transmission shafts.*** These shafts transmit power between the source and the machines absorbing power. The counter shafts, line shafts, over head shafts and all factory shafts are transmission shafts. Since these shafts carry machine parts such as pulleys, gears etc., therefore they are subjected to bending in addition to twisting.

2. ***Machine shafts.*** These shafts form an integral part of the machine itself. The crank shaft is an example of machine shaft.

Stresses in Shafts

The following stresses are induced in the shafts:

1. Shear stresses due to the transmission of torque (*i.e.* due to torsional load).

2. Bending stresses (tensile or compressive) due to the forces acting upon machine elements like gears, pulleys etc. as well as due to the weight of the shaft itself.

3. Stresses due to combined torsional and bending loads.

Design of Shafts

The shafts may be designed on the basis of

1. Strength, and **2.** Rigidity and stiffness.

In designing shafts on the basis of strength, the following cases may be considered:

(*a*) Shafts subjected to twisting moment or torque only,

(*b*) Shafts subjected to bending moment only,

(*c*) Shafts subjected to combined twisting and bending moments, and

(*d*) Shafts subjected to axial loads in addition to combined torsional and bending loads.

Shafts Subjected to Twisting Moment Only

a) Solid shaft:

When the shaft is subjected to a twisting moment (or torque) only, then the diameter of the shaft may be obtained by using the torsion equation. We know that

$$\frac{T}{J} = \frac{\tau}{r}$$

Where T = Twisting moment (or torque) acting upon the shaft,

J = Polar moment of inertia of the shaft about the axis of rotation,

τ = Torsional shear stress, and

r = Distance from neutral axis to the outer most fibre

= d / 2; where d is the diameter of the shaft.

We know that for round solid shaft, polar moment of inertia,

$$J = \frac{\pi}{32} d^4$$

Then we get, $$T = \frac{\pi d^3}{16} \tau$$

From this equation, diameter of the solid shaft (*d*) may be obtained.

b) Hollow Shaft:

We also know that for hollow shaft, polar moment of inertia,

$$J = \frac{\pi}{32}\left[(d_o)^4 - (d_i)^4\right]$$

Where d_o and d_i = Outside and inside diameter of the shaft, and $r = d_0 / 2$.

Substituting these values in equation (*i*), we have

$$\frac{T}{\frac{\pi}{32}\left[(d_o)^4 - (d_i)^4\right]} = \frac{\tau}{\frac{d_o}{2}} \quad \text{or} \quad T = \frac{\pi}{16} \times \tau \left[\frac{(d_o)^4 - (d_i)^4}{d_o}\right]$$

Let k = Ratio of inside diameter and outside diameter of the shaft = d_i / d_o

Now the equation (*iii*) may be written as

$$T = \frac{\pi}{16} \times \tau \times \frac{(d_o)^4}{d_o}\left[1-\left(\frac{d_i}{d_o}\right)^4\right] = \frac{\pi}{16} \times \tau\,(d_o)^3\,(1-k^4)$$

From the equations, the outside and inside diameter of a hollow shaft may be determined.

It may be noted that

1. The hollow shafts are usually used in marine work. These shafts are stronger per kg of material and they may be forged on a mandrel, thus making the material more homogeneous than would be possible for a solid shaft. When a hollow shaft is to be made equal in strength to a solid shaft, the twisting moment of both the shafts must be same. In other words, for the same material of both the shafts,

$$T = \frac{\pi}{16} \times \tau \left[\frac{(d_o)^4 - (d_i)^4}{d_o}\right] = \frac{\pi}{16} \times \tau \times d^3$$

$$\therefore \qquad \frac{(d_o)^4 - (d_i)^4}{d_o} = d^3 \quad \text{or} \quad (d_o)^3\,(1-k^4) = d^3$$

2. The twisting moment (T) may be obtained by using the following relation:

We know that the power transmitted (in watts) by the shaft,

$$P = \frac{2\pi N \times T}{60} \quad \text{or} \quad T = \frac{P \times 60}{2\pi N}$$

Where T = Twisting moment in N-m, and

N = Speed of the shaft in r.p.m.

3. In case of belt drives, the twisting moment (T) is given by

$T = (T_1 - T_2)\,R$

Where T_1 and T_2 = Tensions in the tight side and slack side of the belt respectively, and R = Radius of the pulley.

Shafts Subjected to Bending Moment Only

a) Solid Shaft:

When the shaft is subjected to a bending moment only, then the maximum stress (tensile or compressive) is given by the bending equation. We know that

$$\frac{M}{I} = \frac{\sigma_b}{y}$$

Where M = Bending moment,

I = Moment of inertia of cross-sectional area of the shaft about the axis of rotation,

σ_b = Bending stress, and

y = Distance from neutral axis to the outer-most fibre.

We know that for a round solid shaft, moment of inertia,

$$I = \frac{\pi}{64} \times d^4 \quad \text{and} \quad y = \frac{d}{2}$$

Substituting these values in equation

$$\frac{M}{\frac{\pi}{64} \times d^4} = \frac{\sigma_b}{\frac{d}{2}} \quad \text{or} \quad M = \frac{\pi}{32} \times \sigma_b \times d^3$$

From this equation, diameter of the solid shaft (d) may be obtained.

b) Hollow Shaft:

We also know that for a hollow shaft, moment of inertia,

$$I = \frac{\pi}{64}\left[(d_o)^4 - (d_i)^4\right] = \frac{\pi}{64}(d_o)^4 (1 - k^4) \quad \text{...(where } k = d_i / d_o)$$

And $y = d_0/2$

Again substituting these values in equation, we have

$$\frac{M}{\frac{\pi}{64}(d_o)^4 (1 - k^4)} = \frac{\sigma_b}{\frac{d_o}{2}} \quad \text{or} \quad M = \frac{\pi}{32} \times \sigma_b (d_o)^3 (1 - k^4)$$

From this equation, the outside diameter of the shaft (do) may be obtained.

Shafts Subjected to Combined Twisting Moment and Bending Moment

When the shaft is subjected to combined twisting moment and bending moment, then the shaft must be designed on the basis of the two moments simultaneously. Various theories have been suggested to account for the elastic failure of the materials when they are subjected to various types of combined stresses. The following two theories are important from the subject point of view:

1. Maximum shear stress theory or Guest's theory. It is used for ductile materials such as mild steel.

2. Maximum normal stress theory or Rankine's theory. It is used for brittle materials such as cast iron.

Let τ = Shear stress induced due to twisting moment, and

σ_b = Bending stress (tensile or compressive) induced due to bending moment.

a) Solid Shaft:

According to maximum shear stress theory, the maximum shear stress in the shaft,

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$$

Substituting the values of σ_b and τ

$$\tau_{max} = \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d^3}\right)^2 + 4\left(\frac{16T}{\pi d^3}\right)^2} = \frac{16}{\pi d^3}\left[\sqrt{M^2 + T^2}\right]$$

or $$\frac{\pi}{16} \times \tau_{max} \times d^3 = \sqrt{M^2 + T^2}$$

The expression $\sqrt{M^2 + T^2}$ is known as ***equivalent twisting moment*** and is denoted by T_e. The equivalent twisting moment may be defined as that twisting moment, which when acting alone, produces the same shear stress (τ) as the actual twisting moment. By limiting the maximum shear stress (τ_{max}) equal to the allowable shear stress (τ) for the material, the equation (*i*) may be written as

$$T_e = \sqrt{M^2 + T^2} = \frac{\pi}{16} \times \tau \times d^3$$

From this expression, diameter of the shaft (d) may be evaluated.

Now according to maximum normal stress theory, the maximum normal stress in the shaft,

$$\sigma_{b(max)} = \frac{1}{2}\sigma_b + \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$$

$$= \frac{1}{2} \times \frac{32M}{\pi d^3} + \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d^3}\right)^2 + 4\left(\frac{16T}{\pi d^3}\right)^2}$$

$$= \frac{32}{\pi d^3}\left[\frac{1}{2}(M + \sqrt{M^2 + T^2})\right]$$

or $$\frac{\pi}{32} \times \sigma_{b\,(max)} \times d^3 = \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right]$$

The expression $\frac{1}{2}[M + \sqrt{M^2 + T^2}]$ is known as ***equivalent bending moment*** and is denoted by M_e. The equivalent bending moment may be defined as that moment which when acting alone produces the same tensile or compressive stress (σ_b) as the actual bending moment. By limiting the maximum normal stress [$\sigma_b(max)$] equal to the allowable bending stress (σb), then the equation (*iv*) may be written as

$$M_e = \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right] = \frac{\pi}{32} \times \sigma_b \times d^3$$

From this expression, diameter of the shaft (d) may be evaluated.

b) Hollow shaft:

Problem:

A shaft is supported by two bearings placed 1 m apart. A 600 mm diameter pulley is mounted at a distance of 300 mm to the right of left hand bearing and this drives a pulley directly below it with the help of belt having maximum tension of 2.25 kN. Another pulley 400 mm diameter is placed 200 mm to the left of right hand bearing and is driven with the help of electric motor and belt, which is placed horizontally to the right. The angle of contact for both the pulleys is 180° and μ = 0.24. Determine the suitable diameter for a solid shaft, allowing working stress of 63 MPa in tension and 42 MPa in shear for the material of shaft. Assume that the torque on one pulley is equal to that on the other pulley.

Solution. Given : $AB = 800$ mm ; $\alpha_C = 20°$; $D_C = 600$ mm or $R_C = 300$ mm ; $AC = 200$ mm ; $D_D = 700$ mm or $R_D = 350$ mm ; $DB = 250$ mm ; $\theta = 180° = \pi$ rad ; $W = 2000$ N ; $T_1 = 3000$ N ; $T_1/T_2 = 3$; $\tau = 40$ MPa $= 40$ N/mm^2

The space diagram of the shaft is shown in Fig (*a*).

We know that the torque acting on the shaft at *D*,

$$T = (T_1 - T_2)\,R_D = T_1\left(1 - \frac{T_2}{T_1}\right)R_D$$

$$= 3000\left(1 - \frac{1}{3}\right)350 = 700 \times 10^3 \text{ N-mm} \qquad \ldots(\because T_1/T_2 = 3)$$

The torque diagram is shown in Fig. (*b*).

Assuming that the torque at *D* is equal to the torque at *C*, therefore the tangential force acting on the gear *C*,

$$F_{tc} = \frac{T}{R_C} = \frac{700 \times 10^3}{300} = 2333 \text{ N}$$

and the normal load acting on the tooth of gear *C*,

$$W_C = \frac{F_{tc}}{\cos\alpha_C} = \frac{2333}{\cos 20°} = \frac{2333}{0.9397} = 2483 \text{ N}$$

The normal load acts at 20° to the vertical as shown in Fig. Resolving the normal load vertically and horizontally, we get

Vertical component of W_C *i.e.* the vertical load acting on the shaft at *C*,

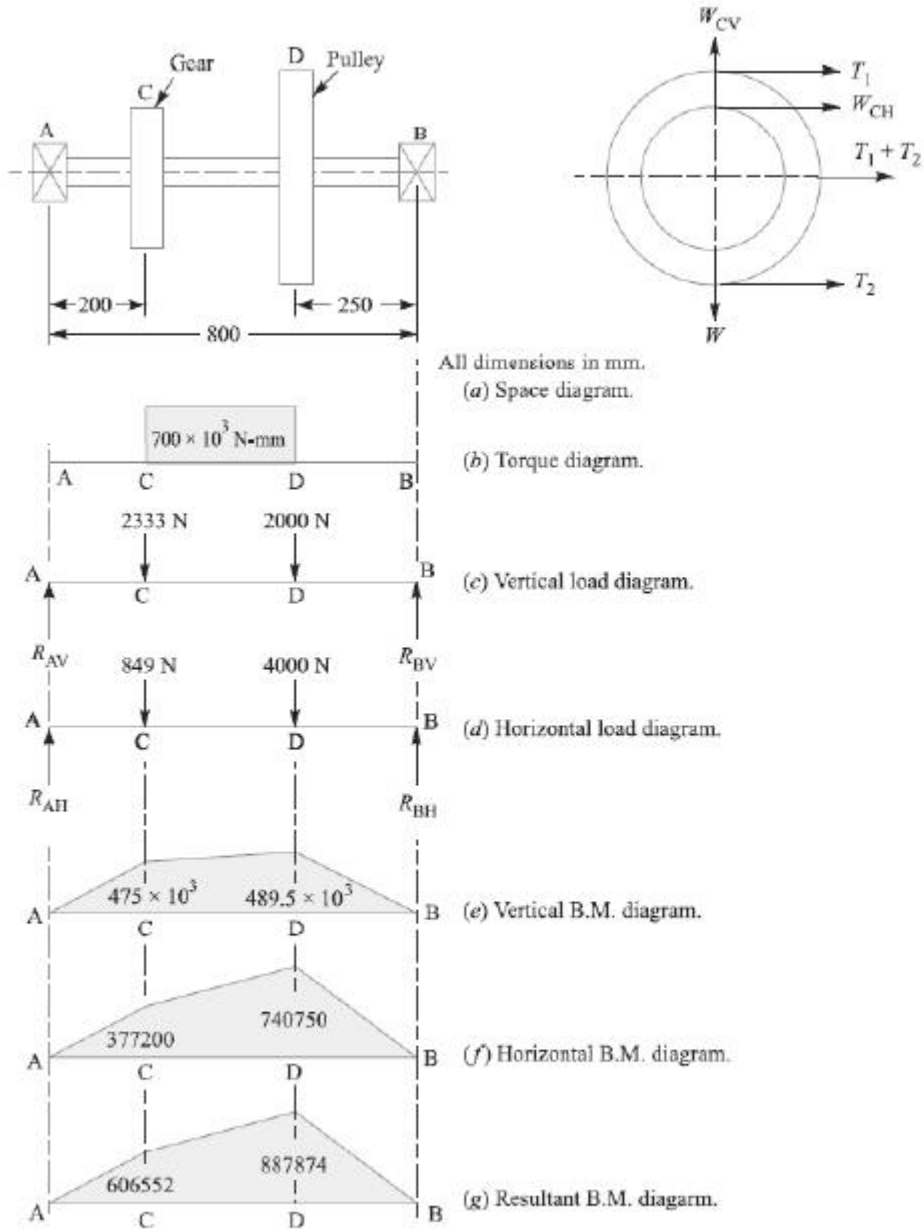
$$W_{CV} = W_C \cos 20°$$
$$= 2483 \times 0.9397 = 2333 \text{ N}$$

and horizontal component of W_C *i.e.* the horizontal load acting on the shaft at *C*,

$$W_{CH} = W_C \sin 20°$$
$$= 2483 \times 0.342 = 849 \text{ N}$$

Since $T_1 / T_2 = 3$ and $T_1 = 3000$ N, therefore

$$T_2 = T_1 / 3 = 3000 / 3 = 1000 \text{ N}$$



All dimensions in mm.
(*a*) Space diagram.
(*b*) Torque diagram.
(*c*) Vertical load diagram.
(*d*) Horizontal load diagram.
(*e*) Vertical B.M. diagram.
(*f*) Horizontal B.M. diagram.
(*g*) Resultant B.M. diagarm.

∴ Horizontal load acting on the shaft at *D*,

$$W_{DH} = T_1 + T_2 = 3000 + 1000 = 4000 \text{ N}$$

and vertical load acting on the shaft at *D*,

$$W_{DV} = W = 2000 \text{ N}$$

The vertical and horizontal load diagram at *C* and *D* is shown in Fig. 14.6 (*c*) and (*d*) respectively.

Now let us find the maximum bending moment for vertical and horizontal loading.

First of all considering the vertical loading at *C* and *D*. Let R_{AV} and R_{BV} be the reactions at the bearings *A* and *B* respectively. We know that

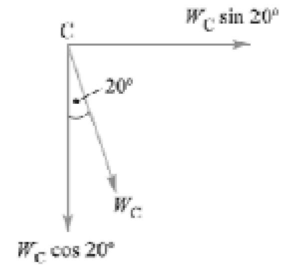


Fig. 14.7

$$R_{AV} + R_{BV} = 2333 + 2000 = 4333 \text{ N}$$

Taking moments about *A*, we get

$$R_{BV} \times 800 = 2000\ (800 - 250) + 2333 \times 200$$
$$= 1\ 566\ 600$$

$\therefore$ $$R_{BV} = 1\ 566\ 600 / 800 = 1958 \text{ N}$$

and $$R_{AV} = 4333 - 1958 = 2375 \text{ N}$$

We know that B.M. at *A* and *B*,

$$M_{AV} = M_{BV} = 0$$

B.M. at *C*, $$M_{CV} = R_{AV} \times 200 = 2375 \times 200$$
$$= 475 \times 10^3 \text{ N-mm}$$

B.M. at D, $$M_{DV} = R_{DV} \times 250 = 1958 \times 250 = 489.5 \times 10^3 \text{ N-mm}$$

The bending moment diagram for vertical loading is shown in Fig. 14.6 (*e*).

Now consider the horizontal loading at *C* and *D*. Let R_{AH} and R_{BH} be the reactions at the bearings *A* and *B* respectively. We know that

$$R_{AH} + R_{BH} = 849 + 4000 = 4849 \text{ N}$$

Taking moments about *A*, we get

$$R_{BH} \times 800 = 4000\ (800 - 250) + 849 \times 200 = 2\ 369\ 800$$

$\therefore$ $$R_{BH} = 2\ 369\ 800 / 800 = 2963 \text{ N}$$

and $$R_{AH} = 4849 - 2963 = 1886 \text{ N}$$

We know that B.M. at *A* and *B*,

$$M_{AH} = M_{BH} = 0$$

B.M. at *C*, $$M_{CH} = R_{AH} \times 200 = 1886 \times 200 = 377\ 200 \text{ N-mm}$$

B.M. at *D*, $$M_{DH} = R_{BH} \times 250 = 2963 \times 250 = 740\ 750 \text{ N-mm}$$

The bending moment diagram for horizontal loading is shown in Fig. 14.6 (*f*).

We know that resultant B.M. at *C*,

$$M_C = \sqrt{(M_{CV})^2 + (M_{CH})^2} = \sqrt{(475 \times 10^3)^2 + (377\ 200)^2}$$
$$= 606\ 552 \text{ N-mm}$$

and resultant B.M. at *D*,

$$M_D = \sqrt{(M_{DV})^2 + (M_{DH})^2} = \sqrt{(489.5 \times 10^3)^2 + (740\ 750)^2}$$
$$= 887\ 874 \text{ N-mm}$$

Maximum bending moment

The resultant B.M. diagram is shown in Fig. 14.6 (g). We see that the bending moment is maximum at *D*, therefore

Maximum B.M., $M = M_D = 887\ 874$ N-mm **Ans.**

Diameter of the shaft

Let d = Diameter of the shaft.

We know that the equivalent twisting moment,

$$T_e = \sqrt{M^2 + T^2} = \sqrt{(887\,874)^2 + (700 \times 10^3)^2} = 1131 \times 10^3 \text{ N-mm}$$

We also know that equivalent twisting moment (T_e),

$$1131 \times 10^3 = \frac{\pi}{16} \times \tau \times d^3 = \frac{\pi}{16} \times 40 \times d^3 = 7.86\, d^3$$

$\therefore$ $d^3 = 1131 \times 10^3 / 7.86 = 144 \times 10^3$ or $d = 52.4$ say 55 mm **Ans.**

Problem:

A steel solid shaft transmitting 15 kW at 200 r.p.m. is supported on two bearings 750 mm apart and has two gears keyed to it. The pinion having 30 teeth of 5 mm module is located 100 mm to the left of the right hand bearing and delivers power horizontally to the right. The gear having 100 teeth of 5 mm module is located 150 mm to the right of the left hand bearing and receives power in a vertical direction from below. Using an allowable stress of 54 MPa in shear, determine the diameter of the shaft.

Solution. Given : P = 15 kW = 15 × 10^3 W ; N = 200 r.p.m. ; AB = 750 mm ; T_D = 30 ; m_D = 5 mm ; BD = 100 mm ; T_C = 100 ; m_C = 5 mm ; AC = 150 mm ; τ = 54 MPa = 54 N/mm^2

The space diagram of the shaft is shown in Fig. 14.8 (*a*).

We know that the torque transmitted by the shaft,

$$T = \frac{P \times 60}{2\pi N} = \frac{15 \times 10^3 \times 60}{2\pi \times 200} = 716 \text{ N-m} = 716 \times 10^3 \text{ N-mm}$$

The torque diagram is shown in Fig. 14.8 (*b*).

We know that diameter of gear

= No. of teeth on the gear × module

$\therefore$ Radius of gear C,

$$R_C = \frac{T_C \times m_C}{2} = \frac{100 \times 5}{2} = 250 \text{ mm}$$

and radius of pinion D,

$$R_D = \frac{T_D \times m_D}{2} = \frac{30 \times 5}{2} = 75 \text{ mm}$$

Assuming that the torque at C and D is same (*i.e.* 716 × 10^3 N-mm), therefore tangential force on the gear C, acting downward,

$$F_{tC} = \frac{T}{R_C} = \frac{716 \times 10^3}{250} = 2870 \text{ N}$$

Problem: Design and make a neat dimensioned sketch of a muff coupling which is used to connect two steel shafts transmitting 40 kW at 350 r.p.m. The material for the shafts and key is plain carbon steel for which allowable shear and crushing stresses may be taken as 40 MPa and 80 MPa respectively. The material for the muff is cast iron for which the allowable shear stress may be assumed as 15 MPa.

Solution.

Given: $P = 40$ kW $= 40 \times 10^3$ W; $N = 350$ r.p.m.; $\tau_s = 40$ MPa $= 40$ N/mm2; $\sigma_{cs} = 80$ MPa $= 80$ N/mm^2; $\sigma_c = 15$ MPa $= 15$ N/mm^2.

$$T - \frac{P \times 60}{2\ \pi N} - \frac{40 \times 10^3 \times 60}{2\ \pi \times 350} - 1100 \text{ N-m}$$

$$= 1100 \times 10^3 \text{ N-mm}$$

We also know that the torque transmitted (T),

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3 - \frac{\pi}{16} \times 40 \times d^3 = 7.86\ d^3$$

$\therefore \quad d^3 = 1100 \times 10^3/7.86 = 140 \times 10^3$ or $d = 52$ say 55 mm Ans.

2. Design for sleeve

We know that outer diameter of the muff,

D = 2d + 13 mm = 2 × 55 + 13 = 123 say 125 mm **Ans.**

and length of the muff,

L = 3.5 d = 3.5 × 55 = 192.5 say 195 mm **Ans.**

Let us now check the induced shear stress in the muff. Let τ_c be the induced shear stress in the muff which is made of cast iron. Since the muff is considered to be a hollow shaft, therefore the torque transmitted (T),

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_c \left(\frac{D^4 - d^4}{D} \right) = \frac{\pi}{16} \times \tau_c \left[\frac{(125)^4 - (55)^4}{125} \right]$$

$$= 370 \times 103\ \tau_c$$

$\therefore \quad \tau_c = 1100 \times 10^3/370 \times 10^3 = 2.97$ N/mm^2

Since the induced shear stress in the muff (cast iron) is less than the permissible shear stress of 15 N/mm2, therefore the design of muff is safe.

3. Design for key

From Design data Book, we find that for a shaft of 55 mm diameter,

Width of key, w = 18 mm **Ans.**

Since the crushing stress for the key material is twice the shearing stress, therefore a square key may be used.

Then, Thickness of key, t = w = 18 mm **Ans.**

We know that length of key in each shaft,

1 = L / 2 = 195 / 2 = 97.5 mm **Ans.**

Let us now check the induced shear and crushing stresses in the key. First of all, let us consider shearing of the key. We know that torque transmitted (T),

$$1100 \times 10^3 = l \times w \times \tau_s \times \frac{d}{2} = 97.5 \times 18 \times \tau_s \times \frac{55}{2} = 48.2 \times 10^3 \tau_s$$

$$\tau_s = 1100 \times 10^3 / 48.2 \times 10^3 = 22.8 \text{ N/mm}^2$$

Now considering crushing of the key. We know that torque transmitted (*T*),

$$1100 \times 10^3 = l \times \frac{t}{2} \times \sigma_{cs} \times \frac{d}{2} = 97.5 \times \frac{18}{2} \times \sigma_{cs} \times \frac{55}{2} = 24.1 \times 10^3 \sigma_{cs}$$

$$\sigma_{cs} = 1100 \times 10^3 / 24.1 \times 10^3 = 45.6 \text{ N/mm}^2$$

Since the induced shear and crushing stresses are less than the permissible stresses, therefore the design of key is safe.

1. Unprotected type flange coupling. In an unprotected type flange coupling, as shown in Fig.1, each shaft is keyed to the boss of a flange with a counter sunk key and the flanges are coupled together by means of bolts. Generally, three, four or six bolts are used. The keys are staggered at right angle along the circumference of the shafts in order to divide the weakening effect caused by keyways.

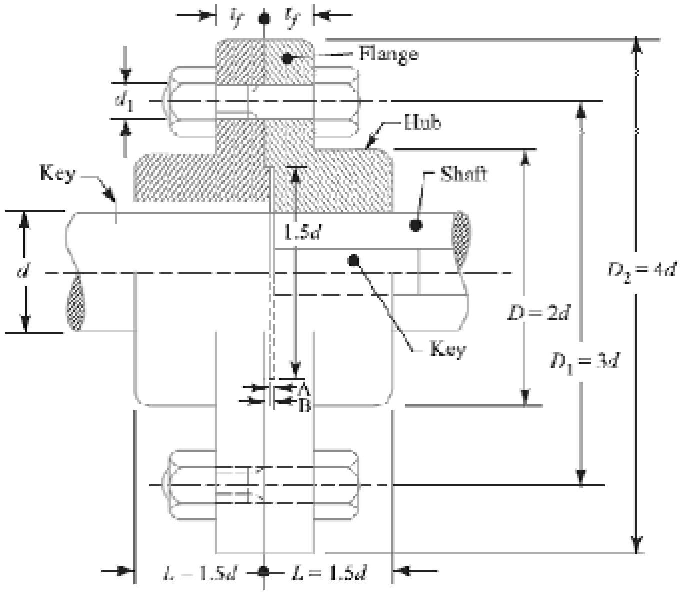


Fig.1 Unprotected Type Flange Coupling.

The usual proportions for an unprotected type cast iron flange couplings, as shown in Fig.1, are as follows:

If d is the diameter of the shaft or inner diameter of the hub, then Outside diameter of hub,

$D = 2\ d$

Length of hub, $L = 1.5\ d$

Pitch circle diameter of bolts, $D_1 = 3d$

Outside diameter of flange,

$D_2 = D_1 + (D_1 - D) = 2\ D_1 - D = 4\ d$

Thickness of flange, $t_f = 0.5\ d$

Number of bolts = 3, for d upto 40 mm

= 4, for d upto 100 mm

= 6, for d upto 180 mm

2. Protected type flange coupling. In a protected type flange coupling, as shown in Fig.2, the protruding bolts and nuts are protected by flanges on the two halves of the coupling, in order to avoid danger to the workman. The thickness of the protective circumferential flange (t_p) is taken as 0.25 d. The other proportions of the coupling are same as for unprotected type flange coupling.

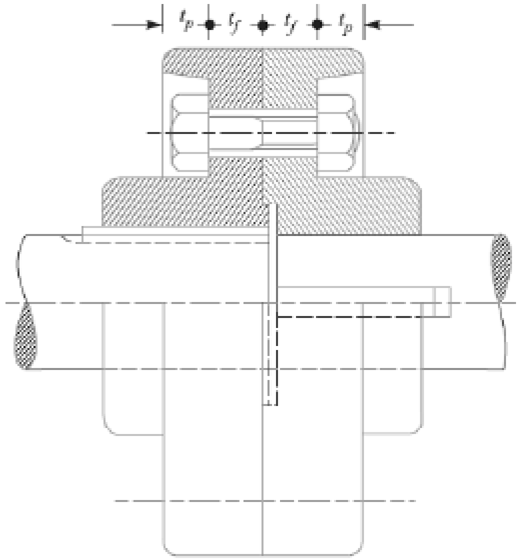


Fig.2. Protected Type Flange Coupling.

3. Marine type flange coupling. In a marine type flange coupling, the flanges are forged integral with the shafts as shown in Fig.3.

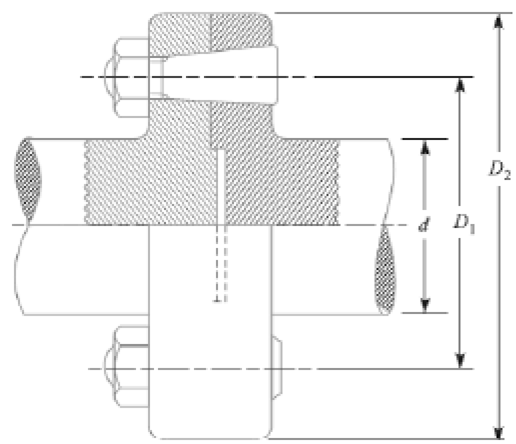


Fig.3. Solid Flange Coupling or Marine Type flange coupling.

The flanges are held together by means of tapered headless bolts, numbering from four to twelve depending upon the diameter of shaft. The other proportions for the marine type flange coupling are taken as follows:

Thickness of flange = d / 3

Taper of bolt = 1 in 20 to 1 in 40

Pitch circle diameter of bolts, $D_1 = 1.6$ d

Outside diameter of flange, $D_2 = 2.2$ d

Design of Flange Coupling

Consider a flange coupling as shown in Fig.1 and Fig.2.

Let d = Diameter of shaft or inner diameter of hub,

D = Outer diameter of hub,

D_1 = Nominal or outside diameter of bolt,

D_1 = Diameter of bolt circle,

n = Number of bolts,

t_f= Thickness of flange,

τ_s, τ_b and τ_k = Allowable shear stress for shaft, bolt and key material respectively

τ_c = Allowable shear stress for the flange material i.e. cast iron,

σ_{cb}, and σ_{ck} = Allowable crushing stress for bolt and key material respectively.

The flange coupling is designed as discussed below:

1. Design for hub

The hub is designed by considering it as a hollow shaft, transmitting the same torque (T) as that of a solid shaft.

$$T = \frac{\pi}{16} \times \tau_c \left(\frac{D^4 - d^4}{D} \right)$$

The outer diameter of hub is usually taken as twice the diameter of shaft. Therefore from the above relation, the induced shearing stress in the hub may be checked.

The length of hub (L) is taken as 1.5 d.

2. Design for key

The key is designed with usual proportions and then checked for shearing and crushing stresses. The material of key is usually the same as that of shaft. The length of key is taken equal to the length of hub.

3. Design for flange

The flange at the junction of the hub is under shear while transmitting the torque. Therefore, the torque transmitted,

T = Circumference of hub × Thickness of flange × Shear stress of flange × Radius of hub

$$= \pi D \times t_f \times \tau_c \times \frac{D}{2} = \frac{\pi D^2}{2} \times \tau_c \times t_f$$

The thickness of flange is usually taken as half the diameter of shaft. Therefore from the above relation, the induced shearing stress in the flange may be checked.

4. Design for bolts

The bolts are subjected to shear stress due to the torque transmitted. The number of bolts (n) depends upon the diameter of shaft and the pitch circle diameter of bolts (D_1) is taken as 3 d.

We know that

Load on each bolt

$$= \frac{\pi}{4} (d_1)^2 \ \tau_b$$

Then, Total load on all the bolts

$$= \frac{\pi}{4} (d_1)^2 \ \tau_b \times n$$

And torque transmitted,

$$T = \frac{\pi}{4} (d_1)^2 \ \tau_b \times n \times \frac{D_1}{2}$$

From this equation, the diameter of bolt (d_1) may be obtained. Now the diameter of bolt may be checked in crushing.

We know that area resisting crushing of all the bolts $= n \times d_1 \times t_f$

And crushing strength of all the bolts $= (n \times d_1 \times t_f)\ \sigma_{cb}$

Torque,

$$T = (n \times d_1 \times t_f \times \sigma_{cb}) \ \frac{D_1}{2}$$

From this equation, the induced crushing stress in the bolts may be checked.

Unit III Design of Temporary and Permanent Joints

Introduction

A key is a piece of mild steel inserted between the shaft and hub or boss of the pulley to connect these together in order to prevent relative motion between them. It is always inserted parallel to the axis of the shaft. Keys are used as temporary fastenings and are subjected to considerable crushing and shearing stresses. A keyway is a slot or recess in a shaft and hub of the pulley to accommodate a key.

Types of Keys

The following types of keys are important from the subject point of view :

1. Sunk keys, **2.** Saddle keys, **3.** Tangent keys, **4.** Round keys, and **5.** Splines.

Sunk Keys

The sunk keys are provided half in the keyway of the shaft and half in the keyway of the hub or boss of the pulley. The sunk keys are of the following types :

1. Rectangular sunk key. A rectangular sunk key is shown in Fig. The usual proportions of this key are :

Width of key, $w = d / 4$; and thickness of key, $t = 2w / 3 = d / 6$

where d = Diameter of the shaft or diameter of the hole in the hub.

The key has taper 1 in 100 on the top side only.

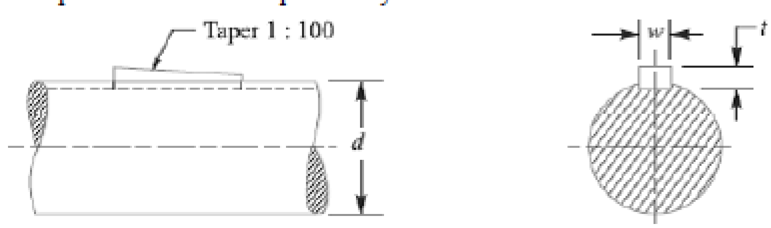


Fig. Sunk Key

2. Square sunk key. The only difference between a rectangular sunk key and a square sunk key is that its width and thickness are equal, i.e. $w = t = d / 4$

3. Parallel sunk key. The parallel sunk keys may be of rectangular or square section uniform in width and thickness throughout. It may be noted that a parallel key is a taper less and is used where the pulley, gear or other mating piece is required to slide along the shaft.

4. Gib-head key. It is a rectangular sunk key with a head at one end known as **gib head.**

It is usually provided to facilitate the removal of key. A gib head key is shown in Fig.

(a) and its use in shown in Fig. (b).

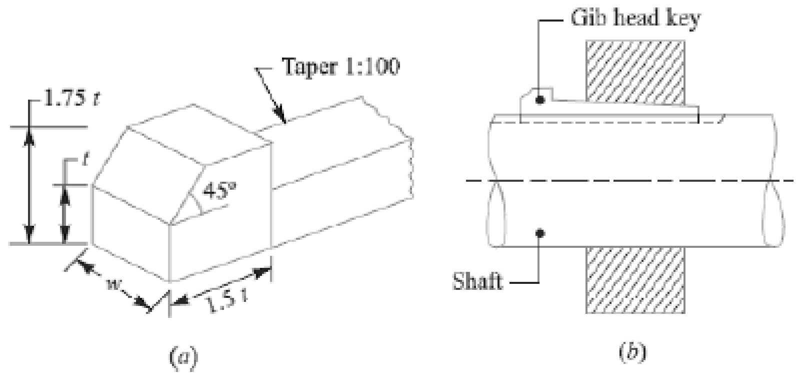


Fig. Gib head key and its use.

The usual proportions of the gib head key are:

Width, w = d / 4 ; and thickness at large end, t = 2w / 3 = d / 6

5. Feather key. A key attached to one member of a pair and which permits relative axial movement is known as **feather key.** It is a special type of parallel key which transmits a turning moment and also permits axial movement. It is fastened either to the shaft or hub, the key being a sliding fit in the key way of the moving piece.

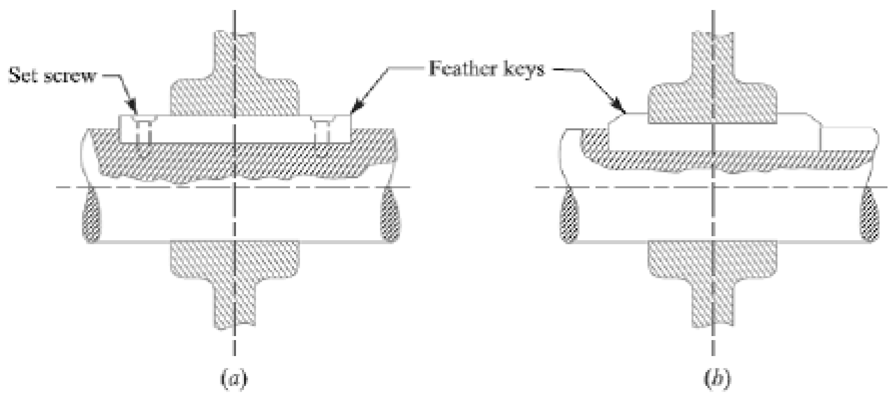


Fig. Feather Keys

6. Woodruff key. The woodruff key is an easily adjustable key. It is a piece from a cylindrical disc having segmental cross-section in front view as shown in Fig. A woodruff key is capable of tilting in a recess milled out in the shaft by a cutter having the same curvature as the disc from which the key is made. This key is largely used in machine tool and automobile construction.

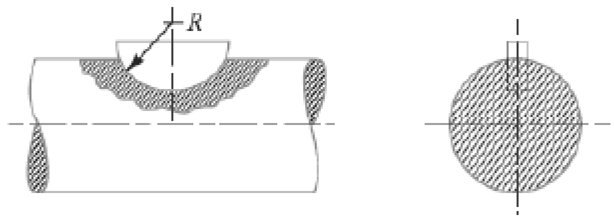


Fig. Woodruff Key

The main advantages of a woodruff key are as follows:

1. It accommodates itself to any taper in the hub or boss of the mating piece.

2. It is useful on tapering shaft ends. Its extra depth in the shaft prevents any tendency to turn over in its keyway.

The disadvantages are:

1. The depth of the keyway weakens the shaft.

2. It can not be used as a feather.

Saddle keys

The saddle keys are of the following two types:

1. Flat saddle key, and **2.** Hollow saddle key.

A flat saddle key is a taper key which fits in a keyway in the hub and is flat on the shaft as shown in Fig. It is likely to slip round the shaft under load. Therefore it is used for comparatively light loads.

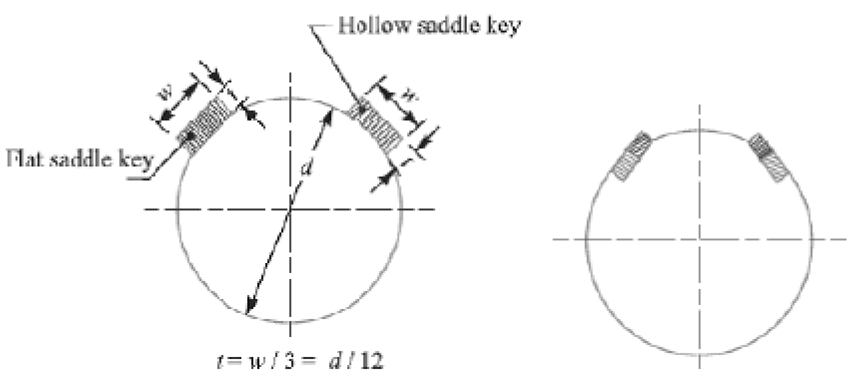


Fig. Flat saddle key and Tangent keys

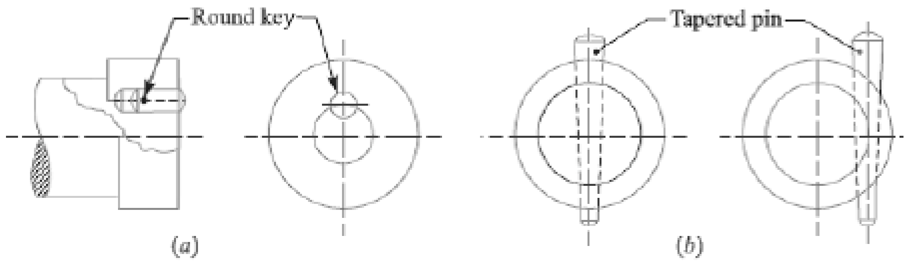
A hollow saddle key is a taper key which fits in a keyway in the hub and the bottom of the key is shaped to fit the curved surface of the shaft. Since hollow saddle keys hold on by friction, therefore these are suitable for light loads. It is usually used as a temporary fastening in fixing and setting eccentrics, cams etc.

Tangent Keys

The tangent keys are fitted in pair at right angles as shown in Fig. Each key is to withstand torsion in one direction only. These are used in large heavy duty shafts.

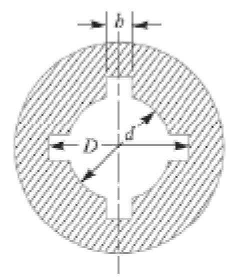
Round Keys

The round keys, as shown in Fig. (a) are circular in section and fit into holes drilled partly in the shaft and partly in the hub. They have the advantage that their keyways may be drilled and reamed after the mating parts have been assembled. Round keys are usually considered to be most appropriate for low power drives.



Splines

Sometimes, keys are made integral with the shaft which fits in the keyways broached in the hub. Such shafts are known as **splined** shafts as shown in Fig. These shafts usually have four, six, ten or sixteen splines. The splined shafts are relatively stronger than shafts having a single keyway.



$D = 1.25\,d$ and $b = 0.25\,D$

Stresses in Keys:

Forces acting on a Sunk Key

When a key is used in transmitting torque from a shaft to a rotor or hub, the following two types of forces act on the key:

1. Forces (F1) due to fit of the key in its keyway, as in a tight fitting straight key or in a tapered key driven in place. These forces produce compressive stresses in the key which are difficult to determine in magnitude.

2. Forces (F) due to the torque transmitted by the shaft. These forces produce shearing and compressive (or crushing) stresses in the key.

The forces acting on a key for a clockwise torque being transmitted from a shaft to a hub are shown in Fig.

Cottered Joints:

A cotter is a flat wedge shaped piece of rectangular cross-section and its width is tapered (either on one side or both sides) from one end to another for an easy adjustment. The taper varies from 1 in 48 to 1 in 24 and it may be increased up to 1 in 8, if a locking device is provided. The locking device may be a taper pin or a set screw used on the lower end of the cotter. The cotter is usually made of mild steel or wrought iron. A cotter joint is a temporary fastening and is used to connect rigidly two co-axial rods or bars which are subjected to axial tensile or compressive forces. It is usually used in connecting a piston rod to the crosshead of a reciprocating steam engine, a piston rod and its extension as a tail or pump rod, strap end of connecting rod etc.

Types of Cotter Joints

Following are the three commonly used cotter joints to connect two rods by a cotter:

1. Socket and spigot cotter joint, **2.** Sleeve and cotter joint, and **3.** Gib and cotter joint.

Socket and Spigot Cotter Joint

In a socket and spigot cotter joint, one end of the rods (say *A*) is provided with a socket type of end as shown in Fig., and the other end of the other rod (say *B*) is inserted into a socket. The end of the rod which goes into a socket is also called ***spigot.*** *A* rectangular hole is made in the socket and spigot. *A* cotter is then driven tightly through a hole in order to make the temporary connection between the two rods. The load is usually acting axially, but it changes its direction and hence the cotter joint must be designed to carry both the tensile and compressive loads. The compressive load is taken up by the collar on the spigot.

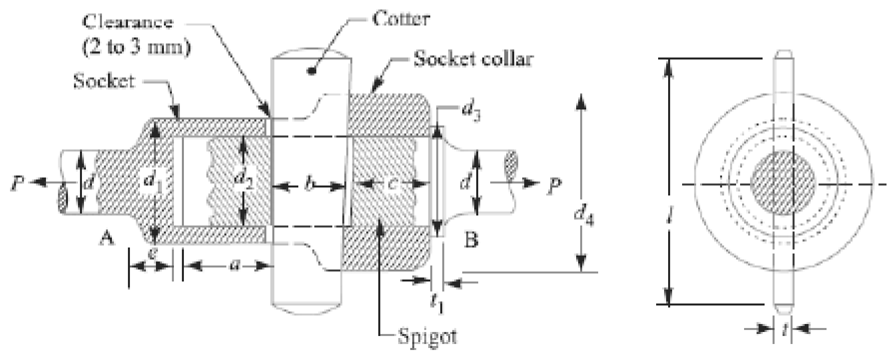


Fig. Socket and spigot cotter joint

Design of Socket and Spigot Cotter Joint

The socket and spigot cotter joint is shown in Fig.

Let P = Load carried by the rods,

d = Diameter of the rods,

d_1 = Outside diameter of socket,

d_2 = Diameter of spigot or inside diameter of socket,

d_3 = Outside diameter of spigot collar,

t_1= Thickness of spigot collar,

d_4 = Diameter of socket collar,

c = Thickness of socket collar,

b = Mean width of cotter,

t = Thickness of cotter,

l = Length of cotter,

a = Distance from the end of the slot to the end of rod,

σ_t = Permissible tensile stress for the rods material,

τ = Permissible shear stress for the cotter material, and

σ_c = Permissible crushing stress for the cotter material.

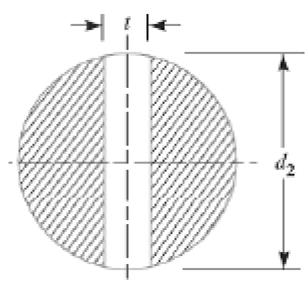
The dimensions for a socket and spigot cotter joint may be obtained by considering the various modes of failure as discussed below:

1. Failure of the rods in tension

$$P = \frac{\pi}{4} \times d^2 \times \sigma_t$$

From this equation, diameter of the rods (d) may be determined.

2. Failure of spigot in tension across the weakest section (or slot)



$$P = \left[\frac{\pi}{4}(d_2)^2 - d_2 \times t\right]\sigma_t$$

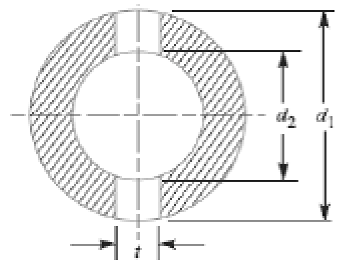
From this equation, the diameter of spigot or inside diameter of socket (d_2) may be determined. In actual practice, the thickness of cotter is usually taken as d_2 / 4.

3. Failure of the rod or cotter in crushing

$$P = d_2 \times t \times \sigma_c$$

From this equation, the induced crushing stress may be checked.

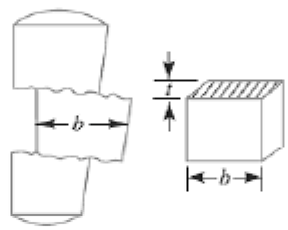
4. Failure of the socket in tension across the slot



$$P = \left\{\frac{\pi}{4}\left[(d_1)^2 - (d_2)^2\right] - (d_1 - d_2)\, t\right\} \sigma_t$$

From this equation, outside diameter of socket (d_1) may be determined.

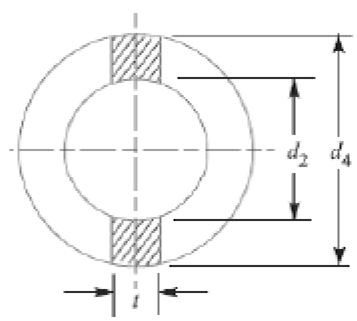
5. Failure of cotter in shear



$$P = 2\, b \times t \times \tau$$

From this equation, width of cotter (b) is determined.

6. Failure of the socket collar in crushing



$$P = (d_4 - d_2)\, t \times \sigma_c$$

From this equation, the diameter of socket collar (d_4) may be obtained.

7. Failure of socket end in shearing

$$P = 2\,(d_4 - d_2)\, c \times \tau$$

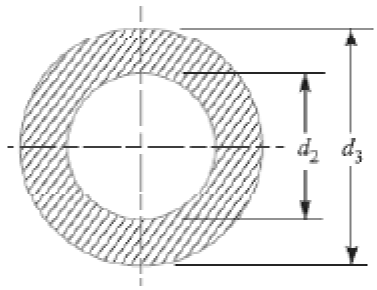
From this equation, the thickness of socket collar (c) may be obtained.

8. Failure of rod end in shear

$$P = 2\,a \times d_2 \times \tau$$

From this equation, the distance from the end of the slot to the end of the rod (a) may be obtained.

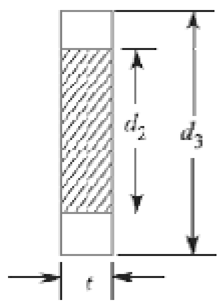
9. Failure of spigot collar in crushing



$$P = \frac{\pi}{4}\left[(d_3)^2 - (d_2)^2\right]\sigma_c$$

From this equation, the diameter of the spigot collar (d_3) may be obtained.

10. Failure of the spigot collar in shearing

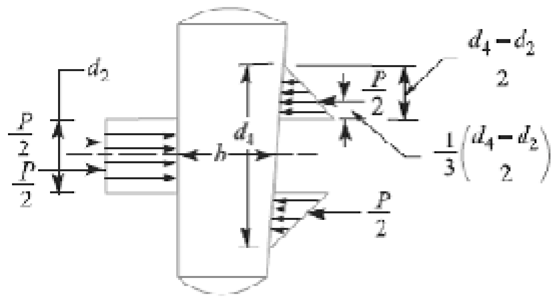


$$P = \pi\, d_2 \times t_1 \times \tau$$

From this equation, the thickness of spigot collar (t_1) may be obtained.

11. Failure of cotter in bending

The maximum bending moment occurs at the centre of the cotter and is given by



$$M_{max} = \frac{P}{2}\left(\frac{1}{3} \times \frac{d_4 - d_2}{2} + \frac{d_2}{2}\right) - \frac{P}{2} \times \frac{d_2}{4}$$

$$= \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{2} - \frac{d_2}{4}\right) = \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)$$

We know that section modulus of the cotter,

$$Z = t \times b^2 / 6$$

Bending stress induced in the cotter,

$$\sigma_b = \frac{M_{max}}{Z} = \frac{\frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)}{t \times b^2 / 6} = \frac{P\,(d_4 + 0.5\, d_2)}{2\, t \times b^2}$$

This bending stress induced in the cotter should be less than the allowable bending stress of the cotter.

12. The length of cotter (l) in taken as 4 d.

13. The taper in cotter should not exceed 1 in 24. In case the greater taper is required, then a locking device must be provided.

14. The draw of cotter is generally taken as 2 to 3 mm.

Notes: 1. when all the parts of the joint are made of steel, the following proportions in terms of diameter of the rod (d) are generally adopted:

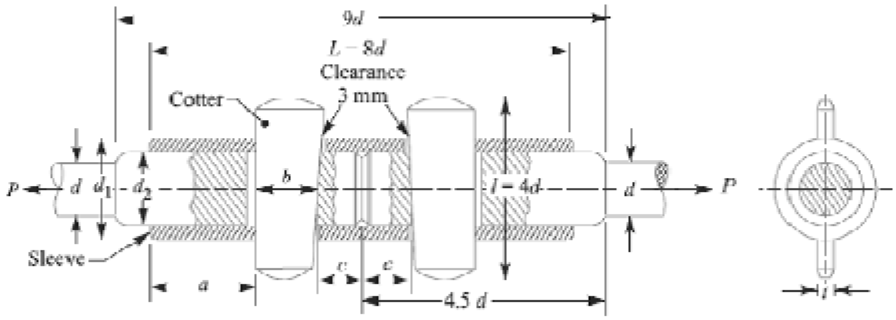
d_1 = 1.75 d , d_2 = 1.21 d , d_3 = 1.5 d , d_4 = 2.4 d , a = c = 0.75 d , b = 1.3 d, l = 4 d , t = 0.31 d ,t_1 = 0.45 d , e = 1.2 d.

Taper of cotter = 1 in 25, and draw of cotter = 2 to 3 mm.

2. If the rod and cotter are made of steel or wrought iron, then $\tau = 0.8\, \sigma_t$ and $\sigma_c = 2\, \sigma_t$ may be taken.

Sleeve and Cotter Joint

Sometimes, a sleeve and cotter joint as shown in Fig., is used to connect two round rods or bars. In this type of joint, a sleeve or muff is used over the two rods and then two cotters (one on each rod end) are inserted in the holes provided for them in the sleeve and rods. The taper of cotter is usually 1 in 24. It may be noted that the taper sides of the two cotters should face each other as shown in Fig. The clearance is so adjusted that when the cotters are driven in, the two rods come closer to each other thus making the joint tight.



The various proportions for the sleeve and cotter joint in terms of the diameter of rod (d) are as follows :

Outside diameter of sleeve,

$d_1 = 2.5$ d

Diameter of enlarged end of rod,

d_2 = Inside diameter of sleeve = 1.25 d

Length of sleeve, L = 8 d

Thickness of cotter, t = d2/4 or 0.31 d

Width of cotter, b = 1.25 d

Length of cotter, l = 4 d

Distance of the rod end (a) from the beginning to the cotter hole (inside the sleeve end) = Distance of the rod end (c) from its end to the cotter hole = 1.25 d

Design of Sleeve and Cotter Joint

The sleeve and cotter joint is shown in Fig.

Let P = Load carried by the rods,

d = Diameter of the rods,

d_1 = Outside diameter of sleeve,

d_2 = Diameter of the enlarged end of rod,

DESIGN OF KNUCKLE JOINT

The following figure shows a knuckle joint with the size parameters and proportions indicated. In general, the rods connected by this joint are subjected to tensile loads, although if the rods are guided, they may support compressive loads as well.

Let F. = tensile load to be resisted by the joint

d = diameter of the rods

d_1 = diameter of the knuckle pin

D = outside diameter of the eye

A =thickness of the fork

B =thickness of the eye

Obviously, if the rods are made of the same material, the parameters, *A* and *B* are related as,

B=2A

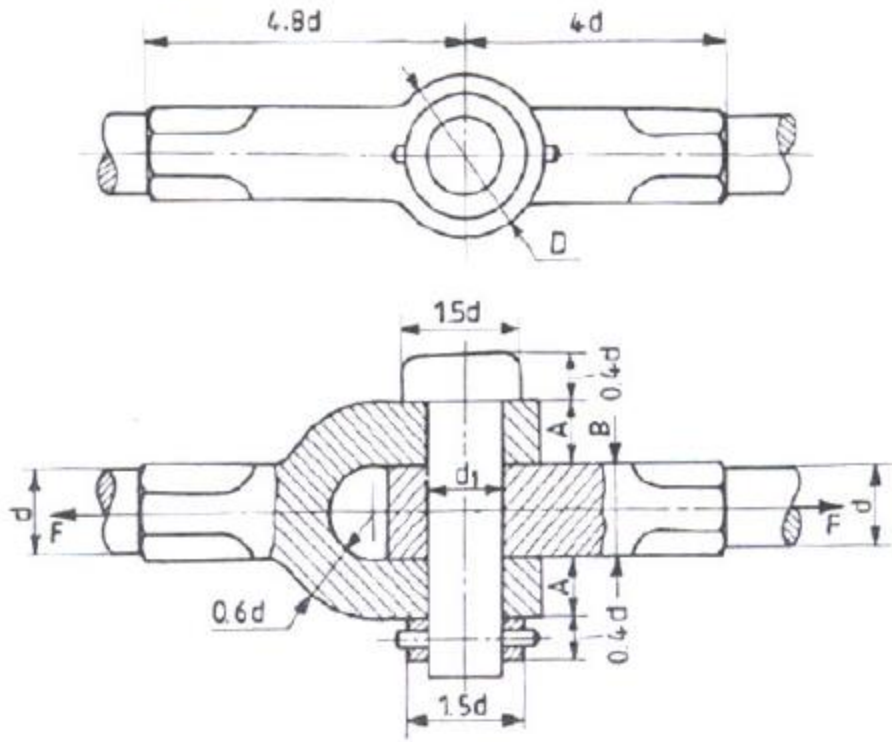


Fig. Knuckle Joint

Let the rods and pin are made of the same material, with σ_t, σ_c and τ as the permissible stresses. The following are the possible modes of failure, and the corresponding design equations, which may be considered for the design of the joint:

1. Tension failure of the rod, across the section of diameter, *d*

$$F = \frac{\pi d^2}{4} \tau$$

2. Tension failure of the eye (fig.1)

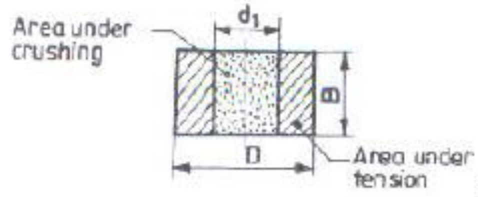


Fig.1

$$F = (D-d_1)\, B\, \sigma_t$$

3. Tension failure of the fork (fig.2)

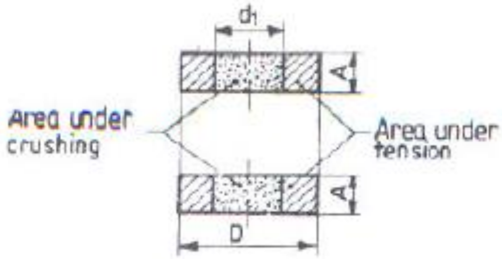


Fig.2

$$F = 2\, (D - d_1)\, A\, \sigma_t$$

4. Shear failure of the eye (Fig.3)

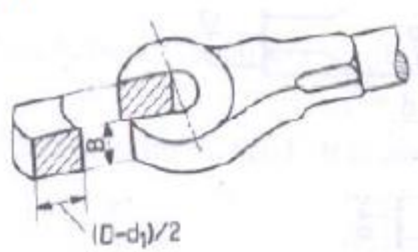


Fig.3

$$F = (D-d_1)\, B\, \tau$$

5. Shear failure of the fork (Fig.4)

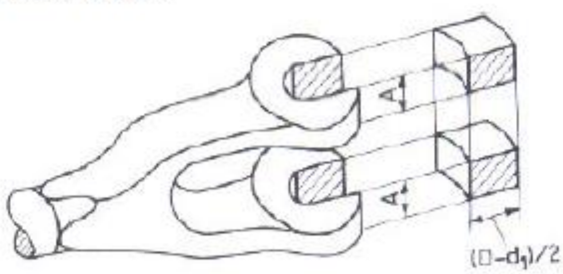


Fig.4

$$F = 2\, (D-d_1)\, A\, \tau$$

6. Shear failure of the pin. It is under double shear.

$$F = 2x\frac{\pi}{4}d^2 x\tau$$

7. Crushing between the pin and eye (fig.1)

$$F = d_1 B \sigma_c$$

8. Crushing between the pin and fork (fig.2)

$$F = 2 d_1 A \sigma_c$$

For size parameters, not covered by the above design equations; proportions as indicated in the figure may be followed.

Problem:

Design a knuckle joint to transmit 150 kN. The design stresses may be taken as 75 MPa in tension, 60 MPa in shear and 150 MPa in compression.

Solution. Given : $P = 150$ kN $= 150 \times 10^3$ N ; $\sigma_t = 75$ MPa $= 75$ N/mm^2 ; $\tau = 60$ MPa $= 60$ N/mm^2 ; $\sigma_c = 150$ MPa $= 150$ N/mm^2

ailure of the solid rod in tension

Let d = Diameter of the rod

We know that the load transmitted (P),

$$150 \times 10^3 = \frac{\pi}{4} \times d^2 \times \sigma_t = \frac{\pi}{4} \times d^2 \times 75 = 59\, d^2$$

$\therefore$ $d^2 = 150 \times 10^3 / 59 = 2540$ or $d = 50.4$ say 52 mm **Ans.**

Now the various dimensions are fixed as follows :

Diameter of knuckle pin,

$$d_1 = d = 52 \text{ mm}$$

Outer diameter of eye, $d_2 = 2d = 2 \times 52 = 104$ mm

Diameter of knuckle pin head and collar,

$$d_3 = 1.5\,d = 1.5 \times 52 = 78 \text{ mm}$$

Thickness of single eye or rod end,

$$t = 1.25\,d = 1.25 \times 52 = 65 \text{ mm}$$

Thickness of fork, $t_1 = 0.75\,d = 0.75 \times 52 = 39$ say 40 mm

Thickness of pin head, $t_2 = 0.5\,d = 0.5 \times 52 = 26$ mm

ailure of the knuckle pin in shear

Since the knuckle pin is in double shear, therefore load (P),

$$150 \times 10^3 = 2 \times \frac{\pi}{4} \times (d_1)^2\,\tau = 2 \times \frac{\pi}{4} \times (52)^2\,\tau = 4248\,\tau$$

$\therefore \quad \tau = 150 \times 10^3 / 4248 = 35.3 \text{ N/mm}^2 = 35.3 \text{ MPa}$

3. ***Failure of the single eye or rod end in tension***

The single eye or rod end may fail in tension due to the load. We know that load (P),

$$150 \times 10^3 = (d_2 - d_1)\, t \times \sigma_t = (104 - 52)\, 65 \times \sigma_t = 3380\, \sigma_t$$

$$\therefore \quad \sigma_t = 150 \times 10^3 / 3380 = 44.4 \text{ N / mm}^2 = 44.4 \text{ MPa}$$

4. ***Failure of the single eye or rod end in shearing***

The single eye or rod end may fail in shearing due to the load. We know that load (P),

$$150 \times 10^3 = (d_2 - d_1)\, t \times \tau = (104 - 52)\, 65 \times \tau = 3380\, \tau$$

$$\therefore \quad \tau = 150 \times 10^3 / 3380 = 44.4 \text{ N/mm}^2 = 44.4 \text{ MPa}$$

5. ***Failure of the single eye or rod end in crushing***

The single eye or rod end may fail in crushing due to the load. We know that load (P),

$$150 \times 10^3 = d_1 \times t \times \sigma_c = 52 \times 65 \times \sigma_c = 3380\, \sigma_c$$

$$\therefore \quad \sigma_c = 150 \times 10^3 / 3380 = 44.4 \text{ N/mm}^2 = 44.4 \text{ MPa}$$

6. ***Failure of the forked end in tension***

The forked end may fail in tension due to the load. We know that load (P),

$$150 \times 10^3 = (d_2 - d_1)\, 2\, t_1 \times \sigma_t = (104 - 52)\, 2 \times 40 \times \sigma_t = 4160\, \sigma_t$$

$$\therefore \quad \sigma_t = 150 \times 10^3 / 4160 = 36 \text{ N/mm}^2 = 36 \text{ MPa}$$

7. ***Failure of the forked end in shear***

The forked end may fail in shearing due to the load. We know that load (P),

$$150 \times 10^3 = (d_2 - d_1)\, 2\, t_1 \times \tau = (104 - 52)\, 2 \times 40 \times \tau = 4160\, \tau$$

$$\therefore \quad \tau = 150 \times 10^3 / 4160 = 36 \text{ N/mm}^2 = 36 \text{ MPa}$$

8. ***Failure of the forked end in crushing***

The forked end may fail in crushing due to the load. We know that load (P),

$$150 \times 10^3 = d_1 \times 2\, t_1 \times \sigma_c = 52 \times 2 \times 40 \times \sigma_c = 4160\, \sigma_c$$

$$\therefore \quad \sigma_c = 150 \times 10^3 / 4180 = 36 \text{ N/mm}^2 = 36 \text{ MPa}$$

From above, we see that the induced stresses are less than the given design stresses, therefore the joint is safe.

Eccentrically Loaded Welded Joints

An eccentric load may be imposed on welded joints in many ways. The stresses induced on the joint may be of different nature or of the same nature. The induced stresses are combined depending upon the nature of stresses. When the shear and bending stresses are simultaneously present in a joint (see case 1), then maximum stresses are as follows:

Maximum normal stress,

$$\sigma_{t(max)} = \frac{\sigma_b}{2} + \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$$

And Maximum shear stress,

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$$

Where σ_b = Bending stress, and

τ = Shear stress.

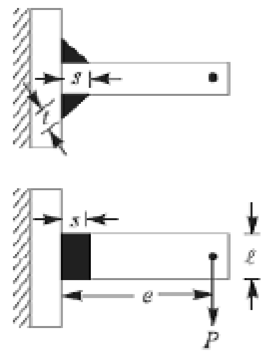


Fig.1. Eccentrically loaded welded joint

When the stresses are of the same nature, these may be combined vectorially (see case 2).

We shall now discuss the two cases of eccentric loading as follows:

Case 1

Consider a *T*-joint fixed at one end and subjected to an eccentric load *P* at a distance *e* as shown in Fig. 1

Let *s* = Size of weld,

l = Length of weld, and

t = Throat thickness.

The joint will be subjected to the following two types of stresses:

1. Direct shear stress due to the shear force *P* acting at the welds, and

2. Bending stress due to the bending moment $P \times e$.

We know that area at the throat,

$$A = \text{Throat thickness} \times \text{Length of weld}$$

$$= t \times l \times 2 = 2\,t \times l \text{ ... (For double fillet weld)}$$

$$= 2 \times 0.707\,s \times l = 1.414\,s \times l \text{ ... (since, } t = s\cos 45° = 0.707\,s\text{)}$$

Shear stress in the weld (assuming uniformly distributed),

$$\tau = \frac{P}{A} = \frac{P}{1.414\,s \times l}$$

Section modulus of the weld metal through the throat,

$$Z = \frac{t \times l^2}{6} \times 2 \qquad \text{...(For both sides weld)}$$

$$= \frac{0.707\, s \times l^2}{6} \times 2 = \frac{s \times l^2}{4.242}$$

Bending moment, $M = P \times e$

$$\therefore \text{ Bending stress, } \sigma_b = \frac{M}{Z} = \frac{P \times e \times 4.242}{s \times l^2} = \frac{4.242\ P \times e}{s \times l^2}$$

We know that the maximum normal stress,

$$\sigma_{t(max)} = \frac{1}{2}\sigma_b + \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\,\tau^2}$$

And maximum shear stress,

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\,\tau^2}$$

Case 2

When a welded joint is loaded eccentrically as shown in Fig.2, the following two types of the stresses are induced:

1. Direct or primary shear stress, and

2. Shear stress due to turning moment.

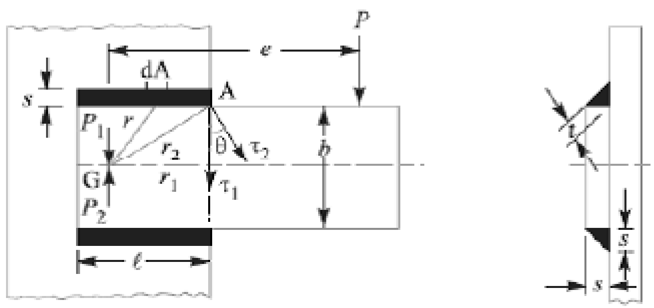


Fig.2 eccentrically loaded welded joint.

Let P = Eccentric load,

e = Eccentricity i.e. perpendicular distance between the line of action of load and centre of gravity (G) of the throat section or fillets,

l = Length of single weld,

s = Size or leg of weld, and

t = Throat thickness.

Let two loads P_1 and P_2 (each equal to P) are introduced at the centre of gravity 'G' of the weld system. The effect of load P_1 = P is to produce direct shear stress which is assumed to be uniform over the entire weld length. The effect of load P_2 = P is to produce a turning moment of magnitude P × e which tends of rotate the joint about the centre of gravity 'G' of the weld system. Due to the turning moment, secondary shear stress is induced.

We know that the direct or primary shear stress,

$$\tau_1 = \frac{\text{Load}}{\text{Throat area}} = \frac{P}{A} = \frac{P}{2\,t \times l}$$
$$= \frac{P}{2 \times 0.707\,s \times l} = \frac{P}{1.414\,s \times l}$$

Since the shear stress produced due to the turning moment (T = P × e) at any section is proportional to its radial distance from G, therefore stress due to P × e at the point A is proportional to AG (r2) and is in a direction at right angles to AG. In other words,

$$\frac{\tau_2}{r_2} = \frac{\tau}{r} = \text{Constant}$$
$$\tau = \frac{\tau_2}{r_2} \times r \qquad ...(i)$$

Where τ_2 is the shear stress at the maximum distance (r_2) and τ is the shear stress at any distance r. Consider a small section of the weld having area dA at a distance r from G.

Shear force on this small section

$$= \tau \times dA$$

And turning moment of this shear force about G,

$$dT = \tau \times dA \times r = \frac{\tau_2}{r_2} \times dA \times r^2 \qquad \text{... [From equation } (i)]$$

Total turning moment over the whole weld area,

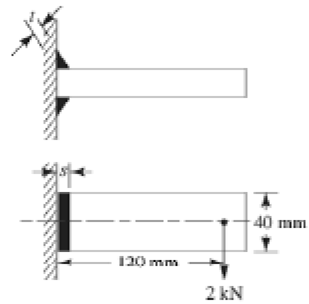
Problem:

A welded joint as shown in Fig. 10.24, is subjected to an eccentric load of 2 kN. Find the size of weld, if the maximum shear stress in the weld is 25 MPa.

Solution. Given: $P = 2\text{kN} = 2000$ N ; $e = 120$ mm ; $l = 40$ mm ; $\tau_{max} = 25$ MPa $= 25$ N/mm²

Let s = Size of weld in mm, and

t = Throat thickness.



The joint, as shown in Fig. 10.24, will be subjected to direct shear stress due to the shear force, $P = 2000$ N and bending stress due to the bending moment of $P \times e$.

We know that area at the throat,

$$A = 2t \times l = 2 \times 0.707\, s \times l$$
$$= 1.414\, s \times l$$
$$= 1.414\, s \times 40 = 56.56 \times s \text{ mm}^2$$

$\therefore$ Shear stress, $\tau = \dfrac{P}{A} = \dfrac{2000}{56.56 \times s} = \dfrac{35.4}{s}$ N/mm²

Bending moment, $M = P \times e = 2000 \times 120 = 240 \times 10^3$ N-mm

Section modulus of the weld through the throat,

$$Z = \frac{s \times l^2}{4.242} = \frac{s\,(40)^2}{4.242} = 377 \times s \text{ mm}^3$$

$\therefore$ Bending stress, $\sigma_b = \dfrac{M}{Z} = \dfrac{240 \times 10^3}{377 \times s} = \dfrac{636.6}{s}$ N/mm²

We know that maximum shear stress (τ_{max}),

$$25 = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\,\tau^2} = \frac{1}{2}\sqrt{\left(\frac{636.6}{s}\right)^2 + 4\left(\frac{35.4}{s}\right)^2} = \frac{320.3}{s}$$

$\therefore$ $s = 320.3 / 25 = 12.8$ mm **Ans.**

Problem:

A bracket carrying a load of 15 kN is to be welded as shown in Fig. Find the size of weld required if the allowable shear stress is not to exceed 80 MPa.

Solution. Given : $P = 15$ kN $= 15 \times 10^3$ N ; $\tau = 80$ MPa $= 80$ N/mm² ; $b = 80$ mm ; $= 50$ mm; $e = 125$ mm

Let s = Size of weld in mm, and

t = Throat thickness.

We know that the throat area,

$$A = 2 \times t \times l = 2 \times 0.707\, s \times l$$
$$= 1.414\, s \times l = 1.414 \times s \times 50 = 70.7\, s \text{ mm}^2$$

Problem:

A steam engine cylinder has an effective diameter of 350 mm and the maximum steam pressure acting on the cylinder cover is 1.25 N/mm^2. Calculate the number and size of studs required to fix the cylinder cover, assuming the permissible stress in the studs as 33 MPa.

Solution. Given: $D = 350$ mm ; $p = 1.25$ N/mm^2 ; $\sigma_t = 33$ MPa $= 33$ N/mm^2

Let d = Nominal diameter of studs,

d_c = Core diameter of studs, and

n = Number of studs.

We know that the upward force acting on the cylinder cover,

$$P = \frac{\pi}{4} \times D^2 \times p = \frac{\pi}{4} (350)^2 \, 1.25 = 120\ 265 \text{ N} \quad ...(i)$$

Assume that the studs of nominal diameter 24 mm are used. From Table 11.1 (coarse series), we find that the corresponding core diameter (d_c) of the stud is 20.32 mm.

∴ Resisting force offered by n number of studs,

$$P = \frac{\pi}{4} \times (d_c)^2 \, \sigma_t \times n = \frac{\pi}{4} (20.32)^2 \, 33 \times n = 10\ 700 \, n \text{ N} \quad ...(ii)$$

From equations (*i*) and (*ii*), we get

n = 120 265 / 10 700 = 11.24 say 12 **Ans.**

Taking the diameter of the stud hole (d_1) as 25 mm, we have pitch circle diameter of the studs,

$$D_p = D_1 + 2t + 3d_1 = 350 + 2 \times 10 + 3 \times 25 = 445 \text{ mm}$$

...(Assuming t = 10 mm)

∴ *Circumferential pitch of the studs

$$= \frac{\pi \times D_p}{n} = \frac{\pi \times 445}{12} = 116.5 \text{ mm}$$

We know that for a leak-proof joint, the circumferential pitch of the studs should be between $20\sqrt{d_1}$ to $30\sqrt{d_1}$, where d_1 is the diameter of stud hole in mm.

∴ Minimum circumferential pitch of the studs

$$= 20\sqrt{d_1} = 20\sqrt{25} = 100 \text{ mm}$$

and maximum circumferential pitch of the studs

$$= 30\sqrt{d_1} = 30\sqrt{25} = 150 \text{ mm}$$

Since the circumferential pitch of the studs obtained above lies within 100 mm to 150 mm, therefore the size of the bolt chosen is satisfactory.

∴ Size of the bolt = M 24 **Ans.**

Eccentric Load Acting Parallel to the Axis of Bolts

Consider a bracket having a rectangular base bolted to a wall by means of four bolts as shown in Fig.1. A little consideration will show that each bolt is subjected to a direct tensile load of

$$W_{t1} = \frac{W}{n}, \text{ where } n \text{ is the number of bolts.}$$

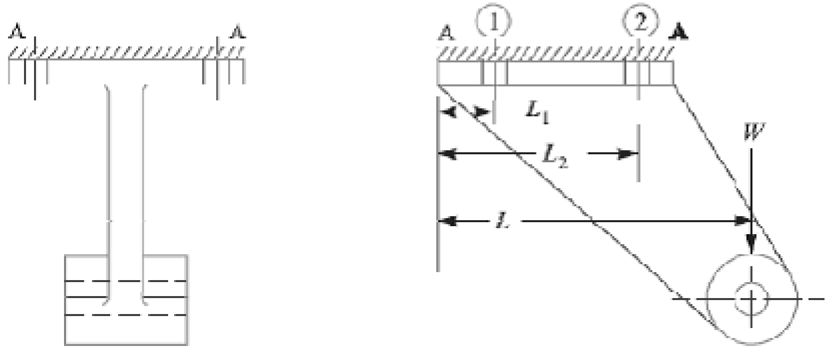


Fig.1. Eccentric load acting parallel to the axis of bolts.

Further the load W tends to rotate the bracket about the edge A-A. Due to this, each bolt is stretched by an amount that depends upon its distance from the tilting edge. Since the stress is a function of elongation, therefore each bolt will experience a different load which also depends upon the distance from the tilting edge. For convenience, all the bolts are made of same size. In case the flange is heavy, it may be considered as a rigid body.

Let w be the load in a bolt per unit distance due to the turning effect of the bracket and let W_1 and W_2 be the loads on each of the bolts at distances L_1 and L_2 from the tilting edge.

Load on each bolt at distance L_1,

$W_1 = w.L_1$

And moment of this load about the tilting edge

$= w.L_1 \times L_1 = w\,(L_1)^2$

Similarly, load on each bolt at distance L_2,

$W_2 = w.L_2$

And moment of this load about the tilting edge

$= w.L_2 \times L_2 = w\,(L_2)^2$

So, Total moment of the load on the bolts about the tilting edge

$$= 2w\,(L_1)^2 + 2w\,(L_2)^2 \quad ...(i)$$

... (Since, there are two bolts each at distance of L_1 and L_2)

Also the moment due to load W about the tilting edge

$$= W.L \quad ...(ii)$$

From equations (*i*) and (*ii*), we have

$$W.L = 2w(L_1)^2 + 2w(L_2)^2 \quad \text{or} \quad w = \frac{W.L}{2[(L_1)^2 + (L_2)^2]} \quad ...(iii)$$

It may be noted that the most heavily loaded bolts are those which are situated at the greatest distance from the tilting edge. In the case discussed above, the bolts at distance $L2$ are heavily loaded.

So, Tensile load on each bolt at distance L_2,

$$W_{t2} = W_2 = w.L_2 = \frac{W.L.L_2}{2[(L_1)^2 + (L_2)^2]} \quad \text{... [From equation } (iii)]$$

And the total tensile load on the most heavily loaded bolt,

$$W_t = W_{t1} + W_{t2} \quad ...(iv)$$

If d_c is the core diameter of the bolt and σt is the tensile stress for the bolt material, then total tensile load,

$$W_t = \frac{\pi}{4}(d_c)^2 \sigma_t \quad ...(v)$$

From equations (*iv*) and (*v*), the value of dc may be obtained.

Problem:

A bracket, as shown in Fig.1, supports a load of 30 kN. Determine the size of bolts, if the maximum allowable tensile stress in the bolt material is 60 MPa. The distances are: L_1 = 80 mm, L_2 = 250 mm, and L = 500 mm.

Solution. Given : W = 30 kN ; σ_t = 60 MPa = 60 N/mm^2 ; L_1 = 80 mm ; L_2 = 250 mm ; L = 500 mm

We know that the direct tensile load carried by each bolt,

$$W_{t1} = \frac{W}{n} = \frac{30}{4} = 7.5 \text{ kN}$$

and load in a bolt per unit distance,

$$w = \frac{W.L}{2[(L_1)^2 + (L_2)^2]} = \frac{30 \times 500}{2[(80)^2 + (250)^2]} = 0.109 \text{ kN/mm}$$

Unit –IV DESIGN OF ENERGY STORING ELEMENTS AND ENGINE COMPONENTS

Introduction

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. The various important applications of springs are as follows:

1. To cushion, absorb or control energy due to either shock or vibration as in car springs, railway buffers, air-craft landing gears, shock absorbers and vibration dampers.
2. To apply forces, as in brakes, clutches and spring loaded valves.
3. To control motion by maintaining contact between two elements as in cams and followers.
4. To measure forces, as in spring balances and engine indicators.
5. To store energy, as in watches, toys, etc.

Types of springs:

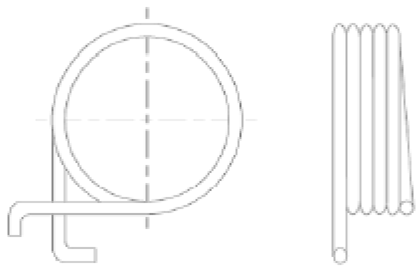
1. Helical springs. The helical springs are made up of a wire coiled in the form of a helix and is primarily intended for compressive or tensile loads.

(*a*) Compression helical spring. (*b*) Tension helical spring.

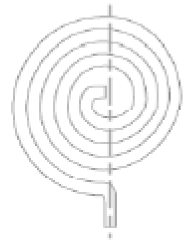
2. Conical and volute springs. The conical and volute springs, as shown in Fig. 23.2, are used in special applications where a telescoping spring or a spring with a spring rate that increases with the load is desired

(*a*) Conical spring. (*b*) Volute spring.

3. Torsion springs. These springs may be of **helical** or **spiral** type as shown in Fig. The **helical type** may be used only in applications where the load tends to wind up the spring and are used in various electrical mechanisms.

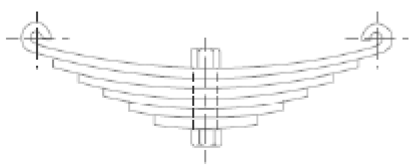


(*a*) Helical torsion spring.

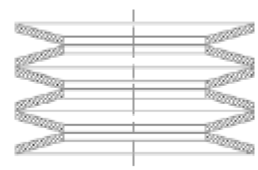


(*b*) Spiral torsion spring.

4. Laminated or leaf springs. The laminated or leaf spring (also known as **flat spring** or **carriage spring**) consists of a number of flat plates (known as leaves) of varying lengths held together by means of clamps and bolts.



Laminated or leaf springs.



Disc or bellevile springs.

5. Disc or bellevile springs. These springs consist of a number of conical discs held together against slipping by a central bolt or tube.

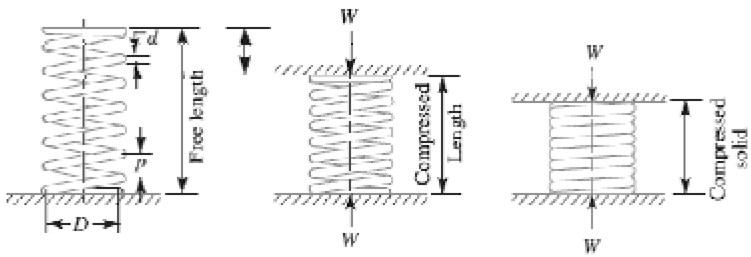
6. Special purpose springs. These springs are air or liquid springs, rubber springs, ring springs etc. The fluids (air or liquid) can behave as a compression spring. These springs are used for special types of application only.

<u>Terms used in Compression Springs</u>

1. Solid length. When the compression spring is compressed until the coils come in contact with each other, then the spring is said to be **solid.**

Solid length of the spring, $L_s = n'.d$ where n' = Total number of coils, and d = Diameter of the wire.

2. Free length. The free length of a compression spring, as shown in Fig., is the length of the spring in the free or unloaded condition.



Free length of the spring,

L_F = Solid length + Maximum compression + *Clearance between adjacent coils (or clash allowance)

$= n'.d + \delta_{max} + 0.15\ \delta_{max}$

3. Spring index. The spring index is defined as the ratio of the mean diameter of the coil to the diameter of the wire. Spring index, C = D / d where D = Mean diameter of the coil, and d = Diameter of the wire.

4. Spring rate. The spring rate (or stiffness or spring constant) is defined as the load required per unit deflection of the spring. Mathematically, Spring rate, k = W / δ where W = Load, and δ = Deflection of the spring.

5. Pitch. The pitch of the coil is defined as the axial distance between adjacent coils in uncompressed state. Mathematically, Pitch of the coil,

$$p = \frac{\text{Free Length}}{n' - 1}$$

<u>**Stresses in Helical Springs of Circular Wire**</u>

Consider a helical compression spring made of circular wire and subjected to an axial load *W*, as shown in Fig.(*a*).

Let *D* = Mean diameter of the spring coil,

d = Diameter of the spring wire,

n = Number of active coils,

G = Modulus of rigidity for the spring material,

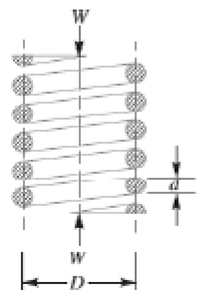
W = Axial load on the spring,

τ = Maximum shear stress induced in the wire,

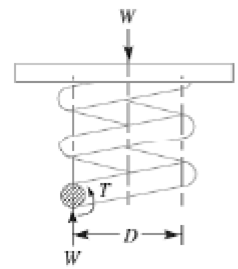
C = Spring index = *D*/*d*,

p = Pitch of the coils, and

δ = Deflection of the spring, as a result of an axial load *W*.



a) Axially loaded helical spring.



(b) Free body diagram showing that wire is subjected to torsional shear and a direct shear.

Now consider a part of the compression spring as shown in Fig. (*b*). The load W tends to rotate the wire due to the twisting moment (T) set up in the wire. Thus torsional shear stress is induced in the wire.

A little consideration will show that part of the spring, as shown in Fig.(*b*), is in equilibrium under the action of two forces W and the twisting moment T. We know that the twisting moment,

$$T = W \times \frac{D}{2} = \frac{\pi}{16} \times \tau_1 \times d^3$$

$$\tau_1 = \frac{8 W.D}{\pi\, d^3} \qquad \text{...(}i\text{)}$$

The torsional shear stress diagram is shown in Fig. (*a*).

In addition to the torsional shear stress (τ_1) induced in the wire, the following stresses also act on the wire:

1. Direct shear stress due to the load W, and

2. Stress due to curvature of wire.

We know that the resultant shear stress induced in the wire,

$$\tau = \tau_1 \pm \tau_2 = \frac{8 W.D}{\pi\, d^3} \pm \frac{4 W}{\pi\, d^2}$$

Maximum shear stress induced in the wire,

= Torsional shear stress + Direct shear stress

$$= \frac{8 W.D}{\pi\, d^3} + \frac{4 W}{\pi\, d^2} = \frac{8 W.D}{\pi\, d^3}\left(1 + \frac{d}{2D}\right)$$

Problem: A helical spring is made from a wire of 6 mm diameter and has outside diameter of 75 mm. If the permissible shear stress is 350 MPa and modulus of rigidity 84 kN/mm^2, find the axial load which the spring can carry and the deflection per active turn.

Solution. Given : $d = 6$ mm ; $D_o = 75$ mm ; $\tau = 350$ MPa $= 350$ N/mm^2 ; $G = 84$ kN/mm^2 $= 84 \times 10^3$ N/mm^2

We know that mean diameter of the spring,

$$D = D_o - d = 75 - 6 = 69 \text{ mm}$$

$\therefore$ Spring index, $C = \dfrac{D}{d} = \dfrac{69}{6} = 11.5$

Let W = Axial load, and

δ / n = Deflection per active turn.

1. *Neglecting the effect of curvature*

We know that the shear stress factor,

$$K_S = 1 + \frac{1}{2C} = 1 + \frac{1}{2 \times 11.5} = 1.043$$

and maximum shear stress induced in the wire (τ),

$$350 = K_S \times \frac{8\,W.D}{\pi\,d^3} = 1.043 \times \frac{8\,W \times 69}{\pi \times 6^3} = 0.848\,W$$

$\therefore$ $W = 350 / 0.848 = 412.7$ N **Ans.**

We know that deflection of the spring,

$$\delta = \frac{8\,W.D^3.n}{G.d^4}$$

$\therefore$ Deflection per active turn,

$$\frac{\delta}{n} = \frac{8\,W.D^3}{G.d^4} = \frac{8 \times 412.7\,(69)^3}{84 \times 10^3 \times 6^4} = 9.96 \text{ mm } \textbf{Ans.}$$

2. *Considering the effect of curvature*

We know that Wahl's stress factor,

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} = \frac{4 \times 11.5 - 1}{4 \times 11.5 - 4} + \frac{0.615}{11.5} = 1.123$$

We also know that the maximum shear stress induced in the wire (τ),

$$350 = K \times \frac{8W.C}{\pi\,d^2} = 1.123 \times \frac{8 \times W \times 11.5}{\pi \times 6^2} = 0.913\,W$$

$\therefore$ $W = 350 / 0.913 = 383.4$ N **Ans.**

and deflection of the spring,

$$\delta = \frac{8\,W.D^3.n}{G.d^4}$$

$\therefore$ Deflection per active turn,

$$\frac{\delta}{n} = \frac{8\,W.D^3}{G.d^4} = \frac{8 \times 383.4\,(69)^3}{84 \times 10^3 \times 6^4} = 9.26 \text{ mm } \textbf{Ans.}$$

Problem: Design a spring for a balance to measure 0 to 1000 N over a scale of length 80 mm. The spring is to be enclosed in a casing of 25 mm diameter. The approximate number of turns is 30. The modulus of rigidity is 85 kN/mm^2. Also calculate the maximum shear stress induced.

Solution:

Design of spring

Let D = Mean diameter of the spring coil,

d = Diameter of the spring wire, and

C = Spring index = D/d.

Since the spring is to be enclosed in a casing of 25 mm diameter, therefore the outer diameter of the spring coil ($D_o = D + d$) should be less than 25 mm.

We know that deflection of the spring (δ),

$$80 = \frac{8\,W.C^3.n}{G.d} = \frac{8 \times 1000 \times C^3 \times 30}{85 \times 10^3 \times d} = \frac{240\,C^3}{85\,d}$$

$$\therefore \quad \frac{C^3}{d} = \frac{80 \times 85}{240} = 28.3$$

Let us assume that $d = 4$ mm. Therefore

$$C^3 = 28.3\,d = 28.3 \times 4 = 113.2 \quad \text{or} \quad C = 4.84$$

and $D = C.d = 4.84 \times 4 = 19.36$ mm Ans.

We know that outer diameter of the spring coil,

$$D_o = D + d = 19.36 + 4 = 23.36 \text{ mm Ans.}$$

Since the value of $D_o = 23.36$ mm is less than the casing diameter of 25 mm, therefore the assumed dimension, $d = 4$ mm is correct.

Maximum shear stress induced

We know that Wahl's stress factor,

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} = \frac{4 \times 4.84 - 1}{4 \times 4.84 - 4} + \frac{0.615}{4.84} = 1.322$$

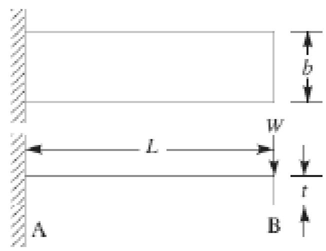
$\therefore$ Maximum shear stress induced,

$$\tau = K \times \frac{8\,W.C}{\pi\,d^2} = 1.322 \times \frac{8 \times 1000 \times 4.84}{\pi \times 4^2}$$

$$= 1018.2 \text{ N/mm}^2 = 1018.2 \text{ MPa Ans.}$$

Leaf Springs

Leaf springs (also known as **flat springs**) are made out of flat plates. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. Consider a single plate fixed at one end and loaded at the other end as shown in Fig. This plate may be used as a flat spring.



W

Let t = Thickness of plate,

b = Width of plate, and

L = Length of plate or distance of the load from the cantilever end.

We know that the maximum bending moment at the cantilever end A,

$$M = W.L$$

And section modulus,

$$Z = \frac{I}{y} = \frac{b\,t^3/12}{t/2} = \frac{1}{6} \times b.t^2$$

Bending stress in such a spring,

$$\sigma = \frac{M}{Z} = \frac{W.L}{\frac{1}{6} \times b.t^2} = \frac{6\ W.L}{b.t^2}$$

We know that the maximum deflection for a cantilever with concentrated load at the free end is given by

$$\delta = \frac{W.L^3}{3E.I} = \frac{W.L^3}{3E \times b.t^3/12} = \frac{4\ W.L^3}{E.b.t^3}$$

$$= \frac{2\ \sigma.L^2}{3\ E.t}$$

If the spring is not of cantilever type but it is like a simply supported beam, with length $2L$ and load $2W$ in the centre, as shown in Fig. then Maximum bending moment in the centre,

$M = W.L$

Section modulus, $Z = b.t2 / 6$

Bending stress,

$$\sigma = \frac{M}{Z} = \frac{W.L}{b.t^2/6}$$

$$= \frac{6\ W.L}{b.t^2}$$

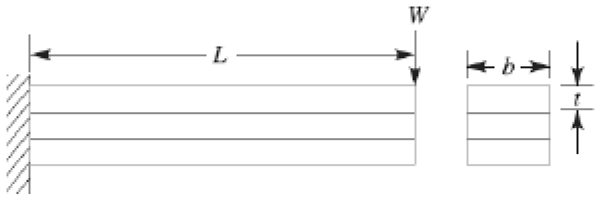
We know that maximum deflection of a simply supported beam loaded in the centre is given by

$$\delta = \frac{W_1\ (L_1)^3}{48\ E.I} = \frac{(2W)\ (2L)^3}{48\ E.I} = \frac{W.L^3}{3\ E.I}$$

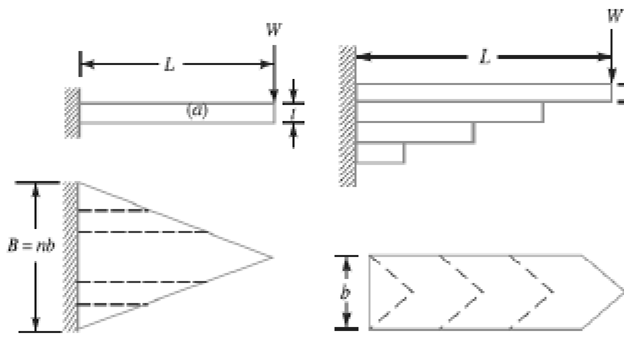
From above we see that a spring such as automobile spring (semi-elliptical spring) with length $2L$ and loaded in the centre by a load $2W$, may be treated as a double cantilever. If the plate of cantilever is cut into a series of n strips of width b and these are placed as shown in Fig., then equations (*i*) and (*ii*) may be written as

$$\sigma = \frac{6\ W.L}{n.b.t^2} \quad \text{...(iii)}$$

And $$\delta = \frac{4\ W.L^3}{n.E.b.t^3} = \frac{2\ \sigma.L^2}{3\ E.t} \quad \text{...(iv)}$$



The above relations give the stress and deflection of a leaf spring of uniform cross section. The stress at such a spring is maximum at the support.



If a triangular plate is used as shown in Fig., the stress will be uniform throughout. If this triangular plate is cut into strips of uniform width and placed one below the other, as shown in Fig. to form a graduated or laminated leaf spring, then

$$\sigma = \frac{6\,W.L}{n.b.t^2} \qquad \ldots(v)$$

$$\delta = \frac{6\,W.L^3}{n.E.b.t^3} = \frac{\sigma.L^2}{E.t} \qquad \ldots(vi)$$

where n = Number of graduated leaves.

A little consideration will show that by the above arrangement, the spring becomes compact so that the space occupied by the spring is considerably reduced.

When bending stress alone is considered, the graduated leaves may have zero width at the loaded end. But sufficient metal must be provided to support the shear. Therefore, it becomes necessary to have one or more leaves of uniform cross-section extending clear to the end. We see from equations (*iv*) and (*vi*) that for the same deflection, the stress in the uniform cross-section leaves (*i.e.* full length leaves) is 50% greater than in the graduated leaves, assuming that each spring element deflects according to its own elastic curve. If the suffixes

F and G are used to indicate the full length (or uniform cross section) and graduated leaves, then

$$\sigma_F = \frac{3}{2}\sigma_G$$

$$\frac{6 W_F.L}{n_F.b.t^2} = \frac{3}{2}\left[\frac{6 W_G.L}{n_G.b.t^2}\right] \quad \text{or} \quad \frac{W_F}{n_F} = \frac{3}{2}\times\frac{W_G}{n_G}$$

$$\frac{W_F}{W_G} = \frac{3 n_F}{2 n_G} \qquad ...(vii)$$

Adding 1 to both sides, we have

$$\frac{W_F}{W_G} + 1 = \frac{3 n_F}{2 n_G} + 1 \quad \text{or} \quad \frac{W_F + W_G}{W_G} = \frac{3 n_F + 2 n_G}{2 n_G}$$

$$W_G = \left(\frac{2 n_G}{3 n_F + 2 n_G}\right)(W_F + W_G) = \left(\frac{2 n_G}{3 n_F + 2 n_G}\right) W \qquad ...(viii)$$

where W = Total load on the spring = $W_G + W_F$

W_G = Load taken up by graduated leaves, and

W_F = Load taken up by full length leaves.

From equation (*vii*), we may write

$$\frac{W_G}{W_F} = \frac{2 n_G}{3 n_F}$$

or

$$\frac{W_G}{W_F} + 1 = \frac{2 n_G}{3 n_F} + 1$$

$$\frac{W_G + W_F}{W_F} = \frac{2 n_G + 3 n_F}{3 n_F}$$

$$\therefore \quad W_F = \left(\frac{3 n_F}{2 n_G + 3 n_F}\right)(W_G + W_F) = \left(\frac{3 n_F}{2 n_G + 3 n_F}\right) W \qquad ...(ix)$$

Bending stress for full length leaves,

$$\sigma_F = \frac{6 W_F.L}{n_F.b\, t^2} = \frac{6 L}{n_F.b.t^2}\left(\frac{3 n_F}{2 n_G + 3 n_F}\right) W = \frac{18 W.L}{b.t^2 (2 n_G + 3 n_F)}$$

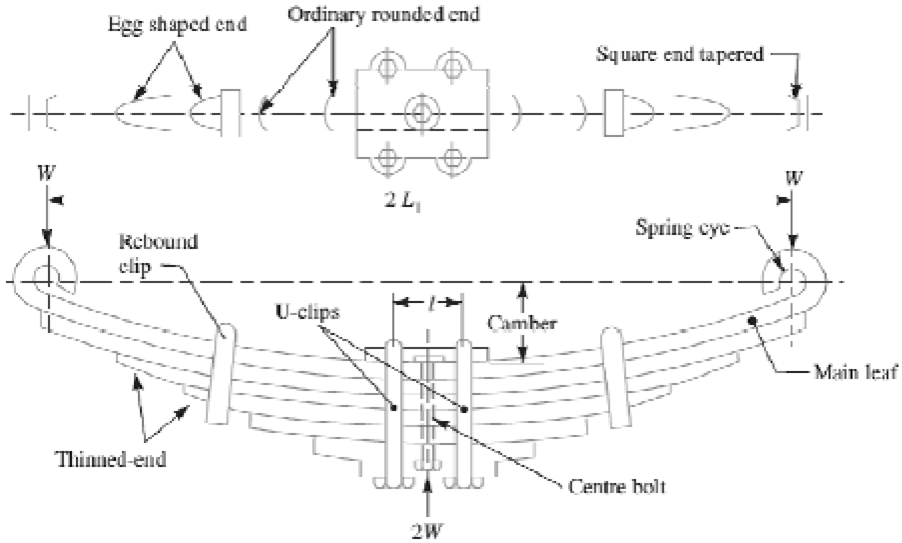
Since

$$\sigma_F = \frac{3}{2}\sigma_G, \text{ therefore}$$

$$\sigma_G = \frac{2}{3}\sigma_F = \frac{2}{3}\times\frac{18 W.L}{b.t^2 (2 n_G + 3 n_F)} = \frac{12 W.L}{b.t^2 (2 n_G + 3 n_F)}$$

The deflection in full length and graduated leaves is given by equation (*iv*), *i.e.*

$$\delta = \frac{2\,\sigma_F \times L^2}{3\,E.t} - \frac{2\,L^2}{3\,E.t}\left[\frac{18\,W.L}{b.t^2\,(2\,n_G + 3\,n_F)}\right] - \frac{12\,W.L^3}{E.b.t^3\,(2\,n_G + 3\,n_F)}$$



Equalised Stress in Spring Leaves (Nipping)

We have already discussed that the stress in the full length leaves is 50% greater than the stress in the graduated leaves. In order to utilise the material to the best advantage, all the leaves should be equally stressed.

