Unit 1 - Concepts of Design

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Introduction to Machine Design

Outcomes

- Know stages in design, right from conception to final product after production
- Factors to be considered while designing
- Various types of designs
- Know about fundamental and derived units used in engineering design
- Importance of standardization, its advantages and use in design
- International standards and designation of standard mechanical components
- Preferred numbers, their advantages, and use of various series for selection

1.1 Introduction

Machine is a device, which facilitates the working for which it is designed. For example, sewing machine facilitates stitching, automobiles facilitate travelling. Machines could be of many types, as given below, but here the scope is limited to mechanical machines only. A machine, unless specified, is a Mechanical machine. Input to this machine could be mechanical, electric, or any other type of power.

- Electric machine, which uses electric energy;
- Pneumatic machine, which uses compressed air; and
- Hydraulic machine, which uses any fluid like water (turbines) or oil, etc.

A machine comprises of many machine elements, like shafts to accommodate the machine elements like pulleys, gears, etc., to transmit power; bearings to support the shaft; frame to support and keep all the parts in the required position.

Machine Design is a subject, which deals with the design of machine elements and other aspects like shape, colour, etc. The design is mainly from the strength point of view. The size is calculated so that under the given conditions of loading, the part will not break or deform beyond accepted allowable limit.

1.2 Stages in Design

The design of a machine which is seen today is not the original design. Rather, it is being modified every year. For example, models of cars are changing every year. The design is modified as new materials are developed, which could be stronger than the existing ones. Aesthetic sense of users changes with time, which forces the design to change. Following are the stages in design:

1. **Conceptual design** When a new machine is designed, the idea is first conceived in the mind as to how a machine will work. This idea is jotted down in the form of a rough sketch of the machine on a paper. A list of all the parts it will have is prepared and then each part is sketched.
2. **Design for strength** Material is selected for each part and its properties, like tensile strength, shear strength, etc., are noted from a data book. Then, the size of each part is calculated based on its strength and allowable deformation limits.
3. **Part and assembly drawings** Finished drawings are made for each part. An assembly drawing is also made showing the relative position of each part.
4. **Manufacturing processes** For each part, a manufacturing process is selected as to how that part will be made: in one process or in many processes, one after the other. Any special treatment of hardening, etc., if required, is mentioned.
5. **Production drawings** Manufacturing tolerances are also considered for the various processes and are mentioned on the production drawings. Such drawings also contain the fits for the mating parts, geometric tolerances such as squareness, flatness, circularity, etc., and surface roughness expected from the various processes.
6. **Manufacturing** The machine is manufactured as per the drawings and assembled.
7. **Testing** The machine is tested for the function it is designed for. If it works satisfactorily, it is manufactured in mass as per the requirement. If any malfunctioning appears, the whole cycle from Stage 1 to Stage 7 is repeated.
8. **Sales feedback** If the machine functions satisfactorily, it is mass produced and sent to the market. Any feedback from the customer is sent to the design section, which works mainly for stages 2 and 3. Thus, design is final only for a short period, like six months or 1 year, and is always updated from the information received. Modification is a dynamic process and is done for a machine.

1.3 Design Considerations

Following