This condition may be obtained in the following two ways:

1. By making the full length leaves of smaller thickness than the graduated leaves. In this way, the full length leaves will induce smaller bending stress due to small distance from the neutral axis to the edge of the leaf.

2. By giving a greater radius of curvature to the full length leaves than graduated leaves, as shown in Fig. before the leaves are assembled to form a spring. By doing so, a gap or clearance will be left between the leaves. This initial gap, as shown by *C* in Fig, is called ***nip***.

Problem: Design a leaf spring for the following specifications:

Total load = 140 kN ; Number of springs supporting the load = 4 ; Maximum number of leaves = 10; Span of the spring = 1000 mm ; Permissible deflection = 80 mm.

Take Young's modulus, E = 200 kN/mm2 and allowable stress in spring material as 600 MPa.

Solution. Given : Total load = 140 kN ; No. of springs = 4; n = 10 ; $2L$ = 1000 mm or L = 500 mm ; δ = 80 mm ; E = 200 kN/mm^2 = 200 × 10^3 N/mm^2 ; σ = 600 MPa = 600 N/mm^2

We know that load on each spring,

$$2W = \frac{\text{Total load}}{\text{No. of springs}} = \frac{140}{4} = 35 \text{ kN}$$

$$\therefore \quad W = 35 / 2 = 17.5 \text{ kN} = 17\,500 \text{ N}$$

Let t = Thickness of the leaves, and

b = Width of the leaves.

We know that bending stress (σ),

$$600 = \frac{6\,W.L}{n.b.t^2} = \frac{6 \times 17\,500 \times 500}{n.b.t^2} = \frac{52.5 \times 10^6}{n.b.t^2}$$

$$\therefore \quad n.b.t^2 = 52.5 \times 10^6 / 600 = 87.5 \times 10^3 \quad \text{...(i)}$$

and deflection of the spring (δ),

$$80 = \frac{6\,W.L^3}{n.E.b.t^3} = \frac{6 \times 17\,500\,(500)^3}{n \times 200 \times 10^3 \times b \times t^3} = \frac{65.6 \times 10^6}{n.b.t^3}$$

$$\therefore \quad n.b.t^3 = 65.6 \times 10^6 / 80 = 0.82 \times 10^6 \quad \text{...(ii)}$$

Dividing equation (*ii*) by equation (*i*), we have

$$\frac{n.b.t^3}{n.b.t^2} = \frac{0.82 \times 10^6}{87.5 \times 10^3} \quad \text{or} \quad t = 9.37 \text{ say } 10 \text{ mm } \textbf{Ans.}$$

Now from equation (*i*), we have

$$b = \frac{87.5 \times 10^3}{n.t^2} = \frac{87.5 \times 10^3}{10\,(10)^2} = 87.5 \text{ mm}$$

and from equation (*ii*), we have

$$b = \frac{0.82 \times 10^6}{n.t^3} = \frac{0.82 \times 10^6}{10\,(10)^3} = 82 \text{ mm}$$

Taking larger of the two values, we have width of leaves,

$$b = 87.5 \text{ say } 90 \text{ mm } \textbf{Ans.}$$

Problem:

A truck spring has 12 number of leaves, two of which are full length leaves.

Unit V-DESIGN OF BEARINGS AND MISCELLANEOUS ELEMENTS

A journal of nominal or basic size of 75 mm runs in a bearing with close running fit. Find the limits of shaft and bearing. What is the maximum and minimum clearance?

Solution. Given: Nominal or basic size = 75 mm

From Table 3.5, we find that the close running fit is represented by *H* 8/g 7, *i.e.* a shaft *g* 7 should be used with *H* 8 hole.

Since 75 mm lies in the diameter steps of 50 to 80 mm, therefore the geometric mean diameter,

$$D = \sqrt{50 \times 80} = 63 \text{ mm}$$

We know that standard tolerance unit,

$$i = 0.45 \sqrt[3]{D} + 0.001\,D = 0.45 \sqrt[3]{63} + 0.001 \times 63$$

$$= 1.79 + 0.063 = 1.853 \text{ micron}$$

$$= 1.853 \times 0.001 = 0.001\,853 \text{ mm}$$

∴ Standard tolerance for hole '*H*' of grade 8 (*IT* 8)

$$= 25\,i = 25 \times 0.001\,853 = 0.046 \text{ mm}$$

and standard tolerance for shaft '*g*' of grade 7 (*IT* 7)

$$= 16\,i = 16 \times 0.001\,853 = 0.03 \text{ mm}$$

From Table 3.7, we find that upper deviation for shaft *g*,

$$es = -2.5\,(D)^{0.34} = -2.5\,(63)^{0.34} = -10 \text{ micron}$$

$$= -10 \times 0.001 = -0.01 \text{ mm}$$

Problem:

A hollow shaft is subjected to a maximum torque of 1.5 kN-m and a maximum bending moment of 3 kN-m. It is subjected, at the same time, to an axial load of 10 kN. Assume that the load is applied gradually and the ratio of the inner diameter to the outer diameter is 0.5. If the outer diameter of the shaft is 80 mm, find the shear stress induced in the shaft.

Solution. Given: T = 1.5 kN-m = 1.5×10^3 N-m ; M = 3 kN-m = 3×10^3 N-m ;

F = 10 kN = 10×10^3 N ; $k = d_i / d_o = 0.5$; d_o = 80 mm = 0.08 m

Let τ = Shear stress induced in the shaft.

Since the load is applied gradually, therefore from DDB, we find that K_m =1.5 ; and K_t = 1.0

We know that the equivalent twisting moment for a hollow shaft,

$$T_e = \sqrt{\left[K_m \times M + \frac{\alpha F d_o (1+k^2)^2}{8}\right] + (K_t \times T)^2}$$

$$= \sqrt{\left[1.5 \times 3 \times 10^3 + \frac{1 \times 10 \times 10^3 \times 0.08 (1+0.5^2)^2}{8}\right] + (1 \times 1.5 \times 10^3)^2}$$

$$= \sqrt{(4500+125)^2 + (1500)^2} = 4862 \text{ N-m} = 4862 \times 10^3 \text{ N-mm}$$

We also know that the equivalent twisting moment for a hollow shaft (T_e),

$$4862 \times 10^3 = \frac{\pi}{16} \times \tau (d_o)^3 (1-k^4) = \frac{\pi}{16} \times \tau (80)^3 (1-0.5^4) = 94\,260\,\tau$$

$$\therefore \quad \tau = 4862 \times 10^3 / 94\,260 = 51.6 \text{ N/mm}^2 = 51.6 \text{ MPa}$$ **Ans.**

Problem:

A hollow shaft of 0.5 m outside diameter and 0.3 m inside diameter is used to drive a propeller of a marine vessel. The shaft is mounted on bearings 6 metre apart and it transmits 5600 kW at 150 r.p.m. The maximum axial propeller thrust is 500 kN and the shaft weighs 70 kN.

Determine:

1. The maximum shear stress developed in the shaft, and
2. The angular twist between the bearings.

Solution. Given : $d_o = 0.5$ m ; $d_i = 0.3$ m ; $P = 5600$ kW $= 5600 \times 10^3$ W ; $L = 6$ m ; $N = 150$ r.p.m. ; $F = 500$ kN $= 500 \times 10^3$ N ; $W = 70$ kN $= 70 \times 10^3$ N

1. ***Maximum shear stress developed in the shaft***

Let τ = Maximum shear stress developed in the shaft.

We know that the torque transmitted by the shaft,

$$T = \frac{P \times 60}{2\pi N} = \frac{5600 \times 10^3 \times 60}{2\pi \times 150} = 356\ 460 \text{ N-m}$$

and the maximum bending moment,

$$M = \frac{W \times L}{8} = \frac{70 \times 10^3 \times 6}{8} = 52\ 500 \text{ N-m}$$

Now let us find out the column factor α. We know that least radius of gyration,

$$K = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{\pi}{64}\left[(d_o)^4 - (d_i)^4\right]}{\frac{\pi}{4}\left[(d_o)^2 - (d_i)^2\right]}}$$

$$= \sqrt{\frac{[(d_o)^2 + (d_i)^2]\,[(d_o)^2 - (d_i)^2]}{16\,[(d_o)^2 - (d_i)^2]}}$$

$$= \frac{1}{4}\sqrt{(d_o)^2 + (d_i)^2} = \frac{1}{4}\sqrt{(0.5)^2 + (0.3)^2} = 0.1458 \text{ m}$$

$\therefore$ Slenderness ratio,

$$L / K = 6 / 0.1458 = 41.15$$

and column factor,

$$\alpha = \frac{1}{1 - 0.0044\left(\frac{L}{K}\right)} \qquad \ldots\left(\because \frac{L}{K} < 115\right)$$

$$= \frac{1}{1 - 0.0044 \times 41.15} = \frac{1}{1 - 0.18} = 1.22$$

Assuming that the load is applied gradually, therefore from Table 14.2, we find that

$$K_m = 1.5 \text{ and } K_t = 1.0$$

Also $\quad k = d_i / d_o = 0.3 / 0.5 = 0.6$

We know that the equivalent twisting moment for a hollow shaft,

$$T_e = \sqrt{\left[K_m \times M + \frac{\alpha F d_o\,(1 + k^2)}{8}\right]^2 \quad (K_t \times T)^2}$$

$$= \sqrt{\left[1.5 \times 52\ 500 + \frac{1.22 \times 500 \times 10^3 \times 0.5\,(1 + 0.6^2)}{8}\right]^2 + (1 \times 356\ 460)^2}$$

$$= \sqrt{(78\ 750 + 51\ 850)^2 + (356\ 460)^2} = 380 \times 10^3 \text{ N-m}$$

We also know that the equivalent twisting moment for a hollow shaft (T_e),

$$380 \times 10^3 = \frac{\pi}{16} \times \tau\,(d_o)^3\,(1 - k^4) = \frac{\pi}{16} \times \tau\,(0.5)^3\,[1 - (0.6)^4] = 0.02\,\tau$$

$\therefore \quad \tau = 380 \times 10^3 / 0.02 = 19 \times 10^6$ N/m^2 = 19 MPa **Ans.**

Department of Mechanical Engineering

Lecture Notes

Subject Code : ME3592

Subject Name: METROLOGY AND MEASUREMENTS

Sem/Year : 05/III

Regulation : 2021

ME3592 METROLOGY AND MEASUREMENTS **L T P C**
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COURSE OBJECTIVES

1 To learn basic concepts of the metrology and importance of measurements.
2 To teach measurement of linear and angular dimensions assembly and transmission elements.
3 To study the tolerance analysis in manufacturing.
4 To develop the fundamentals of GD & T and surface metrology.
5 To provide the knowledge of the advanced measurements for quality control in manufacturing industries.

UNIT – I BASICS OF METROLOGY 9

Measurement – Need, Process, Role in quality control; Factors affecting measurement - SWIPE; Errors in Measurements – Types – Control – Measurement uncertainty – Types, Estimation, Problems on Estimation of Uncertainty, Statistical analysis of measurement data, Measurement system analysis, Calibration of measuring instruments, Principle of air gauging- ISO standards.

UNIT – II MEASUREMENT OF LINEAR, ANGULAR DIMENSIONS, ASSEMBLY AND TRANSMISSION ELEMENTS 9

Linear Measuring Instruments – Vernier caliper, Micrometer, Vernier height gauge, Depth Micrometer, Bore gauge, Telescoping gauge; Gauge blocks – Use and precautions, Comparators – Working and advantages; Opto-mechanical measurements using measuring microscope and Profile projector - Angular measuring instruments – Bevel protractor, Clinometer, Angle gauges, Precision level, Sine bar, Autocollimator, Angle dekkor, Alignment telescope. Measurement of Screw threads - Single element measurements – Pitch Diameter, Lead, Pitch. Measurement of Gears – purpose – Analytical measurement – Runout, Pitch variation, Tooth profile, Tooth thickness, Lead – Functional checking – Rolling gear test.

UNIT – III TOLERANCE ANALYSIS 9

Tolerancing– Interchangeability, Selective assembly, Tolerance representation, Terminology, Limits and Fits, Problems (using tables IS919); Design of Limit gauges, Problems. Tolerance analysis in manufacturing, Process capability, tolerance stackup, tolerance charting.

UNIT – IV METROLOGY OF SURFACES 9

Fundamentals of GD & T- Conventional vs Geometric tolerance, Datums, Inspection of geometric deviations like straightness, flatness, roundness deviations; Simple problems – Measurement of Surface finish – Functionality of surfaces, Parameters, Comparative, Stylus based and Optical Measurement techniques, Filters, Introduction to 3D surface metrology- Parameters.

UNIT – V ADVANCES IN METROLOGY 9

Lasers in metrology - Advantages of lasers – Laser scan micrometers; Laser interferometers – Applications – Straightness, Alignment; Ball bar tests, Computer Aided Metrology - Basic concept of CMM – Types of CMM – Constructional features – Probes – Accessories – Software – Applications – Multi-sensor CMMs.

Machine Vision - Basic concepts of Machine Vision System – Elements – Applications - On-line and in-process monitoring in production - Computed tomography – White light Scanners.

TOTAL: 45 PERIODS

UNIT-1 BASICS OF METROLOGY

Standard

The term standard is used to denote universally accepted specifications for devices. Components are processes which ensure conformity and interchangeability throughout a particular industry. A standard provides a reference for assigning a numerical value to a measured quantity. Each basic measurable quantity has associated with it an ultimate standard. Working standards, those used in conjunction with the various measurement making instruments.

The national institute of standards and technology (NIST) formerly called National Bureau of Standards (NBS), it was established by an act of congress in 1901, and the need for such body had been noted by the founders of the constitution. In order to maintain accuracy, standards in a vast industrial complex must be trace able to a single source, which may be national standards.

The following is the generalization of echelons of standards in the national measurement system.

1. Calibration standards

2. Metrology standards

3. National standards

Calibration standards:

Working standards of industrial or government all laboratories.

Metrology standards: Reference standards of industrial or Government all laboratories.

National standards: It includes proto type and natural phenomenon of SI(Systems International), the world wide system of weight and measures standards. Application of precise measurement has increased so much, that a single national laboratory to perform directly all the calibrations and standardization required by large country with high technical development. It has led to the establishment of a considerable number of standardizing laboratories in industry and in various other areas. A standard provides a reference or datum for assigning a numerical value to a measured quantity.

Classification of Standards

To maintain accuracy and interchangeability it is necessary that Standards to be trace able to a single source, usually the National Standards of the country, which are further linked to International Standards.

The accuracy of National Standards is transferred to working standards through a chain of intermediate standards in a manner given below.

•National Standards

•National Reference Standards

•Working Standards

•Plant Laboratory Reference Standards

•Plant Laboratory Working Standards

•Shop Floor Standards

ERRORS IN MEASUREMENTS

It is never possible to measure the true value of a dimension there is always some error. The error in measurement is the difference between the measured value and the true value of the measured dimension.

Error in measurement = Measured value-True value

Absolute Error

True absolute error:

It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.

Apparent absolute error:

If the series of measurement are made and then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

Relative Error: It is the quotient of the absolute error and the value of comparison use or calculation of that absolute error. This value of comparison may be the true value, the conventional true value or the arithmetic mean for series of measurement.

Types of Errors Systematic Error

These errors include calibration errors, error due to variation in the atmospheric condition variation in contact pressure etc. If properly analyzed, these errors can be determined and reduced or even eliminated hence it also called controllable errors. All other systematic errors can be controlled in a magnitude and sense except personal error. These errors results from irregular procedure that is consistent in action. These errors are repetitive in nature and are of constant and similar form.

Random Error

These errors are caused due to variation in position of setting standard and work –piece errors. Due to displacement of level joints of instruments, due to back lash and friction, these error are induced. Specific cause, magnitude and sense of these errors cannot be determined from the knowledge of measuring system or condition of measurement. These errors are non-consistent and hence the name random errors.

Environmental Error

These errors are caused due to effect of surrounding temperature, pressure and humidity on the measuring instrument. External factors like nuclear radiation, vibrations and magnetic field also leads to error. Temperature plays an important role where high precision is required .e.g. while using slip gauges, due to handling the slip gauges may acquire human body temperature, where as the work is at 20°C. A 300mm length will go in error by 5microns which is quite a considerable error. To avoid errors of this kind, all metrology laboratories and standard rooms worldwide are maintained at 20°C.

Precision

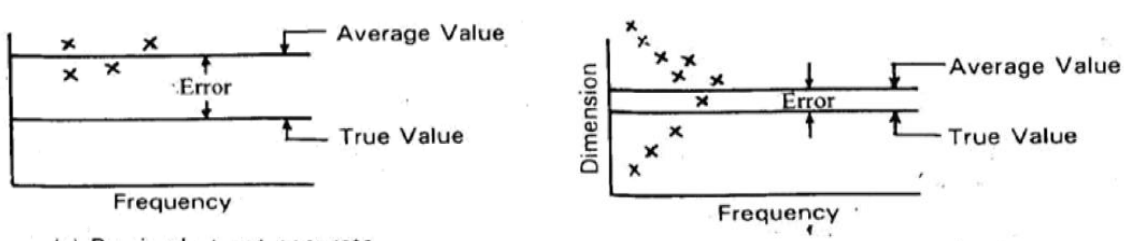
The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process. It refers to the group of measurements for the same characteristics take number identical conditions. It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. These to observations will scatter about the mean. The scatter of these measurements is designated as σ, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of σ, the more precise is the instrument.

Accuracy

Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement. It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

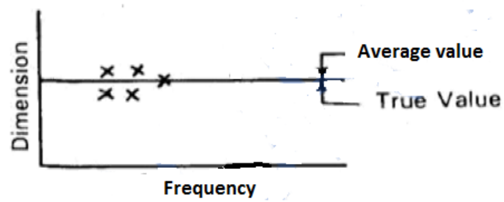
Distinction between Precision and Accuracy

Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the following example. Several measurements are made on a component by different types of instruments (A, B and C respectively) and the results are plotted. In any set of measurements, the individual measurements are scattered about the mean, and the precision signifies how well the various measurements performed by same instrument on the same quality characteristic agree with each other. The difference between the mean of set of readings on the same quality characteristic and the true value is called as error. Less the error more accurate is the instrument. Figure shows that the instrument A is precise since the results of number of measurements are close to the average value. However, there is a large difference (error) between the true value and the average value hence it is not accurate. The readings taken by the instruments are scattered much from the average value and hence it is not precise but accurate as there is a small difference between the average value and true value.



(a) Precise but not accurate

(b) Accurate but not precise



(c) Accurate & Precise

METHODS OF MEASUREMENTS

These are the methods of comparison used in measurement process. In precision measurement various methods of measurement are adopted depending upon the accuracy required and the amount of permissible error.

The methods of measurement can be classified as:

1. Direct method

2. Indirect method

3. Absolute or Fundamental method

4. Comparative method

5. Transposition method

6. Coincidence method

7. Deflection method

8. Complementary method

9. Contact method

10. Contactless method

Direct method of measurement:

This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations. For example, measurements by using scales, vernier calipers, micrometers, bevel protector etc. This method is most widely used in production. This method is not very accurate because it depends on human in sensitiveness in making judgment.

Indirect method of measurement:

In indirect method the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value. E.g. Angle measurement by sine bar, measurement of screw pitch diameter by three wire method etc.

Absolute or Fundamental method:

It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.

Comparative method:

In this method the value of the quantity to be measured is compared with known value of the same quantity or other quantity practically related to it. So, in this method only the deviations from a master gauge are determined, e.g., dial indicators, or other comparators.

Transposition method:

It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, and then the value of the quantity measured is put in place of this known value and is balanced again by another known value B. If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is AB. For example, determination of a mass by means of a balance and known weights, using the Gauss double weighing.

Coincidence method:

It is a differential method of measurement in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals. For example, measurement by vernier caliper micrometer.

Deflection method:

In this method the value of the quantity to be measured is directly indicated by a deflection of a pointer on a calibrated scale.

Complementary method:

In this method the value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value. For example, determination of the volume of a solid by liquid displacement.

Method of measurement by substitution:

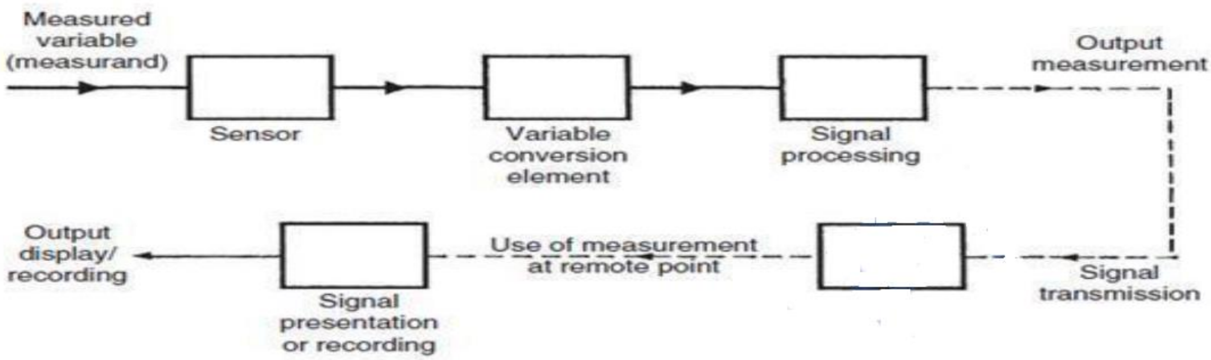
It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.

Method of null measurement:

It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

Generalized measurement system

A measuring system exists to provide information about the physical value of some variable being measured. In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown variable applied to it. However, in more complex measurement situations, a measuring system consists of several separate elements as shown in Figure



The various elements of measurement system are,

a. Primary sensing Element

b. Variable conversion element.

c. Variable manipulation element

d. Data transmission element.

e. Data processing Element

f. Data presentation element.

a. Primary sensing Element

it is the first element which receives energy from the measured medium and it produces an output corresponding to the measurand. This output is then converted into an analogous electrical signal by a transducer.

b. Variable conversion element.

It converts the output electrical signal of the primary sensing element into a more suitable form signal without changing the information containing in the input signal. In some instruments, there is no need of using a variable conversion element while some other instruments require the variable conversion element.

c. Variable manipulation element

This element is used to manipulate the signal presented to it and preserving the original nature of the signal. In other words, it amplifies the input signal to the required magnification. For example an electronic voltage amplifier receives a small voltage as input and it produces greater magnitude of voltage as output. A variable manipulation element does not necessarily follow a variable conversion element and it may precede it.

d. Data transmission element.

It transmits the data from one element to the other. It may be as shaft and gear assembly system or as complicated as a telemetry system which is used to transmit the signal from one place to another.

e. Data processing Element

It is an element which is used to modify the data before displayed or finally recorded. It may be used for the following purposes. To convert the data into useful form To separate the signal hidden in noise It may provide corrections to the measured physical variables to compensate for zero offset, temperature error, scaling etc

f. Data presentation element.

These are the elements that they finally communicate the information of measured variables to a human observer for monitoring, controlling or analyzing purposes. The value of measured variables may be indicated by an analog indicator, digital indicator, or by a recorder.

Repeatability and Reproducibility

Repeatability may be defined as the closeness of agreement among the number of consecutive measurement of the output for the same value of input under the same operating conditions. It may be specified in terms of units for a given period of time.

Reproducibility may be defined as the closeness of agreement among the repeated measurements of the output for the same value of input under the same operating conditions over a period of time. Perfect reproducibility means that the instrument calibration does not gradually shift over a long period of time.

Systematic error and Random error:

It is the error which during several measurements, made under the same conditions, of the same value of a certain quantity, remains constant in absolute value and sign or varies in a predictable way in accordance with a specified law when the conditions change. The causes of these errors may be known or unknown. The errors may be constant or variable. Systematic errors are regularly repetitive in nature.

This error varies in an unpredictable manner in absolute value & in sign when a large number of measurements of the same value of a quantity are made under practically

Static response and Dynamic response

The static characteristics of an instrument are considered for instruments which are used to measure an unvarying process conditions.

The behaviors of an instrument under such time varying input – output conditions called Dynamic response of an instrument. The instrument analysis of such dynamic response is called dynamic analysis of the measurement system.

Generalized measurement system

Components of Generalized Measurement System: A generalized measurement system consists of the following components: Primary Sensing Element Variable Conversion Element Variable Manipulation Element Data Processing Element Data Transmission System Data Presentation Element In addition to the above components, a measurement system may also have a data storage element to store measured data for future use. As the above six components are the most common ones used in many measurement systems, they are discussed in detail below:

1. Primary Sensing Element: The primary sensing element receives signal of the physical quantity to be measured as input. It converts the signal to a suitable form (electrical, mechanical or other form), so that it becomes easier for other elements of the measurement system, to either convert or manipulate it.

2. Variable Conversion Element: Variable conversion element converts the output of the primary sensing element to a more suitable form. It is used only if necessary.

3. Variable Manipulation Element: Variable manipulation element manipulates and amplifies the output of the variable conversion element. It also removes noise (if present) in the signal.

4. Data Processing Element: Data processing element is an important element used in many measurement systems. It processes the data signal received from the variable manipulation element and produces suitable output. Data processing element may also be used to compare the measured value with a standard value to produce required output.

5. Data Transmission System: Data Transmission System is simply used for transmitting data from one element to another. It acts as a communication link between different elements of the measurement system. Some of the data transmission elements used are cables, wireless antennae, transducers, telemetry systems etc.

6. Data Presentation Element: It is used to present the measured physical quantity in a human readable form to the observer. It receives processed signal from data processing element and presents the data in a human readable form. LED displays are most commonly used as data presentation elements in many measurement systems.

Range of measurement

The physical variables that are measured between two values. One is the higher calibration value H, and the other is Lower value L, The difference between H, and L, is called range.

Legal metrology

Legal metrology is part of Metrology and it is directed by a national organization which is called national service of legal Metrology

Sensitivity and range

A Instrument have a scale reading of 0.01mm to 100mm. Here, the sensitivity of the instrument is 0.0lmm i.e. the minimum value in the scale by which the instrument can read. The range is 0.01 to 100mm i.e. the minimum to maximum value by which the instrument can read

System error and correction Error

The deviation between the results of measured value to the actual value. Correction: The numerical value which should be added to the measured value to get the correct result.

Readability

It is a term frequently used for analog type instruments. This characteristic depends on both the instrument and observer.

Calibration

Calibration is the process of determining and adjusting an instruments accuracy to make sure its accuracy is within the manufacturer's specifications

Hysteresis

All the energy put into the stressed component when loaded is not recovered upon unloading. So, the output of measurement partially depends on input called hysteresis.

Measurement and it types

It is the process of comparing the input signal with predefined standard and it gives out the result. It is a word used to describe about physical quantities such as length, weight, temperature, pressure, force etc Types 1. Primary measurements 2. Secondary measurements. 3. Tertiary measurements.

Reliability

Reliability is the ability of a person or system to perform and maintain its functions in routine circumstances.

Static response

Measured variables are many times steady, that is, they do not vary with time. That is they are static in nature.

Precision and accuracy

Accuracy - The maximum amount by which the result differ from true value. Precision - Degree of repetitiveness. If an instrument is not precise it will give different results for the same dimension for the repeated readings.

Sensitivity in measurement

Sensitivity is an absolute quantity, the smallest absolute amount of change that can be detected by a measurement.

Accuracy and precision

Accuracy can be defined as the amount of uncertainty in a measurement with respect to an absolute standard.

Precision describes the reproducibility of the measurement. For example, measure a steady state signal many times.

Traceability

The term "measurement traceability" is used to refer to an unbroken chain of comparisons relating an instrument's measurements to a known standard. Calibration to a traceable standard can be used to determine an instrument's bias, precision, and accuracy.

Gauging and measurements

Gauging is the process of determine the exact dimensions, capacity, quantity, or force of measure.

A **measurement** is a method of determining quantity, capacity, or dimension. Several systems of measurement exist, each one comprising units whose amounts have been arbitrarily set and agreed upon by specific groups.

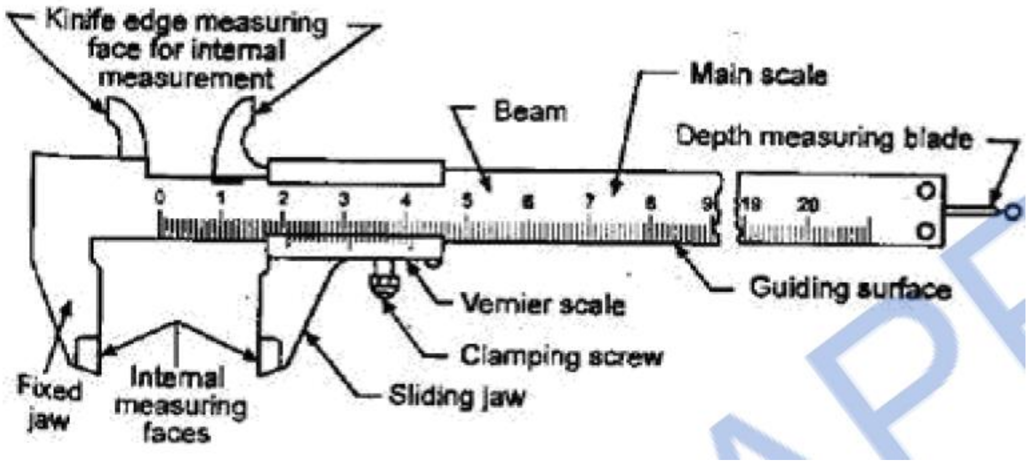
UNIT-II MEASUREMENT OF LINEAR, ANGULAR DIMENSIONS, ASSEMBLY AND TRANSMISSION ELEMENTS

VERNIERCALIPERS

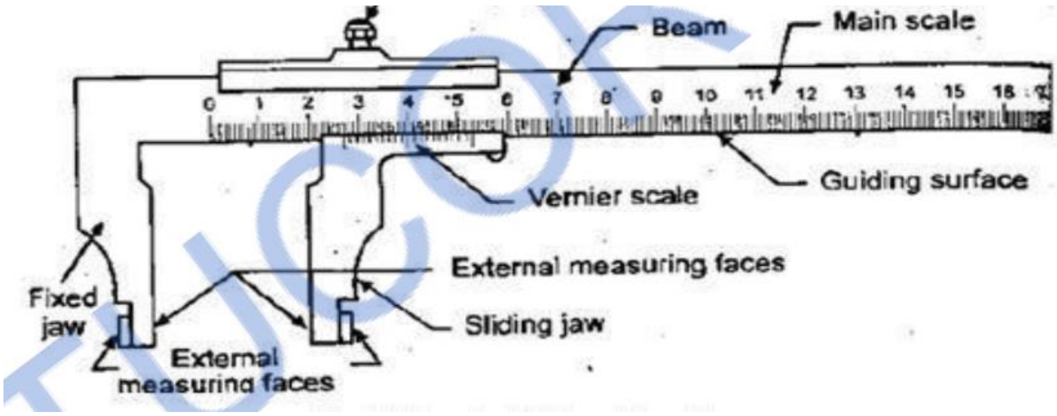
The vernier instruments generally used in workshop and engineering metrology have comparatively low accuracy. The line of measurement of such instruments does not coincide with the line of scale. The accuracy therefore depends upon the straightness of the beam and the squareness of the sliding jaw with respect to the beam. To ensure the squareness, the sliding jaw must be clamped before taking the reading. The zero error must also be taken into consideration. Instruments are now available with a measuring range up to one meter with a scale value of 0.1 or0.2 mm.

Types of Vernier Calipers

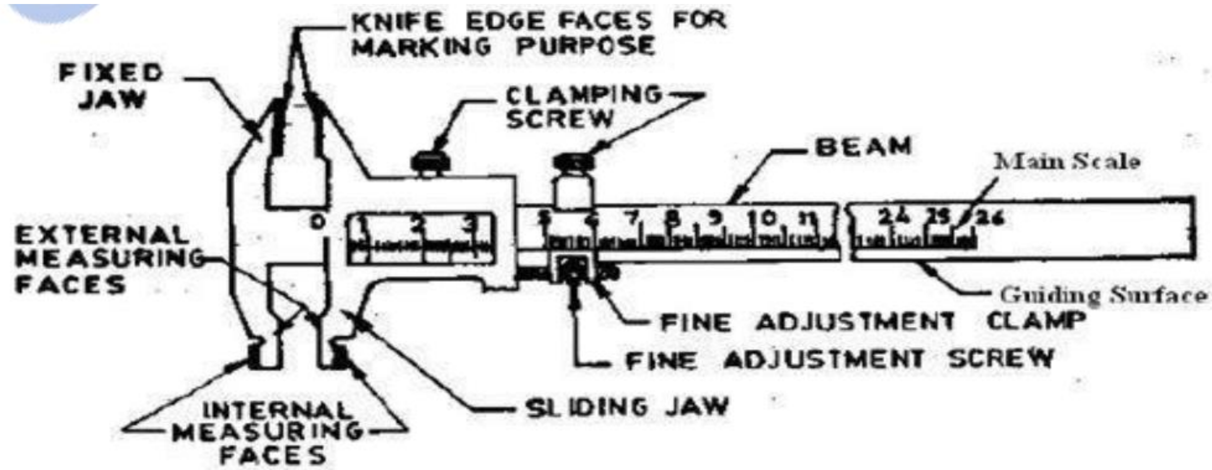
According to Indian Standard IS:3651- 1974, three types of vernier calipers have been specified to make external and internal measurements and are shown in figures respectively. All the three types are made with one scale on the front of the beam for direct reading. **TypeA :**Vernier has jaws on both sides for external and internal measurementsand a blade for depth measurement.



Type B: It is provided with jaws on one side for external and internalmeasurements.



Type C: It has jaws on both sides for making the measurement and for markingoperations



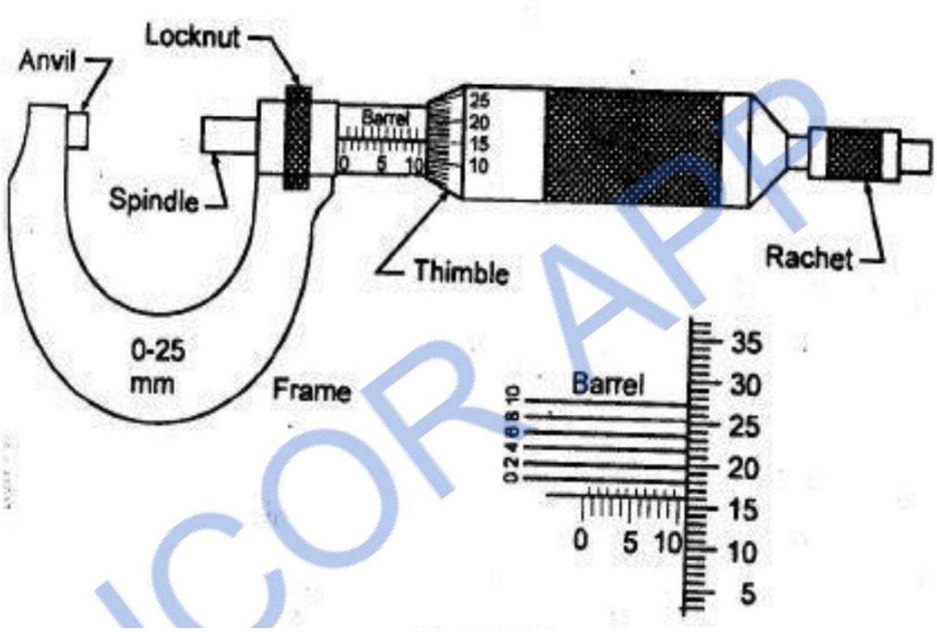
MICROMETERS

There are two types in it.

 Outside micrometer— To measure external dimensions.

 Inside micrometer—To measure internal dimensions

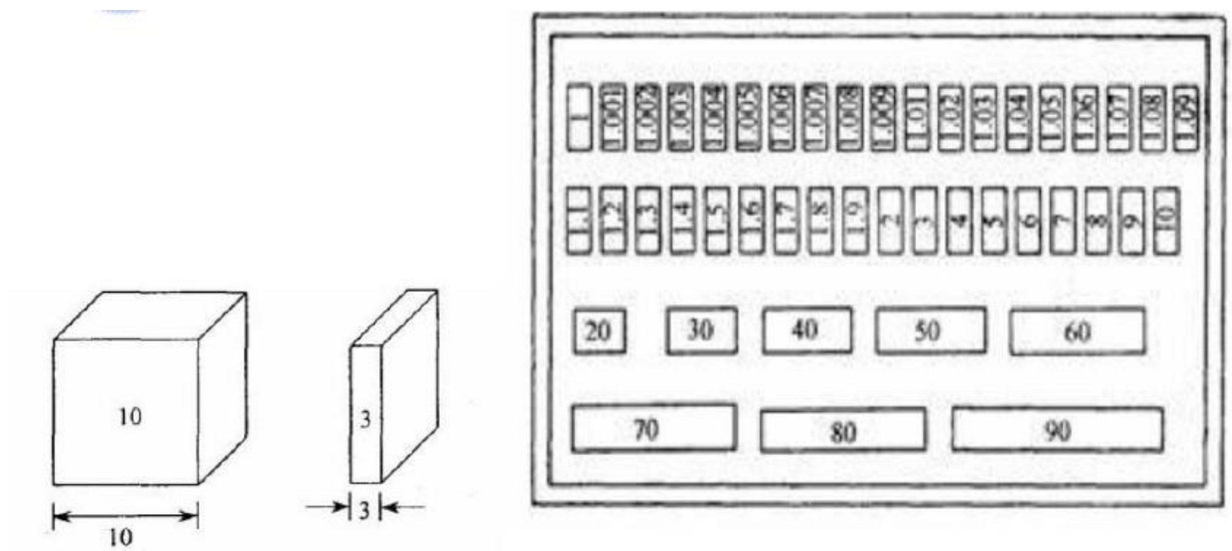
 An outside micrometer is shown. It consists of two scales, main scale and thimble scale. While the pitch of barrel screw is 0.5mm the thimble has graduation of 0.01mm. The **least count** of this micrometer is 0.01 mm.



The micrometer requires the use of an accurate screw thread as a means of obtaining a measurement. The screw is attached to a spindle and is turned by movement of a thimble or ratchet at the end. The barrel, which is attached to the frame, acts as a nut to engage the screw threads, which are accurately made with a pitch of 0.05mm. Each revolution of the thimble advances the screw 0.05mm. On the barrel a datum line is graduated with two sets of division marks.

SLIPGAUGES

These may be used as reference standards for transferring the dimension of the unit of length from the primary standard to gauge blocks of lower accuracy and for the verification and graduation of measuring apparatus. These are high carbon steel hardened, ground and lapped rectangular blocks, having cross sectional area 0f 30mm, 10mm. Their opposite faces are flat, parallel and are accurately the stated distance apart. The opposite faces are of such a high degree of surface finish, that when the blocks are pressed together with a slight twist by hand, they will wring together. They will remain firmly attached to each other. They are supplied in sets of 112 pieces down to 32pieces. Due to properties of slip gauges, they are built up by, wringing into combination which gives size, varying by steps of 0.01 mm and the overall accuracy is of the order of 0.00025mm. Slip gauges with three basic forms are commonly found, these are rectangular, square with center hole, and square without center hole.



Precautions

- The blocks should be kept in the box and it it should not dropped on the irregular surfaces.
- Surfaces of slip gauges should be cleaned before it is used.
- The slip gauge block should be in particular temperature condition to eliminate the thermal expansion which causes in accuracy during measurement.
- While using slip gauses for measurement it should be kept iin a flat surface to get high accurate readings.

LIMITGAUGES

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- The limit gauges are used in inspection by methods of attributes.
- This gives the information about the products which maybe either within the prescribed limit or not.
- By using limit gauges report, the control charts of P and C charts are drawn to control invariance of the products.

 This procedure is mostly performed by the quality control department of each and every industry.
 Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.

Purpose of using limit gauges
 Components are manufactured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
 If the dimensions are outside these limits, the components will be rejected.
 It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, we can make use of gauges known as limit gauges.

The common types are as follows:
1) Plug gauges.
2) Ring gauges.
3) Snap gauges.

PLUGGAUGES

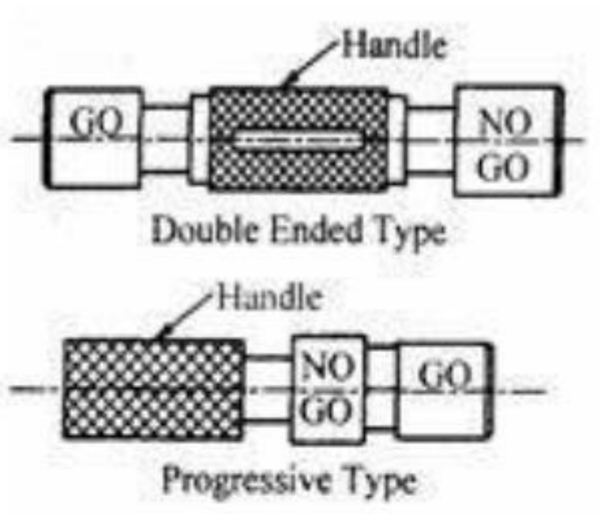
 The ends are hardened and accurately finished by grinding. One end is the GO end and the other end is NOGO end.
 Usually, the GO end will be equal to the lower limit size of the hole and the NOGO end will be equal to the upper limit size of the hole.
 If the size of the hole is within the limits, the GO end should go inside the hole and NOGO end should not go.
 If the GO end and does not go, the hole is under size and also if NOGO end goes, the hole is over size. Hence, the components are rejected in both the cases

1. **Double ended plug gauges**

In this type, the GO end and NOGO end are arranged on both the ends of the plug. This type has the advantage of easy handling.

2. **Progressive type of plug gauges**

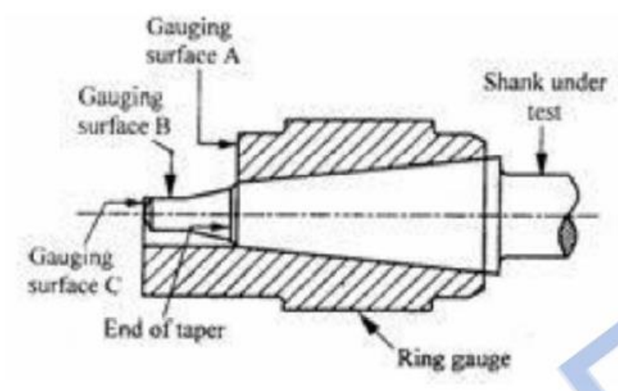
In this type both the GO end and NOGO end are arranged in the same side of the plug. We can use the plug gauge ends progressively one after the other while checking the hole. It saves time. Generally, the GO end is made larger than the NOGO end in plug gauges.

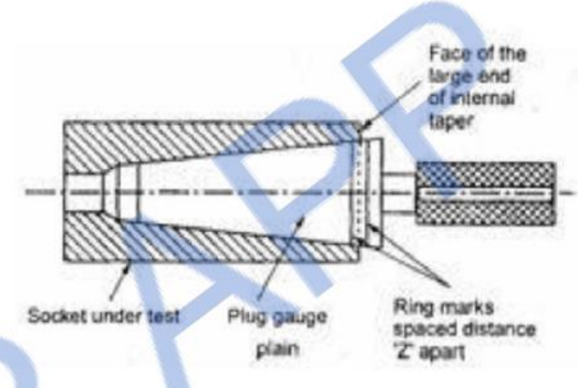


TAPER PLUG GAUGE

Taper plug gauges are used to check tapered holes. It has two check lines. One is a GO line and another is a NOGO line. During the checking of work, NOGO line remains outside the hole and GO line remains inside the hole. They are various types taper plug gauges are available as shown in fig. Such as

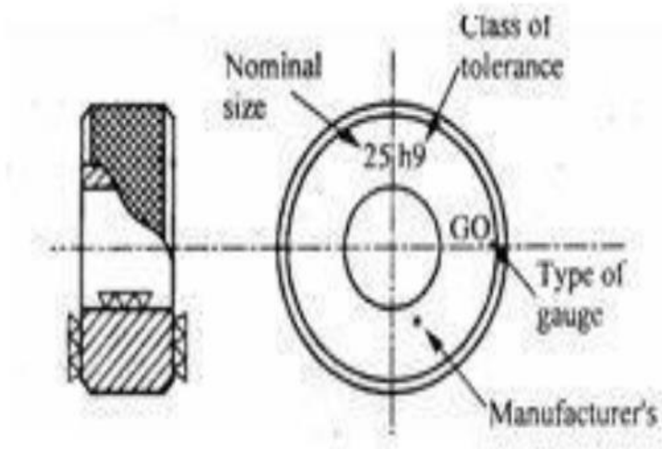
1) Taper plug gauge— plain
2) Taper plug gauge— tanged.
3) Taper ring gauge plain
4) Taper ring gauge — tanged



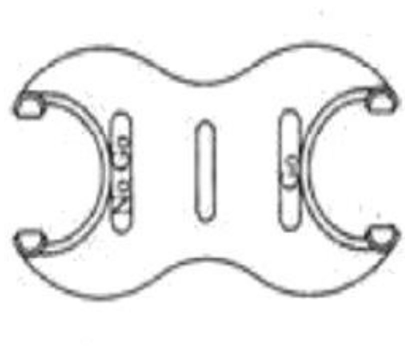


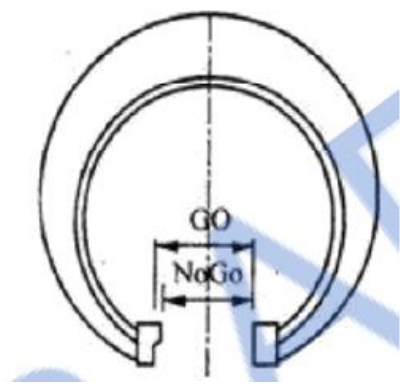
RING GAUGES

 Ring gauges are mainly used for checking the diameter of shafts having a central hole. The hole is accurately finished by grinding and lapping after taking hardening process.
 The periphery of the ring is knurled to give more grips while handling the gauges. We have to make two ring gauges separately to check the shaft such as GO ring gauge and NOGO ring gauge.
 But the hole of GO ring gauge is made to the upper limit size of the shaft and NOGO for the lower limit.
 While checking the shaft, the GO ring gauge will pass through the shaft and NO GO will not pass.
 To identify the NOGO ring gauges easily, are mark or a small groove cut on its periphery.



SNAP GAUGE Snap gauges are used for checking external dimensions. They are also called a snap gauges. The different types of snap gauges are:





Double Ended Snap Gauge

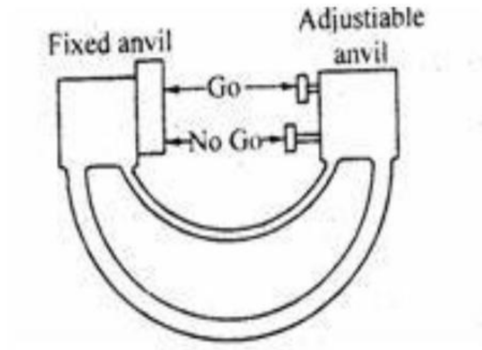
This gauge is having two ends in the form of anvils. Here also, the GO anvil is made to lower limit and NOGO anvil is made to upper limit of the shaft. It is also known as solid snap gauges

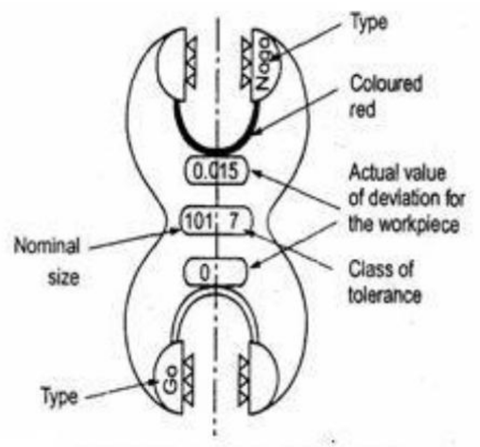
Progressive Snap Gauge

This type of snap gauge is also called caliper gauge. It is mainly used for checking large diameters up to 100mm. Both GO and NOGO anvils at the same end. The GO anvil should be at the front and NOGO anvil at the rear. So, the diameter of the shaft is checked progressively by these two ends. This type of gauge is made of horse shoe shaped frame with I section to reduce the weight of the snap gauges.

Adjustable Snap Gauge

Adjustable snap gauges are used for checking large size shafts made with horse shoe shaped frame of I section. It has one fixed anvil and two small adjustable anvils. The distance between the two anvils is adjusted by adjusting the adjustable anvils by means of set screws. This adjustment can be made with the help of slip gauges for specified limits of size.





Combined Limit Gauges

A spherical projection is provided with GO and NOGO dimension marked in a single gauge. While using GO gauge the handle is parallel to axes of the hole and normal to axes for NOGO gauge.
Position Gauge It is designed for checking the position of features in relation to another surface. Other types of gauges are also available such as contour gauges, receiver gauges, profile gauges etc.

COMPARATORS

Comparators are one form of linear measurement device which is quick and more convenient for checking large number of identical dimensions. Comparators normally will not show the actual dimensions of the work piece. They will be shown only the deviation in size. During the measurement a comparator is able to give the deviation of the dimension from the set dimension. This cannot be used as an absolute measuring device but can only compare two dimensions. Comparators are designed in several types to meet various conditions.

Comparators of every type in corporate some kind of magnifying device. The magnifying device magnifies how much dimension deviates, plus or minus, from the standard size. The comparators are classified according to the principles used for obtaining magnification.
The common types are:
1) Mechanical comparators
2) Electrical comparators
3) Optical comparators
4) Pneumatic comparators

MECHANICAL COMPARATORS

Mechanical comparator employs mechanical means for magnifying small deviations. The method of magnifying small movement of the indicator in all mechanical comparators are effected by means of levers, gear trains or a combination of these elements. Mechanical comparators are available having magnifications from 300 to 5000 to 1. These are mostly used for inspection of small parts machined to close limits.

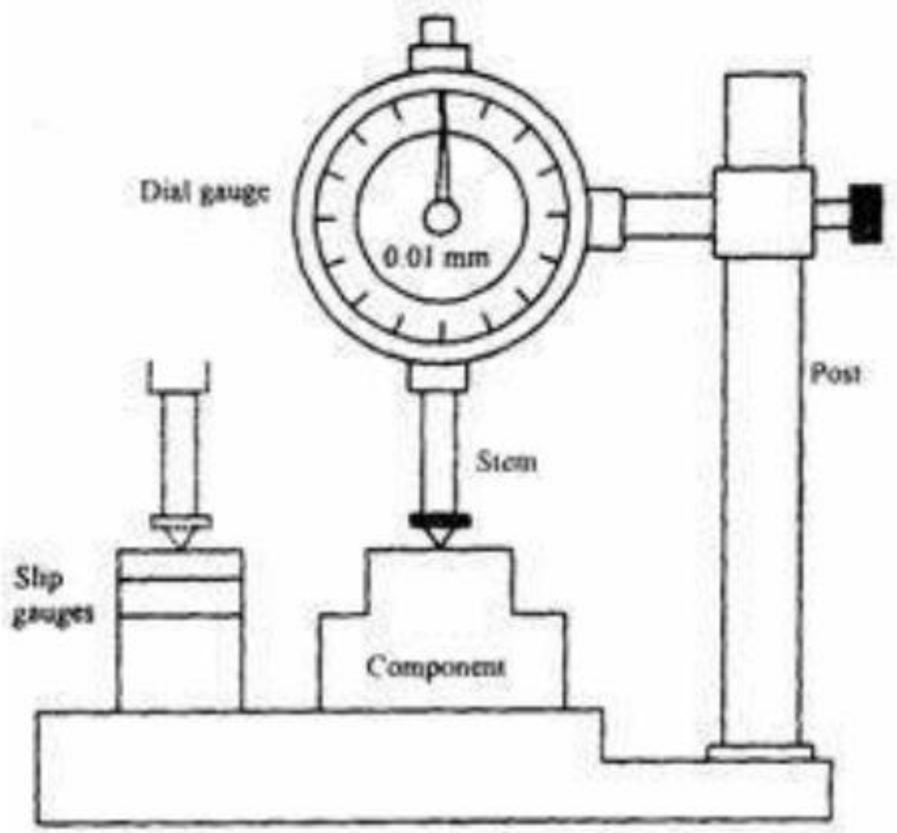
Dial indicator A dial indicator or dial gauge is used as a mechanical comparator. The essential parts of the instrument are like a small clock with a plunger projecting at the bottom as shown in fig. Very slight upward movement on the plunger moves it upward and the movement is indicated by the dial pointer. The dial is graduated into 100 divisions. A full revolution of the pointer about this scale corresponds to1mm travel of the plunger. Thus, a turn of the pointer b one scale division represents a plunger travel of 0.01mm.

Experimental setup

The whole setup consists of worktable, dial indicator and vertical post. The dial indicator is fitted to vertical post by on adjusting screw as shown in fig. The vertical post is fitted on the worktable; the top surface of the work table is finely finished. The dial gauge can be adjusted vertically and locked in position by a screw.

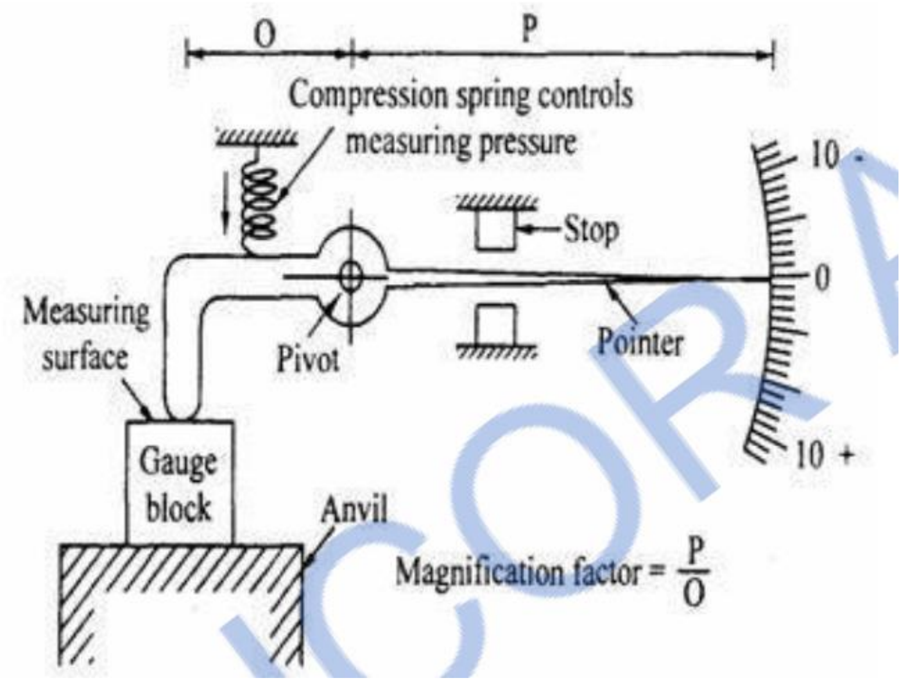
Procedure

Let us assume that the required height of the component is 32.5mm. Initially this height is built up with slip gauges. The slip gauge blocks are placed under the stem of the dial gauge. The pointer in the dial gauge is adjusted to zero. The slip gauges are removed.



Now the component to be checked is introduced under the stem of the dial gauge. If there is any deviation in the height of the component, it will be indicated by the pointer. **Mechanism** The stem has rack teeth. A set of gears engage with the rack. The pointer is connected to a small pinion. The small pinion is independently hinged. i.e. .it is not connected to the stern. The vertical movement of the stem is transmitted to the pointer through a set of gears. A spring gives a constant downward pressure to the stem.

READ TYPE MECHANICAL COMPARATOR



In this type of comparator, the linear movement of the plunger is specified by means of read mechanism. The mechanism of this type is illustrated in fig. A spring- loaded pointer is pivoted. Initially, the comparator is set with the help of a known dimension eg. Set of slip gauges as shown in fig. Then the indicator reading is adjusted to zero. When the part to be measured is kept under the pointer, then the comparator displays the deviation of this dimension either in ± or — side of the set dimension.

Advantages

- It is usually robust, compact and easy to handle.
- There is no external supply such as electricity, air required.
- It has very simple mechanism and is cheaper when compared to other types.
- It is suitable for ordinary workshop and also easily portable.

Disadvantages

- Accuracy of the comparator mainly depends on the accuracy of the rack and pinion arrangement. Any slackness will reduce accuracy.
- It has more moving parts and hence friction is more and accuracy is less.
- The range of the instrument is limited since pointer is moving over a fixed scale.

OPTICAL COMPARATOR In this type of comparator, small plunger displacement is amplified by both mechanical and optical system. The amplification is first done by pivoted lever and then by a simple optical systems.

Construction details

The optical comparator consist of the following parts such as

(1)Pivoted lever

(2)Objective lens

(3)Scale

(4)Plunger
(5)Table and base
(6)Mirror

Pivoted lever

The pivoted lever amplifies the plunger movement mechanically .It is pivoted near the plunger. One end is fitted with the plunger and other end is fitted with a mirror.

Objective lens

The main function of objective lens is to convert the incoming light rays from the source into parallel beams

Screen and scale

It is final display device from which the readings can be obtained.It is semi transparent glass

Plunger It is reciprocating member. During the measurement, the plunger actuates.

Table The work is palced on the table to carry out the task.

Base It is rigid support over which the table is mounted

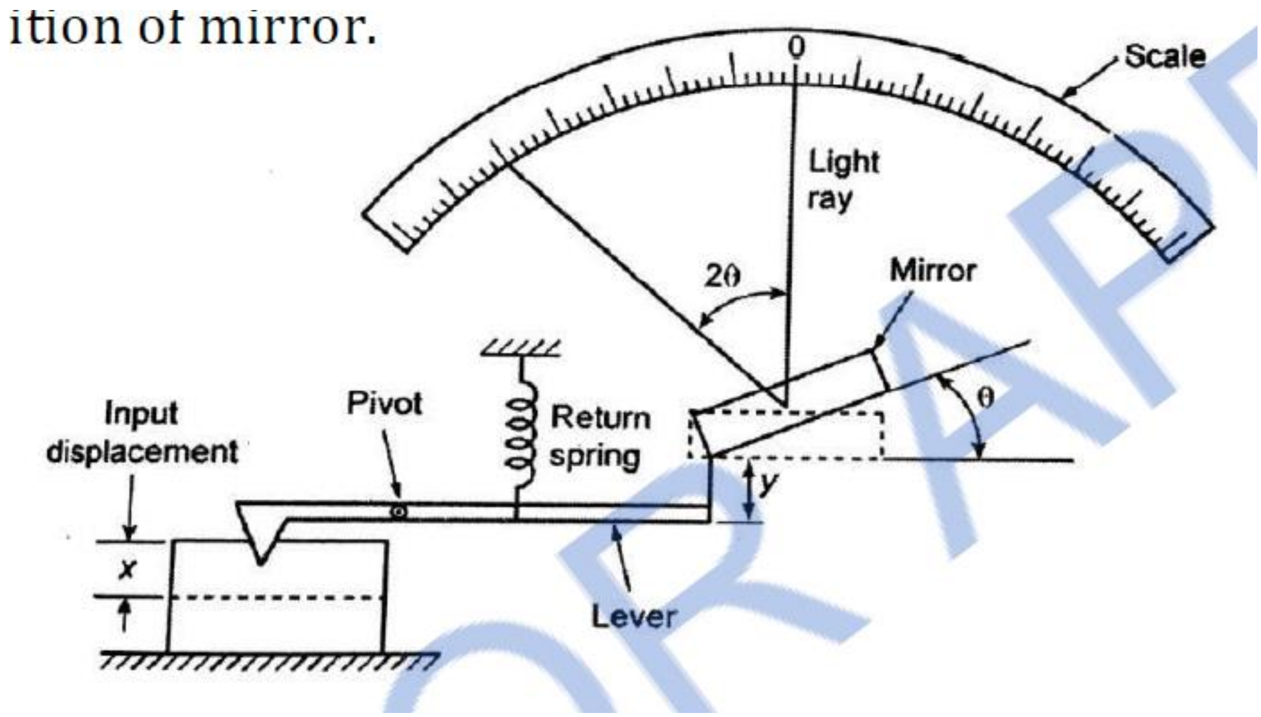
Mirror It reflects the incoming light rays from the source which is hinged at the other end of the lever.

Working Principle During measurement, the vertical displacement of the plunger is magnified by the ratio of the lever arm. The lever title the mirror about its hinged to again magnify. The light rays from the lamp are condensed by a condensing less. Then, the condensed light falls on the objective lens. The light rays are converted into parallel beams again the parallel beam of light ray fall on the mirror. The mirror reflects the light rays on a screen As the screen is the semi transparentglass ,the image of work placed on the table will be reflected. The magnified master drawing is placed over the screen. The projected image is compared with the master drawing .This type of comparator can also used for inspecting small Parts such as screw, thread, saw teeth etc

The differences amplified by a lever to give a vertical displacement and an angular displacement .The difference x between two dimension may be used to actuate a lever to displace by y .same displacement causes a ray of light which is initially at zero angle to get displaced by 2 because the mirror is deflected by .The magnified reading is a measure of displacement x. the scale is calibrated by gauge blocks.

Advantages

- Small parts can also be inspected
- Different amplification can be obtained by adjuisting the projection lens and the position of mirror.

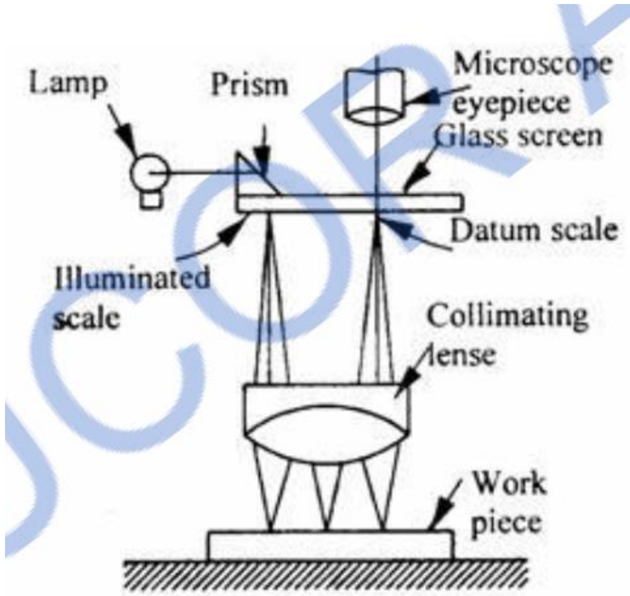


Pneumatic Comparator

In this system, no physical contact is made either with the setting gauge or the part being measured, and that internal dimensions may be readily measured, not only with respect to tolerance boundaries, but also geometric form. Further, the system lends itself to the inspection of a single, or a number of dimensions simultaneously, either during or immediately after the operating cycle of a machine tool.Back-pressure (Pneumatic) comparator: It uses a water manometer for the indication of back pressure. It consists of a vertical metal cylinder filled with water upto a certain level and a dip tube immersed into it upto a depth corresponding to the air pressure required. A calibrated manometer tube is connected between the cylinder and control orifice as shown in fig.. The air from its normal source of supply is filtered and passes through a flow valve.

Its pressure is then reduced and maintained at a constant value by a dip tube into a water chamber, the pressure value being determined by the head of the water displace, excess air escaping to atmosphere. The air at reduced pressure then passes through the control orifice, and escapes from the measuring orifice. The back pressure in the circuit is indicated by the head of water displaced in the manometer tube. The tube is graduated linearly to show changes of pressure resulting from changes in dimension‘d’. Amplifications of up to 50000 are obtainable with this system.

Angle Dekkor



This is also a type of auto -collimator. There is an illuminated scale in the focal plane of the collimating lens. This illuminated scale is projected as a parallel beam by the collimating lens which after striking a reflector below the instrument is refocused by the lens in the field of view of the eyepiece. In the field of view of microscope, there is another datum scale fixed across the center of screen. The reflected image of the illuminated scale is received at right angle to the fixed scale as shown in fig. Thus the changes in angular position of the reflector in two planes are indicated by changes in the point of intersection of the two scales. One division on the scale is calibrated to read1minute.

Uses of Angle Dekkor Measuring angle of a component

Angle dekkor is capable of measuring small variations in angular setting i.e. determining angular tilt. Angle dekkor is used in combination with angle gauge. First the angle gauge combination is set up to the nearest known angle of the component. Now the angle dekkor is set to zero reading on the illuminated scale. The angle gauge build up is then removed and replaced by the component under test. Usually a straightedge being used to ensure that there is no change in lateral positions. The new position of the reflected scale with respect to the fixed scale gives the angular tilt of the component from the set angle.

Checking the slope angle of a V-block

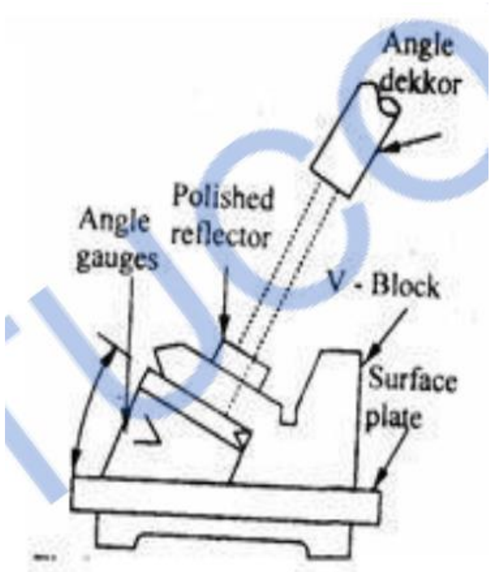


Figure shows the setup for checking the sloping angle of V block. Initially, a polished reflector or slip gauge is attached in close contact with the work surface. By using angle gauge zero reading is obtained in the angle dekkor. Then the angle may be calculated by comparing the reading obtained from the angle dekkor and angle gauge.

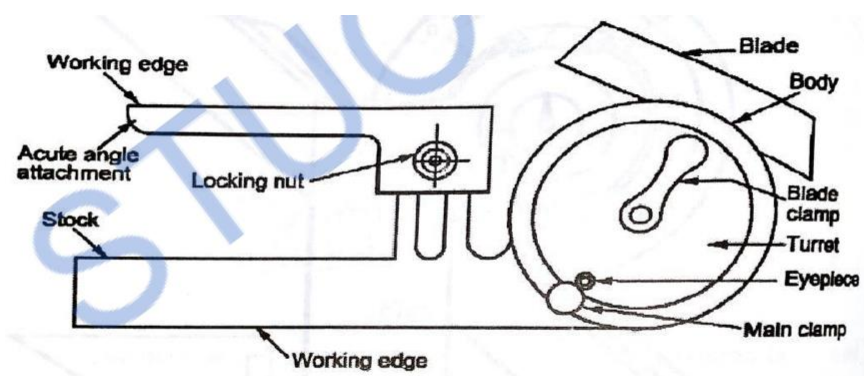
To measure the angle of cone or Taper gauge

Initially, the angle dekkor is set for the nominal angle of cone by using angle gauge or sine bar. The cone is then placed in position with its base resting on the surface plate. A slip gauge or reflector is attached on the cone since no reflection can be obtained from the curved surface. Any deviation from the set angle will be noted by the angle dekkor in the eye piece and indicated by the shifting of the image of illuminated scale.

OPTICAL BENVEL PROTRACTOR

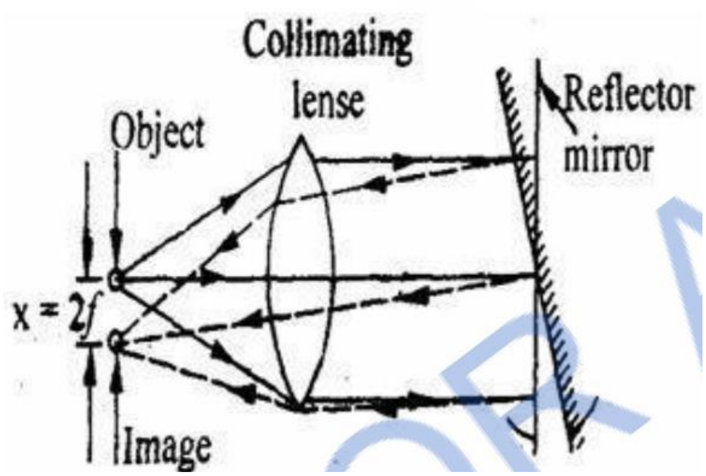
Working Principle

The value can be measured to an accuracy of 2 min by using this type of bevel protractor .The values are obtained against an index line or vernier by means of an optical magnifying system .The optical magnifying system is attached with the bevel protractor itself. A separate arrangement is provided for adjusting the focus of the system for the normal variation of eye sight .The vernier scale are arranged always in focus of the optical system.



AUTO- COLLIMATOR

Auto-collimator is an optical instrument used for the measurement of small angular differences, changes or deflection, plane surface inspection etc. For smallangular measurements, autocollimator provides a very sensitive and accurate approach. An auto-collimator is essentially an infinity telescope and a collimator combined into one instrument.



Basic principle

If a light source is placed in the flows of a collimating lens, it is projected as a parallel beam of light. If this beam is made to strike a plane reflector, kept normal to the optical axis, it is reflected back along its own path and is brought to the same focus. The reflector is tilted through a small angle '0'. Then the parallel beam is deflected twice the angle and is brought to focus in the same plane as the light source. The distance of focus from the object is given

$x = 2\theta \, . f$

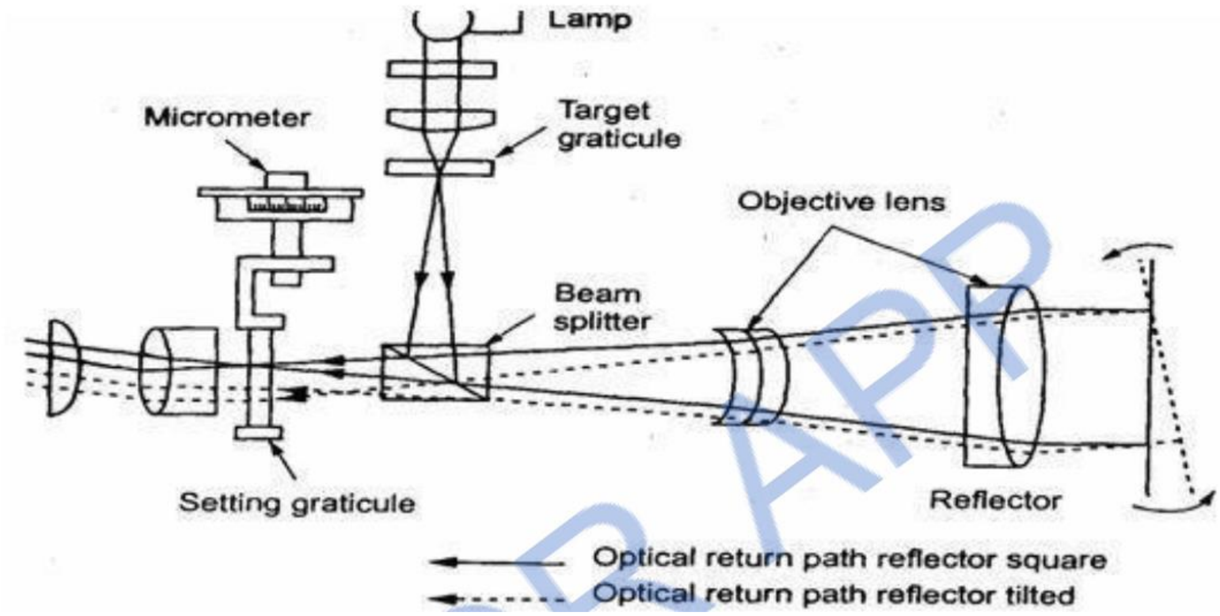
f = Focal length of the lens

θ = Fitted angle of reflecting mirror.

WORKING OF AUTO-COLLIMATOR:

There are three main parts in auto-collimator.
1. Micro meter microscope.
2. Lighting unit and
3. Collimating lens.

Figure shows a line diagram of a modern auto - collimator. A target graticule is positioned perpendicular to the optical axis. When the target graticule is illuminated by a lamp, rays of light diverging from the intersection point reach the objective lens via beam splitter. From objective, the light rays are projected as a parallel rays to the reflector.



A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel rays of light back along their original paths. They are then brought to the target graticule and exactly coincide with its intersection. A portion of the returned light passes through the beam splitter and is visible through the eyepiece. If the reflector is tilted through a smallangle, the reflected beam will be changed its path at twice the angle. It can also be brought to target graticule but linearly displaced from the actual target by the amount 2θxf. Linear displacement of the graticule image in the linear displacement of the graticule image in the plane tilted angle of eye piece is directly proportional to the reflector. This can be measured by optical micrometer. The photo electric auto-collimator is particularly suitable for calibrating polygons, for checking angular indexing and for checking small linear displacements.

APPLICATIONSOFAUTO-COLLIMATOR

Auto-collimators are used for

1) Measuring the difference in height of length standards.
2) Checking the flatness and straightness of surfaces.
3) Checking squareness of two surfaces.
5) Precise angular indexing in conjunction with polygons.Checking alignment or parallelism.
6) Comparative measurement using master angles.
7) Measurement of small linear dimensions.
8) For machine tool adjustment testing.

UNIT-III TOLERANCE ANALYSIS

Tolerance

Engineering tolerance is the permissible limit or limits of variation in:

1. a physical dimension;
2. a measured value or physical property of a material, manufactured object, system, or service;
3. other measured values (such as temperature, humidity, etc.);
4. in engineering and safety, a physical distance or space (tolerance), as in a truck (lorry), train or boat under a bridge as well as a train in a tunnel (see structure gauge and loading gauge);
5. in mechanical engineering, the space between a bolt and a nut or a hole, etc.

Dimensions, properties, or conditions may have some variation without significantly affecting functioning of systems, machines, structures, etc. A variation beyond the tolerance (for example, a temperature that is too hot or too cold) is said to be noncompliant, rejected, or exceeding the tolerance.

Interchangeable parts are parts (components) that are identical for practical purposes. They are made to specifications that ensure that they are so nearly identical that they will fit into any assembly of the same type. One such part can freely replace another, without any custom fitting, such as filing. This interchangeability allows easy assembly of new devices, and easier repair of existing devices, while minimizing both the time and skill required of the person doing the assembly or repair.

The concept of interchangeability was crucial to the introduction of the assembly line at the beginning of the 20th century, and has become an important element of some modern manufacturing but is missing from other important industries.

Interchangeability of parts was achieved by combining a number of innovations and improvements in machining operations and the invention of several machine tools, such as the slide rest lathe, screw-cutting lathe, turret lathe, milling machine and metal planer. Additional innovations included jigs for guiding the machine tools, fixtures for holding the workpiece in the proper position, and blocks and gauges to check the accuracy of the finished parts.[1][*page needed*] Electrification allowed individual machine tools to be powered by electric motors, eliminating line shaft drives from steam engines or water power and allowing higher speeds, making modern large-scale manufacturing possible.[2] Modern machine tools often have numerical control (NC) which evolved into CNC (computerized numeric control) when microprocessors became available.

Methods for industrial production of interchangeable parts in the United States were first developed in the nineteenth century. The term *American system of manufacturing* was sometimes applied to them at the time, in distinction from earlier methods. Within a few decades such methods were in use in various countries, so *American system* is now a term of historical reference rather than current industrial nomenclature.

Selective assembly

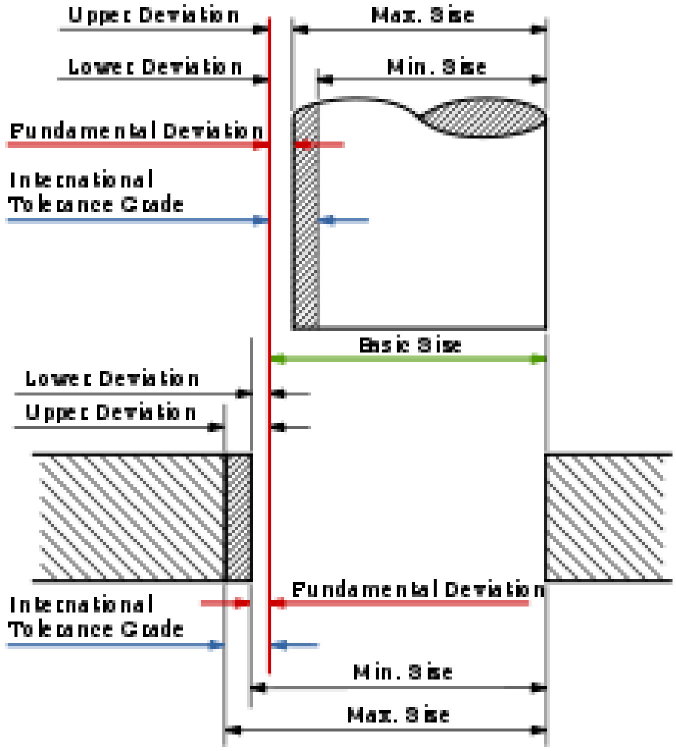
Interchangeability relies on parts' dimensions falling within the tolerance range. The most common mode of assembly is to design and manufacture such that, as long as each part that reaches assembly is within tolerance, the mating of parts can be totally random. This has value for all the reasons already discussed earlier.

There is another mode of assembly, called "selective assembly", which gives up *some* of the randomness capability in trade-off for other value. There are two main areas of application that benefit economically from selective assembly: when tolerance ranges are so tight that they cannot quite be held reliably (making the total randomness unavailable); and when tolerance ranges can be reliably held, but the fit and finish of the final assembly is being maximized by voluntarily giving up some of the randomness (which makes it available but not ideally desirable). In either case the principle of selective assembly is the same: parts are *selected* for mating, rather than being mated at random. As the parts are inspected, they are graded out into separate bins based on what end of the range they fall in (or violate). Falling within the high or low end of a range is usually called being *heavy* or *light*; violating the high or low end of a range is usually called being *oversize* or *undersize*. Examples are given below.

French and Vierck provide a one-paragraph description of selective assembly that aptly summarizes the concept.

One might ask, if parts must be selected for mating, then what makes selective assembly any different from the oldest craft methods? But there is in fact a significant difference. Selective assembly merely grades the parts into several *ranges*; within each range, there is still random interchangeability. This is quite different from the older method of fitting by a craftsman, where each mated set of parts is specifically filed to fit each part with a *specific*, *unique* counterpart.

Mechanical component tolerance



Summary of basic size, fundamental deviation and IT grades compared to minimum and maximum sizes of the shaft and hole

Dimensional tolerance is related to, but different from fit in mechanical engineering, which is a *designed-in* clearance or interference between two parts. Tolerances are assigned to parts for manufacturing purposes, as boundaries for acceptable build. No machine can hold dimensions precisely to the nominal value, so there must be acceptable degrees of variation. If a part is manufactured, but has dimensions that are out of tolerance, it is not a usable part according to the design intent. Tolerances can be applied to any dimension. The commonly used terms are:

Basic size

The nominal diameter of the shaft (or bolt) and the hole. This is, in general, the same for both components.

Lower deviation

The difference between the minimum possible component size and the basic size.

Upper deviation

The difference between the maximum possible component size and the basic size.

Fundamental deviation

The *minimum* difference in size between a component and the basic size.

This is identical to the upper deviation for shafts and the lower deviation for holes.[*citation needed*] If the fundamental deviation is greater than zero, the bolt will always be smaller than the basic size and the hole will always be wider. Fundamental deviation is a form of allowance, rather than tolerance.

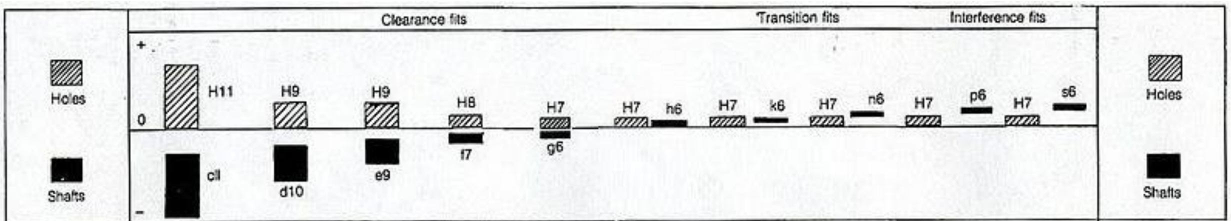
International Tolerance grade

This is a standardised measure of the *maximum* difference in size between the component and the basic size (see below).

For example, if a shaft with a nominal diameter of 10 mm is to have a sliding fit within a hole, the shaft might be specified with a tolerance range from 9.964 to 10 mm (i.e., a zero fundamental deviation, but a lower deviation of 0.036 mm) and the hole might be specified with a tolerance range from 10.04 mm to 10.076 mm (0.04 mm fundamental deviation and 0.076 mm upper deviation). This would provide a clearance fit of somewhere between 0.04 mm (largest shaft paired with the smallest hole, called the *Maximum Material Condition* - MMC) and 0.112 mm (smallest shaft paired with the largest hole, *Least Material Condition* - LMC). In this case the size of the tolerance range for both the shaft and hole is chosen to be the same (0.036 mm), meaning that both components have the same International Tolerance grade but this need not be the case in general.

When no other tolerances are provided, the machining industry uses the following **standard tolerances**:[3][4]

1 decimal place (.x): ±0.2"
2 decimal places (.0x): ±0.01"
3 decimal places (.00x): ±0.005"
4 decimal places (.000x): ±0.0005"



Upper and lower deviations for tolerance class (Values μm)

Basic size (mm) Above	Basic size (mm) Up to and incl.	H11 +	c11 −	H9 +	d10 −	H9 +	e9 −	H8 +	f7 −	H7 +	g6 −	H7 +	h6 +	H7 +	k6 +	H7 +	n6 +	H7 +	p6 +	H7 +	s6 +	Basic size (mm) Above	Basic size (mm) Up to and incl.
0	3	60 / 0	60 / 120	25 / 0	20 / 60	25 / 0	14 / 39	14 / 0	6 / 16	10 / 0	2 / 8	10 / 0	6 / 0	10 / 0	6 / 0	10 / 0	10 / 4	10 / 0	12 / 6	10 / 0	20 / 14	0	3
3	6	75 / 0	70 / 145	30 / 0	30 / 78	30 / 0	20 / 50	18 / 0	10 / 22	12 / 0	4 / 12	15 / 0	9 / 0	15 / 0	10 / 1	15 / 0	19 / 10	15 / 0	24 / 15	15 / 0	32 / 23	3	6
6	10	90 / 0	80 / 170	36 / 0	40 / 98	36 / 0	25 / 61	22 / 0	13 / 28	15 / 0	5 / 14	18 / 0	11 / 0	18 / 0	12 / 1	18 / 0	23 / 12	18 / 0	29 / 18	18 / 0	39 / 28	6	10
10	18	110 / 0	95 / 205	43 / 0	50 / 120	43 / 0	32 / 75	27 / 0	16 / 34	18 / 0	6 / 17	21 / 0	13 / 0	21 / 0	15 / 2	21 / 0	28 / 15	21 / 0	35 / 22	21 / 0	48 / 35	10	18
18	30	130 / 0	110 / 240	62 / 0	80 / 180	62 / 0	50 / 112	39 / 0	25 / 50	25 / 0	9 / 25	25 / 0	16 / 0	25 / 0	18 / 2	25 / 0	33 / 17	25 / 0	42 / 26	25 / 0	59 / 43	18	30
30	40	160 / 0	120 / 280																			30	40
40	50	160 / 0	130 / 290																			40	50
50	65	190 / 0	140 / 330	74 / 0	100 / 220	74 / 0	60 / 134	46 / 0	30 / 60	30 / 0	10 / 29	30 / 0	19 / 0	30 / 0	21 / 2	30 / 0	39 / 20	30 / 0	51 / 32	30 / 0	72 / 53	50	65
65	80	190 / 0	150 / 340																	30 / 0	78 / 59	65	80
80	100	220 / 0	170 / 390	87 / 0	120 / 260	87 / 0	72 / 159	54 / 0	36 / 71	35 / 0	12 / 34	35 / 0	22 / 0	35 / 0	25 / 3	35 / 0	45 / 23	35 / 0	59 / 37	35 / 0	93 / 71	80	100
100	120	220 / 0	180 / 400																	35 / 0	101 / 79	100	120
120	140	250 / 0	200 / 450	100 / 0	145 / 305	100 / 0	84 / 185	63 / 0	43 / 83	40 / 0	14 / 39	40 / 0	25 / 0	40 / 0	28 / 3	40 / 0	52 / 27	40 / 0	68 / 43	40 / 0	117 / 92	120	140
140	160	250 / 0	210 / 460																	40 / 0	125 / 100	140	160
160	180	250 / 0	230 / 480																	40 / 0	133 / 108	160	180
180	200	290 / 0	240 / 530	115 / 0	170 / 355	115 / 0	100 / 215	72 / 0	50 / 96	46 / 0	15 / 44	46 / 0	29 / 0	46 / 0	33 / 4	46 / 0	60 / 31	46 / 0	79 / 50	46 / 0	151 / 122	180	200
200	225	290 / 0	260 / 550																	46 / 0	159 / 130	200	225
225	250	290 / 0	280 / 570																	46 / 0	169 / 140	225	250
250	280	320 / 0	300 / 620	130 / 0	190 / 400	130 / 0	110 / 240	81 / 0	56 / 108	52 / 0	17 / 49	52 / 0	32 / 0	52 / 0	36 / 4	52 / 0	66 / 34	52 / 0	88 / 56	52 / 0	190 / 158	250	280
280	315	320 / 0	330 / 650																	52 / 0	202 / 170	280	315
315	355	360 / 0	360 / 720	140 / 0	210 / 440	140 / 0	125 / 265	89 / 0	62 / 119	57 / 0	18 / 54	57 / 0	36 / 0	57 / 0	40 / 4	57 / 0	73 / 37	57 / 0	98 / 62	57 / 0	226 / 190	315	355
355	400	360 / 0	400 / 760																	57 / 0	244 / 208	355	400
400	450	400 / 0	440 / 840	155 / 0	230 / 480	155 / 0	135 / 290	97 / 0	68 / 131	63 / 0	20 / 60	63 / 0	40 / 0	63 / 0	45 / 5	63 / 0	80 / 40	63 / 0	108 / 68	63 / 0	272 / 232	400	450
450	500	400 / 0	480 / 880																	63 / 0	292 / 252	450	500

Limits and fits establish in 1980, not corresponding to the current ISO tolerances

International Tolerance grades

Main article: IT Grade

When designing mechanical components, a system of standardized tolerances called **International Tolerance grades** are often used. The standard (size) tolerances are divided into two categories: hole and shaft. They are labelled with a letter (capitals for holes and lowercase for shafts) and a number. For example: H7 (hole, tapped hole, or nut) and h7 (shaft or bolt). H7/h6 is a very common standard tolerance which gives a tight fit. The tolerances work in such a way that for a hole H7 means that the hole should be made slightly larger than the base dimension (in this case for an ISO fit 10+0.015−0, meaning that it may be up to 0.015 mm larger than the base dimension, and 0 mm smaller). The actual amount bigger/smaller depends on the base dimension. For a shaft of the same size, h6 would mean 10+0−0.009, which means the shaft may be as small as 0.009 mm smaller than the base dimension and 0 mm larger. This method of standard tolerances is also known as Limits and Fits and can be found in ISO 286-1:2010 (Link to ISO catalog).

The table below summarises the International Tolerance (IT) grades and the general applications of these grades:

	Measuring Tools								Material								
IT Grade	01	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							Fits							Large Manufacturing Tolerances				

Engineering fit

Engineering fits are generally used as part of geometric dimensioning and tolerancing when a part or assembly is designed. In engineering terms, the "fit" is the clearance between two mating parts, and the size of this clearance determines whether the parts can, at one end of the spectrum, move or rotate independently from each other or, at the other end, are temporarily or permanently joined. Engineering fits are generally described as a "shaft and hole" pairing, but are not necessarily limited to just round components. ISO is the internationally accepted standard for defining engineering fits, but ANSI is often still used in North America.

ISO and ANSI both group fits into three categories: clearance, location or transition, and interference. Within each category are several codes to define the size limits of the hole or shaft – the combination of which determines the type of fit. A fit is usually selected at the design stage according to whether the mating parts need to be accurately located, free to slide or rotate, separated easily, or resist separation. Cost is also a major factor in selecting a fit, as more accurate fits will be more expensive to produce, and tighter fits will be more expensive to assemble.

ISO system of limits and fits

Overview

The International Organization for Standardization system splits the three main categories into several individual fits based on the allowable limits for hole and shaft size. Each fit is allocated a code, made up of a number and a letter, which is used on engineering drawings in place of upper & lower size limits to reduce clutter in detailed areas.

Hole and shaft basis

A fit is either specified as shaft-basis or hole-basis, depending on which part has its size controlled to determine the fit. In a hole-basis system, the size of the hole remains constant and the diameter of the shaft is varied to determine the fit; conversely, in a shaft-basis system the size of shaft remains constant and the hole diameter is varied to determine the fit.

The ISO system uses an alpha-numeric code to illustrate the tolerance ranges for the fit, with the upper-case representing the hole tolerance and lower-case representing the shaft. For example, in H7/h6 (a commonly-used fit) H7 represents the tolerance range of the hole and h6 represents the tolerance range of the shaft. These codes can be used by machinists or engineers to quickly identify the upper and lower size limits for either the hole or shaft. The potential range of clearance or interference can be found by subtracting the smallest shaft diameter from the largest hole, and largest shaft from the smallest hole.

Types of fit

The three types of fit are:

1. Clearance: The hole is larger than the shaft, enabling the two parts to slide and / or rotate when assembled, e.g. piston and valves

2. Location / transition: The hole is fractionally smaller than the shaft and mild force is required to assemble / disassemble, e.g. Shaft key
3. Interference: The hole is smaller than the shaft and high force and / or heat is required to assemble / disassemble, e.g. Bearing bush

Clearance fits

Category	Description and Usage	Hole Basis	Shaft Basis
Loose running	Larger clearance where accuracy is not essential, e.g., pivots, latches, parts affected by corrosion, heat, or contamination	H11/c11	C11/h11
Free running	Large clearance where accuracy is not essential and involves high running speeds, large temperature variations, or heavy journal pressures	H9/d9	D9/h9
Close running	Small clearances with moderate requirements for accuracy, e.g., moderate running speeds and journal pressures, shafts, spindles, sliding rods	H8/f7	F8/h7
Sliding	Minimal clearances for high accuracy requirements, which can be easily assembled and will turn & slide freely, e.g., guiding of shafts, sliding gears, crankshaft journals	H7/g6	G7/h6
Location	Very close clearances for precise accuracy requirements, which can be assembled without force and will turn & slide when lubricated, e.g., precise guiding of shafts	H7/h6	H7/h6

For example, using an H8/f7 close-running fit on a 50 mm diameter:[1]

- H8 (hole) tolerance range = +0.000 mm to +0.039
- f7 (shaft) tolerance range = −0.050 mm to −0.025 mm
- Potential clearance will be between +0.025 mm and +0.089 mm

Transition fits

Category	Description and Usage	Hole Basis	Shaft Basis
Similar fit	Negligible clearance or interference fit which can be assembled or disassembled with a rubber mallet, e.g., hubs, gears, pulleys, bushes, bearings	H7/k6	K7/h6
Fixed fit	Negligible clearance or small interference fit which can be assembled or disassembled with light pressing force, e.g., plugs, driven bushes, armatures on shafts	H7/n6	N7/h6

UNIT IV-METROLOGY OF SURFACES

Geometric dimensioning and tolerancing (**GD&T**)

It is a system for defining and communicating engineering tolerances via a symbolic language on engineering drawings and computer-generated 3D models that describes a physical object's nominal geometry and the permissible variation thereof. GD&T is used to define the nominal (theoretically perfect) geometry of parts and assemblies, the allowable variation in size, form, orientation, and location of individual features, and how features may vary in relation to one another such that a component is considered satisfactory for its intended use. Dimensional specifications define the nominal, as-modeled or as-intended geometry, while tolerance specifications define the allowable physical variation of individual features of a part or assembly.

There are several standards available worldwide that describe the symbols and define the rules used in GD&T. One such standard is American Society of Mechanical Engineers (ASME) Y14.5. This article is based on that standard. Other standards, such as those from the International Organization for Standardization (ISO) describe a different system which has very different interpretation rules (see GPS&V). The Y14.5 standard provides a fairly complete set of rules for GD&T in one document. The ISO standards, in comparison, typically only address a single topic at a time. There are separate standards that provide the details for each of the major symbols and topics below (e.g. position, flatness, profile, etc.). BS 8888 provides a self-contained document taking into account a lot of GPS&V standards.

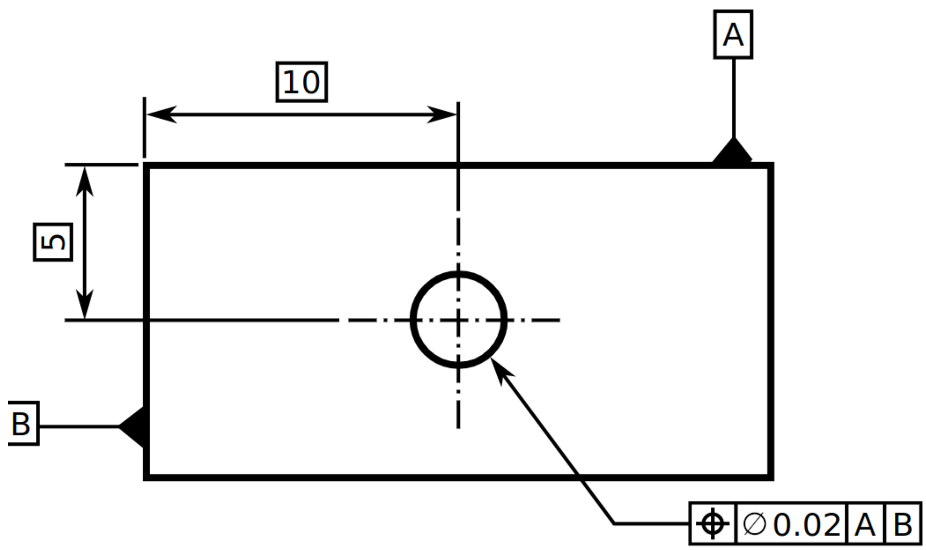


FIG.Example of geometric dimensioning and tolerancing

Dimensioning and tolerancing philosophy

According to the ASME Y14.5-2009[2] standard, the purpose of GD&T is to describe the engineering intent of parts and assemblies. The datum reference frame can describe how the part fits or functions. GD&T can more accurately define the dimensional requirements for a part, allowing over 50% more tolerance zone than coordinate (or linear) dimensioning in some cases. Proper application of GD&T will ensure that the part defined on the drawing has the desired form, fit (within limits) and function with the largest possible tolerances. GD&T can add quality and reduce cost at the same time through producibility.

There are some fundamental rules that need to be applied (these can be found on page 7 of the 2009 edition of the standard):

All dimensions must have a tolerance. Every feature on every manufactured part is subject to variation, therefore, the limits of allowable variation must be specified. Plus and minus tolerances may be applied directly to dimensions or applied from a general tolerance block or general note. For basic dimensions, geometric tolerances are indirectly applied in a related Feature Control Frame. The only exceptions are for dimensions marked as minimum, maximum, stock or reference.

Dimensions define the nominal geometry and allowable variation. Measurement and scaling of the drawing is not allowed except in certain cases.

Engineering drawings define the requirements of finished (complete) parts. Every dimension and tolerance required to define the finished part shall be shown on the drawing. If additional dimensions would be helpful, but are not required, they may be marked as reference.

Dimensions should be applied to features and arranged in such a way as to represent the function of the features. Additionally, dimensions should not be subject to more than one interpretation.

Descriptions of manufacturing methods should be avoided. The geometry should be described without explicitly defining the method of manufacture.

If certain sizes are required during manufacturing but are not required in the final geometry (due to shrinkage or other causes) they should be marked as non-mandatory.

All dimension and tolerance should be arranged for maximum readability and should be applied to visible lines in true profiles.

When geometry is normally controlled by gage sizes or by code (e.g. stock materials), the dimension(s) shall be included with the Gage or code number in parentheses following or below the dimension.

Angles of 90° are assumed when lines (including center lines) are shown at right angles, but no angular dimension is explicitly shown. (This also applies to other orthogonal angles of 0°, 180°, 270°, etc.)

Dimensions and tolerances are valid at 20 °C (68 °F) and 101.3 kPa (14.69 psi) unless stated otherwise.

Unless explicitly stated, all dimensions and tolerances are only valid when the item is in a free state.

Dimensions and tolerances apply to the length, width, and depth of a feature including form variation.

Dimensions and tolerances only apply at the level of the drawing where they are specified. It is not mandatory that they apply at other drawing levels, unless the specifications are repeated on the higher level drawing(s).

(Note: The rules above are not the exact rules stated in the ASME Y14.5-2009 standard.)

Symbols

Tolerances:

Type of tolerances used with symbols in feature control frames can be 1) equal bilateral 2) unequal bilateral 3) unilateral 4) no particular distribution (a "floating" zone)

Tolerances for the profile symbols are equal bilateral unless otherwise specified, and for the position symbol tolerances are always equal bilateral. For example, the position of a hole has a tolerance of .020 inches. This means the hole can move ±.010 inches, which is an equal bilateral tolerance. It does not mean the hole can move +.015/−.005 inches, which is an unequal bilateral tolerance. Unequal bilateral and unilateral tolerances for profile are specified by adding further information to clearly show this is what is required.

Geometric tolerancing reference chart (per ASME Y14.5 M-1982)

Type of control	Geometric characteristics	Symbol	Unicode character	Relevant feature: Surface	Relevant feature: Of size	Virtual condition affected	References datum	Modified by: Ⓜ	Modified by: Ⓢ	Affected by: Bonus	Affected by: Shift
Form	Straightness[3]	⏤	⏤ U+23E4	Yes	Yes	Of size[a]	No	Of size[a]	No[c]	Ⓜ[d]	No
Form	Flatness[4]	⏥	⏥ U+23E5	Yes	No	No	No	No	No[c]	No	No
Form	Circularity[4]	○	○ U+25CB	Yes	No	No	No	No	No[c]	No	No
Form	Cylindricity	⌭	⌭ U+232D	Yes	No	No	No	No	No[c]	No	No
Profile	Profile of a line	⌒	⌒ U+2312	Yes	No	No	Yes[e]	No	No[c]	No	Datum, Ⓜ[b]
Profile	Profile of a surface	⌓	⌓ U+2313	Yes	No	No	Yes[e]	No	No[c]	No	Datum, Ⓜ[b]
Orientation	Perpendicularity	⟂	⟂ U+27C2	Yes	Yes	Of size[a]	Yes	Of size[a]	No[c]	Ⓜ[d]	Datum, Ⓜ[b]
Orientation	Angularity	∠	∠ U+2220	Yes	Yes	Of size[a]	Yes	Of size[a]	No[c]	Ⓜ[d]	Datum, Ⓜ[b]
Orientation	Parallelism	∥	∥ U+2225	Yes	Yes	Of size[a]	Yes	Of size[a]	No[c]	Ⓜ[d]	Datum, Ⓜ[b]
Location	Symmetry[f][g]	⌯	⌯ U+232F	No	Yes	Yes	Yes	No	No	No	No
Location	Position	⌖	⌖ U+2316	No	Yes	Yes	Yes	Yes	Yes	Ⓜ[d]	Datum, Ⓜ[b]
Location	Concentricity[f]	◎	◎	No	Yes	Yes	Yes	No	No[c]	No	No

Symbols used in a "feature control frame" to specify a feature's description, tolerance, modifier and datum references

Symbol	Unicode character	Modifier	Notes
Ⓕ	Ⓕ U+24BB	Free state	Applies only when part is otherwise restrained
Ⓛ	Ⓛ U+24C1	Least material condition (LMC)	Useful to maintain minimum wall thickness
Ⓜ	Ⓜ U+24C2	Maximum material condition (MMC)	Provides bonus tolerance only for a feature of size
Ⓟ	Ⓟ U+24C5	Projected tolerance zone	Useful on threaded holes for long studs
Ⓢ	Ⓢ U+24C8	Regardless of feature size (RFS)	Not part of the 1994 version. See para. A5, bullet 3. Also para. D3. Also, Figure 3-8.
Ⓣ	Ⓣ U+24C9	Tangent plane	Useful for interfaces where form is not required
⟨CF⟩		Continuous feature	Identifies a group of features that should be treated geometrically as a single feature
⟨ST⟩		Statistical tolerance	Appears in the 1994 version of the standard, assumes appropriate statistical process control.
Ⓤ	Ⓤ U+24CA	Unequal bilateral	Added in the 2009 version of the standard, and refers to unequal profile distribution. Number after this symbol indicates tolerance in the "plus material" direction.

Datums and datum references

Further information: Datum reference

A **datum** is a virtual ideal plane, line, point, or axis. A **datum feature** is a physical feature of a part identified by a **datum feature symbol** and corresponding **datum feature triangle**, e.g.,

These are then referred to by one or more 'datum references' which indicate measurements that should be made with respect to the corresponding datum feature .

GD&T Certification

The American Society of Mechanical Engineers (ASME) provides two levels of certification: [5]

- Technologist GDTP, which provides an assessment of an individual's ability to understand drawings that have been prepared using the language of Geometric Dimensioning & Tolerancing.
- Senior GDTP, which provides the additional measure of an individual's ability to select proper geometric controls as well as to properly apply them to drawings.

Data exchange

Exchange of geometric dimensioning and tolerancing (GD&T) information between CAD systems is available on different levels of fidelity for different purposes:

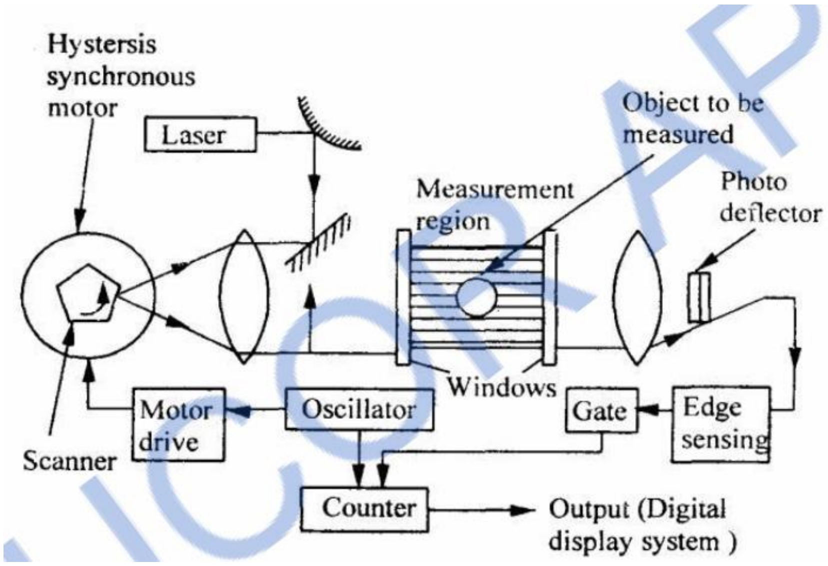
- In the early days of CAD, exchange-only lines, texts and symbols were written into the exchange file. A receiving system could display them on the screen or print them out, but only a human could interpret them.
- *GD&T presentation*: On a next higher level the presentation information is enhanced by grouping them together into *callouts* for a particular purpose, e.g. a *datum feature callout* and a *datum*

reference frame. And there is also the information which of the curves in the file are leader, projection or dimension curves and which are used to form the shape of a product.

- *GD&T representation*: Unlike GD&T presentation, the GD&T representation does not deal with how the information is presented to the user but only deals with which element of a shape of a product has which GD&T characteristic. A system supporting GD&T representation may display GD&T information in some tree and other dialogs and allow the user to directly select and highlight the corresponding feature on the shape of the product, 2D and 3D.
- Ideally both GD&T presentation and representation are available in the exchange file and are associated with each other. Then a receiving system can allow a user to select a GD&T callout and get the corresponding feature highlighted on the shape of the product.
- An enhancement of GD&T representation is defining a formal language for GD&T (similar to a programming language) which also has built-in rules and restrictions for the proper GD&T usage. This is still a research area (see below reference to McCaleb and ISO 10303-1666).
- *GD&T validation*: Based on GD&T representation data (but not on GD&T presentation) and the shape of a product in some useful format (e.g. a boundary representation), it is possible to validate the completeness and consistency of the GD&T information. The software tool FBTol from the Kansas City Plant is probably the first one in this area.
- GD&T representation information can also be used for the software assisted manufacturing planning and cost calculation of parts. See ISO 10303-224 and 238 below.

Unit- V ADVANCES IN METROLOGY

Laser telemetric system



Laser telemetric system is an on-contact gauge that measures with a collimated laser beam. It measures at the rate of 150 scans per second. It basically consists of three components, a transmitter, a receiver and processor electronics. The transmitter module produces a collimated parallel scanning laser beam moving at a high constant, linear speed. The scanning beam appears are line. The receiver module collects and photo electrically senses the laser light transmitted past the object being measured. The processor electronics takes the received signals to convert them 10 a convenient form and displays the dimension being gauged. The transmitter contains a low power helium - neon gas laser and its power supply, a specially designed collimating lens, a synchronous motor, a multifaceted reflector prism, a synchronous pulse photo detector and a protective replaceable window.

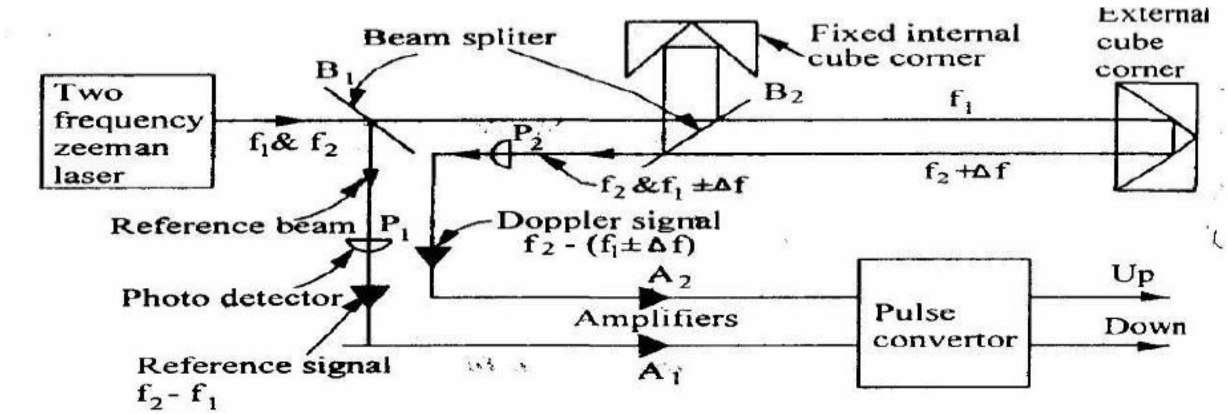
The high speed of scanning permits online gauging and thus it is possible to detect changes in dimensions when components are moving on a continuous product such as in rolling process moving at very high speed. There is no need of waiting or product to cool for taking measurements. This system can also be applied on production machines and control then with closed feedback loops. Since the output of this system is available in digital form, it can run a process controller limit alarms can be provided and output can be taken on digital printer.

AC laser interferometer

It is possible to maintain the quality of interference fringes over longer distance when lamp is replaced by a laser source. Laser interferometer uses AC laser as the light source and the measurements to be made over longer distance. Laser is a monochromatic optical energy, which can be collimated into a directional beam AC. Laser interferometer (ACLI) has the following advantages. High repeatability
 High accuracy
 Long range optical path
 Easy installations

 Wear and tear
 Schematic arrangement of laser interferometer is shown in fig.

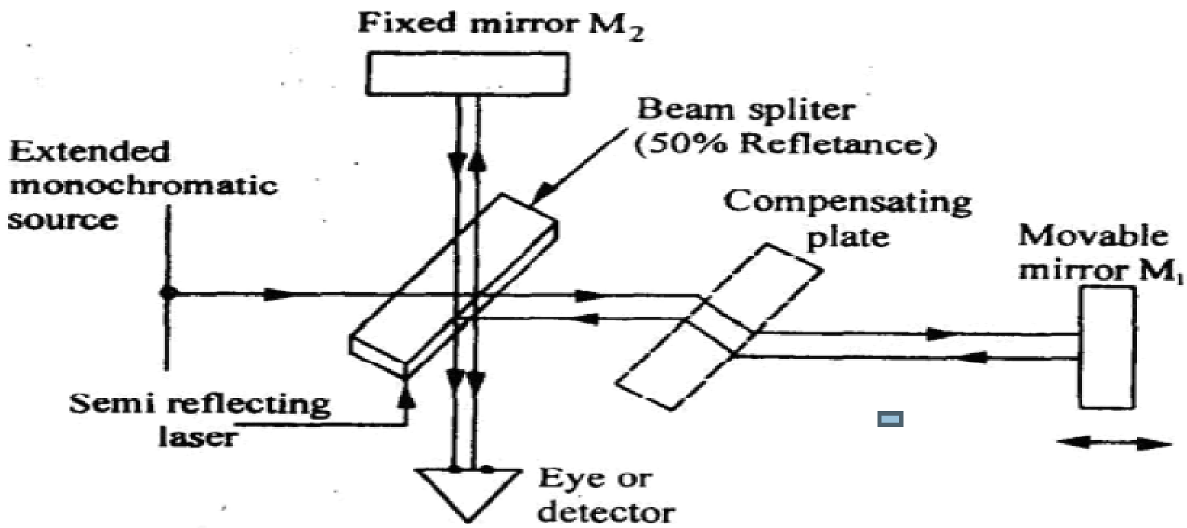
Two-frequency Zeeman laser generates light of two slightly different frequencies with opposite circular polarization. These beams get split up by beam splitter BO ne part travels towards Band from there to external cube corner here the displacement is to the measured.



This interferometer uses cube corner reflectors which reflect light parallel to its angle of incidence. Beam splitter B2 optically separates the frequency J which alone is sent to them ovable cube corner reflector. The second frequency from B2 is sent to a fixed reflector which then rejoins f1 at the beam splitter B2 to produce alternate light and dark interference flicker at about 2 Mega cycles per second. Now if the movable reflector moves, then there turning beam frequency Doppler - shifted slightly up or down by Δf. Thus the light beams moving towards photo detector P2 have frequencies f2 and (f1 ± Δf1) and P2 changes these frequencies into electrical signal. Photo detector P2 receive signal from beam splitter B2 and changes the reference beam frequencies f1 and f2 into electrical signal. An AC amplifier A separates frequency. Difference signal f2 – f1 and A2 separates frequency difference signal. The pulse converter extract signal. One cycle per half wave length of motion. The up - down pulses are counted electronically and displayed in analog or digital form.

Michelson Interferometer

Michelson interferometer consists of a mono chromatic light source a beam splitter and two mirrors. The schematic arrangement of Michelson interferometer is shown in fig. The monochromatic light falls on a beam splitter, which splits the light into two rays of equal intensity at right angles. One ray is transmitted to mirror M1 and other is reflected through beam splitter to mirror M2. From both these mirrors, the rays are reflected back and these return at the semi reflecting surface from where they are transmitted to the eye. Mirror M2 is fixed and mirror M1 is movable. If both the mirrors are at same distance from beam splitter, then light will arrive in phase and observer will see bright spot due to constructive interference. If movable mirror shifts by quarter wavelength, then beam will return to observer 1800 out of phase and darkness will be observed due to destructive interference.



Each half - wavelength of mirror travel produces a change in them easured optical path of one wave length and the reflected beam from the moving mirror shifts through 360° phase change. When the reference beam reflected from the fixed mirror and the beam reflected from the moving mirror rejoin at the beam splitter, they alternately reinforce and cancel each other as the mirror moves. Each cycle of intensity at the eye represent sl/2 of mirror travel. When white light source is used then a compensator plate is introduced in each of the path of mirror M1 So that exactly the same amount of glass is introduced in each of the path.

To improve the Michelson interferometer

- Use of laser the measurements can be made over longer distances and highly accurate measurements when compared to other mono chromatic sources.
- Mirrors are replaced by cube - corner reflector which reflects light parallel to its angle of incidence.
- Photo cells are employed which convert light intensity variation in voltage pulses to give the amount and direction of position change.

Coordinate measuring machine

Measuring machines are used for measurement of length over the outer surfaces of a length bar or any other long member. The member may be either rounded or flat and parallel. It is more useful and advantageous than vernier calipers, micrometer, screw gauges etc. the measuring machines are generally universal character and can be used for works of varied nature. The co-ordinate measuring machine is used for contact inspection of parts. When used for computer-integrated manufacturing these machines are controlled by computer numerical control. General software is provided for reverse engineering complex shaped objects. The component is digitized using CNC, CMM and it is then converted into a computer model which gives the two surface of the component. These advances include for automatic work part alignment on the table. Savings in inspection 5 to 10 percent of the time is required on a CMM compared to manual inspection methods.

Types of Measuring Machines

1. Length bar measuring machine.

2. New all measuring machine.

3. Universal measuring machine.

4. Co-ordinate measuring machine.

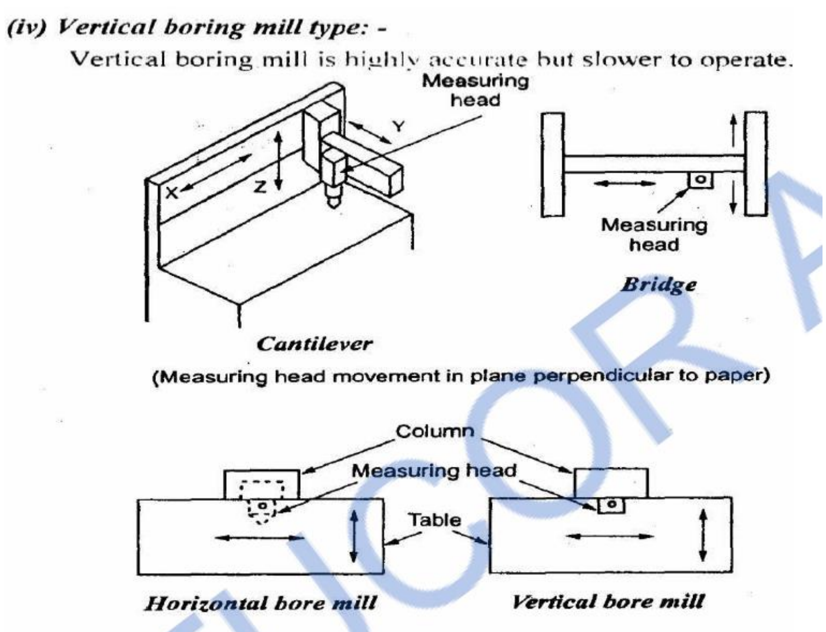
5. Computer controlled co-ordinate measuring machine.

Constructions of CMM

Co-ordinate measuring machines are very useful for three dimensional measurements. These machines have movements in X-Y-Z co-ordinate, controlled and measured easily by using touch probes. These measurements can be made by positioning the probe by hand, or automatically in more expensive machines. Reasonable accuracies are 5 micron. Or 1 micro meter. The method these machines work on is measurement of the position of the probe using linear position sensors. These are based on more fringe patterns (also used in other systems).Transducer is provided in tilt directions for giving digital display and senses positive and negative direction.

Types of CMM a. **Cantilever type**

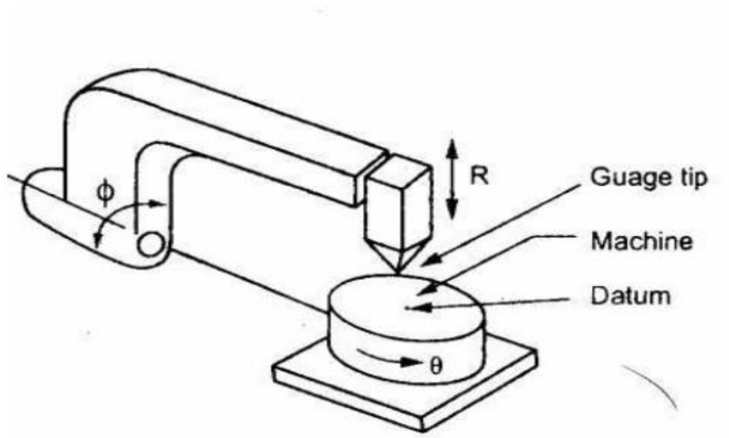
The cantilever type is very easy to load and unload, but mechanical error takes place because of sag or deflection in Y-axis. b. **Bridge type** Bridge type is more difficult to load but less sensitive to mechanical errors. c. **Horizontal boring Mill type** This is best suited for large heavy work pieces.



Types of CMM

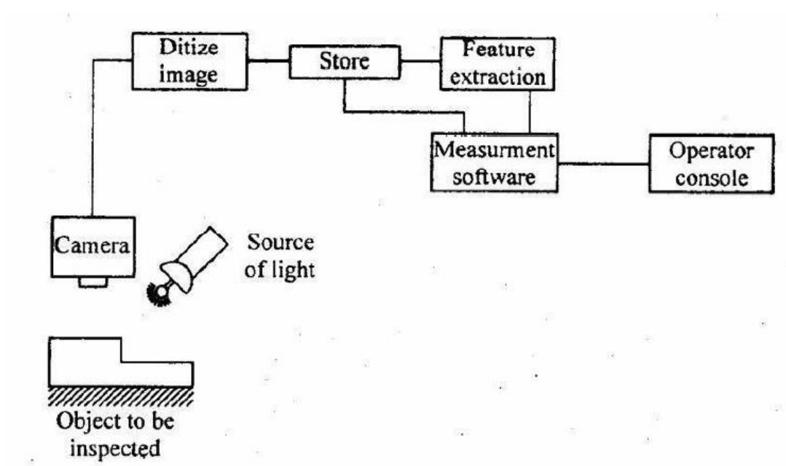
Working Principle

CMM is used for measuring the distance between two holes. The work piece is clamped to the work table and aligned for three measuring slides x, y and z. The measuring head provides at a per probe tip which is seated in first datum hole and the position of probe digital read out is set to zero. The probe is then moved to successive holes, the read out represent the co-ordinate part print hole location with respect to the datum hole. Automatic recording and data processing units are provided to carry out complex geometric and statistical analysis. Special co-ordinate measuring machines are provided both linear and rotary axes. This can measure various features of parts like cone, cylinder and hemisphere. The prime advantage of co-ordinate measuring machine is the quicker inspection and accurate measurements.



Machine vision

The schematic diagram of a typical vision system is shown. This system involves image acquisition; image processing Acquisition requires appropriate lighting. The camera and store digital image processing involves manipulating the digital image to simplify and reduce number of data points. Measurements can be carried out at any angle along the three reference axes x y and z without contacting the part. The measured values are then compared with the specified tolerance which stores in the memory of the computer.



Machine Vision

The main advantage of vision system is reduction of tooling and fixture costs, elimination of need for precise part location for handling robots and integrated automation of dimensional verification and defect detection.

Principle

Four types of machine vision system and the schematic arrangement is shown (i) Image formation. (ii) Processing of image in a form suitable for analysis by computer. (iii) Defining and analyzing the characteristic of image. (iv) Interpretation of image and decision-making. For formation of image suitable light source is required. It consists of incandescent light, fluorescent tube, fiber optic bundle, and arc lamp. Laser beam is used for triangulation system for measuring distance. Ultraviolet light is used to reduce glare or increase contrast. Proper illumination back lighting, front lighting, structured light is required. Back lighting is used to obtain maximum image contrast. The surface of the object is to be inspected by using front lighting. For inspecting three-dimensional feature structured lighting is required. An image sensor vidicon camera, CCD camera is used to generate the electronic signal representing the image. The image sensor collect slight from the scene through a lens, using photo sensitive target, converts into electronic signal.

Vidicon camera

Image is formed by focusing the incoming light through a series of lenses on to the photo conductive face plate of the vidicon tube. The electron beam scans the photo conductive surface and produces an analog voltage proportional to the variation in light intensity for each scan line of the original scene.

Solid-state camera

The image sensors change coupled device (CCD) contain matrix of small array, photo sensitive elements accurately spaced and fabricated on silicon chips using Integrated circuit technology. Each detect or converts into analog signal corresponding to light intensity through the camera lens.

Image processor

A camera may form an image 30 times per sec at 33m sec intervals. A teach time interval the entire image frozen by an image processor for processing. An analog to digital converter is used to convert analog voltage of each detector into digital value. If voltage level for each pixel is given by either 0 or I depending on threshold value. It is called binary system on the other hand grey scale system assigns up to 256 different values depending on intensity to each pixel. Grey scale requires higher degree of image refinement, huge storage processing capability. For analysis 256 x 256 pixels image array up to 256 different pixel values will require 65000-8 bit storage locations at a speed of 30 images per second. Techniques windowing and image restoration are involved.

Windowing

Processing is the desired area of interest and ignores non-interested part of image.

Image restoration

Preparation of image during the pre-processing by removing the degrade. Blurring of lines, poor contrast between images and presence of noise are the degrading. The quality may be improved

1) By improving the contrast by brightness addition.
2) By increasing the relative contrast between high and low intensity elements.
3) By Fourier domain processing.
4) Other techniques to reduce edge detection and run length encoding.

Image Analysis

Digital image of the object formed is analyzed in the central processing Unit of the system. Three important tasks performed by machine vision system are measuring the distance of an object from a vision system camera, determining object orientation and defining object position. The distance of an object from a vision system camera can be determined by triangulation technique. The object orientation can he determined by the methods of equivalent ellipse. The image can be interpreted by two-dimensional image. For complex three-dimensionalobjects boundary locations are determined and the image is segmented into distinct region.

Image Interpretation

This involves identification of on object. In binary system, the image is segmented on the basis of white and black pixels. The complex images can he interpreted by grey scale technique and algorithms. The most common image interpretation is template matching.

Function of Machine Vision

- Lighting and presentation of object to evaluated.
- It has great compact on repeatability, reliability and accuracy.
- I.ighting source and projection should be chosen and give sharp contrast.
- Images sensor compressor TV camera may he vidicon or solid state.
- For simple processing, analog comparator and a computer controller to convert the video information to a binary image is used.
- Data compactor employs a high speed away processor to provide high speed processing of the input image data.
- System control computer communicates with the operator and make decision about the part being inspected.
- The output and peripheral devices operate the control of the system.The output enables the vision system to either control a process or provide caution and orientation information to a robot, etc.
- These operate under the control of the system control of computer.

Applications

- Machine vision can he used to replace human vision fur welding. Machining and maintained relationship between tool and work piece and assembly of parts to analyze the parts.
- This is frequently used for printed circuit board inspection to ensure minimum conduction width and spacing between conductors. These are used for weld seam tracking, robot guideness and control, inspection of microelectronic devices and tooling, online inspection in machining operation, assemblies monitoring high-speed packaging equipment etc. It gives recognition of an object from its image. These are designed to have strong geometric feature interpretation capabilities and handling equipment.

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Department of Mechanical Engineering

Lecture Notes

Subject Code : CME354

Subject Name: FAILURE ANALYSIS AND NDT TECHNIQUES

Sem/Year : 05/III

Regulation : 2021

CME354 FAILURE ANALYSIS AND NDT TECHNIQUES **L T P C**

2 0 2 3

COURSE OBJECTIVES:

1 To introduce need and scope of failure analysis and fundamental sources of failures.
2 To learn about non-destructive testing and basic principles of visual inspection.
3 To study about magnetic testing and principles, techniques.
4 To learn the principle of radiography testing and its inspection techniques and methods.
5 To study the acoutistic testing principle and technique and instrumentation.

UNIT – I INTRODUCTION 9

Introduction and need and scope of failure analysis. Engineering Disasters and understanding failure analysis. Fundamental sources of failures. Deficient design. Improper Manufacturing & Assembly. Tree diagram and FMEA.

UNIT – II VISUAL INSPECTION 9

Introduction to Non-Destructive Testing: An Introduction, Visual examination, Basic Principle, The Eye, Optical aids used for visual inspection, Applications. Liquid Penetrant Testing: Physical principles, Procedure for penetrant testing, Penetrant testing materials, Penetrant testing methods, Sensitivity, Applications, Limitations and Standards

UNIT – III MAGNETIC TESTING 9

Magnetic Particle Testing, Eddy Current Testing: Magnetism-basic definitions and principle of. magnetic particle testing, Magnetizing techniques, induced current flow, Procedure used for testing a component, Equipment Used for magnetic particle testing, Sensitivity, Limitations. Eddy Current Testing: Principles, Instrumentation for eddy current testing Techniques. Sensitivity Advanced Eddy Current Test Methods, Applications, Limitations.

UNIT – IV RADIOGRAPHY TESTING 9

Radiography, Ultrasonic Testing: Basic principle, Electromagnetic radiation, Sources, Radiation attenuation in the specimen. Effect of radiation in film, Radiographic imaging, Inspection techniques, Applications of radiographic inspection, Limitations, Safety in Industrial Radiography, Standards, Neutron radiography. Ultrasonic Testing: Basic properties of sound beam, Ultrasonic transducers, Inspection methods, Techniques for Normal Beam Inspection, Techniques for Angle Beam Inspection, Flaw characterization techniques, Ultrasonic flaw detection equipment, Modes of Display, Immersion Testing, Applications of Ultrasonic Testing, Advantages, Limitations

UNIT – V ACOUTISTIC TESTING 9

Acoustic Emission Testing: Principle of Acoustic Emission Testing, Technique, Instrumentation, Sensitivity, Applications, Standards. Thermograph: Basic Principles, Detectors and Equipment, Techniques, Applications, Codes and Standards. In Situ Metallographic Examination: Approach to the Selection of Site for Metallographic examination, Replication process, Significance of Microstructure observation, Decision making, Applications, Codes and Standards.(digital signal process)

CME354 Failure Analysis and NDT Techniques

UNIT-1 INTRODUCTION

Failure analysis: Tools and methodologies

The purpose of failure analysis is to determine the most fundamental reason which caused the failure (i.e., root cause), ideally with the intention of eliminating it and identifying means to prevent its recurrences.

The basic steps of the failure analysis procedure include the following:

1.Definition of the problem and data collection.

2.Identification of damage modes and mechanisms.

3.Testing for the actual mechanisms taking place, leading to thefailure.

4.Identification of the possible root causes.

5.Confirmation of cause-effect relationships.

6.Tests of the actual root cause.

7.The implemention of corrective actions.

One of the most important steps of the failure analysis process is identifying every mode and possible effect(s). This is covered by the failure mode and effect analysis (FMEA). It works by linking every each component's failure mode to the system's operation. It then focuses the analysis on the contributing modes.

The failure mode and effect analysis (FMEA) is defined as "a formal and systematic approach to identifying potential system failure modes, their causes, and the effects of the failure mode occurrence on the system operation" (ARP5580, Recommended Failure Modes and Effects Analysis (FMEA) Practices for Non-Automobile Applications, 2001).

FMEA is largely applied to the design of safe and reliable products in various industries such as aviation and automotive industries. It is very beneficial for failure investigations, making use of previously identified failures and associated modes and effects in order to focus the analysis.

In addition to its use in failure analysis, FMEA has a broader potential application in gas turbine's operation and maintenance:

1.Improving the gas turbine's reliable operations by addressing modes with the potential adverse effects.

2.Optimizing its operation by identifying any undesired operation conditions.

3.Providing important feedback for design improvements and existing unit modifications.

4.Optimizing its maintenance intervals, scope, and turn-around.

5.Providing the first-hand trouble-shooting guide for the isolation and detection of faults and errors.

The FMEA encompasses the following steps (Failure Analysis, 2015):

1.Identification of all components' failure modes.

2.Determination of the effect of the failure for each mode, both on the components and on the overall system operation.

3.Classification of the failure by tracing its effects on the system operation. This step requires collaboration with various disciplines such as design, operation, and service engineering.

4.Determination of the failure probability of occurrence.

5.Identification of how the failure mode can be detected.

6.Identification of any compensating provisions or design changes to mitigate the failure effects.

Depending on the failure modes' postulation, FMEA can be classified into one of the following: functional, interface, or detailed. First, the functional FMEA is performed for the manufacturing of the gas turbine or a specific component. It is based on the design concept and plays an important role in its final architecture. This is because any deficiencies highlighted during the FMEA process are translated into design modifications to the baseline requirements.

Second, the interface, similar to the functional FMEA, helps in verifying and correcting the design in order to comply with the requirements. In this case however, the failure modes are those at the interface between the interconnected subsystems or components.

Finally, the detailed FMEA determines the failure modes associated with each component and their subsequent effects on the gas turbine operation.

Engineering Disasters and Learning from Failure

The role of the engineer is to respond to a need by building or creating something along a certain set of guidelines (or specifications) which performs a given function. Just as importantly, that device, plan or creation should perform its function without fail. Everything, however, must eventually fail (in some way) to perform its given function with a sought after level of performance. Hence, the engineer must struggle to design in such a way as to avoid failure, and, more importantly, catastrophic failure which could result in loss of property, damage to the environment of the user of that technology, and possibly injury or loss of life. Through analysis and study of engineering disasters, modern engineering designers can learn what not to do and how to create designs with less of a chance of failure.

Engineering Disaster

Much of the reason why we consider an engineering failure to be an engineering "disaster" has to do with public perception of risk. For example, in 1992 roughly the same number of fatalities occurred (in the United States) in transportation accidents involving airplanes (775), trains (755), and bicycles (722). Yet the public perception of the risk associated with air travel is often much higher than that for trains and certainly for bicycles. This stems from two reasons: (1) the large loss of life (and associated wide spread news reporting) resulting from a single air crash, and (2) the air passenger's lack of control over their environment in the case of air or, to a lesser degree, rail accidents. Both of these reasons results in increased fear, and hence a higher degree of perceived risk.

Primary Causes of Engineering Disasters

The primary causes of engineering disasters are usually considered to be

- human factors (including both 'ethical' failure and accidents)
- design flaws (many of which are also the result of unethical practices)
- materials failures
- extreme conditions or environments, and, most commonly and importantly
- combinations of these reasons

A recent study conducted at the Swiss federal Institute of technology in Zurich analyzed 800 cases of structural failure in which 504 people were killed, 592 people injured, and millions of dollars of damage incurred. When engineers were at fault, the researchers classified the causes of failure as follows:

Insufficient knowledge 36%
Underestimation of influence 16%
Ignorence, carelessness, negligence 14%
Forgetfulness, error 13%
Relying upon others without sufficient control 9%
Objectively unknown situation 7%
Unprecise definition of responsibilities 1%
Choice of bad quality 1%
Other 3%

Engineering Ethics

Often, a deficiency in engineering ethics is found to be one of the root causes of an engineering failure. An engineer, as a professional, has a responsibility to their client or employer, to their profession, and to the general public, to perform their duties in as conscientious a manner as possible. Usually this entails far more than just acting within the bounds of law. An ethical engineer is one who avoids conflicts of interest, does not attempt to misrepresent their knowledge so as to accept jobs outside their area of expertise, acts in the best interests of society and the environment, fulfills the terms of their contracts or agreements in a thorough and professional manner, and promotes the education of young engineers within their field. Many of these issues are discussed in detail at the ethics homepage of the National Society of Professional Engineers. There you will find an example of an engineering Code of Ethics and links to additional information on engineering ethics. Or check here our list of some codes of Engineering Ethics. Failures in engineering ethics can have many legal consequences as well, as in the case of a mall collapse in Korea.

Thirty five faculty members from around the country have created a number of case problems in several engineering disciplines which intertwine technical calculations with engineering ethics. These were presented at a 1995 workshop at Texas A&M, sponsored by the National Science Foundation.

The site for Applied Ethics in Professional Practice Case of the Month Club created and maintained by then Professional Engineering Practice Liaison Program in the College of Engineering at University of Washington, provides the opportunity to review a particular case study which involves engineering ethics and then vote on which course of action should be taken. All cases are based on actual professional engineering experiences as contributed by a board of practicing engineers nationally. Background information on codes of ethics is also provided at this site.

Design defect

A design defect means that the product was manufactured correctly, but the defect is inherent in the design of the product itself, which makes the product dangerous to consumers. For example, mechanical defects, which are common in cars and other motor vehicles.

Design defects often serve as the basis for a products liability or defective product lawsuit, especially if someone is injured as a result of the defective design. In a products liability case, a plaintiff can only establish a design defect exists when they prove there is a hypothetical alternative design that would be safer than the original design, as economically feasible as the original design, and as practical as the original design, retaining the primary purpose behind the original design despite the changes made.

Improper Manufacturing & Assembly

A manufacturing defect may also arise if a manufacturer uses the correct materials but makes an error when putting them together. An incorrect assembly can come in different forms; for example: A manufacturer can wire an electrical circuit backward.

Failure modes and effects analysis

• Failure modes and effects analysis (FMEA) is a thorough analysis of the malfunctions that can be produced in the components of an engineering system.
• The thrust is on how to redesign the components to improve system reliability.
To carry out an FMEA, the system is broken into assemblies.
• Engineering design data is appraised for each subassembly.
• This is done by making block diagrams of system, subsystem and components to enable analysis.
• A complete list of the components of each assembly and the function of each component are prepared.
• From an analysis of the operating and environmental conditions, the failure mechanisms that could affect each component are identified.
• Then the failure modes of all components are researched.
• Some components may have more than one failure mode.
• Each failure mode is analyzed as to ascertain whether it has an effect on the next higher item in the assembly and whether it has an effect on the entire system or product.
• The preventive measures or corrective actions that have been taken to control or eliminate the hazard are listed.
The probability of failure of each component, based on published data or company experience, is listed, and the probabilities of failure of the subassemblies, assemblies, and the complete system are calculated from reliability theory.
• Often, FMEA is used in conjunction with fault tree analysis which pinpoints the areas in a complex system where FMEA is needed.

Fault tree analysis

• Fault trees are diagrams that show how the data developed by FMEA should be interlinked to lead to a specific event.
• FMEA is very effective when applied to a single unit or single failure.
• When it is applied to a complex system, its effectiveness decreases to a large extent.
• Fault tree analysis (FTA) provides a graphic description of the possible combinations in a system that can result in failure or accidents.
• In FTA, the emphasis is on "how things can fail to work" rather than on "design performance".
• Basically, fault tree is a logic diagram in which logic gates are used to determine the relations between input events and output events.
• A full quantitative FTA uses probabilities of failure computed for each event.
• The present discussion of FTA will be restricted to qualitative level.

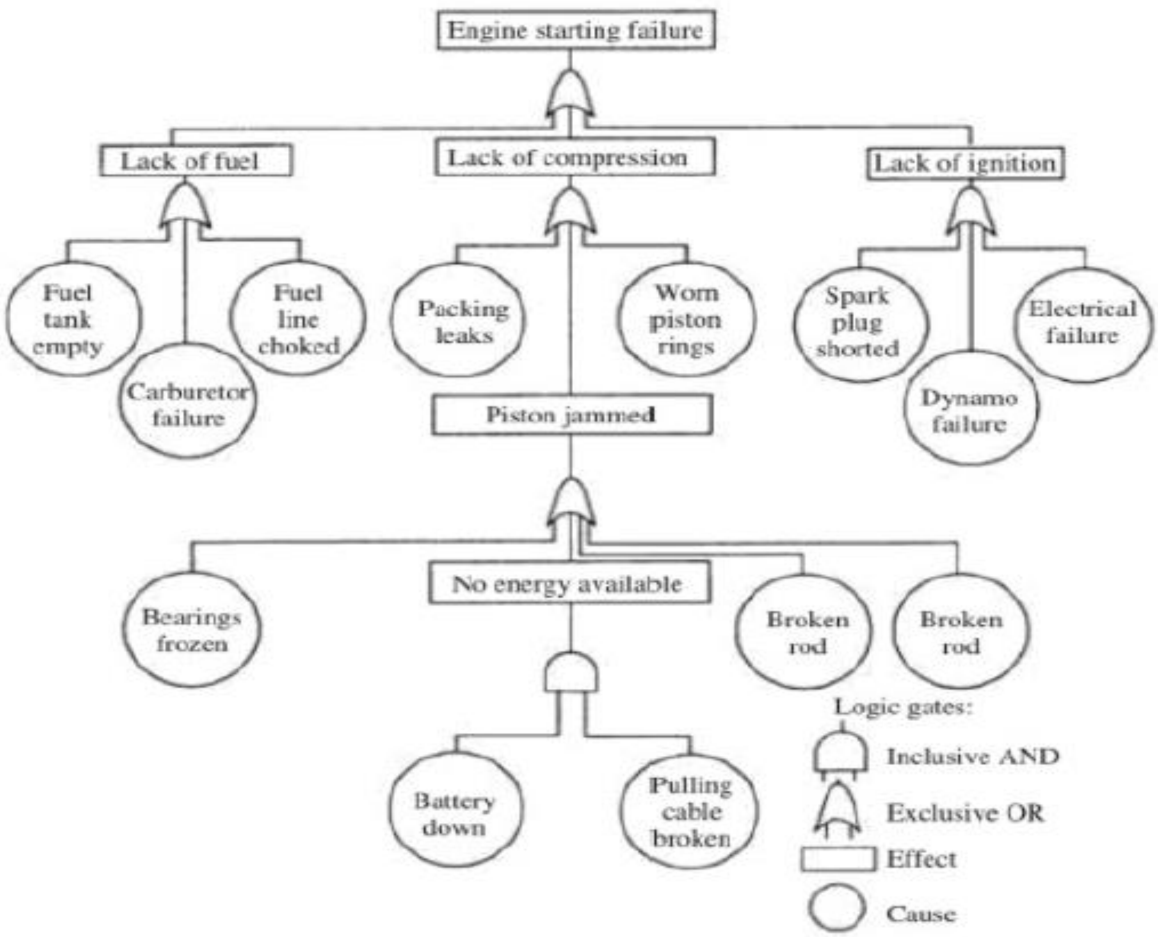


Fig. Failure of an engine – Fault tree diagram

Each fault tree deals with a specific event, e.g. failure to start an engine.
• FTA is a "top-down approach" that starts with the top event and then determines the contributory events that would lead to the failure event.
• Failures can be either component failures or ergonomic failures.
• Figure shows a fault tree diagram which depicts inability of an engine to start.

Unit-II Visual Inspection

NON-DESTRUCTIVE TESTING

Up to this point we have learnt various testing methods that somehow destruct the test specimens. These were, tensile testing, hardness testing, etc. In certain applications, the evaluation of engineering materials or structures without impairing their properties is very important, such as the quality control of the products, failure analysis or prevention of the engineered systems in service. This kind of evaluations can be carried out with Non destructive test (NDT) methods. It is possible to inspect and/or measure the materials or structures without destroying their surface texture, product integrity and future usefulness. The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. Certain standards has been also implemented to assure the reliability of the NDT tests and prevent certain errors due to either the fault in the equipment used, the miss-application of the methods or the skill and the knowledge of the inspectors. Successful NDT tests allow locating and characterizing material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and variety of less visible, but equally troubling events. However, these techniques generally require considerable operator skill and interpreting test results accurately may be difficult because the results can be subjective. These methods can be performed on metals, plastics, ceramics, composites, cermets, and coatings in order to detect cracks, internal voids, surface cavities, delamination, incomplete crack defective welds and any type of flaw that could lead to premature failure.

Visual inspection:

VI is particularly effective detecting macroscopic flaws, such as poor welds. Many welding flaws are macroscopic: crater cracking, undercutting, slag inclusion, incomplete penetration welds, and the like. Like wise, VI is also suitable for detecting flaws in composite structures and piping of all types. Essentially, visual inspection should be performed the way that one would inspect a new car prior to delivery, etc. Bad welds or joints, missing fasteners or components, poor fits, wrong dimensions, improper surface finish, delaminations in coatings, large cracks, cavities, dents, inadequate size, wrong parts, lack of code approval stamps and similar proofs of testing.

Radiography:

Radiography has an advantage over some of the other processes in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed. The x-ray emitted from a source has an ability to penetrate metals as a function of the accelerating voltage in the x-ray emitting tube. If a void present in the object being radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure than in the non-void areas. The sensitivity of x-rays is nominally 2% of the materials thickness. Thus for a piece of steel with a 25mm thickness, the smallest void that could be detected would be 0.5mm in dimension. For this reason, parts are often radiographed in different planes. A thin crack does not show up unless the x-rays ran parallel to the plane 0 the crack. Gamma radiography is identical to x-ray radiography in function. The difference is the source of the penetrating electromagnetic radiation which is a radioactive material such m Co 60. However this method is less popular because of the hazards of handling radioactive materials.

Liquid (Dye) penetrant method:

Liquid penetrant inspection (LPI) is one of the most widely used nondestructive evaluation (NDE) methods. Its popularity can be attributed to two main factors, which are its relative ease of use and its flexibility.
The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. . This method is an inexpensive and convenient technique for surface defect inspection. The limitations of the liquid penetrant technique include the inability to inspect subsurface flaws and a loss of resolution on porous materials. Liquid penetrant testing is largely used on nonmagnetic materials for which magnetic particle inspection is not possible. Materials that are commonly inspected using LPI include the following; metals (aluminum, copper, steel, titanium, etc.), glass, many ceramic materials, rubber, plastics. Liquid penetrant inspection is used to inspect of flaws that break the surface of the sample. Some of these flaws are listed below; fatigue cracks, quench cracks grinding cracks, overload and impact fractures, porosity, laps seams, pin holes in welds, lack of fusion or braising along the edge of the bond line.

Magnetic particles:

Magnetic particle inspection is one of the simple, fast and traditional nondestructive testing methods widely used because of its convenience and low cost. This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components. The only requirement from an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such iron, nickel, cobalt, or some of their alloys, since these materials are materials that can be magnetized to a level that will allow the inspection to be effective. On the other hand, an enormous volume of structural steels used in engineering is magnetic. In its simplest application, an electromagnet yoke is placed on the surface of the part to be examined, a kerosene-iron filling suspension is poured on the surface and the electromagnet is energized. If there is a discontinuity such as a crack or a flaw on the surface of the part, magnetic flux will be broken and a new south and north pole will form at each edge of the discontinuity. Then just like if iron particles are scattered on a cracked magnet, the particles will be attracted to and cluster at the pole ends of the magnet, the iron particles will also be attracted at the edges of the crack behaving poles of the magnet. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection. For the best sensitivity, the lines of magnetic force should be perpendicular to the defect.

Eddy current testing:

Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field developsin and around the conductor. This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close proximity to this changing magnetic field, current will be induced in this second conductor. These currents are influenced by the nature of the material such as voids, cracks, changes in grain size, as well as physical distance between coil and material. These currents form an impedance on a second coil which is used to as a sensor. In practice a probe is placed on the surface of the part to be inspected, and electronic equipment monitors the eddy current in the work piece through the same probe. The sensing circuit is a part of the sending coil. Eddy currents can be used for crack detection, material thickness measurements, coating thickness measurements, conductivity measurements for material identification, heat damage detection, case depth determination, heat treatment monitoring. Some of the advantages of eddy current inspection include; sensitivity to small cracks and other defects, ability to detect surface and near surface defects, immediate results, portable equipment, suitability for many different applications, minimum part preparation, no necessity to contact the part under inspection, ability to inspect complex shapes and sizes of conductive materials. Some limitation of eddy current inspection; applicability just on conductive materials, necessity for an accessible surface to the probe, skillful and trained personal, possible interference of surface finish and roughness, necessity for reference standards for setup, limited depth of penetration, inability to detect of the flaws lying parallel to the probe coil winding and probe scan direction.

Ultrasonic Inspection:

Ultrasonic Testing (UT) uses a high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection I evaluation, dimensional measurements, material characterization, and more. A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulse. Driven by the pulser, the transducer of various types and shapes generates high frequency ultrasonic energy operating based on the piezoelectricity technology with using quartz, lithium sulfate, or various ceramics. Most inspections are carried out in the frequency rang of 1 to 25MHz. Couplants are used to transmit the ultrasonic waves from the transducer to the test piece; typical couplants are water, oil, glycerin and grease. The sound energy is introduced and propagates through the materials in the form of waves and reflected from the opposing surface. An internal defect such as crack or void interrupts the waves' propagation and reflects back a portion of the ultrasonic wave. The amplitude of the energy and the time required for return indicate the presence and location of any flaws in the work-piece. The ultrasonic inspection method has high penetrating power and sensitivity. It can be used from various directions to inspect flaws in large parts, such as rail road wheels pressure vessels and die blocks. This method requires experienced personnel to properly conduct the inspection and to correctly interpret the results. As a very useful and versatile NDT method, ultrasonic inspection method has the following advantages; sensitivity to both surface and subsurface discontinuities, superior depth of penetration for flaw detection or measurement, ability to single-sided access for pulse-echo technique, high accuracy in determining reflector position and estimating size and shape, minimal part preparation, instantaneous results with electronic equipment, detailed imaging with automated systems, possibility for other uses such as thickness measurements.
Its limitations; necessity for an accessible surface to transmit ultrasound, extensive skill and training, requirement for a coupling medium to promote transfer of sound energy into test specimen, limits for roughness, shape irregularity, smallness, thickness or not homogeneity, difficulty to inspect of coarse grained materials due to low sound transmission and high signal noise, necessity for the linear defects to be oriented parallel to the sound beam, necessity for reference standards for both equipment calibration, and characterization of flaws.

Acoustic Method:

There are two different kind of acoustic methods: (a) acoustic emission; (b) acoustic impact technique.

Acoustic emission:

This technique is typically performed by elastically stressing the part or structure, for example, bending a beam, applying torque to a shaft, or pressurizing a vessel and monitoring the acoustic responses emitted from the material. During the structural changes the material such as plastic deformation, crack initiation, and propagation, phase transformation, abrupt reorientation of grain boundaries, bubble formation during boiling in cavitation, friction and wear of sliding interfaces, are the source of acoustic signals. Acoustic emissions are detected with sensors consisting of piezoelectric ceramic elements. This method is particularly effective for continuous surveillance of load-bearing structures.

Acoustic impact technique:

This technique consists of tapping the surface of an object and listening to and analyzing the signals to detect discontinuities and flaws. The principle is basically the same as when one taps walls, desktops or countertops in various locations with a finger or a hammer and listens to the sound emitted. Vitrified grinding wheels are tested in a similar manner to detect cracks in the wheel that may not be visible to the naked eye. This technique is easy to perform and can be instrumented and automated.

However, the results depend on the geometry and mass of the part so a reference standard is necessary for identifying flaws.

NON-DESTRUCTIVE TESTING – VISUAL TESTING – GENERAL PRINCIPLES

Direct visual testing

Direct visual testing may usually be made for local visual testing when access is sufficient to place the eye within 600 mm of the surface to be tested and at an angle not less than 30° to the surface to be tested. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens, endoscope and fibre optic may be used to assist testing.
Direct visual testing may also be made at greater distances than 600 mm specifically for general visual testing. A viewing distance appropriate to the test shall be used. The specific part, component, vessel, or section thereof, under immediate test, shall be illuminated, if necessary, with auxiliary lighting, to attain a minimum of 160 lx for general visual testing and a minimum of 500 lx for local visual testing.
Consideration shall be given to the application of illuminance to maximize the effectiveness of the test by:
a) using the optimum direction of light with respect to the viewing point;
b) avoiding glare;
c) optimizing the colour temperature of the light source;
d) using an illumination level compatible with the surface reflectivity.

Remote visual testing
When direct visual testing cannot be utilized, remote visual testing may have to be substituted. Remote visual testing uses visual aids such as endoscopes and fibre optics, coupled to cameras or other suitable instruments. The suitability of the remote visual testing system to perform the designated task shall be proven.

Personnel

Personnel who carry out tests according to this standard shall be shown to:
a) be familiar with relevant standards, rules, specifications, equipment procedures/instructions;
b) be familiar with the relevant manufacturing procedure used and/or with the operating conditions of the component to be tested;
c) have satisfactory vision in accordance with EN 473. In addition, when performing general visual testing far vision shall be checked using the standard optotype in
All visual tests shall be evaluated in terms of the acceptance criteria specified (e.g. product standard, contract).

Post-test documentation
When required (e.g. product standard, contract) a written test report shall be provided detailing the following:

a) date and place of test;
b) method used according to clauses 5 or 6;
c) acceptance criteria and/or written procedure/instruction reference;
d) equipment and/or system utilized including set-up;
e) reference to customer's order;
f) name of organization carrying out test;
g) description and identification of test object;
h) details of test findings with respect to the acceptance criteria (e.g. size, location);
i) extent of test coverage;
j) name and signature of person conducting test with date;
k) name and signature of person supervising test with date, if required;
l) marking of component tested, when appropriate;
m) results.
This may be accomplished by referencing the visual testing written procedure and/or the instruction.

Records
Records shall be maintained as required (e.g. product standard, contract).

2.1 Liquid penetrant method:
In this method the surfaces to be inspected should be free from any coatings, paint, grease. dirt, dust, etc., therefore, should be cleaned with an appropriate way. Special care should be taken not to give additional damage to the surface to be inspected during the cleaning process. Otherwise, the original nature of surface could be disturbed and the results could be erroneous with the additional interferences of the surface features formed during the cleaning process. Surface cleaning can be performed with alcohol. Special chemicals like cleaner-remover can also be applied if needed. In the experiment, only cleaner remover will be sufficient. Subsequent to surface cleaning, the surface is let to dry for 2 minutes. Commercially available cans of liquid penetrant dyes with different colors are used to reveal the surface defects.

2.2 Steps used in the experiment
:
- Clean the surface with alcohol and let surface dry for 5 min.
- Apply the liquid penetrant spray (red can) to the surface and brush for further penetration. Then, wait for 20 min.
- Wipe the surface with a clean textile and subsequently apply remover spray (blue can) to remove excess residues on the surface and wait for a few min.
- Apply the developer spray (yellow can) at a distance of about 30cm from the surface. Thedeveloper will absorb the penetrant that infiltrated to the surface features such as cracks, splits, etc., and thenreacted with it to form a geometric shape which is the negative of the
- geometry of the surface features from which the penetrant is sucked.
- The polymerized material may be collected on a sticky paper for futureevaluation and related documentation, if needed

2.3 Penetrants
Penetrants are carefully formulated to produce the level of sensitivity desired by the inspector. The penetrant must possess a number of important characteristics:
- spread easily over the surface of the material being inspected to provide complete and even coverage.
- be drawn into surface breaking defects by capillary action.
- remain in the defect but remove easily from the surface of the part.

- remain fluid so it can be drawn back to the surface of the part through the drying and developing steps.
- be highly visible or fluoresce brightly to produce easy to see indications.
- not be harmful to the material being tested or the inspector.

Penetrant materials are not designed to perform the same. Penetrant manufactures have developed different formulations to address a variety of inspection applications. Some applications call for the detection of the smallest defects possible while in other applications, the rejectable defect size may be larger. The penetrants that are used to detect the smallest defects will also produce the largest amount of irrelevant indications. Standard specifications classify penetrant materials according to their physical characteristics and their performance.

Penetrant materials come in two basic types:

Type 1 - Fluorescent Penetrants: they contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation.
Type 2 - Visible Penetrants: they contain a red dye that provides high contrast against the white developer background.

Fluorescent penetrant systems are more sensitive than visible penetrant systems because the eye is drawn to the glow of the fluorescing indication. However, visible penetrants do not require a darkened area and an ultraviolet light in order to make an inspection.
Penetrants are then classified by the method used to remove the excess penetrant from the part. The four methods are:

Method A - Water Washable: penetrants can be removed from the part by rinsing with water alone. These penetrants contain an emulsifying agent (detergent) that makes it possible to wash the penetrant from the part surface with water alone.Water washable penetrants are sometimes referred to as self-emulsifying systems.

Method B - Post-Emulsifiable, Lipophilic: the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible.

Method C - Solvent Removable: they require the use of a solvent to remove the penetrant from the part.

Method D - Post-Emulsifiable, Hydrophilic: they use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash.
Penetrants are then classified based on the strength or detectability of the indication that is produced for a number of very small and tight fatigue cracks. The five sensitivity levels are:
Level ½ - Ultra Low Sensitivity
Level 1 - Low Sensitivity
Level 2 - Medium Sensitivity
Level 3 - High Sensitivity
Level 4 - Ultra-High Sensitivity
The procedure for classifying penetrants into one of the five sensitivity levels uses specimens with small surface fatigue cracks. The brightness of the indication produced is measured using a photometer.

Developers
The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector. Developers used with visible penetrants create a white background so there is a greater degree of contrast between the indication and the surrounding background. On the other hand, developers used with fluorescent penetrants both reflect and refract the

incident ultraviolet light, allowing more of it to interact with the penetrant, causing more efficient fluorescence.
According to standards, developers are classified based on the method that the developer is applied (*as a drypowder, or dissolved or suspended in a liquid carrier*). The six standard forms of developers are:

Form a - Dry Powder
Form b - Water Soluble
Form c - Water Suspendable
Form d - Nonaqueous Type 1: Fluorescent (Solvent Based)
Form e - Nonaqueous Type 2: Visible Dye (Solvent Based)
Form f - Special Applications

Dry Powder
Dry powder developers are generally considered to be the least sensitive but they are inexpensive to use and easy to apply. Dry developers are white, fluffy powders that can be applied to a thoroughly dry surface in a number of ways; by dipping parts in a container of developer, by using a puffer to dust parts with the developer, or placing parts in a dust cabinet where the developer is blown around. Since the powder only sticks to areas of indications since they are wet, powder developers are seldom used for visible inspections.

Water Soluble
As the name implies, water soluble developers consist of a group of chemicals that are dissolved in water and form a developer layer when the water is evaporated away. The best method for applying water soluble developers is by spraying it on the part. The part can be wet or dry. Dipping, pouring, or brushing the solution on to the surface is sometimes used but these methods are less desirable. Drying is achieved by placing the wet, but well drained part, in a recirculating warm air dryer with a temperature of 21°C. Properly developed parts will have an even, light white coating over the entire surface.

Water Suspendable
Water suspendable developers consist of insoluble developer particles suspended in water. Water suspendable developers require frequent stirring or agitation to keep the particles from settling out of suspension. Water suspendable developers are applied to parts in the same manner as water soluble developers then the parts are dried using warm air.

Nonaqueous
Nonaqeous developers suspend the developer in a volatile solvent and are typically applied with a spray gun. Nonaqueous developers are commonly distributed in aerosol spray cans for portability. Th solvent tends to pull penetrant from the indications by solvent action. Since the solvent is highly volatile, forced drying is not required

2.5 Steps of Liquid Penetrant Testing

The exact procedure for liquid penetrant testing can vary from case to case depending on several factors such as the penetrant system being used, the size and material of the component being inspected, the type of discontinuities being expected in the component and the condition and environment under which the inspection is performed. However, the general steps can be summarized as follows:

1. *Surface Preparation*: One of the most critical steps of a liquid penetrant testing is the surface preparation. The surface must be free of oil, grease, water, or other contaminants that may prevent penetrant from entering flaws. The sample may also require etching if mechanical operations such as

machining, sanding, or grit blasting have been performed. These and other mechanical operations can smear metal over the flaw opening and prevent the penetrant from entering.

2. *Penetrant Application*: Once the surface has been thoroughly cleaned and dried, the penetrant material is applied by spraying, brushing, or immersing the part in a penetrant bath.

3. *Penetrant Dwell*: The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn or to seep into a defect. Penetrant dwell time is the total time that the penetrant is in contact with the part surface. Dwell times are usually recommended by the penetrant producers or required by the specification being followed. The times vary depending on the application, penetrant materials used, the material, the form of the material being inspected, and the type of discontinuity being inspected for. Minimum dwell times typically range from 5 to 60 minutes. Generally, there is no harm in using a longer penetrant dwell time as long as the penetrant is not allowed to dry. The ideal dwell time is often determined by experimentation and may be very specific to a particular application.

4. *Excess Penetrant Removal*: This is the most delicate step of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects Depending on the penetrant system used, this step may involve cleaning with a solvent, direct rinsing with water, or first treating the part with an emulsifier and then rinsing with water.

5. *Developer Application*: A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. Developers come in a variety of forms that may be applied by dusting (*dry powders*), dipping, or spraying (*wet developers*

6. *Indication Development*: The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws. This development time is usually a minimum of 10 minutes. Significantly longer times may be necessary for tight cracks.

7. *Inspection*: Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

8. *Clean Surface*: The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.

Advantages
- High sensitivity (*small discontinuities can be detected*).
- Few material limitations (*metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected*).
- . Rapid inspection of large areas and volumes.
- Suitable for parts with complex shapes.
- Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
- Portable (materials are available in aerosol spray cans)
- Low cost (materials and associated equipment are relatively inexpensive)

Disadvantages
- Only surface breaking defects can be detected.
- Only materials with a relatively nonporous surface can be inspected.
- Pre-cleaning is critical since contaminants can mask defects.
- Metal smearing from machining, grinding, and grit or vapor blasting must be removed.
- The inspector must have direct access to the surface being inspected.

- Surface finish and roughness can affect inspection sensitivity.
- Multiple process operations must be performed and controlled.
- Post cleaning of acceptable parts or materials is required.
- Chemical handling and proper disposal is required

UNIT-III MAGNETIC TESTING

Magnetic Particle Testing

Magnetic particle testing is one of the most widely utilized NDT methods since it is fast and relatively easy to apply and part surface preparation is not as critical as it is for some other methods. This mithod uses magnetic fields and small magnetic particles (*i.e.iron filings*) to detect flaws in components. The only requirement from an inspectability standpoint is that the component being inspected must be made of a ferromagnetic material (*a materials that can be magnetized*) such as iron, nickel, cobalt, or some of their alloys.The method is used to inspect a variety of product forms including castings, forgings, and weldments. Many different industries use magnetic particle inspection such as structural steel, automotive, petrochemical, power generation, and aerospace industries. Underwater inspection is another area where magnetic particle inspection may be used to test items such as offshore structures and underwater pipelines.

2.6.1 Basic Principles

In theory, magnetic particle testing has a relatively simple concept. It can be considered as a combination of two nondestructive testing methods:

1. Magnetic flux leakage testing and
2. visual testing.

For the case of a bar magnet, the magnetic field is in and around the magnet. Any place that a magnetic line of force exits or enters the magnet is called a “pole” (*magnetic lines of force exit the magnet from north pole and enter from the south pole*).When a bar magnet is broken in the center of its length, two complete bar magnets with magnetic poles on each end of each piece will result. If the magnet is just cracked but not broken completely in two, a north and south pole will form at each edge of the crack.
The magnetic field exits the North Pole and reenters at the south pole. The magnetic field spreads out when it encounters the small air gap created by the crack because the air cannot support as much magnetic field per unit volume as the magnet can. When the field spreads out, it appears to leak out of the material and, thus is called a flux leakage field.

If iron particles are sprinkled on a cracked magnet, the particles will be attracted to and cluster not only at the poles at the ends of the magnet, but also at the poles at the edges of the crack. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspectioThe first step in a magnetic particle testing is to magnetize the component that is to be inspected. If any defects on or near the surface are present, the defects will create a leakage field. After the component has been magnetized, iron particles, either in a dry or wet suspended form, are applied to the surface of the magnetized part. The particles will be attracted and cluster at the flux leakage fields, thus forming a visible indication that the inspector can detect.

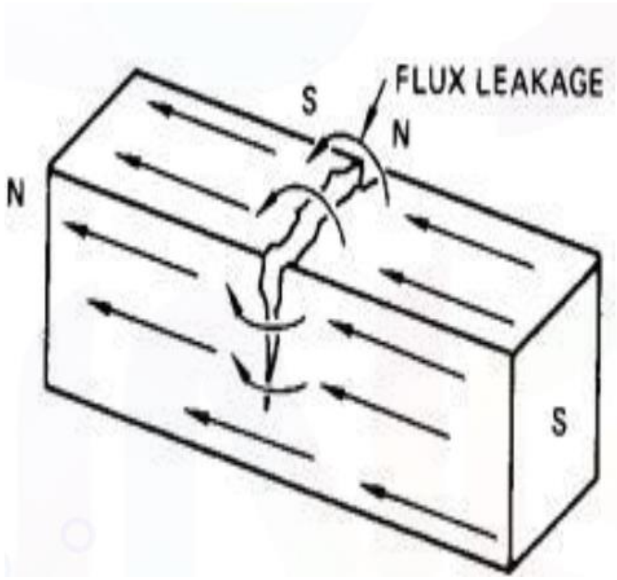


Fig.Flux leakage

Advantages
 High sensitivity (*small discontinuities can be detected*).
 Indications are produced directly on the surface of the part and constitute a visual representation of flaw.
 Minimal surface preparation (*no need for paint removal*)
 Portable (*small portable equipment & materials available in spray cans*)
 Low cost (*materials and associated equipment are relatively inexpensive*)

Disadvantages
 Only surface and near surface defects can be detected.
 Only applicable to ferromagnetic materials.
 Relatively small area can be inspected at a time.
 Only materials with a relatively nonporous surface can be inspected.

2.7 Magnetism
The concept of magnetism centers around the magnetic field and what is known as a dipole. The term "*magnetic field*" simply describes a volume of space where there is a change in energy within that volume.
The location where a magnetic field exits or enters a material is called a magnetic pole. Magnetic poles have never been detected in isolation but always occur in pairs, hence the name dipole. Therefore, a dipole is an object that has a magnetic pole on one end and a second, equal but opposite, magnetic pole on the other. A bar magnet is a dipole with a north pole at one end and south pole at the other.The source of magnetism lies in the basic building block of all matter, the atom. Atoms are composed of protons, neutrons and electrons. The protons and neutrons are located in the atom's nucleus and the electrons are in constant motion around the nucleus. Electrons carry a negative electrical charge and produce a magnetic field as they move through space. A magnetic field is produced whenever an electrical charge is in motion.
The strength of this field is called the magnetic moment.nWhen an electric current flows through a conductor, the movement of electrons through the conductor causes a magnetic field to form around the conductor. The magnetic field can be detected using a compass. Since all matter is comprised of atoms, all materials are affected in some way by a magnetic field; however, materials do not react the same way to the magnetic field.

Reaction of Materials to Magnetic Field

When a material is placed within a magnetic field, the magnetic forces of the material's electrons will be affected. This effect is known as Faraday's Law of Magnetic Induction. However, materials can react quite differently to the presence of an external magnetic field. The magnetic moments associated with atoms have three origins: the electron motion, the change in motion caused by an external magnetic field, and the spin of the electrons. In most atoms, electrons occur in pairs where these pairs spin in opposite directions.
The opposite spin directions of electron pairs cause their magnetic fields to cancel each other. Therefore, no net magnetic field exists. Alternately, materials with some unpaired electrons will have a net magnetic field and will react more to an external field.

According to their interaction with a magnetic field, materials can be classified as:

Diamagnetic materials
Diamagnetic materials have a weak, negative susceptibility to magnetic fields. Diamagnetic materials are slightly repelled by a magnetic field and the material does not retain the magnetic properties when the external field is removed. In diamagnetic materials all the electrons are paired so there is no permanent net magnetic moment per atom. Most elements in the periodic table, including copper, silver, and gold, are diamagnetic.

Paramagnetic materials
Paramagnetic materials have a small, positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed. Paramagnetic materials have some unpaired electrons. Examples of paramagnetic materials include magnesium, molybdenum, and lithium.

Ferromagnetic materials
Ferromagnetic materials have a large, positive susceptibility to an external magnetic field. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains. In these domains, large numbers of atom's moments are aligned parallel so that the magnetic force within the domain is strong (*this happens during the solidification of the material where the atom moments are aligned within each crystal "i.e., grain" causing a strong magnetic force in one direction*). When a ferromagnetic material is in theunmagnetized state, the domains are nearly randomly organized (*since the crystals are in arbitrary directions*) and the net magnetic field for the part as a whole is zero. When a magnetizing force is applied, the domains become aligned to produce a strong magnetic field within the part. Iron, nickel, and cobalt are examples of ferromagnetic materials. Components made of these materials are commonly inspected using the magnetic particle method.

2.9 Magnetic Field Characteristics

2.9.1 Magnetic Field In and Around a Bar Magnet

The magnetic field surrounding a bar magnet can be seen in the magnetograph below. A magnetograph can be created by placing a piece of paper over a magnet and sprinkling the paper with iron filings. The particles align themselves with the lines of magnetic force produced by the magnet. It can be seen in the magnetograph that there are poles all along the length of the magnet but that the poles are concentrated at the ends of the magnet (*the north and south poles*).

2.9.2 Magnetic Fields in and around Horseshoe and Ring Magnets

Magnets come in a variety of shapes and one of the more common is the horseshoe (U) magnet. The horseshoe magnet has north and south poles just like a bar magnet but the magnet is curved so the poles lie in the same plane. The magnetic lines of force flow from pole to pole just like in the bar magnet. However, since the poles are located closer together and a more direct path exists for the lines of flux to travel between the poles, the magnetic field is concentrated between the poles.

General Properties of Magnetic Lines of Force

Magnetic lines of force have a number of important properties, which include:

They seek the path of least resistance between opposite magnetic poles (*in a single bar magnet shown, they attempt to form closed loops from pole to pole*).

They never cross one another.

They all have the same strength.

Their density decreases with increasing distance from the poles.

Their density decreases (*they spread out*) when they move from an area of higher permeability to an area of lower permeability.

They are considered to have direction as if flowing, though no actual movement occurs.

They flow from the south pole to the north pole within a material and north pole to south pole in air.

Electromagnetic Fields

Magnets are not the only source of magnetic fields. The flow of electric current through a conductor generates a magnetic field. When electric current flows in a long straight wire, a circular magnetic field is generated around the wire and the intensity of this magnetic field is directly proportional to the amount of current carried by the wire. The strength of the field is strongest next to the wire and diminishes with distance. In most conductors, the magnetic field exists only as long as the current is flowing However, in ferromagnetic materials the electric current will cause some or all of the magnetic domains to align and a residual magnetic field will remain. Also, the direction of the magnetic field is dependent on the direction of the electrical current in the wire. The direction of the magnetic field around a conductor can be determined using a simple rule called the "*right-hand clasp rule*". If a person grasps a conductor in one's right hand with the thumb pointing in the direction of the current, the fingers will circle the conductor in the direction of the magnetic field.

Magnetic Field Produced by a Coil

When a current carrying wire is formed into several loops to form a coil, the magnetic field circling each loop combines with the fields from the other loops to produce a concentrated field through the center of the coil (*the field flows along the longitudinal axis and circles back around the outside of the coil*).

When the coil loops are tightly wound, a uniform magnetic field is developed throughout the length of the coil. The strength of the magnetic field increases not only with increasing current but also with each loop that is added to the coil. A long, straight coil of wire is called a *solenoid* and it can be used to generate a nearly uniform magnetic field similar to that of a bar magnet. The concentrated magnetic field inside a coil is very useful in magnetizing ferromagnetic materials for inspection using the magnetic particle testing method.

Quantifying Magnetic Properties

The various characteristics of magnetism can be measured and expressed quantitatively. Different systems of units can be used for quantifying magnetic properties. SI units will be used in this material. The advantage of using SI units is that they are traceable back to an agreed set of four base units; meter, kilogram, second, and Ampere. The unit for magnetic *field strength* **H** is *ampere/meter* (*A/m*). A magnetic field strength of *1 A/m* is produced at the center of a single circular conductor with a *1 meter* diameter carrying a steady current of *1 ampere*.

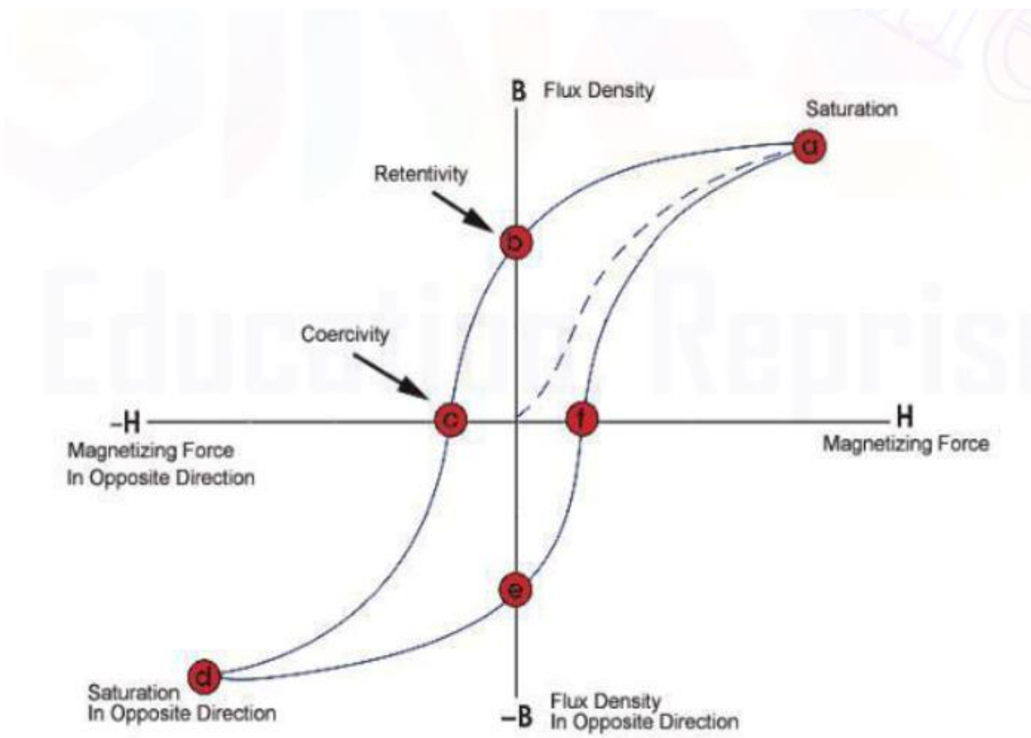
The number of magnetic lines of force cutting through a plane of a given area at a right angle is known as the magnetic *flux density*, **B**. The flux density or magnetic induction has the *Tesla* as its unit. One *Tesla* is equal to *1 Newton/(A/m)*. From these units, it can be seen that the flux density is a measure of the force applied to a particle by the magnetic field.

The total number of lines of magnetic force in a material is called magnetic *flux*, **ϕ**. The strength of the flux is determined by the number of magnetic domains that are aligned within a material. The *total flux* is simply the flux density applied over an area. Flux carries the unit of a *weber*, which is simply a *Teslameter* ^{2}.

The *magnetization* **M** is a measure of the extent to which an object is magnetized. It is a measure of the magnetic dipole moment per unit volume of the object. Magnetization carries the same units as a magnetic field *A/m*

The Hysteresis Loop and Magnetic Properties

A great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density (**B**) and the magnetizing force (**H**). It is often referred to as the *B-H* loop. An example hysteresis loop is shown below.



The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H** is increased. As the line demonstrates, the greater the amount of current applied (***H***+), the stronger the magnetic field in the component (***B***+). At point "***a***"almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When **H** is reduced to zero, the curve will move from point "***a***" to point "***b***". At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to at the point of retentivity on the graph and indicates the level of residual magnetism in the material (*Some of the magnetic domains remain aligned but some have lost their alignment*). As the magnetizing force is reversed, the curve moves to point "***c***", where the flux has been reduced to zero. This is called the point of coercivity on the curv (*the reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero*). The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material. As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction, point "***d***". Reducing **H** to zero brings the curve to point "***e***". It will have a level of residual magnetism equal to that achieved in the other direction. Increasing **H** back in the positive direction will return **B** to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "***f***" back to the saturation point where it with complete the loop.

From the hysteresis loop, a number of primary magnetic properties of a material can be determined:

1. ***Retentivity* -** A measure of the residual flux density corresponding to the saturation induction of a magnetic material. In other words, it is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation (The value of **B** at point ***b*** on the hysteresis curve).

2. ***Residual Magnetism or Residual Flux* -** The magnetic flux density that remains in a material when the magnetizing force is zero. Note that residual magnetism and retentivity are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentivity value when the magnetizing force did not reach the saturation level.

3. ***Coercive Force* -** The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero (The value of **H** at point ***c*** on the hysteresis curve).

***4. Permeability, μ* -** A property of a material that describes the ease with which a magnetic flux is established in the material.

5. ***Reluctance* -** Is the opposition that a ferromagnetic material shows to the establishment of a magnetic field. Reluctance is analogous to the resistance in an electrical circuit.

Permeability

As previously mentioned, permeability (μ) is a material property that describes the ease with which a magnetic flux is established in a component. It is the ratio of the flux density (B) created within a material to the magnetizing field (H) and it is represented by the following equation:

μ = B/H

This equation describes the slope of the curve at any point on the hysteresis loop. The permeability value given in letrature for materials is usually the maximum permeability or the maximum relative permeability. The maximum permeability is the point where the slope of the B/H curve for the unmagnetized material is the greatest. This point is often taken as the point where a straight line from the origin is tangent to the B/H curve. The shape of the hysteresis loop tells a great deal about the material being magnetized. The hysteresis curves of two different materials are shown in the graph.

Relative to other materials, a material with a wider hysteresis loop has:
- Lower Permeability
- Higher Retentivity
- Higher Coercivity
- Higher Reluctance
- Higher Residual Magnetism

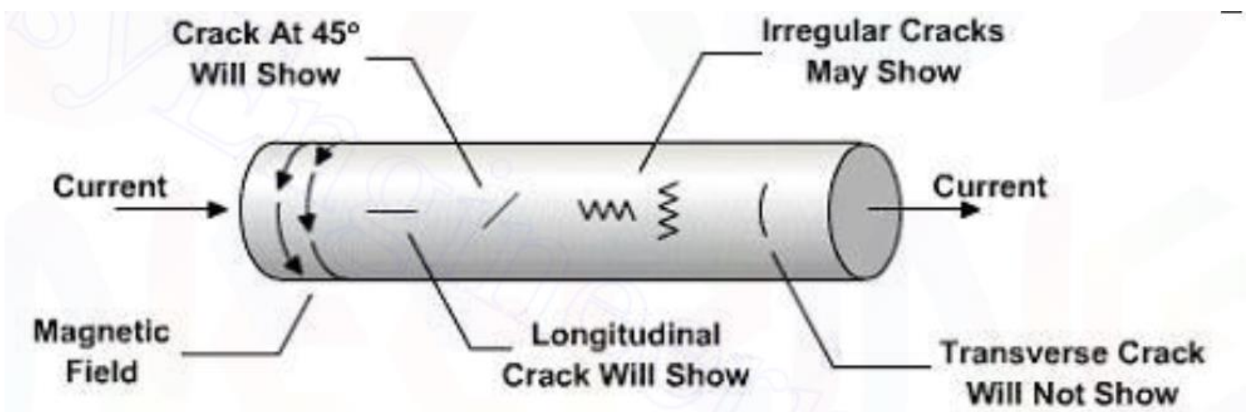
Relative to other materials, a material with a narrower hysteresis loop has:
- Higher Permeability
- Lower Retentivity
- Lower Coercivity
- Lower Reluctance
- Lower Residual Magnetism

In magnetic particle testing, the level of residual magnetism is important. Residual magnetic fields are affected by the permeability, which can be related to the carbon content and alloying of the material. A component with high carbon content will have low permeability and will retain more magnetic flux than a material with low carbon content.

Magnetic Field Orientation and Flaw Detectability

To properly inspect a component for cracks or other defects, it is important to understand that the orientation of the crack relative to the magnetic lines of force determinies if the crack can or cannot be detected. There are two general types of magnetic fields that can be established within a component.
A longitudinal magnetic field has magnetic lines of force that run parallel to the long axis of the part. Longitudinal magnetization of a component can be accomplished using the longitudinal field set up by a coil or solenoid. It can also be accomplished using permanent magnets or electromagnets.
A circular magnetic field has magnetic lines of force that run circumferentially around the perimeter of a part. A circular magnetic field is induced in an article by either passing current through the component or by passing current through a conductor surrounded by the component.

The type of magnetic field established is determined by the method used to magnetize the specimen.



Being able to magnetize the part in two directions is important because the best detection of defects occurs when the lines of magnetic force are established at right angles to the longest dimension of the defect.

This orientation creates the largest disruption of the magnetic field within the part and the greatest flux leakage at the surface of the part. If the magnetic field is parallel to the defect, the field will see little disruption and no flux leakage field will be produced An orientation of 45 to 90 degrees between the magnetic field and the defect is necessary to form an indication. Since defects may occur in various and unknown directions, each part is normally magnetized in two directions at right angles to each other.
If the component shown is considered, it is known that passing current through the part from end to end will establish a circular magnetic field that will be 90 degrees to the direction of the current.
Therefore, defects that have significant dimension in the direction of the current (*longitudinal defects*) should be detectable, while transverse-type defects will not be detectable with circular magnetization.

2.11.1 Magnetization of Ferromagnetic Materials

There are a variety of methods that can be used to establish a magnetic field in a component for evaluation using magnetic particle inspection. It is common to classify the magnetizing methods as either direct or indirect.
Magnetization Using Direct Induction (Direct Magnetization) With direct magnetization, current is passed directly through the component. The flow of current causes a circular magnetic field to form in and around the conductor. When using the direct magnetization method, care must be taken to ensure that good electrical contact is established and maintained between the test equipment and the test component to avoid damage of the the component (*due to arcing or overheating at high resistance ponts*).

There are several ways that direct magnetization is commonly accomplished.
One way involves *clamping the component between two electrical contacts* in a special piece of equipment. Current is passed through the component and a circular magnetic field is established in and around the component. When the magnetizing current is stopped, a residual magnetic field will remain within the component. The strength of the induced magnetic field is proportional to the amount of current passed through the component.

- A second technique involves using *clamps or prods*, which are attached or placed in contact with the component. Electrical current flows through the component from contact to contact. The current sets up a circular magnetic field around the path of the current.

Magnetization Using Indirect Induction (Indirect Magnetization)

Indirect magnetization is accomplished by using a strong external magnetic field to establish a magnetic field within the component. As with direct magnetization, there are several ways that indirect magnetization can be accomplished. The use of *permanent magnets* is a low cost method of establishing a magnetic field. However, their use is limited due to lack of control of the field strength and the difficulty of placing and removing strong permanent magnets from the component.
Electromagnets in the form of an adjustable horseshoe magnet (*called a yoke*) eliminate the problems associated with permanent magnets and are used extensively in industry. Electromagnets only exhibit a magnetic flux when electric current is flowing around the soft iron core. When the magnet is placed on the component, a magnetic field is established between the north and south poles of the magnet.Another way of indirectly inducting a magnetic field in a material is by using the magnetic field of a current carrying conductor. A circular magnetic field can be established in cylindrical components by using a *central conductor*. Typically, one or more cylindrical components are hung from a solid copper bar running through the inside diameter. Current is passed through the copper bar and the resulting circular magnetic field establishes a magnetic field within the test components. The use of *coils and solenoids* is a third method of indirect magnetization. When the length of a component is several times larger than its

diameter, a longitudinal magnetic field can be established in the component. The component is placed longitudinally in the concentrated magnetic field that fills the center of a coil or solenoid. This magnetization technique is often referred to as a "*coil shot*".

Types of Magnetizing Current

As mentioned previously, electric current is often used to establish the magnetic field in components during magnetic particle inspection. Alternating current (AC) and direct current (DC) are the two basic types of current commonly used. The type of current used can have an effect on the inspection results, so the types of currents commonly used are briefly discussed here.

Direct Current

Direct current (DC) flows continuously in one direction at a constant voltage. A battery is the most common source of direct current. The current is said to flow from the positive to the negative terminal, though electrons flow in the opposite direction. DC is very desirable when inspecting for subsurface defects because DC generates a magnetic field that penetrates deeper into the material. In ferromagnetic materials, the magnetic field produced by DC generally penetrates the entire cross-section of the component.

Alternating Current

Alternating current (AC) reverses its direction at a rate of 50 or 60 cycles per second. Since AC is readily available in most facilities, it is convenient to make use of it for magnetic particle inspection. However, when AC is used to induce a magnetic field in ferromagnetic materials, the magnetic field will be limited to a thin layer at the surface of the component. This phenomenon is known as the "*skin effect*" and it occurs because the changing magnetic field generates eddy currents in the test object. The eddy currents produce a magnetic field that opposes the primary field, thus reducing the net magnetic flux below the surface. Therefore, it is recommended that AC be used only when the inspection is limited to surface defects.

Rectified Alternating Current

Clearly, the skin effect limits the use of AC since many inspection applications call for the detection of subsurface defects. Luckily, AC can be converted to current that is very much like DC through the process of rectification. With the use of rectifiers, the reversing AC can be converted to a one directional current. The three commonly used types of rectified current are described below.

Half Wave Rectified Alternating Current (HWAC)

When single phase alternating current is passed through a rectifier, current is allowed to flow in only one direction. The reverse half of each cycle is blocked out so that a one directional, pulsating current is produced. The current rises from zero to a maximum and then returns to zero. No current flows during the time when the reverse cycle is blocked out. The HWAC repeats at same rate as the unrectified current (50 or 60 Hz). Since half of the current is blocked out, the amperage is half of the unaltered AC. This type of current is often referred to as *half wave DC or pulsating DC*. The pulsation of the HWAC helps in forming magnetic particle indications by vibrating the particles and giving them added mobility where that is especially important when using dry particles. HWAC is most often used to power electromagnetic yokes.

Full Wave Rectified Alternating Current (FWAC) (Single Phase)

Full wave rectification inverts the negative current to positive current rather than blocking it out. This produces a pulsating DC with no interval between the pulses. Filtering is usually performed to soften the sharp polarity switching in the rectified current. While particle mobility is not as good as half-wave AC due to the reduction in pulsation, the depth of the subsurface magnetic field is improved.

Three Phase Full Wave Rectified Alternating Current
Three phase current is often used to power industrial equipment because it has more favorable power transmission and line loading characteristics. This type of electrical current is also highly desirable for magnetic particle testing because when it is rectified and filtered, the resulting current very closely resembles direct current. Stationary magnetic particle equipment wired with three phase AC will usually have the ability to magnetize with AC or DC (*three phase full wave rectified*), providing the inspector with the advantages of each current form

Magnetic Fields Distribution and Intensity

Longitudinal Fields

When a long component is magnetized using a solenoid having a shorter length, only the material within the solenoid and about the same length on each side of the solenoid will be strongly magnetized. This occurs because the magnetizing force diminishes with increasing distance from the solenoid. Therefore, a long component must be magnetized and inspected at several locations along its length for complete inspection coverage.

Circular Fields

When a circular magnetic field forms in and around a conductor due to the passage of electric current through it, the following can be said about the distribution and intensity of the magnetic field:
- The field strength varies from zero at the center of the component to a maximum at the surface.
- The field strength at the surface of the conductor decreases as the radius of the conductor increases (*when the current strength is held constant*).
- the field strength inside the conductor is dependent on the current strength, magnetic permeability of the material, and, if ferromagnetic, the location on the B-H curve.
- The field strength outside the conductor is directly proportional to the current strength and it decreases with distance orom the conductor.

The images below show the magnetic field strength graphed versus distance from the center of the conductor when current passes through a solid circular conductor.
In a nonmagnetic conductor carrying DC, the internal field strength rises from zero at the center to a maximum value at the surface of the conductor.
In a magnetic conductor carrying DC, the field strength within the conductor is much greater than it is in the nonmagnetic conductor. This is due to the permeability of the magnetic material. The external field is exactly the same for the two materials provided the current level and conductor radius are the same
When the magnetic conductor is carrying AC, the internal magnetic field will be concentrated in a thin layer near the surface of the conductor (*skin effect*). The external field decreases with increasing distance from the surface same as with DC.
a hollow circular conductor there is no magnetic field in the void area. The magnetic field is zero at the inner surface and rises until it reaches a maximum at the outer surface.
Same as with a solid conductor, when DC current is passed through a magnetic conductor, the field strength within the conductor is much greater than in nonmagnetic conductor due to the permeability of the magnetic material. The external field strength decreases with distance from the surface of the conductor.

The external field is exactly the same for the two materials provided the current level and conductor radius are the same.
When AC current is passed through a hollow circular magnetic conductor, the skin effect concentrates the magnetic field at the outside diameter of the component. As can be seen from these three field

distribution images, the field strength at the inside surface of hollow conductor is very low when a circular magnetic field is established by direct magnetization. Therefore, the direct method of magnetization is not recommended when inspecting the inside diameter wall of a hollow component for shallow defects (*if the defect has significant depth, it may be detectable using DC since the field strength increases rapidly as one moves from the inner towards the outer surface*).

A much better method of magnetizing hollow components for inspection of the ID and OD surfaces is with the use of a central conductor. As can be seen in the field distribution image, when current is passed through a nonmagnetic central conductor (copper bar), the magnetic field produced on the inside diameter surface of a magnetic tube is much greater and the field is still strong enough for defect detection on the OD surface.

Demagnetization

After conducting a magnetic particle inspection, it is usually necessary to demagnetize the component. Remanent magnetic fields can:
- affect machining by causing cuttings to cling to a component.
- interfere with electronic equipment such as a compass.
- create a condition known as "*arc blow*" in the welding process. Arc blow may cause the weld arc to wonder or filler metal to be repelled from the weld
- cause abrasive particles to cling to bearing or faying surfaces and increase wear.

Removal of a field may be accomplished in several ways. The most effective way to demagnetize a material is by heating the material above its curie temperature (*for instance, the curie temperature for a low carbon steel is 770°C*). When steel is heated above its curie temperature then it is cooled back down, the the orientation of the magnetic domains of the individual grains will become randomized again and thus the component will contain no residual magnetic field. The material should also be placed with its long axis in an east-west orientation to avoid any influence of the Earth's magnetic field However, it is often inconvenient to heat a material above its curie temperature to demagnetize it, so another method that returns the material to a nearly unmagnetized state is commonly used Subjecting the component to a reversing and decreasing magnetic field will return the dipoles to a nearly random orientation throughout the material. This can be accomplished by pulling a component out and away from a coil with AC passing through it. With AC Yokes, demagnetization of local areas may be accomplished by placing the yoke contacts on the surface, moving them in circular patterns around the area, and slowly withdrawing the yoke while the current is applied. Also, many stationary magnetic particle inspection units come with a demagnetization feature that slowly reduces the AC in a coil in which the component is placed.

A field meter is often used to verify that the residual flu x has been removed from a component. Industry standards usually require that the magnetic flux be reduced to less than 3 Gauss ($3x10^{-4}$ *Tesla*) after completing a magnetic particle inspectio**n.**

Measuring Magnetic Fields

When performing a magnetic particle inspection, it is very important to be able to determine the direction and intensity of the magnetic field. The field intensity must be high enough to cause an indication to form, but not too high to cause nonrelevant indications to mask relevant indications. Also, after magnetic inspection it is often needed to measure the level of residual magnetezmSince it is impractical to measure the actual field strength within the material, all the devices measure the magnetic field that is outside of the material. The two devices commonly used for quantitative measurement of magnetic fields n magnetic particle inspection are the field indicator and the Hall-effect meter, which is also called a gauss meter.

Field Indicators
Field indicators are small mechanical devices that utilize a soft iron vane that is deflected by a magnetic field. The vane is attached to a needle that rotates and moves the pointer on the scale. Field indicators can be adjusted and calibrated so that quantitative information can be obtained. However, the measurement range of field indicators is usually small due to the mechanics of the device (*the one shown in the image has a range from plus 20 to minus 20 Gauss*). This limited range makes them best suited for measuring the residual magnetic field after demagnetization.

Hall-Effect (Gauss/Tesla) Meter
A Hall-effect meter is an electronic device that provides a digital readout of the magnetic field strength in Gauss or Tesla units. The meter uses a very small conductor or semiconductor element at the tip of the probe. Electriccurrent is passed through the conductor. In a magnetic field, a force is exerted on the moving electrons which tends to push them to one side of the conductor. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The probe is placed in the magnetic field such that the magnetic lines of force intersect the major dimensions of the sensing element at a right angle.

Magnetization Equipment for Magnetic Particle Testing
To properly inspect a part for cracks or other defects, it is important to become familiar with the different types of magnetic fields and the equipment used to generate them. As discussed previously, one of the primary requirements for detecting a defect in a ferromagnetic material is that the magnetic field induced in the part must intercept the defect at a 45 to 90 degree angle. Flaws that are normal (90 degrees) to the magnetic field will produce the strongest indications because they disrupt more of the magnet flux. Therefore, for proper inspection of a component, it is important to be able to establish a magnetic field in at least two directions. A variety of equipment exists to establish the magnetic field for magnetic particle testing. One way to classify equipment is based on its portability. Some equipment is designed to be portable so that inspections can be made in the field and some is designed to be stationary for ease of inspection in the laboratory or manufacturing facility.

Portable Equipment
Permanent Magnets
Permanent magnets can be used for magnetic particle inspection as the source of magnetism (*bar magnets or horseshoe magnets*). The use of industrial magnets is not popular because they are very strong (*they require significant strength to remove them from the surface, about 250 N for some magnets*) and thus they are difficult and sometimes dangerous to handle. However, permanent magnets are sometimes used by divers for inspection in underwater environments or other areas, such as explosive environments, where electromagnets cannot be used. Permanent magnets can also be made small enough to fit into tight areas where electromagnets might not fit.

Electromagnetic Yokes
An electromagnetic yoke is a very common piece of equipment that is used to establish a magnetic field. A switch is included in the electrical circuit so that the current and, therefore, the magnetic field can be turned on and off. They can be powered with AC from a wall socket or by DC from a battery pack.

This type of magnet generates a very strong magnetic field in a local area where the poles of the magne touch the part being inspected. Some yokes can lift weights in excess of 40 pounds.

Prods
Prods are handheld electrodes that are pressed against the surface of the component being inspected to make contact for passing electrical current (*AC or DC*) through the metal. Prods are typically made from copper and have an insulated handle to help protect the operator. One of the prods has a trigger

switch so that the current can be quickly and easily turned on and off. Sometimes the two prods are connected by any insulator, as shown in the image, to facilitate one hand operation. This is referred to as a dual prod and is commonly used for weld inspections.

However, caution is required when using prods because electrical arcing can occur and cause damage to the component if proper contact is not maintained between the prods and the component surface. For this reason, the use of prods is not allowed when inspecting aerospace and other critical components. To help prevent arcing, the prod tips should be inspected frequently to ensure that they are not oxidized, covered with scale or other contaminant, or damaged.

Portable Coils and Conductive Cables

Coils and conductive cables are used to establish a longitudinal magnetic field within a component. When a preformed coil is used, the component is placed against the inside surface on the coil. Coils typically have three or five turns of a copper cable within the molded frame. A foot switch is often used to energize the coil. Also, flexible conductive cables can be wrapped around a component to form a coil.

The number of wraps is determined by the magnetizing force needed and of course, the length of the cable. Normally, the wraps are kept as close together as possible. When using a coil or cable wrapped into a coil, amperage is usually expressed in ampere-turns. Ampere-turns is the amperage shown on the amp meter times the number of turns in the coil.

Portable Power Supplies

Portable power supplies are used to provide the necessary electricity to the prods, coils or cables. Power supplies are commercially available in a variety of sizes. Small power supplies generally provide up to 1,500A of half-wave DC or AC. They are small and light enough to be carried and operate on either 120V or 240V electrical service. When more power is necessary, mobile power supplies can be used. These units come with wheels so that they can be rolled where needed. These units also operate on 120V or 240V electrical service and can provide up to 6,000A of AC or half-wave DC.

Stationery Equipment

Stationary stationary system is the wet horizontal (bench) unit. Wet horizontal units are designed to allow for batch inspections of a variety of components. The units have head and tail stocks (*similar to a lathe*) with electrical contact that the part can be clamped between. A circular magnetic field is produced with direct magnetization.

Most units also have a movable coil that can be moved into place so the indirect magnetization can be used to produce a longitudinal magnetic field. Most coils have five turns and can be obtained in a variety of sizes.
The wet magnetic particle solution is collected and held in a tank. A pump and hose system is used to apply the particle solution to the components being inspected. Some of the systems offer a variety of options in electrical current used for magnetizing the component (*AC, half wave DC, or full wave DC*). In some units, a demagnetization feature is built in, which uses the coil and decaying AC. magnetic particle inspection equipment is designed for use in laboratory or production environment.

Magnetic Field Indicators

The most common Magnetic Field Indicators Determining whether a magnetic field is of adequate strength and in the proper direction is critical when performing magnetic particle testing. There is actually no easy-to-apply method that permits an exact measurement of field intensity at a given point within a material. Cutting a small slot or hole into the material and measuring the leakage field that crosses the air gap with a Hall-effect meter is probably the best way to get an estimate of the actual field strength within a part. However, since that is not practical, there are a number of tools and methods that are used to determine the presence and direction of the field surrounding a component.

Hall-Effect Meter (Gauss Meter)

As discussed earlier, a Gauss meter is commonly used to measure the tangential field strength on the surface of the part. By placing the probe next to the surface, the meter measures the intensity of the field in the air adjacent to the component when a magnetic field is applied. The advantages of this device are: it provides a quantitative measure of the strength of magnetizing force tangential to the surface of a test piece, it can be used for measurement of residual magnetic fields, and it can be used repetitively. The main disadvantage is that such devices must be periodically calibrated.

Quantitative Quality Indicator (QQI)

The Quantitative Quality Indicator (QQI) or *Artificial Flaw Standard* is often the preferred method of assuring proper field direction and adequate field strength (*it is used with the wet method only*). The QQI is a thin strip (*0.05 or 0.1 mm thick*) of AISI 1005 steel with a specific pattern, such as concentric circles or a plus sign, etched on it. The QQI is placed directly on the surface, with the itched side facing the surface, and it is usually fixed to the surface using a tape then the component is then magnetized and particles applied. When the field strength is adequate, the particles will adhere over the engraved pattern and provide information about the field direction.

Pie Gage

The pie gage is a disk of highly permeable material divided into four, six, or eight sections by nonferromagnetic material (*such as copper*). The divisions serve as artificial defects that radiate out in different directions from the center. The sections are furnace brazed and copper plated. The gage is placed on the test piece copper side up and the test piece is magnetized. After particles are applied and the excess removed, the indications provide the inspector the orientation of the magnetic field. Pie gages are mainly used on flat surfaces such as weldments or steel castings where dry powder is used with a yoke or prods. The pie gage is not recommended for precision parts with complex shapes, for wet-method applications, or for proving field magnitude. The gage should be demagnetized between readings.

Slotted Strips

Slotted strips are pieces of highly permeable ferromagnetic material with slots of different widths. These strips can be used with the wet or dry method. They are placed on the test object as it is inspected. The indications produced on the strips give the inspector a general idea of the field strength in a particular area.

Magnetic Particles

As mentioned previously, the particles that are used for magnetic particle inspection are a key ingredient as they form the indications that alert the inspector to the presence of defects. Particles start out as tiny milled pieces of iron or iron oxide. A pigment (*somewhat like paint*) is bonded to their surfaces to give the particles color. The metal used for the particles has high magnetic permeability and low retentivity. High magnetic permeability is important because it makes the particles attract easily to small magnetic leakage fields from discontinuities, such as flaws. Low retentivity is important because the particles themselves never become strongly magnetized so they do not stick to each other or the surface of the part. Particles are available in a dry mix or a wet solution.

Dry Magnetic Particles

Dry magnetic particles can typically be purchased in red, black, gray, yellow and several other colors so that a high level of contrast between the particles and the part being inspected can be achieved. The size of the magnetic particles is also very important. Dry magnetic particle products are produced to include a range of particle sizes. The fine particles have a diameter of about 50 µm while the course particles have a diameter of 150 µm (*fine particles are more than 20 times lighter than the coarse particles*).
This makes fine particles more sensitive to the leakage fields from very small discontinuities. However, dry testing particles cannot be made exclusively of the fine particles where coarser particles are needed to bridge large discontinuities and to reduce the powder's dusty nature. Additionally, small particles easily adhere to surface contamination, such as remnant dirt or moisture, and get trapped in surface roughness features.
It should also be recognized that finer particles will be more easily blown away by the wind; therefore, windy conditions can reduce the sensitivity of an inspection. Also, reclaiming the dry particles is not recommended because the small particles are less likely to be recaptured and the "once used" mix will result in less sensitive inspections. The particle shape is also important. Long, slender particles tend to align themselves along the lines of magnetic force. However, if dry powder consists only of elongated particles, the application process would be less than desirable since long particles lack the ability to flow freely. Therefore, a mix of rounded and elongated particles is used since it results in a dry powder that flows well and maintains good sensitivity. Most dry particle mixes have particles with L/D ratios between one and two.

Wet Magnetic Particles

Magnetic particles are also supplied in a wet suspension such as water or oil. The wet magnetic particle testing method is generally more sensitive than the dry because the suspension provides the particles with more mobility and makes it possible for smaller particles to be used (*the particles are typically 10 µm and smaller*) since dust and adherence to surface contamination is reduced or eliminated. The wet method also makes it easy to apply the particles uniformly to a relatively large area.
Wet method magnetic particles products differ from dry powder products in a number of ways. One way is that both visible and fluorescent particles are available. Most non-fluorescent particles are ferromagnetic iron oxides, which are either black or brown in color. Fluorescent particles are coated with pigments that fluoresce when exposed to ultraviolet light. Particles that fluoresce green-yellow are most common to take advantage of the peak color sensitivity of the eye but other fluorescent colors are also available.
The carrier solutions can be water or oil-based. Water-based carriers form quicker indications, are generally less expensive, present little or no fire hazard, give off no petrochemical fumes, and are easier to clean from the part.

Water-based solutions are usually formulated with a corrosion inhibitor to offer some corrosion protection. However, oil-based carrier solutions offer superior corrosion and hydrogen embrittlement protection to those materials that are prone to attack by these mechanisms. Also, both visible and fluorescent wet suspended particles are available in aerosol spray cans for increased portability and ease of application.

Dry Particle Inspection

In this magnetic particle testing technique, dry particles are dusted onto the surface of the test object as the item is magnetized. Dry particle inspection is well suited for the inspections conducted on rough surfaces. When an electromagnetic yoke is used, the AC current creates a pulsating magnetic field that provides mobility to the powder. Dry particle inspection is also used to detect shallow subsurface cracks. Dry particles with half wave DC is the best approach when inspecting for lack of root penetration in welds of thin materials.

Steps for performing dry particles inspection:

Surface preparation **-** The surface should be relatively clean but this is not as critical as it is with liquid penetrant inspection. The surface must be free of grease, oil or other moisture that could keep particles from moving freely. A thin layer of paint, rust or scale will reduce test sensitivity but can sometimes be left in place with adequate results. Specifications often allow up to 0.076 mm of a nonconductive coating (*such as paint*) or 0.025 mm of a ferromagnetic coating (*such as nickel*) to be left on the surface. Any loose dirt, paint, rust or scale must be removed.o Some specifications require the surface to be coated with a thin layer of white paint in order to improve the contrast difference between the background and the particles (*especially when gray color particles are used*).

Applying the magnetizing force **-** Use permanent magnets, an electromagnetic yoke, prods, a coil or other means to establish the necessary magnetic flux.

Applying dry magnetic particles **-** Dust on a light layer of magnetic particles.

Blowing off excess powder **-** With the magnetizing force still applied, remove the excess powder from the surface with a few gentle puffs of dry air. The force of the air needs to be strong enough to remove the excess particles but not strong enough to remove particles held by a magnetic flux leakage field.

Terminating the magnetizing force **-** If the magnetic flux is being generated with an electromagnet or an electromagnetic field, the magnetizing force should be terminated. If permanent magnets are being used, they can be left in place.

Inspection for indications **-** Look for areas where the magnetic particles are clustered.

Wet Suspension Inspection

Wet suspension magnetic particle inspection, more commonly known as wet magnetic particle inspection, involves applying the particles while they are suspended in a liquid carrier. Wet magnetic particle inspection is most commonly performed using a stationary, wet, horizontal inspection unit but suspensions are also available in spray cans for use with an electromagnetic yoke. A wet inspection has several advantages over a dry inspection. First, all of the surfaces of the component can be quickly and easily covered with a relatively uniform layer of particles. Second, the liquid carrier provides mobility to the particles for an extended period of time, which allows enough particles to float to small leakage fields to form a visible indication. Therefore, wet inspection is considered best for detecting very small discontinuities on smooth surfaces. On rough surfaces, however, the particles (*which are much smaller in wet suspensions*) can settle in the surface valleys and lose mobility, rendering them less effective than dry powders under these conditions.

Steps for performing wet particle inspection:

Surface preparation **-** Just as is required with dry particle inspections, the surface should be relatively clean. The surface must be free of grease, oil and other moisture that could prevent the suspension from wetting the surface and preventing the particles from moving freely. A thin layer of paint, rust or scale will reduce test sensitivity, but can sometimes be left in place with adequate results. Specifications often allow up to 0.076 mm of a nonconductive coating (*such as paint*) or 0.025 mm of a ferromagnetic coating (*such as nickel*) to be left on the surface. Any loose dirt, paint, rust or scale must be removed. Some specifications require the surface to be coated with a thin layer of white paint when inspecting using visible particles in order to improve the contrast difference between the background and the particles (*especially when gray color particles are used*).

Applying suspended magnetic particles **-** The suspension is gently sprayed or flowed over the surface of the part. Usually, the stream of suspension is diverted from the part just before the magnetizing field is applied.

Applying the magnetizing force **-** The magnetizing force should be applied immediately after applying the suspension of magnetic particles. When using a wet horizontal inspection unit, the current is applied in two or three short busts (*1/2 second*) which helps to improve particle mobility.

Inspection for indications **-** Look for areas where the magnetic particles are clustered. Surface discontinuities will produce a sharp indication. The indications from subsurface flaws will be less defined and lose definition as depth increases.

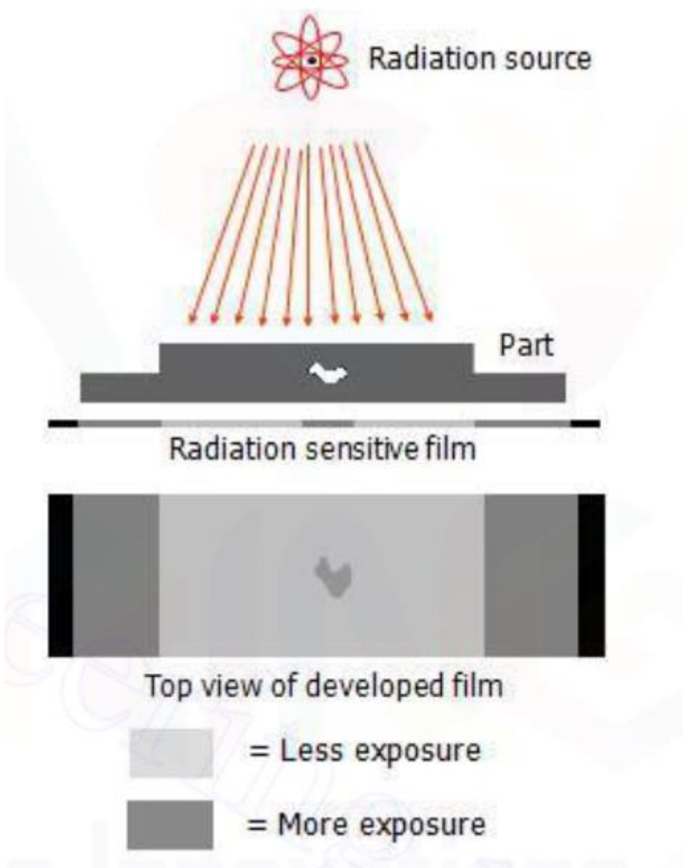
UNIT-IV RADIOGRAPHY TESTING

Introduction

Radiography is used in a very wide range of aplications including medicine, engineering, forensics, security, etc. In NDT, radiography is one of the most important and widely used methods. Radiographic testing (RT) offers a number of advantages over other NDT methods, however, one of its major disadvantages is the health risk associated with the radiation.

In general, RT is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by a radiation sensitive film (*Film Radiography*) or by a planer array of radiation sensitive sensors (*Real-time Radiography*). Film radiography is the oldest approach, yet it is still the most widely used in NDT.

5.1.1 Basic Principles



In radiographic testing, the part to be inspected is placed between the radiation source and a piece of radiation sensitive film.

The radiation source can either be an X ray machine or a radioactive source (*Ir-192, Co-60, or in rare cases Cs-137*).

The part will stop some of the radiation where thicker and more dense areas will stop more of the radiation.

The radiation that passes through the part will expose the film and forms a shadowgraph of the part.

The film darkness (*density*) will vary with the amount of radiation reaching the film through the test object where darker areas indicate more exposure (*higher radiation intensity*) and lighter areas indicate less exposure (low*er radiation intensity*).
This variation in the image darkness can be used to determine thickness or composition of material and would also reveal the presence of any flaws or discontinuities inside the material.

Advantages and Disadvantages

The primary advantages and disadvantages in comparison to other NDT methods are:

Advantages

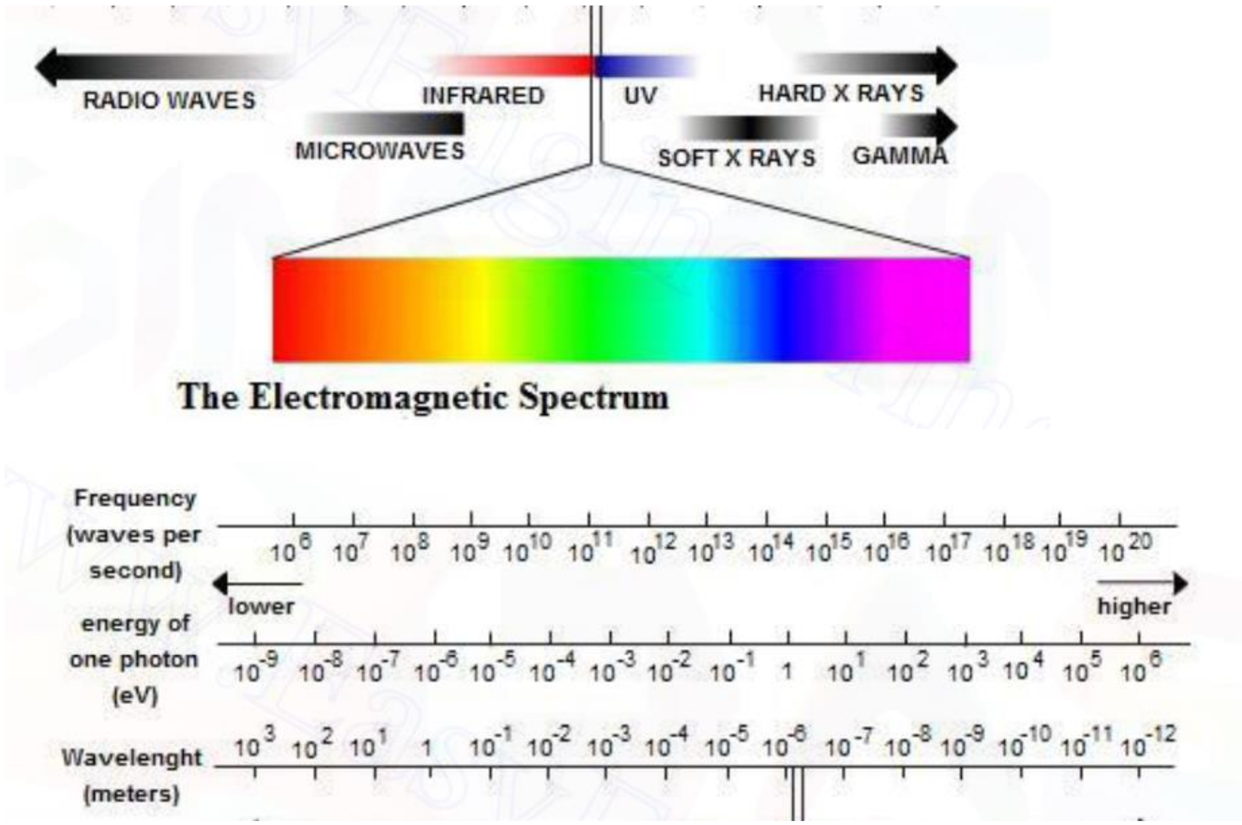
Both surface and internal discontinuities can be detected.
Significant variations in composition can be detected.
It has a very few material limitations.
Can be used for inspecting hidden areas (*direct access to surface is not required*)
Very minimal or no part preparation is required.
Permanent test record is obtained.
Good portability especially for gamma-ray sources.

Disadvantages

Hazardous to operators and other nearby personnel.
High degree of skill and experience is required for exposure and interpretation.
The equipment is relatively expensive (*especially for x-ray sources*).
The process is generally slow.
Highly directional (*sensitive to flaw orientation*).
Depth of discontinuity is not indicated.

Nature of Penetrating Radiation

Both X-rays and gamma rays are electromagnetic waves and on the electromagnetic spectrum they ocupy frequency ranges that are higher than ultraviolate radiation. In terms of frequency, gamma rays generaly have higher frequencies than X-rays as seen in the figure. The major distenction between X-rays and gamma rays is the origion where X-rays are usually artificially produced using an X-ray generator and gamma radiation is the product of radioactive materials. Both X-rays and gamma rays are waveforms, as are light rays, microwaves, and radio waves. X-rays and gamma rays cannot been seen, felt, or heard. They
possess no charge and no mass and, therefore are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light.



The Electromagnetic Spectrum

Electromagentic radiation act somewhat like a particle at times in that they occur as small "packets" of energy and are referred to as "*photons*". Each photon contains a certain amount (*or bundle*) of energy, and all electromagnetic radiation consists of these photons. The only difference between the various types of electromagnetic radiation is the amount of energy found in the photons.

Due to the short wavelength of X-rays and gamma rays, they have more energy to pass through matter than do the other forms of energy in the electromagnetic spectrum. As they pass through matter, they are scattered and absorbed and the degree of penetration depends on the kind of matter and the energy of the rays.

Properties of X-Rays and Gamma Rays

They are not detected by human senses (cannot be seen, heard, felt, etc.).
They travel in straight lines at the speed of light.
Their paths cannot be changed by electrical or magnetic fields.
They can be diffracted, refracted to a small degree at interfaces between two different materials, and in some cases be reflected.
They pass through matter until they have a chance to encounter with an atomic particle.
Their degree of penetration depends on their energy and the matter they are traveling through.
They have enough energy to ionize matter and can damage or destroy living cells.

X Radiation

X-rays are just like any other kind of electromagnetic radiation. They can be produced in packets of energy called photons, just like light. There are two different atomic processes that can produce X-ray photons. One is called *Bremsstrahlung* (*a German term meaning "braking radiation"*) and the other is called *K-shell emission*. They can both occur in the heavy atoms of tungsten which is often the material chosen for the target or anode of the X-ray tube.
Both ways of making X-rays involve a change in the state of electrons. However, Bremsstrahlung is easier to understand using the classical idea that radiation is emitted when the velocity of the electron shot at the tungsten target changes. The negatively charged electron slows down after swinging around the nucleus of a positively charged tungsten atom and this energy loss produces X-radiation. Electrons are scattered elastically or inelastically by the positively charged nucleus. The inelastically scattered electron loses energy, and thus produces X-ray photon, while the elastically scattered electrons generally change their direction significantly but without loosing much of their energy.

Bremsstrahlung Radiation

X-ray tubes produce X-ray photons by accelerating a stream of electrons to energies of several hundred kiloelectronvolts with velocities of several hundred kilometers per hour and colliding them into a heavy target material.
The abrupt acceleration of the charged particles (electrons) produces Bremsstrahlung photons. X-ray radiation with a continuous spectrum of energies is produced with a range from a few *keV* to a maximum of the energy of the electron beam.
The Bremsstrahlung photons generated within the target material are attenuated as they pass through, typically, 50 microns of target material. The beam is further attenuated by the aluminum or beryllium vacuum window. The results are the elimination of the low energy photons, *1 keV* through *15 keV*, and a significant reduction in the portion of the spectrum from *15 keV* through *50 keV*. The spectrum from an Xray tube is further modified by the filtration caused by the selection of filters used in the setup.

K-shell Emission Radiation

Remember that atoms have their electrons arranged in closed "shells" of different energies. The K-shell is the lowest energy state of an atom. An incoming electron can give a K-shell electron enough energy to knock it out of its energy state. About *0.1%* of the electrons produce K-shell vacancies; most produce heat. Then, a tungsten electron of higher energy (from an outer shell) can fall into the Kshell.
The energy lost by the falling electron shows up as an emitted X-ray photon. Meanwhile, higher energy electrons fall into the vacated energy state in the outer shell, and so on. After losing an electron, an atom remains ionized for a very short time (about 10^{-14} second) and thus an atom can be repeatedly ionized by the incident electrons which arrive about every 10^{-12} second. Generally, K-shell emission produces higher-intensity X-rays than Bremsstrahlung, and the X-ray photon comes out at a single wavelength

Gamma Radiation

Gamma radiation is one of the three types of natural radioactivity. Gamma rays are electromagnetic radiation just like X-rays. The other two types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation. Gamma radiation is the product of radioactive atoms. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as "*radioactive decay*" and such material is called "*radioactive material*".

5.4 Types of Radiation Produced by Radioactive Decay

When an atom undergoes radioactive decay, it emits one or more forms of high speed subatomic particles ejected from the nucleus or electromagnetic radiation (gamma-rays) emitted by either the nucleus or orbital electrons.

Alpha Particles

Certain radioactive materials of high atomic mass (*such as Ra-226, U-238, Pu-239*), decay by the emission of alpha particles.
These alpha particles are tightly bound units of two neutrons and two protons each (*He-4 nucleus*) and have a positive charge.
Emission of an alpha particle from the nucleus results in a decrease of two units of atomic number (*Z*) and four units of mass number (*A*).
Alpha particles are emitted with discrete energies characteristic of the particular transformation from which they originate. All alpha particles from a particular radionuclide transformation will have identical energies.

Beta Particles

A nucleus with an unstable ratio of neutrons to protons may decay through the emission of a high speed electron called a beta particle. In beta decay a neutron will split into a positively charged proton and a negatively charged electron. This results in a net change of one unit of atomic number (*Z*) and no change in the mass number (*A*). Beta particles have a negative charge and the beta particles emitted by a specific radioactive material will range in energy from near zero up to a maximum value, which is characteristic of the particular transformation.

Gamma-rays

A nucleus which is in an excited state (*unstable nucleus*) may emit one or more photons of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from *a higher to a lower energy state* (*unstable to stable*). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

Activity (*of Radioactive Materials*)

The quantity which expresses the radiation producing potential of a given amount of radioactive material is called "*Activity*". The *Curie* (***Ci***) was originally defined as that amount of any radioactive material that disintegrates at the same rate as one gram of pure radium. The International System (SI) unit for activity is the *Becquerel* (***Bq***), which is that quantity of radioactive material in which one atom is transformed per second. The radioactivity of a given amount of radioactive material does not depend upon the mass of material present. For example, two one-curie sources of the same radioactive material might have very different masses depending upon the relative proportion of non-radioactive atoms present in each source.

The concentration of radioactivity, or the relationship between the mass of radioactive material and the activity, is called "*specific activity*". Specific activity is expressed as the number of *Curies* or *Becquerels* per unit mass or volume. Each gram of Cobalt-60 will contain approximately *50 Ci*. Iridium-192 will contain *350 Ci* for every gram of material. The higher specific activity of iridium results in physically smaller sources. This allows technicians to place the source in closer proximity to the film while maintaining the sharpness of the radiograph

Radiation Energy, Intensity and Exposure

Different radioactive materials and X-ray generators produce radiation at different energy levels and at different rates. It is important to understand the terms used to describe the energy and intensity of the radiation.

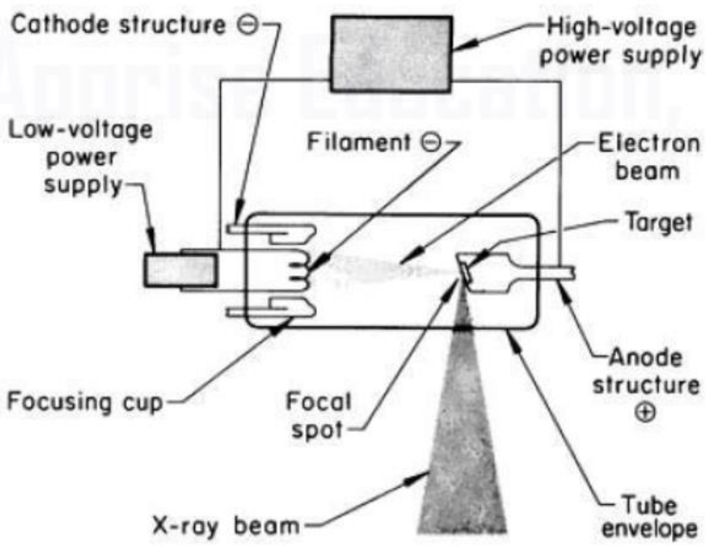
Radiation Energy

The energy of the radiation is responsible for its ability to penetrate matter. Higher energy radiation can penetrate more and higher density matter than low energy radiation. The energy of ionizing radiation is measured in *electronvolts* (***eV***). One electronvolt is an extremely small amount of energy so it is common to use kiloelectronvolts (***keV***) and megaelectronvolt (***MeV***). An electronvolt is a measure of energy, which is different from a volt which is a measure of the electrical potential between two positions. Specifically, an electronvolt is the kinetic energy gained by an electron passing through a potential difference of one volt. X-ray generators have a control to adjust the radiation energy, *keV* (or *kV*).The energy of a radioisotope is a characteristic of the atomic structure of the material. Consider, for example, Iridium-192 and Cobalt-60, which are two of the more common industrial Gamma ray sources. These isotopes emit radiation in two or three discreet wavelengths. Cobalt-60 will emit *1.17 and 1.33 MeV* gamma rays, and Iridium-192 will emit *0.31, 0.47, and 0.60 MeV* gamma rays. It can be seen from these values that the energy of radiation coming from Co-60 is more than twice the energy of the radiation coming from the Ir-192. From a radiation safety point of view, this difference in energy is important because the Co-60 has more material penetrating power and, therefore, is more dangerous and requires more shielding

EQUIPMENT & MATERIALS

X-ray Generators

The major components of an X-ray generator are the tube, the high voltage generator, the control console, and the cooling system. As discussed earlier in this material, X-rays are generated by directing a stream of high speed electrons at a target material such as tungsten, which has a high atomic number. When the electrons are slowed or stopped



by the interaction with the atomic particles of the target, X-radiation is produced. This is accomplished in an X-ray tube such as the one shown in the figure. The tube cathode (*filament*) is heated with a low-voltage current of a few amps.
The filament heats up and the electrons in the wire become loosely held. A large electrical potential is created between the cathode and the anode by the high-voltage generator.
Electrons that break free of the cathode are strongly attracted to the anode target. The stream of electrons between the cathode and the anode is the tube current.
The tube current is measured in milliamps and is controlled by regulating the low-voltage heating current applied to the cathode. The higher the temperature of the filament, the larger the number of electrons that leave the cathode and travel to the anode. The milliamp or current setting on the control console regulates the filament temperature, which relates to the intensity of the X-ray output.
The high-voltage between the cathode and the anode affects the speed at which the electrons travel and strike the anode. The higher the kilovoltage, the more speed and, therefore, energy the electrons have when they strike the anode. Electrons striking with more energy result in X-rays with more penetrating power.

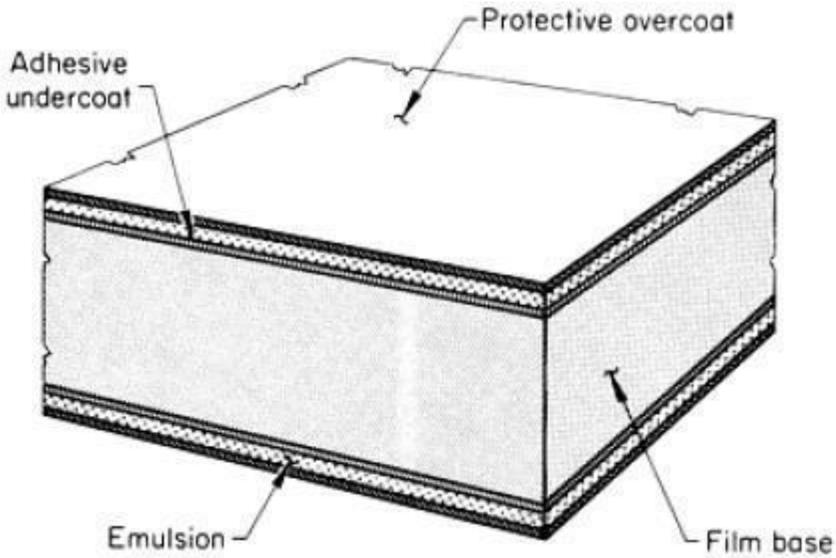
The highvoltage potential is measured in kilovolts, and this is controlled with the voltage or kilovoltage control on the control console. An increase in the kilovoltage will also result in an increase in the intensity of the radiation.
The figure shows the spectrum of the radiated X-rays associated with the voltage and current settings. The top figure shows that increasing the kV increases both the energy of X-rays and also increases the intensity of radiation (*number of photons*). Increasing the current, on the other hand, only increases the intensity without shifting the spectrum.

A focusing cup is used to concentrate the stream of electrons to a small area of the target called the "*focal spot*". The focal spot size is an important factor in the system's ability to produce a sharp image. Much of the energy applied to the tube is transformed into heat at the focal spot of the anode. As mentioned above, the anode target is commonly made from tungsten, which has a high melting point in addition toa high atomic number. However, cooling of the anode by active or passive means is necessary. Water or oil re-circulating systems are often used to cool tubes. Some low power tubes are cooled simply with the use of thermally conductive materials and heat radiating fins.

In order to prevent the cathode from burning up and to prevent arcing between the anode and the cathode, all of the oxygen is removed from the tube by pulling a vacuum. Some systems have external vacuum pumps to remove any oxygen that may have leaked into the tube. However, most industrial X-ray tubes simply require a warm-up procedure to be followed. This warm-up procedure carefully raises the tube current and voltage to slowly burn any of the available oxygen before the tube is operated at high power.
In addition, X-ray generators usually have a filter along the beam path (*placed at or near the x-ray port*). Filters consist of a thin sheet of material (*often high atomic number materials such as lead, copper, or brass*) placed in the useful beam to modify the spatial distribution of the beam. Filtration is required to absorb the lower-energy X-ray photons emitted by the tube before they reach the target in order to produce a cleaner image (*since lower energy X-ray photons tend to scatter more*).

The other important component of an X-ray generating system is the control console. Consoles typically have a keyed lock to prevent unauthorized use of the system. They will have a button to start the generation of Xrays and a button to manually stop the generation of X-rays. The three main adjustable controls regulate the tube voltage in *kilovolts*, the tube amperage in *milliamps*, and the exposure time in *minutes and seconds*.Some systems also have a switch to change the focal spot size of the tube X-ray films for general radiography basically consist of an emulsion-gelatin containing radiation-sensitive silver halide crystals (*such as silver bromide or silver chloride*). The emulsion is usually coated on both sides of a flexible, transparent, blue-tinted base in layers about *0.012 mm* thick. An adhesive undercoat

fastens the emulsion to the film base and a very thin but tough coating covers the emulsion to protect it against minor abrasion. The typical total thickness of the X-ray film is approximately *0.23 mm*.
Though films are made to be sensitive for X-ray or gamma-ray, yet they are also sensitive to visible light.
When X-rays,vgamma-rays, or light strike the film, some of the halogen atoms are liberated from the silver halide crystal and thus leaving the silver atoms alone. This change is of such a small nature that it cannot be detected by ordinary physical methods and is called a "*latent (hidden) image*". When the film is exposed to a chemical solution (*developer*) the reaction results in the formation of black, metallic silver.



Film Selection
Selecting the proper film and developing the optimal radiographic technique for a particular component depends on a number of different factors;
Composition, shape, and size of the part being examined and, in some cases, its weight and location.
Type of radiation used, whether X-rays from an X-ray generator or gamma rays from a radioactive source.
Kilovoltage available with the X-ray equipment or the intensity of the gamma radiation.
Relative importance of high radiographic detail or quick and economical results.

Film Packaging
Radiographic film can be purchased in a number of different packaging options and they are available in a variety of sizes. The most basic form is as individual sheets in a box. In preparation for use, each sheet must be loaded into a cassette or film holder in a darkroom to protect it from exposure to light. Industrial X-ray films are also available in a form in which each sheet is enclosed in a light-tight envelope. The film can be exposed from either side without removing it from the protective packaging. A rip strip makes it easy to remove the film in the darkroom for processing. Packaged film is also available in the form of rolls where that allows the radiographer to cut the film to any length. The ends of the packaging are sealed with electrical tape in the darkroom. In applications such as the radiography of circumferential welds and the examination of long joints on an aircraft fuselage, long lengths of film offer great economic advantage.

Film Handling
X-ray film should always be handled carefully to avoid physical strains, such as pressure, creasing, buckling, friction, etc. Whenever films are loaded in semi-flexible holders and external clamping devices are used, care should be taken to be sure pressure is uniform. Marks resulting from contact with fingers

that are moist or contaminated with processing chemicals, as well as crimp marks, are avoided if large films are always grasped by the edges and allowed to hang free. Use of envelope-packed films avoids many of these problems until the envelope is opened for processing.

5.10 RADIOGRAPHY CONSIDERATIONS & TECHNIQUES

Radiographic Sensitivity

The usual objective in radiography is to produce an image showing the highest amount of detail possible. This requires careful control of a number of different variables that can affect image quality. Radiographic sensitivity is a measure of the quality of an image in terms of the smallest detail or discontinuity that may be detected. Radiographic sensitivity is dependant on the contrast and the definition of the image.

Radiographic contrast is the degree of density (*darkness*) difference between two areas on a radiograph. Contrast makes it easier to distinguish features of interest, such as defects, from the surrounding area. The image to the right shows two radiographs of the same stepwedge.

The upper radiograph has a high level of contrast and the lower radiograph has a lower level of contrast. While they are both imaging the same change in thickness, the high contrast image uses a larger change in radiographic density to show this change. In each of the two radiographs, there is a small dot, which is of equal density in both radiographs. It is much easier to see in the high contrast radiograph.

5.11RADIATION SAFETY

Radiation Health Risks

As mentioned previously, the health risks associated with the radiation is considered to be one the major disadvantages of radiogaphy. The amount of risk depends on the amount of radiation dose received, the time over which the dose is received, and the body parts exposed. The fact that X-ray and gamma-ray radiation are not detectable by the human senses complicates matters further. However, the risks can be minimized and controlled when the radiation is handled and managed properly in accordance to the radiation safety rules.

The active laws all over the world require that individuals working in the field of radiography receive training on the safe handling and use of radioactive materials and radiation producing devices.
Today, it can be said that radiation ranks among the most thoroughly investigated (and somehow understood) causes of disease. The primary risk from occupational radiation exposure is an increased risk of cancer. Although scientists assume low-level radiation exposure increases one's risk of cancer, medical studies have not demonstrated adverse health effects in individuals exposed to small chronic radiation doses.

The occurrence of particular health effects from exposure to ionizing radiation is a complicated function of numerous factors including:

Type of radiation involved. All kinds of ionizing radiation can produce health effects. The main difference in the ability of alpha and beta particles and gamma and X-rays to cause health effects is the amount of energy they have. Their energy determines how far they can penetrate into tissue and how much energy they are able to transmit directly or indirectly to tissues.

Size of dose received. The higher the dose of radiation received, the higher the likelihood of health effects.

Rate at which the dose is received. Tissue can receive larger dosages over a period of time. If the dosage occurs over a number of days or weeks, the results are often not as serious if a similar dose was received in a matter of minutes.

Part of the body exposed. Extremities such as the hands or feet are able to receive a greater amount of radiation with less resulting damage than blood forming organs housed in the upper body.

The age of the individual. As a person ages, cell division slows and the body is less sensitive to the effects of ionizing radiation. Once cell division has slowed, the effects of radiation are somewhat less damaging than when cells were rapidly dividing.

Biological differences. Some individuals are more sensitive to radiation than others. Studies have not been able to conclusively determine the cause of such differences.

Unit-V Acoustic Testing

Acoustic Emission

Acoustic emission (AE) is one of the most promising methods for structural health monitoring (SHM) of materials and structures. Because of its passive and non-invasive nature, it can be used during the operation of a structure and supply information that cannot be collected in real time through other techniques. It is based on the recording and study of the elastic waves that are excited by irreversible processes, such as crack nucleation and propagation. These signals are sensed by transducers and are transformed into electric waveforms that offer information on the location and the type of the source. This chapter intends to present the basic principles, the equipment, and the recent trends and applications in aeronautics, highlighting the role of AE in modern non-destructive testing and SHM. The literature in the field is vast; therefore, although the included references provide an idea of the basics and the contemporary interest and level of research and practice , they are just a fraction of the total possible list of worthy studies published in the recent years.

Introduction

The safety of structures is of paramount importance. Operational loads, environmental influences and random phenomena such as impacts accumulate damage and compromise the durability of structures. To avoid human casualties as well as loss of capital, structural health monitoring (SHM) procedures are implemented in all fields of engineering, including aeronautics. These procedures involve detection, geometric localization and characterization of damage that allows proper engineering decisions concerning maintenance or replacement of the component. Because of the deterioration of materials and structures, the necessity for suitable inspection and maintenance is crucial. In addition, AE is a valuable tool in any platform for investigation and development of materials in laboratory conditions. It can be applied in intervals or continuously to supply the information in real time as well as a reliable evaluation of the damage condition in materials and structures .

AE is a monitoring technology that offers certain advantages in the evaluation of materials as well as structures. Some of the basic features include the high sensitivity, which leads to the detection of the actual onset of micro-cracking and the possibility of characterization of the failure mode based on the recorded waveform.

In addition, it offers the localization of the sources in one, two or three dimensions.

The sensitivity of AE is demonstrated if we consider that the absolute energy of AE signals is measured with the unit of atto-Joule (or 10_18J!). Therefore, the method allows the detection of the actual initiation of micro-cracking or any other event that would be impossible to detect through other techniques.

It is characteristic that a common mosquito of mass 2.5 mg, flying at a speed of 10 cm/s obtains a kinetic energy of approximately 1.25 _ 10_8 J, which is already 10 orders of magnitude higher than the limit of the technique.

Advantage

Another advantage is the potential to characterise the fracture mode or generally the source or excitation type. This may seem to some as a ‘detail’, since for many people, the fact that damage exists is important, disregarding the actual mode.
However, for composites the mode of the crack in a matrix or the type of failure, such as delamination or fiber pull-out is indicative of the current deterioration stage, and thus, it allows projections on the useful life of the component. This mode characterization is due to the fact that distinct processes involve different motions of the crack tips and emit elastic waveforms with different characteristics.
A common example is the fracture of fibrous composite materials.
At low load or fatigue cycles, the matrix is expected to crack first. Then, as loading progresses, the density of debonding and pull-out events will increase, whereas eventually, fiber rupture is also possible. The analysis of the waveforms recorded at each loading stage enables the classification of the signals to the different original sources and the evaluation of the current operation stage.

Source localization is an additional strong feature of AE. By applying multiple sensors, the coordinates of the active sources can be defined with good engineering accuracy in one, two or three dimensions, which means that even if a crack is inside the volume of the material and not visible, its location can be evaluated.
The localization in most cases is based on the delay of recording of successive signals of the same source event at the different sensors. Considering the material’s wave speed, which can be measured using the same sensors, the location of the source can be determined. Certainly, the different wave modes excited in plate components
typical in aeronautics structures, complicate the assessment, but there are strategies to overcome the difficulties, which will be explained in the corresponding section.

Because of the extensive use of AE technology in fracture monitoring studies, some people hesitate to call it a non-destructive testing technique. However, it should be clear that the AE sensors themselves do not inflict any damage (they do not even excite elastic waves as happens in ultrasonics). AE is a ‘passive’ technique.

It is similar to filming an impact or a blast by a high-resolution camera. The camera monitors a destructive process, but it is just the monitoring tool, not the cause of damage. Because of the aforementioned advantages, AE is used for fracture monitoring, which is a very demanding and dynamic process, but it is also used for problems of different nature, e.g. the detection of gas leakage from a pipe network or corrosion development in industrial settings.

Basic Experimental Details and Parameters

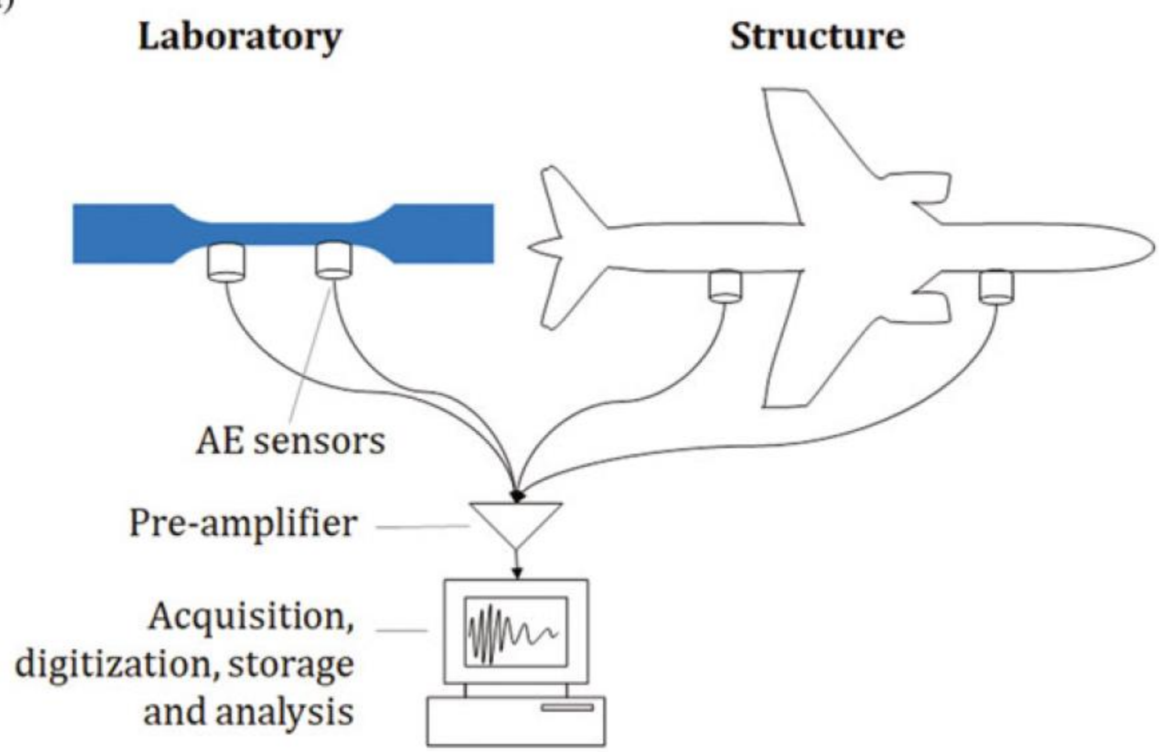
The AE technique detects and monitors the transient elastic waves that are emitted after an irreversible phenomenon or process in the material. In most cases, piezoelectric transducers are placed on the surface of the material under test. A layer of 'couplant' or viscous liquid is applied between the sensor and the material surface to
ensure adequate wave transmission.

The couplant may well be petroleum jelly, or roller bearing grease. The sensors transform the pressure on their surface into electric signals.

These signals are pre-amplified and are led to the digitization and acquisition board to obtain the signal as a function of time.

Apart from recording the full signals, which is always an option in most contemporary systems, the basic parameters of each signal (waveform) are measured and stored as well. Figure a shows a typical AE system with the main elements, and Fig. b presents some indicative photographs of measurements.

(a)



Therefore, considering the expected sequence of occurrence of the different fracture mechanisms, being able to identify the dominant one in real time offers information on the current structural condition and allows projections to the useful life span.

As understood, fracture in composites is a fairly complicated and stochastic process because of several mechanisms as well as their possible overlap in time.

This complexity is inevitably transferred to the AE signal making the interpretation less than straightforward. Still, some basic indicative principles can be mentioned as the starting point of the effort to understand the connection between AE signals and the original event.

As Fig. shows, a crack propagation event extending vertical to the axis of the plate results in waveform with different characteristics from a similar crack in the parallel direction. In the case of plates, the reason can be sought in the different amount of energy forming the ‘symmetric’ and ‘antisymmetric’ wave modes ,depending on each case.

When a vertical crack is extended (Fig. a top), this motion excites mostly symmetric components that have higher propagation velocities than antisymmetric, as already discussed in Chap. 5.2. A waveform containing stronger symmetric component is expected to have higher energy in the opening part rather than the later part; see example of Fig. . By contrast, when a horizontal crack (delamination in the case of laminated plates) is extended (Fig. 7.6a bottom), the transient motion gives rise to the antisymmetric wave mode. Thus, it is reasonable that for the extreme cases of event orientation, differences are noticed in the waveform shape, practically

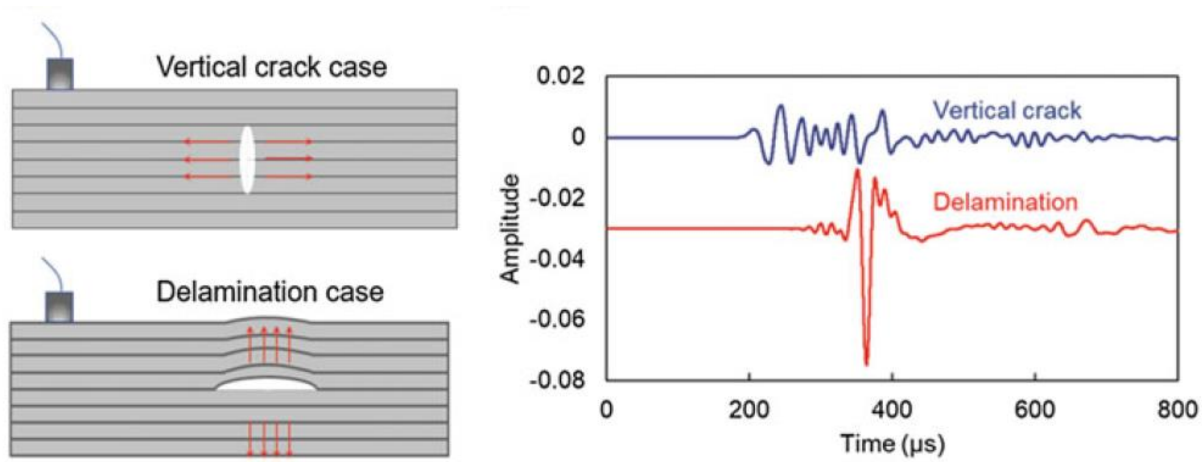


Fig. 7.6 (**a**) Representation of vertical crack (top) and delamination (bottom) in a laminated composite plate and (**b**) typical AE waveforms from the two events

resulting in shorter rise time for vertical cracks and longer durations for delaminations. Possible single fiber or fiber bundle rupture is expected to obtain even shorter duration characteristics and higher frequency content, as the fracture incident is usually shorter in time due to the limited fiber cross section to be fractured in one

step and the higher speed of crack propagation within the high modulus fiber.

The final waveform shape will be influenced by a number of aforementioned factors apart from the orientation, such as the position of the crack in the thickness (non-central sources will yield combination of modes instead of a single one), their displacement increment and speed and the propagation distance to the sensor and sensor characteristics as mentioned below.

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Department of Mechanical Engineering

Lecture Notes

Subject Code : CME384

Subject Name: POWER PLANT ENGINEERING

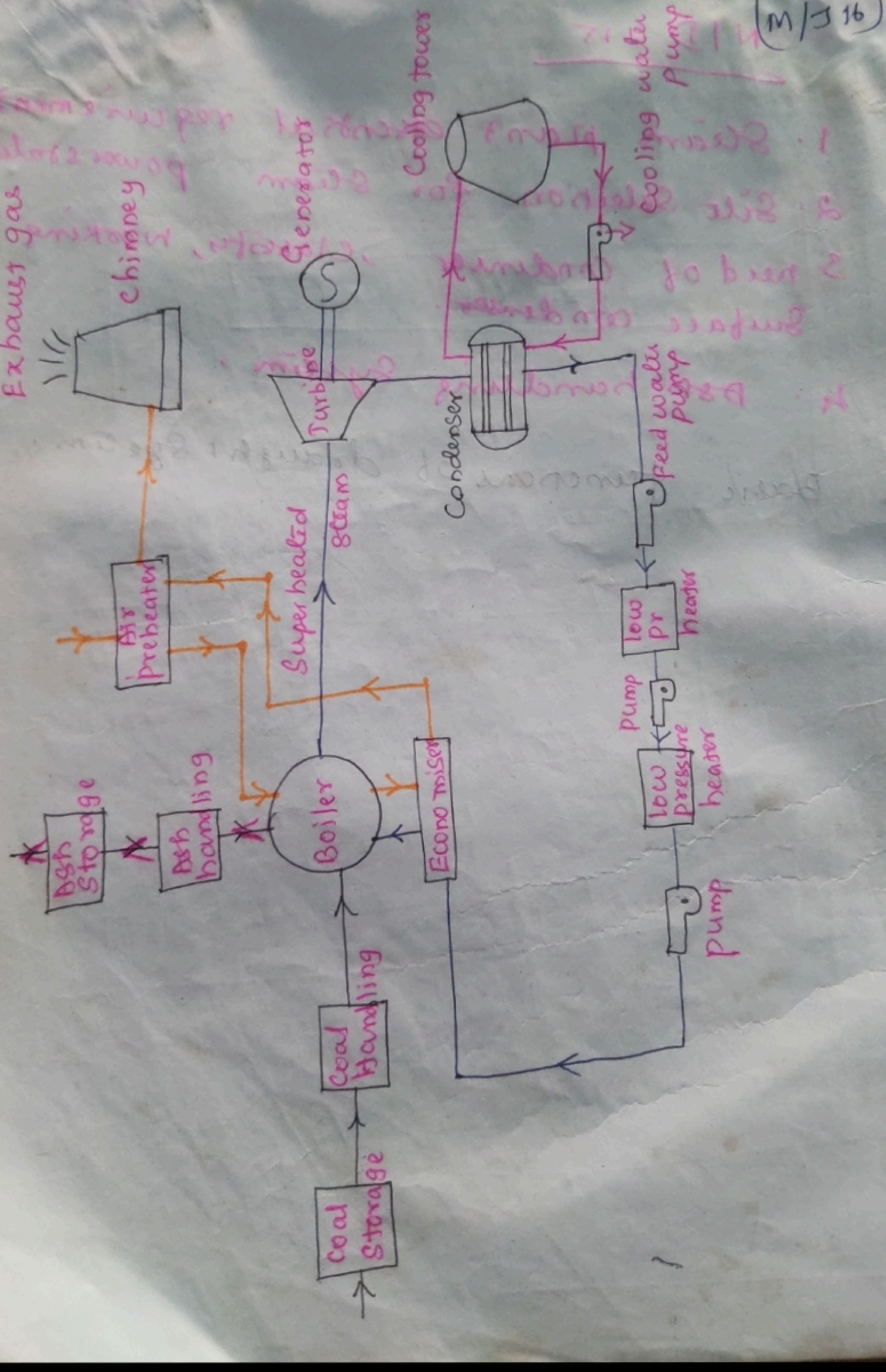
Sem/Year : 05/III

Regulation : 2021

1.2 Layout of modern coal power plant :-

(May / June 2014)
(16 M)

(M/J 16)



either through F.D or I.D fan.
(or) by using both. dust removed,
The exhaust gases carrying
sufficient quantity of heat and
ash are passed through the air
heater. where exhaust heat of the
gases is given to the air and
then it is passed through the dust
collectors where most of the dust is
removed before exhausting the gases
to the atm through chimney.

Feed water and steam circuit:-

Steam generated in the boiler
is fed to the steam prime mover to
develop power. The steam coming out
of the condenser is condensed in the
condenser and then fed to the boiler
with the help of pump. The condensate
is heated in the feed heaters using the
steam tapped from diff points of the
turbine. The feed heaters may be of
mixed type or indirect heating type.

Feed water is added to
compensate the losses from different
components. It has to purify to avoid

Scaling of The boiler tubes.

Cooling water circuit:-

The quantity of cooling water required to condense the steam is considerably and it is taken either from lake, river or sea. The cooling water is taken from the upper side of the river it is passed through the condenser and heated water is discharged to the lower side of the river. This is called open system. When adequate water is not available the water coming out from the condenser is cooled either in cooling pond or cooling tower, This called closed cooling system.

- 400MW require 5000 to 6000 tons of coal per day.
- 20 to 40% ash. 1500 to 2000 tons per day, 400MW require nearly 10 hectare area per year dumped to height of 6.5m.

1.3 Super Critical Boilers:-

Steam generating plants working ranges between 125 atm & 510°C to 300 atm and 660°C.

Super critical Boiler requires only economizer and super heater. for capacity above 300 MW capacity.

Advantages:- 1. High Thermal η.

2. Heat transfer rate is high
3. erosion & corrosion minimized.
4. stable pressure level maintained.
5. for peak load.

1.4 Fluidized Bed Boilers (FBC):-

Types → Bubbling (May/June 2014) (16 M)
→ Circulating (May/June 16)

Bubbling:-

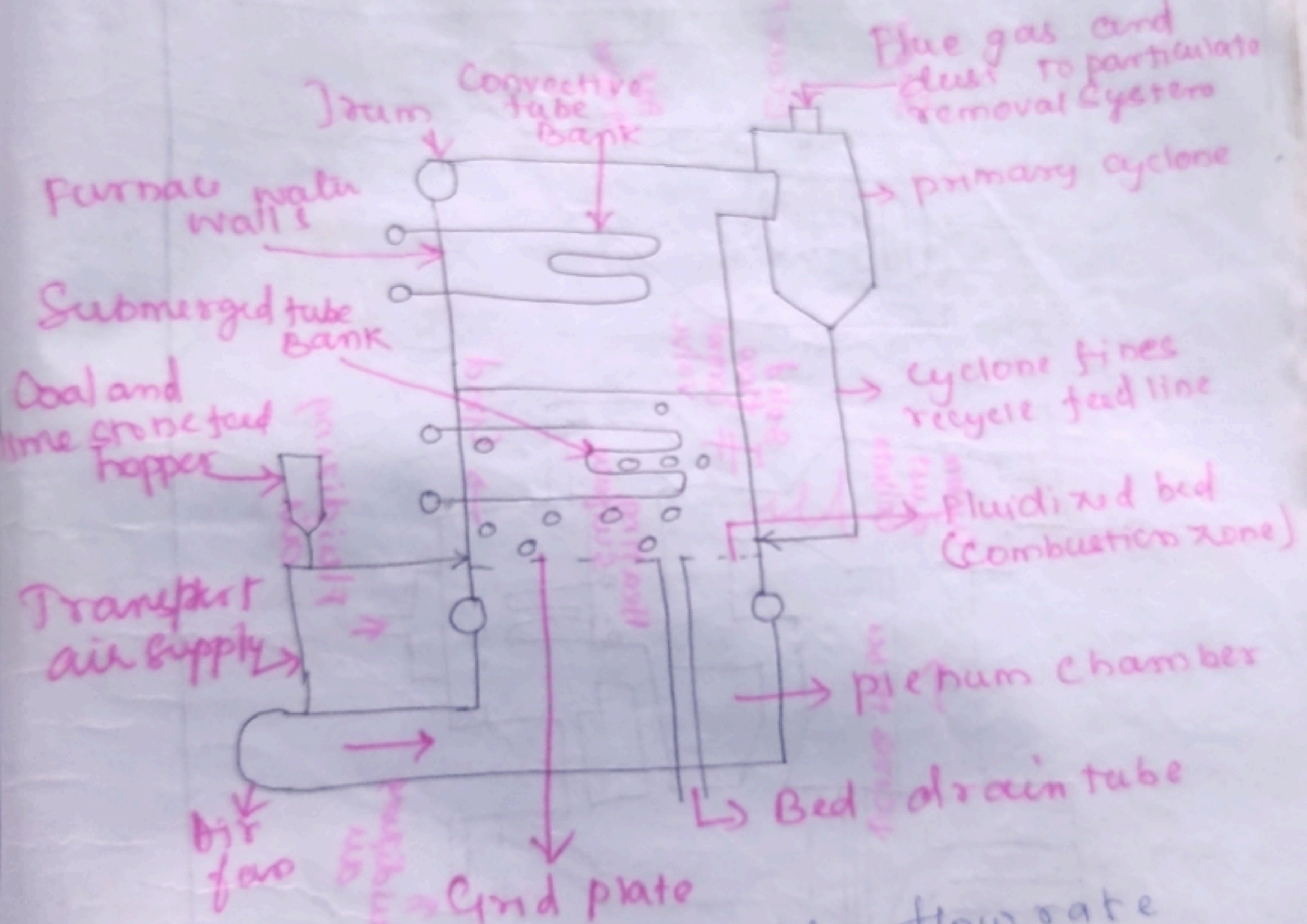
Crushed coal (6-20mm) injected into the fluidized bed of limestone just above air distribution grid which located at the bottom of the bed.

→ Combustion product collected in Cyclone Separator to remove Carbon particle.

→ gases can be cooled to lower temperature before leaving the stack

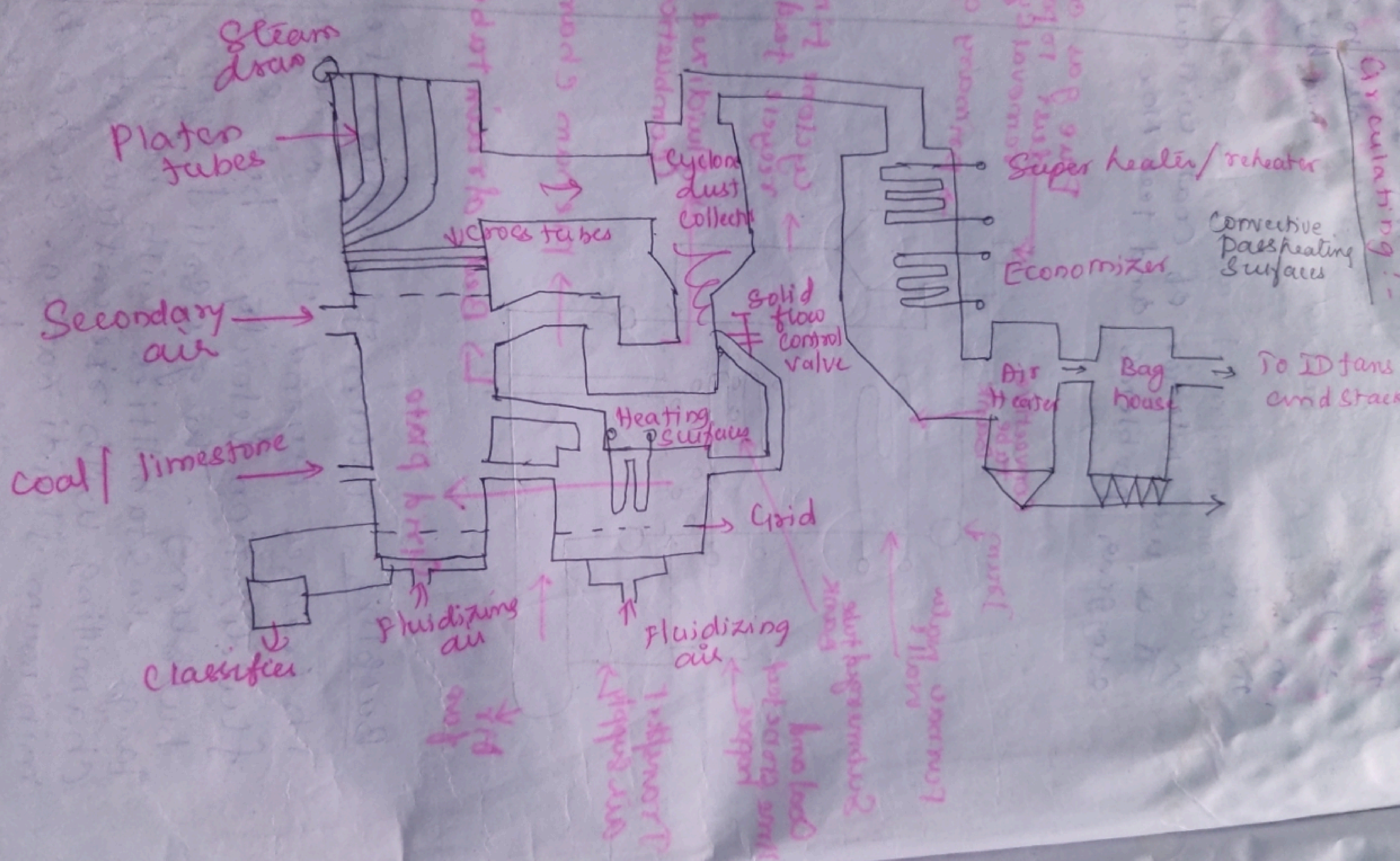
→ H_2SO_4 acid formation less due to sulphur in coal is retained in the bed by limestone.

→ Due to low combustion temp (800-900°c) lower. It is use inferior of coal without slagging problems and less NO_x.



Bubbling when the flow rate increases beyond the minimum fluidization velocity, bed starts bubbling. The gas solid system shows large instabilities with bubbling and gas channelling with rise inflow rate beyond minimum fluidization. Such a bed is called aggregative, heterogeneous or bubbling fluidized

Circulating:-



a) Furnace or fast fluidized bed
b) gas - solid separator (cyclone)
c) solid recycle device (L-valve)
d) external heat exchanger (optional)

Bed temperature 800-900°C.

Sorbent (limestone)

- Second section Remaining heat from the flue gas absorbed by Reheater, Superheater, Economiser, Air preheater.

→ Unburned char and particles of limestone recycle back to furnace.

→ Finer solid residues (ash and solid sorbents) by ESP.

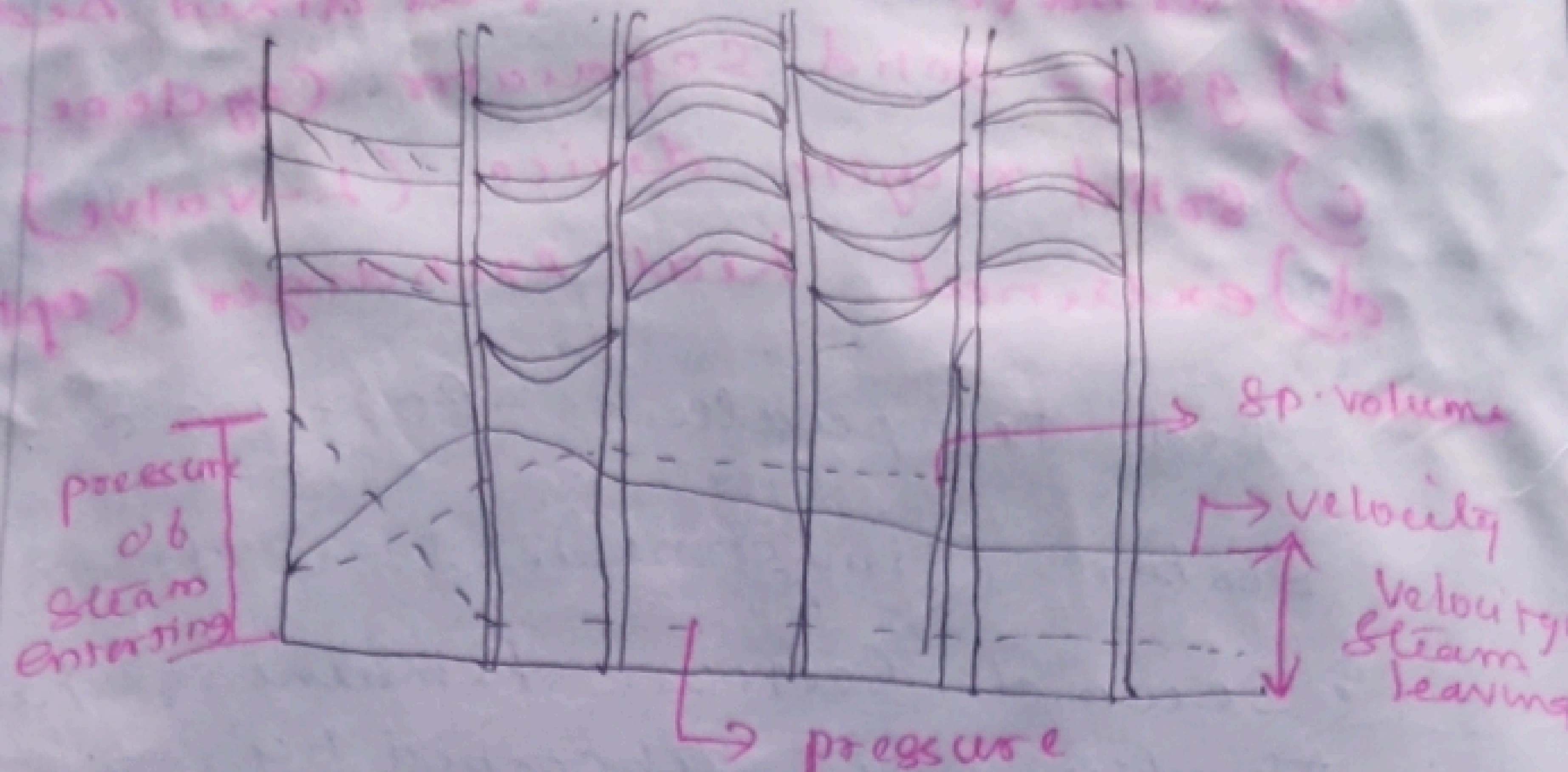
1.5 Turbines:-

1. Impulse → High velocity from nozzle Through the fixed nozzles impinges on The blades fixed on the periphery of a rotor. The resulting motive force gives the rotation to the turbine shaft.

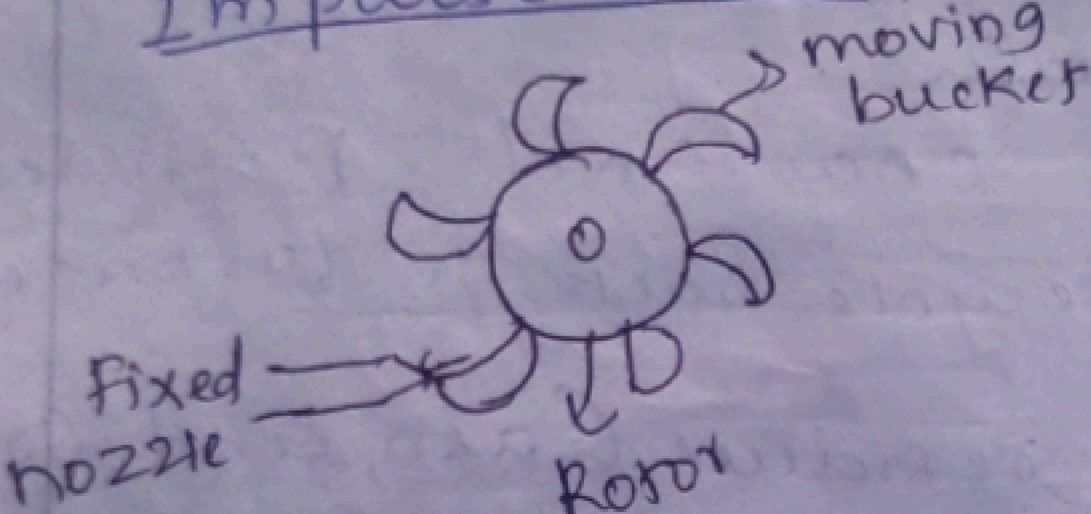
ex. Delavel, Curties & Reteau.

2. Reaction - steam expands both in fixed and moving blades continuosly as the steam passes over them.

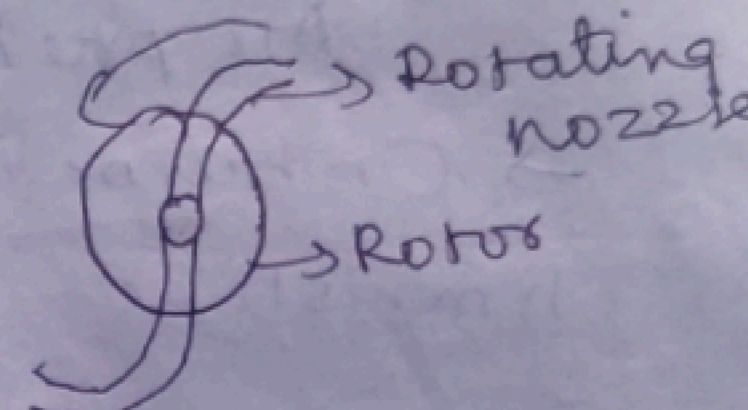
ex parson's turbine.

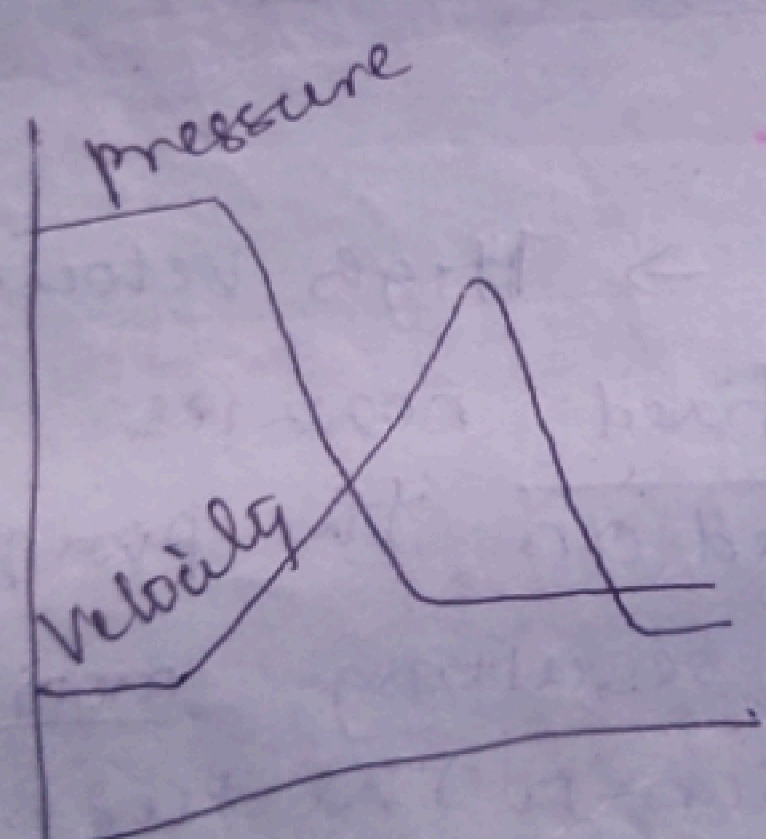


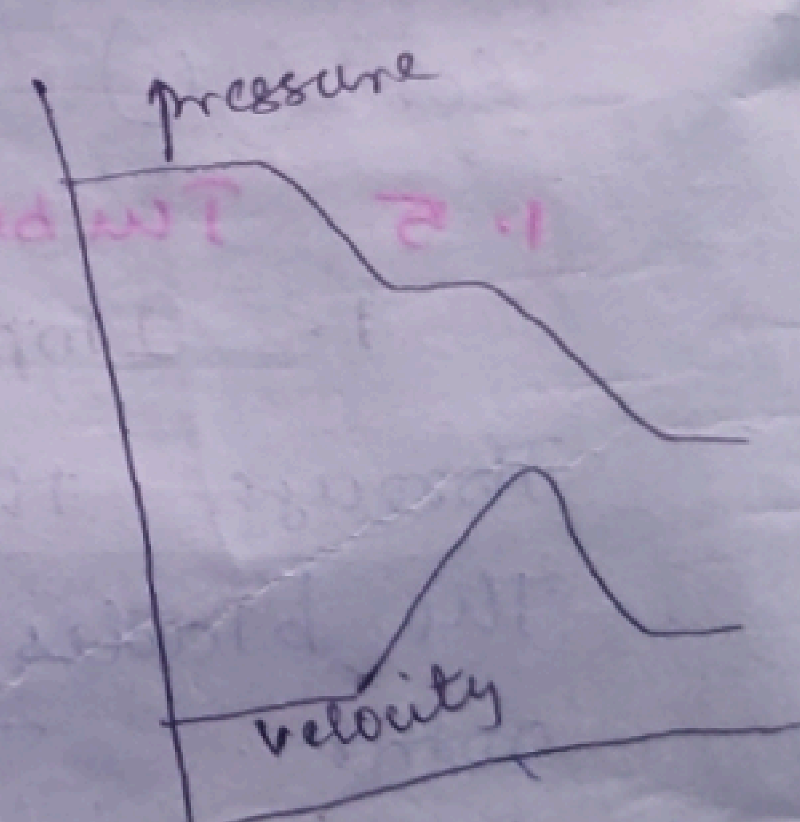
Impulse Turbine :-



Reaction turbine.







pr comp: A no. of simple Impulse turbine sets arranged in series

Governors: Maintain the spec const irrespective of load on the terbin

Direct Contact type Condensers:-

where the condensate and Cooling water directly mix and come out as a single stream.

Surface condensers:-

which are shell and tube heat exchangers where the two fluids donot come in direct contact and the heat released by the Condensation of steam is transferred through the walls of the tubes into the cooling water continuously circulating inside them.

Direct contact:- Spray condenser, Barometric, Jet.

Surface condenser:-

Downflow type, Central flow, Evaporation or

Downflow type:-

It consists of an air-tight cylinderical shell closed at each end. The exhaust steam from the prime mover enters at the top of the condenser and surrounds the condenser tubes through which cooling water is circulated under force.

The steam gets condensed as it comes in contact with cold surface of the tubes. The cooling water flows in one direction through the first set of tubes located in the lower half of condenser and returns in the opposite direction through the second set of tubes.

Central flow Condenser:-

Air cooling section is provided at the centre of the tube nest and air is extracted from this section. condensate collected from bottom.

Evaporation Condenser:-

Steam to be condensed is passed through a series of tubes and cooling water falls over these tube in the form of spray.

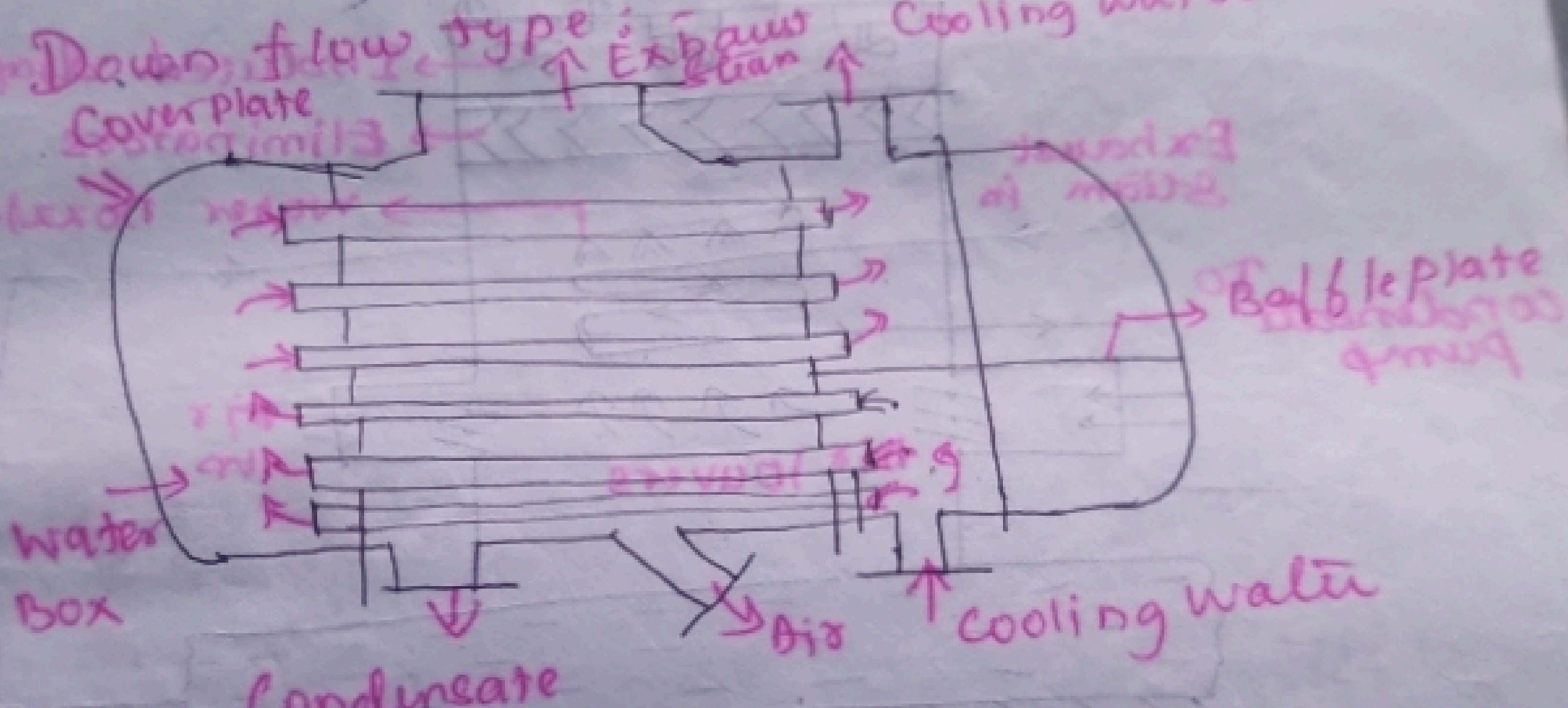
1.6 Condenser

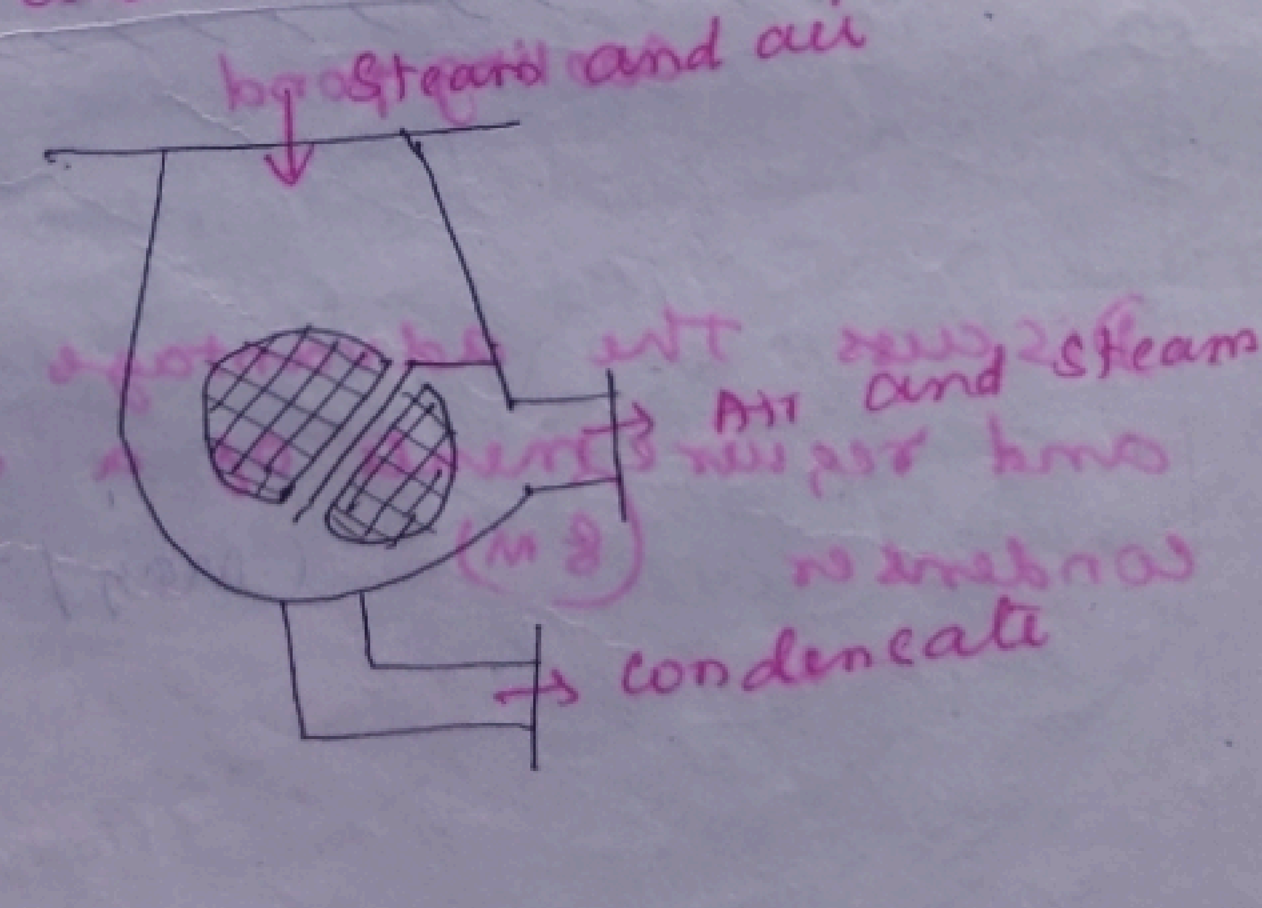
Types → Mixing Type (or) Jet condenser
→ Non Mixing Type (or) Surface condenser

Surface condenser :- Cooling water inside the tube. (M) J 16, (16M)
Steam surrounds

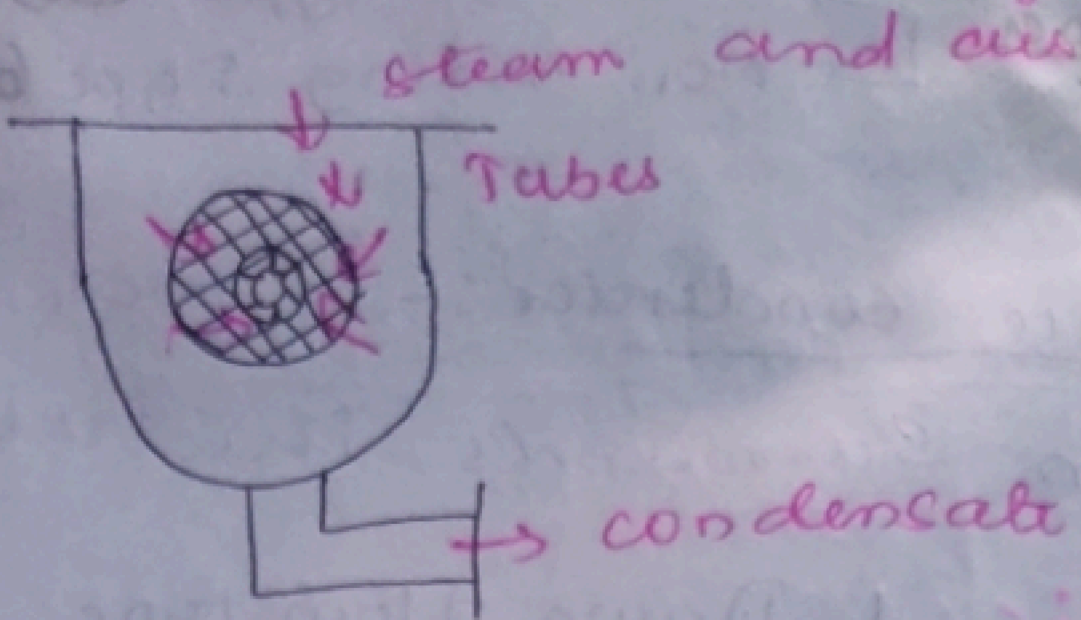
Types :- 1 Down flow type
2. Central flow condenser
3. Evaporation condenser

Down flow type :-

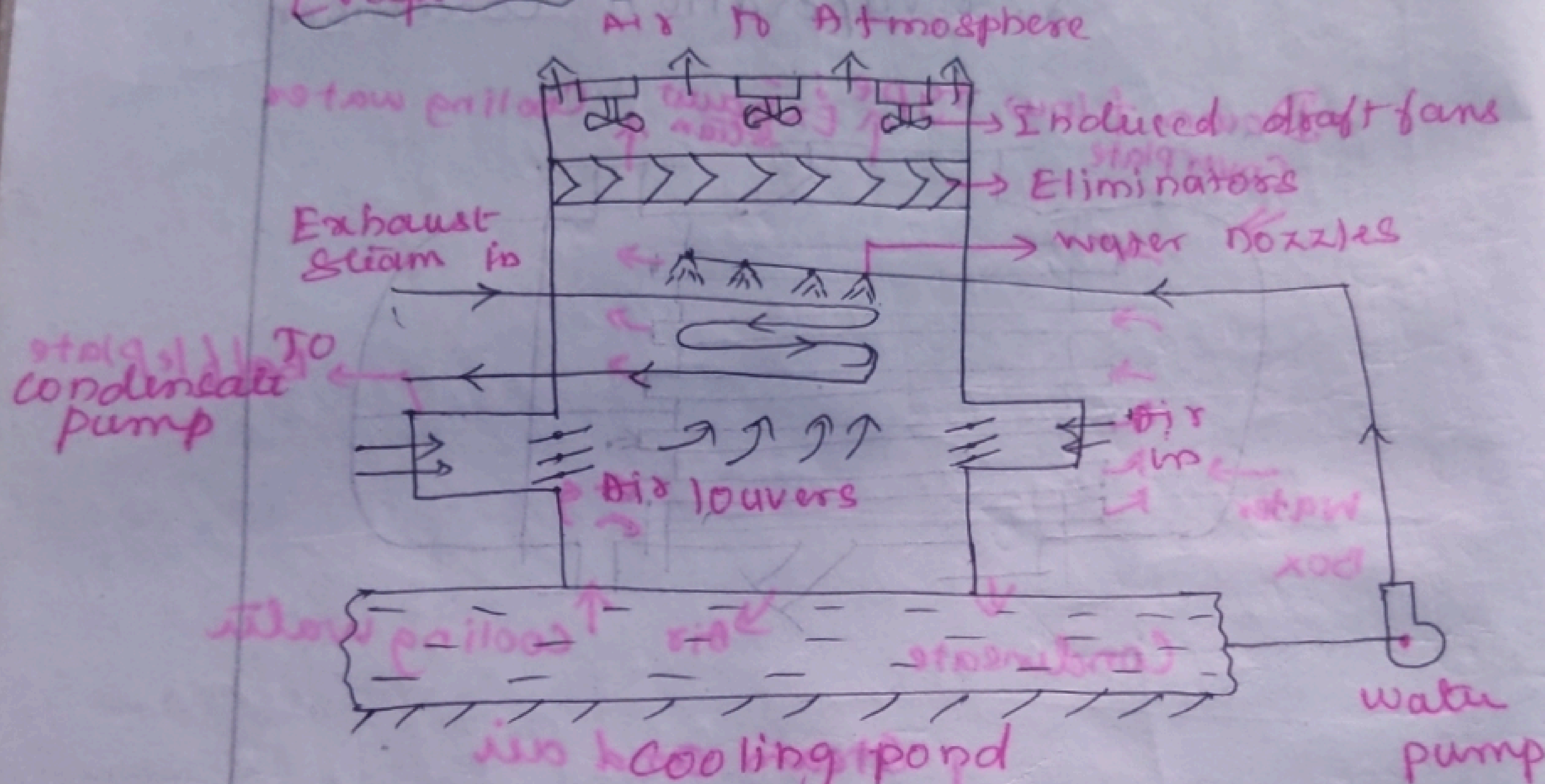




Central flow Condenser:-



Evaporative Condenser:-



Discuss the advantages, disadvantages and requirements of a surface condenser (8M) (May / June 13)

Requirements:-

→ Steam should be evenly distributed whole cooling surface.

→ Should not be Under cooling of condensate

→ deposition of dirt on outer Surface prevented. This is achieved by cooling water in tube, steam in shell.

→ no air leakage. If it is pump should be used.

Advantages:-

1. High Vacuum (about 73.5 cm of Hg) it ↑ the η thermal

2. Condensate can be feed water for Boiler.

3. poor cooling water can be used. (tube)

Disadvantages:-

→ Bulk, Require space

→ capital cost high

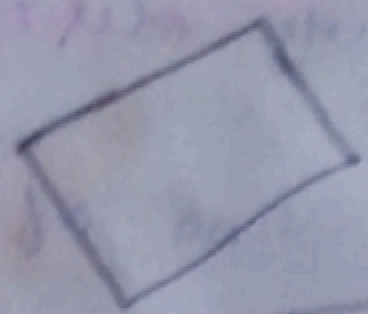
→ maintenance, running cost high.

1.7 Fuel and Ash handling:-

Coal preparation:-

Sizing, removal of rock originating from mine roof,

→ Crusher, Sizer, Dryers, magnetic Separator.



Crusher
Sizers
Dryer
Magnetic
Separators.

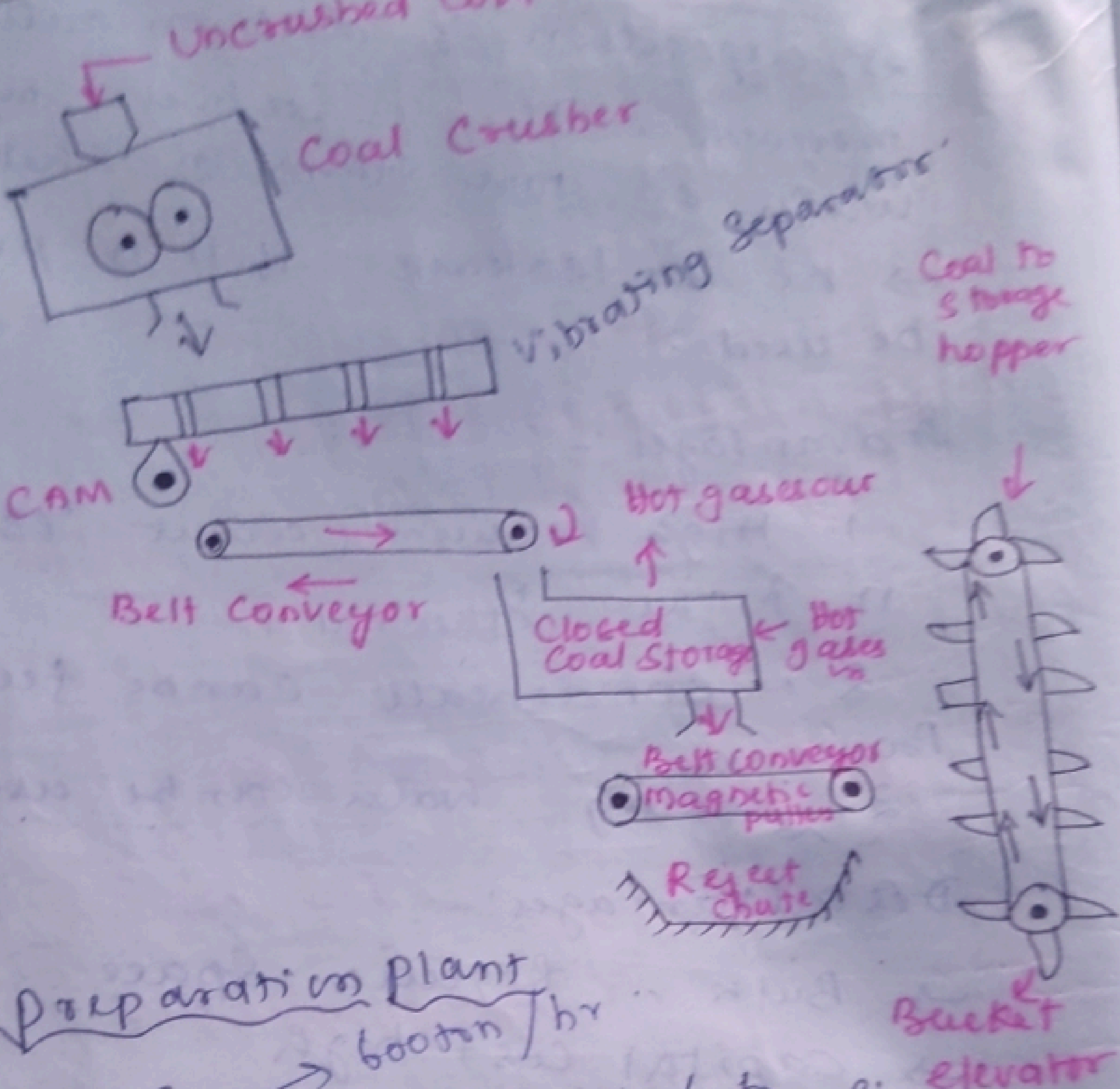


Fig: Coal preparation plant
600ton/hr

-> Coal Crusher are used to size before feeding to combustion chamber.

-> Sizers - Separation of coal to the required size.

-> Dries - remove moisture by using hot flue gas.

-> Before coal goes to storage hopper the iron scrap are removed.

. Iron - may choke the burners and may increase the wear of the handling equipment.

→ India was The Third top coal producer in 2010.

→ Coal – 185,172 MW, Oil – 24,508 MW, Gas – 10 1075 MW
→ Renewable – 84000 MW. 5,331 MW 993 MW 411 MW

→ N – 986.50 H – 2182.20 Or 8423.15

→ Conventional – non conventional
Wind, Solar, Biomass, Hydel. waste to power.

→ Solar – 6 acre Land needed / MW.

→ India 5th wind power capacity in The world. Tamilnadu (1st in india) 30%.

→ One kg of Uranium → 3100 ton of coal, 17000 ton oil

→ Renewable energy is generally defined as energy that is collected from resources which are naturally replenished on a human timescale sunlight, wind, rain tides. wave, geothermal heat.

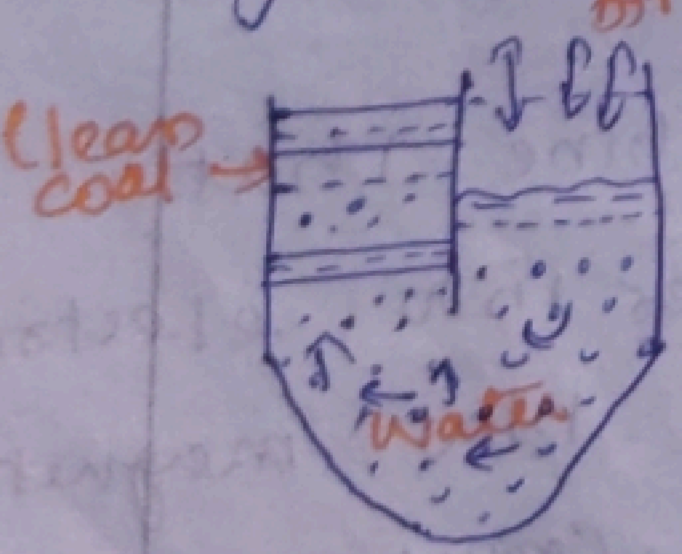
→ generator – rotating machine that converts mechanical power into electrical power. The relative motion b/w magnetic field and a conductor creates an electric current.
(Movement of matter) (metal wire)

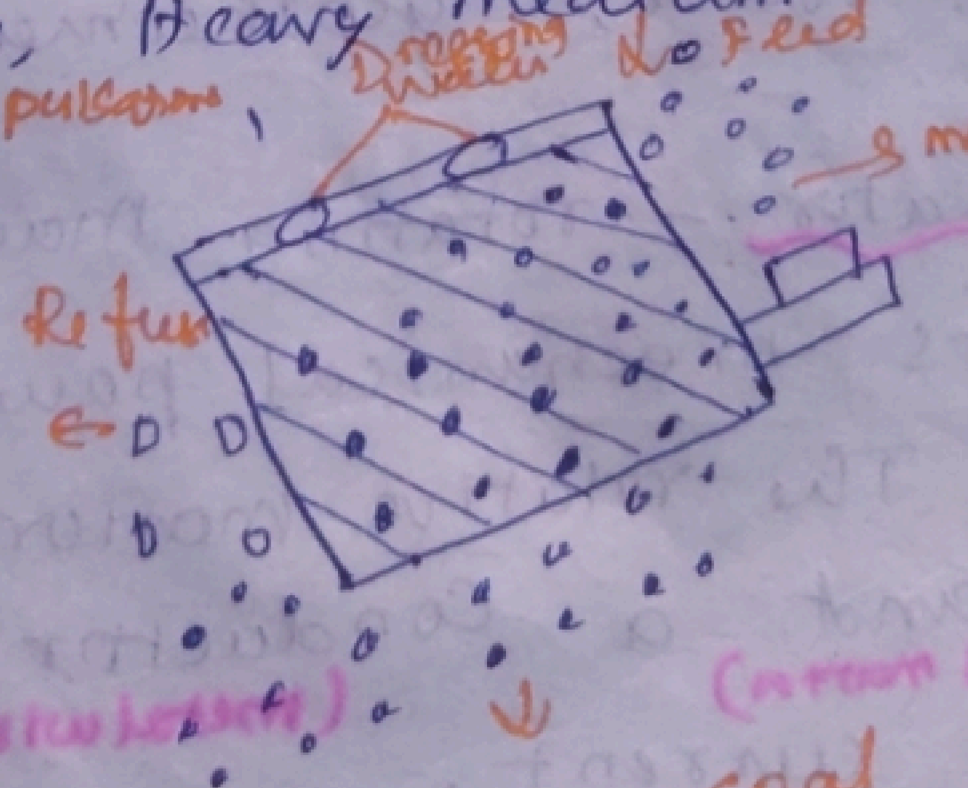
Mechanical moving energy into electrical energy

Coal cleaning equipments:-

1. coal cleaning
2. coal sizing
3. Size classification
4. coal drying equipments.
5. concentrating equipments
6. Dewatering equipments.

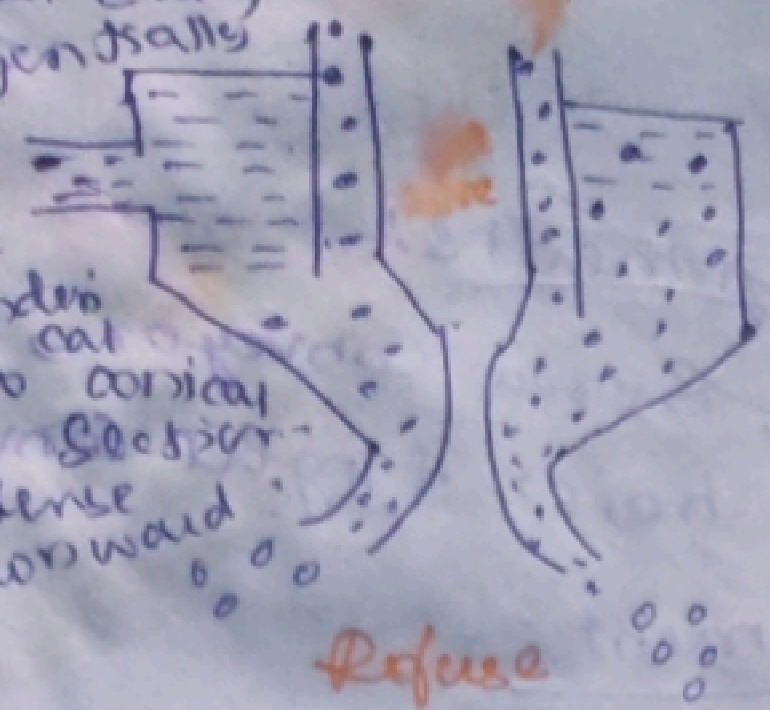
1. **Removal of dirt** - less Than 8cm size cleaned by washing. greater Than 8cm cleaned by hand.
2. **Coal drying** - (1) Steam drying (2) oil drying moisture removed 10%. (3) fuel gas drying by flue gas heating.
3. **Coal sizing** - Uniform in size is required for better Utilization of coal.
4. **Sulphur removal** - upto 2.5% accepted fouling, corrosion. i) phyritic - 50 to 80% ii) organic 40%.
5. **Washing**:- Water jigs, Concentrating tables Hydro cyclone, Heavy medium



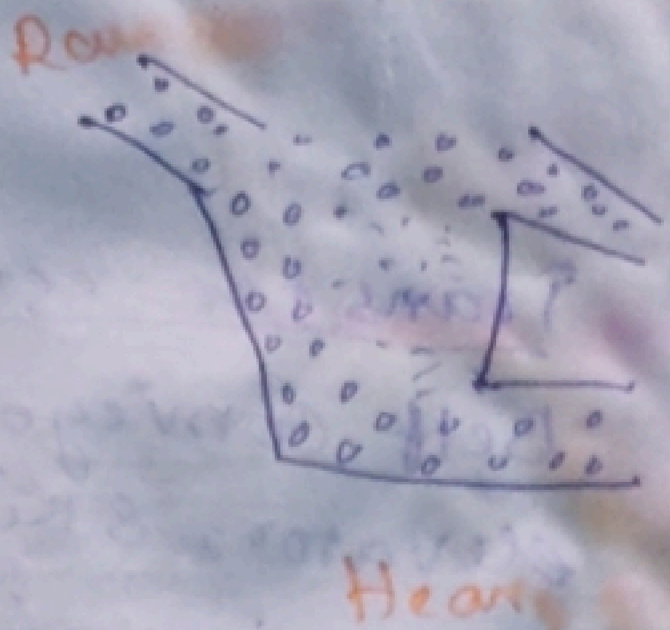


Beam type Jig

• The feed slurry flows tangentially under pressure into cylinder. Coal moves to conical section.
• High dense move downward.



Hydro cyclone



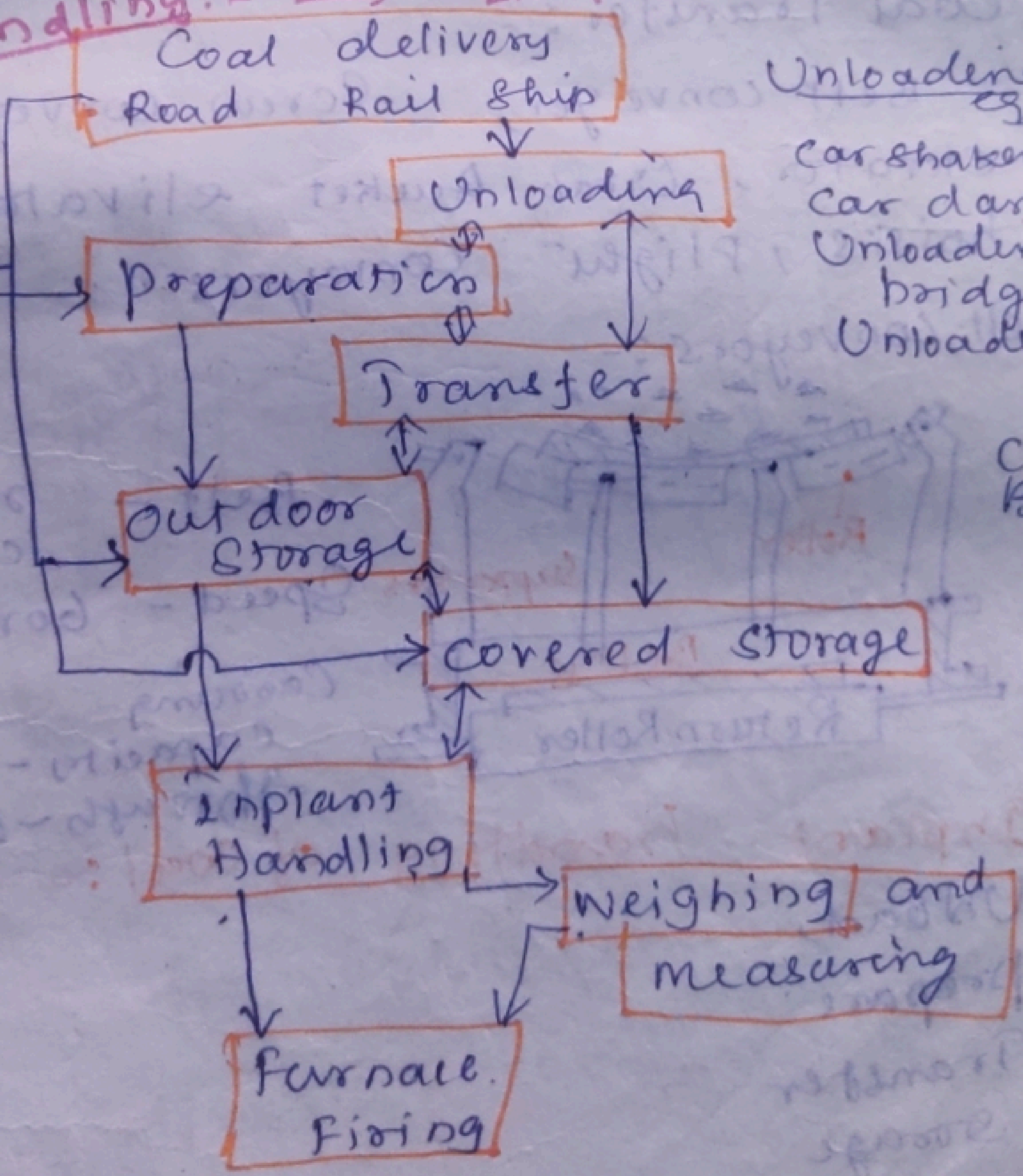
• used to clean course Coal (6mm).
• low sp. gravity particles float on the surface and discharged.

Advantages of coal preparation:-
1. Improves coal quality 2. Reduced Transportation of waste is eliminated 3. maintenance cost is less. Boiler performance is improved. 5. Sulphur removal is easier.

Ash handling easy ⟹ out plant handling / In plant handling

Coal Handling:-

Preparing equipment
Crusher
Sizes,
dryer



Unloading equipment
Car shaker, rotary car dampers.
Unloading tower bridges, Self Unloading boats, lift, truck, Crane, Bucket.

Transfer equipments:-

Belt conveyor, Screw conveyor, Bucket elevator, Skip hoist fligh conveyor

Storage equipment:-

Bulldozer, Scraper, tramways, Cranes, Conveyor System.

Covered Storage equipment:-

Bin, Bunker, indicator gate Valves

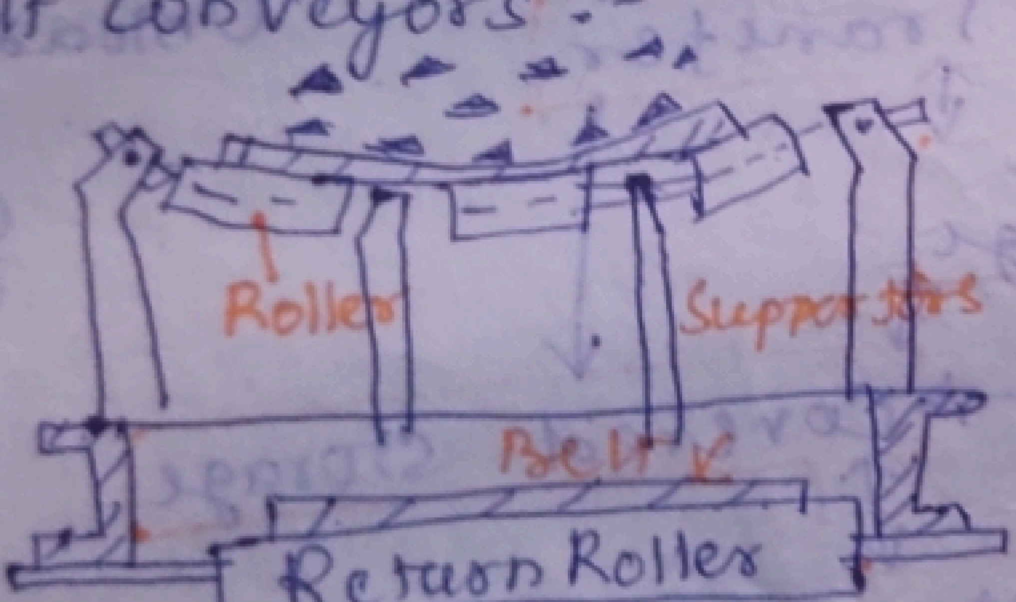
weighing devices:-

Scales, Coal metres, Samplers.

Coal Transfer:-

Belt conveyor, Screw conveyor, Bucket elevator, Grab Bucket elivator, Skip hoists, Flight Conveyors.

Belt conveyors:-



Belt - rubber canvas.

Speed - 60m to 100m/min

Carrying capacity - 50 to 100 ton/hr

through - 400 meters

handling of coal:-

Inplant

Unload,

prepare

Transfer

storage

Covered storage

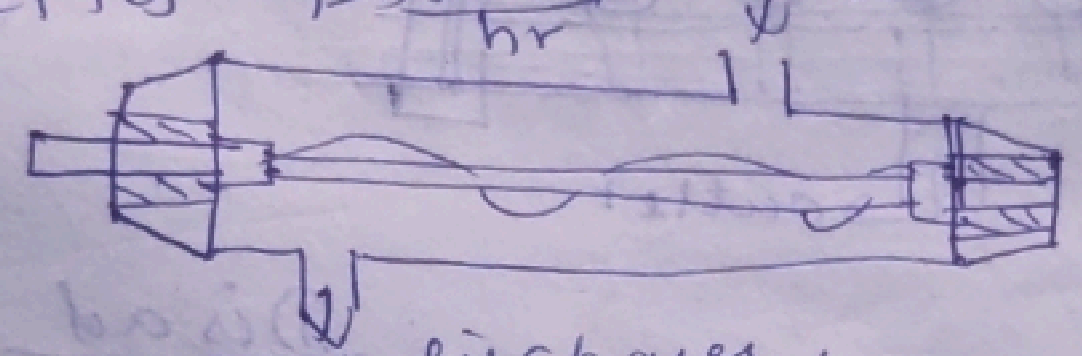
weighting devices.

advantages
1. most economical method.
2. Coal transfer easy.
4. repair and maintenance cost minimum
5. power consumption minimum.

Disadvantages:- ① not suitable for short distance, greater heights.
② It cannot be used to carry the coal greater heights and inclination 20°.

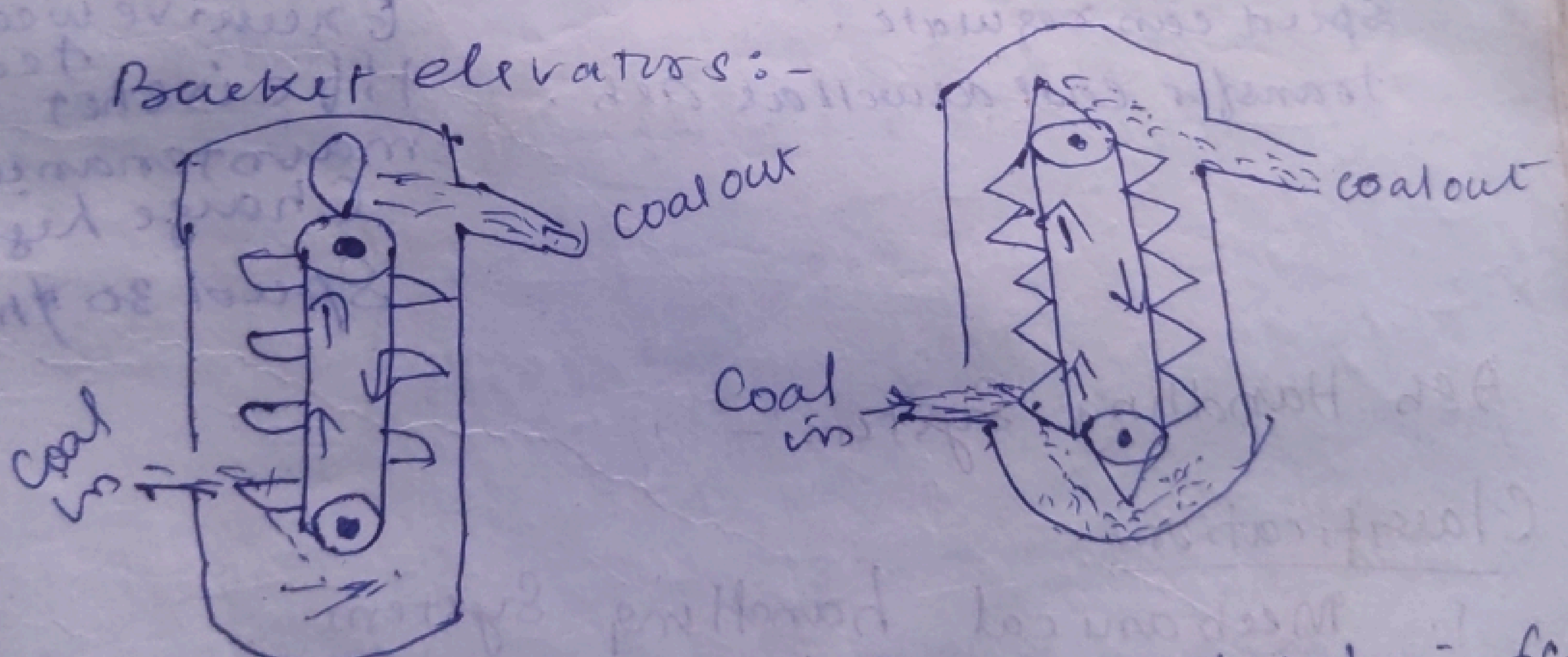
Screw conveyer:-
Capacites - 125 tons/hr

disad
①. power high



helicoid screw.
Screw dia - 15 cm to 50 cm
Speed - 70 to 120 rpm
driving mechanism.
Ball Bearing.

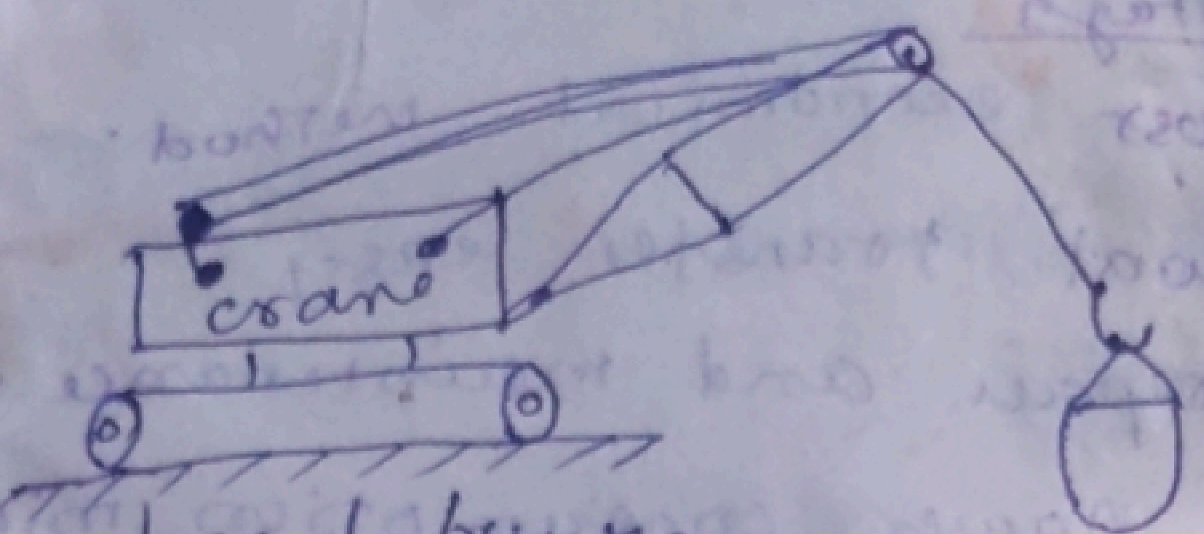
Bucket elevators:-



height - 30.5 m.
Speed - 75 m/min (cen)
35 m/min (cont)

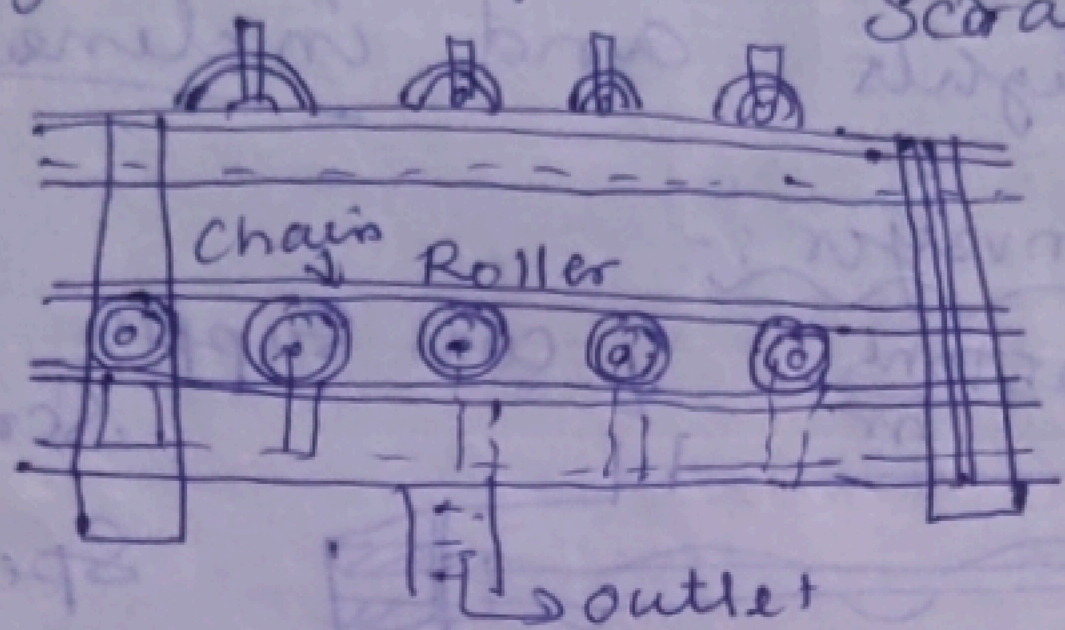
for 60 ton capacity / hour.

inclination - 60°.



: Over head bunker.
: 23 cu.m Bucket, distance 60m
transfers 100 ton of coal / hour.

Flight Conveyor:-



transfer of coal under the conveyor.

advantage
Small head room
Speed can regulate.
transfer coal as well as ash.

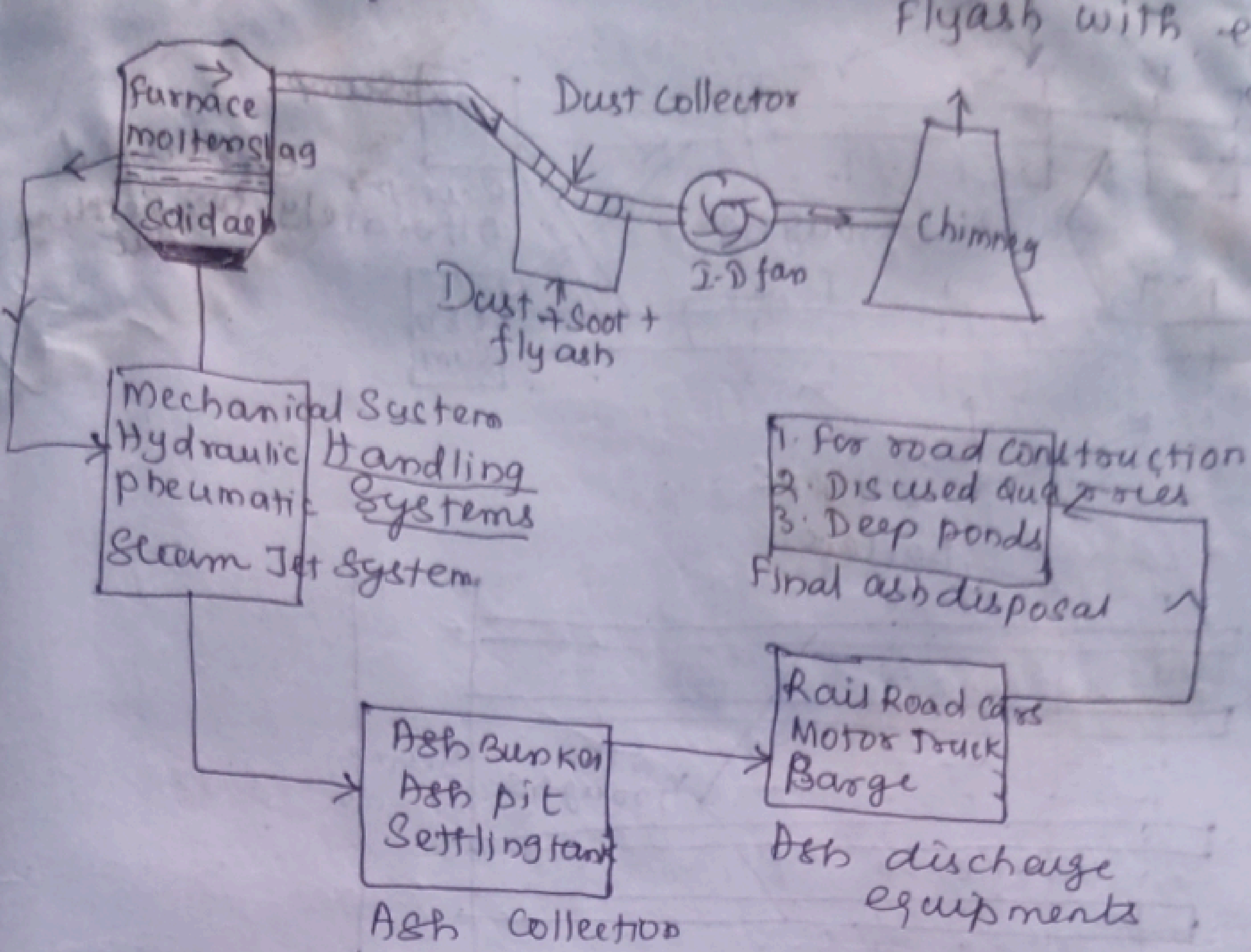
Dis ad
Excessive wear and tear.
life is short.
maintenance charge high.
Speed 30 m/min

Ash Handling System:-

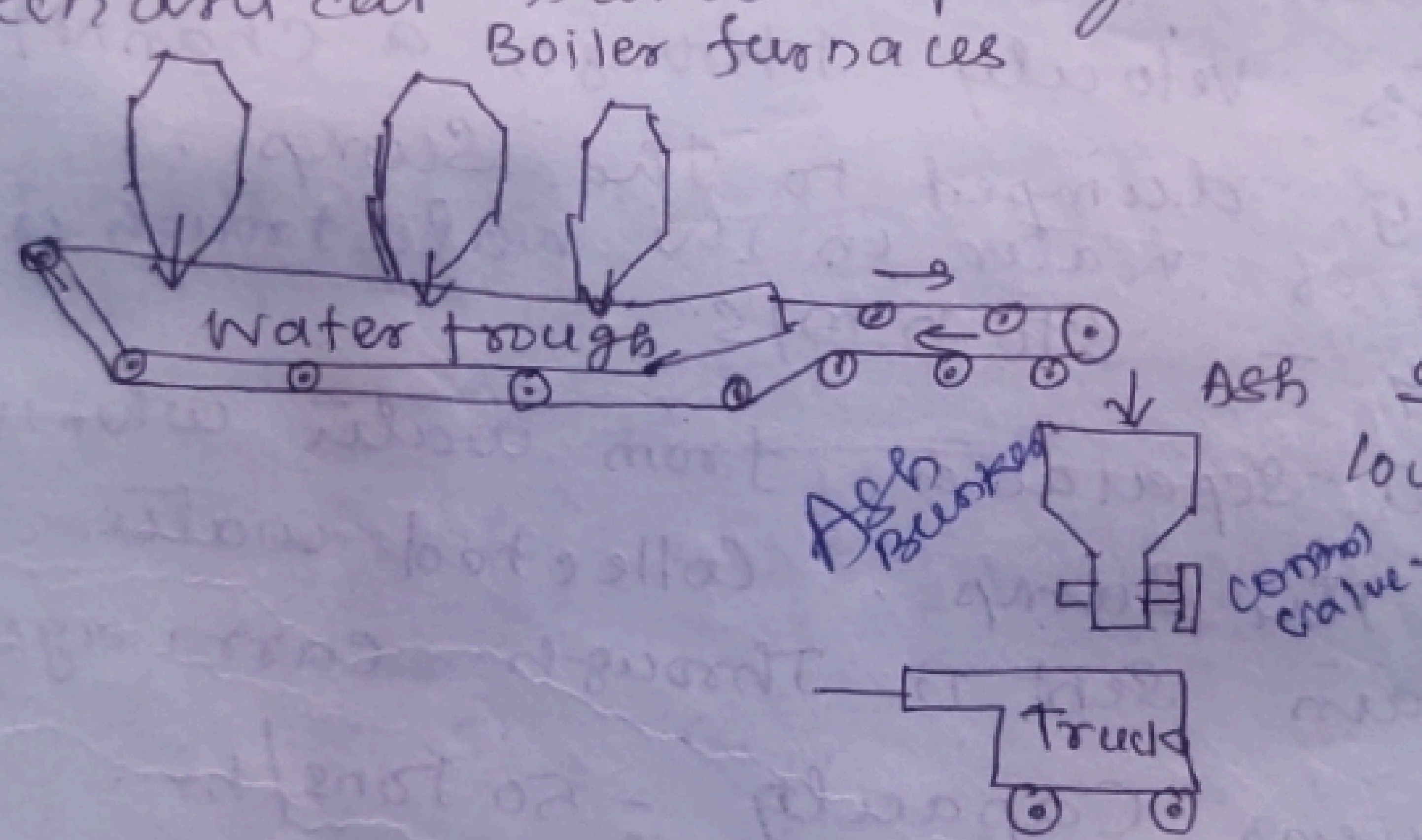
Classification:-
1. Mechanical handling system
2. Hydraulic system
3. pneumatic system
4. steam jet system.

General Layout of ash handling and dust collection system :-

(M) J-12 (4m)



Mechanical Handling System:-



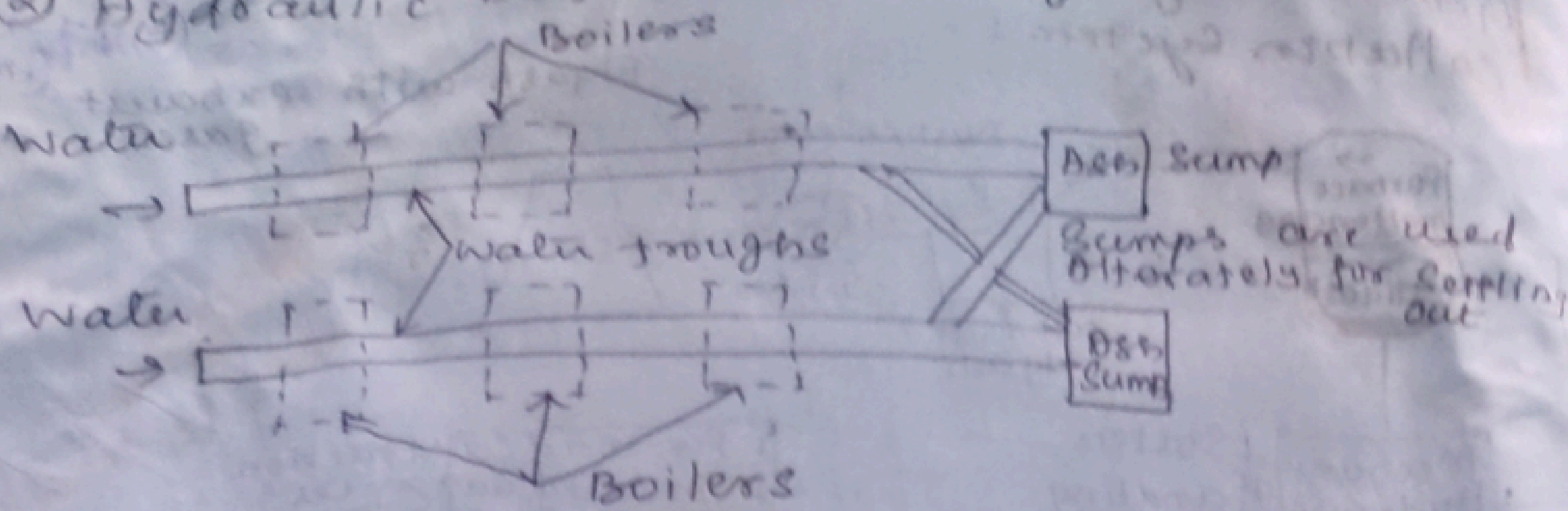
(ii) low capacity
5 tons/hr

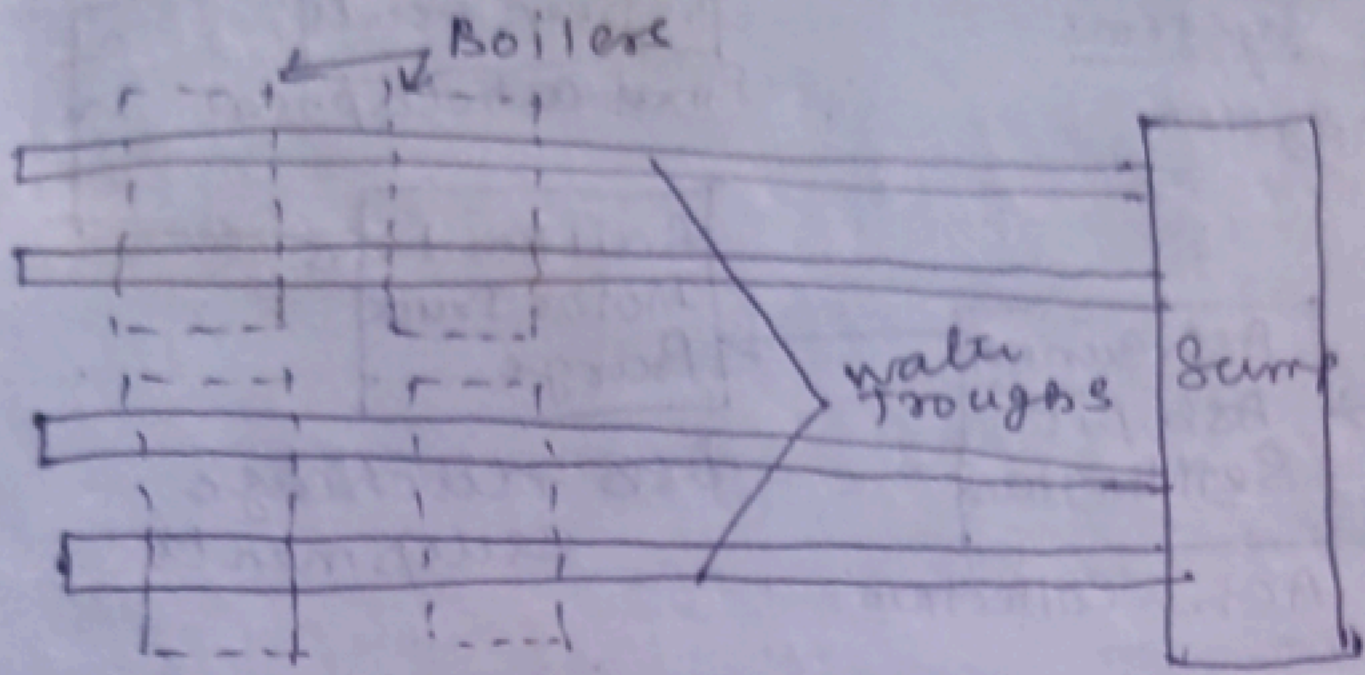
advantages:-
low power consumption

Hot ash → Belt conveyor (water Seal) → dumping site → Truck (or) Overhead Bunker

- life - 5 to 10 years.
- Hot ash is made to fall over the belt conveyor through a water seal.
- Control valve is opened and closed manually to load the truck.

② Hydraulic Ash Handling System:-





- Carries ash with the flow of water with high velocity through a channel and finally dumped to the sump.
- The velocity of water in the water trough is 3 to 5 m/s.

→ low velocity –

- The ash is separated from water when it reaches to the sump. Collected water reused again sent it through carriages.
- ash carrying capacity – 50 tons/hr.
- Distance covered – 500 metres.

High velocity :-

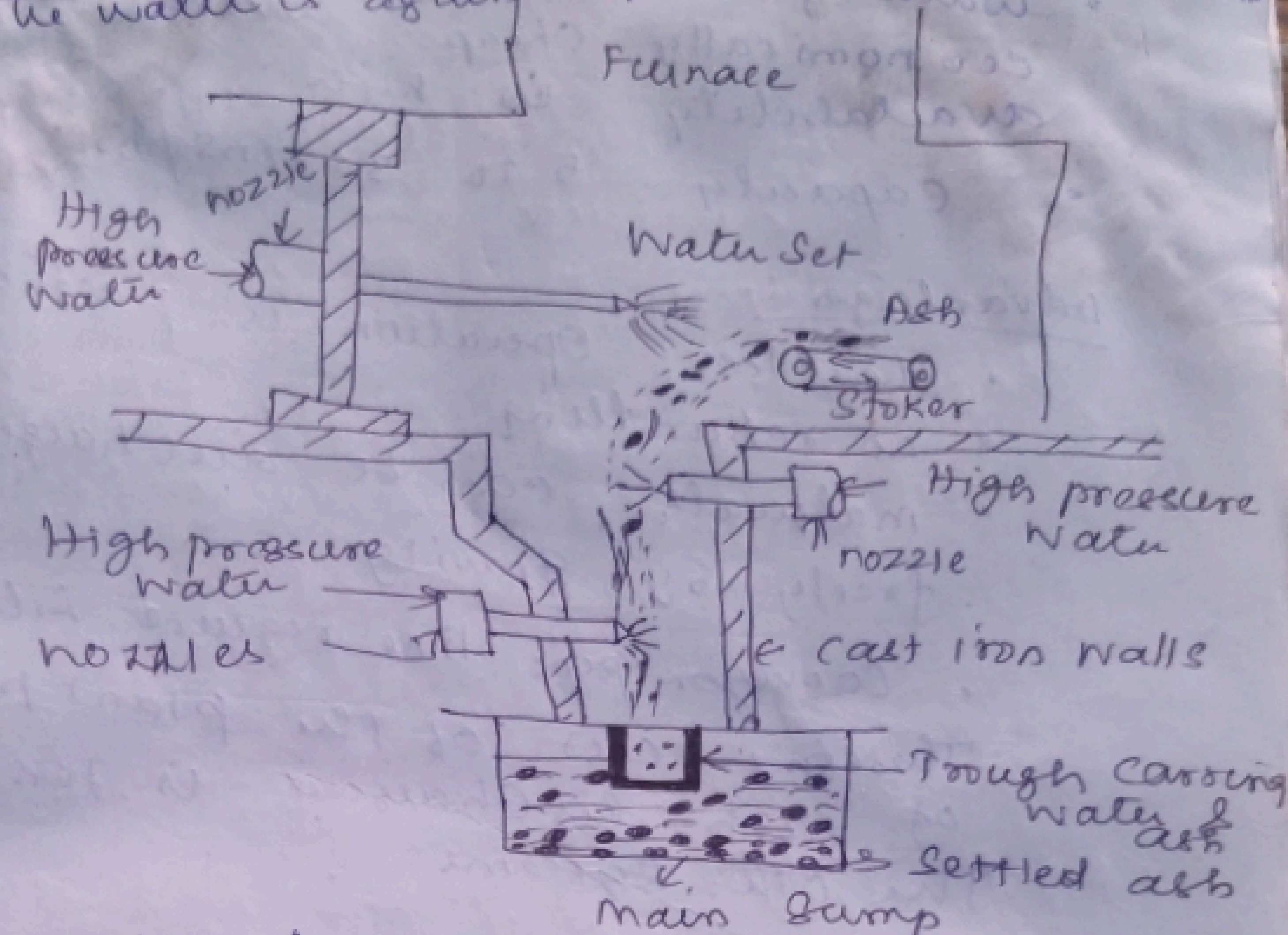
Capacity – 120 tons/hr.

Distance – 1000 m.

- The molten slag produced in the pulverised carried our high pr hydraulic system high pr water jigs & disintegrate into small particle slag. It has to flow sluice.

The hoppers below the boiler are fitted with water nozzles at the top and on the sides.

- Top nozzle cool the ash and side nozzle provide the driving force to carry ash through trough.
- The water is again separated and recirculated.



Pneumatic Ash Handling System :-

This system has been developed for

- abrasive as well as fine dusty material such as fly-ash and soot.
- The ash carried by the air is separated into the primary and secondary separators working on cyclone principle.

high velocity air stream

- Exhauster - I.D fan.
- Mechanical exhauster is used for large tonnage of material.
- power required for mechanical exhauster 5 H.P./ton of material.
- Steam - jet exhauster for small and medium size plant

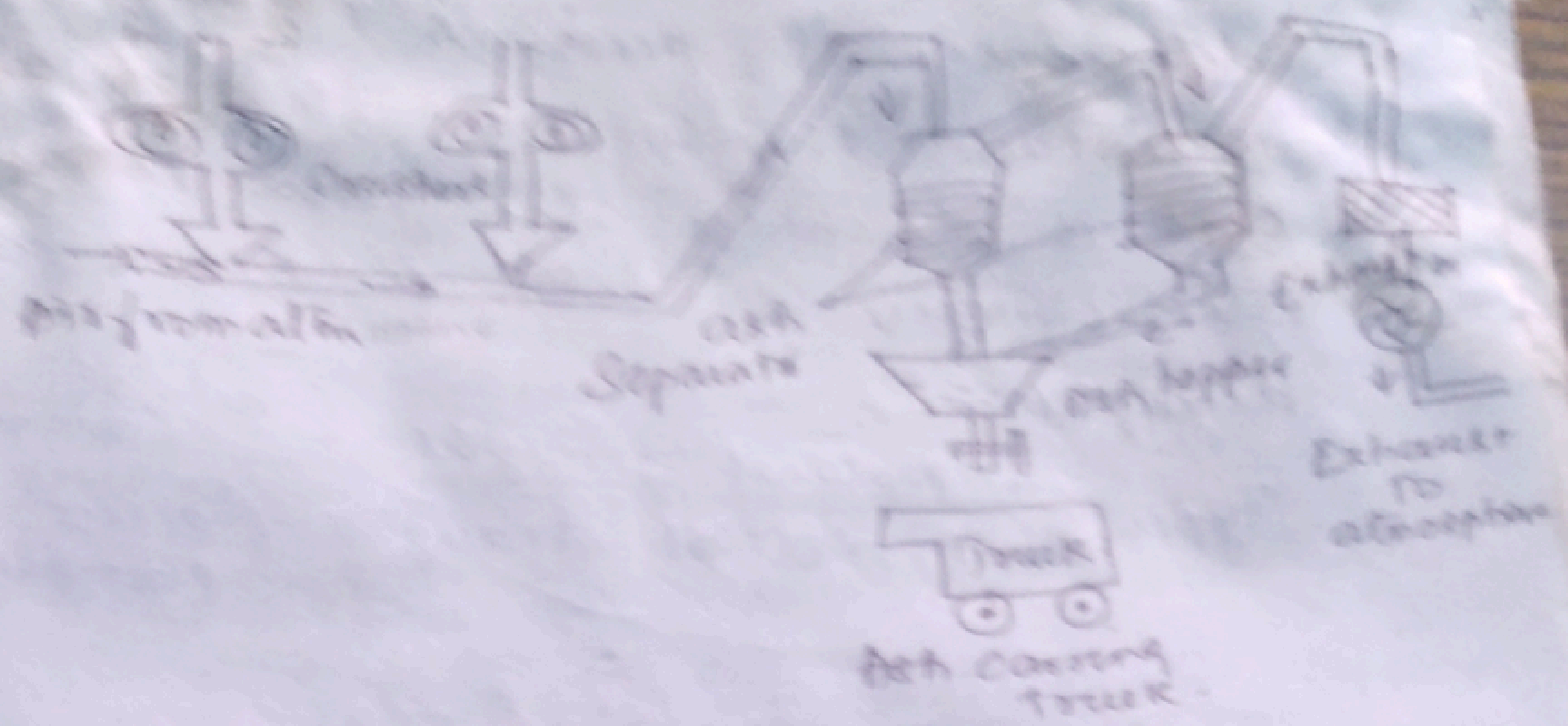
- Steam consumption 120 kg / ton
- water jet exhauster easily available economically cheap. where water availability is high.
- capacity 5 to 30 tons / hr.

Advantages :-
- dustless operation is possible.
- no rehandling
- materials can be discharged freely by gravity.
- conveyor pipe line require little space Therefore cost of the plant per ton of ash discharged is less than the other systems.

Steam Jet System :-
high velocity. which is capable of carrying dry solid materials

Advantages, disadvantages
- capital cost of this system / ton of ash
- It require less space.

Disadvantage :- • pipe has to be lined with nickel alloy.
- operation is noisy.
- capacity 15 tons per hour.



Draught System :-

The purpose of draught is to supply required quantity of air for combustion and remove the burnt products from the system.

To move the air through the fuel bed and to produce a flow of hot gases through the boiler, economizer, preheater and chimney requires a difference of pressure equal to that necessary to accelerate the burnt gases to their final velocity and to overcome the pressure losses.

equivalent to pressure head. The difference of pressure required to maintain the constant flow of air and to discharge the gases through the chimney to atm is known as draught.

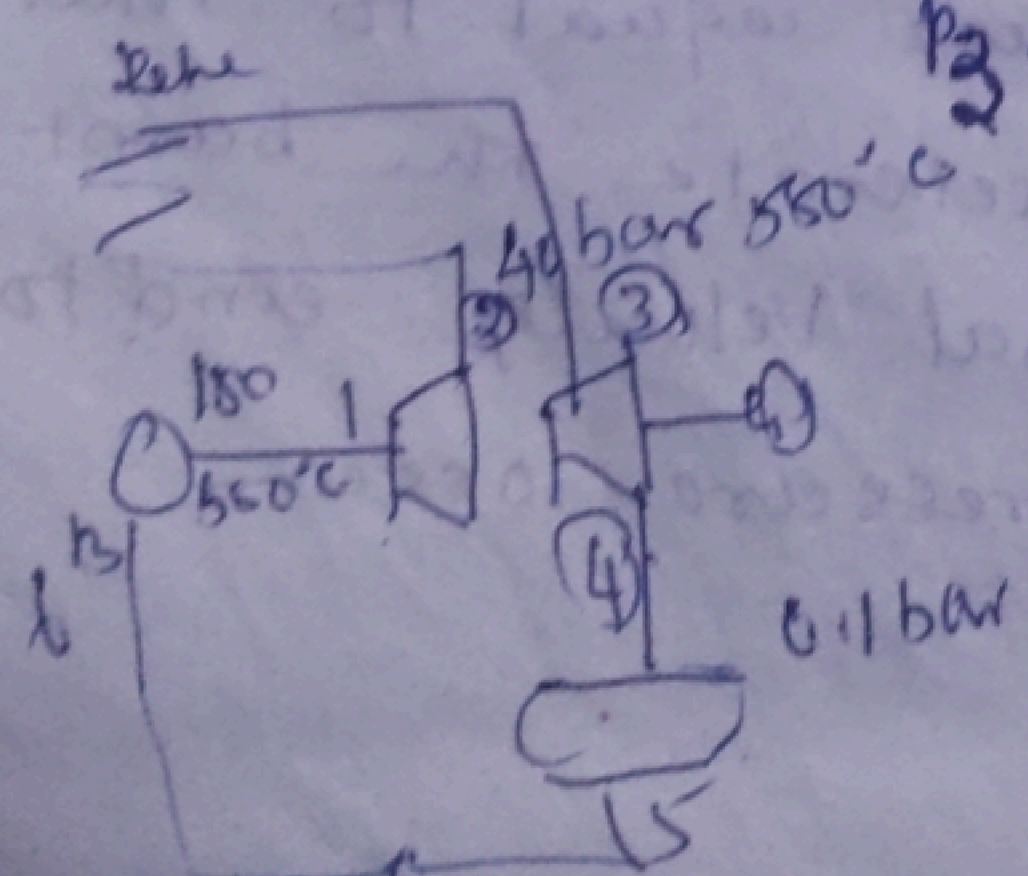
Types → Natural draught (help of chimney)
→ Artificial draught (except chimney)

A steam power plant uses steam at boiler pressure of 150 bar and temp 550°C with reheat at 40 bar and 550°C at condenser pressure of 0.1 bar. Find the quality of steam at turbine exhaust, cycle efficiency and steam rate.

<u>Given</u> $P_1 = 150$ bar

$T_1 = 550°C$

$P_2 = 40$ bar, $T_3 = 550°C$, $P_4 = 0.1$ bar.



Solution:-

properties of steam from steam table

at 150 bar & 550°C.

$h_1 = 3445.2 \ kJ/kg$, $s_1 = 6.5125 \ kJ/kgK$.

At 40 bar & 550°C.

$h_3 = 3558.9 \ kJ/kg$, $S_3 = 7.2295 \ kJ/kgK$

At 40 bar → 6.069 = S_g

$T_{sat} = 250.3°C = 523.3K$

$h_f = 1087.4 kJ/kg$ $h_{fg} = 1712.9 kJ/kg$.

$S_f = 2.797 \ kJ/kgK$ $S_{fg} = 3.272 \ kJ/kgK$

At 0.1 bar

$h_f = 191.8 kJ/kg$ $h_{fg} = 2392.9 kJ/kg$.

$S_f = 0.649 kJ/kgK$, $S_{fg} = 7.502 kJ/kgK$.

1-2 ⇒ Isentropic.

$S_1 = S = 6.5125 \ kJ/kg.K$ — S_g ⇓ 8.151 (0.1 bar)

$S_2 > S_g$ at 40 bar.

Exit of HP turbine is superheat

$T_{sup} = 332°C$. $h_2 = 3047.18 \ kJ/kg$

$S_4 < S_g$ at 0.1 bar.

Steam is at wet condition.

$S_4 = S_3 = 7.2295 \ kJ/kgK$.

$S_4 = S_{f4} + x_4 \times S_{fg4}$

$$x_4 = \frac{s_4 - s_{f4}}{s_{fg4}} = \frac{7.2295 - 0.649}{7.502} = 0.87$$

$$h_4 = h_{f4} + x_4 \times h_{fg4} = 191.8 + 0.87 \times 2392.9$$

$$\boxed{h_4 = 2290.37 \text{ KJ/kgK}}$$

$$\eta = \frac{(h_1 - h_2) + (h_3 - h_4)}{(h_1 - h_{f4}) + (h_3 - h_2)}$$

$$= \frac{(3445.2 - 3047.15) + (3558.9 - 2290.37)}{(3445.2 - 191.8) + (3558.9 - 3047.18)}$$

$$= 0.4426 \times 100 = 44.26\%$$

$$\text{Steam rate} = \frac{3600}{(h_1 - h_2) + (h_3 - h_4)}$$

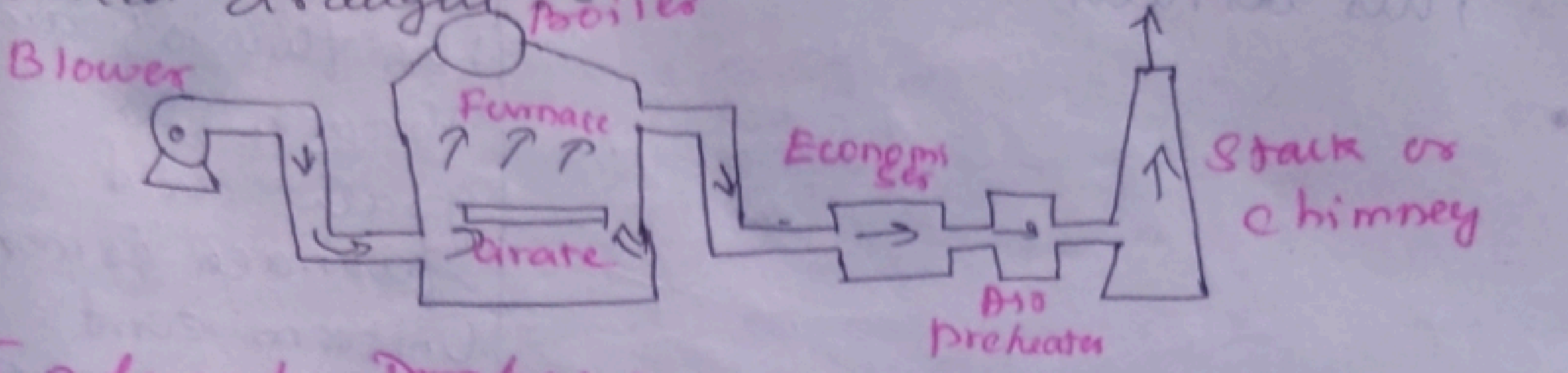
$$= \frac{3600}{(3445.2 - 3047.18) + (3558.9 - 2290.37)}$$

$$= 2.16 \text{ kg/kw hr}$$

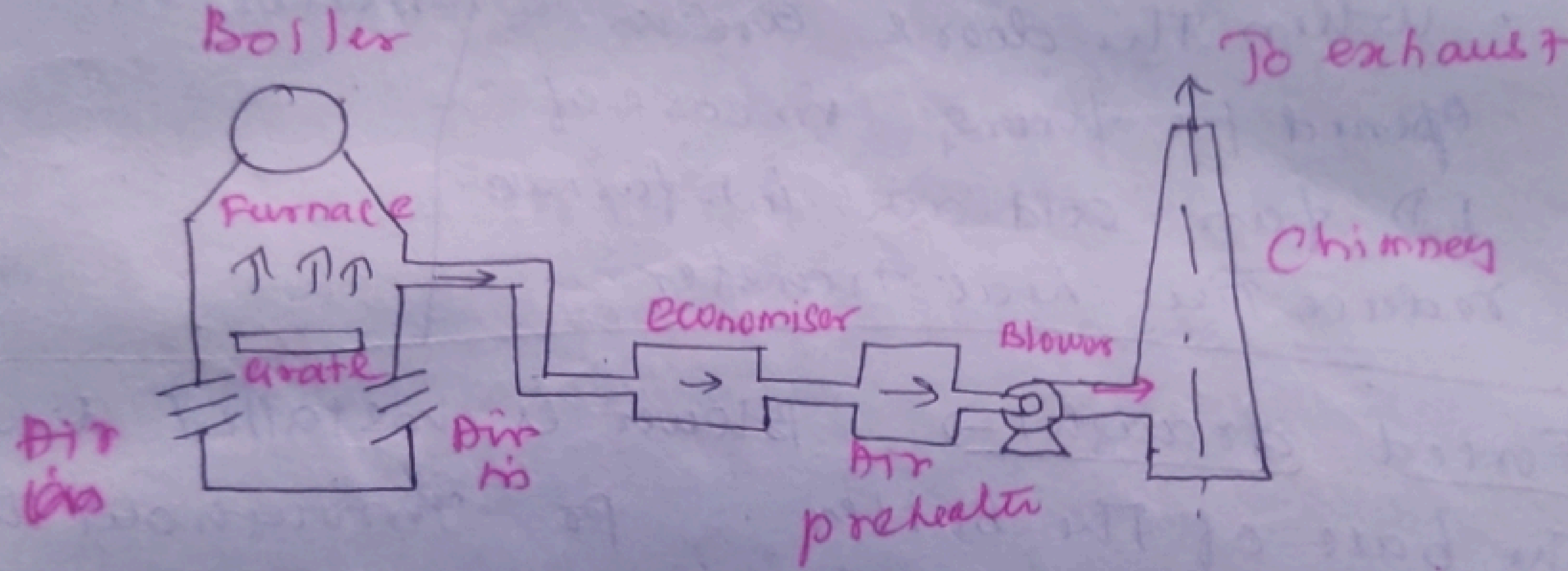
Artificial draught (Forced and Induced Draughts):-

- 20000 ton steam / hr.
- Advantages of fan → reduce the height of the chimney.

Forced draught boiler



Induced Draught:-



Induced draught	Forced draught
• Size and power required is high because it handles more gases (air and fuel).	There is no leakage of air.
• 1.3 times the size of forced draught fan.	
• Water cooled bearings are required.	

- There is continuous leakage of air in the furnace with induced draught as the pressure inside the furnace is less than the atm pr. This dilutes the combustion.

-

- When the doors are opened for firing in case of ID fan cold air into furnace reduce the heat transfer

The flow of air through the grate and furnace is more uniform and it penetrates better in.

Forced draught → Blower is installed near the base of the boiler. pr throughout the system is above atm pressure.

Induced fan:- Fan is located near the base of the chimney; instead of near the grate. Suction pressure in this system is below atm.

$$\text{power input} = \frac{W_f (1 + A/F) \times V_g \, \Delta P_{ID}}{\eta_{ID}}$$

W_f - fuel burning rate

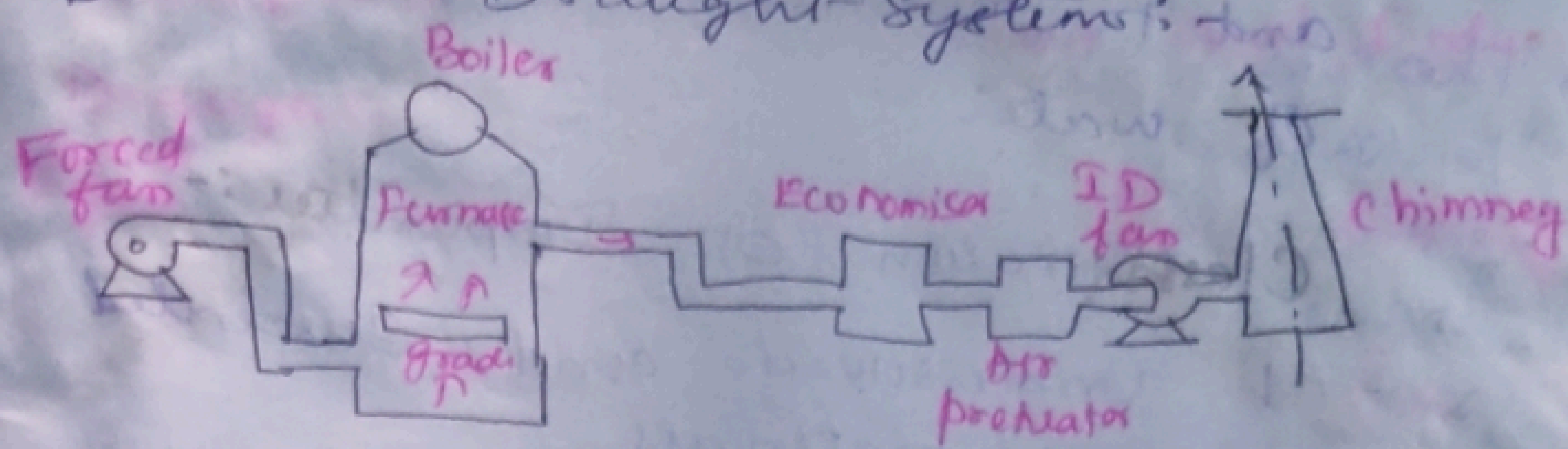
A/F - Airfuel ratio

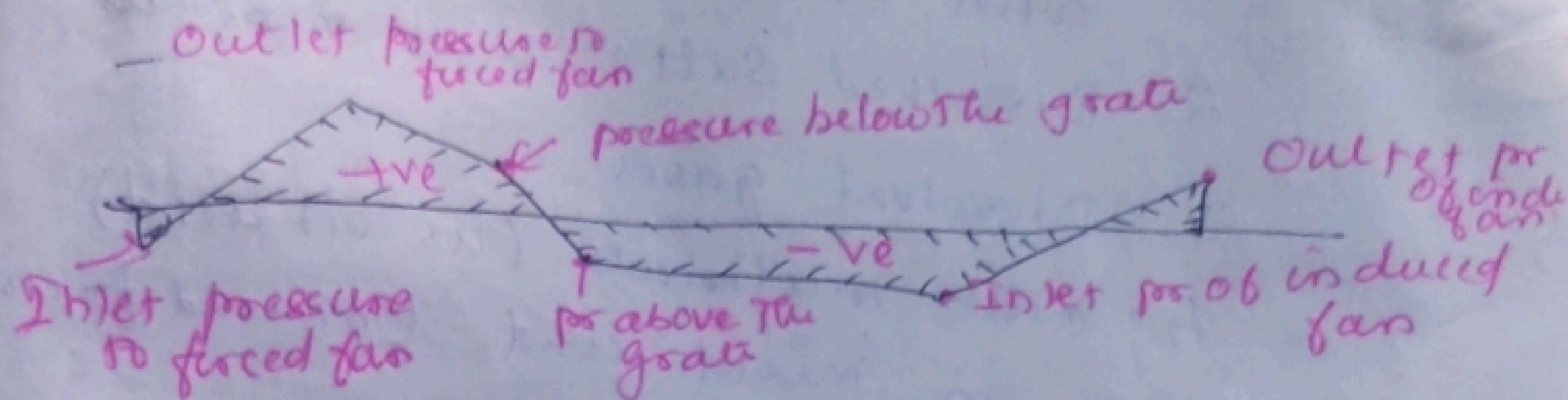
V_g - Specific volume of flue gases

ΔP_{ID} - pressure head developed

η_{ID} - η of Induced draught

Balanced Draught Systems:





- It is the Combination of induced and forced draught system.
- The forced draught is used to force the air through the bed and induced draught is used to suck the gases from the boiler and discharges them to the chimney.

Feed water treatment:- Boiler make up water 1.5-2%.. fittings, Bearings

Maintain the operation at the best possible levels of availability economy and efficiency and control the chemical in the water. prevent the ~~Steam~~ To prevent scale and deposit formations on heating surfaces to prevent the scale and deposit formation. of corrosion.

1) Elimination of corrosion damage
2) Prevention of Silica deposition and to turbine blad
1) control of carry over to eliminate deposition on superheater

and to maintain higher level purity of water.

Classification of Impurities:-

1. Undissolved and Suspended Solid materials
2. Dissolved Salts and minerals
3. Dissolved gases
4. Other materials (as oil acid) either in mixed and Unmixed forms.

1. Undissolved and Suspended materials:-

a) Turbidity and Sediment -
Coarse particles (mud, Sediment, sand) should not exceed 5ppm, removed by Settling coagulation.

- Hardness is taken as calcium Carbonate ($CaCO_3$) in ppm.

b) Sodium potassium Salts.

c) Chlorides - cause corrosion.

d) Iron - ferrous bicarbonate, even 0.3 ppm can create trouble in the feed water System by Soft Scale formation accelerating the corrosion.

e) Ma

f) Si
1 to 1
in b

g) Mi
flow
rate

h) C
re
by

2)
a)

3)

e) Manganese -

f) Silica - most water contains from 1 to 100ppm. It form very hard scale in boilers and forms insoluble deposits.

g) Microbiological growth - Can form clog. flow passages reduce heat-transfer rate.

h) Colour - Cause in foaming in boilers. removed by chlorination or absorption by activated carbon.

2) Dissolved Salts and Minerals:-

a) Calcium and Magnesium Salts:-

Calcium magnisium in the form of Bicarbonates, Sulphates, Chlorides. Temporary Hardness - Bicarbonates of calcium and magnesium, can be removed by Boiling. permanent Hardness caused by presence of chlorides, Sulphates nitrates of calcium and magnesium removed by blowdown method.

3) Dissolved gases:-

a) oxygen:- As it corrosive to iron, zinc, brass and other metals. It causes pitting of water lines boilers and heat exchangers.

• Boiler makeup water to the extent of 1.5 - 2 % of the total flow rate is required to replenish. The losses from fittings, bearings, blow down, turbine glands, other causes

b) Carbon dioxide:- river water 50ppm and well water contains 2 to 50 ppm of CO_2. corrosion.

$CO_2 + H_2O \rightarrow H_2CO_3$ (carbonic acid)

4) other materials:-

a) free Mineral acid - Usually present as sulphuric or hydro chloric acid. causes corrosion.

b) oil - form scale, foam, removed by strainers, baffle separators.

Different methods of water Treatment:-

Dissolved solids in the water removed in the boiler itself by a chemical treatment then the method is known as "Internal treatment". If they are removed from the water before supplying to the boiler is External treatment.

Internal Treatment:-

Treating water in the boiler during evaporation.

compounds in raw water	Treating Chemicals	Sludge formed
calcium bicarbonate		

External Treatment :-

- Chlorinate - prevent bio fouling
- Suspended solids removed by aluminium sulphate ($Al_2(SO_4)_3$).
- gravity filter, pressure type filters are used
- Activated carbon can absorb organics and remove residual chlorine from the chlorination process.
- The dissolved salts of calcium and magnesium give to water a quality called hardness.

(1) Lime Soda process:-

lime - calcium hydroxide.
Soda ash - Sodium carbonate.
normal temp - cold process. near boiling point - hot process.

$$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl.$$

(2) Hot phosphate softening :-

- Calcium and magnesium hardness is removed by phosphate and caustic soda. Tricalcium phosphate ($Ca_3(PO_4)_2$) and magnesium hydroxide are precipitated

• process is carried out above 100°c
• This is costlier than lime soda process for water hardness 60ppm or less.

$$CaCO_3 + 2Na_3PO_4 \rightarrow Ca_3(PO_4)_2 + 2Na_2CO_3.$$

(3) Sodium Zeolite Softening:-
water passed through sodium Zeolite bed.

$$CaCO_3 + Na_2Z = CaZ + Na_2CO_3$$

• The bed can be regenerated by flushing it with brine (NaCl).

$$CaZ + 2NaCl = Na_2Z + CaCl_2.$$

Reasons:-
(1) water of high or low ph have a deleterious effect on Zeolites.
(2) High temperatures also have a bad effect.
(3) Turbid waters coat the Zeolite material. reducing its efficiency.
(4) There is no reduction in alkalinity or total solids.

(4) Hydrogen Zeolite Softening:-

$$Mg(HCO_3)_2 + H_2Z = MgZ + 2H_2CO_3.$$

$$MgZ + H_2SO_4 = H_2Z + MgSO_4.$$

• Calcium, magnesium and Sodium ions is passed Through hydrogen Zeolite These ions are exchanged for bicarbonate, Sulphate, chloride and nitrate.

(5) Anion Exchangers:-

It can remove anions like Chlorides, Sulphates and nitrates present in hydro Zeolite effluent by resinous materials which absorb Them.

$$2HCl + RCO_3 = RCl_2 + H_2CO_3.$$

• Carbonic acid Sprayed in a Shower to expose area CO_2 is released.

(6) Demineralizing plant:-

• Removing dissolved Solids in water by ion exchange is called demineralization

• ~~Anion~~ (The cation resin hydrogen where hydrogen ion exchanged Zeolite for Calcium, magnesium, Sodium. anions chlorides, nitrates and sulphates.

• electrodialysis (or) reverse osmosis

(7) Condensate polishing

• Condensate passing Through mixed bed Units which contain both cation and anion resins,

• Resins act as filters.

(8) Deaeration:-

- Degasification.
- depends on solubility of dissolved gases.

(9) evaporation:

B Internal treatment:-

$$HOH = H^+ + (OH)^-$$

- pH is > 7 water is alkaline, if pH < 7 it is acidic.
- Tri sodium phosphate, Na_3PO_4 is increase alkalinity. Mono sodium phosphate NaH_2PO_4 is used to decrease alkalinity.
- Scale formation and corrosion determines the pH value.
- pH 10.5 is usually maintained for Boiler,

Scale prevention - (1) periodic (or) continuous blowdown (2) External or internal treatment

Boiler Blowdown:-

% Blowdown = $\frac{\text{quantity of water blown down}}{\text{quantity of feed water}} \times 100$

Steam purity:-

electrical conductivity is ∝ solids in the water.

Foaming - formation of bubbles
priming - Violent, Uneven water circulation, and rapid changes in steaming rate. For the desired steam purity both foaming & priming controlled

Binary Vapour Cycle:-

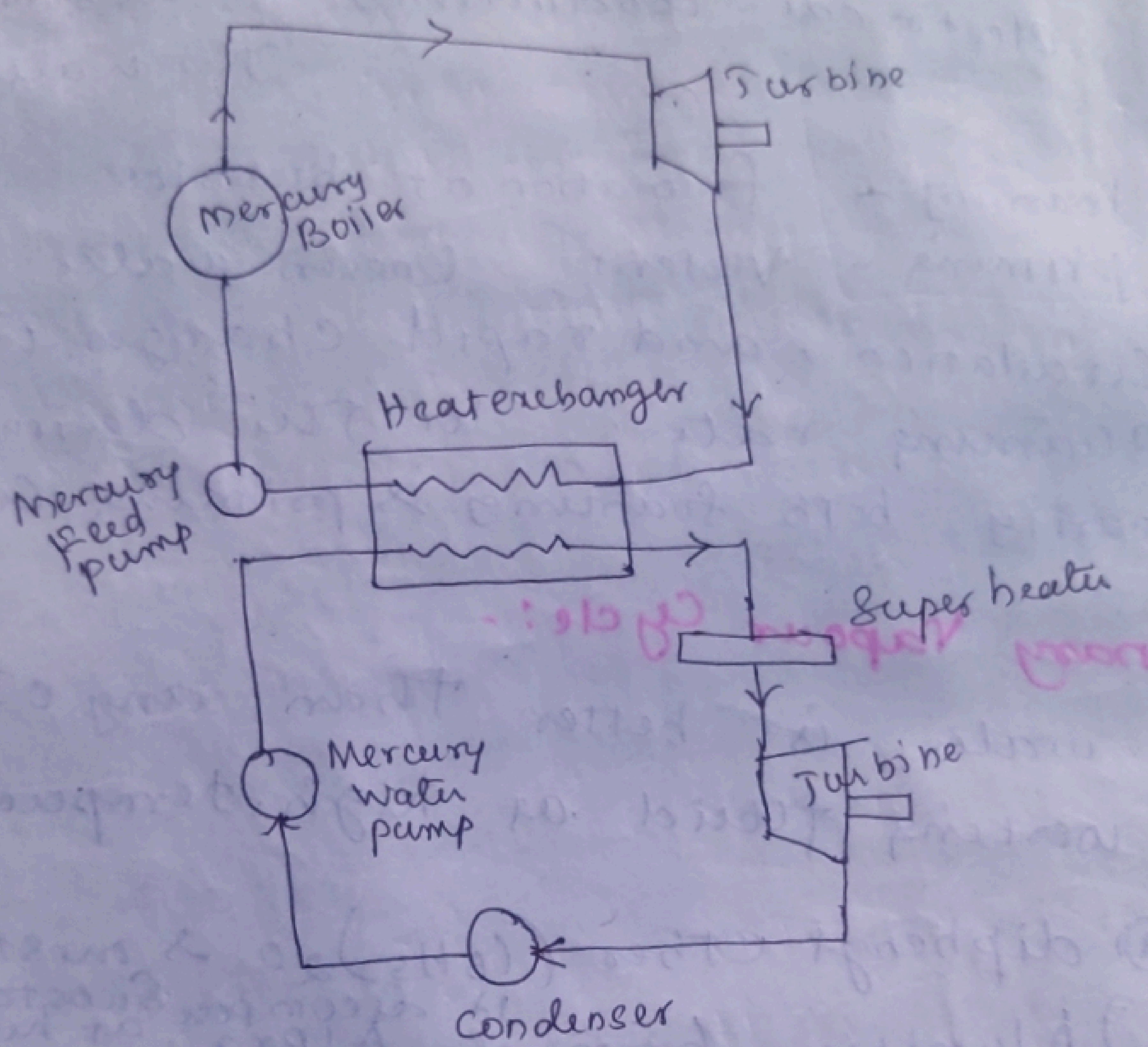
- water is better than any other working fluid at high temperature.

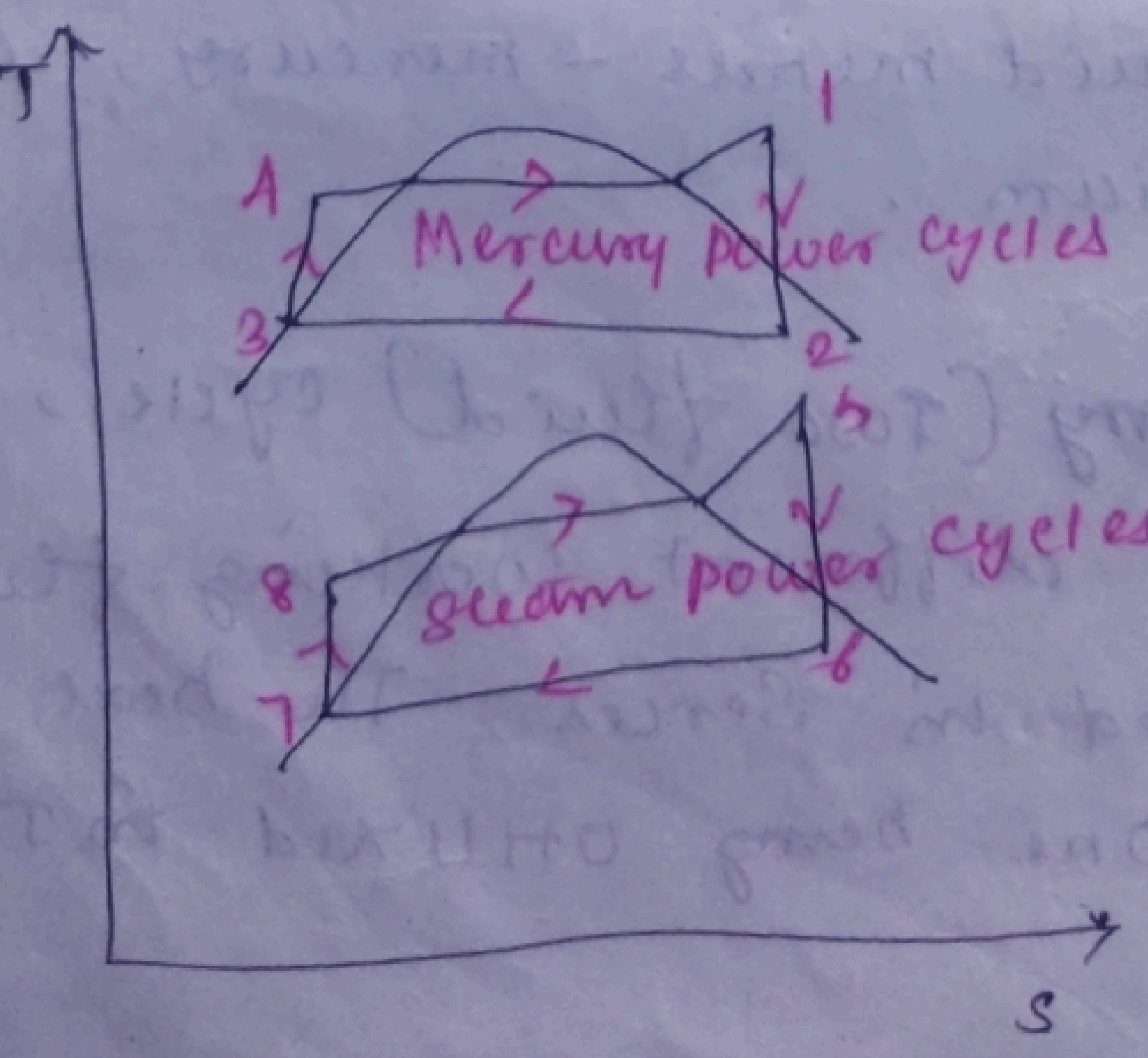
(a) diphenyl ether $(C_6H_5)_2O$ → most organic substances. It decompose at higher temp.
b) Aluminium bromide $AlBr_3$.
c) liquid metals - mercury, sodium, potassium.

- Binary (Two fluid) cycle, two cycles with different working fluids are coupled in series, the heat rejected by one being utilized in the other.

at 12 bar.

- Mercury – Saturation temp – 560°c
- Critical pressure & Temp ⇒ 1080 bar and 1460°C respectively.

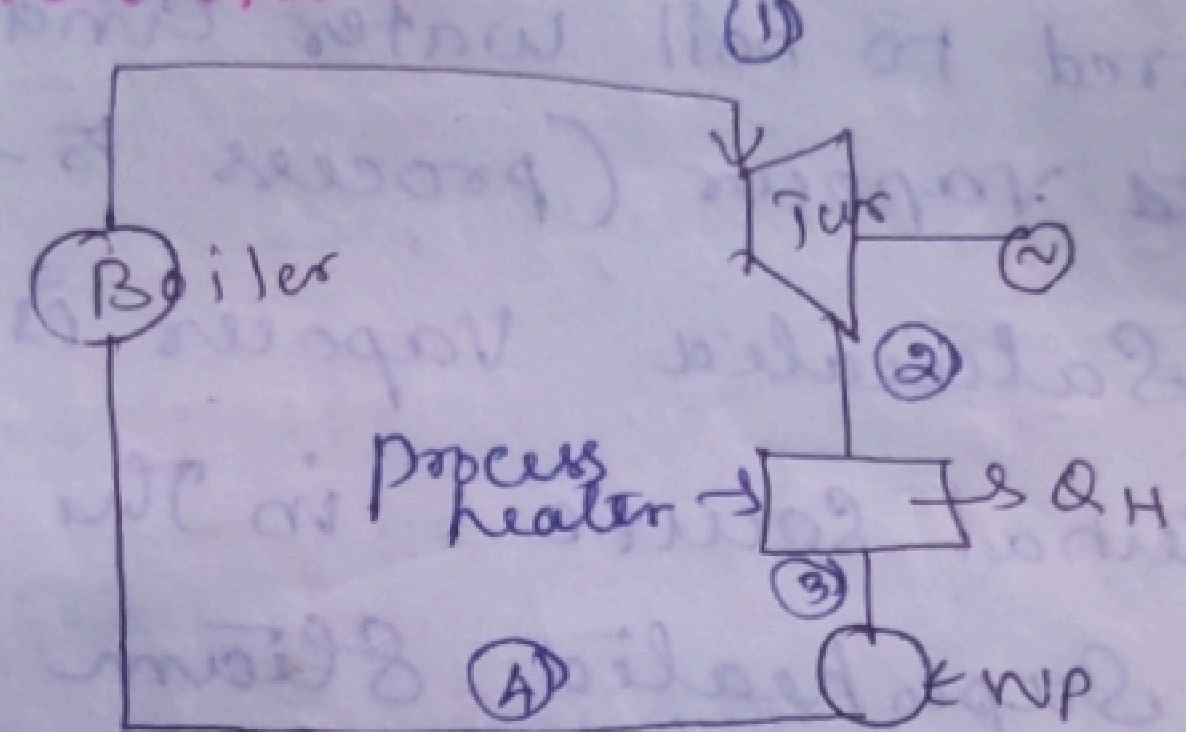




The cycle has one high temperature region and one low temperature region. This is called a Binary Vapour cycle. In this cycle, the condenser of the high temperature cycle called topping cycle, and low temperature cycle termed as bottoming cycle.

Cogeneration:-

process heater is replaced condenser.



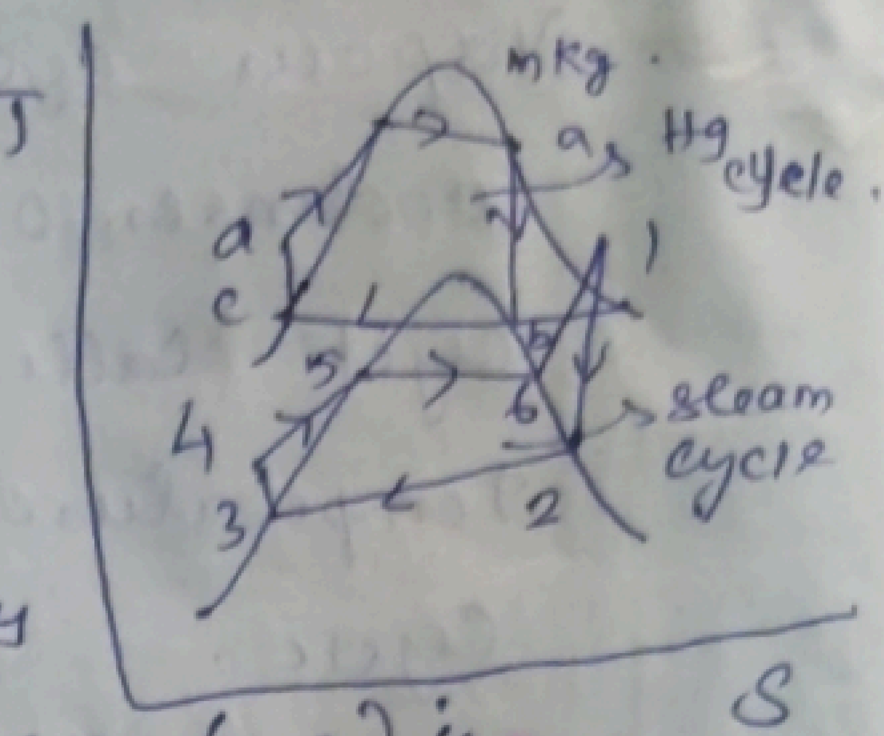
- A plant producing both electrical power and process heat simultaneously is called Cogeneration plant.
- Exhaust steam from the turbine is utilized for process heating, the process heater replacing the condenser of the ordinary Rankine cycle.

$$\eta_{co} = \frac{W_T + Q_H}{Q_1}$$

iii Binary Cycle :-

As at pr 12 bar, water, aluminium Bromide
mercury - 187°c 482.5°C, 560°C

The mercury cycle a-b-c-d is a simple Rankine cycle using saturated vapour. The heat rejected by mercury during condensation (process b-c) is transferred to boil water and form saturated vapour (process 5-6).



- The saturated vapour is heated from the external source in the superheater (6-1). Superheated steam expands in the turbine and is then condensed.
- The condensate is then pumped to the economiser where it is heated till it becomes saturated liquid by the outgoing flue gases (4-5)

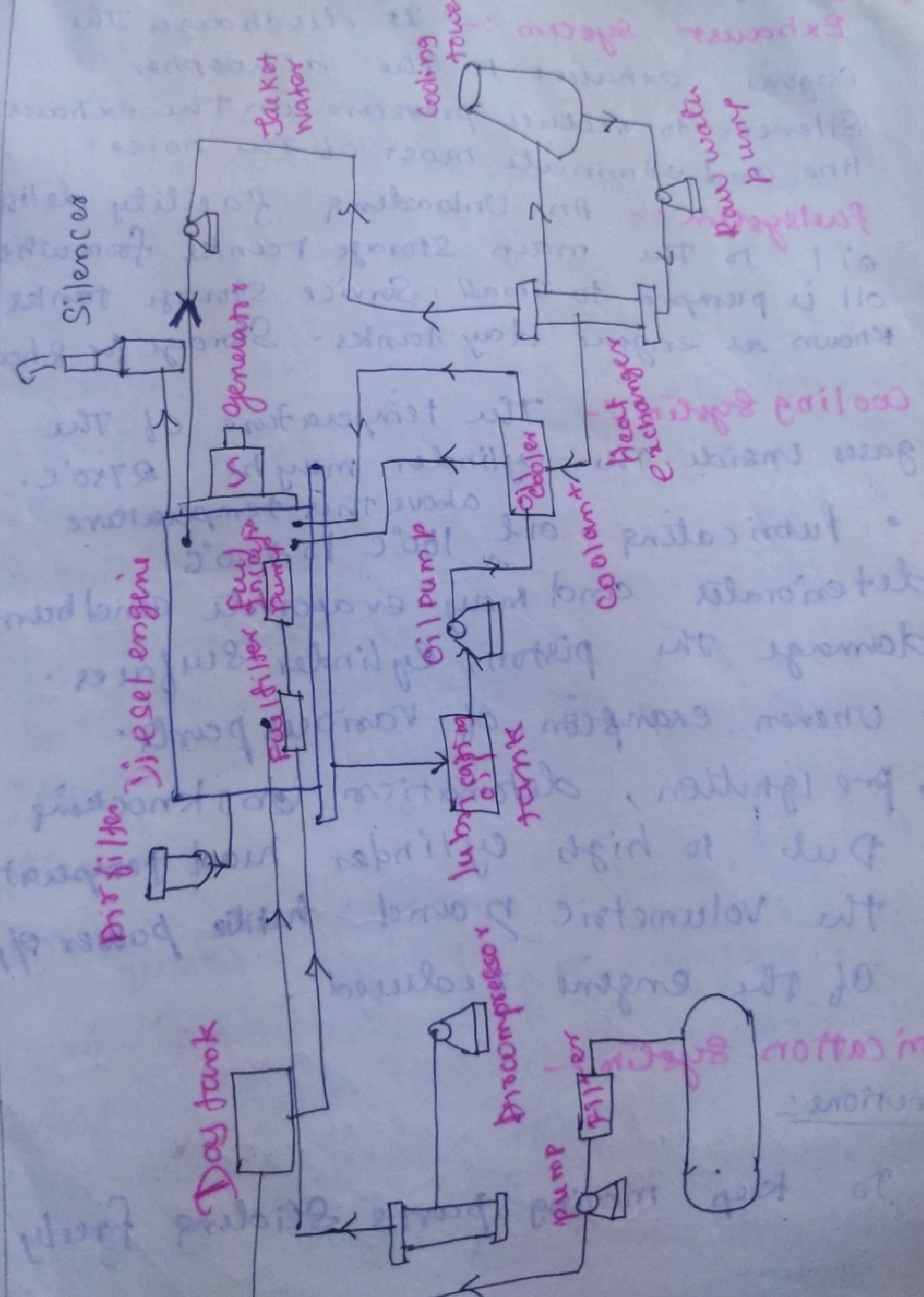
Back pressure turbine :-

The pressure at exhaust from the turbine is the saturation pressure corresponding to the temperature desired in the process heater. Such a turbine is called a back pressure turbine.

UNIT - II

Diesel, Gas turbine and Combined cycle power plants.

Components of diesel power plants:- (N/D 13) (16M)



Engine :- It is the main component of the plant and is directly coupled to the generator

(a) Air intake System :- It conveys fresh air (and) air filters removes dirt.

Exhaust System :- It discharges the engine exhaust to the atmospher. Silencer to reduce pressure on the exhaust line and eliminate most of the noise.

Fuel system :- An Unloading facility delivers oil to the main storage tanks from where oil is pumped to small Service storage tanks known as engine day tanks. Storage for 8 hours.

Cooling System :- The temperature of the gases inside the Cylinder may be 2750°C.

- lubricating oil above this temperature 160°C to 200°C deteriorates and may evaporate and burn damage the piston, cylinder surfaces.
- Uneven expansion of various parts.
- pre ignition, detonation (or) knocking.
- Due to high cylinder head temperature the volumetric η and hence power o/p of the engine reduced.

Lubrication System :-

Functions :-

1. To keep moving parts sliding freely

Thus reduce The engine friction and wear.

- Cooling – ~~Taking~~ away a part of heat caused by friction.
- Cleaning To keep bearings and piston rings clean products of Combustion by washing Them away.
- Sealing – good seal b/w piston rings and cylinder walls.
- Reducing noise – To reduce The noise of The engine by absorbing vibration

Starting of engine

i) By an Auxilary engine – which is mounted close to The main engine and drives The latter Through a cluth and gears.

ii) By using electric motor – Storage battery of 12 to 36 volts is used to supply power to an electric motor that drives the engine.

iii) By Compressed air System – 17 bar air admitted to a few engine cylinders making Them work like reciprocating air motors to run the engine shaft. It is used for starting large plant.

a) Filter the fuel

b) meter the correct quantity of the fuel to be injected

c) Time the injection process.

d) Regulate the fuel supply

e) Secure fine atomization of fuel oil

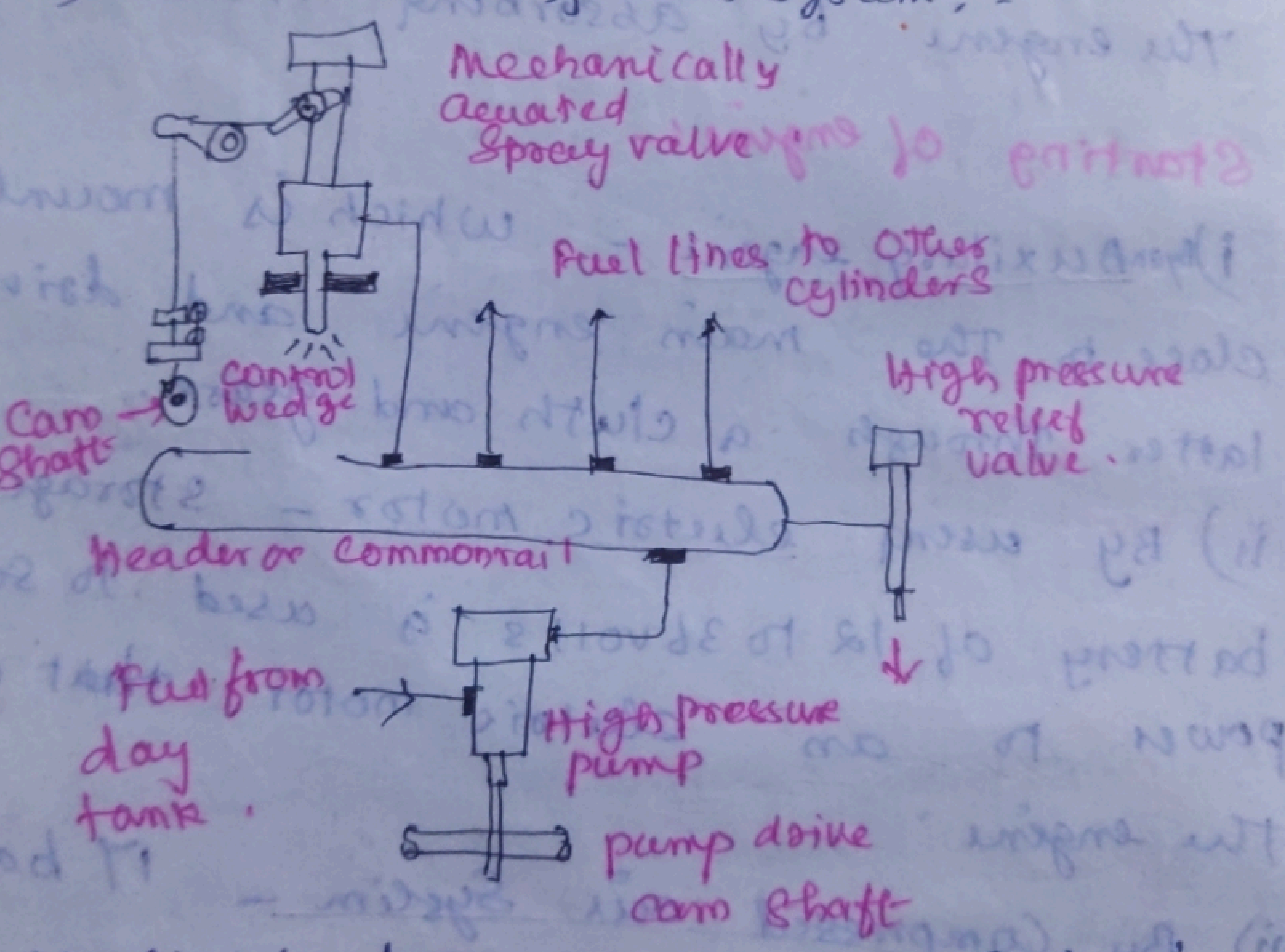
f) Distribute the atomized fuel properly in the combustion chamber.

Fuel system of diesel power plant:- (M)J-13)

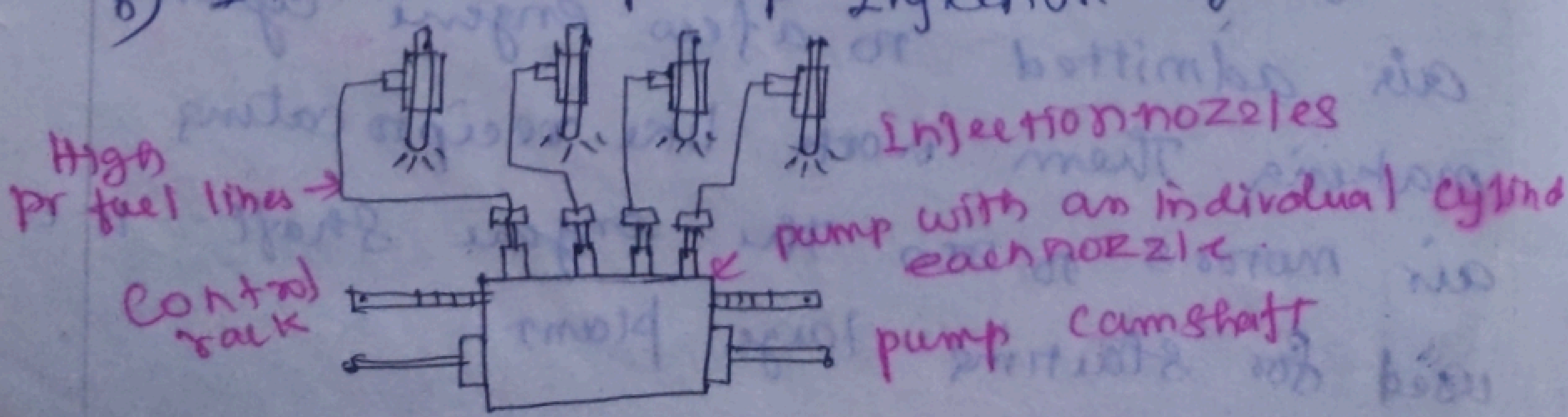
Injection System:-

8m.

a) common rail injection system:-



b) Individual pump Injection System:-

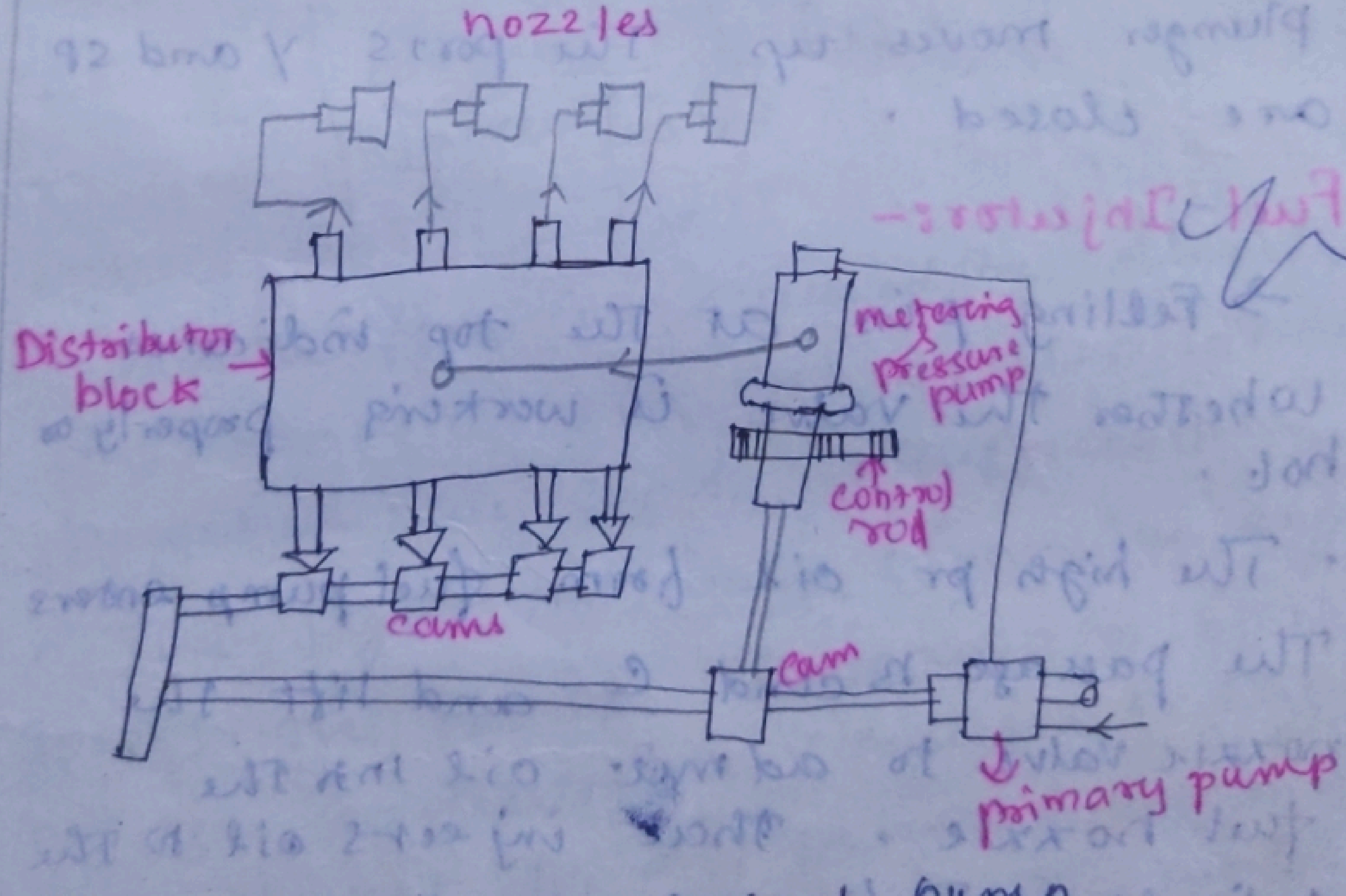


Common rail injection system -

1. The high pressure in the header forces the fuel to each of the nozzles located in the cylinders. at the proper time a mechanically operated valve

b) Individual pump injection system: each cylinder is provided with one pump and one injector.

c) Distributor System:-



Fuel metered at central pump.
Fuel distributed to cylinders in correct firing order by cam operated poppet valves

Fuel pump:- (Tappet mechanism)

plunger(L) driven by a cam, reciprocates inside a barrel (B).

2. The delivery valve (V) lifts off its seat under oil pressure against the spring force.

- When the plunger is at the Bottom the supply port Y and spill port (SP) are uncovered and low pressure filtered oil is forced into the barrel. As the plunger moves up the ports Y and SP are closed.

Fuel Injector:-

→ Feeling pin at the top indicates whether the valve is working properly or not.

- The high pr oil from fuel pump enters the passage B and C and lift the nozzle valve to admit oil into the fuel nozzle, that injects oil to the cylinder in fine atomized spray.

- As the oil pr falls, the nozzle valve comes back to its seat under spring force and the fuel supply is cut off.

- ori
pin
parti
i) Bi
fini
ii) wa
The

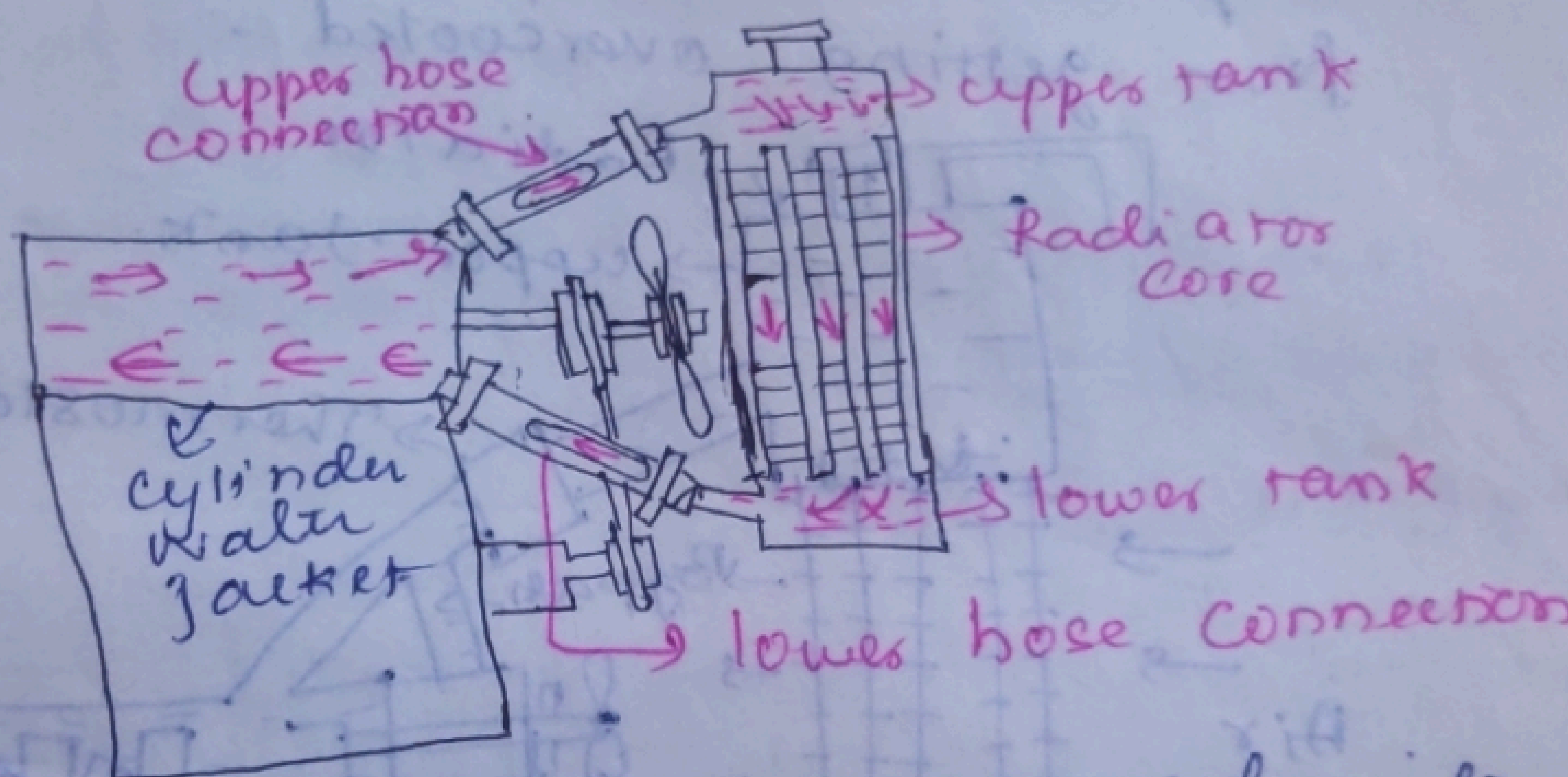
• orifice Single orifice, Multiorifice pintle orifice (clogged by less by carbon particles and less expensive).

i) Air cooling:-

It is used in small engines. fins.

ii) water cooling:-

Thermosyphon Cooling:-



• Water flow is caused by density difference. The rate of circulation however slow and insufficient

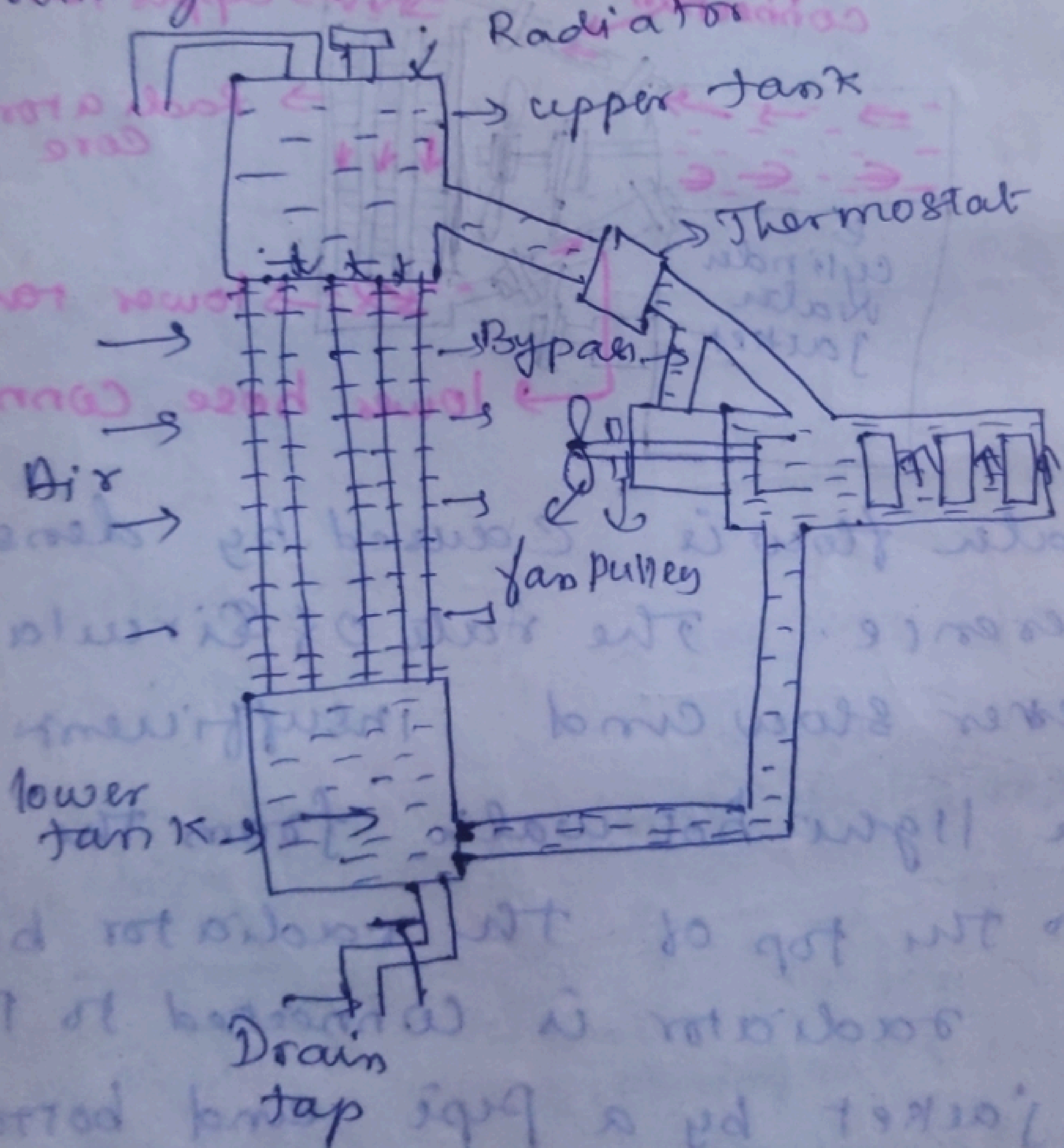
• The light hot water from the engine goes to the top of the radiator by itself. Top of radiator is connected to the top of water jacket by a pipe and bottom of the water jacket to the bottom of the radiator

Forced cooling by pump:-

Forces water to circulate, ensure engine cooling under all operating condition. There may be over cooling which may cause corrosion.

Thermostat cooling:-

• This is a method in which a thermostat maintains the desired temperature and protects the engine from getting overcooked.



• The Volatile liquid changes into Vapour at the correct working temperature and creates enough pressure to expand the bellows. The movement of bellows opens the main valve in the ratio of temperature rise.

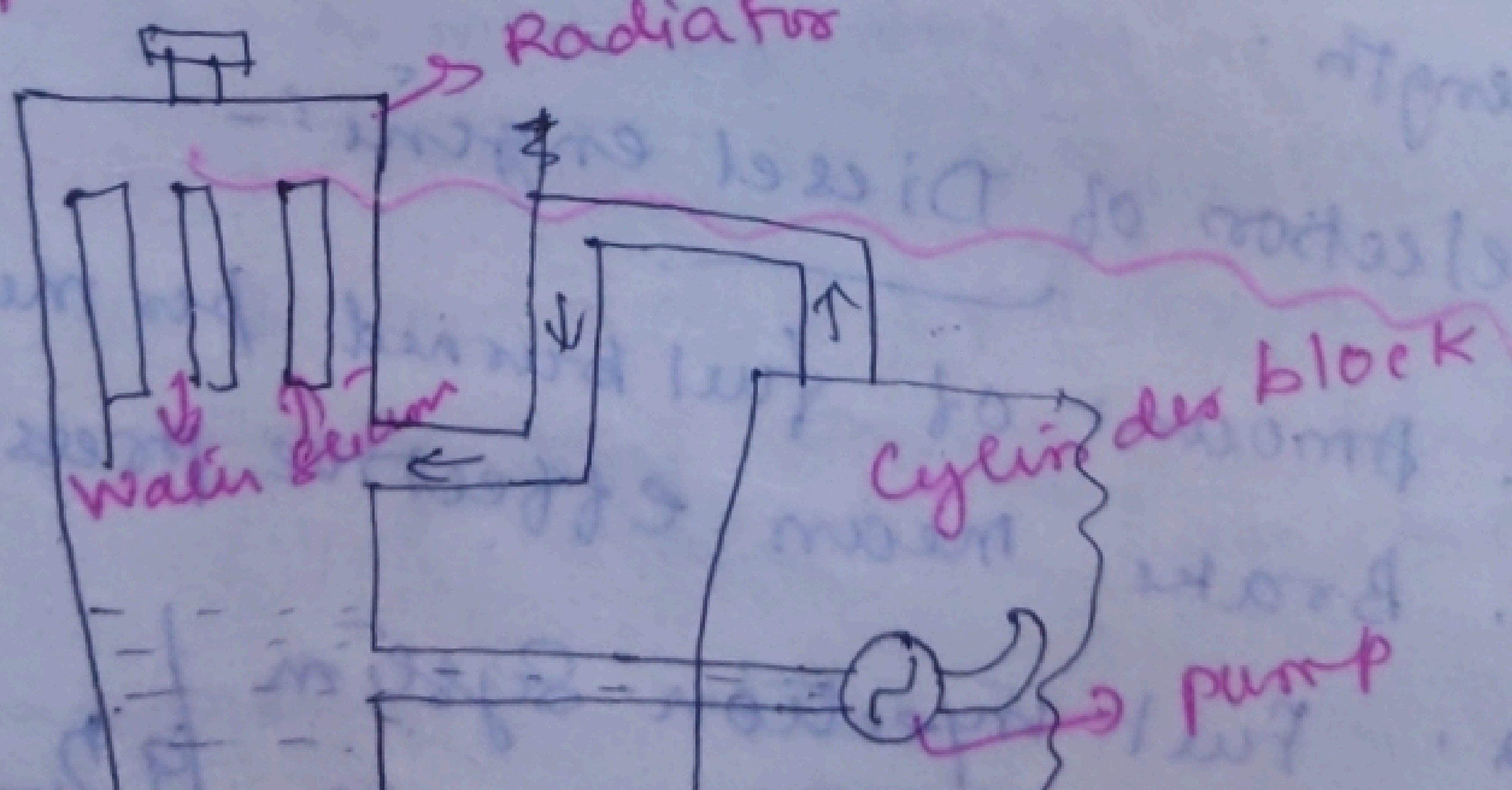
• Temp of water rises it causes Thermo stat valve to open. The pr of water pumped falls.

pressurized water cooling:-

→ 1.5 to 2 bar is maintained to increase heat transfer in the radiator.

→ A pr relief valve is provided against any pressure drop.

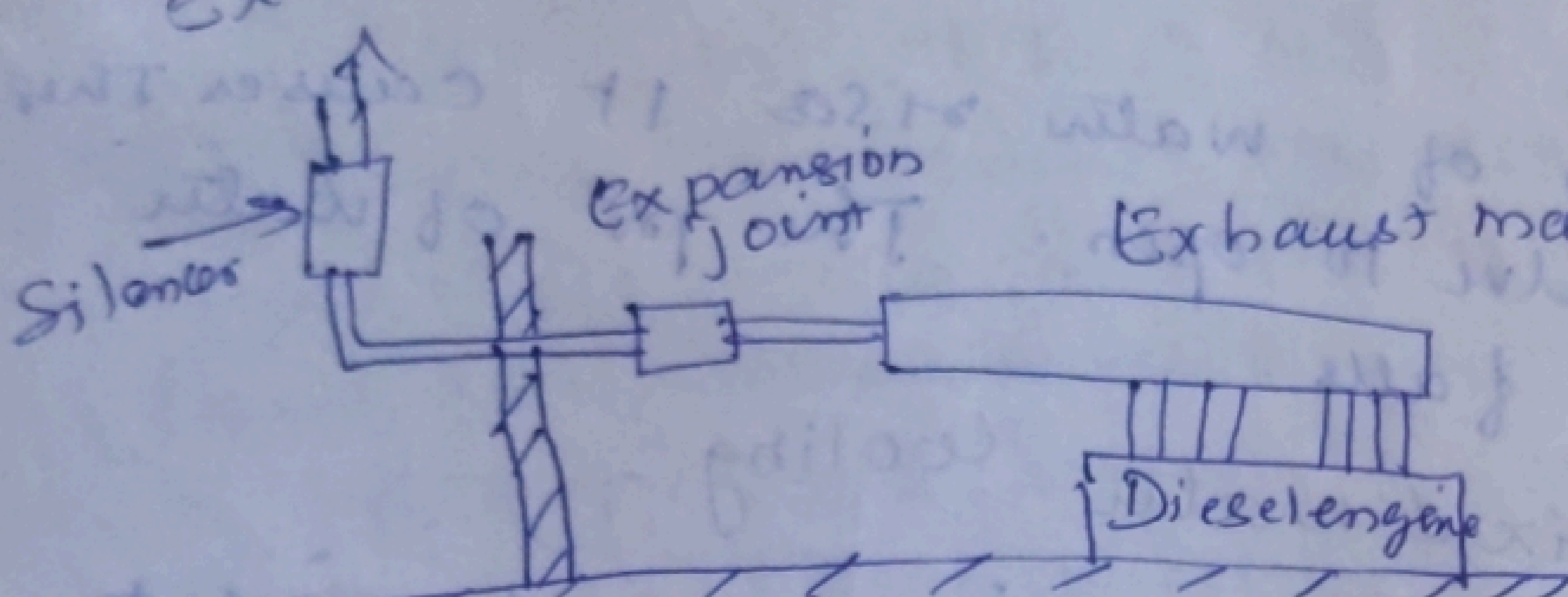
Evaporative Cooling:-



Water is allowed to evaporate by absorbing the latent heat of evaporation from the cylinder walls.

Coolant is always liquid but steam formed is flashed off in the separate vessel. The make up water formed is sent back for cooling.

Exhaust System:-



The purpose of the exhaust system is to discharge the engine exhaust to the atm outside. The exhaust gas is used to preheat the oil and air. The exhaust pipe should be short in length.

Selection of Diesel engine:-

1. Amount of fuel burned per minute
2. Brake mean effective pressure
3. Fuel injection system
4. Combustion process
5. fuel air ratio
6. Type of engine
7. Cooling method
8. size of cylinder
9. ηvol
10. Sp. weight

1. Foundation sub soil condition
2. Distance from the load centre
3. Access to the site
4. Availability of water
5. Fuel transportation.

Hot gas is used to run the turbine used in Aircraft engine, electric power generation, marine propulsion.

1. According to the cycle of operation
2. According to the process
3. According to the use.
4. According to the type of load.
5. Application
6. Type of fuel
7. Number of shafts.

- Application:-

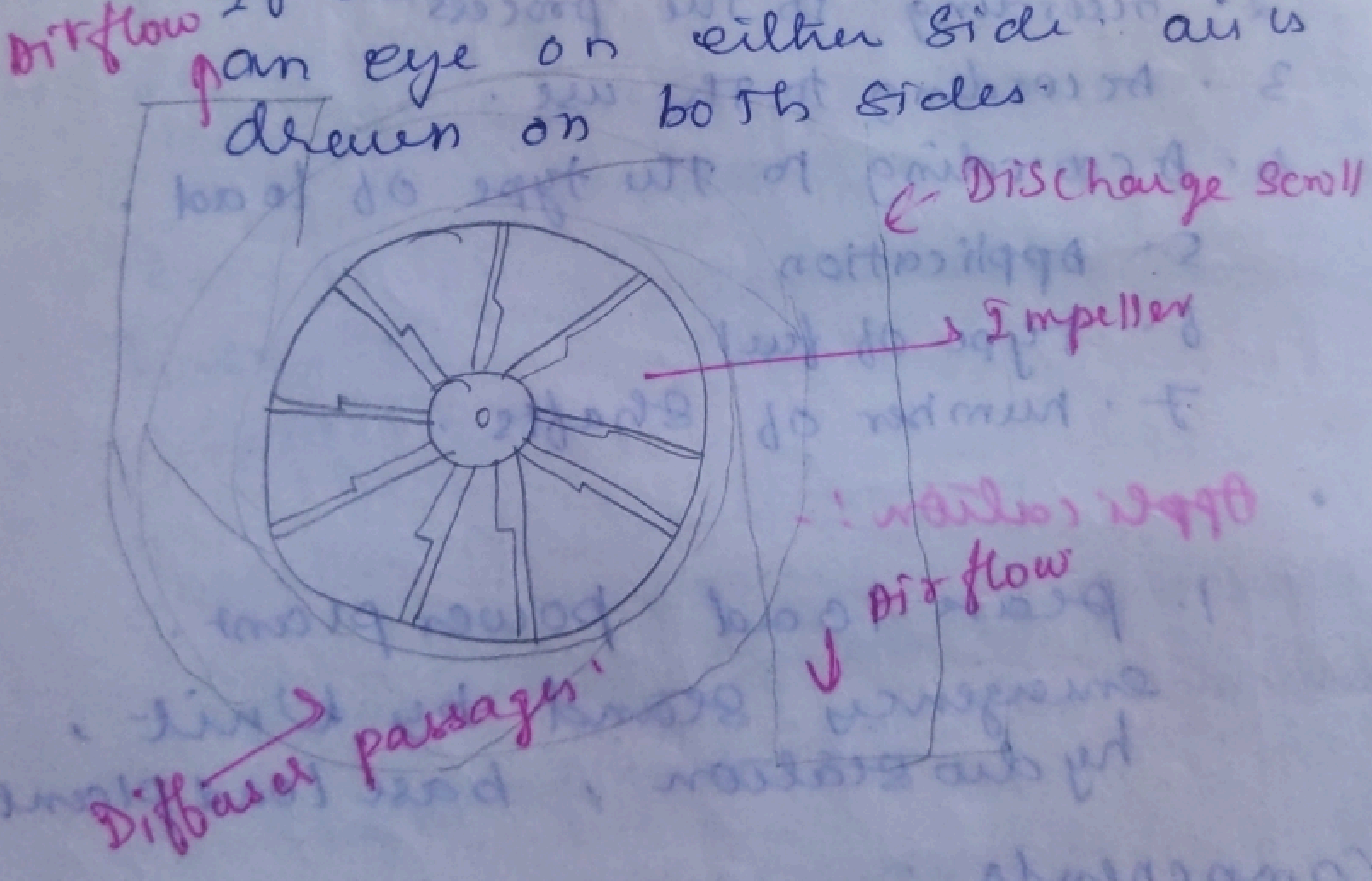
1. peak load power plant. emergency stand by unit, hydro station, base load plant.

Components:-

1. Centrifugal Compressors
2. Axial flow compressors.

Centrifugal compressor :-

It consists of an impeller with a series of curved radial vanes. Air is sucked near the hub called impeller eye and is whirled round at high speed by the vanes on the impeller rotating at high rpm. The static pr of air increases from the eye to the tip of the impeller. Air leaving the impeller tip flows through diffuser passages which convert the kinetic energy to pr energy. If double inlet impeller having an eye on either side air is drawn on both sides.

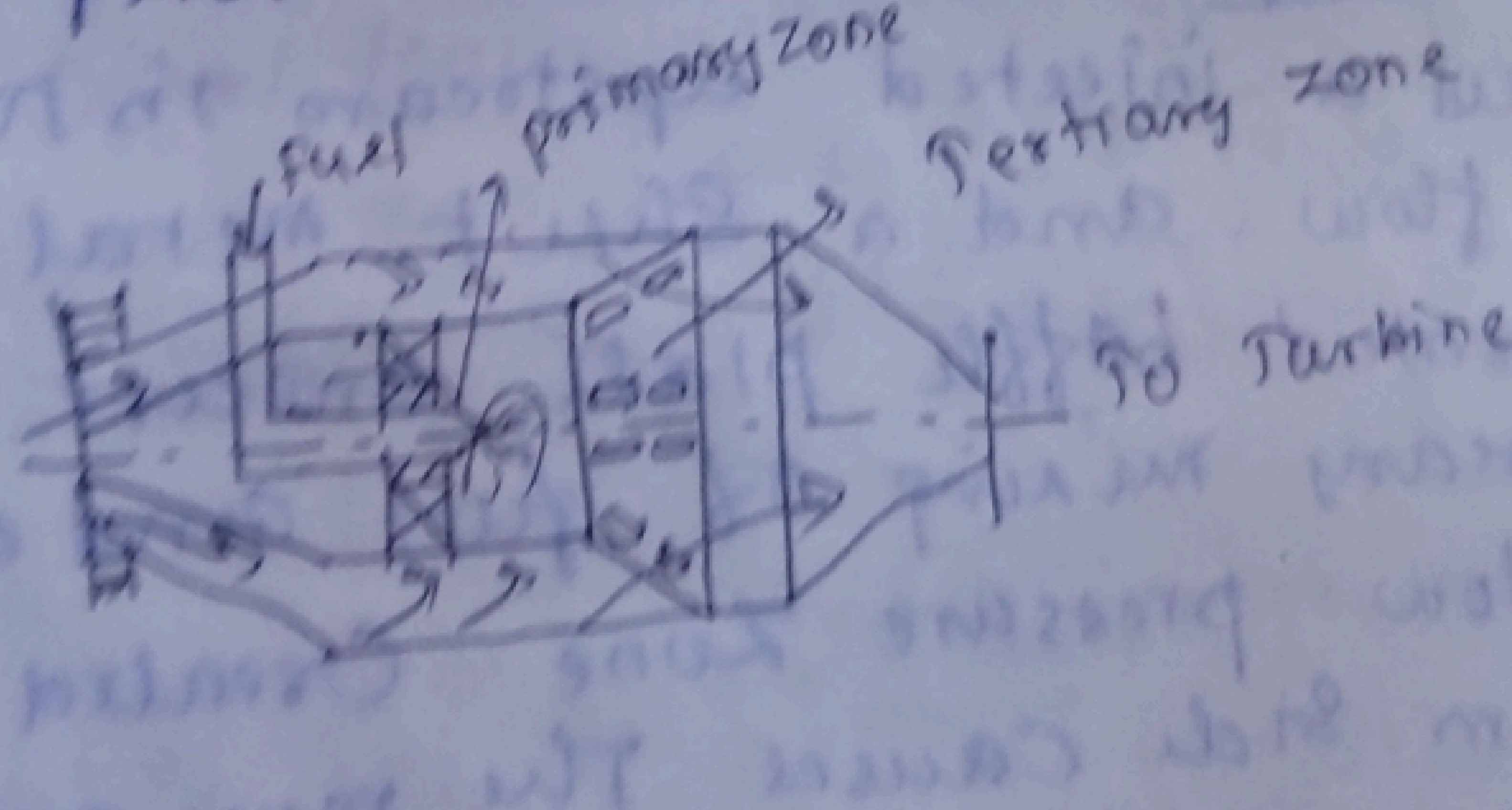


Axial flow Compressor:-

with a succession of moving blades on the rotor shaft and fixed blades arranged around the stator (casing). Air flows axially through the moving and fixed blades with diffuser passage throughout which continuously increase the pressure and decrease the velocity.

Combustion Chamber:-

- It require steady and stable flame inside the combustion chamber.
- Bluff and swirl for flame stabilization. It is creating different methods to create the pilot zone for flame stabilization.



- Combustion is initiated by an electric spark. Once the fuel starts burning, the flame is required to be stabilized.

→ About 20% of the total air from the compressor is directly fed through a swirler to the burner as primary air

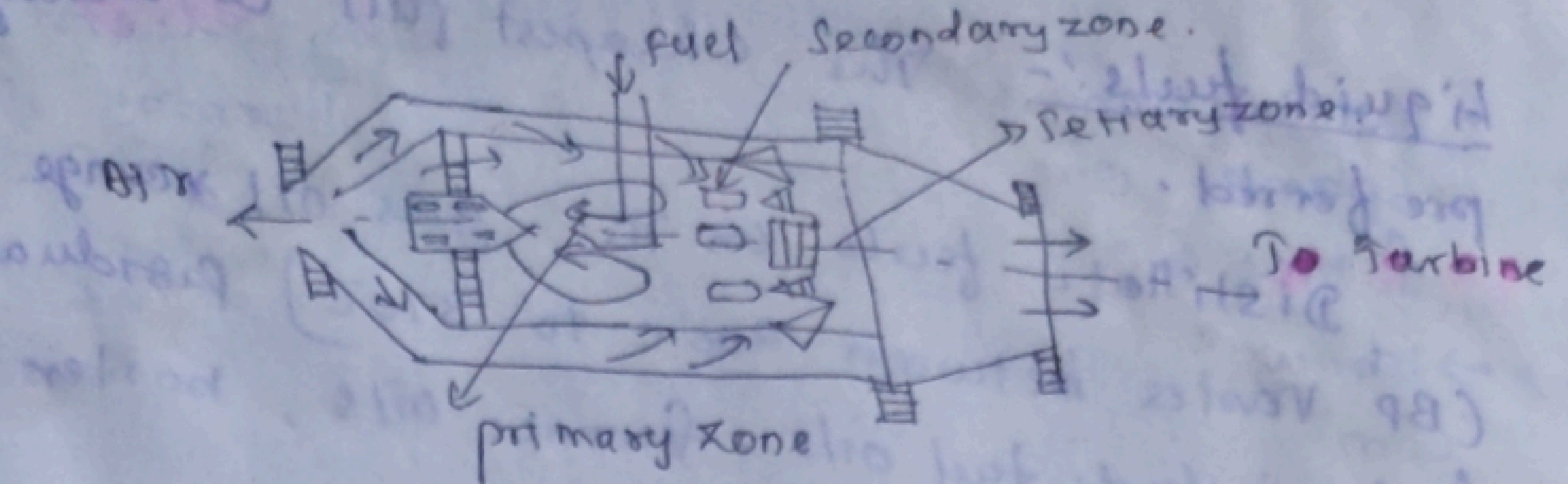
→ 30% fuel of total air is supplied through dilution holes in the secondary zone through the annulus round the flame tube to complete the combustion.

→ The secondary air not only helps to complete the combustion process but also helps to cool the flame tube.

→ The remaining 50% of air is mixed with burnt gases in the tertiary zone to cool the gases down to the temperature suited for the turbine blade turbines.

Bluff Body:-

Fuel is injected upstream in to the air flow and a sheet metal cone and perforated baffle plate ensure the necessary mixing of fuel and air. The low pressure zone created down stream side causes the reversal of flow along the axis of CC.



→ The air fuel ratio varies from 60/1 to 120/1 and air velocity at entry 75 m/s.

Combustion η = Theoritical fuel- air ratio for actual Temperature rise / Actual fuel air ratio for actual Temperature rise.

Gas Turbines:-

More stages are always preferred in gas turbine powerplants it helps to reduce the stresses in the blades. increases the overall life of the turbine.

Axial flow turbines are used.

Turbines are light weight, high efficiency reliability in operation, long working life.

Gas Turbine fuels:- (N/D - 13) (16M)

Natural gas:- It contains major percentage of methane and small percentage of ethane, propane butane. Sulphur compound (H_2S) is kept below 0.1 percent by volume.

Liquid fuels:- The cheapest fuel is always preferred.

Distillate fuels in the gas oil range (BP varies between 200°C to 370°C) Residual fuels include fuel oils, furnace oils, boiler fuel oils

Solid fuels:- coal → i) Integrated Gasification, where coal is completely or partially gasified and the fuel gas produced is consumed in the gas turbine combustor. ii) pressurized bubbling or circulating fluidized bed, where the fuel gas, after it is adequately filtered, expands in the gas turbine. Ceramic or others is the key to its use.

Gas Turbine materials:-

i) Materials must withstand high temp & high stress.

ii) It must have low creep rate.

iii) It must have high resistance to oxidation, corrosion, erosion.

iv) It must maintain structural stability.

Metals for turbine rotor discs:-

Steel - 12 to 18 %. Chromium
8 to 12 %. nickel.

Small percentage of tungsten.

Material for turbine rotor blade:-

Stainless steel alloy & 8-20 nickel Chromium alloys → Nimonic alloys.

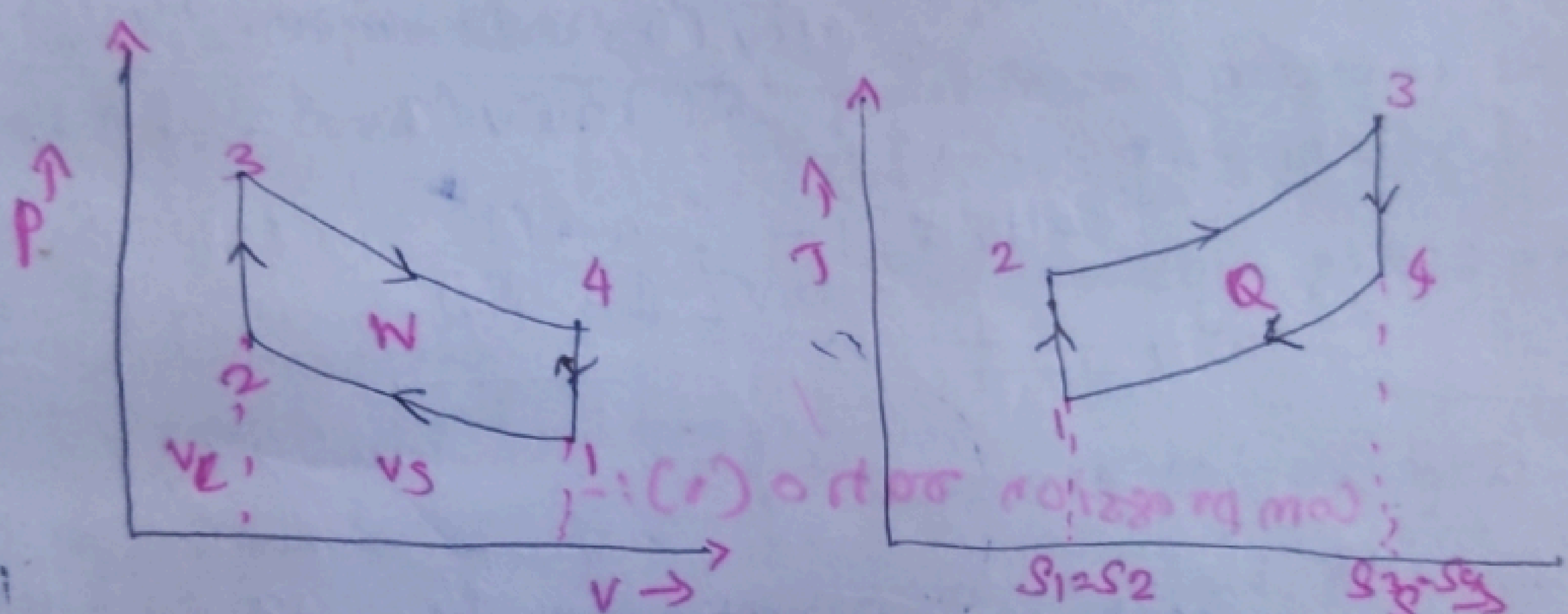
Material for combustion chamber - Nimonic 75 alloy. capacity to with stand heavy thermal Shock.

Material for Compressor:-

Aluminium alloys.

Axial flow - titanium alloys and are Strongly resistance to corrosion.

Otto cycle:-



process 1-2:-

Isentropic Compression process pr increases from P_1 to P_2 and temperature increases from T_1 to T_2. Volume decreases from V_1 to V_2 and entropy remains constant

process 2-3:-

process 2-3 is Constant volume heat addition process. pr increases P_2 to P_3 Temperature increase T_2 to T_3 entropy increases from S_2 to S_3. volume Constant $V_2 = V_3$.

process 3-4 :- Isentropic expansion process.

pressure decreases P_3 to P_4. The Temperature decreses T_3 to T_4. volume increases from V_3 to V_4.

process 4-1 :- Constant volume heat rejection process. pr decreases P_4 to P_1. Temperature decreases from T_4 to T_1. entropy decreases S_4 to S_1.

$$Q_R = mC_v(T_4 - T_1)$$

$$\eta = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{mC_v(T_3 - T_2) - mC_v(T_4 - T_1)}{mC_v(T_3 - T_2)}$$

$$\eta_{otto} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

Compression ratio (r) :-

Compression ratio is the ratio between the total cylinder volume and clearance volume.

$$r = \frac{V_1}{V_2} =$$

$$\eta_{otto} = 1 - \frac{1}{(r)^{\gamma - 1}}$$

Mean effective pressure (P_m) :-

$$k = \frac{P_4}{P_1} = \frac{P_3}{P_2}$$

$$P_m = \frac{\text{Workdone}}{\text{Stroke volume}}$$

$$\text{Workdone} = \frac{P_1 r}{\gamma - 1}\left(r^{\gamma-1} - 1\right)(k-1)$$

Stroke Volume = $V_1 - V_2$.

$$P_m = P_1 r \left(\frac{k-1}{\gamma-1}\right)\left(\frac{r^{\gamma-1}-1}{r-1}\right)$$

$$P_m = \frac{W}{V_1 - V_2}$$

- A Spark ignition engine working on ideal otto cycle has the compression ratio 6. The initial pressure and temperature of air are 1 bar and 37°C. The maximum pressure in the cycle is 30 bar. For unit mass flow calculate
  i) P, V and T at various salient points of the cycle and
  ii) the ratio of heat supplied to the heat rejected. Assume $\gamma = 1.4$ and $R = 8.314$ KJ/Kmol K.

Given data:-

$r = 6$, $P_1 = 1$ bar $= 100$ KN/m^2

$T_1 = 37°C = 37 + 273 = 310$ K

$P_3 = 30$ bar $= 3000$ KN/m^2.

Solution:-

Consider process 1-2 (adiabatic process):-

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}.$$

$$P_2 = \left(\frac{V_1}{V_2}\right)^{\gamma} \times P_1$$

$$= (6)^{1.4} \times 100 = 1228.6\ kN/m^2.$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \times T_1$$

$$= (6)^{1.4-1} \times 310 = 634.78K.$$

Consider process 2-3 Constant Volume process:-

$$\frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$$T_3 = \frac{P_3}{P_2} \times T_2 \Rightarrow \frac{3000}{100} \times 634.78$$

$$T_3 = 19043.4K$$

Consider process 3-4 (adiabatic process):-

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma}$$

$$= \left(\frac{V_3}{V_4}\right)^{\gamma} \times P_3 \Rightarrow \left(\frac{1}{6}\right)^{1.4} \times 3000$$

$$P_4 = 244.18\ KN/m^2$$

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$

$$= \left(\frac{V_3}{V_4}\right)^{\gamma-1} \times T_3 = \left(\frac{1}{6}\right)^{0.4} \times 19043.4$$

$T_4 = 9300 K$

Heat Supplied $Q_s = mc_v (T_3 - T_2)$

$= 1 \times 0.718 (19043.4 - 634.78)$

$Q_s = 13217.39 kJ/kg$

Heat Rejected $Q_R = mc_v (T_4 - T_1)$

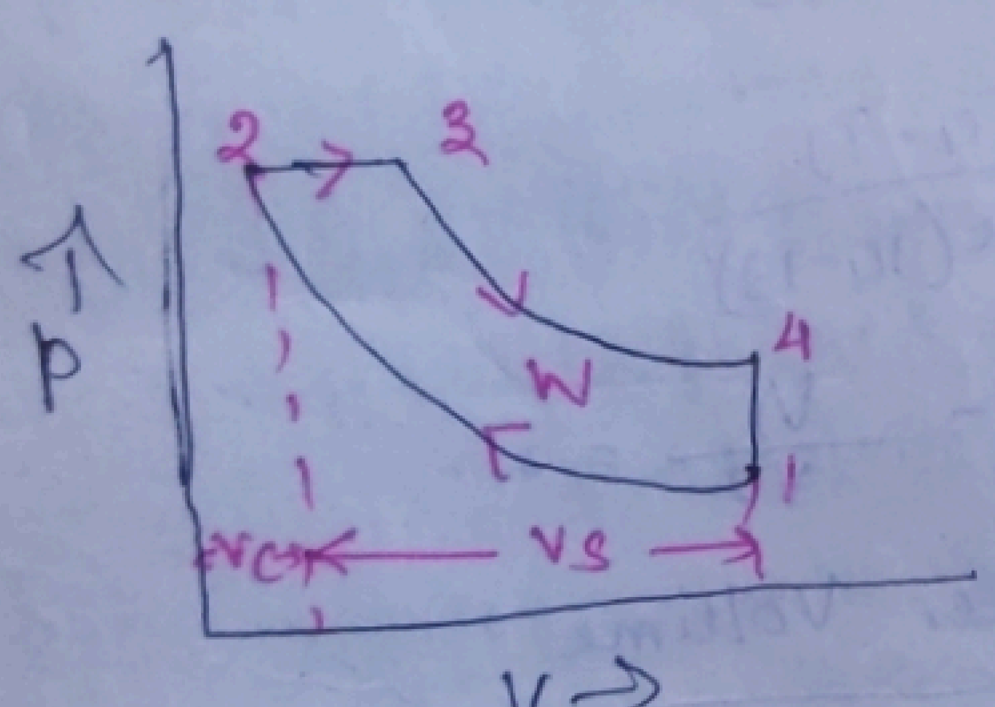
$= 1 \times 0.718 (9300 - 310)$

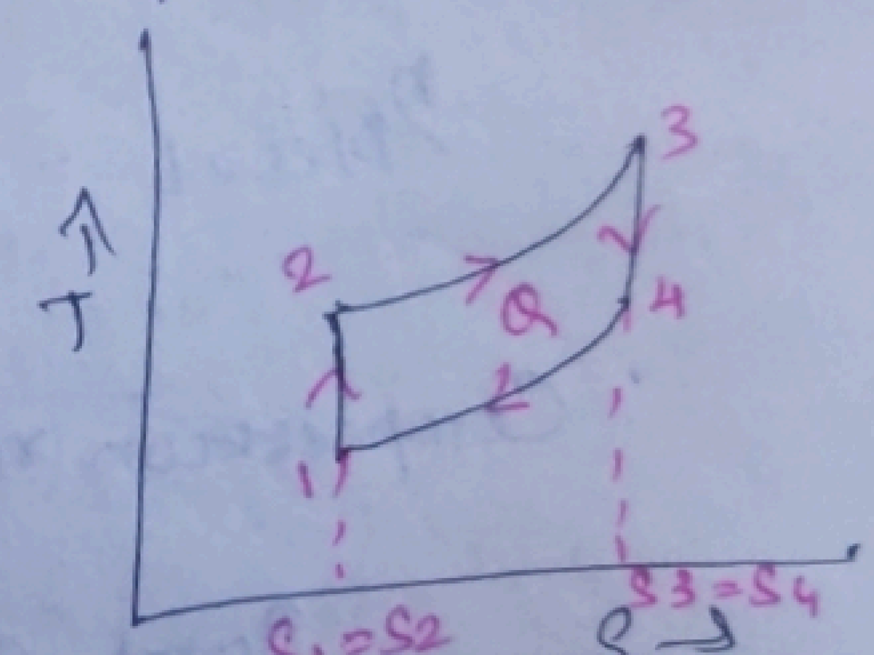
$Q_R = 6454.82 kJ/kg$

$\frac{Q_S}{Q_R} = \frac{13217.39}{6454.82} = 2.0848$

Diesel cycle:-

1. Two reversible adiabatic or isentropic
2. One constant volume.
3. One constant pressure processes.





process 1-2 - Isentropic Compression process.
During the process, the air is isentropically Compressed from P_1 to P_2. entropy remains constant ($S_1 = S_2$).

process 2-3 - constant pressure heat addition process:-
During the process the air is heated from

T_2 to T_3 but the pressure remains constant ($p_2 = p_3$)

$$Q_S = mc_p(T_3 - T_2)$$

process 3-4 Isentropic expansion process:-
During process, the air isentropically expands from p_3 to p_4. Temperature decreases from T_3 to T_4.

process 4-1:- Constant volume heat rejection process.

Temperature decreases from T_4 to T_1.

$$Q_R = mc_v(T_4 - T_1)$$

$$\eta_{Diesel} = \frac{Q_S - Q_R}{Q_S}$$

$$\eta_{Diesel} = 1 - \frac{T_4 - T_1}{\gamma(T_4 - T_3)}$$

Compression ratio - $\frac{V_1}{V_2} = r$.

$$= \frac{\text{Total cylinder volume}}{\text{Clearance volume}}$$

Cut off ratio - Ratio between volume at the point of cut off and clearance volume.

$$\text{Cut off ratio } \rho = \frac{\text{Cut off volume}}{\text{Clearance volume}} = \frac{V_3}{V_2}$$

$$\text{Expansion ratio} = \frac{V_4}{V_3} = r/\rho$$

$$\eta_{Diesel} = 1 - \frac{1}{\gamma r^{\gamma-1}}\left(\frac{\rho^{\gamma}-1}{\rho-1}\right)$$

$$P_m = \frac{p_1 r^{\gamma}\left[\gamma(\rho-1) - r^{1-\gamma}(\rho^{\gamma}-1)\right]}{(\gamma-1)(r-1)}$$

In an air standard diesel cycle, The pressure and temperature of air at the beginning of cycle are 1 bar and 40°C. The Temperatures before and after the heat supplied are 400°C and 1500°C. Find the air standard efficiency and mean effective pressure of the cycle. What is the power output if it makes 100 cycles/min?

Given data:- $p_1 = 1\,bar = 100\,kN/m^2$

$T_1 = 40°C = 40 + 273 = 313K$

$T_2 = 400°C = 673K$.

$T_3 = 1500°C = 1773K$.

Solution:- Consider the process 1-2 Isentropic compression)

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

Compression ratio,

$$r = \frac{v_1}{v_2} = \left(\frac{T_2}{T_1}\right)^{1/\gamma-1} = \left(\frac{673}{313}\right)^{1/1.4-1} = 6.779.$$

Consider the process 2-3 Constant Pressure heating,

$$\frac{v_2}{T_2} = \frac{v_3}{T_3}$$

Cut off ratio $\rho = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{1773}{673} = 2.634$.

$$\eta = 1 - \frac{1}{\gamma (r)^{\gamma-1}} \left(\frac{\rho^{\gamma}-1}{\rho - 1} \right)$$

$$= 1 - \frac{1}{1.4 (6.779)^{1.4-1}} \left(\frac{2.634^{1.4}-1}{2.634-1} \right)$$

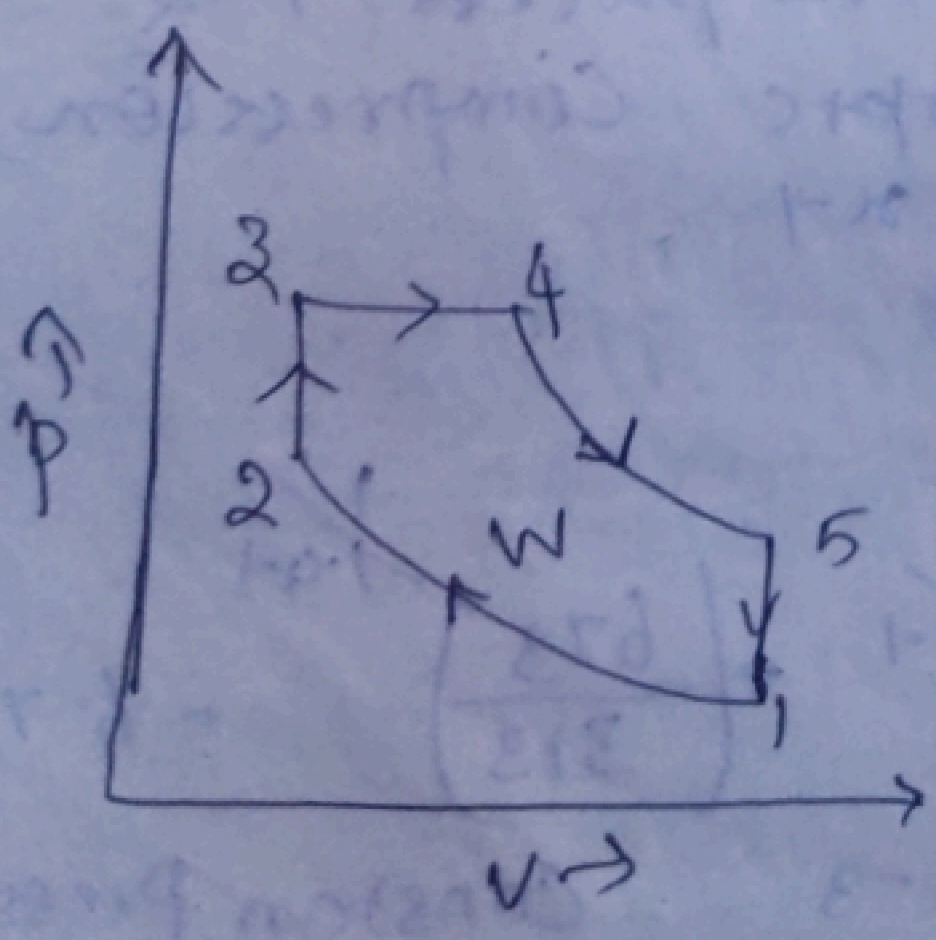
$$\boxed{\eta = 41.42\%}$$

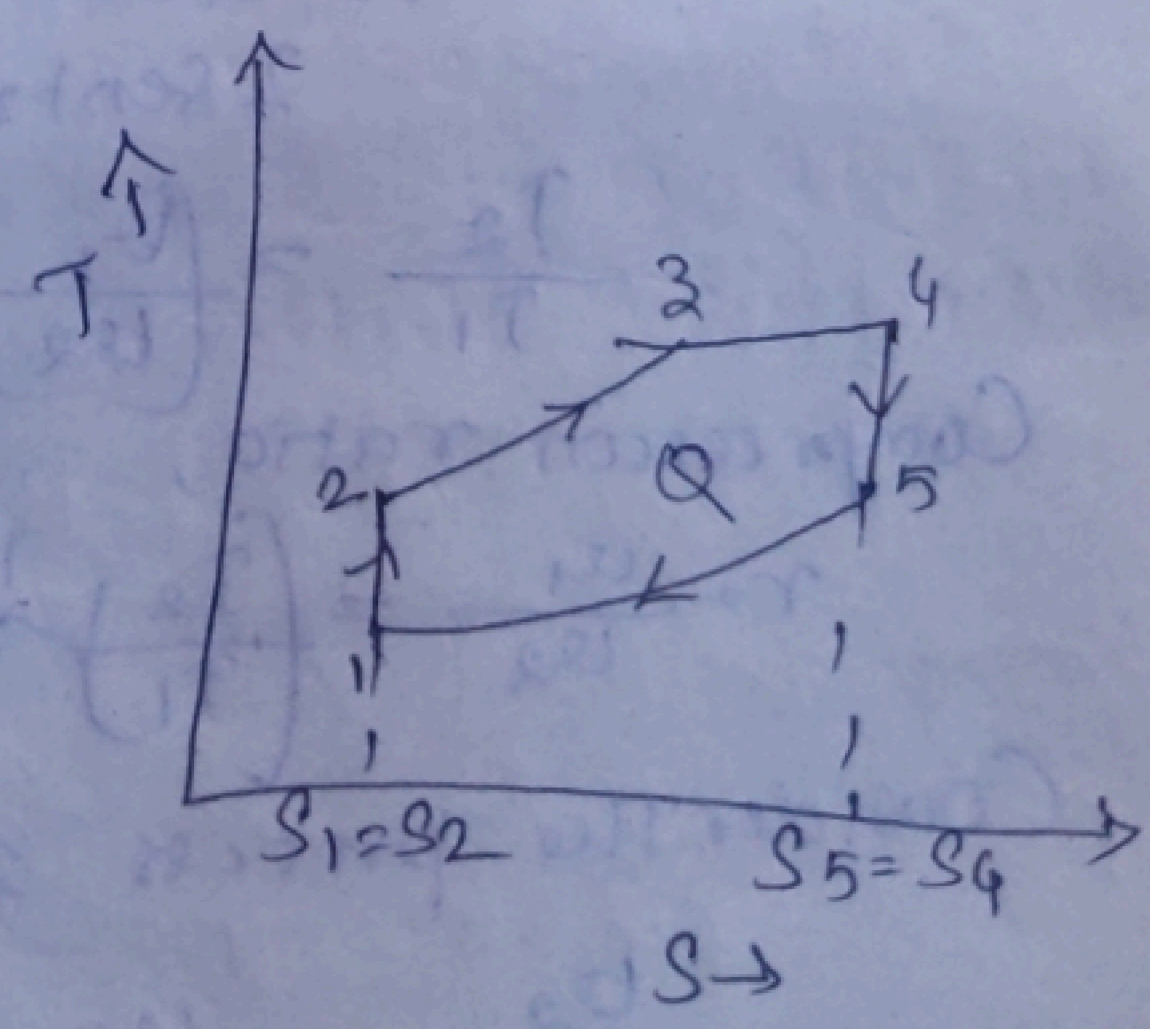
Dual cycle: -

1. Two reversible adiabatic or Isentropic
2. Two constant volume
3. One constant pressure processes.

process 1-2 - Isentropic compression process.

During the process, The air is isentropically Compressed from P_1 to P_2. entropy remains constant $S_1 = S_2$.





process 2-3 Constant volume heat addition process:-

The compressed air is partially heated by constant volume process $V_2 = V_3$. Both temperature and entropy increases T_2 to T_3, S_2 to S_3.

$$Q_{S_1} = mC_V (T_3 - T_2)$$

process 3-4 - constant pressure heat addition process.

The partially heated air is then heated by constant pressure process $P_3 = P_4$. Both temperature and entropy increase from T_3 to T_4 and S_3 to S_4.

$$Q_{S_2} = mC_P (T_4 - T_3).$$

process 4-5 - Isentropic expansion process:-

During the process the heated air isentropically expands from P_4 to P_5. Temperature decreases T_4 to T_5.

process 5-1 - Constant volume heat rejection process:- Temperature decreases from S_5 to S_1. The system attain its original position.

$$Q_R = mC_V (T_5 - T_1)$$

$$Q_S = Q_{S_1} + Q_{S_2} = mC_V (T_3 - T_2) + mC_P (T_4 - T_3)$$

$$\eta = \frac{W}{Q_S}$$

$$\eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma (T_4 - T_3)} \quad \left(\frac{C_P}{C_V} = \gamma\right)$$

Compression ratio $r = \frac{V_1}{V_2}$

pressure ratio $k = \frac{P_3}{P_2}$

Cut off ratio $\rho = \frac{V_4}{V_3}$

$$\begin{bmatrix} V_5 = V_1 \\ V_3 = V_2 \end{bmatrix}$$

Expansion ratio $= \frac{V_5}{V_4} = \frac{V_1}{V_4} = \frac{V_1}{V_2} \times \frac{V_2}{V_4}$

$$= \frac{V_1}{V_2} \times \frac{V_3}{V_4} = \frac{r}{\rho}.$$

$$\eta_{Dual} = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{k\rho^{\gamma} - 1}{(k-1) + \gamma k(\rho - 1)} \right]$$

$$P_m = \frac{P_1 r^{\gamma} \left[k\gamma(\rho-1) + (k-1) - r^{1-\gamma}(k\rho^{\gamma} - 1) \right]}{(\gamma-1)(r-1)}$$

In engine working on a dual cycle, the temperature and pressure at the beginning of the cycle are 90°C and 1 bar. The compression ratio is 9. The maximum pressure is limited to 68 bar and total heat supplied per kg of air is 1750 kJ. Determine the air standard efficiency and mean effective pressure.

Given data:-

$P_1 = 1\,bar$,

$T_1 = 90°C = 363\,K$.

$p_3 = p_4 = 68$ bar
$r = 9$
$Q_s = 1750$ KJ/kg.

Solution:- Isentropic compression process,

$p_2 = (r)^{\gamma} \times p_1 = (9)^{1.4} \times 1 = 21.67$ bar

$T_2 = (r)^{\gamma-1} \times T_1 = (9)^{0.4} \times 363 = 874$ K.

$T_3 = \left(\frac{p_3}{p_2}\right) T_2 \Rightarrow \frac{68}{21.67} \times 874 = 2743$ K.

Constant pressure heat addition process,

$Q_s = C_v (T_3 - T_2) + C_p (T_4 - T_3)$

$1750 = 0.718 (2743 - 874) + 1.005 (T_4 - 2743)$

$T_4 = 3149$ K.

$v_1 = \frac{RT_1}{P_1} = \frac{287 \times 363}{1 \times 10^5} = 1.04181$ m3/kg

$v_3 = v_2 = \frac{v_1}{r} = \frac{1.04181}{9} = 0.11576$ m3/kg

$v_4 = \left(\frac{T_4}{T_3}\right) v_3$

$= \left(\frac{3149}{2743}\right) 0.11576 = 0.132894$ m3/kg

$\rho = \frac{v_4}{v_3} = \frac{0.13289}{0.11576} = 1.148$

$k = \frac{p_3}{p_2} = \frac{68}{21.67} = 3.138$.

$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{k\rho^{\gamma} - 1}{(k-1) + k\gamma(\rho-1)}\right]$

$$= 1 - \frac{1}{(9)^{1.4-1}}\left[\frac{3.138 \times 1.148^{1.4} - 1}{(3.138-1) + 3.138 \times 1.4(1.148)}\right]$$

$= 58.19\%$.

$W_{net} = \eta \times Q_s$

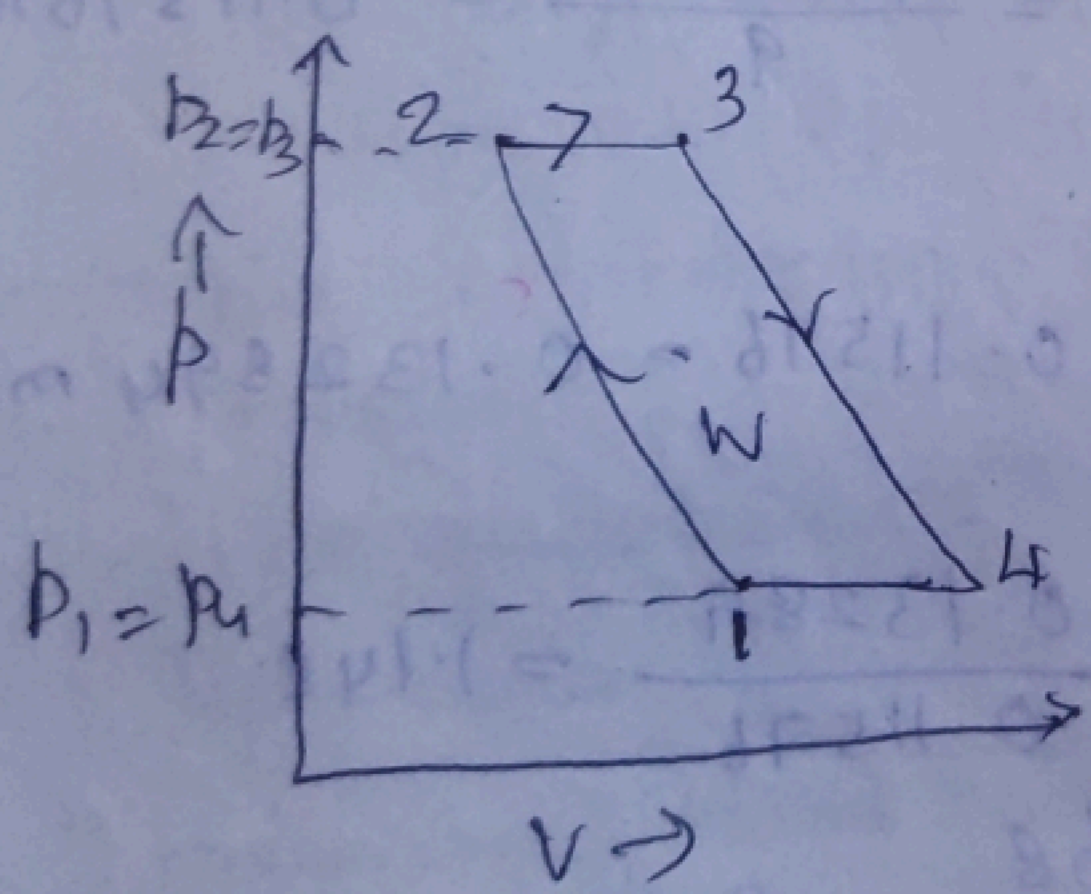
$= 0.5819 \times 1750 = 1018.33 \text{ kJ/kg}$.

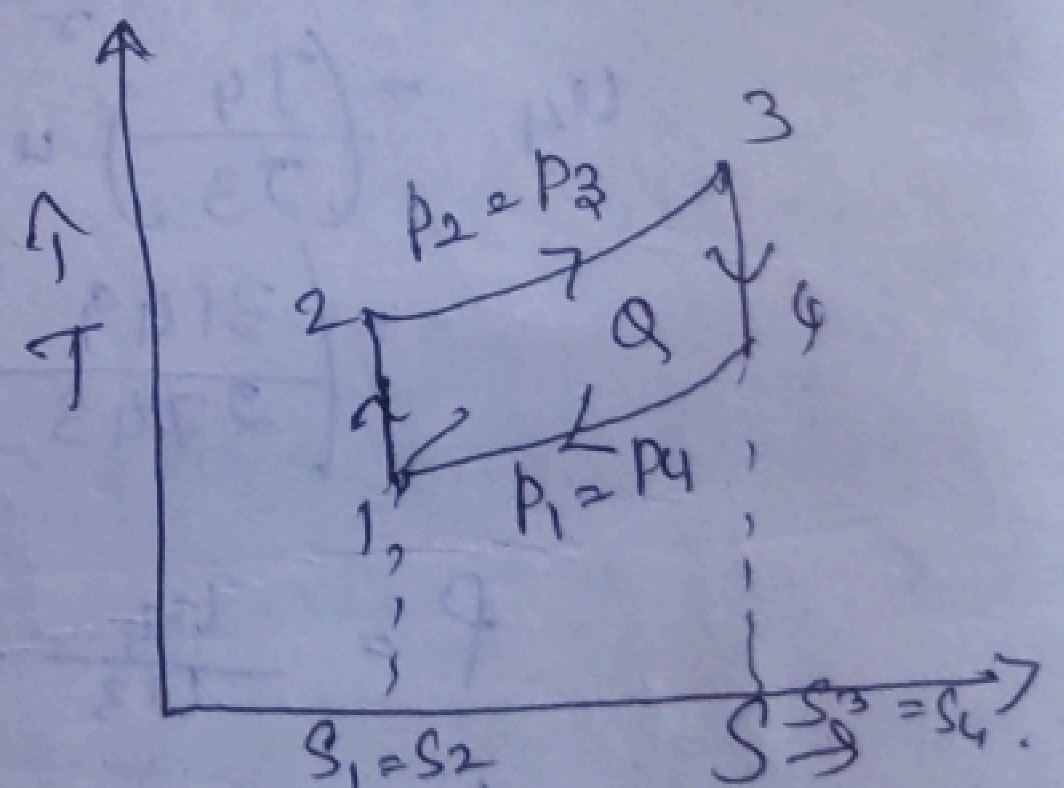
$$P_m = \frac{W_{net}}{v_1 - v_2} = \frac{1018.33}{1.04181 - 0.11576}$$

$$\boxed{P_m = 10.98 \text{ bar}}$$

Brayton Cycle or Joule Cycle:-

It consists of two reversible adiabatic processes and two constant pressure processes. This cycle is therefore also called constant pressure cycle.





⇒ Brayton cycle is the Theoritical cycle for gas turbines.

process 1-2 Isentropic compression process.

$W_C = mc_p(T_2 - T_1)$

pressure increases P_1 to P_2 and Temperature increases T_1 to T_2, volume reduces to V_1 to V_2.

2-3 - Constant pressure heat addition process.

The compressed air is passed through the combustion chamber where the fuel is injected and burned at constant pressure P_2 and temperature increases from T_2 to T_3

$$Q_S = mc_p(T_3 - T_2)$$

3-4 Isentropic expansion process,

$$W_T = mc_p(T_3 - T_4)$$

process 4-1 => constant pressure heat rejection process.

$$Q_R = mc_p(T_4 - T_1)$$

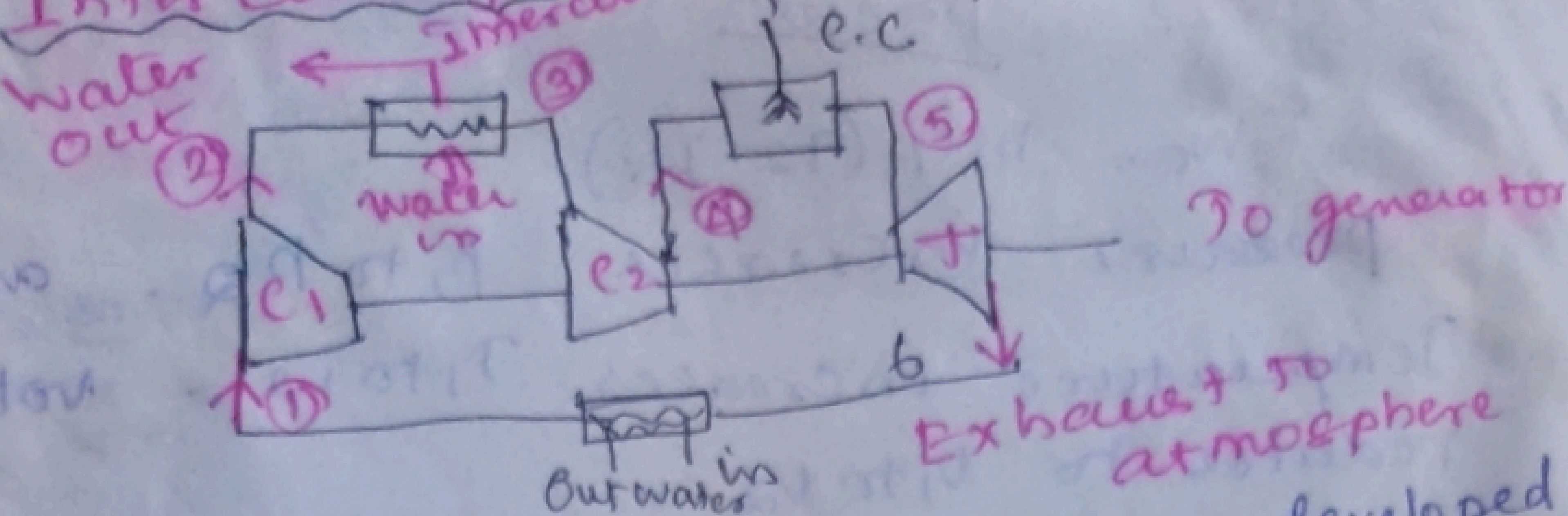
$$\eta_{Brayton} = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S}$$

$$\boxed{\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}}$$

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

$$R_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}.$$

Inter cooling:-



Major percentage of power developed (66%) by the turbine is used to run the compressor. ~~The power required to run the →~~

Isentropic compression,

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$$T_2 = T_1 (r)^{\gamma-1}$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$$T_3 = T_4 (r)^{\gamma-1}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}, \quad T_3 = T_4 (R_P)^{\frac{\gamma-1}{\gamma}}$$

$$\eta = 1 - \frac{T_4 - T_1}{T_4 (R_P)^{\frac{\gamma-1}{\gamma}} - T_1 (R_P)^{\frac{\gamma-1}{\gamma}}}$$

$$\boxed{\eta_{Brayton} = 1 - \frac{1}{(R_P)^{\frac{\gamma-1}{\gamma}}}}$$

$$\eta_{Brayton} = 1 - \frac{1}{(r)^{\gamma-1}}$$

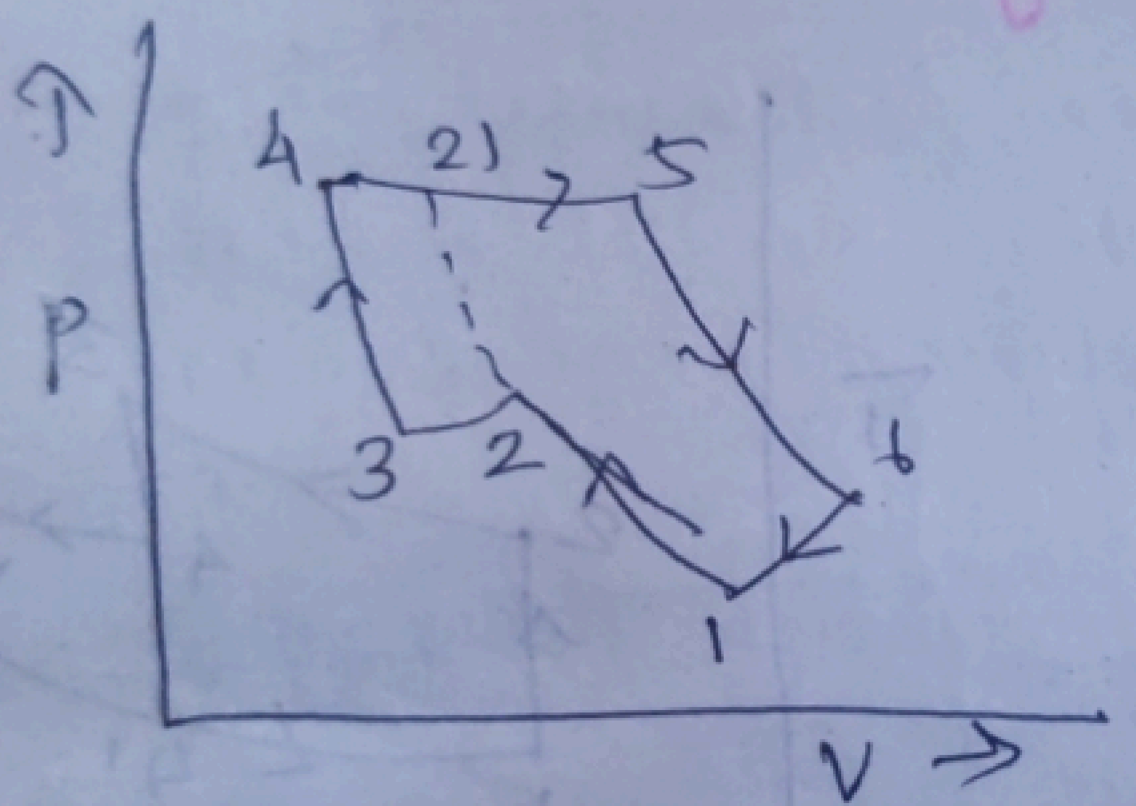
Work ratio:-

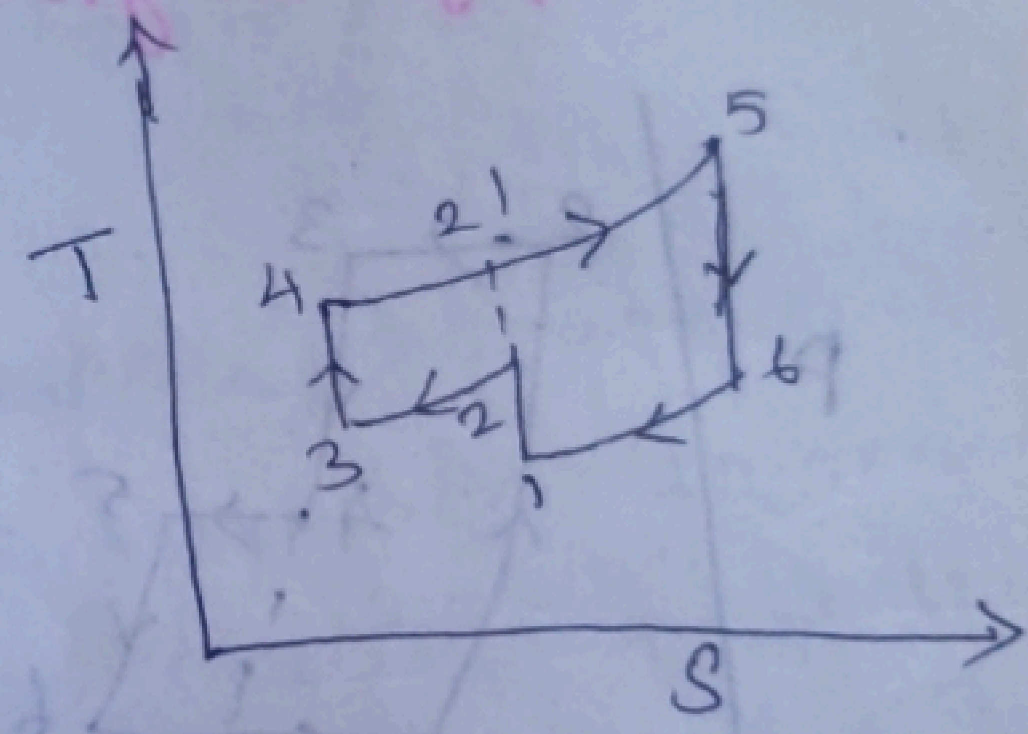
$$\text{work ratio} = \frac{\text{Net work transfer}}{\text{positive work transfer}}$$

$$= 1 - \frac{T_1\left((R_p)^{\frac{\gamma-1}{\gamma}} - 1\right)}{T_3\left[1 - \frac{1}{(R_p)^{\frac{\gamma-1}{\gamma}}}\right]}$$

$$\text{Work ratio} = 1 - \frac{T_1}{T_3}(R_p)^{\frac{\gamma-1}{\gamma}}$$

Inter cooling:-





$$W_T = C_p(T_5 - T_6)$$

$$W_C = C_p(T_2 - T_1) + C_p(T_4 - T_3)$$

$$\text{Network} = W = W_T - W_C$$

for perfect inter cooling $T_1 = T_3$ and $T_2 = T_4$.

Intermediate pressure for perfect intercooling

$$P_3 = P_2 = \sqrt{P_1 \times P_4} = \sqrt{P_5 \times P_6}$$

Brayton cycle with Reheater :-

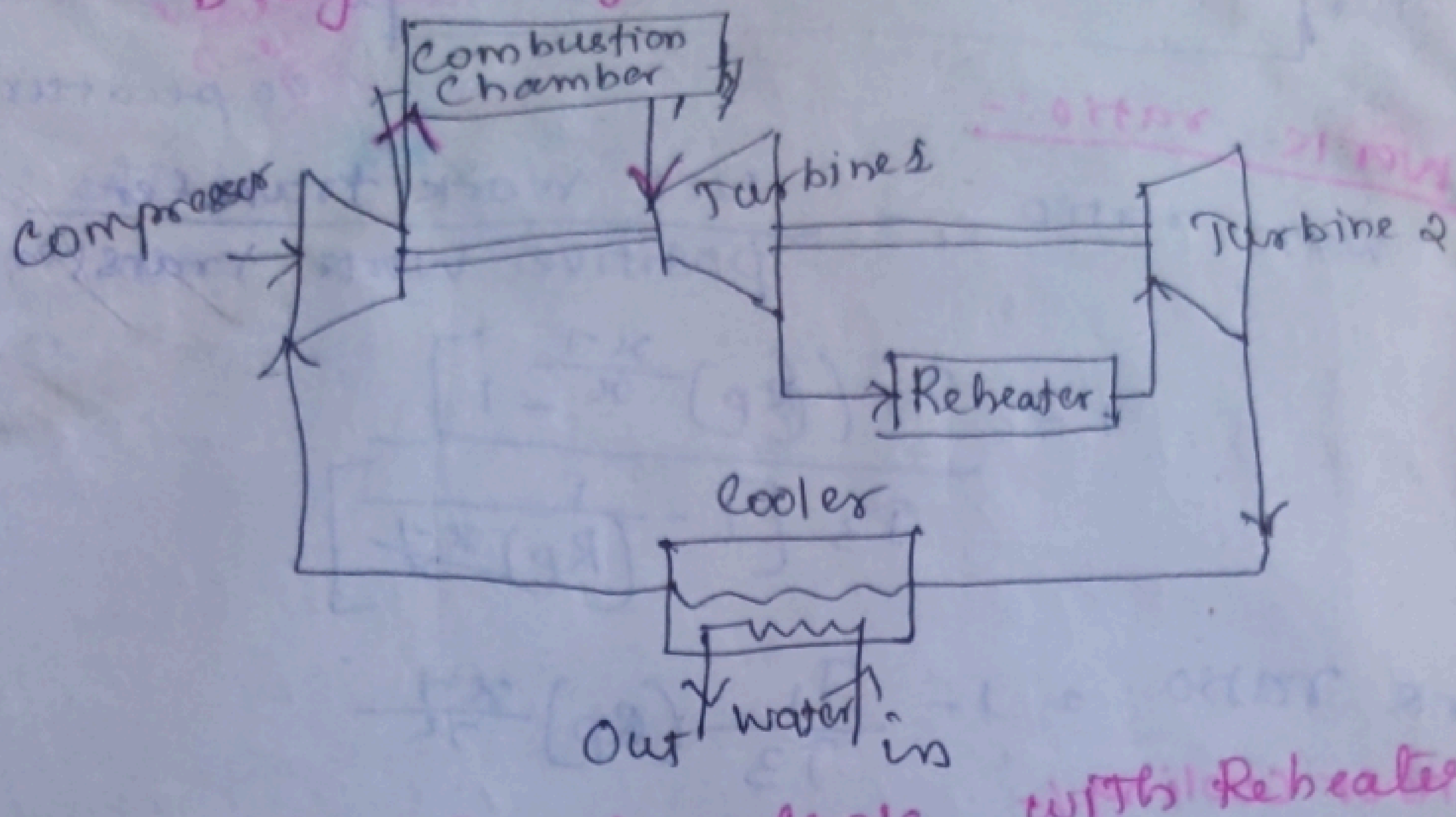
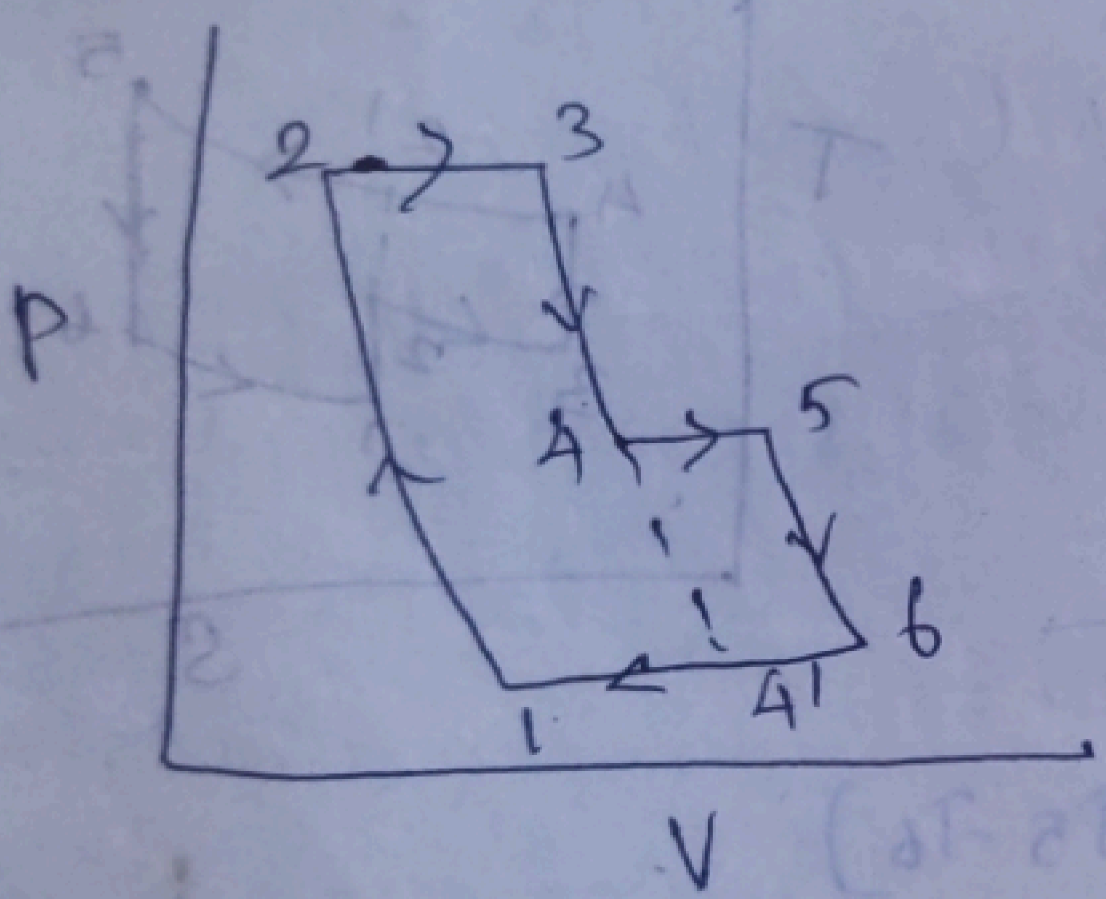
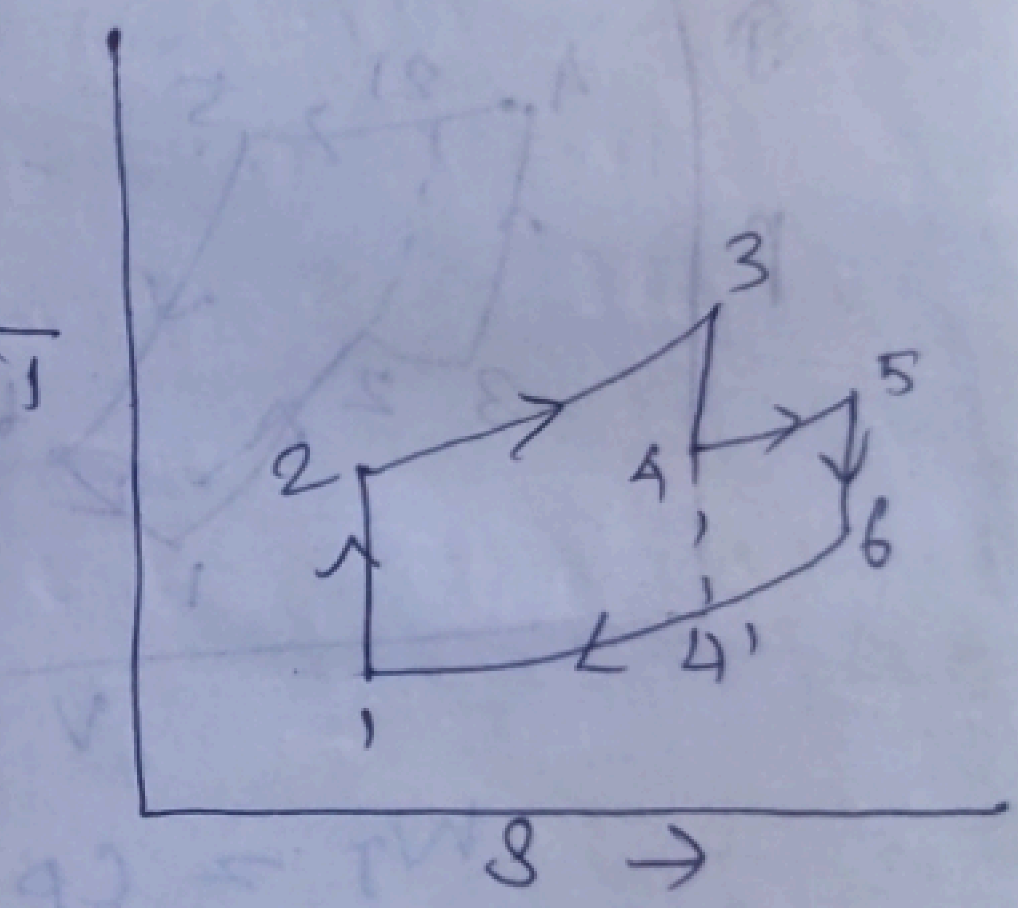


Fig: Brayton cycle with Reheater





$$W_C = C_p(T_2 - T_1)$$

$$W_T = C_p(T_3 - T_4) + C_p(T_5 - T_0)$$

Network W_I $W_T - W_C$

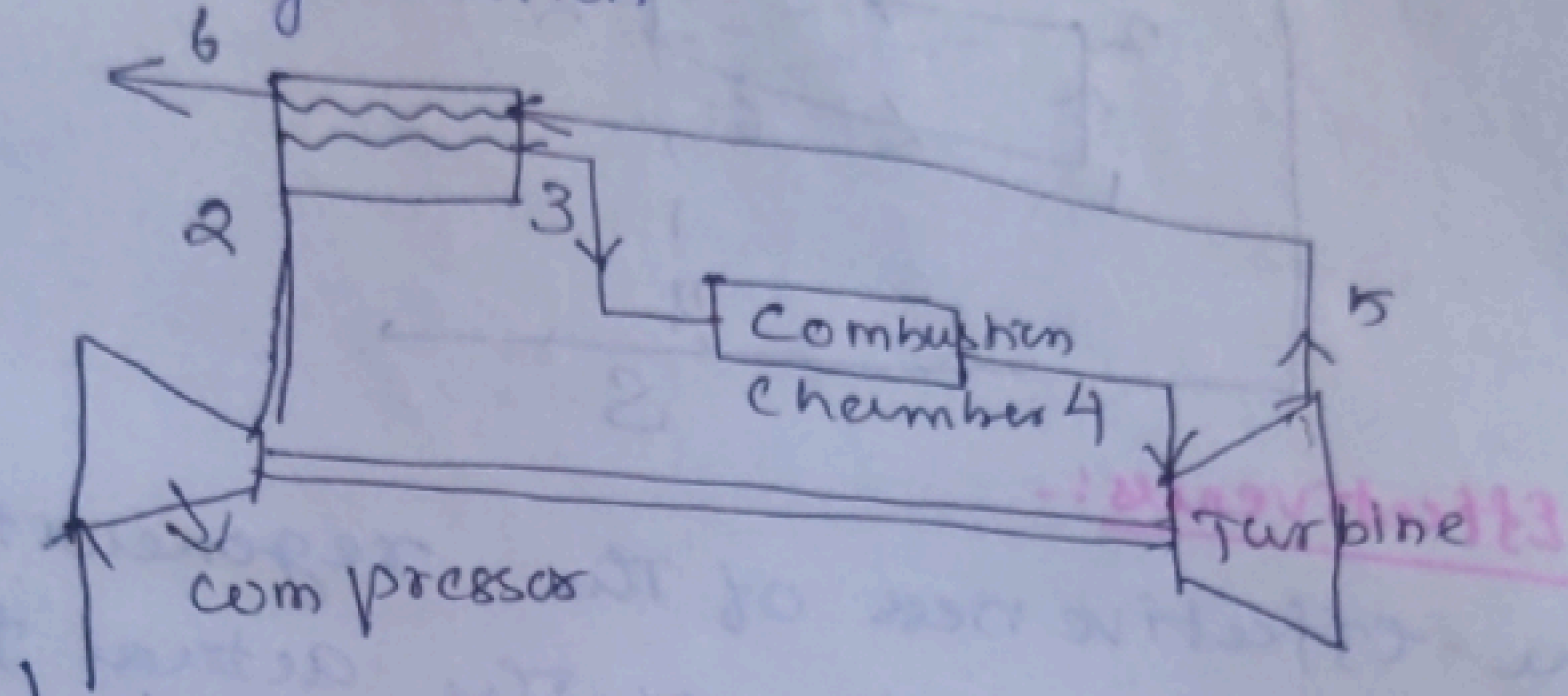
For obtaining maximum work $\frac{P_3}{P_4} = \frac{P_5}{P_6}$

$$P_4 = P_5 = \sqrt{P_3 \times P_6} = \sqrt{P_1 \times P_2}$$

$$\begin{bmatrix} P_1 = P_6 \\ P_2 = P_3 \end{bmatrix}$$

Brayton with Regeneration:-

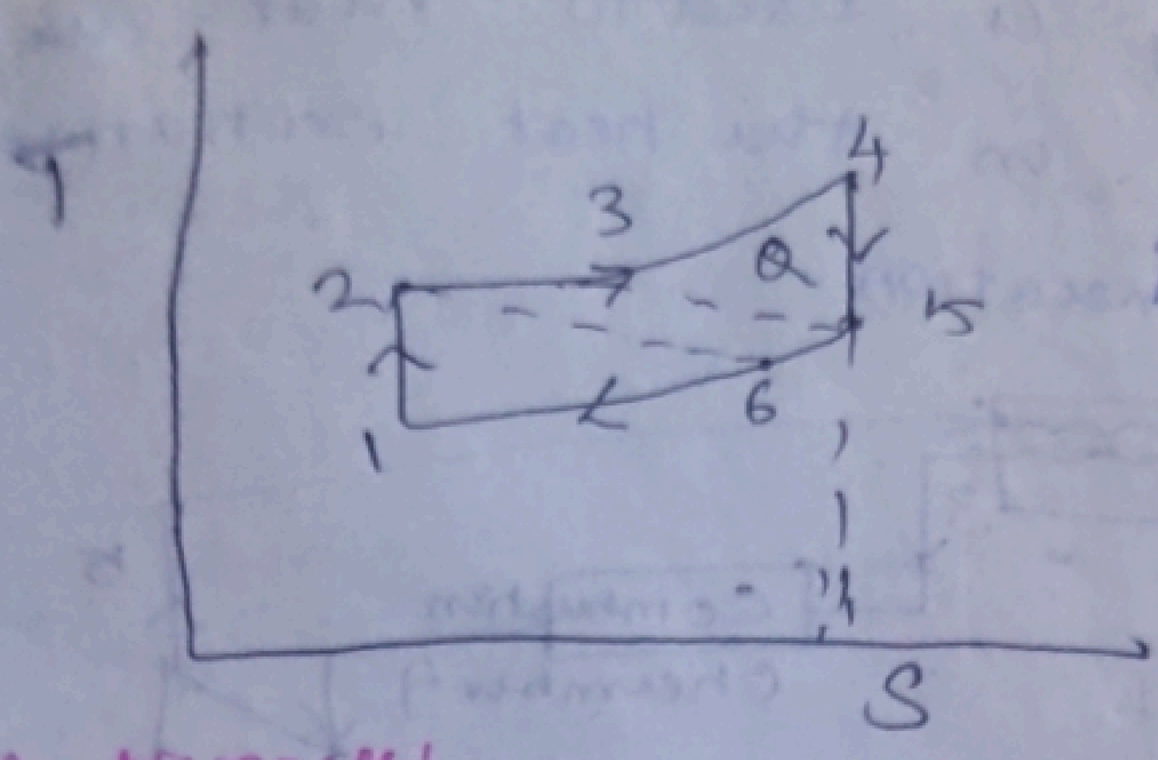
The temperature of the exhaust gases of the turbine is higher than the temperature of the air after compression; If the Heat energy is used to heat air after compression in the heat exchanger. It is called regeneration.



Air is drawn from the atmospher into the compressor and isentropically compressed to state 2. It is then healed at constant pressure in the regenerator to state 3 by the exhaust gases from the turbine.

Since the temperature of the air is increased before it reaches the combustion chamber, less amount of fuel will be required to attain the designed turbine inlet temperature of the products of combustion

After the combustion at constant pressure in the combustion chamber the gas enters the turbine at state 4. and expands to 5. It then enters the regenerator the stack earlier. exhaust gives a portion of its heat energy to the compressed air from the compressor and leaves the regenerator at state 6



Ideal = $T_3 = T_5$

Effectiveness:-

The effectiveness of the regenerator is given by the ratio of the actual temperature rise to the maximum possible rise.

$$\text{Effectiveness } \epsilon = \frac{T_3 - T_2}{T_5 - T_6} = \frac{T_3 - T_2}{T_5 - T_2} \quad (T_2 = T_6)$$

$$Q_S = C_p(T_4 - T_3)$$

$$Q_R = C_p(T_6 - T_1)$$

$$W_T = C_p(T_4 - T_5), \quad W_C = C_p(T_2 - T_1)$$

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{T_6 - T_1}{T_4 - T_5}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_5}{T_4} = \left(\frac{P_5}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

η =

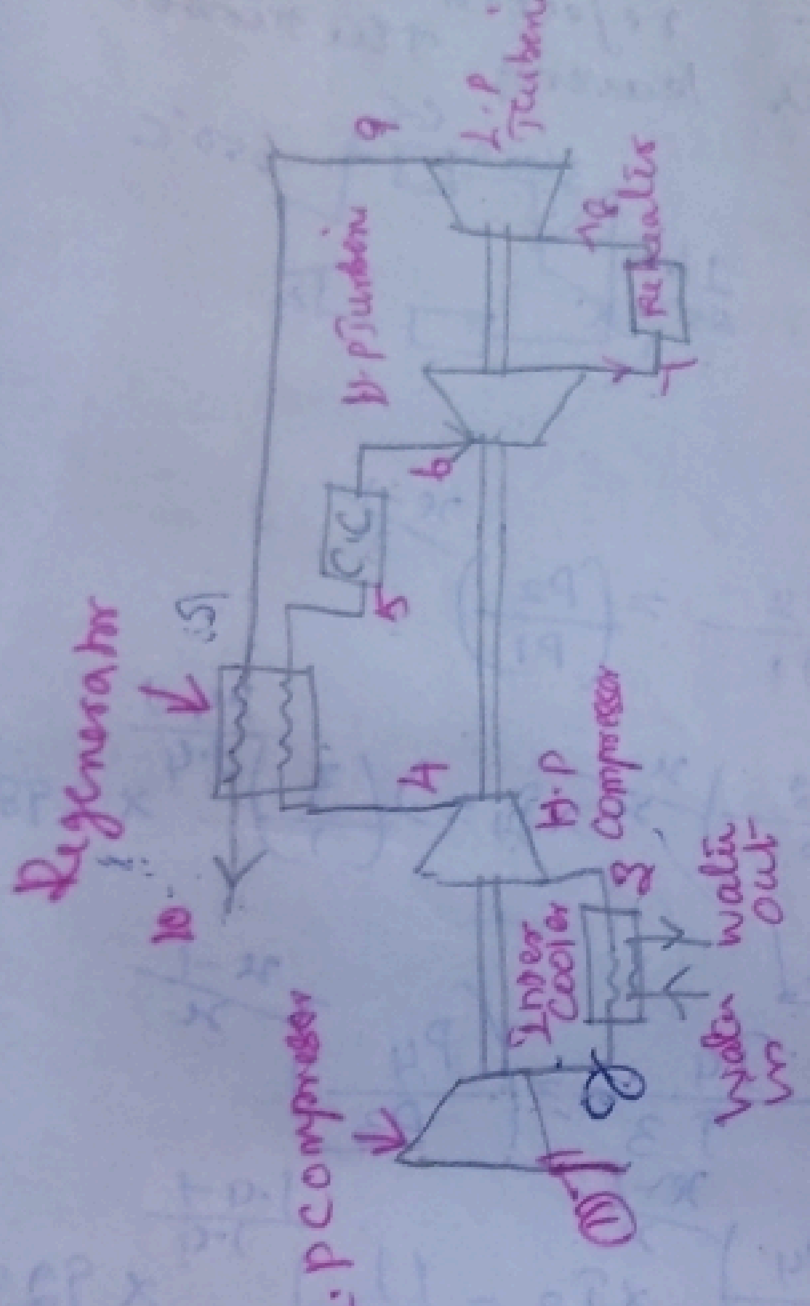
Brayton and R

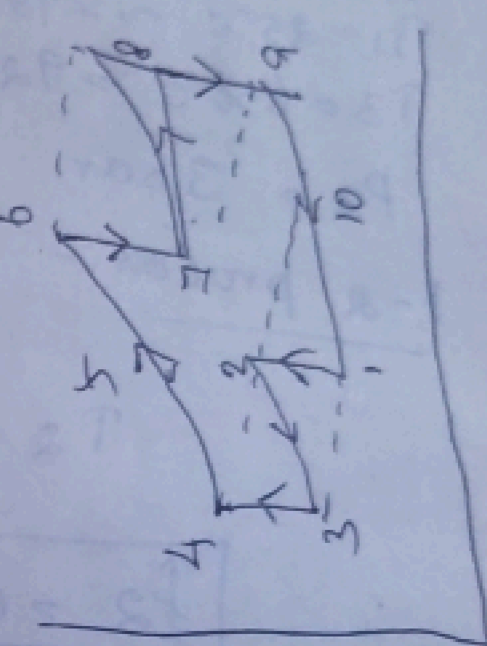
Regenerator

$$\eta = 1 - \frac{T_1}{T_4}\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\boxed{\eta = 1 - \frac{T_1}{T_4}(R_P)^{\frac{\gamma-1}{\gamma}}}$$

Brayton Cycle with inter cooling, Reheating and Regenerations:-





$$W_C = C_P(T_2 - T_1) + C_P(T_4 - T_3)$$

$$W_T = C_P(T_6 - T_7) + C_P(T_8 - T_9)$$

$$W = W_T - W_C$$

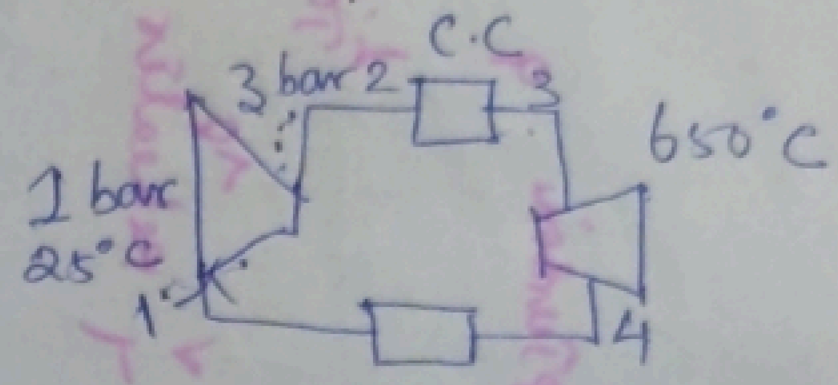
$$Q_S = C_P(T_6 - T_5) + C_P(T_8 - T_7)$$

$$Q_R = C_P(T_{10} - T_1) + C_P(T_2 - T_3)$$

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{(T_6 - T_5) + (T_8 - T_7)}{(T_{10} - T_1) + (T_2 - T_3)}$$

In a Brayton cycle, the air enters the compressor at 1 bar and 25°C. The pressure of air leaving the compressor is 3 bar and temperature at turbine inlet is 650°C. Determine per kg of air i) cycle efficiency, heat supplied to air, work input, heat rejected in the cooler, temperature of air leaving the turbine.

Solution:-



$P_1 = 1$ bar

$T_1 = 25°C = 298 K$

$T_3 = 650°C = 923 K$.

$P_2 = 3$ bar.

1-2 process:- $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \times T_1 \Rightarrow \left(\frac{3}{1}\right)^{\frac{1.4-1}{1.4}} \times 298$

$T_2 = 408 K$

3-4 process:- $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$

$T_4 = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} \times T_3 = \left(\frac{1}{3}\right)^{\frac{1.4-1}{1.4}} \times 923$

$T_4 = 674.3 K$

$\eta = 1 - \frac{1}{(R_p)^{\frac{\gamma-1}{\gamma}}}$

$= 1 - \frac{1}{(3)^{\frac{1.4-1}{1.4}}}$

$\eta = 26.94\%$

$Q_S = C_p(T_3 - T_2) \Rightarrow 1.005\,(923 - 408)$

$Q_S = 517.575\ kJ/kg$

$Q_R = C_p(T_4 - T_1) \Rightarrow 1.005\,(673.4 - 298)$

$Q_R = 377.277\ kJ/kg$

$W_C = C_p(T_2 - T_1) = 1.005\,(408 - 298)$
$= 110.55\ kJ$

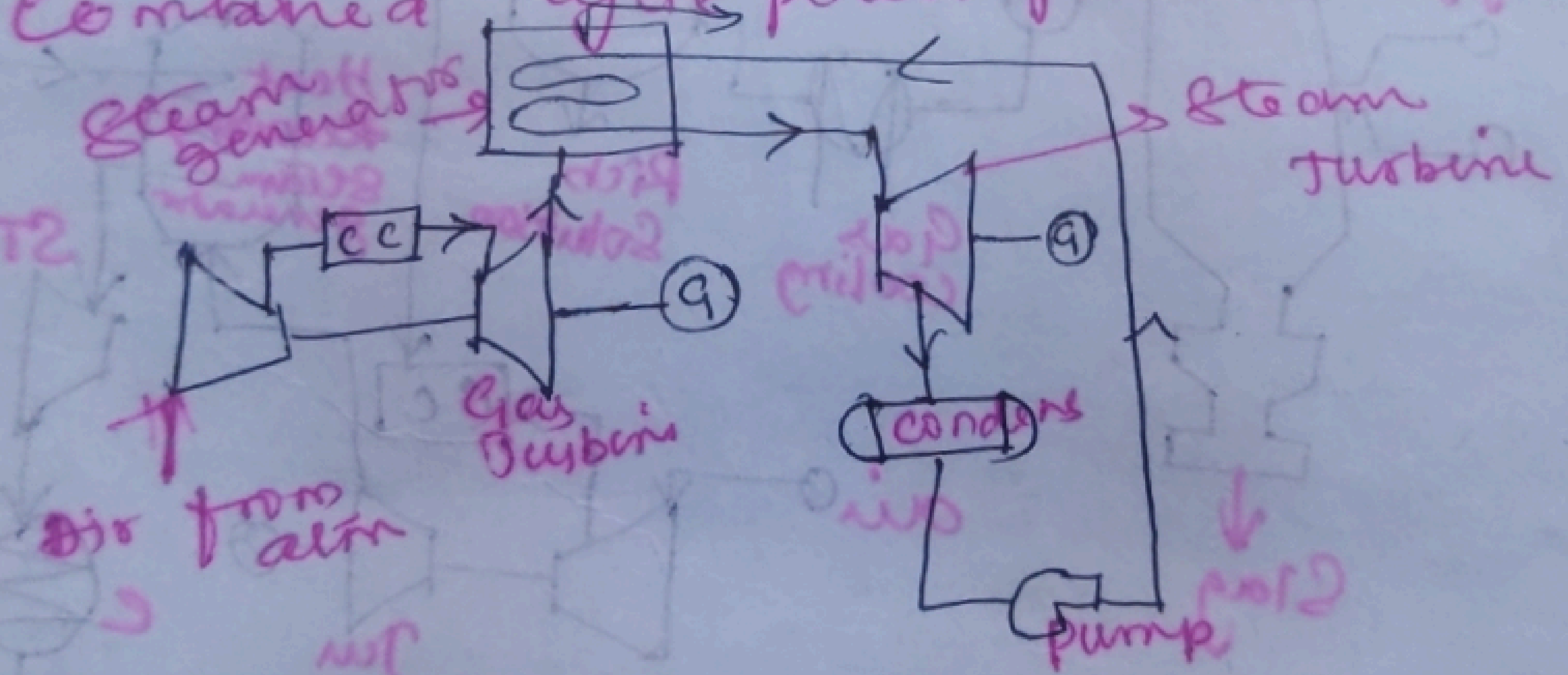
$W_T = C_p(T_3 - T_4) = 1.005\,(923 - 673.4)$
$= 250.848\ kJ$

Work output $W = W_T - W_C$
$= 250.848 - 110.55$
$= 140.298\ kJ/kg$

Temperature of air leaving the turbine,

$T_4 = 673.4\ K$

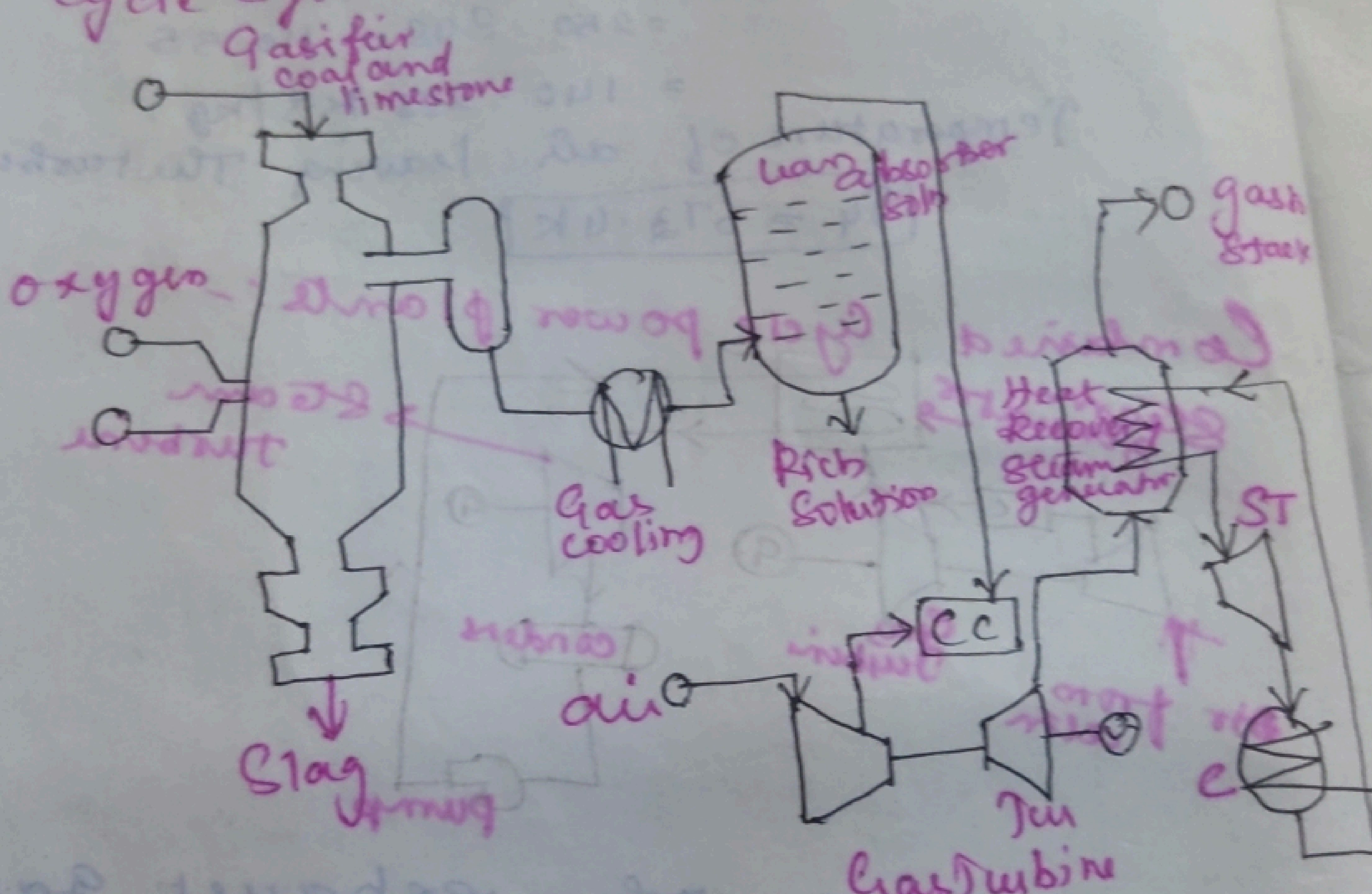
Combined cycle power plants :-



The heat in the exhaust gases of a simple gas turbine plant can be used to generate steam in waste heat Boiler. The regenerator is replaced by waste heat Boiler.

• The heat in the exhaust and O_2 carried with the exhaust gases be are used in the waste heat Boiler by supplying the fuel in the combustion chamber. The secondary steam generated is used with steam power plant.

Integrated Gasifier based Combined Cycle systems:-



Coal is gasified, synthetic gas produced after clean up is burnt in the Combustion chamber of the gas turbine. It is called an

Integrated gasification combined cycle (IGCC). Coal and lime stone are fed to a pressure vessel. The coal being gasified by oxygen and steam. The use of air instead of oxygen produces a gas of lower calorific value. The exhaust gases from the GT raise steam in the heat recovery steam generator (HRSG).

- A gas turbine power plant takes air in 15°C and 1.01 bar and the pressure ratio is 6. The Isentropic efficiencies of the compressor and turbin

- In a gas turbine power plant working on Brayton cycle. The inlet air temp 30°C and pr 1.0 bar. pressure ratio 6.25 maximum temp 827°C. Find compressor work, turbine work, cycle η, work ratio.

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{x-1}{x}} = 6.25)^{\frac{1.4-1}{1.4}} = 511.5K.$$

$$3\text{-}4, \quad \frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{x-1}{x}}.$$

$$T_4 = \left(1/6.25\right)^{\frac{x-1}{x}} \times 1100 = 651.63K$$

$W_C = C_P (T_2 - T_1) = 1.005 (511.5 - 303)$

$= 209.54$ kJ/kg

$W_T = C_P (T_3 - T_4) = 1.005 (1100 - 651.63)$

$= 450.61$ kJ/kg.

$\eta = 1 - \frac{1}{(R_P)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{(6.25)^{\frac{1.4-1}{1.4}}} =$

$0.4076 = 40.76$

$WR = \frac{\text{Net work}}{\text{Gross work}} = \frac{450.61 - 209.54}{450.61} =$

0.535

$1 - \frac{T_1}{T_2} = 1 - \frac{303}{1100} = 0.7245 = 72.46\%$

Increase in $\eta = 72.46 - 40.76 = 31.7\%$

$= \frac{72.46 - 40.76}{72.46} = 43.75\%$

UNIT - III

Basics of Nuclear Engineering, layout and Subsystems of Nuclear power plants, working of Nuclear Reactors - BWR, PWR, CANDU Breeder, Gas cooled and Liquid metal Cooled Reactors. Safety measures for Nuclear power plants.

3.1 Basics of Nuclear Engineering:-

→ large amount of energy that can be released from a small mass of active material.

→ Complete fission of 1 kg of Uranium contains the energy equivalent to 3100 tons of coal (or) 1700 tons of oil.

→ Nuclear power Not only available abundance, It is cheaper.

→ Large deposits of thorium in Beach Sand compare to low grade Uranium.

→ Tarapur - 1400MW (Maharastra) - PHWR, Rawatbhata - 1,180 (Rajastan) - PHWR

Kundankulam - 1000MW. (TN)

→ Total - 5,480 MW from Nuclear power in India.

→ VVER - (water - water energy reaction) Russian.

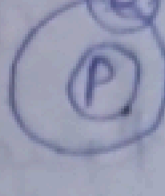
→ 5th Source, 7 plants, production - 7480. MW

TN - 2000MW, 440MW

- Horizontal steam generators.
- Hexagonal fuel assemblies, No Bottom penetrations in the pressure vessel.

- **Atomic Nuclei:-**

Positively charged nucleus surrounded by no of (-)ve charged electrons.



- Nucleus - protons and neutrons both are nucleons. proton - (+)ve charge, neutron - Uncharged.
- The no. of electron on the orbit = No. of protons in the nucleus.
- Any addition of electron to the neutral atom makes the atom negative charged. Subtraction of electron will make it positively charged. Such atoms Ion. process of charging atom is known as Ionization.

- **Atomic Number** - The no. of protons in a given atom (number of positive charges) Symbol Z.
- **Mass Number** - The total no. of protons and neutrons in an atomic nucleus is called mass number. A.

Isotopes - Same atomic number, different mass number.

- Uranium - 0.006% of $_{92}U^{233}$
  0.714% $_{92}U^{235}$
  99.28% $_{92}U^{238}$

Atomic mass Unit:-

$1\ amu = \frac{1}{6.0225 \times 10^{23}}$ grams $= 1.6604 \times 10^{-24}$ gram

mass of electron - 0.00055 amu

" proton - 1.00758 amu

neutron - 1.00897 amu

Half life time:- The half life time of particular isotope is defined as The time required for The number of active nuclei to decay to half of the initial number.)

InElastic Scattering:-

Neutron

O—— Nucleus ↘ neutron

When a neutron Undergoes in elastic Scattering, It is first captured by The target to form a Compound nucleus. Then a neutron of lower kinetic energy is expelled from The target nucleus leaving The nucles in excited State.

Elastic Scattering:- Kinetic energy of The neutron is conserved. When the neutron strikes the target nucleus, It impart The part of kinetic energy to The target nucleus and Its Original Kinetic energy is reduced.

Neutron Capture:- The Colliding neutron is absorbed by the target nucleus and increases its mass number by unity.

- Horizontal Steam generators.
  Hexagonal fuel assemblies, No Bottom penetrations in the pressure vessel.

- **Atomic Nuclei:-**
  positively Charged nucleus (P)
  Surrounded by no of
  (-)ve charged electrons.

- Nucleus - protons and neutrons both are nucleons. proton - (+)ve charge, neutron - Uncharged.
- The no. of electron on the orbit = No. of protons in the nucleus.
- Any addition of electron to the neutral atom makes the atom negative charged. Subtraction of electron will make it positively charged. Such atoms Ion. process of charging atom is known as Ionization.

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Isotopes - Same atomic number, different mass number.

- Uranium - 0.006% of $_{92}U^{233}$
  0.714% $_{92}U^{235}$
  99.28% $_{92}U^{238}$

Fission products:-

The fission products $_{92}U^{235}$ are given below

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q$$

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{57}La^{147} + {}_{35}Br^{87} + 2{}_0n^1 + Q$$

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{38}Sr^{94} + {}_{54}Xe^{139} + 3{}_0n^1 + Q$$

The fission chain reaction:- (M)J -13)

The no. of neutrons produced must be sufficient to maintain the chain reaction and to supply the losses (escape, absorption, non-fission reactions). Therefore the essential condition to maintain the chain reaction is that the fission nucleus must produce at least one secondary neutron to cause fission of other nucleus.

multiplication factor (or) Reproduction factor:-

$$K = \frac{\text{Number of neutrons of any one generation}}{\text{Number of neutrons of immediately preceding generation}}$$

When $K < 1$ → Subcritical (Stopping the reactor)

$K > 1$ – Super Critical (atom bomb)

$K = 1$ → Critical → desirable requirement for power reactors.

Fertile materials:-

There are materials like $_{92}U^{238}$ and $_{90}Th^{232}$ which are not fissible but can be converted into fissile materials by the bombardment of neutrons. Such materials are known as fertile materials.

Fissile Products – $_{94}Po^{239}$, $_{92}U^{233}$

Breeding:-

The process of converting more fertile material into fissile material in a reactor is known as Breeding.

Controlling of Chain reaction:- (M/17)

If neutron is <1, reaction will not produced. >1 - atomic explosion

In the controlled chain reaction of a nuclear reactor fuel assemblies are connected and the control rods are slowly lifted to initiate the chain reaction the fissionable atoms of fuel rod allow the reaction to proceed spontaneously in a controlled manner.

Difference between Fission and Fusion (N/D-12)

Nuclear Fission	Nuclear fusion
(1) It is the process of spliting a heavy nucleus with some projectiles into two or more light fragments with liberation of a large amount of energy.	It is the process of fusing two light nuclei into single nucleus with the liberation of a large amounts of heat.
(2) Emission of radioactive rays.	does not emit radio active rays.
(3) new elements are considered less than Reactive materials	mass & atomic no high than starting elements.
(4) neutrons are emitted	protons are emitted.

Critical mass: m/7 -12

The minimum amount of fissile material needed to maintain a nuclear chain reaction.

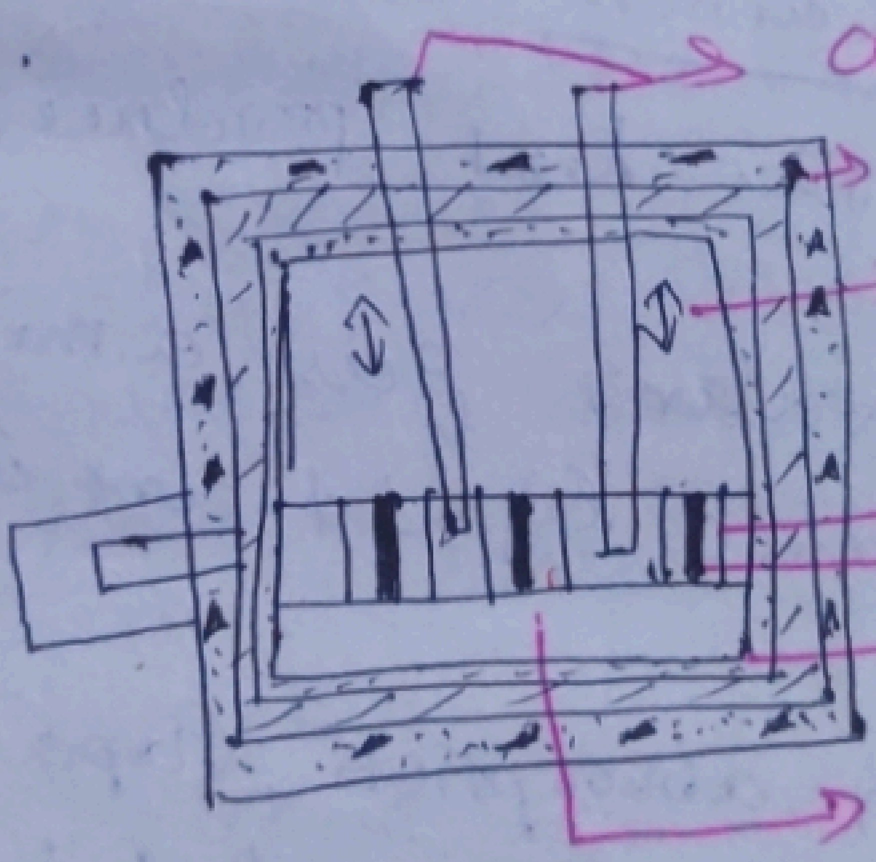
Critical size:-

The actual size of material which allows the escape of neutrons to such an extent that at least one neutron is positively left behind per fission reaction.

Components of Nuclear reactor:-

Fuel, moderator, Reflector, Coolant, control rods. Shielding.

Function of moderator:- which reduce the kinetic energy of fast neutron (1 MeV to 13200 km/s 0.25 eV) 2200 m/s.



Fuel:-

$_{94}Pu^{239}$, $_{92}U^{233}$ → are formed in the nuclear reactor during fission process from $_{92}U^{238}$+1, $_{90}Th^{232}$+$_0^1n$

$_{92}U^{235}$, $_{92}U^{238}$.

Moderator materials:- → light elements H_2, D_2, N_2, O_2, graphite, Heavy water, Beryllium.

Desirable properties:- must be light, able to slow down the neutrons earliest possible but it must not absorb them. High resistance to corrosion. High melting point. must be cheap.

Reflector:- It is always necessary to conserve the neutrons as much as possible in order to reduce the consumptions of fissile material; to keep the size of the reactor small.

Required properties:- low absorption and high reflection for neutron. high resistance to oxidation.

• H_2O, D_2O and Carbon are used as reflectors.

Coolant:- Transfer the heat produced in the reactor.

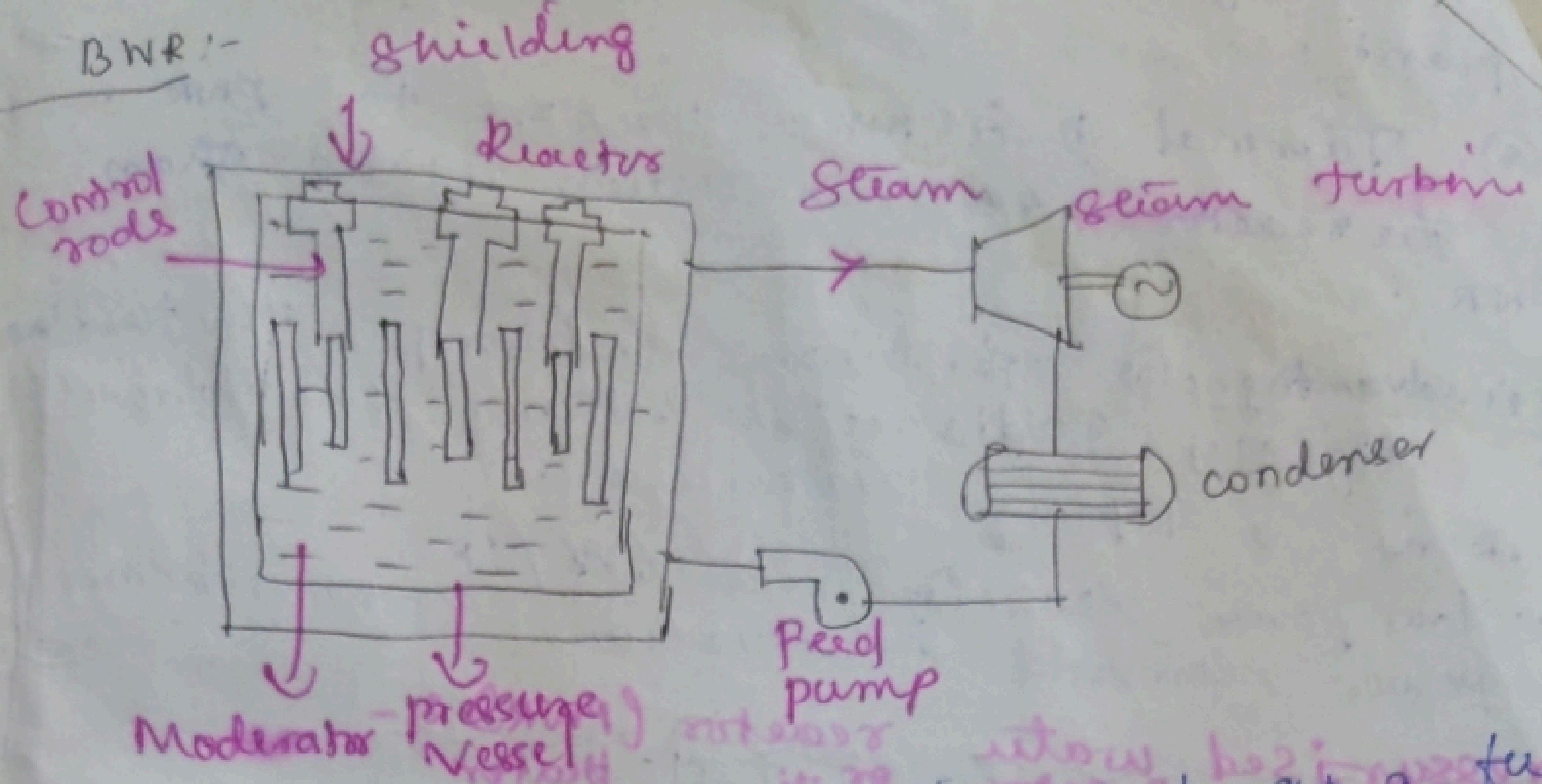
The water, heavy water, gas a metal in liquid form (Na), organic liquid are used as coolant.

Control rod:- High absorption capacity for neutrons. Cadmium, boron, hafnium.

Shielding Radiations are very harmful. Shielding - absorbed by the concrete and steel. 50 to 60cm thick steel plate. Thermal shield is cooled by the circulation of water.

Reactor Vessel It has to with stand Rod] above.

BWR:-



· Enriched Uranium is used as a fuel and water is used as moderator. Coolant and reflector is ....

· BWR is that in a the steam is generated in the reactor itself instead of a separate steam generator.

· water enters the reactor at the bottom. This water is heated by the heat released due to this fission of fuel and gets converted into steam. The steam which leaves from the top of the reactor is passed through the turbine and expanded.

· Exhaust steam from the turbine passes through the condenser and condensed and is again recirculated again by using feed pump.

Advantage (1) There is no H.E, pressuriser, circulating pump. This reduces cost of the plant.

(2) Thermal η is more compare to PWR.

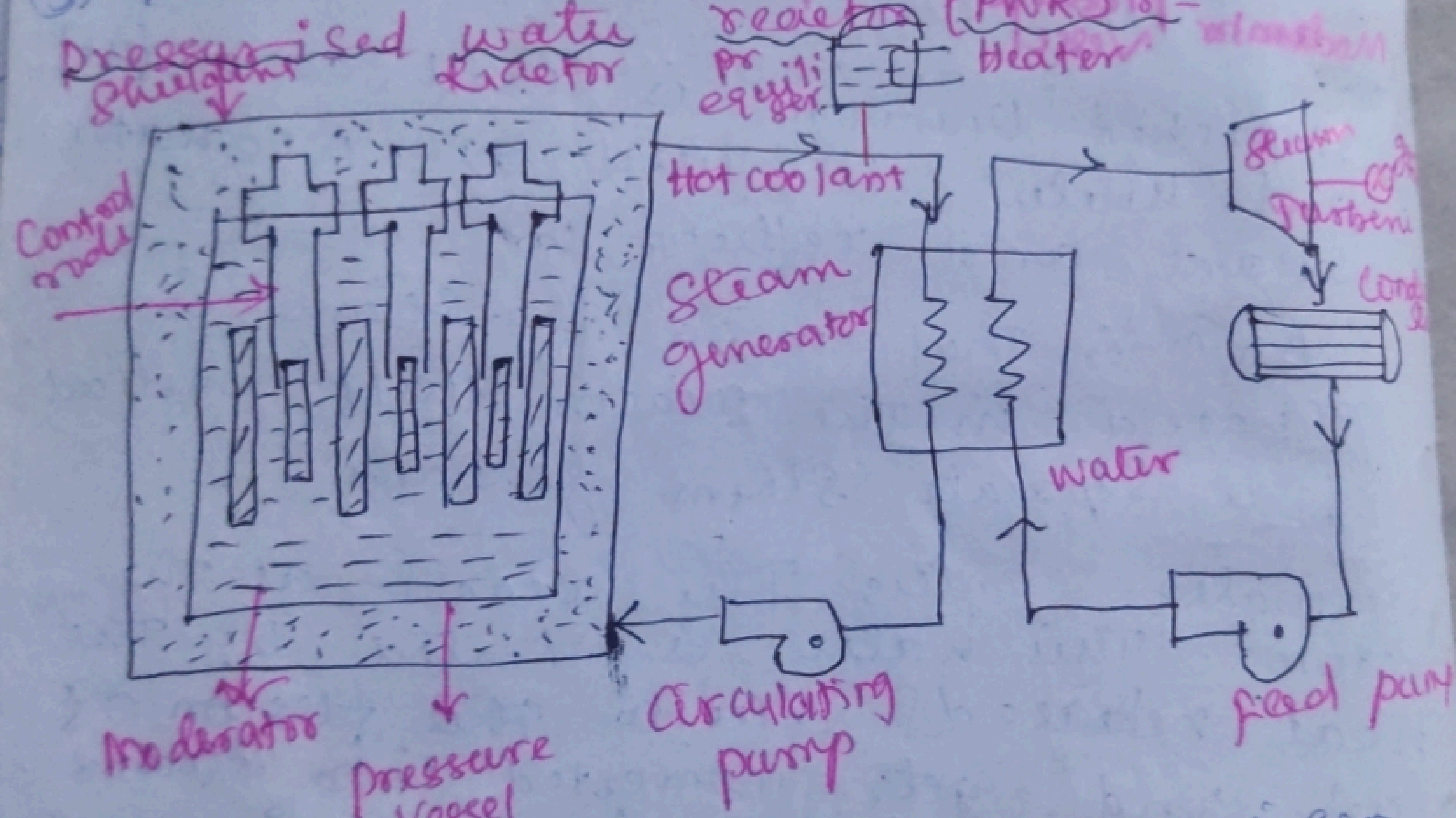
(3) The reactor vessel is much lighter than PWR.

Disadvantage: (1) The steam entering the turbine is slightly radioactive. Hence shielding of turbine, piping are needed.

(2) low power density 33.6 kW/lt.

(3) power demand fluctuations cannot be met.

Pressurised water reactor (PWR) :-



primary circuit (Reactor, pressuriser, Heat exchanger, coolant pump)

Secondary Circuit (steam turbine, condenser, feed pump, heat exchanger)

→ The coolant in the primary circuit is pumped to the reactor core. Coolant absorb heat energy which is liberated during nuclear fission in the reactor core.

, hot coolant passes through the

Department of Mechanical Engineering

Lecture Notes

Subject Code : CME396

Subject Name: PROCESS PLANNING AND COST ESTIMATION

Sem/Year : 05/III

Regulation : 2021

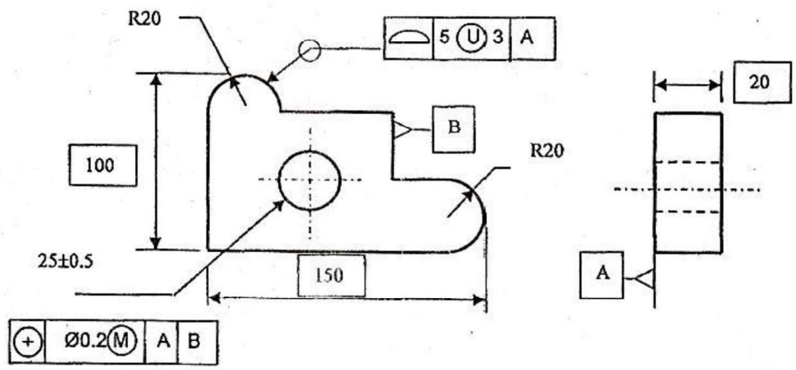
Unit -1 Introduction to Process Planning

Part A

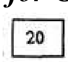
1. What are the details required for process planning? (AU A/M '18)

- Detailed engineering drawings
- Knowledge of materials for manufacture
- Knowledge of manufacturing processes
- Knowledge of jigs and fixtures
- Knowledge of the relative costs of materials, processes and tooling
- Manufacturing parameters (speed, feed etc) and costs
- Knowledge of inspection/QA procedures and specifications

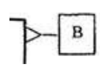
2. Study the drawing shown in fig and interpret any one geometric tolerance symbol (AU A/M '18)



Symbols used for Geometric tolerance



Boxed dimension (theoretically exact)



Datum indication


Circular or cylindrical tolerance

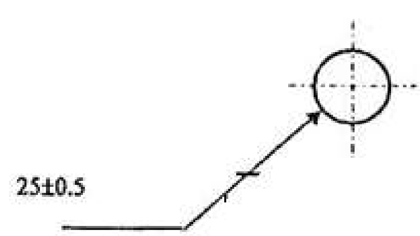

Location (position)

3. List the objectives of process planning (AU N/D '17)

- To manufacture a product that meets its design specification
- The manufacture of the product must be cost-effective, that is, maximize the added value, and meet the agreed deadlines, that is, be completed on time.

4. What is bilateral tolerance? Give examples (AU N/D '17)

Bilateral Tolerances are those when variation in actual dimension of the part can be tolerated to both sides of the given Nominal value .e.g. ϕ 25 (+/- 0.5).



Upper deviation : + 0.5; lower deviation: - 0.5

5. **Define process planning. (AU A/M'17) (AU N/D '16) (AU N/D '15)**

   Process planning is defined as the determination of the processes and the sequence of operations required making the product. It consists of devising, selecting and specifying processes, machine tools and other equipment to transform the raw material into finished product as per the specifications called for by the drawings.

6. **Write any four cutting tool materials (AU A/M'17)**

   Carbon steels, High speed steels, cobalt alloys and carbides.

7. **Write the approaches to process planning (AU N/D '13) (AU M/J '13) (AU M/J '12)**
   - Manual process planning
   - Computer Aided process planning
     - Varient approach
     - Generative approach

8. **List out factors considered on the selection of machinery (AU N/D '13)**
   - Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.
   - Quality of finished product, and
   - Advantages and disadvantages of the various types of equipment capable of doing the work.

9. **Write the Advantages of computer aided process planning (AU N/D '12)**
   - Efficient processing
   - Standardized procedures
   - Shorter development time
   - Lower hardware costs

10. **Define: Contingency allowance(AU N/D '14)**

    In a shop, there may be small delays due to

    1. Waiting for the inspector.
    2. Consulting the supervisor.
    3. Obtaining special tools etc.

    These delays are of very short duration. The allowance given to compensate these delays is called contingency allowance. Generally 5% of basic time is given as contingency allowance.

Part – B

1. **Why is process planning required to estimate cost? State its advantages. Discuss in detail the methods how computer can be used in cost estimations (13 marks) (AU N/D '18)**

Estimating is the calculation of the costs which are expected to be incurred in manufacturing a component in advance before the component is actually manufactured.

In this rapid developing and competitive age, it is necessary for a factory that the advance information about the cost of a job or a manufacturing order to be put through should be available before taking up the actual production. Estimating which is predetermination of cost is mainly concerned with the factory owner. It helps him to decide about the manufacturing, and selling prices.

Reasons for doing Estimates

Cost estimates are developed for a variety of different reasons. The most important reasons are shown below.

Should the product be produced? When a company designs a new product, a detailed estimate of cost is developed to assist management in making an intelligent decision about producing the product. This detailed estimate of cost includes an estimate of material cost, labour cost, purchased components and assembly cost.

In addition to product cost, many other elements must be estimated. These include all tooling costs. A cost estimate must be developed for jigs, fixtures, tools, dies and gauges. Also, the cost of any capital equipment must be entered into the estimate. These figures are usually supplied through quotation by vendors. An estimate of this nature will include a vast amount of details, because if management approves the project, the estimate now becomes the budget.

Computer Estimating

Use of group technology

GT can be used very efficiently in estimating cost. Assume a company manufactures shaft-type parts. Also arsum there is a computer data base named SHAFT that contains 10-digit code followed by a part number, that is, code part number, and so on. When an estimator must estimate the cost of a new shaft, the process starts by developing a code that describes the characteristics of the part. The first digit in the code might be assigned the part length, while the second digit is assigned the largest diameter and so on. Next, the code is keyed in and the computer finds all the parts that meet the numeric descriptions and points out the part numbers. The best fit is selected to be modified into a new part. All the details of each description are retrieved. These include diameter, length of cut, number of surfaces, and the like. The estimator can alter these features and make the old part into a new one.

Advantages and disadvantages

Shown below are some of the major advantages of computer cost estimating.

Accuracy versus consistency - Computer estimates are very consistent, provided they calculate the detail of an estimate. Because these estimates are consistent, they can be made to be accurate. Through the use of consistent efficiency factors or leaving curves, estimates can be adjusted up or down. This is one of the chief advantages of computer cost estimating.

Levels of details

Some computer estimating systems provide different levels of estimating cost. The level of detail selected by the user depends on the dollar risk. Many estimators produce an estimate in more detail because the computer can calculate speeds and feeds, for example, much faster than an estimator can a hand-held calculators.

Refinements

Some computer estimating systems provide many refinements that would be impossible for the estimator to do in any timely manner. One example is to adjust speeds and feeds for material hardness. Typically, the harder the material the more slowly a part will be turned or bored. Another refinement is the ability to calculate a feed state and adjust it based on the width of a form tool.

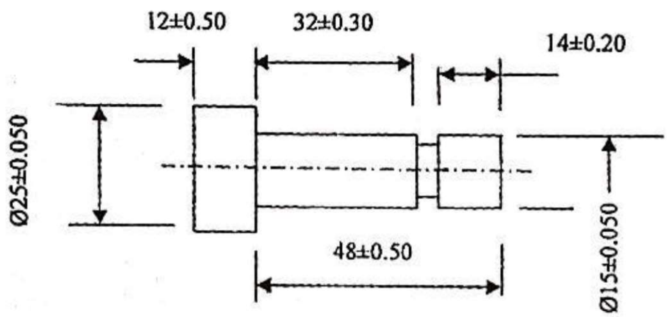
Source code

Some companies offer the source code uncompiled to their users. This is important because it affords the user the opportunity to customize the software. In addition, many companies have written their own software to do something that is not available on the market. If the source code is not compiled, the users can build upon a computer estimating system.

Disadvantages

The chief disadvantage of computer estimating is that no one estimating system can suit everyone's need. This is especially true if the source code is compiled and not customizable. Another problem with computer estimating is that the estimator will, in all probability, have to change some estimating methods. Computer software for estimating cost is seldom written around one method of estimating.

2. Discuss the production equipment and tool selection for the component shown in fig undercut diameter is 12mm. (13 marks) (AU N/D '18)



Solution

a. *Evaluation of process and machine selection*. As stated in the problem, the process identified is turning and the machine tool is a small bench lathe. This limits the tools to select from to those we have in machine shop

b. *Analysis of machining operations*. The operations identified are facing, roughing, finishing and parting off. From this, two specific tools can be identified:

Turning/facing tool- facing, roughing and finishing;

Parting off tool- parting off

c. *Analysis of workpiece characteristics.* The fact that the workpiece material is brass means that HSS tooling is more than sufficient to carry out all operations. This is due to brass being highly machinable material.

However, in terms of workpiece and tool geometry, there are two issues to be considered. In terms of the facing and roughing out, a left-handed tool will not be able to completely finish the arc in the middle of the part. There are two options that can be considered. The first is to produce half the arc with the left-handed tool and change to a right-handed tool for the other half. However, it would be much simpler to use a contouring tool for the complete arc. Furthermore, a contouring tool will be required for the 'chamfered groove' to the left-hand end of the part.

Therefore, it makes sense to use the contouring tool for both features, rake angles permitting, as this uses the least number of tools.

d. *Tooling analysis*. From the above stages, the following tooling list and operation description can be generated:

Facing: left-hand turning tool
Roughing: left-hand turning tool
Finishing: contouring tool
Parting off: parting-off tool

Face the end and rough out the excess material with the left-hand tuming tool. The majority of the finish turning can be carried out with the left-hand turning tool. However, the radius and the chamfered groove will be machined with the contour tool and finally the part will be cut from the billet by the parting off tool.

As the problem is simply to identify the tooting, the problem is basically solved. Therefore, there is no need to go to the stage of selecting a suitable tool holder. It can also be seen from the above example that even fairly simple geometries will require more than one cutting tool.

3. **Explain with neat sketch various methods of process planning (AU N/D '18) (AU N/D '16) (or) Describe various approaches to process planning (AU N/D '15) (or) Explain the use of computers in process planning and cost estimation and list out the advantages of CAPP. (AU N/D '14) (AU N/D '12) (or) How will you distinguish retrieval and generative computer aided planning systems? Which is more effective? State reasons. (AU M/J '16) (16 Marks)**

Approaches of process planning

- Manual Process Planning
- Computer Aided Process Planning

Manual process planning

This type of planning is known as non-variant process planning. It is the commonest type of planning used for production today.

Planning the operations to be used to produce a part requires knowledge of two groups of variables.

(a) The part requirements, and

(b) The available machines and processes and the capabilities of each process.

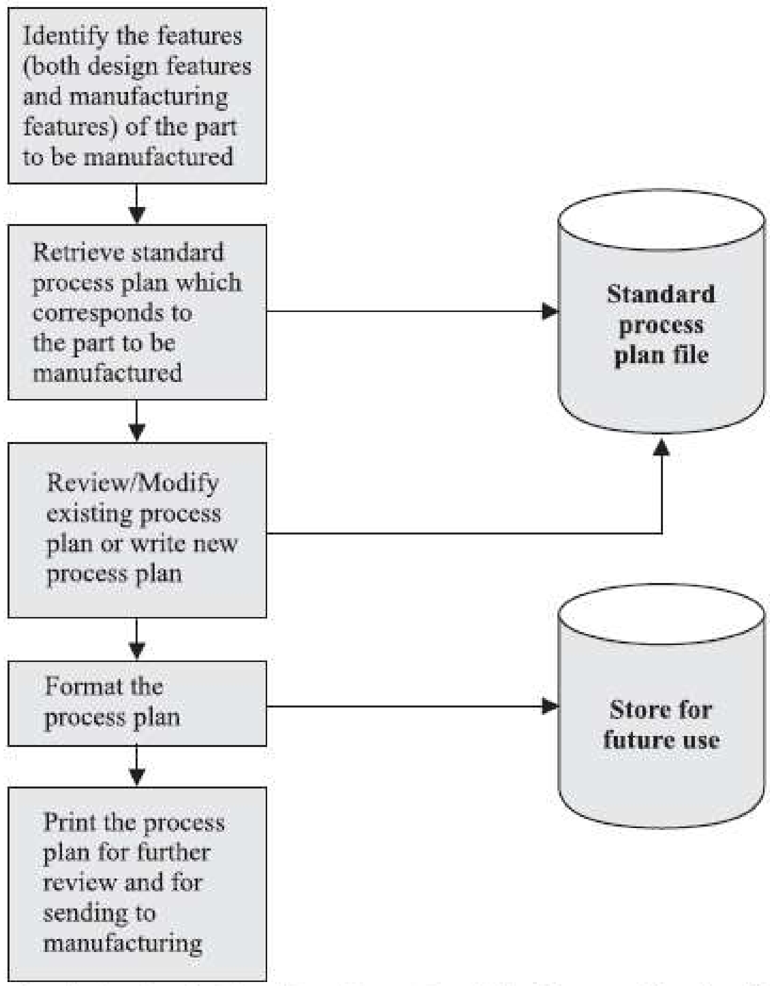
The manual approach to process planning begins when a detailed engineering drawing and data on batch size are issued to a production engineer. This information is used to determine the following:

- The manufacturing processes involved.
- The machine tools required to execute these processes.
- The tools required at each stage of processing.
- The fixtures required at each stage of processing.
- The number and depth of passes in a machining operation.
- The feeds and speeds appropriate to each operation.
- The type of finishing process necessary to achieve the specified tolerances and surface quality.

As a first step, the production engineer examines the part drawing to identify similarities with previously produced parts. If similarities are recognized, a process plan is manually retrieved for the similar item. The process plan is either used without modifications for identical parts or modified to meet the manufacturing requirements of the new part. Although old process plans are used as references for similar parts, there is still significant duplication of effort due to the lack of efficient information retrieval, comparison, and editing techniques. The manual method may also lead to inconsistency in the final plans because it is unlikely that two process planners will generate identical process plans.

It is difficult or impossible to achieve consistent, optimized process plans with the conventional manual method. As a consequence planning and manufacturing costs are increased because of the duplication of effort in the process planning function as well as specification of excessive tooling and material requirements. Production lead times also increase due to redundancies in the planning function.

Computer Aided process planning



Procedure for developing the Retrieval type Computer—Aided Process Planning (CAPP) system

Computer Aided Process Planning represents the link between design and manufacturing in a CAD/CAM system. Process planning is concerned with determining the sequence of processing and assembly steps that must be accomplished to make the product. The processing sequence is documented on a sheet called a route sheet. The route sheet typically lists the production operations, machine tools, work centres or work stations where each operation is performed, jigs, fixtures and tooling required and standard time for each task.

Computer Aided Process Planning (CAPP) Systems are designed with two approaches in mind. These approaches are called:
(a) Retrieval CAPP Systems, and (*b*) Generative CAPP Systems

Variant or Retrieval Method of Process Planning (Retrieval CAPP System)

In this method, the computer makes a search of its storage or a data base or a no. of standard or completed process plans that have been previously developed by the company's process planners.

The development of the data base of these process plans requires substantial knowledge of machining, time and efforts. Using the current design data supplied by the CAD system, (after a component has been designed and dimensioned), it searches for a process plan that was based on a part of similar design. (This search can make effective use of GT, Group Technology, design coding to simplify the search for similar part design).

The process plan **retrieved** is then modified or suitably **varied** (*i.e.*, altered) by the process planner, to suit the exact requirements of the current part design. The use of Computer and Group Technology (GT) to search for the most appropriate or similar part design, and to retrieve the process plan for that design, significantly reduces the work required of the process planners. This also saves considerable amount of time required to develop a process plan for a new part.

The task of process planner becomes one of modifying the existing plan to suit the particular dimensions of the current part. (*i.e.,* the selected process plan is provided to the user for modification and variation). Process planners are required to perform the entire process planning method only in the case of a completely new part design. This approach of process planning is also known as Retrieval CAPP system. This is based on the principles of Group Technology and parts classification and coding. One of the pre-requisites for implementation of this method is that the industries must develop and maintain a large computer data base of standard completed process plans. In addition, the part designs are to be developed using CAD systems.

Generative Method of Process Planning (Generative CAPP System)

The second method of computerized process planning is the generative method. In this method the computer uses the stored manufacturing and design data to generate a complete list of all possible process plans that could be used to manufacture the current part. It then exhaustively searches this list for the one which optimizes the cost function. This method always yields the optimum process plan for manufacturing a particular part.

However, it has a very high cost in terms of time and computer processing expenses. The computations required to provide even a single process plan for an arbitrary part design can be enormously complex. To repeat this for every feasible process plan or a part can become very costly. This approach of process planning is also known as **Generative CAPP System.**

Both the approaches viz. Variant (or retrieval) method of process planning and Generative method of process planning involves a systematic development of Code Numbers using Group Technology concepts and principles for the design and manufacture of the part.

Both of these methods of computerized process planning can be enhanced through the application of AI (Artificial Intelligence) in the form of expert systems.

Benefits of CAPP

The benefits derived from computer aided process planning are the following

1. Process rationalization and standardization: Automated process planning leads to more logical and consistent process plans than when process planning is done completely manually.

2. CAPP helps in arriving at standard and consistent process plans : Standard plans tend to result in lower manufacturing costs and higher product quality.

3. Increased productivity of process planners : The systematic approach and the availability of standard process plans in the data files permit more work to be accomplished by the process planners.

4. Reduced lead time for process planning : Process planners working with the CAPP system can provide route sheets in a shorter lead time compared to manual preparation.

5. Improved legibility and readability : Computer prepared route sheets are legible and easier to read than manually prepared route sheets.

6. Incorporation of other application programmes : The CAPP programme can be integrated with other application programmes, such as estimation of standard time, cost estimating and formulation of work standards.

4. **Write down the procedure to be followed during material selection. Discuss the factors that are taken into account in process selection and equipment selection. (AU N/D '16) (10 Marks) (or)**
   What are the factors influencing process selection and write down the process selection parameters (AU N/D '14) (16 marks)

Factors Influencing Process Selection

After a product design is made process selection is to be carried out. There are several factors which influence the process selection, These are :

- Shape requirements
- Size or dimensional requirements
- Tolerance requirements
- Surface finish requirements
- Annual volume requirements (*i.e.*, production quantity required per annum)
- Material characteristics.

Process selection requires a broad and extensive knowledge of various materials and the associated manufacturing processes. A good understanding of the capabilities and limitations of the various processes available is an asset to any process planner. Evaluation of alternative processes can also be carried out simultaneously and a logical decision taken with respect to proper selection of the process. It must be emphasized that the selection of a process is done and evaluated in the context of p**roduct design - material - manufacturing process** in an integrated manner.

Process Selection Parameters

There are several factors which govern the selection of a manufacturing process:

1. Shape requirements of the final product *i.e.*, Geometric Form :

Geometric parameters such as solid shape, hollow shape, flat shape, flanged shape, concave shape, convex shape, cylindrical shape, presence of any part feartures such as groove, threaded shape, hole, chamfer, etc. are considered in the selection of a manufacturing process. Each process has its own capabilities and limitations with respect to the production of the above shapes and part features.

2. Size or Dimensional requirements :

Some processes are capable of handling parts of small sizes and some processes can handle large sized parts economically and effectively.

3. Tolerance requirements :

Each manufacturing process has got its own capability with regard to tolerance or accuracy of parts that can be produced using that process *e.g.* grinding process always gives close tolerances when compared with turning process. Depending upon the tolerance specified on the part drawing, suitable machining process is to be selected.

4. Surface finish requirements:

Each manufacturing process has got its own capability with regard to the surface finish which it can provide on the part machined, *e.g.* reaming process can provide a better surface finish in a hole when compared with drilling process. Similarly cylindrical grinding give a better surface finish, than a plain turning process. Depending on the finish requirements specified on the component drawing, appropriate machining process need to be selected.

5. Production volume requirements:

The economics of any machining process depends on the production volume, *i.e.*, no. of components required on a weekly, monthly or annual basis as the case may be. Existing order quantity as well as any anticipated future orders and their quantity need to be considered in the process selection. Some of the processes and additional cost incurred in the specialized toolings, jigs and fixtures can be justified only when there is a large volume of production.

6. Material requirements:

The hardness and strength characteristics of the material influence the tooling required. To machine hard and tough materials, carbide and ceramic tools are required. If slender or thin materials are machined, proper work holding devices and specially designed jigs and fixtures are required is order to avoid distortion and bending of work pieces during machining. Thus material requirements of the part also influence the appropriate selection of machining process.

Material Selection

Material selection is done by the product designer considering the requirements of the parts designed and the hardness, strength properties and other mechanical characteristics of the material. Cost and availability of the material are also considered. Material should be strong enough and at the same time manufacturing or producibility of the part using the given material and the process are also equally important.

In the initial stages of design, the broad material groups such as ferrous or non-ferrous or other non-metallic materials can be considered. At a later stage specific material in the group can be identified.

In certain products or components specific properties of materials such as fatigue strength, thermal conductivity, electrical properties like conductivity, magnetic permeability and insulation resistance may have to be considered.

Material Selection parameters

(*i*) Functional requirements:

The primary function of the part for which the material is selected is the foremost consideration. A good knowledge of the product application is important. The properties of materials which have a direct bearing on the functional requirement of the part are : fatigue characteristics, strength, hardness, electrical and thermal properties.

(*ii*) Reliability:

Reliability of the materials refers to the consistency with which the material will meet all the products requirement throughout its service life. This is important for trouble-free maintenance of the product during its life time.

(*iii*) Service life durability :

The length of service (years or hours of operation of the product) over which material is able to perform its function satisfactorily.

(*iv*) Aesthetics and appearance :

Factors like colour, texture, lusture, smoothness and finish play an important role in the aesthetics or appearance of the final product.

(*v*) Environmental Factors :

Environmental factors such as temperature, humidity, corrosive atmosphere affects the product and its performance. Hence proper materials which can with stand such environmental effects should be selected and they should be given suitable protective coatings.

(*vi*) Compatibility with other materials during service :

When one type of material is used in combination with another type of material in a product or in an assembly the properties of both types of materials should be compatible and should suit each other. Otherwise deterioration in the performance of the product or assembly such as excessive wear & tear, and corrosion of parts in fitment are likely to take place.

(*vii*) Producibility or manufacturability: The extent to which the material can be processed effectively and easily using a particular machine tool or process should also be considered in the selection of the material. Machinability of materials for machined components is an important factor.

(***viii***) **Cost:** The cost of material is a significant factor in many situations. The availability of the material is equally important. Appropriate material for the product or component is to be selected taking into consideration all the above factors.

5. **Explain how to develop manufacturing logic and knowledge (8 marks) (AU N/D '15) (or) Write short notes on developing manufacturing logic and knowledge (AU M/J '16) (8 marks)**

Developing manufacturing logic and knowledge :

(i) Product : design, (*i.e.*, parts requirements) manufacturing process and materials characteristics all must be considered together in an integrated manner while developing a process plan.
(ii) Identify the datum surface on the component drawings which will form the basis for measurement and inspection of dimensions.
(iii) Adequate attention must be paid so that the component is properly located and clamped. The accuracy of the machined part and the time taken depend on these factors. This will also avoid any distortion that might occur on the machined component. Three point support (locating pins) are suitable for positioning large flat surfaces.
(iv) The no. of settings required to machine a part may be reduced to a minimum. Less no. of settings more is the accuracy of the part machined.
(v) Frequent tool changing can be reduced to a minimum.
(vi) Rough machining operations must be carried out first before finish machining operations.
(vii) Identify critical operations and provide for inspection immediately after critical operations.
(viii) Use appropriate cutting fluid depending on the severity of the operation, the work material and the tool material used.
(ix) Use of jigs and fixtures are justified when the production quantity is large.

6. **What are the factors to be considered in machine selection (8 marks) (AU M/J '13)**

Machine Selection

Product manufacturing requires tools and machines that can produce economically as well as accurately. Economy depends to a large extent on the proper selection of the machine or process for the job that will give a satisfactory finished product. The selection of the machine is influenced, in turn by the quantity of items to be produced. Usually there is one machine best suited for a certain output.

In small lot or jobbing type manufacture, general purpose machines such as the lathe, drill press, and milling machine may prove to be the best type since they are adoptable, have lower initial cost, require less maintenance, and possess the flexibility to meet changing conditions in the shop. However, a special purpose machine should be considered when large quantities of a standard product are to be produced. A machine built for one type of work or operation, such as the grinding of a piston or the machining of a cylinder head, will do the job well, quickly and at a low cost requiring only the service of a semi-skilled operator.

Many of the special-purpose machines or tools differ from the usual standard type in that they have built into them some of the skill of the operator. A simple bolt may be produced on either a lathe or an automatic screw machine. The lathe operator must not only know how to make the bolt but must also be sufficiently skilled to operate the lathe. On the automatic machine the sequence of operations and movements of tools are controlled by cams and stops, and each item produced is identical with the previous one. This "transfer of skill" into the machine makes possible the use of less skillfull operators, but it does requires greater skill in supervision and maintenance. Often it is not economical to make a machine completely automatic, as the cost may become prohibitive.

The selection of the best machine or process for a given product requires knowledge of all possible production methods. Factors that must be considered are:

- Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.
- Quality of finished product, and
- Advantages and disadvantages of the various types of equipment capable of doing the work.

Too much emphasis cannot be given to the fact that production can be by several methods, but usually there is one way that is most economical.

7. **Explain the technological frame work of process planning by using a block diagram. (16 marks) (AU M/J '13)**

Process planning

Process planning has been defined as the sub-system responsible for the conversion of design data to work instruction. Process planning can also be defined as the systematic determination of the methods by which a product is to be manufactured economically and competitively. It consists of devising, selecting and specifying processes, machine tools and other equipment to convert raw material into finished and assembled products.

Purpose of Process Planning

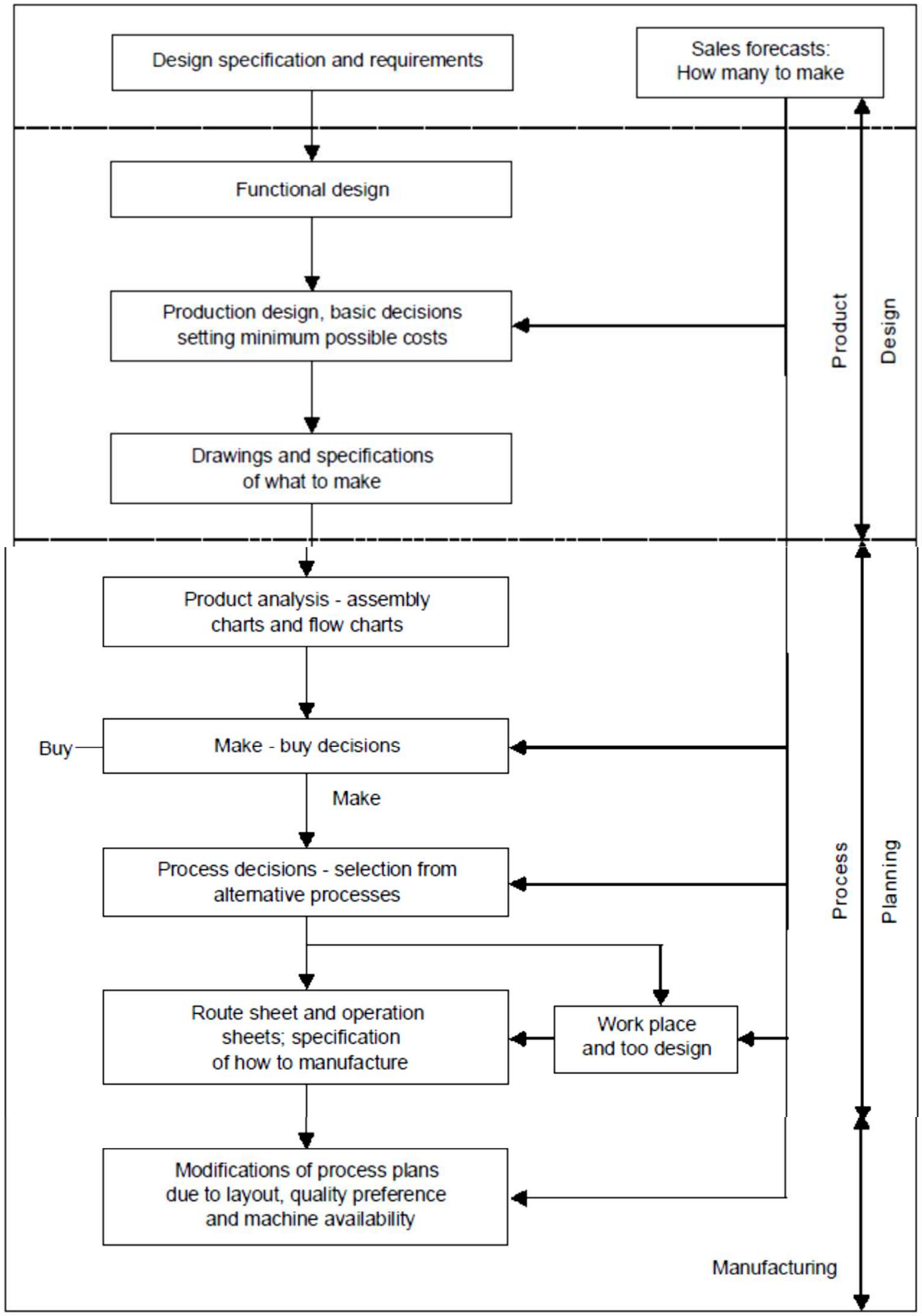
The purpose of process planning is to determine and describe the best process for each job so that,

1. Specific requirements are established for which machines, tools and others equipment can be designed or selected.

2. The efforts of all engaged in manufacturing the product are coordinated.

3. A guide is furnished to show the best way to use the existing or the providing facilities.

Process planning is an intermediate stage between designing the product and manufacturing it (fig).



Where the product design ends, the process planning begins. However, the basic process planning must begin during the product design stages where the selection of materials and initial forms, such as casting, forging and die casting take place. The accepted end point for production design is manifested by the drawing release, which summarizes the exact specifications of what is to be made.

Process planning takes over from this point and develops the broad plan of manufacture for the part of product. Process planning takes as its inputs the drawings or other specifications which indicate what is to be made and how many are to be made.

The drawings are then analysed to determine the overall scope of the project. If it is a complex assembled product, considerable effort may go into exploding the product into its components and subassemblies.

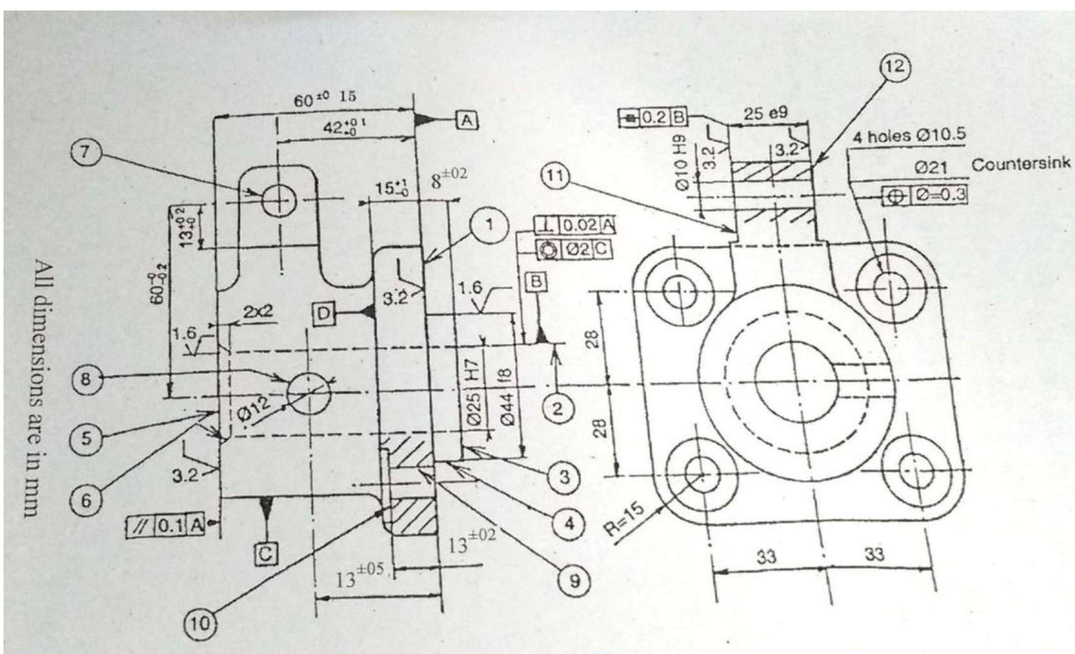
Preliminary decisions about subassembly groupings to determine which parts to make and which to buy, as well as to determine the general level of tooling expenditure, may be made at this point.

Then, for each part, a detailed routing is developed. Here technical knowledge of processes, machines, and their capabilities is required, but of almost equal importance is knowledge of production economics.

In brief, the engineering drawing of the component is interpreted in terms of the manufacturing process to be used. This step is referred to as process planning and it is concerned with the preparation of a route sheet.

The route sheet is a listing of the sequence of operations which must be performed on the component. It is called a route sheet because it also lists the machines through which the part must be routed in order to accomplish the sequence of operations.

8. **In the figure, interpret the meaning of any two**
   a. **Dimensional tolerance symbols (4 marks)**
   b. **Form tolerance feature control frames (8 marks)**
   c. **Surface finish symbols (4 marks)** **(AU A/M'17)**



a. Dimensional tolerance symbols

Parallelism

//	**0.1**	**A**

Position

⌖	Ó = 0.3

Perpendicularity

⊥	0.02	A

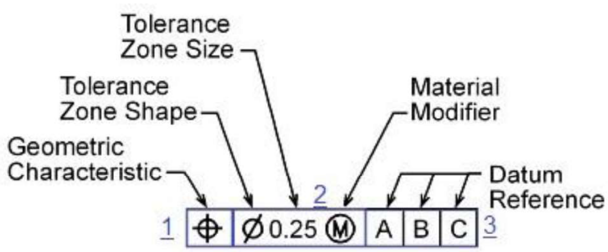
Symmetry

═	0.2	B

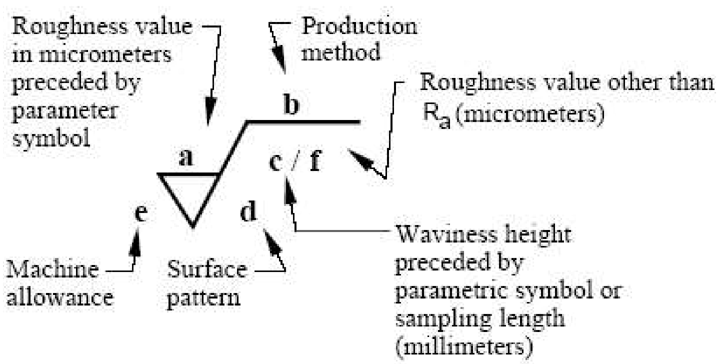
Concentricity

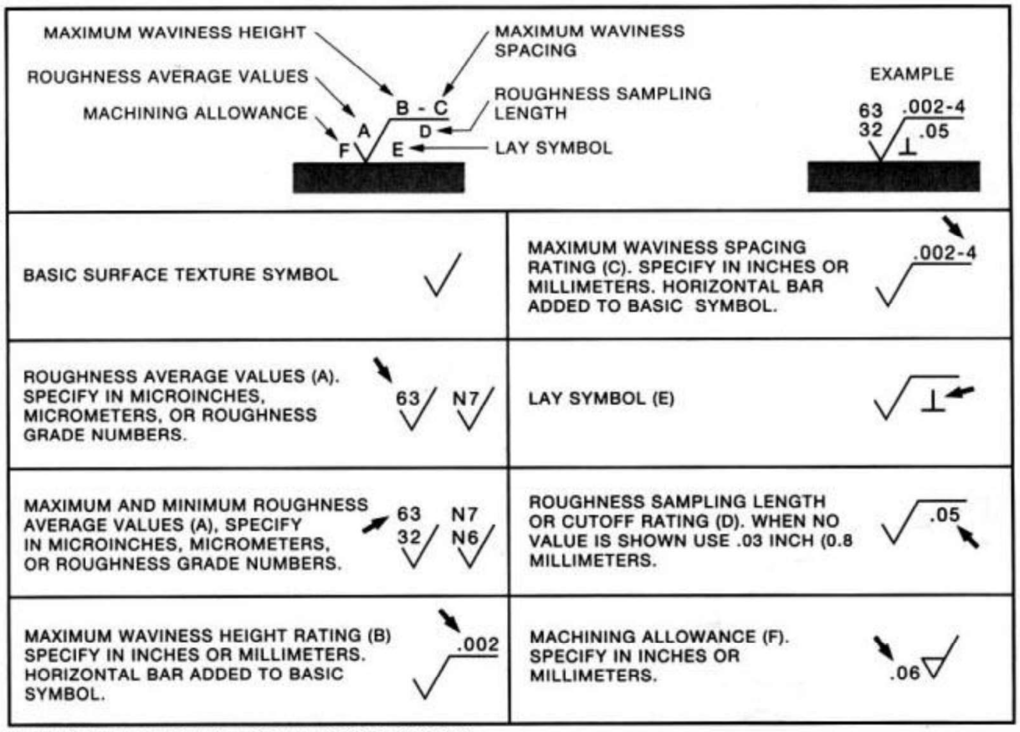
◎	Ó 2	C

b. Form tolerance feature control frame



b. Surface finish symbols





NOTE: WAVINESS IS NOT USED IN ISO STANDARDS.

Unit -2 Process Planning Activities

Part A

11. What is activity based costing? (AU A/M '18)

Activity-based costing (ABC) is a costing methodology that identifies activities in an organization and assigns the cost of each activity with resources to all products and services according to the actual consumption by each. This model assigns more indirect costs (overhead) into direct costs compared to conventional costing.

12. What are the main reasons for using jigs and fixtures? (AU N/D '17)

The main purpose of any work holding device is to position and hold a work piece in a precise location while manufacturing operation is being performed

13. What are the most influential factors in terms of tool performance? (AU N/D '17)

Factors affecting tool performance

- Cutting tool materials
- Cutting tool geometry
- Cutting fluids

14. What are the factors to be considered during the selection of a process? (AU N/D '16)

- Quality of work to be completed
- Availability of equipments, tools and personnels
- Sequence in which operations will be performed on the raw material
- Standard time for each operation

15. Enumerate the documents required for process planning (AU N/D '15) (AU N/D '12) (AU M/J '13)

- Product design and the engineering drawings pertaining to all the components of the product.
- Machining/Machinability Data Handbook
- Catalogues of various cutting tools and tool inserts.
- Specifications of various machine tools available in the shop/catalogues of machine tools in the shop
- Sizes of standard materials commercially available in the market.
- Machine Hr. cost of all equipment available in the shop.
- Design Data Handbook.
- Charts of Limits, Fits & Tolerances.
- Tables showing tolerances and surface finish obtainable for different machining processes.
- Tables of standard cost.
- Table of allowances (such as Personal Allowance, Fatigue Allowance etc. in % of standard time followed by the company).

16. State the parameters involved in material selection (AU N/D '14) (AU M/J '16)

(*i*) Functional requirements

(*ii*) Reliability

(*iii*) Service life durability
(*iv*) Aesthetics and appearance
(*v*) Environmental Factors
(*vi*) Compatibility with other materials during service
(*vii*) Producibility or manufacturability
(*viii*) Cost

17. What are the activities associated with process planning? (AU M/J '12)

- Analyse the part requirements
- Determine operation sequence
- Select the equipment
- Calculate processing times
- Select inspection methods
- Estimate manufacturing cost
- Document process plan
- Communicate to manufacturing engineer

18. State the procedure to select cost optimal process (AU N/D'11)

- Break even point
- Break even chart
- Break even analysis

19. What is the difference between routing sheet and operations list? (AU A/M'17)

A route sheet determines the sequence or order of arrangement of various departments in a facility. Thus, a route sheet is a document which has information and data inputs and a step wise listing of all the processes or transactions performed. It also contains details such as date and time, remarks, log in/out, point of contact etc.

It is a list of operations has to be performed in a process without sequence.

20. What is the relation between tolerance and surface finish? (AU A/M'17)

Components must fit together and function properly in a predicted dimension is defined as tolerance, whereas surface finish is the depth of irregularities and vertical deviations of a surface resulting from the manufacturing process used to produce it.

21. What is the purpose of a work holding device?

The main purpose of any work holding device is to position and hold a work piece in a precise location while the manufacturing operation is being performed.

22. List the types of work holding devices.

- General work holding devices
    - Vices
    - Clamps
    - Mandrels
    - Chucks
- Specialist work holding devices
    - Jigs
    - Fixtures

23. What is meant by Statistical Quality Control (SQC)?

SQC is about employing inspection methodologies derived from statistical sampling theory to ensure conformance to requirements

24. List seven statistical tools of quality that are used in quality control

(i) Flowchart
(ii) Cause and effect diagram
(iii) Check sheet
(iv) Scatter diagram
(v) Histogram
(vi) Control chart
(vii) Pareto diagram

25. What is meant by break even analysis (BEA)?

BEA also known as cost volume profit analysis is the study of inter-relationships among a firms sales, costs and operating profit at various levels of output.

Part – B

1. Describe the basic method employed for the selection of cutting tools. (AU N/D '17)

(i) ***Evaluation of process and machine selections-*** Provided the selection of processes and machines is satisfactory, the range of tools that can be used should be limited to those suitable for the processes and machines selected. Therefore, this limits the initial list of possible suitable tooling.

(ii) ***Analysis of machining operations-*** A specific machine will carry out every operation required. Each machine tool to be used will have specific tool types to carry out certain operations. Therefore, this analysis should enable the identification of specific tool types for specific operations.

(iii) ***Analysis of workpiece characteristics -*** The focus of the workpiece analysis is on the workpiece material and geometry and the capability in terms of dimensional and geometric accuracy and surface finish. The analysis of the first two characteristics enables suitable tool materials and geometry (in terms of size and shape) to be identified. The third characteristic allows the tool type and geometry to be refined further to suit the operations.

(iv) ***Tooling analysis***- Using the tooling data available, the general tooling specifications generated at the third stage can be translated into a statement of tooling requirements for the job, that is, a tooling list. This will obviously reflect whatever tooling is actually available for the operations required.

(v) ***Selection of tooling*** - There are two routes that the tool selection can take at this point. If single-piece tooling is being used, then a suitable toolholder should be selected before fully defining the tool geometry and material. However, if insert-type tooling is being used then the following steps should be followed:

i. select clamping system;
ii. select toolholder type and size;
iii. select insert shape;
iv. select insert size;
v. determine tool edge radius;
vi. select insert type;

vii. select tool material.

Once all of the above is completed, the machining parameters can be calculated. These will be the speeds, feeds and machining times for each operation. All of the above factors will have a significant influence on the determination of these parameters.

2. **Explain the process planning procedure and List out the information required for process planning. (16 marks) (AU N/D '16) (AU M/J '13) (or)**

What are the Set of documents required for process planning? (16 marks) (AU N/D '17) (10 marks) (AU N/D '13) (or)

Explain the steps involved in process planning. (16 marks) (AU N/D '17) (8 marks) (AU N/D '13)(AU M/J '12)

Set of documents required for process planning

(i) Product design and the engineering drawings pertaining to all the components of the product. (*i.e.,* components drawings, specifications and a bill of materials that defines how many of each component go into the product).
(ii) Machining/Machinability Data Handbook (Tables of cutting speeds, depth of cut, feeds for different processes and for different work materials).
(iii) Catalogues of various cutting tools and tool inserts.
(iv) Specifications of various machine tools available in the shop/catalogues of machine tools in the shop (speeds, feeds, capacity/power rating of motors, spindle size, table sizes etc.).
(v) Sizes of standard materials commercially available in the market.
(vi) Machine Hr. cost of all equipment available in the shop.
(vii) Design Data Handbook.
(viii) Charts of Limits, Fits & Tolerances.
(ix) Tables showing tolerances and surface finish obtainable for different machining processes.
(x) Tables of standard cost.
(xi) Table of allowances (such as Personal Allowance, Fatigue Allowance etc. in % of standard time followed by the company).
(xii) Process plans of certain standard components such as shafts, bushings, flanges etc.
(xiii) Handbooks (such as Tool Engineers Handbook, Design Data Handbook).

Steps in process planning

(i) Required operations must be determined by examining the design data and employing basic machining data such as :
(a) Holes can be made conveniently on drilling machines.
(b) Flat surfaces can be machined easily on milling machines.
(c) Cylindrical parts can be made using lathe. Design data can be obtained from the part-drawing or from the finished part design file from the CAD system.

(ii) The machines required for each operation must be determined. This selection depends on knowledge of machine factors, such as availability of the machine, specifications of machine tools available in the shop, accuracy grade of the m/c, table size, spindle size, speed and feed ranges available, torque, power, machining rate and other size limitations.

(iii) The required tools for each identified machine or process must be determined. For selection of specialized tools knowledge and prior experience of process planner will be useful.

(iv) The optimum cutting parameters for each selected tool must be determined. These parameters include cutting speed, feed rate, depth of cut, and type of coolant/lubricant to be used. This determination depends on design data, such as work material, tool material, surface finish specifications and behaviour of cutting tool. Again expertise knowledge and prior experience of process planner and methods engineer will be useful in this regard. Machining data handbooks can also be referred.

(v) Finally an optimum combination of these machining processes must be determined. The best process plan is the one which minimizes manufacturing time and cost. This provides a detailed plan for the economical manufacturing of the part.

(vi) The results of each of these five basic steps can be seen in the final form of the process plan

3. What are the factors that influence process planning? Discuss (8 marks) (AU N/D '12) (AU M/J '12) (or)
Explain the steps in process selection with suitable example (16 marks) (AU N/D '17)

Practices of Process Planning

The practices of process planning vary widely in modern industry, depending on such factors as :

- Type of product
- The equipment available, and
- The volume of production (*i.e.,* production quantity)

The individual responsible for carrying out process planning / process analysis is the Process Engineer also known as process planner, process analyst or methods engineer. To be effective on his or her job, the process analyst must be familiar with material characteristics and manufacturing processes. Knowledge of the nature, types, and properties of standard materials and new materials will assist the process analyst in selecting the most appropriate process, equipment and methods for manufacturing a particular product. The process analyst must also be familiar with engineering drawings and product design. Drawings provide the part configuration and the dimensional tolerances and specifications that need to be met by the manufacturing process selected

In addition, the process planner must be familiar with the operating characteristics and costs of the production and tooling equipment, either available in the plant or to be purchased.

Process Planning starts with a careful examination of the drawing or design of the part. The process planner must be able to analyze the engineering drawing and visualize the three dimensional part configuration. The part configuration must then be analyzed to determine its basic geometric components. Identifying these basic geometric elements assists the process planner in selecting the most appropriate process to manufacture the product.

Process Selection

Consideration should be given to the following factors in selecting a particular process

(a) Nature of part, including materials, tolerances, desired surface finish and operation required.
(b) Method of fabrication including machining or assembling of similar parts or components.
(c) Limitation of facilities including the plant and equipment available.
(d) Possibility of likely product design changes to facilitate manufacturability or cost reduction.
(e) In-plant and outside materials handling systems.
(f) Inherent process to produce specified shape, surface, finish to give desired mechanical properties.
(g) Available skill level of operators for the production. Sometimes the following additional factors affect the selection of a particular process.
(a) Proposed or anticipated production requirements, including volume requirements, production rates and short- term or long- term production runs.
(b) Total end-product costs.
(c) Time available for tooling-up.
(d) Materials receipt, storage, handling and transportation. Careful consideration of these factors will result in the selection of the most appropriate process for the manufacture of a particular product. Selection of an appropriate manufacturing process depends on many factors and requires considerable knowledge, skill and competence of the process planner or process analyst.

Machine Selection

Product manufacturing requires tools and machines that can produce economically as well as accurately. Economy depends to a large extent on the proper selection of the machine or process for the job that will give a satisfactory finished product. The selection of the machine is influenced, in turn by the quantity of items to be produced. Usually there is one machine best suited for a certain output.

In small lot or jobbing type manufacture, general purpose machines such as the lathe, drill press, and milling machine may prove to be the best type since they are adoptable, have lower initial cost, require less maintenance, and possess the flexibility to meet changing conditions in the shop. However, a special purpose machine should be considered when large quantities of a standard product are to be produced. A machine built for one type of work or operation, such as the grinding of a piston or the machining of a cylinder head, will do the job well, quickly and at a low cost requiring only the service of a semi-skilled operator.

Many of the special-purpose machines or tools differ from the usual standard type in that they have built into them some of the skill of the operator. A simple bolt may be produced on either a lathe or an automatic screw machine. The lathe operator must not only know how to make the bolt but must also be sufficiently skilled to operate the lathe. On the automatic machine the sequence of operations and movements of tools are controlled by cams and stops, and each item produced is identical with the previous one. This "transfer of skill" into the machine makes possible the use of less skillfull operators, but it does requires greater skill in supervision and maintenance. Often it is not economical to make a machine completely automatic, as the cost may become prohibitive.

The selection of the best machine or process for a given product requires knowledge of all possible production methods. Factors that must be considered are:

- Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.
- Quality of finished product, and
- Advantages and disadvantages of the various types of equipment capable of doing the work.

Too much emphasis cannot be given to the fact that production can be by several methods, but usually there is one way that is most economical.

Material selection

Material selection is done by the product designer considering the requirements of the parts designed and the hardness, strength properties and other mechanical characteristics of the material. Cost and availability of the material are also considered. Material should be strong enough and at the same time manufacturing or producibility of the part using the given material and the process are also equally important.

In the initial stages of design, the broad material groups such as ferrous or non-ferrous or other non-metallic materials can be considered. At a later stage specific material in the group can be identified.

In certain products or components specific properties of materials such as fatigue strength, thermal conductivity, electrical properties like conductivity, magnetic permeability and insulation resistance may have to be considered.

Material Selection parameters

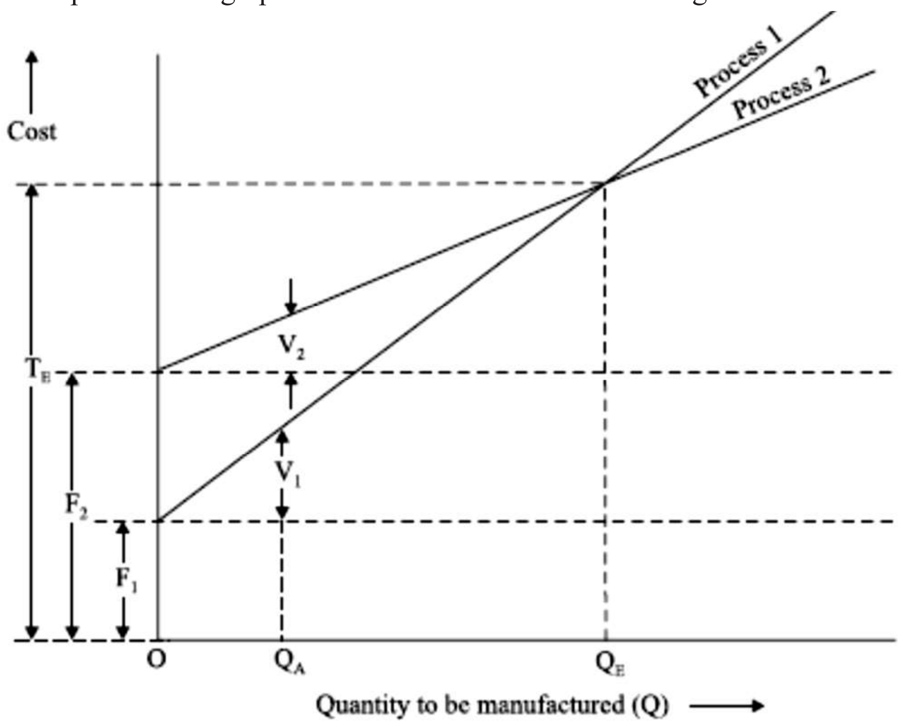
- Functional requirements
- Reliability

- Service life durability
- Aesthetics and appearance
- Environmental Factors
- Compatibility with other materials during service
- Producibility or manufacturability
- Cost

4. **Write notes on selection of cost for optimal processes. (or) write notes on economics of process planning (8 marks) (AU M/J '16) (AU A/M '18)**

Two different types of processes can be used for the same job. The processes can be compared and optimum process selected with the help of break-even charts.

Break-even charts: Break-even charts give the production engineer a powerful tool by which feasible alternative processes can be compared and the process which gives minimum cost can be selected. The fixed and variable costs for two alternative processes are plotted on a graph to a suitable scale as shown in Fig.



F_1 = Fixed costs for process (1)
F_2 = Fixed costs for process (2)
V_1 = Variable costs for process (1)
V_2 = Variable costs for process (2)
Q_E = Break-even quantity at quantity Q_A
T_E = Total costs of manufacture at quantity Q_E

For each process generally the variable cost is a linear function of the quantity manufactured. Therefore, once the fixed costs have been plotted, only one value for the variable costs is required at some value Q_A and the total cost lines can be drawn. Where these lines intersect is known as the break-even point, *i.e.*, the point where the total cost of manufacture of quantity Q_E is same for both process (1) and process (2). The break-even chart tells us to :

Use process (1) if the quantity to be manufactured $\leq Q_E$

Use process (2) if the quantity to be manufactured ≥ Q_E

The value of QE can be scaled directly from the chart with sufficient accuracy, although it can also easily be calculated.

5. A component can be produced with equal ease on either a capstan lathe or on a single spindle cam operated automatic lathe. Find the break-even quantity Q_E if the following information is known. (8 marks) (AU N/D '15)

		Capstan Lathe	*Automatic Lathe*
(*a*)	Tooling cost	Rs. 30.00	Rs. 30.00
(*b*)	Cost of cams	—	Rs. 150.00
(*c*)	Material cost/Component	Rs. 0.25	Rs. 0.25
(*d*)	Operating labour cost	Rs. 2.50/hour	Rs. 1.00/hour
(*e*)	Cycle time/Component	5 minutes	1 minute
(*f*)	Setting up labour cost	Rs. 4.00/hour	Rs. 4.00/hour
(*g*)	Setting up time	1 hour	8 hours
(*h*)	Machine overheads (setting and operating)	300 % of (d)	1000 % of (d)

Capstan lathe :

$$\text{Overheads} = \frac{300}{100} \times 2.50 = \text{Rs. } 7.50/\text{hour}$$

$$\begin{aligned}\text{Fixed Costs} &= \text{tooling cost} + \text{setting-up cost}\\ &= 30.00 + 1(4.00 + 7.50)\\ &= 30.00 + 11.50 = \text{Rs. } 41.50\\ &= \text{Rs. } 42\end{aligned}$$

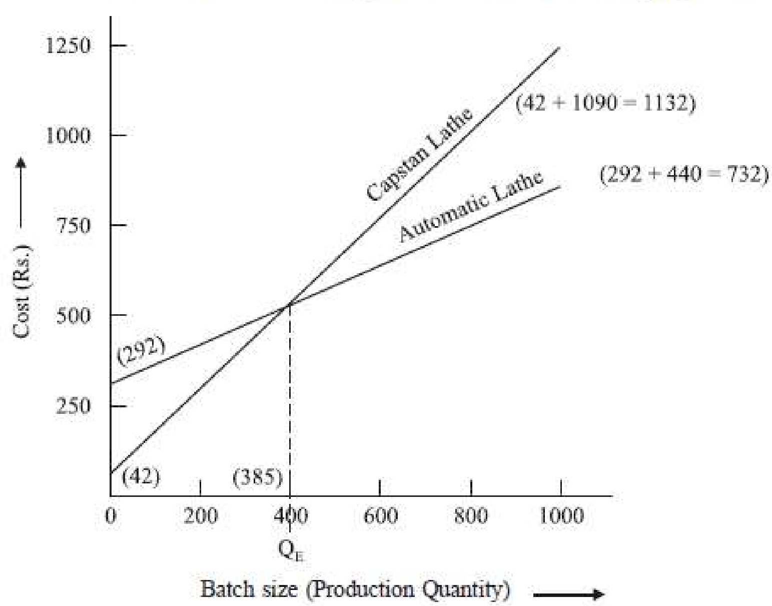
$$\begin{aligned}\text{Variable costs/Component} &= \left(2.50 \times \frac{5}{60}\right) + 0.25 + \left(7.50 \times \frac{5}{60}\right)\\ &= 0.21 + 0.25 + 0.63 = \text{Rs. } 1.09\end{aligned}$$

$$\text{Variable costs/1000 components} = \text{Rs. } 1090.00$$

Automatic lathe :

$$\text{Overheads} = \frac{1000}{100} \times 1.00 = \text{Rs. } 10.00/\text{h}$$

$$\text{Fixed costs} = \text{tooling cost} + \text{cam cost} + \text{setting-up cost}$$



= 30.00 + 150.00 + 8 (4.00 + 10.00)
= 180.00 + 112.00
= Rs. 292.00

$$\text{Variable costs/Component} = \left(1.00 \times \frac{1}{60}\right) + 0.25 + \left(10.00 \times \frac{1}{60}\right)$$

= 0.02 + 0.25 + 0.17
= Rs. 0.44

Variable costs/1000 components = Rs. 440.00.

These costs can now be plotted on a break-even chat (Fig.) to find the value of Q_E. Q_E is scaled from the break-even chart (Fig.) and found to be 385. If the batch size to be manufactured is equal to or less than 385 use the capstan lathe.

If the batch size to be manufactured is equal to or greater than 385 use the automatic lathe. The above is the graphical method of determining Break-even Quantity.

6. **What is Inspection? Write briefly about the different methods of inspections followed in industries. (AU A/M'17)**

Inspection is the function by which the product quality is maintained

The objectives of the Inspection are
(i) To sort out confirm and non-conforming product
(ii) To initiate means to determine variations during manufacture
(iii)To provide means to discover inefficiency during manufacture

Stages of Inspection

Inspection of incoming materials

It consists of inspecting and checking all the purchased raw materials and parts that are supplied before they are taken on to stock or used in actual manufacturing.

This inspection performed either at supplier's place or at manufacturer dispatch or gate.

Inspection of production process

The inspection is done in parallel while the production is in processing. Inspection can be done at different work centers and at the critical production points.

This has the advantages of minimize the wastage of time and money on defective units and preventing delays in assembly.

Inspection of finished goods

This is the last stage when finished goods are inspected and carried out before marketing to see that quality may be either rejected or sold at reduced price.

Methods of inspection

There are two methods of inspection. They are:
i) 100% inspection, and

ii) Sampling inspection,

A. **100% inspection**

100% or cent percent inspection is quite common when the number of parts to be inspection is relatively small.

Here every part is examined as per the specification or standard established and acceptance or rejection of the part depend on the examination.

B. **Sampling inspection**

The use of sampling inspection is made when it is not practical or too costly to inspect each piece. A random sample from a batch is inspected and the batch is accepted if the sample is satisfactory. If the sample is not to the desired specification then either entire batch may be inspected piece by piece or rejected as a whole.

Statistical methods are employed to determine the portion of total quality of batch which will serve as reliable sample.

Types of inspection

Inspection can be classified according to the type of data involved as:

1. Inspection of variable, and
2. Inspection of attributes.

All qualitative characteristics are know as attributes. All characteristics that can be quantified and measurable are known as variables.

Attributes	Variables
• Number of defective pieces found in a sample. • Percentage of accurate invoices. • Weekly number of accidents in a factory. • Number of complaints. • Mistakes per week. • Monthly number of tools rejected. • Errors per thousand lines of code • Percentage of absenteeism.	• Dimension of a measured. • Temperature during heat treatment. • Tensile strength of steel bar. • Hours per week correcting documents. • Time to process travel expense accounts. • Days from order receipt to shipment. • Cost of engineering changes per month. • Time between system crashes. • Cost of rush shipment.

Measurement instruments

The selection of appropriate measurement instrument to be employed is basically depends on the type of quality characteristic of the component considered.

Measurement: The different types of quality characteristics that are to be measured are:

(i) Dimensions/size,

(ii) Physical properties,

(iii)Functionality, and

(iv)Appearance.

7. Discuss about factors to be considered in the selection of jigs and fixtures for cost reduction (8 Marks) (AU A/M '18)

Function of work holders

The main purpose of any Work holding device is to position and hold a workpiece in a precise location while the manufacturing operation is being performed. In order to perform this function adequately, all work holders consist of four basic elements:

Locating elements - that allow the work piece to be positioned correctly

Structural elements- that can withstand the forces applied during the manufacturing operation.

Clamping elements - that can withstand the forces applied during the manufacturing operation and maintain the position of the work piece.

Fixing elements - that attach the work holder to the machine; There are many devices that adhere to the above definition that can be classified as general work holding devices as opposed to specialist work holding devices, that is, jigs and fixtures. General work holding devices can be classified as:

- Vices
- Clamps and abutments
- Chucks
- Collets
- Centers
- Mandrels
- Face plates

The entire above are sometimes referred to as low-cost jigs and fixtures.

Use of jigs and fixtures

For many machining and assembly operations, general-purpose work holding devices may not be sufficient. In these instances, these special work holding requirements are generally satisfied by designing and building special-purpose work holding devices known as jigs and fixtures. The design of special jigs, fixtures and tools is considered as one of three essential activities for facilitating interchangeable manufacture, along with process planning and the design of suitable limit gauges and gauging equipment. Consequently, the main reasons for the use of jigs and fixtures are:

- Components can be produced quicker;
- Greater interchangeability is obtained due to repeatability of manufacture which subsequently reduces assembly time;
- Accuracy can be easily obtained and maintained;
- Unskilled or semi-skilled labour may be used on a machine, resulting in reduced manufacturing costs.

Jigs:

A jig is a work holding device. However, jigs have a further important function and that is determining the location dimensions of specific features. In order to fully understand this function, the distinction between location and size dimensions must be defined. Strictly speaking, not all jigs provide guidance for tools. This is because in many assembly processes, such as welding, the jig merely holds the parts together in the correct orientation with respect to each other while the tool carries out the joining process.

However, in the case of jigs being used with machining processes, they generally always provide guidance for the cutting tool. In summary, a jig is a specially designed and built work holding device, usually made of metal, and performs three basic functions

- holding the component;
- providing guidance for the cutting tools to determine the location dimension for the machining of a feature;
- Positively locating the component so that subsequent components are machined in the same manner.

Jigs can usually be generally classified as either drilling jigs or boring jigs and are used for operations such as drilling, reaming, tapping, chamfering, counterboring, countersinking and boring operations.

Fixture:

A fixture is similar to a jig and can be defined as a special-purpose workholding device used during machining or assembly. However, fixtures are generally of heavier construction than jigs and also usually fixed to the machine table. The main function of a fixture is to positively locate the workpiece. However, unlike a jig, no guidance is provided for cutting tools. Fixtures are used in a variety of processes including milling, broaching, planing, grinding and turning.

8. Explain the importance of selection of the right quality assurance method during manufacturing. (13 marks) (AU A/M '18)

All manufacturing organizations have the common goal of making a profit. The basic model of added value previously presented focuses on the main input of materials undergoing some transformation process and value being added to that material. A profit is made if the value added is greater than the cost to process the material. However, a profit will only be made if the customer is satisfied with the product. In the globally competitive market, this is where the factor of product quality is seen to be important.

The transformation processes mentioned above in this instance are obviously manufacturing processes. However, all manufacturing processes have some degree of inherent variability, even highly automated processes such as CNC milling. Therefore, steps must be taken to ensure that the product specification is adhered to in spite of this variability. The starting point for this is the establishment of the capability of the processes being used.

However, except in the case of the introduction of new processes, the capability of available processes should be known. These data should be documented and available to the process planner if required.

Based on the capability of the process being employed, the process planner will determine which are the most appropriate quality assurance (QA) tools and techniques to employ. These will range from basic measurement tools such as callipers, micrometers and gauges to the use of coordinate measuring machines (CMMs). Also covered will be the application of statistical process control (SPC) methods. Although SPC and process capability studies will most probably be designed and carried out by quality engineering, it is essential that the process planner has an understanding of these in order to enter into meaningful dialogue with regards to process capability. In fact, the process planner will have to liaise closely with the quality function on a number of issues with regards to the process plan. These include:

- identifying inspection locations;
- identifying appropriate inspection and testing methods;
- the frequency of inspection and testing;
- evaluation of inspection and test data;
- Identifying corrective action where appropriate.

All of the above will influence the processes, equipment, tools and manufacturing parameters to be used for a given job, particularly in the case where corrective action involves changing any of these. Therefore, the process planner requires a knowledge and understanding of all of these aspects of product quality.

9. Explain the factors to be considered in selection of process parameters (13 marks) (AU A/M '18)

The three Process parameters to be calculated for each operation during process planning are

- Cutting Speed
- Feed Rate
- Depth of Cut

Cutting Speed:

Cutting speed is known as surface cutting speed or surface speed, can be defined as Relative speed between the tool and the work piece

Unit: meteres per minute

Factors affecting the selection of cutting speed

- Nature of the cut
  - Continuous cut like turning, boring are done at higher cutting speed
  - Shock initiated cuts in shaping, planning, slotting machine are done at lower cutting speed.
  - Intermittent cuts as in milling, hobbing are done at quite lower speed for dynamic loading
- Work material
  - Harder and stronger materials are machined at lower cutting speed
  - Soft, non-sticky materials can be machined at higher cutting speed
- Cutting tool material
- Cutting fluid application
- Purpose of machining
  - Rough machining (lower cutting speed)
  - Finish machining (higher cutting speed)
- Kind of machining operation
- Capacity of machine tool
- Condition of machine tool

Feed and feed rate

Feed is the distance through which the tool advances into the work piece during one revolution of the workpiece or the cutter

Feed rate is the speed at which the cutting tool penetrates the work piece

Unit: millimeters per minute

Factors affecting feed rate:

- Nature of the cut
- Work material
- Cutting tool material
- Cutting fluid application
- Purpose of machining
- Kind of machining operation
- Capacity of machine tool

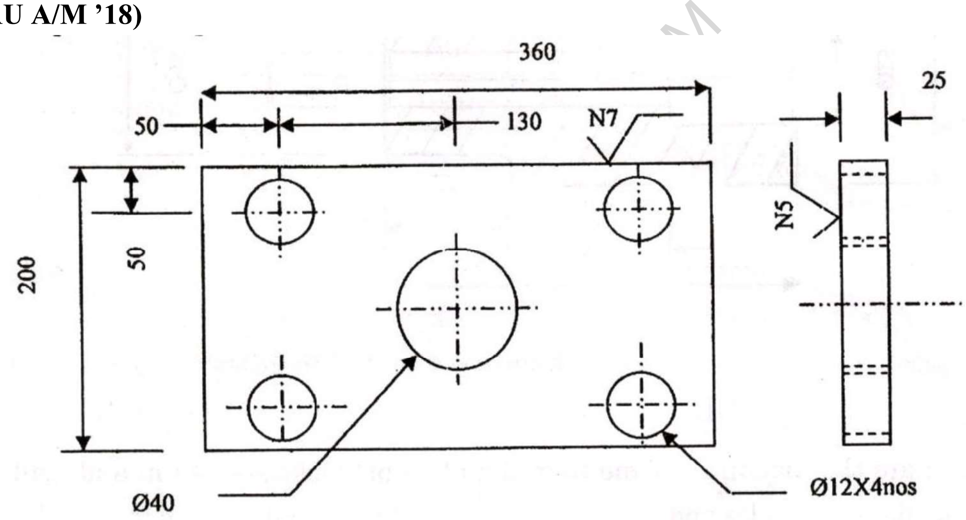
Depth of cut:

Depth of cut is the thickness of the layer of metal removed in one cut or pass, measured in a direction perpendicular to the machined surface

Unit : millimeter

The feed and depth of cut for a particular operation depend on the material to be machined, surface finish required and tool used.

10. Prepare the operation and route sheet for the component shown in fig (15 marks) (AU A/M '18)



Solution

Operation Sheet:

Comp Procedure	**A.R.C**	**Inc: Part Name Drill Plate**			**Prepared by**		
		Drilling Part No :18			**Date**		
Operation No.	*Operation Description*	*Machine Type*	*Tool*	*Dept*	*Set up Time (m)*	*Operation Time (min)*	*Material /Part*
01	Cutting	Cutter	Cutting Wheel	Machine Shop	30	20	Steel Plate
02	Surface Grinding	Grinder	Grinding Wheel	Machine Shop	15	30	Steel Plate
03	Drilling 4 Nos	Drilling Machine	Drill tool -12mm	Machine Shop	15	20	Steel Plate
04	Drilling	Drilling Machine	Drill tool -40 mm	Machine Shop	15	20	Steel Plate

Rout Sheet

Routing sheet		
Part name	Part no	Drg no
Quantity	Material	Planner
Date	Page 1 of 1	Order no
Operation no	Description	Machine tool
01	Cut off 200x360 mm bar to 25 mm thick	Hor. Bandsaw
02	Drill 40 mm dia.	Drill press no 1
03	Drill 12 mm dia x 4 nos	Drill press no 2
04	Surface Grind 5 micro meter	Grinding machine no 1

Unit – 3 Introduction to Cost Estimation

Part – A

1. **Classify the allowances considered in cost estimation (AU N/D '17)**
    - Relaxation Allowance
        - Fatigue allowance
        - Personal need allowance
    - Process allowance
    - Interference allowance
    - Contingency allowance
    - Special allowance
2. **What do you meant by cost accounting? (AU N/D '16) (AU N/D '15) (AU N/D '13) (AU N/D '12) (AU M/J '13)**

    Costing may be defined as a system of accounts which systematically and accurately records every expenditure in order to determine the cost of a product after knowing the different expenses incurred in various department.
3. **Define overhead cost. (AU N/D '16) (AU N/D '14) (AU M/J '12)**

    Overhead is the sum of indirect labour cost, indirect material cost and other expenses including service which cannot be conveniently charged to specific cost unit. These can be further classified as
    - Production expenses/Factory expenses.
    - Administrative expenses.
    - Selling expenses.
    - Distribution expenses.
4. **Distinguish between cost estimation and cost accounting (AU N/D '15) (AU A/M '17) (AU N/D '17)**

S.No	Point of comparison	Cost estimating	Cost accounting
1.	Type of cost	It gives an expected cost of the product based on the calculations by means of standard formulae or certain established rules.	It gives actual cost of the product cost based on the data collected from the different expenditures actually done

5. **List the types of estimates (AU N/D '15)**
    - Guesstimates
    - Budgetary
    - Using Past History
    - Estimating in Some Detail
    - Estimating in Complete Detail
    - Parametric Estimating
    - Project Estimating
6. **What are the sources of for cost estimation? (AU N/D '15)**
    - Cost of design.
    - Cost of drafting.

- Cost of research and development.
- Cost of raw materials.
- Cost of labour.
- Cost of inspection.
- Cost of tools, jigs and fixtures.
- Overhead cost.

7. Brief about the procedure to calculate material cost (AU N/D '15)

- Study the drawing carefully and break up the component into simple geometrical shapes. (Cubes, prisms, cylinders, etc.)
- Add the necessary machining allowances on all sides which are to be machined.
- Determine the volume of each part by applying the formulae of mensuration.
- Add the volumes of all the simple components to get total volume of the product.
- Multiply the total volume of the product by the density of the material to get the weight of the material.
- Find out the cost of the material by multiplying the cost per unit weight to the total weight of the material.

8. Define: Under estimate (AU N/D '14)

The estimated cost is below the actual cost of product, then the firm will face huge financial loss which may cause utter failure or closure of the firm. This estimation is called under estimate.

9. Define: Contingency Allowance (AU N/D '14)

Contingency Allowance: This is a small allowance of time which may be included in the standard time to meet unforeseen items of work, or delays (*e.g.* waiting for raw materials, tools). Contingency allowance is 5% (maximum) or Normal Time.

10. What is meant by conceptual cost estimating? (AU N/D '14)

In the conceptual design stage, the geometry of parts and materials has not been specified, unless they dictate essential product functions. In the conceptual design stage, the costs associated with a change in the design are low. In the conceptual design stage, the incurred costs are only 5 to 7% of the total cost whereas the committed costs are 75 to 85% of the total cost.

The accuracy of the conceptual cost estimate depends on the accuracy of the data base. The accuracy of conceptual cost estimating is approximately – 30% to + 50%. Accuracy in conceptual cost estimating is important since at the conceptual design stage only significant cost savings can occur.

11. List the elements of prime cost (AU N/D '13)

Prime cost = Direct material cost + Direct labour cost + Direct expenses

12. What is the need to include allowances in cost estimation? (AU N/D '13)

A worker cannot work for 8 hours continuously without rest. Also efficiency decreases as the time passes due to fatigue etc. He also requires for tool sharpening, checking measurements and personal calls. All these allowances come under this category. These allowances generally consumes 15 to 20% of total time.

13. Give the methods of costing. (AU N/D '13)

- Process costing.
- Job costing.

- Batch costing.
- Hybrid costing systems.

14. List the various elements of cost. (AU M/J '16) (AU A/M '18)

- Material cost,
- Labour cost and
- Other expenses

15. What shall be the effect of overestimate (AU M/J '16)

If a job is over estimated, i.e the estimated cost is much more than the actual cost of the product, then the firm will not be able to compete with its competitors who estimated the price correctly and losses the order to its competitors.

16. Mention any two functions of estimating. (AU M/J '16) (AU M/J '13) (AU M/J '12)

- To calculate the cost of new material needed to manufacture a product.
- To find the cost of parts to be purchased from outside vendors.
- To find the cost of equipment, machinery, tools, jigs and fixtures etc. required to be purchased to make the product.
- To calculate the direct and indirect labour cost associated with the manufacture of the product, based upon work study.
- To calculate various overhead charges associated with the product.
- To decide about the profit to be charged, taking into consideration other manufacturers of same product in the market.
- To calculate the selling price of the product.
- To maintain records of previous estimating activities of the company for future references.
- To decide the most economical method of making the product.
- To submit cost estimates with the competent authority for further action.

17. Differentiate direct and indirect overheads. (AU M/J '16)

Direct expenses: Direct expenses include all that expenditure which can be directly allocated and charged to a particular job. The direct expenses include cost of special jigs or fixtures, patterns, tooling made for job, or cost of research and development work done for that specific job.

Indirect expenses: Except direct expenses, all other indirect expenditure incurred by the manufacturer is called indirect expenses. The indirect expenses are also called overhead expenses or on-cost.

The indirect expenses are further classified as:

(i) Factory expenses.

(ii) Administrative expenses.

(iii) Selling and distribution expenses.

18. What is meant by direct material? Give example. (AU M/J '13) (AU M/J '12)

It is the cost of those materials which are directly used for the manufacture of the product and become a part of the finished product. This expenditure can be directly allocated and charged to the manufacture of a specific product or job and includes the scrap and waste that has been cut away from original bar or casting.

19. What is meant by direct labour cost? (AU M/J '13) (AU M/J '12)

Direct labourer is one who actually works and processes the materials to convert it into the final shape. The cost associated with direct labour is called direct labour cost. The direct labour cost can be identified and allocated to the manufacture of a specific product. Examples of the direct labour are the workers operating lathes, milling machines or welders, or assemblers in assembly shop. The direct labour cost may be allocated to a product or job on the basis of time spent by a worker on a job.

20. What is fatigue allowance? (AU M/J '13)

The efficiency of the worker decreases due to fatigue (or) working at a stretch and also due to working conditions such as poor lighting, heating (or) ventilation. The efficiency is also affected by the psychology of the worker. It may be due to domestic worries, job securities etc. For normal work, the allowance for fatigue is about 5% of the total time. This allowance can be increased depending upon the type and nature of work and working conditions.

21. What do you meant by realistic estimate? (AU M/J '12) (AU N/D '12) (AU M/J '13)

Both over-estimate and under-estimate may prove to be dangerous and harmful for a concern. Assume that on the basis of an estimate, the concern has to fill up a tender enquiry. The overestimate means the concern will quote a higher rate and thus will not get the job or contract. In case of an under-estimate, the concern will get the contract but it will not be able to complete the work within that small quoted amount and hence will suffer heavy losses. This emphasizes the importance of making realistic estimates. Realistic estimates are very essential for the survival and growth of a concern.

Part – B

1. Discuss various methods of costing in detail. (8 marks) (AU N/D '16) (AU M/J '12) (AU M/J '16) (AU M/J '13)

Methods of Costing

(a) Process costing.
(b) Job costing.
(c) Batch costing.
(d) Hybrid costing systems.

(a) Process costing

This method is employed when a standard product is being made which involves a number of distinct processes performed in a definite sequence.

- In oil refining, chemical manufacture, paper making, flour milling, and cement manufacturing etc., this method is used.
- The object i.e., record and trace cots for each distinct stage.
- While costing, the by-products of each process should be considered.
- This method indicates the cost of a product at different stages as it passes through various processes.

- The total time spent and materials used on each process, as well as services such as power, light and heating are all charged. For this purpose cost sheet may be employed.

The process cost sheet is a summary of all operations for the month. The current operating charges are entered on the sheet showing

1. The transfer cost from the previous operation.
2. The costs incurred by each operation showing materials, labour and overhead in separate columns.

This separation of transfer cost and conversion cost is extremely important for the charges incurred by a department are its measures of efficiency.

The sheet can be used as a basis for:

1. Closing entries at the end of each month.
2. Operating statements, without need to look up the ledger accounts.

Within the cost ledger an account is kept for each process. The direct material, direct labour and factory overhead costs are transferred from the process cost sheet. There are debited to the process account, and then any completed units are credited to cover the transfer to the next process. The balance on the account represents the work-in-progress at the end of the period, which, of course, becomes the opening balance for the next period.

(b) Job costing or order costing

- Job costing is concerned with finding the cost of each individual job or contract. Examples are to be found in general (job order) engineering industries, ship building, building contracts, etc.
- The main features of the system is that each job has to be planned and costed separately.
- Overhead costs may be absorbed on jobs on the basis of actual costs incurred or on predetermined costs.
- The process of determining in advance what a job or order will cost is known as estimating.

It involves consideration of the following factors for each job/order:

1. Materials requirements and prices to arrive at the direct material cost.
2. Labour hours and rates to determine labour costs.
3. Overhead costs.
4. Percentage added to total cost to cover profit.

A record of above costs per unit time is kept in separate cost sheets.

(c) Batch costing

Batch costing is a form of job costing. Instead of costing each component separately, each batch of components are taken together and treated as a job.

Thus, for example, if 100 units of a component, say a reflector are to be manufactured, then the costing would be as far a single job. The unit price would be ascertained by dividing the cost by 100.

Besides maintaining job cost sheets it may also be necessary to keep summary sheets on which the cost of each component can be transferred and the cost of the finished product can be calculated. This applies in general engineering where many hundreds of components may go towards making the finished machine or other product.

(d) Hybrid costing systems

- Many costing systems do not fall nearly into the category of either job costing or process costing. Often systems use some features of both main costing systems.
- Many engineering companies use batch costing, which treats each batch of components as a job and then finds the average cost of a single unit.
- Another variation is multiple costing, used when many different finished products are made. Many components are made which are subsequently assembled into the completed article, which may be bicycles, cars, etc. Costs have to be ascertained for operations, processes, units and jobs, building together until the total cost is found.
- Different names may be used to describe either process costing or job costing. Thus, for example, unit costing is the name given to one system where there is a natural unit, such as sack of flour, a barrel of beer etc.
- In unit costing method, the expenses on various items are charged per unit quantity or production.
- Operation costing is a variation of unit costing, and is used when production is carried out on a large scale, popularly known as mass production.
- Operation costing is the term applied to describe the system used to find the cost of performing a utility service such as transport, gas, water or electricity.
- In this method, the cost per unit is found on the basis of operating expenses incurred on various items of expenditure.
- Unit costing, operation costing and operating costing are variations of process costing.
- Contract or terminal costing is the name given to job costing employed by builders and constructional engineers.
- All these methods ascertain the actual cost.

2. **Explain the procedure followed for estimating the cost of an individual product. (8 marks) (AU N/D ’16) (AU N/D ’14) (AU N/D ’13) (AU M/J ’12)**

The basic steps in the cost estimation of any product are given below:

- Make thorough study of cost estimation request to understand it fully.
- Make an analysis of the product and prepare a bill of materials.
- Make separate lists of parts to be purchased from the market and parts to be manufactured in plant.

- Determine the cost of parts to be purchased from outside.
- Estimate the material cost for the parts/components to be manufactured in plant.
- Make manufacturing process plan for the parts to be manufactured in plant.
- Estimate the machining time for each operation listed in the manufacturing process plan.
- Multiply each operation time by the labour wage rate and add them up to find direct labour cost.
- Add the estimate of step 4, 5, and 8 to get prime cost of component.
- Apply overhead costs to get the total cost of the component.

3. Discuss the objectives of the cost estimation (10 marks) (AU N/D '15)

The main purpose or objectives of estimating are

- To establish the selling price of a product.
- To ascertain whether a proposed product can be manufactured and marketed profitably.
- To determine how much must be invested in equipment.
- To find whether parts or assemblies can be more cheaply fabricated or purchased from outside (make or buy decision).
- To determine the most economical process, tooling or material for making a product.
- To establish a standard of performance at the start of project.
- For feasibility studies on possible new products.
- To assist in long term financial planning.
- To prepare production budget.
- To help in responding to tender enquiries.
- To evaluate alternate designs of a product.
- To set a standard estimate of costs.
- To initiate programs of cost reduction that result in economics due to the use of new materials, which produce lower scrap losses and which create savings due to revisions in methods of tooling and processing, and
- To control actual operating costs by incorporating these estimates into the general plan of cost accounting.

4. Describe the classification and elements of cost. (16 marks) (AU N/D '15) (AU M/J '13)

Elements of cost

For the purpose of calculations, the total cost of the product is divided into the following:

(A) Material cost, (B) Labour cost, (C) Other expenses.

(A) Material Cost

Material cost consists of the cost of materials which are used in the manufacture of product. It is divided into the following

(*a*) Direct material cost: It is the cost of those materials which are directly used for the manufacture of the product and become a part of the finished product. This expenditure can be directly allocated and charged to the manufacture of a specific product or job and includes the scrap and waste that has been cut away from original bar or casting. The procedure for calculating the direct material cost is as follows:

(i) From the product drawing, make a list of all the components required to make the final product.

(ii) Calculate the volume of each component from the drawing dimensions after adding machining allowances, where ever necessary.

(iii) The volume of component multiplied by the density of material used gives the weight of the material per component.

(iv) Add process rejection and other allowances like cutting allowance to get the gross weight per component.

(v) Multiply the gross weight by the cost of material per unit weight to get the cost of raw material per component.

(vi) The cost of raw material for all the components is, similarly, calculated and added up which gives the cost of direct material for the product.

(*b*) Indirect material cost: In addition to direct materials a number of other materials are necessary to help in the conversion of direct materials into final shape. Though these materials are consumed in the production, they don't become a part of the finished product and their cost cannot be directly booked to the manufacture of a specific product. Such materials are called indirect materials. The indirect materials include oils, general tools, grease, sand papers, coolants, cotton waste etc. The cost associated with indirect materials is called indirect material cost.

In some cases certain direct materials like nails, screws, glue, putty etc., are used in such small quantity that it is not considered worthwhile to identify and charge them as direct materials. In such cases these materials are also charged as indirect materials.

Depending upon the product manufactured, the same may be direct materials for one concern and indirect materials for others.

(B) Labour Cost

It is the expenditure made on the salaries, wages, overtime, bonuses, etc. of the employees of the enterprise. It can be classified as :

(*a*) Direct labour cost: Direct labourer is one who actually works and processes the materials to convert it into the final shape. The cost associated with direct labour is called direct labour cost. The direct labour cost can be identified and allocated to the manufacture of a specific product. Examples of the direct labour are the workers operating lathes, milling machines or welders, or assemblers in assembly shop. The direct labour cost may be allocated to a product or job on the basis of time spent by a worker on a job.

(*b*) Indirect labour cost: Indirect labourer is one who is not directly employed in the manufacturing of the product but his services are used in some indirect manner. The indirect labour includes supervisors, inspectors, foreman, storekeeper, gatekeeper, maintenance staff, crane driver etc. The cost associated with indirect labour is called indirect labour cost. The indirect labour costs cannot be identified with a particular job or product but are charged on the total number of products made during a particular period in a plant.

To make the concept of direct and indirect labour cost clear, consider an operator working on a drilling machine. The operator in this case is direct labour whereas the man supervising the job, inspector and store man supplying the material are indirect labour.

(C) Other Expenses

In addition to the material cost and labour cost, several other expenses such as rent of building, depreciation of plant and machinery, cost of packing materials, transport and distribution expenses, wages and salaries of administrative staff and executives are also incurred by the manufacturer. All this expenditure including the indirect material cost and indirect labour cost is called other expenses. We can say that except direct material and direct labour costs all other expenditure incurred by the manufacturer is known as "Other Expenses". Expenses are further classified as:

(*a*) Direct expenses: Direct expenses include all that expenditure which can be directly allocated and charged to a particular job. The direct expenses include cost of special jigs or fixtures, patterns, tooling made for job, or cost of research and development work done for that specific job.

(*b*) Indirect expenses: Except direct expenses, all other indirect expenditure incurred by the manufacturer is called indirect expenses. The indirect expenses are also called overhead expenses or on-cost.
The indirect expenses are further classified as:

- Factory expenses.
- Administrative expenses.
- Selling and distribution expenses.

(*i*) Factory expenses: Factory expenses comprise of the indirect expenses incurred from the receipt of the order to the completion of production. In addition to indirect material and indirect labour cost it includes rent of factory building, licence fee, electricity and telephone bills of factory, insurance charges etc. Factory expenses are also called "Works expenses", or "Factory or Works overhead".

(*ii*) Administrative expenses: Administrative expenses or office expenses include the expenditure incurred on control and administration of the factory. It includes the salaries of office and administrative staff, rent of office building, postage and telephone charges, water and electricity charges for office, Director's fee, legal and audit charges etc. Administrative expenses are also known as 'Administrative overheads'.

(*c*) Selling and distribution expenses: This is the expenditure incurred on Sales Department for selling the product, *i.e.,* wages, salaries, commission and travelling allowances of salesmen and officers in Sales Department, cost of advertisement, packing, delivery and distribution expenses, rent of warehouses etc.

5. Discuss various types of estimates (10 marks) (AU N/D '15) (AU M/J '13)

Types of Estimate

Estimates can be developed in a variety of different ways depending upon the use of the estimates and the amount of detail provided to the estimator. Every estimator should understand every estimating method and when to apply each, because no one estimating method will solve all estimating problems.

Guesstimates

Guesstimate is a slang term used to describe as estimate than lacks detail. This type of estimate relies on the estimators experience and judgment. There are many reasons why some estimates are developed using his method. One example can be found in the tool and die industry. Usually, the tool and die estimator is estimating tool cost without any tool or die drawings. The estimator typically works from a piece part drawing and must visualize what the tool or die looks like. Some estimators develop some level of detail in their estimate. Material cost, for example, is usually priced out in some detail, and this brings greater accuracy to the estimator by reducing error. If the material part of the estimate has an estimating error of plus or minus 5 per cent and the reminder of the estimate has an estimating error of plus or minus 10 per cent, the overall error is reduced.

Budgetary

The budgetary estimate can also be a guesstimate but is used for a different purpose. The budgetary estimate is used for planning the cost of a piece part, assembly, or project. This type of estimate is typically on the high side because the estimator understands that a low estimate could create real problems.

Using Past History

Using past history is a very popular way of developing estimates for new work. Some companies go to great lengths to ensure that estimates are developed in the same way actual cost is conducted. This provides a way past history in developing new estimates. New advancements in group technology now provide a way for the microcomputer to assist in this effort.

Estimating in Some Detail

Some estimators vary the amount of detail in an estimate depending on the risk and dollar amount of the estimate. This is true in most contract shops. This level of detail might be at the operation level where operation 10 might be a turning operation and the estimator would estimate the setup time at 0.5 hours and the run time at 5.00 minutes. The material part of the estimate is usually calculated out in detail to reduce estimating error.

Estimating in Complete Detail

When the risk of being wrong is high or the dollar amount of the estimate is high, the estimator will develop the estimate in as much detail as possible. Detailed estimates for machinery operations, for example, would include calculations for speeds, feeds, cutting times, load and unload times and even machine manipulations factors. These time values are calculated as standard time and adjusted with an efficiency factor to predict actual performance.

Parametric Estimating

Parametric estimating is an estimating method developed and used by trade associations. New housing constructions can be estimated on the basis of cost per square. There would be different figures for wood construction as compared with brick and for single strong construction as compared with multilevel construction. Some heat-beating companies price work on a cost per pound basis and have different cost curves for different heat-treating methods.

Project Estimating

Project estimating is by far the most complex of all estimating tasks. This is especially true if the project is a lengthy one. A good example of project estimating is the time and cost of developing a new missile. The project might take 5 years and cost millions of dollars. The actual manufacturing cost of the missile might be a fraction of the total cost. Major projects of this nature will have a PERT network to keep track of the many complexities of the project. A team of people with a project leader is usually required to develop a project estimate.

6. Explain the data requirements for cost estimation (6 marks) (AU N/D ’15) (AU N/D ’14) (AU M/J ’12) (AU M/J ’16) (AU M/J ’13)

1. Man-hour cost (Labour rate) *i.e.,* hourly cost of skilled, semi-skilled and unskilled labours of the company.
2. Machine-hour cost for different types of equipment and machinery available in the company.
3. Material cost in respect of commercially available materials in the market :
   - Cost in Rs. per kg for different categories of materials like ferrous, non-ferrous, special steel etc., for rods of different diameters and for different thicknesses in respect of flats/sheet metals.
4. Scarp rates *i.e.,* scarp values of different materials in Rs. per kg.
5. In respect of welding operations, information such as electrode cost, gas cost, flux cost, power cost, etc.
6. Set-up time for different processes.
7. % allowances to be added for computing standard time, relaxation allowance, process allowance, special allowance as % of normal time as per the policy of the management.
8. Standard time for different types of jobs, if available.
9. Overhead charges in terms of % direct labour cost or overhead rate in Rs. per hr.
10. Life in years permitted for various types of equipment and machines available in the plant for calculation of depreciation, for cost recovery and for calculation of machine—hour rate.
11. Data base of cost calculations carried out by the company in respect of earlier products or jobs (Historical cost data).
12. Cost data of products available in the market similar to the ones manufactured by the company.

13. Budget estimates prepared by the company for new projects/products.
14. Journals or Data sheets of Professional Associations dealing with Costs and Accounting.

7. Describe different methods of estimates (10 marks) (AU N/D '15) (AU M/J '16)

Methods of Estimates

Computer Estimating

Computer estimating has become very popular in recent years primarily because of the advent of the microcomputer. Early efforts of computer estimating date back to the early 1970s but were cumbersome to use because they were on a mainframe and were card-driven. No less than 15 U.S. companies now offer estimating software for a microcomputer. Because the computer estimating industry is new, there are no real standards for estimating programs. Some programs are nothing more than a way to organize the calculations of an estimate, while others calculate all the details of the estimate.

Advantages and disadvantages

Shown below are some of the major advantages of computer cost estimating.

Accuracy versus consistency

Computer estimates are very consistent, provided they calculate the detail of an estimate. Because these estimates are consistent, they can be made to be accurate. Through the use of consistent efficiency factors or leaving curves, estimates can be adjusted up or down. This is one of the chief advantages of computer cost estimating.

Levels of details

Some computer estimating systems provide different levels of estimating cost. The level of detail selected by the user depends on the dollar risk. Many estimators produce an estimate in more detail because the computer can calculate speeds and feeds, for example, much faster than an estimator can a hand-held calculators.

Refinements

Some computer estimating systems provide many refinements that would be impossible for the estimator to do in any timely manner. One example is to adjust speeds and feeds for material hardness. Typically, the harder the material the more slowly a part will be turned or bored. Another refinement is the ability to calculate a feed state and adjust it based on the width of a form tool.

Source code

Some companies offer the source code uncompiled to their users. This is important because it affords the user the opportunity to customize the software. In addition, many companies have written their own software to do something that is not available on the market. If the source code is not compiled, the users can build upon a computer estimating system.

Disadvantages

The chief disadvantage of computer estimating is that no one estimating system can suit everyone's need. This is especially true if the source code is compiled and not customizable.

Another problem with computer estimating is that the estimator will, in all probability, have to change some estimating methods. Computer software for estimating cost is seldom written around one method of estimating.

Group Technology

Group technology is not new. It was invented by a Russian engineer over 30 years ago. Unfortunately the subject is not taught in many of our colleges and universities. Group technology (GT) is a coding system to describe something.
Several proprietary systems are on the market. One such system, the MICAPP system, uses four code lengths, a 10-, 15-, 20-, 25- digit code. The code length selected is based on the complexity of the piece part or tool being described.

Use for group technology

Shown below are several uses for group technology along with several examples of use both internally and externally.

Cost estimating

GT can be used very efficiently in estimating cost. Assume a company manufactures shaft-type parts. Also arsum there is a computer data base named SHAFT that contains 10-digit code followed by a part number, that is, code part number, and so on. When an estimator must estimate the cost of a new shaft, the process starts by developing a code that describes the characteristics of the part. The first digit in the code might be assigned the part length, while the second digit is assigned the largest diameter and so on. Next, the code is keyed in and the computer finds all the parts that meet the numeric descriptions and points out the part numbers. The best fit is selected to be modified into a new part. All the details of each description are retrieved. These include diameter, length of cut, number of surfaces, and the like. The estimator can alter these features and make the old part into a new one.

Actual performance

As the part is being produced, the estimated information is updated with actual performance and refined. This gives the estimator the ability to improve estimating accuracy, because the next time, the computer finds that part as one to be modified into a new one, the estimator is working with actual performance.

Parametric Estimating

Parametric estimating is the act of estimating cost or time by the application of mathematical formulas. These formulas can be as simple as multiplices or as complex as regression models.
Parametric estimating, sometimes refused as statistical modeling, was first documented by the Rard Corporation in the early 1950's in an attempt to predict military hardware cost.

Use of parametric estimating

Many companies use some form of parametric estimating to develop sales forecasting. The four examples cited below will give the reader a good feel of how parametric estimating is used in a variety of different industries.

Construction industry

In developing a cost estimate for residential buildings, some cost estimators use a dollar value per square foot. The estimator constitutes curves based on different construction such as wood on brick buildings and single or multi-storey dwellings. These numbers can then be multiplied by the number of square feet in the building.

Some construction companies have refined this process to provide additional detail carpeting, for example, could have a separate multiplier.

Heat treating

Most commercial heat-treating companies price their work based on a cost per pound and heat treating method. Heat-treating costs are very difficult to define because many times more than one type of part is in the heat-treating furnace at the same time. It is difficult to think of a more effective way to estimate cost for this type of industry.

Statistical Estimating

The analysis of data through the use of statistical methods has been used for centuries. These data can be cost versus other information that leads to cost development. The practitioner must have a well-founded background in the use and application of statistical methods because an endless array of methods is available, several of which are described below.

Parametric estimating

Statistical estimating is another form of parametric estimating. The parametric methods made industry oriented whereas the methods discussed below are universal.

Regression analysis

They form most popular of regression analysis are simple regression, multiple regression, log-linear regression and curvilinear regression. Each math model is different and is designed for a specific use.

8. Explain the allowances in estimation (6 marks) (AU N/D ’15) (AU M/J ’12) (AU M/J ’16)

Allowances in estimation

Normal Time = Observed time × Rating factor

Observed time and rating factor are obtained during the time study of an operation or a job.

Various allowances are considered in estimating the standard time for a job. These allowances are always expressed as % of Normal Time and are added to Normal Time to compute the Standard Time.

Standard Time = Normal Time + Allowances

Standard Time is time required to complete one cycle of operation (usually expressed in minutes).

Standard Time for a job is the basis for determining the standard output of the operator in one day or shift.

Need for Allowances

Any operator will not be able to carry out his work throughout the day without any interruptions. The operator requires some time for his personal needs and rest, and hence such time should be included in standard time. There are different types of allowances, and they can be classified as follows :

1. Relaxation Allowance : This is also known as **Rest Allowance**. This allowance is given to enable the operator to recover from the physiological and psychological effects (Fatigue) of carrying out the specified work and to attend to personal needs.

Relaxation allowance consists of :

(*i*) Fatigue allowance, and

(*ii*) Personal needs allowance.

(*i*) Fatigue allowance is intended to cater for the physiological and psychological effects of carrying out the work.

This time allowance is provided to enable to operator to overcome the effect of fatigue which occurs due to continuous doing of the work (monotony etc.).

Relaxation allowance (Fatigue allowance and Personal needs allowance put together) is commonly 5% to 10% (of normal time).

(*ii*) Personal needs allowance: This allowance is provided to enable the operator to attend to his personal needs (*e.g.* going to toilet, rest room, etc.).

2. Process Allowance: It is an allowance to compensate for enforced idleness of the worker.

During the process, it may be likely that the operator is forced to be idle due to certain reasons, such as:

- When the process is carried out on automatic machines, (the operator is idle after loading the job on the machine).
- When the operator is running more than one machine (as in the case of cellular manufacturing)

Process allowance varies from one manufacturing situation to another depending on factors such as hazardous working conditions, handling of heavy loads, strain involved, mental alertness required etc. Generally 5% of the normal time is provided towards process allowance.

Interference Allowance : This allowance is provided where in a cycle of operation, there are certain elements which are machine controlled. The operator cannot speed up those elemental operations.

This allowance is also provided when one worker is working on several machines.

4. Contingency Allowance : This is a small allowance of time which may be included in the standard time to meet unforeseen items of work, or delays (*e.g.* waiting for raw materials, tools). Contingency allowance is 5% (maximum) or Normal Time.

5. Special Allowances : These allowances are a policy matter of the management, *e.g.* when the job is newly introduced or when a new machine or new method is introduced, because worker takes some time to learn the new method or job; Special allowance is also provided depending on the working conditions such as noise, dust, etc.

Once the normal time is obtained, the standard time can be estimated or obtained by adding all the allowances to normal time.

Standard time = Normal time + Allowances

9. Write the difference between cost accounting and cost estimation (8 marks) (AU N/D '14) (AU N/D '13) (AU M/J '12) (AU M/J '13)

Points of comparison	Cost estimating	Cost accounting
1.Types of	It gives an expected cost of the	It gives actual cost of the product

cost	product based on the calculations by means of standard formula.	based on the data collected from the different expenditures actually done for a product.
2.Duration of process	It is generally carried out before actual production of a product Due to certain unexpected expenses coming to light at a later stage, estimates may be modified or revised.	It usually starts with the issue of order for production of a product and ends after the product is dispatched for sale. For sale commitments like free repair or replacement, the process continuous up to the expiry period of guarantee because the overhead expenses incurred in the above case will be included in the production cost.
3.Nature of quality	A qualified technical person or engineer having a thorough knowledge of the drawings and manufacturing process is required.	It can be done by a person qualified for accounts instead of a technical person. Thus, this work instead of being of technical nature is more of a clerical work

10. What are the methods used in conceptual cost estimation? Explain (8 marks) (AU N/D '14) (AU A/M '17)

There are different methods of estimates of cost. These are in addition to conventional method of estimating of cost such as calculating material cost, labour cost, factory expenses and overhead expenses and adding all these cost elements.

The methods of estimates are :

1. Conceptual Cost Estimating

It is estimating during the conceptual design stage. In the conceptual design stage, the geometry of parts and materials have not been specified, unless they dictate essential product functions. In the conceptual design stage, the costs associated with a change in the design are low. In the conceptual design stage, the incurred costs are only 5 to 7% of the total cost whereas the committed costs are 75 to 85% of the total cost.

The accuracy of the conceptual cost estimate depends on the accuracy of the data base. The accuracy of conceptual cost estimating is approximately – 30% to + 50%. Accuracy in conceptual cost estimating is important since at the conceptual design stage only significant cost savings can occur.

Conceptual cost estimating methods include :

(*a*) Expert opinion,

(*b*) Analogy methods, and

(*c*) Formula based methods.

(a) Conceptual Method Based on Expert Opinion

If back-up and/or historical cost data are not available, getting expert opinion is the only way for estimating cost.

The disadvantages of this method are

i. The estimate is subjected to bias.
ii. The estimate can't be quantified accurately.
iii. The estimate may not reflect the complexity of the product or project.
iv. Reliable data base for future estimates are not possible.

In spite of these disadvantages, the expert opinion is useful when historical data base is not available. It is also useful to verify cost estimate arrived at using other methods of conceptual estimating (like analogy methods and formula based methods).

(b) Conceptual Method Based on Analogy

Analogy estimating derives the cost of a new product based on past cost data of similar products. Cost adjustments are made depending on the differences between the new and previous product/system. Analogy estimating requires that the products be analogous or similar and products manufactured using similar facilities or technology. If the technology changes, the analogy estimating relationship has to changed to reflect the changes in technology. Another limitation of this method is that analogy estimates often omit important details that makes cost considerably higher than the original cost estimates.

(c) Conceptual Method Based on Formula

There are formula based methods that are primarily used in the conceptual cost estimating. These are :

(*i*) Factor method,
(*ii*) Material cost method,
(*iii*) Function method, and
(*iv*) Cost-size relationship.

These methods are known as **Global cost estimation methods** and they generally use one of the above methods only.

(i) Factor method

This is the simplest method, but it can give reliable estimates if the data are kept up-to-date, taking into consideration factors such as inflation, and environmental issues which tend to increase the cost.

(ii) Material cost method

Material cost method is justified since the material cost is the largest cost item in the prime cost of many manufacturing companies.

According to this method :

Estimated cost of an item $= \frac{m\text{aterial cost of the item being estimated}}{m\text{aterial cost share of item being estimated (in \%)}}$

(iii) Function method

In function method more variables are used and the expressions are non-linear. The function is basically a mathematical expression with constants and variables that provides a mathematical function for the cost estimate. One expression is given below:

Cost of turbo fan engine development, (in Rs. Lakhs)

$$= 41.2 \times a^{0.74} \times b^{0.08}$$

where a = Maximum engine thrust, in kg

and b = No. of engines produced

11. Discuss about determination of material and labour cost. (8 marks) (AU N/D ’13)

Determination of Material Cost

To calculate the material cost of the product the first step is to study drawing of the product and split it into simple standard geometrical shapes and to find the volume of the material in the product and then to find the weight. The volume is multiplied by density of the metal used in the product.

The exact procedure to find the material cost is like this:

1. Study the drawing carefully and break up the component into simple geometrical shapes. (Cubes, prisms, cylinders, etc.)
2. Add the necessary machining allowances on all sides which are to be machined.
3. Determine the volume of each part by applying the formulae of mensuration.
4. Add the volumes of all the simple components to get total volume of the product.
5. Multiply the total volume of the product by the density of the material to get the weight of the material.
6. Find out the cost of the material by multiplying the cost per unit weight to the total weight of the material.

12. Discuss in detail about the computation of price of a product using the ladder of cost with appropriate example. (16 marks) (AU N/D ’13)

The elements of cost can be combined to give following types of cost:

				Profit (or) Loss	
			Selling + Distribution expenses		
		Administrative expenses	Office cost (or) production	Total (or) selling cost	Selling price (or) Market price
	Factory expenses	Factory cost (or)	(or) Manufacturing cost	(or)	Catalogue price
Direct material	Prime cost (or)	Works cost	(or)		
Direct labour	Direct cost				
Direct expense					

1. Prime cost: It consists of direct material cost, direct labour cost and direct expenses.

Prime cost = Direct material cost + Direct labour cost + Direct expenses.

Prime cost is also called as direct cost.

2. Factory cost: It consists of prime cost and factory expenses.

Factory cost = prime cost + factory expenses.

Factory cost is also named as works cost.

3. Office cost: It consists of factory cost and administrative expenses.
Office cost = Factory cost + Administrative expenses
It is also named as manufacturing cost (or) cost of production.
4. Total cost: It includes manufacturing cost and selling and distribution expenses.
Total cost = Manufacturing cost + selling and distribution expenses.

Selling price
If the profit is added in the total cost of the product, it is called selling price. The customers get the
articles by paying the price which is named as selling price.
Selling price = Total cost + Profit
= Total cost – Loss
Making price (or) catalogue price: Some percentage of discount allowed to the distributors of product is added into the selling price. The result obtained is called the market price (or) catalogue price (figure).

13. Explain the various methods used in an industry for allocation of overheads with an example. (16 marks) (AU M/J '16) (AU N/D '12)

After estimating the total on-cost, next step is the allocation of this on-cost over the production. To run the business in economical way, it is necessary to know, the variation of on-cost with the variation of production. Several methods are available for the allocation of on-cost. The choice of a particular method depends upon the nature of work, type of organisation and types of machine used, etc.
Following are the different methods of on-cost allocation:

- Percentage on direct material cost.
- Percentage on direct labour cost.
- Percentage on prime cost.
- Manhour method.
- Machine hour method.
- Combination of man hour and machine hour method.
- Unit of production method.
- Space rate method.

These methods for estimation the overheads are discussed below:

Percentage on Direct Material Cost

This method is based on the theory that the overhead expense is incurred in proportion to the value of the direct materials consumed. This method is simple, but does not allow for the usual situation where in some of the materials is fabricated without the use of much equipment whereas other material in the same plant requires extensive machinery, requiring considerably more labour, power, maintenance and floor space.

However, for the allocation of material expenses such as purchasing, storage and handling, this method is useful. This method is also useful when major part of the cost is of material line foundries and mines.

$$\text{Overhead rate} = \frac{\text{Total overhead expenses}}{\text{Total direct material cost}}$$

Percentage on Direct Labour Cost

In this method, allocation of on-cost depends upon the wages paid to the direct labour. This method is very reasonable and simple in calculation. Therefore, this method is very popular. It is the ratio of the total overhead to the direct labour cost for a particular period.

$$\text{Overhead rate} = \frac{\text{Total overhead for a period}}{\text{Total direct labour for that period}}$$

It is also called as labour burden rate. It is the ratio of the annual total overheads to the annual direct labour cost.

Overhead cost = Overhead rate X Direct labour cost/unit.

This is very suitable where production is mainly carried out by hand. It may not be an accurate indicator where machines of greatly different capacity and sizes are operated. Also if two products take the same time but labour rate for both is different then this method will give less overhead cost where labour is cheap and high overhead cost where labour is costly. Therefore, this method increases the cost of a component which has already higher labour cost. Also, in many case it gives very approximate results because sometimes of overhead such as depreciation and taxes have very little relationship to labour costs.

Percentage on Prime Cost

This is a very simple method. So it has gained popularity. This method is suitable, where labour and material both play equal role. This method will give the same overhead cost for two products with equal prime cost, even though their labour and material costs will be different. This will be useful where only one type of product is being manufactured and when direct labour and direct materials costs are nearly equal.

$$\text{Overhead rate} = \frac{\text{Total overhead over a period}}{\text{Prime cost over a period}} \times 100$$

Then, overhead cost/unit = Overhead rate X Prime cost/unit.

Man-Hour Rate

This method is very similar to the percentage on direct labour cost method. The difference in the two methods is that in which the basis of allocation was the total direct labour cost, whereas in this basis of the total hours spent by the direct labour and not the wages paid to them. This is an important method over the direct labour cost method.

$$\text{Man-hour rate} = \frac{\text{Total overheads}}{\text{Total direct man hour spent}}$$

Unit Rate Method

This is also known as production unit basis method. In this, on-cost is allocated on the basis of unit of production. Unit of production is generally piece, kilogram, tonne, litres, metre, etc. This method is mostly used where only one type of production is carried out. This method cannot be used in factories, where different kinds of products are manufactured. Unit rate is the overheads for one unit. It can be calculated as the ratio of total overheads to the quantity of production during a particular period.

$$\text{Overhead/Unit} = \frac{\text{Total overheads}}{\text{Quantity of production}}$$

Space Rate Method

The amount of space occupied by a machine has a relationship to certain overhead expenses. For example, building expense, heat, light, ventilation and service equipment such as cranes and conveyors

Space rate/m^2 for a department is

$$\text{Rs.} = \frac{\text{Total overhead assigned to a department}}{\text{Total area of the production department in square metre}}$$

∴ Space charges to the individual machine for the defined period of time = Space rate × Total area with which the machine should be charged.

14. A factory has 15 lathes of same make and capacity and 5 shapers of same make and capacity. Lathes occupy 30 m^2 area while shapers occupy 15 m^2. During one calender year, factory expenses for this section area are as follows:

***(i)* Building rent and depreciation**	**Rs. 5000**
***(ii)* Indirect labour and material**	**Rs. 15000**
***(iii)* Insurance**	**Rs. 2000**
***(iv)* Depreciation charges of lathes**	**Rs. 5000**
***(v)* Depreciation charges of shapers**	**Rs. 3000**
***(vi)* Power consumption for the lathes**	**Rs. 2000**
***(vii)* Power consumption for the shapers**	**Rs. 1000**

Find out the machine hour rate for lathes and shapers work for 25000 hours and 8000 hours respectively. (16 marks) (AU N/D '12) (AU A/M '18)

Solution

(a) Lathe section

Total overheads for the lathe section will be as follows:

(i) Building rent and depreciation (charged on the basis of floor area occupied)

= (5000 × 30) / (30 + 15)

= Rs. 3333.33

(ii) Indirect labour and material = (15000 × 30) / (30 + 15)

= Rs.10000

(iii) Insurance = (2000 × 30) / (30 + 15)

= Rs. 1333.33

(iv) Depreciation = Rs. 5000

(v) Power = Rs. 2000

∴ Total overheads = Rs. 21666.66

∴ Machine hour rate for lathes = 21666.66 / 25000

= Rs. 0.87

(b) Shaper section

Total overhead for the shaper section will be as follows

(i) Building rent and depreciation = (5000 ×15) / (30+15)

= Rs. 1666.66

(ii) Indirect labour and material = (15000×15) / (30+15)

= Rs.5000

(iii) Insurance = (2000 ×15) / (30+15)
= Rs. 666.66
(iv) Power consumption = Rs. 1000.00
(v) Depreciation = Rs. 3000.00
Total overheads = Rs. 11332.32
∴ Machine hour rate for shapers = 11332.32/ 8000
= Rs. 1.42

15. Calculate prime cost, factory cost, production cost, total cost and selling price per item from the data given below for the year 2003-04.

Cost of raw material in stock as on 1-04-2003	**Rs. 25,000**
Raw material purchased	**Rs. 40,000**
Direct labour cost	**Rs. 14,000**
Direct expenses	**Rs. 1,000**
Factory/Works overhead	**Rs. 9,750**
Administrative expenditure	**Rs. 6,500**
Selling and distribution expenses	**Rs. 3,250**
No. of items produced	**Rs. 650**
Cost of raw material in stock as on 31-03-2004	**Rs. 15,000**

Net profit/item is 10 percent of total cost of the product.

(16 marks) (AU N/D '14)

Solution :

For 650 units produced during 2003-04

(*i*) Direct material used = Stock of raw material on 1-04-2003 + raw material purchased – stock of raw material on 31-03-2004
= 25,000 + 40,000 – 15,000
= Rs. 50,000

(*ii*) Direct labour = Rs. 14,000
(*iii*) Direct expenses = Rs. 1,000
Prime cost = 50,000 + 14,000 + 1,000
= Rs. 65,000

Factory cost = Prime cost + Factory expenses
= 65,000 + 9,750
= Rs. 74,750

Production cost = Factory cost + Administrative expenses
= 74,750 + 6,500
= Rs. 81,250

Total cost = Production cost + Selling expenses
= 81,250 + 3,250
= Rs. 84,500

Selling price = 84,500 + 10 percent of 84,500
= 84,500 × 1.10 = Rs. 92,950

$$\text{Prime cost/item} = \frac{65,000}{650} = \text{Rs. } 100$$

$$\text{Factory cost/item} = \frac{74,750}{650} = \text{Rs. } 115$$

$$\text{Production cost/item} = \frac{81,250}{650} = \text{Rs. } 125$$

$$\text{Total cost/item} = \frac{84,500}{650} = \text{Rs. } 130$$

$$\text{Selling price/item} = \frac{92,950}{650} = \text{Rs. } 143$$

16. From the following data for a sewing machine manufacturer, prepare a statement showing prime cost, Works/factory cost, production cost, total cost and profit.

	Rs.
Value of stock of material as on 1-04-2003	**26,000**
Material purchased	**2,74,000**
Wages to labour	**1,20,000**
Depreciation of plant and machinery	**8,000**
Depreciation of office equipment	**2,000**
Rent, taxes and insurance of factory	**16,000**
General administrative expenses	**3,400**
Water, power and telephone bills of factory	**9,600**
Water, lighting and telephone bills of office	**2,500**
Material transportation in factory	**2,000**
Insurance and rent of office building	**2,000**
Direct expenses	**5,000**
Commission and pay of salesman	**10,500**
Repair and maintenance of plant	**1,000**
Works Manager salary	**30,000**
Salary of office staff	**60,000**
Value of stock of material as on 31-03-2004	**36,000**
Sale of products	**6,36,000**

(16 marks) (AU N/D '13)

Solution :

(*i*) Material cost = Opening stock value + Material purchases – Closing balance
= 26,000 + 2,74,000 – 36,000
= Rs. 2,64,000

Prime cost = Direct material cost + Direct labour cost + Direct expenses
= 2,64,000 + 1,20,000 + 5,000
= Rs. 3,89,000

(*ii*) Factory overheads are :

	Rs.
Rent, taxes and insurance of factory	16,000
Depreciation of plant and machinery	8,000
Water, power and telephone bill of factory	9,600
Material transportation in factory	2,000
Repair and maintenance of plant	1,000

Work Manager salary	30,000
Factory overheads or Factory cost	**66,600**

Factory cost = Prime cost + Factory expenses
= 3,89,000 + 66,600
= Rs. 4,55,600

(*iii*) Administrative/office expenses are :

	Rs.
Depreciation of office equipment	2,000
General administrative expenses	3,400
Water, lighting and telephone bills of office	2,500
Rent, insurance and taxes on office building	2,000
Salary of office staff	60,000
Total	**69,900**

Production cost = Factory cost + Office expenses
= Rs. 4,55,600 + Rs. 69,900
= Rs. 5,25,500

(*iv*) Selling overheads are :

Commission and pay to salesmen = Rs. 10,500

Total cost = Production cost + Selling expenses
= 5,25,500 + 10,500
= Rs. 5,36,000

(*v*) Profit = Sales – Total cost
= 6,36,000 – 5,36,000
= Rs. 1,00,000

17. In a manual operation, observed time for a cycle of operation is 0.5 minute and the rating factor as observed by the time study engineer is 125%. All allowances put together is 15% of N.T. (Normal Time). Estimate the Standard Time.
(8marks) (AU N/D '2014)

Solution :

Observed time for a cycle = 0.5 min.
Rating factor = 125%
Normal time = Observed time × Rating factor
= 0.5 × 1.25
= 0.625 min.
Allowances = 15% of Normal Time
Standard Time = Normal Time + Allowances
= 0.625 min. + (0.15 × 0.625) min.
= 0.625 min. + 0.094 min.
= 0.719 min.
= 0.72 min.

18. In a manufacturing process, the observed time for 1 cycle of operation is 0.75 min. The rating factor is 110%. The following are the various allowances as % of normal time :

Personal allowance = 3%
Relaxation allowance = 10%
Delay allowance = 2%

Estimate the standard time. (8 marks) (AU N/D '2014)

Solution :

Basic time or normal time = Observed time × Rating factor
= 0.75 min × 110%
= 0.75 × 1.1
= 0.825 min.

Standard time = Normal time + All allowances
= Normal time + [3% + 10% + 2%] of normal time
= 0.825 min. + (0.15 × 0.825) min.
= 0.825 min. + 0.124 min.
= 0.949 min.
= 0.95 min.

Standard time is the basis for calculation of standard output (*i.e.,* no. of components produced) in 1 day or in 1 shift (of 8 hours). Incentive schemes are based on the standard output.

19. From the records of an oil mill, the following data are available,

***(a)* Raw materials**
- **Opening stock = Rs. 1,40,000**
- **Closing stock = Rs. 1,00,000**
- **Total purchases during the year = Rs. 2,00,000**

***(b)* Finished goods**
- **Opening stock = Rs. 20,000**
- **Closing stock = Rs. 30,000**
- **Sales = Rs. 6,00,000**

***(c)* Direct wages = Rs. 1,00,000**
***(d)* Factory expenses = Rs. 1,00,000**
***(e)* Non-manufacturing expenses = Rs. 85,500**

Find out what price should be quoted for a product involving an expenditure of Rs. 35,000 in material and Rs. 45,000 wages. Factory expenses to labour cost is 100%. (16marks) (AU M/J '2012)

Solution

Direct material cost = Opening stock + Total purchases – Closing stock
= 1,40,000 + 2,00,000 – 1,00,000
= Rs. 2,40,000

Direct material cost = Rs. 2,40,000
Direct wages = Rs. 1,00,000
Factory expenses = Rs. 1,00,000

Factory cost = Direct material + Direct labour + Factory overheads

= 2,40,000 + 1,00,000 + 1,00,000

= Rs. 4,40,000/-

Non-manufacturing expenses = Rs. 85,000

Total cost = Factory cost + Non-manufacturing expenses

= 4,40,000 + 85,000

= Rs. 5,25,000/-

Factory expenses of direct labour cost = 100%

Non-manufacturing expenses = 85000/4, 40,000 = 19.31%

Cost of finished goods = Opening stock + cost of goods – Closing stock

= 20,000 + 5,25,000 – 30,000

= 5,15,000

Cost of finished goods = Rs. 5,15,000/-

Total sales = Rs. 6,00,000

Profit = Rs. 6,00,000 – 5,15,000

Profit to sales cost = 85,000/5,15,000 = 16.5%

The cost of the product to be quoted is listed down as follows:

Direct material cost = Rs. 35,000

Direct labour cost = Rs. 45,000

Factory expenses = 100% of wages

= Rs. 45,000

Factory cost = Direct material cost + Labour cost + Factory expenses

= 35000 + 45000 + 45000 = 1,25,000

Factory cost = Rs. 1,25,000

Administrative and selling expenses = Non-manufacturing expenses

= 19.31% of factory cost

= Rs. 24,137.50

Total cost = 1,25,000 + 24137.50

= Rs. 1,49,137.50

Total cost = Rs. 1,49,137.50

Profit = 16.5% total cost

= Rs. 24,607.68

Profit = Rs. 24,607,68/-

Quotation price = 1,49,137.50 + 24,607.68 = 1,73,745.1875

Quotation price = Rs. 1,73,745.1875/-

Selling price = Total cost + Profit

= 3410 + 682 = Rs. 4092/-

Cost per unit = 4092 / Number of units

= 4092 / 50

= Rs. 81.84

List price = Selling price + Discount

= Selling price + 20% list price

Let us assume 'list price' be ('x/-Rs.')

Now, x = 81.84 + (20x/100)

x = 81.84 + 0.2 x

0.8 x = 81.84

x = 102.30

List price = Rs. 102.30.

20. Calculate the selling price per unit from the following data :

Direct material cost = Rs. 8,000
Direct labour cost = 60 percent of direct material cost
Direct expenses = 5 percent of direct labour cost
Factory expenses = 120 percent of direct labour cost
Administrative expenses = 80 percent direct labour cost
Sales & distribution expenses = 10 percent of direct labour cost
Profit = 8 percent of total cost
No. of pieces produced = 200 (16 marks) (AU A/M '17) (AU N/D '17)

Solution :

Direct material cost = Rs. 8,000

Direct labour cost = 60 percent of direct material cost

$$= \frac{60 \times 8,000}{100} = \text{Rs. } 4,800$$

Direct expenses = 5 percent of direct labour cost

$$= \frac{4,800 \times 5}{100} = \text{Rs. } 240$$

Prime cost = 8,000 + 4,800 + 240

= Rs. 13,040

Factory expenses = 120 percent of direct labour cost

$$= \frac{4,800 \times 120}{100} = \text{Rs. } 5,760$$

Administration Expenses = 80 percent of direct labour cost

$$= \frac{4,800 \times 80}{100} = \text{Rs. } 3,840$$

Sales and distribution expenses = 10 percent of direct labour cost

$$= \frac{10 \times 4,800}{100} = \text{Rs. } 480$$

Total cost = Prime cost + Factory expenses + Office expenses + Sales and distribution expenses

= 13,040 + 5,760 + 3,840 + 480

= Rs. 23,120

Profit = 8 percent of Total cost

$$= \frac{23,120 \times 8}{100} = \text{Rs. } 1,849.60$$

= Rs. 1,850 (say)

Selling price = Total cost + Profit

= 23,120 + 1,850

= Rs. 24,970

$$\text{Selling price 1 unit} = \frac{24,970}{200} = \text{Rs. } 124.85$$

$$= \text{Rs. } 125$$

21. Describe the various components of job estimate. (16 marks) (AU N/D ’17)

Components of a cost estimate or job estimate

The total estimated cost of a product consists of the following cost components :

1. Cost of design.
2. Cost of drafting.
3. Cost of research and development.
4. Cost of raw materials.
5. Cost of labour.
6. Cost of inspection.
7. Cost of tools, jigs and fixtures.
8. Overhead cost.

1. Cost of Design

The cost of design of a component or product is estimated by ascertaining the expected time for the design of that component. This may be done on the basis of similar job previously manufactured but for new and complicated jobs the estimator has to consult the designer who gives the estimated time of design. The estimate design time multiplied by the salary of designer per unit time gives the estimated cost of design. If the design of the component is done by some outside agency, the total amount paid to outside agency gives the cost of design.

2. Cost of Drafting

Once the design of the component is complete, its drawings have to be prepared by draftsman. The expected time to be spent in drawing or drafting is estimated and is then multiplied by the standard drafting rate or by the salary of the draftsman per unit time to get estimated cost of drafting.

3. Cost of Research and Development Work

Before taking up the manufacturing of actual components/parts considerable time and money has to be spent on research and development. The research may be theoretical, experimental or developmental research. The cost of R and D can be estimated by considering various items of expenditure incurred during R and D work which include :

(*i*) Cost of labour involved.

(*ii*) Cost of material used.

(*iii*) Cost of special equipment used or fabricated for the prototype.

(*iv*) Depreciation, repair and maintenance cost of experimental set-up.

(*v*) Cost of services of highly qualified and trained personnel needed for experimentation.

(*vi*) Cost of preparing Test Reports, if any.

In some cases the cost of R and D may be estimated on the basis of research involved in similar products produced in the past.

4. Cost of Raw Material

The estimation of cost of materials used in production of a component/product consists of following steps:

(*i*) A list of all the materials used in the manufacture of the product is made which includes the direct as well as indirect materials.

(*ii*) The quantity (weight or volume) of all the material expected to be used in the manufacture of the product is estimated. The allowance for material wastage, spoilage and scarp are also added for each component/part.

(*iii*) Cost of each material is estimated by multiplying the estimated quantity of each material with its estimated future price. The estimate of future price of a material is made keeping in view of present prices and general trends and variations.

(*iv*) Estimated cost of all the materials is added to get the overall estimated material cost.

5. Cost of Labour

The cost of labour involved in the manufacture of a product is estimated by estimating the labour time needed to manufacture the product and multiplying it by cost of labour per hour. In order to estimate the labour time expected to be spent on a job, one must have thorough knowledge of the various operations to be performed, machines to be used, sequence of operations, tools to be used and labour rates. For this purpose, the estimator may consult engineers, supervisors or foremen from production or industrial engineering departments.

6. Cost of Inspection

A product being manufactured is inspected at various stages during its manufacture. It may be inspection of raw material or in-process inspection or inspection of finished goods. The cost of inspection equipment, gauges and consumable involved in the inspection and testing are taken into account while estimating the cost of the product.

7. Cost and Maintenance Charges of Tools, Jigs and Fixtures

Estimated cost of a product includes the estimated cost and maintenance charges for the tools, jigs, fixtures and dies required in the production. The cost of tools, jigs, fixtures etc., is estimated considering their present prices, market trend and the number of times a particular tool can be used during its life-time. The estimated cost divided by the number of jobs, it can make, gives the tool cost per unit produced.

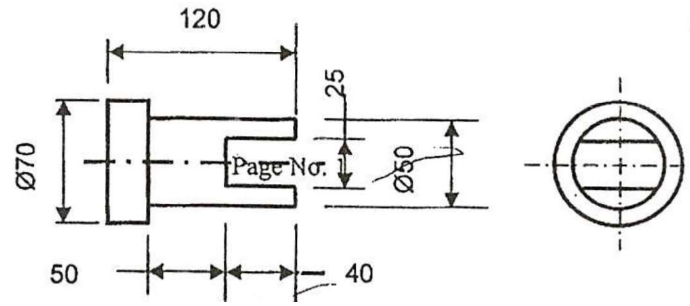
8. Overhead Costs

Overhead or indirect costs are those which are not incurred specifically for any one order or product and these cannot be charged directly to a specific order or product. The overhead costs may be estimated by referring to the records of overhead costs in similar items produced in past. The overhead cost per unit varies considerably with the volume of production *i.e.* number of components produced.

Unit – 4 Production Cost Estimation

Part – A

1. **Estimate the weight of the component shown in fig. the material is CI (AU A/M '18)**



Volume of the component = volume of A + Volume of B – Volume of C

$= (\frac{\pi}{4} d^2 l) + (\frac{\pi}{4} d^2 l) - (b \times l)$

$= \left(\frac{\pi}{4} \times 70^2 \times 30\right) + \left(\frac{\pi}{4} \times 50^2 \times 90\right) - (50 \times 25)$

= 115454 + 176715 +1250

= 290919 cm^3

Weight of the component = Volume x Density

Assume density of CI = 7.2 g/cc

Weight of the component = 290919 x 7.2

= 2094617 g = 2094.62 kg

2. **What are the causes of depreciation? (AU A/M '18)**

Depreciation due to physical condition

- Wear and tear
- Physical decay
- Accident
- Poor maintenance of equipment

Depreciation due to functional conditions

- Inadequacy
- Obsolescence

3. **Give the formula for calculating the cost of power consumed in arc welding (AU N/D '17)**

Power cost = $\frac{V \times A}{1000} \times \frac{t}{60} \times \frac{1}{\eta} \times \frac{1}{r} \times C$

V = voltage in volts

A = current in amperes

t = welding time in minutes

η = efficiency of the welding machine

r = ratio of operating time to connecting time taken by operator

C = rate of electricity per kWhr in Rs

4. **Define roll forging (AU N/D '17)**

Roll forging is used to draw out sections of bar stock, *i.e.,* reducing the cross-section and increasing the length. Special roll forging machines, with dies of decreasing cross-section are used for roll forging.

5. **List the losses to be considered in estimating the gross weight of a forging component? (AU M/J '16) (AU N/D '16) (AU N/D '14) (AU N/D '13) (AU A/M '17)**
   - Scale loss
   - Flash loss
   - Tonghold loss
   - Sprue loss
   - Shear loss
6. **Differentiate leftward and rightward welding. (AU N/D '16) (AU A/M '18)**
   Leftward welding: In this method, welding is started from right hand side of the joint and proceeds towards left. This method is used for welding plates upto 5 mm thick. No edge preparation is required in case of the plates of thickness upto 3 mm.
   Rightward welding: This method is adopted for welding thicker plates. Welding proceeds from left to right. The flame is directed towards the deposited metal and rate of cooling is very slow.
7. **Brief about the procedure to calculate material cost. (AU N/D '15)**
   Direct material cost = Gross weight × Price/kg.
   Gross weight = Net weight + Material loss in the process.
   Net weight = Volume of forging × Density of metal.
8. **How can you calculate the labour cost for a turning process in lathe? (AU N/D '13)**
   Direct labour cost $= t \times l$
   Where t = Time for truning process per piece (in hrs)
   l = Labour rate per hour
9. **Define Flash loss (AU N/D '13)**
   There is a certain quantity of metal which comes between the flat surfaces of the two dies after the die cavity has been filled in. This material equal to the area of the flat surface is wastage. For finding the flash loss, the circumference is determined which multiplied by cross-sectional area of flash will give the volume of the flash. The volume multiplied by material density gives the flash loss. Generally, it is taken as 3 mm thick and 2 mm wide all round the circumference.
10. **What are the various elements considered while calculating the cost of a welded joint? (AU N/D '12)**
    The total cost of welding consists of the following elements :
    - Direct material cost.
    - Direct labour cost.
    - Direct other expenses.
    - Overheads.
11. **State any four pattern allowances. (AU N/D '12)**
    (i) Shrinkage Allowance
    (ii) Machining Allowance
    (iii) Draft Allowance
    (iv) Distortion Allowance

12. Define production cost (AU A/M '17)

Prime cost = Direct material cost + Direct labour cost + Direct expenses (if any)

Factory cost = Prime cost + Factory overheads

Cost of production = Factory cost + Administrative overheads + Miscellaneous overheads (if any)

13. What are overhead costs? (AU A/M '17)

Overhead expenses include all expenditure incurred by the manufacturer on the product except the direct material cost, direct labour cost and direct chargeable expenses.

(a) Indirect material expenses.

(b) Indirect labour expenses.(supervisors, inspectors, foremen, store-keeper, gatekeepers, repair and maintenance staff, crane drivers, sweepers, administrative office staff and sales and distribution staff, etc.)

(c) Other indirect.(water and electricity charges, rent of factory building, licence fee, insurance premia stationery, legal expenses, audit fee etc.

Part – B

1. **Market price of a CNC lathe is Rs. 50,000 and discount is 20% of market price. Here factory cost is 4 times selling cost and 1 : 4 : 2 is ratio of material, labour and overhead charges. Material cost is Rs. 4000. What is profit value?(16 marks) (AU M/J '16)**

Solution

Material cost	= 4000
From ratio, Labour cost	= 16,000/-
Overheat charges	= 8000/-
Factory cost	= 4000 + 16000 + 8000
	= Rs. 28000/-
Now selling price	= 28000 / 4
Total cost	= 28000 + 7000
	= Rs. 35000/-
Selling price	= Market rate – Discount
Profit	= Selling price – Total cost
	= 40000 – 35000
	= 5000

Company incurs Rs. 5000/- as profit.

2. **Explain the different items involved in the estimation of arc welding cost of job. (6 marks) (AU M/J '16) (AU N/D '16)**

Estimation of Cost in Welding

The total cost of welding consists of the following elements:

1. Direct material cost.
2. Direct labour cost.
3. Direct other expenses.
4. Overheads.

1. Direct Material Cost

The direct material cost in a welded component consists of the following :

- Cost of base materials to be welded *i.e.,* sheet, plate, rolled section, casting or forging. This cost is calculated separately.
- Cost of electrodes/filler material used. The electrode consumption can be estimated by using the charts supplied by the suppliers. Another way to find the actual weight of weld metal deposited is to weigh the component before and after the welding and making allowance for stub end and other losses during welding.

Also the weight of weld metal = Volume of weld × Density of weld material

2. Direct Labour Cost

The direct labour cost is the cost of labour for preparation, welding and finishing operations. Preparation or pre-welding labour cost is the cost associated with preparation of job for welding, *i.e.,* the edge preparation, machining the sections to be welded etc. If gas is used in cutting/preparation of edges, its cost is also taken care of.

Cost of labour in actual welding operation is calculated considering the time in which arc is actually in operation.

The cost of labour for finishing operation is the cost of labour involved in grinding, machining, sand or shot blasting, heat treatment or painting of welded joints.

3. Direct Other Expenses

The direct other expenses include the cost of power consumed, cost of fixtures used for a particular job etc.

Cost of power : The cost of power consumed in arc welding can be calculated from the
following formula :

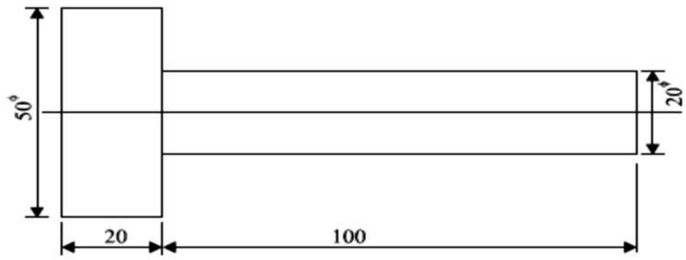
$$\text{Power cost} = \frac{V \times A}{1{,}000} \times \frac{t}{60} \times \frac{1}{E} \times \frac{1}{r} \times C$$

Where V = Voltage
A = Current in Amperes
t = Welding time in minutes
E = Efficiency of the welding machine
= 0.6 for welding transformer
= 0.25 for welding generator
r = Ratio of operating time to connecting time taken by the operator
C = Cost of electricity per kWh *i.e.,* Unit.

Overheads

The overheads include the expenses due to office and supervisory staff, lighting charges of office and plant, inspection, transport, cost of consumables and other charges. The cost of equipment is also apportioned to the individual components in the form of depreciation.

3. **150 components, as shown in Fig. are to be made by upsetting a dia 20 mm bar. Calculate the net weight, gross weight and length of dia 20 mm bar required. The density of material may be taken as 7.86 gms/cc. (10 marks) (AU M/J '16)**



Solution :

$$\text{Net volume of material} = \frac{\pi}{4}[(5)^2 \times 2 + (2)^2 \times 10]$$

$$= \frac{\pi}{4}(50 + 40) = 70.72 \text{ cm}^3$$

Net weight per component = 70.72 × 7.86 = 556 gms

Net weight for 150 components = 556 × 150 = 83,400 gms

= 83.4 kgs

Losses :

Shear loss = 5 percent of net weight

$$= \frac{5}{100} \times 556 = 27.8 \text{ gms}$$

Scale loss = 6% of net weight

$$= \frac{6}{100} \times 556 = 33.4 \text{ gms}$$

Gross weight/component = 556 + 27.8 + 33.4

= 617 gms

Gross weight for 150 components = 617 × 150 = 92,550 gms

= 92.550 kgs

$$\text{Length of 20 mm f bar required} = \frac{92550}{\frac{\pi}{4}(2)^2 \times 7.86}$$

= 3744 cms = 37.44 meters.

4. **Two 1 m long M.S plates of 10 mm thickness are to be welded by a lap joint with a 8 mm electrode. Calculate the cost of welding. Assume the following data.**
   - ***(i)*** **Current used = 30 amperes**
   - ***(ii)*** **Voltage = 300 V**
   - ***(iii)*** **Welding speed = 10 m/hr**
   - ***(iv)*** **Electrode used = 0.1 kg/m of welding**
   - ***(v)*** **Labour charges = Rs. 4.00/hr**
   - ***(vi)*** **Power charges = Rs. 0.2/kWh**
   - ***(vii)*** **Cost of electrode = Rs. 40.00/kg**

(viii) **Efficiency of machine = 70%** **(16 marks) (AU M/J ’12)**

Solution

(a) Cost of electrode required for 1 m length of welding = 0.1 kg

Cost of electrode as Rs. 40/kg = 40×0.1 = Rs. 4.

(b) Labour cost

Time required for welding 1 m length

$$= \frac{1}{10} \text{ hr}$$

Labour charge $= \frac{1}{10} \times 4$ = Rs. 0.4

(c) Power charges, as power consumed

$$= \frac{V \times I}{\text{Efficiency of the machine}}$$

$$= \frac{300 \times 30}{0.7} = 12.85 \text{ kW}$$

Energy consumed for welding 1 m length

$$= 12.85 \times \frac{1}{10} = 1.285 \text{ kWh}$$

Power charges at Rs. 0.1/kWh $= 1.28 \times 0.4$

= Rs. 0.512

Total welding cost = Cost of electrode + Labour charges + Power charges

= 4 + 0.4 + 0.512 = Rs. 4.912.

5. **Generalize the meaning of Tonghold loss in forging. (6 marks) (AU N/D ’16)**

This is the loss of material due to a projection at one end of the forging to be used for holding it with a pair of tongs and turning it round and round to give the required cross section in drop forging. About 1.25 cm and 2.5 cm of the size of the bar is used for tonghold. The tonghold loss is equal to the volume of the protections. For example, the tonghold loss for a bar of 2 cm diameter will be

$$= \frac{\pi}{2}(2)^2 \times 1.25 \; cu.cm$$

6. **State and explain various losses which are to be considered in a forging shop. (8 marks) (AU N/D ’16) (AU N/D ’17)**

Losses in Forging

It is well known that some metal is always lost in the different operations of forging and this lost metal must be added to the net weight before calculating the material cost. The different losses to be considered are:

a) Scale loss
b) Flash loss
c) Tonghold loss
d) Sprue loss
e) Shear loss

(i) Scale loss

This is the material lost because of the surface oxidation in heating and forging the piece. When iron is heated at a high temperature in atmospheric conditions a thin of iron oxide is formed all round the surface of the heated metal which goes as a waste. The iron oxide film is known as scale and it falls from the surface of the metal on being beaten up by the hammer. Scale loss depends upon the surface area, heating time and the type of material. For forgings under 5 kg loss is 7.5 per cent of the net weight, and for forgings from 5 to 12.5 kg and over an addition of 6 per cent and 5 per cent of the net weight is necessary for scale loss.

(ii) Flash loss

There is a certain quantity of metal which comes between the flat surfaces of the two dies after the die cavity has been filled in. This material equal to the area of the flat surface is a wastage. For finding the flash loss, the circumference is determined which multiplied by cross-sectional area of flash will give the volume of the flash. The volume multiplied by material density gives the flash loss. Generally, it is taken as 3 mm thick and 2 mm wide all round the circumference.

(iii) Tonghold loss

This is the loss of material due to a projection at one end of the forging to be used for holding it with a pair of tongs and turning it round and round to give the required cross section in drop forging. About 1.25 cm and 2.5 cm of the size of the bar is used for tonghold. The tonghold loss is equal to the volume of the protections. For example, the tonghold loss for a bar of 2 cm diameter will be

$$= \frac{\pi}{2}(2)^2 \times 1.25 \text{ cu.cm}$$

(iv) Sprue loss

The connection between the forging and tonghold is called the sprue or runner. The material loss due to this portion of the metal used as a contact is called sprue loss. The sprue must be heavy enough to permit lifting the workpiece out of the impression die without bending. The sprue loss is generally 7.5 per cent of the net weight.

(v) Shear loss

In forging, the long bars or billets are cut into required length by means of a sawing machine. The material consumed in the form of saw-dust or pieces of smaller dimensions left as defective pieces is called shear loss. This is usually taken as 5% of the net weight. From above we see that nearly 15 to 20% of the net weight of metal is lost during forging. And as already said these losses must be added to the net weight to get the gross weight of the material.

7. **A factory produces 100 bolts and nuts per hour on a machine. Material cost is Rs. 375, labour Rs. 245 and direct expense is Rs. 80. The factory on cost is 150% and office on cost is 30%. If sales price is Rs. 11.30 find whether company incurs profit or loss. (10 marks) (AU N/D ’15)**

Solution

Material cost	= 375.00
Labour	= 245.00
Direct expenses	= 80.00
Factory expenses	= 150% of labour cost

= 245 × 1.5 = Rs. 367.50

Factory cost = 375 + 245 + 80 + 367.5
= Rs. 1067.50

Office on cost = 30% of factory cost
= 1067.50 X 0.3
= Rs. 320.25

Total cost = 1067.50 + 320.25
= 1387/-

Cost per nut = 1387/100
= 13.87/-

Sales price = 11.30

Hence, company incurs a loss of Rs. 2.57/-.

8. Estimate the selling price per piece of a casting component from the following data :

Net weight of cast component = 5.117 kg
Density of material = 7.2 gms/cc
Cost of molten metal at cupola spout = Rs. 20 per kg
Process scrap = 20 percent of net weight
Scrap return value = Rs. 6 per kg
Administrative overheads = Rs. 30 per hour
Sales overheads = 20 percent of factory cost
Profit = 20 percent of factory cost

Other expenditures are:

Operation	*Time (min)*	*Labour cost/hr (Rs.)*	*Shop overheads/hr (Rs.)*
Moulding and pouring	15	20	60
Shot blasting	5	10	40
Fettling	6	10	40

(16 marks) (AU N/D '13)

(*i*) *Material cost :*

Net weight of cast component = 5.117 kg
Process scrap = 20 percent of 5.117 kg
= 0.2 × 5.117 = 1.02 kg
Total metal required per component = 5.12 + 1.02 = 6.14 kg
Cost of metal poured = 6.14 × 20 = Rs. 122.8
Process return value = 1.02 × 6 = Rs. 6.12
Material cost per component = 122.8 – 6.1 = Rs. 116.7

(*ii*) *Labour cost and factory overheads :*

Labour cost = Rs. 6.83
Shop overheads = Rs. 22.33

Process	Time per piece (Minutes)	Labour cost per piece (Rs.)	Shop overheads per piece (Rs.)
Melting and pouring	15	5.00	15.00
Shot blast	5	0.83	3.33
Fettling	6	1.00	4.00
Total	**26 min**	**6.83**	**22.33**

(*iii*) Factory cost per component = 116.70 + 6.83 + 22.33 = Rs. 145.86

(*iv*) Administrative overheads = (30 × 26) /60 = Rs. 13

(*v*) Sales overheads = 0.2 × 145.86 = Rs. 29.17

(*vi*) Profit = 0.2 × 145.86 = Rs. 29.17

Selling price per component = Factory cost + Administrative overheads+ Sales overheads + profit

= 145.86 + 13 + 29.17 + 29.17

= Rs. 217.2

9. Calculate the net weight and gross weight for the component shown in Fig. Density of material used is 7.86 gm/cc. (6 marks)

Also calculate :

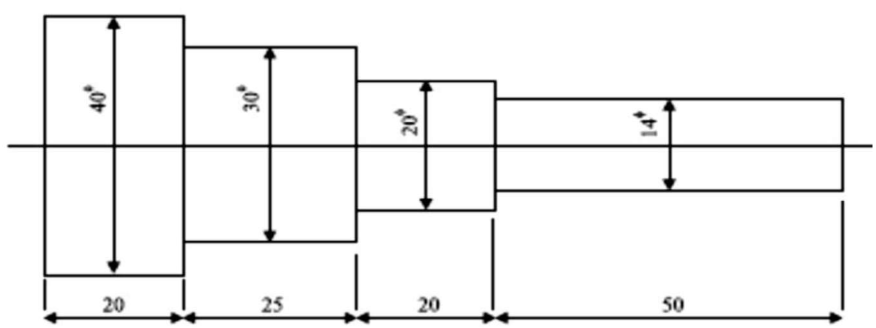
(*i*) Length of 14 mm dia bar required to forge one component. (4 marks)

(*ii*) Cost of forging/piece if: (6 marks)

Material cost = Rs. 80 per kg

Labour cost = Rs. 5 per piece

Overheads = 150 percent of labour cost. (16 marks) (AU N/D '13) (AU A/M '17)



$$\text{Net volume of forged component} = \frac{\pi}{4}\,[(4)^2 \times 2 + (3)^2 \times 2.5 + (2)^2 \times 2 + (1.4)^2 \times 5]$$

$$= \frac{\pi}{4}\,(72.3) = 56.76 \text{ cc}$$

$$\text{Net weight} = 56.76 \times 7.86 = 446 \text{ gms}$$

Losses :

Shear loss = 5 percent of net weight

$$= \frac{5}{100} \times 446 = 22.30 \text{ gms}$$

Scale loss = 6 percent of net weight

$$= \frac{6}{100} \times 446 = 26.76 \text{ gms}$$

Taking flash width = 20 mm

Flash thickness = 3 mm

Flash loss = (periphery of parting line) × 2 × 0.3 × 7.86

= [2 (2 + 2.5 + 2 + 5) + 1.4 + (2 – 1.4) + (3 – 2) + (4 – 3) + 4] × 2 × 0.3 × 7.86

= 31.0 × 2 × 0.3 × 7.86 = 146 gms

Tonghold loss = 2 × Area of cross-section of bar × 7.86

$$= 2 \times \frac{\pi}{4}(1.4)^2 \times 7.86 = 24.22 \text{ gms}$$

Sprue loss = 7 percent of net weight

$$= \frac{7}{100} \times 446 \text{ gms}$$

= 31.22 gms

Total material loss = 22.3 + 26.8 + 146 + 24.22 + 31.22

= 250 gms

Gross weight = Net weight + Losses

= 446 + 250 = 696 gms

(*i*) New length of 14 mm f bar required per piece

$$= \frac{\text{Volume of forging}}{\text{Area of X – Section of bar}}$$

$$= \frac{56.76}{\frac{\pi}{4}(1.4)^2} = 36.86 \text{ cm}$$

$$\text{Direct material cost} = \frac{696}{1{,}000} \times 8$$

= Rs. 5.57

Direct labour cost = Rs. 5 per piece

Overheads = 150 percent f labour cost

= 1.5 × 5 = Rs. 7.5

Cost per piece = 5.57 + 5 + 7.5

= Rs. 18

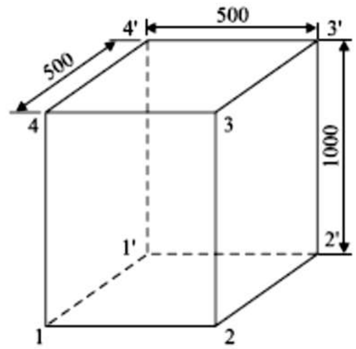
10. A container open on one side of size 0.5 m × 0.5 m × 1 m is to be fabricated from 6 mm thick plates Fig. The plate metal weighs 8 gms/cc. If the joints are to be welded, make calculations for the cost of container. The relevant data is :

Cost of plate = Rs. 10 per kg

Sheet metal scarp (wastage) = 5 percent of material

Cost of labour = 10 percent of sheet metal cost

Cost of welding material = Rs. 20 per meter of weld. (16 marks) (AU A/M '17)



Solution :

(*i*) To calculate material cost :

Net volume of material used = (4 × 50 × 100 × 0.6) + (50 × 50 × 0.6) = 13,500 cc

Net weight of container = Volume × density of material

= 13,500 × 8 = 1,08,000 gm = 108 kgs

Sheet metal scrap = 5 percent of net weight

$$= \frac{108 \times 5}{100} = 5.40 \text{ kgs}$$

Total weight of sheet metal required for fabrication of one container

= 108 + 5.4 = 113.4 kgs

Cost of sheet metal per container = 113.4 × 10 = Rs. 1134

(*ii*) To calculate labour charges :

Cost of labour = 10 percent of sheet metal cost

$$= \frac{1134 \times 10}{100} = \text{Rs. } 113$$

(*iii*) To calculate cost of welding material :

Length to be welded = (4 × 50) + (4 × 100) = 600 cm = 6 meters

Cost of welding material = 6 × 20 = Rs. 120

(*iv*) Cost of container = Cost of sheet metal material + Cost of labour + Cost of welding material

= 1134 + 113 + 120 = Rs. 1367

11. Work out the welding cost for a cylindrical boiler drum 2 ½ × 1 m diameter which is to be made from 15 mm thick m.s plates. Both the ends are closed by arc welding of circular plates to the drum. Cylindrical portion is welded along the longitudinal seam and welding is done both in inner and outer sides. Assume the following data:

(*i*) Rate of welding = 2 meters per hour on inner side and 2.5 meters per hour on outer side

(*ii*) Length of electrodes required = 1.5 m/ meter of weld length

(*iii*) Cost of electrode = Rs. 0.60 per meter

(*iv*) Power consumption = 4 kWh/meter of weld

(*v*) Power charges = Rs. 3/kWh

(*vi*) Labour charges = Rs. 40/hour

(*vii*) Other overheads = 200 percent of prime cost

(*viii*) Discarded electrodes = 5 percent

(*ix*) Fatigue and setting up time = 6 percent of welding time. (16 marks) (AU N/D '17) (AU A/M '18)

Diameter of drum = 1 meter

Length of drum = 2.5 meter

As the cylindrical portion is welded on both sides and both the ends are closed by welding circular plates, the welding on circular plates being on one side only.

Length of weld = 2 × p × dia of drum + (2 × length of drum)
= 2 × p × 1 + (2 × 2.5)
= 11.28 meters ≈11.3 meters.

(*i*) To calculate direct material cost: In this example the cost of electrodes is the direct materiel cost.

Length of electrode required = 1.5 m/m of weld

Net electrode length required for 11.3 meters weld length = 1.5 × 11.3 = 16.95 meters

Discarded electrode = 5 percent

Total length of electrodes required = 16.95 + [(5 × 16.95)/100] = 17.8 meters

Cost of electrodes = 0.6 × 17.8 = Rs. 10.68.

(*ii*) To calculate direct labour cost: To calculate the labour charges, first we have to calculate the time required for making the weld (assuming that side plates have single side welding and longitudinal seam is welded on both sides).

Length of weld on inside of drum = 2.5 meter

Length of weld on outside of drum = 2 × p × 1 + (2.5) = 8.8 meters

Time taken for inside weld = (2.5 × 1)/2 = 1.25 hrs

Time taken for outside weld = (8.8 × 1)/2.5 = 3.5 hrs

Net time required for welding = 1.25 + 3.5 = 4.75 hrs

Fatigue and setting up allowances = 4.75 × 0.06 = 0.28 hrs

Total time required = 4.75 + 0.28 = 5 hrs

Direct labour cost = 40 × 5 = Rs. 200

(*iii*) To calculate cost of power consumed

Power consumption = 4 × 11.3 = 45.2 kWh

Cost of power consumed = 45.2 × 3 = Rs. 135.6

(*iv*) To calculate the overhead charges:

Prime cost = Direct material cost + Direct labour cost + Direct other expenses

Prime cost = 10.68 + 200 + 135.60 = Rs. 346

Overheads = (200 x 346)/100 = Rs. 692

(*v*) Total cost of making boiler drum = 10.68 + 200 + 135.6 + 692 = Rs. 1038

12. List the various sections that will be normally found in a foundry shop. (4 marks) (AU N/D '17)

Generally a foundry shop has the following sections :

1. Pattern Making Section

In this section the patterns for making the moulds are manufactured. The machines involved in making the patterns are very costly and small foundries may not be able to afford these machines. In such cases the pattern are got made for outside parties who are specialists in pattern making. Patterns are made either from wood or from a metal.

2. Sand-mixing Section

In this section raw sand is washed to remove clay etc., and various ingredients are added in the sand for making the cores and moulds.

3. Core-making Section

Cores are made in this section and used in moulds to provide holes or cavities in the castings.

4. Mould Making Section

This is the section where moulds are made with the help of patterns. The moulds may be made manually or with moulding machines.

5. Melting Section

Metal is melted in the furnace and desired composition of metal is attained by adding various constituents. Metal may be melted in a cupola or in an induction or in an arc furnace. In some cases pit furnace is also used for melting the metals.

6. Fettling Section

The molten metal after pouring in the moulds is allowed to cool and the casting is then taken out of mould. The casting is then cleaned to remove sand and extra material and is shot blasted in fettling section. In fettling operation risers, runners and gates are cut off and removed.

7. Inspection Section

The castings are inspected in the inspection section before being sent out of the factory.

Unit – 5 Machining Time Calculation

Part – A

1. Write steps involved in cutting time calculation (AU A/M '18)

Step 1: Calculation of length of cut (L)

Step 2: Calculation of feed (f) and depth of cut

Step 3: Calculation of speed (S); [rpm (N) = 1000 S/π D]

Step 3: Calculation of machining time by using the formula ($\frac{L}{f \times N}$)

2. What are the typical data required for cutting time calculation in shaping (AU A/M '18)

Shaping time T_m = [{L x B x (1+ k)} / (1000 v f)] x number of cuts

B = width of the work

N = Number of stroke/min

f = Feed/stroke in mm

V = Cutting speed m/min

K = Return time/Cutting time

3. Write short notes on tear down time (AU N/D '17)

It is the time taken to remove the tools, jigs and fixtures from the machine and to clean the machine and tools after the operation has been done on the last component of batch. The tear down time is usually small. The tear down time occurs only once for a complete lot or batch taken for machining. Standard data are available for tear down time for various machines.

4. Give the formula for estimation of machining time for drilling (AU N/D '17)

Time for drilling = $\frac{\text{Depth of hole to be produced}}{\left(\frac{\text{feed}}{\text{rev}}\right) \times (\text{rpm})} = \frac{L}{f \times N}$

5. Define cutting speed. List various factors affecting cutting speed. (AU N/D '16) (AU A/M '17)

Cutting speed is the speed at which the cutting edge of tool passes over the job and it is usually expressed in meters per minute. The cutting speed depends on the cutting tool material, the work piece material and the operation. Once the cutting speed has been selected, the revolutions per minute of job/machine are calculated as follows:

S = π DN/1000 or N = 1000 S/π D

Where S = Surface cutting speed in meters per minute

D = Diameter of the job in mm

N = r.p.m. of machine/job.

6. What is machining time? (AU N/D '16)

It is the time for which the machine works on the component, i.e. from the time when the tool touches the work piece to when the tool leaves the component after completion of operation. The machining time depends on the type and extent of machining required, material being machined, speed, feed, depth of cut and number of cuts required.

7. Derive an expression for machining time in planning machine. (AU N/D '11)

Planing time Tm = [(L + 250) (B + 50) (1+ k)] / (1000 v f)

B = width of the work

N = Number of stroke/min

f = Feed/stroke in mm
V = Cutting speed m/min
K = Return time/Cutting time

8. Derive an expression for machining time for plain turning in lathe. (AU N/D '10)

Turning, on a lathe, is the removal of excess material form the workpiece by means of a pointed tool, to produce a cylindrical or cone shaped surface. From cutting speed, r.p.m. of job are calculated by using the formula.

$$N = \frac{1000\,S}{\pi D}$$

where N = r.p.m. of job
S = Surface cutting speed in meters/minute
D = Diameter of the stock to be turned (in mm)
if f = Feed per revolution (in mm)
L = Length of stock to be turned (in mm)
T = Time required for turning (in minutes)

$$\text{Then } T = \frac{L}{f \, X \, N}$$

9. What are the different types of milling operations? (AU M/J '07)

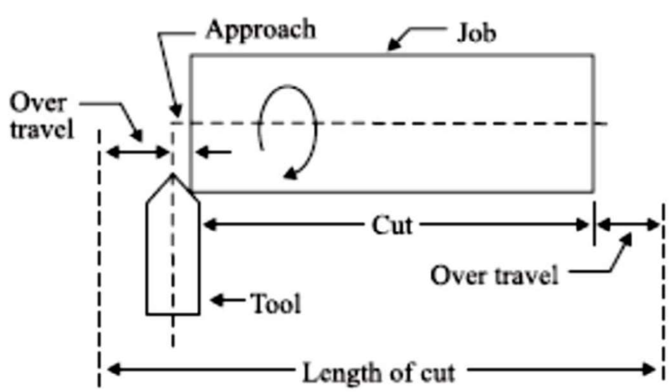
- Face milling
- Slab milling
- Profile milling
- Keyway cutting
- Slotting

10. Define tool approach and tool travel (AU A/M '17)

Length of cut : It is the distance travelled by the tool to machine the work piece and is calculated as follows :

Length of cut (L) = Approach length + Length of work piece to be machined + Over travel

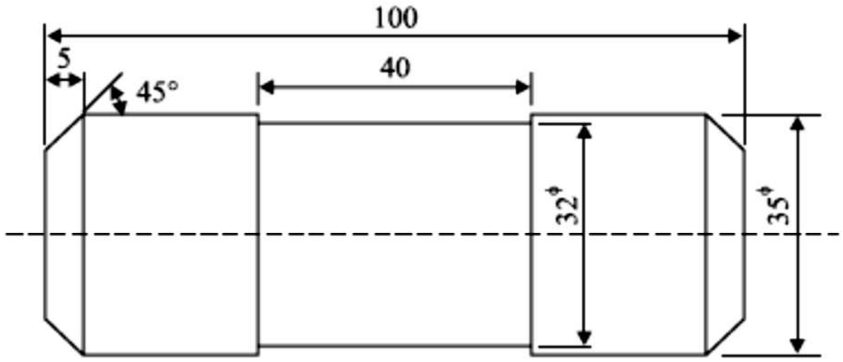
Approach is the distance a tool travels, from the time it touches the work piece until it is cutting to full depth. Over travel is the distance the tool is fed while it is not cutting. It is the distance over which the tool idles before it enters and after it leaves the cut. These terms are explained in the Fig. for a cutting operation on lathe.



Total tool travel = length of job + approach + over travel

Part – B

1. **A mild steel bar 100 mm long and 38 mm in diameter is turned to 35 mm dia. And was again turned to a diameter of 32 mm over a length of 40 mm as shown in the Fig. 5.23. The bar was machined at both the ends to give a chamfer of 45° × 5 mm after facing. Calculate the machining time. Assume cutting speed of 60 m/min and feed 0.4 mm/rev. The depth of cut is not to exceed 3 mm in any operation. (16 marks) (AU N/D'16) (AU N/D'17)**



Solution : *Ist operation* : Turning from f 38 mm to f 35 mm

$$S = 60 \text{ meters/min.}$$

$$D = 38 \text{ mm}$$

$$N = \frac{1,000\ S}{\pi D} = \frac{1,000 \times 60}{\pi \times 38}$$

$$= 503 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{\text{Length of cut}}{\text{r.p.m.} \times \text{Feed/rev.}}$$

$$= \frac{100}{503 \times 0.4} = 0.5 \text{ min.}$$

2nd operation : External relief

$$L = 40 \text{ mm.}$$

$$D = 35 \text{ mm.}$$

$$S = 60 \text{ m/min.}$$

$$N = \frac{60 \times 1,000}{\pi \times 35} = 545 \text{ r.p.m.}$$

$$\text{Time taken for second operation} = \frac{\text{Length}}{\text{r.p.m.} \times \text{Feed/rev.}}$$

$$= \frac{40}{545 \times 0.4} = 0.18 \text{ min.}$$

3rd operation : Facing of both ends

$$L = \text{Length of cut}$$

$$= \frac{35}{2} = 17.5 \text{ mm}$$

$$D = 35 \text{ mm}$$

$$S = 60 \text{ m/min}$$

$$N = \frac{60 \times 1{,}000}{\pi \times 35} = 545 \text{ r.p.m.}$$

$$\text{Time for facing one end} = \frac{17.5}{0.4 \times 545} = 0.08 \text{ min}$$

$$\text{Time for facing both ends} = 2 \times 0.08 = 0.16 \text{ min}$$

4th operation : Chamfering 45° × 5 mm

$$\text{Length of cut} = 5 \text{ mm}$$

$$N = 545 \text{ r.p.m.}$$

$$\text{Time taken for chamfering on one side} = \frac{5}{545 \times 0.4} = 0.02 \text{ min}$$

$$\text{Time taken for chamfering on both sides} = 0.02 \times 2 = 0.04 \text{ min}$$

$$\text{Total machining time} = 0.50 + 0.18 + 0.16 + 0.04$$

$$= 0.88 \text{ min}$$

2. **Find the time required to drill 4 holes in a cast iron flange each of 2 cm depth, if the hole diameter is 2 cm. Assume cutting speed as 21.9 m/min. and feed as 0.02 cm/rev. (8 marks) (AU N/D '16)**

   Solution

   Depth of hole = 2 cm = 20 mm
   Diameter of hole = 2 cm = 20 mm
   Cutting speed = 21.9 m/min
   Feed = 0.02 cm/rev,
   Depth hole = l + 0.3 d
   = 2 + 0.3 (2) = 2.6
   Number of holes = 4

   (i) N = (1000 V) / π D
   = (1000 x 21.9) / 3.14 x 20
   = 350 rpm

   (ii) T_m = Depth of hole / (Feed x rpm)
   = 2.6 / (0.02 x 350)
   = 0.3714 min

   (ii) Time for drilling four holes = 0.3714 × 4 = 1.486 min.

3. **A keyway has to be cut in spindle whose dimensions are 40 cm long 4 cm diameter with a 1 cm width. The cutter diameter is 10 cm. If the cutter is revolving at 120 rpm, what time will be required to cut one cm deep keyway at a feed of 0.05 cm/rev of cutter? (8 marks) (AU N/D '16)**

$$\text{Table travel} = \sqrt{d(D-d)} + 0.5 = \sqrt{1(10-1)} + 0.5 = 3.5 \text{ cm}$$

$$\text{Total table movement} = 40 + 35 = 43.5 \text{ cm}$$

$$\text{Time required} = \frac{\text{Total table travel}}{N \times \text{Feed}}$$

$$= \frac{43.5}{120 \times .05} = 7.25 \text{ min}.$$

4. **A 20 × 5 cm CI surface is to be faced on a milling m/c with a cutter having a diameter of 10 cm and having 16 tooth for the cutting speed and feed are 50 m/min and 5 cm/min respectively, determine the milling time, rpm, and feed/tooth. (8 marks) (AU N/D '15)**

$$N = \frac{1000 \times V}{\pi \times D} = \frac{1000 \times 50}{\pi \times 100} = 160 \text{ rpm}$$

$$\text{Feed/min} = f_t = n \times N = f_t \times 16 \times 160$$

$$\text{Feed/tooth } f_t = \frac{50}{16 \times 160} = 0.0196 \text{ mm}$$

$$\text{Milling time } T = \frac{L + \frac{1}{2}\left[D - \sqrt{D^2 - W^2}\right] + 7}{(f_t \times n) \times N}$$

$$= \frac{200 + \frac{1}{2}\left[100 - \sqrt{100^2 - 50^2}\right] + 7}{0.0196 \times 16 \times 160}$$

$$\boxed{T = 4.27 \text{ min}}$$

5. **A T-slot is to be cut in a C.I. slab as shown in Fig. Estimate the machining time. Take cutting speed 25 m/min, feed is 0.25 mm/rev. Dia of cutter for channel milling is 80 mm. (16 marks) (AU N/D '14) (AU N/D '17)**

Solution:

The T-slot will be cut in two steps :

Step I **:** Cut a 20 mm wide and 35 mm deep channel along the length

Dia of cutter = 80 mm

Cutting speed = 25 m/min

Length of job = 260 mm

$$\text{r.p.m. of cutter} = \frac{25 \times 1000}{\pi \times 80} = 100$$

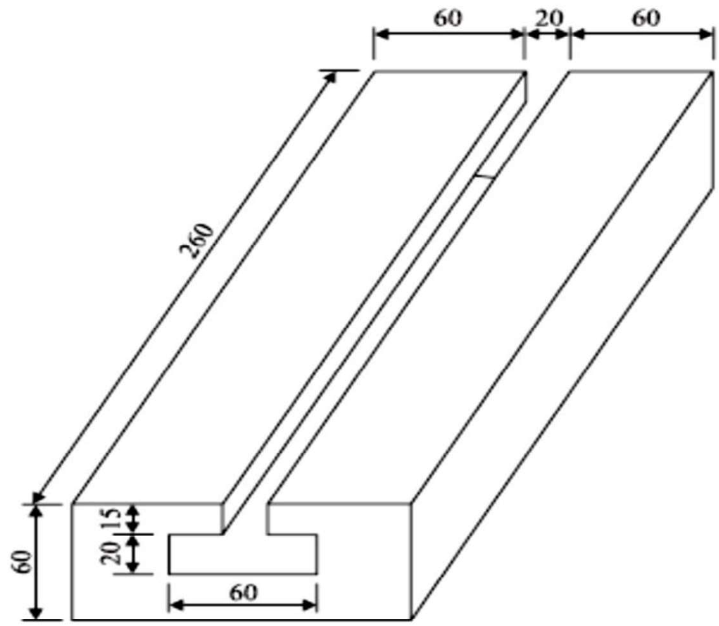
$$\text{Over travel} = \sqrt{Dd - d^2}$$

$$= \sqrt{80 \times 35 - 35^2} = 40 \text{ mm}$$

$$\text{Total tool travel} = 260 + 40 = 300 \text{ mm}$$

$$\text{Time for cutting slot} = \frac{\text{Length of cut}}{\text{Feed/min.}}$$

$$= \frac{300}{0.25 \times 100} = 12 \text{ min.}$$



Step II **:** Cut T-slot of dimensions 60 × 20 with a T-slot cutter
Here dia of cutter = 60 mm

$$\text{r.p.m. of cutter} = \frac{25 \times 1{,}000}{\pi \times 60} = 133$$

$$\text{In this case the over travel of tool} = \frac{1}{2} \text{ Dia of cutter,}$$

$$\text{since} \quad \text{dia of cutter} = \text{width of slot}$$

$$\text{Over travel} = \frac{60}{2} = 30 \text{ mm}$$

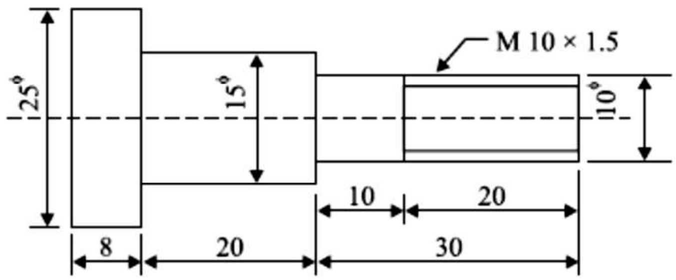
$$\text{Total tool/Table travel} = 260 + 30 = 290 \text{ mm}$$

$$\text{Time taken} = \frac{290}{0.25 \times 133} = 8.7 \text{ min}$$

Total time to cut T-slot = 12 + 8.7
= 20.7 minutes

6. **Calculate the machining time required to produce one piece of the component shown in Fig. given below starting from f 25 mm bar. The following data is available. (16 marks) (AU N/D '14) (AU N/D '13)**

For turning:
Cutting speed = 40 m/min.
Feed = 0.4 mm/rev.
Depth of cut = 2.5 mm/per pass
For thread cutting:
Cutting speed = 8 m/min.



Solution:

Step I **:** Time for turning to 15 mm dia from 25 mm dia.

As depth of material to be removed is

$$\frac{(25-15)}{2} = 5 \text{ mm.}$$

it will be accomplished in 2 cuts.

$$\text{Average Dia} = D_{av} = \frac{25+15}{2} = 20 \text{ mm.}$$

$$\text{Spindle r.p.m.} = \frac{40 \times 1{,}000}{20 \times \pi} = 637 \text{ rev/min.}$$

$$\text{Time taken} = \frac{50}{637 \times 0.4} = 0.2 \text{ min.}$$

For 2 cuts time taken = 0.4 min.

Step 2 **:** Turning from 15 mm to 10 mm dia over a length of 30 mm in one pass

$$N = \frac{40 \times 1{,}000}{\pi \times 15} = 850 \text{ rev/min..}$$

$$\text{Time taken} = \frac{30}{0.4 \times 850} = 0.09 \text{ min.}$$

Step 3 **:** Threading

$$N = \frac{8 \times 1{,}000}{\pi \times 10} = 255 \text{ r.p.m.}$$

$$\text{Feed} = \text{pitch} = 1.5 \text{ mm}$$

$$\text{Threads per cm} = \frac{10}{1.5} = \frac{100}{15}$$

$$\text{No. of cuts} = \frac{25}{\text{Threads per cm}}$$

$$= \frac{25 \times 15}{100} = 3.75 = 4 \text{ cuts}$$

$$\text{Time for one cut} = \frac{\text{Length of cut}}{\text{Feed/rev.} \times \text{r.p.m.}}$$

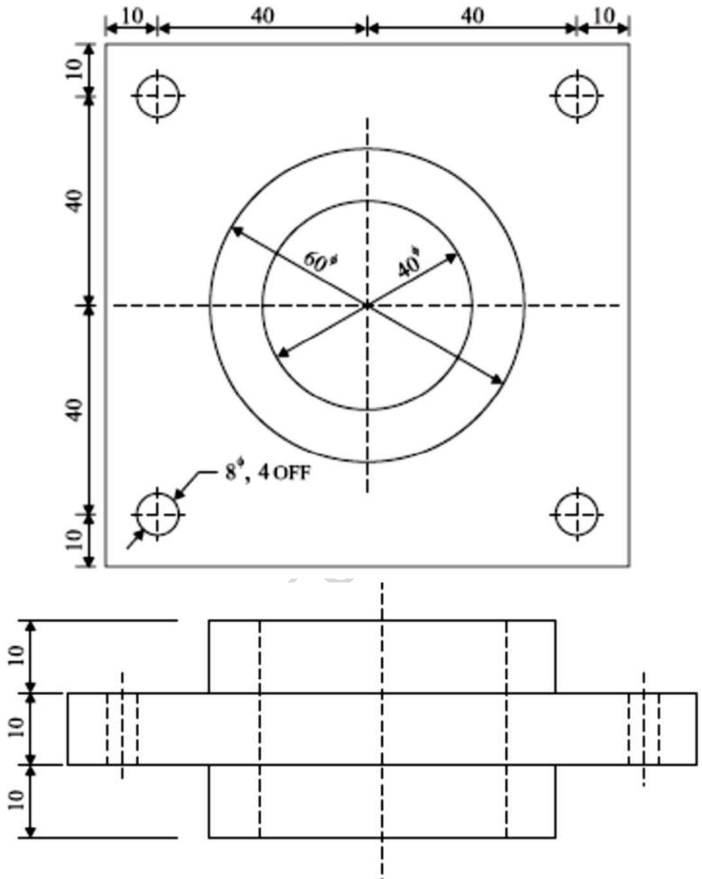
$$= \frac{20}{1.5 \times 255} = 0.05 \text{ min.}$$

Time for 4 cuts = 0.05 × 4 = 0.2 min.

Total time for producing one component = 0.4 + 0.09 + 0.2

= 0.69 min.

7. **Calculate the machining time to drill four 8 mm dia holes and one 40 mm dia central hole in the flange shown in Fig. 20 mm dia hole is drilled first and then enlarged to 40 mm f hole. Take cutting speed 10 m/min, feed for 8 mm drill 0.1 mm/rev, for 20 mm drill feed is 0.2 mm/rev. and for 40 mm f drill feed is 0.4 mm/rev. (16 marks) (AU A/M '17) (AU A/M '18)**



Solution :

(*i*) Time to drill four 8 mm dia holes

S = 10 m/min.

Dia of drill D = 8 mm.

L = 10 mm

f = 0.1 mm/rev.

$$N = \frac{S \times 1{,}000}{\pi D} = \frac{10 \times 1{,}000}{\pi 8}$$

$$= 398 \text{ r.p.m.}$$

$$\text{Time taken to drill one hole} = \frac{L}{f \times N} = \frac{10}{0.1 \times 398}$$

$$= 0.25 \text{ min.}$$

$$\text{Time to drill 4 holes} = 0.25 \times 4 = 1 \text{ minute.}$$

(*ii*) Time to drill one hole of 40 mm diameter :

This hole is made in two steps :

(*a*) Drill 20 mm £ hole — 30 mm long

$$N = \frac{10 \times 1{,}000}{\pi \times 20} = 159 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{30}{0.2 \times 159} = 0.95 \text{ min.}$$

(*ii*) Enlarge 20 mm £ hole with 40 mm £ drill

Here $$N = \frac{10 \times 1{,}000}{\pi \times 40} = 80 \text{ r.p.m.}$$

$$f = 0.4 \text{ mm/rev.}$$

$$\text{Time taken} = \frac{30}{0.4 \times 80} = 0.94 \text{ min.}$$

Total time taken to drill all the holes = 1.0 + 0.95 + 0.94
= 2.9 min.

11. Find the time required on a shaper to machine a plate 600 mm × 1,200 mm, if the cutting speed is 15 meters/min. The ratio of return stroke time to cutting time is 2 : 3. The clearance at each end is 25 mm along the length and 15 mm on width. Two cuts are required, one roughing cut with cross feed of 2 mm per stroke and one finishing cut with feed of 1 mm per stroke. (8 marks) (AU N/D '17)

Solution :

S = 15 m/minute

Length of stroke = L = Length of plate + clearance on both sides
= 1200 + 2 × 25 = 1,250 mm.

Cross travel of table = W = Width of job + clearance
= 600 + 2 × 15 = 630 mm.

K = 2/3 = 0.67

Cross feed for rough cut = 2 mm/stroke

Cross feed for finish cut = 1 mm/stroke

$$\text{Time for one complete stroke} = \frac{L(1+K)}{1000 \times S} = \frac{1{,}250\,(1+0.67)}{1{,}000 \times 15} = 0.14 \text{ min}$$

$$\text{No. of strokes for roughing cut} = \frac{\text{Cross travel of table}}{\text{Feed/stroke (Roughing)}} = \frac{630}{2} = 315$$

$$\text{No. of strokes for finishing cut} = \frac{\text{Cutting travel of table}}{\text{Feed/stroke (Finishing)}}$$

$$= \frac{630}{1} = 630$$

Total no. complete strokes required = 630 + 315 = 945

Total machining time = 945 × 0.14 = 132 min.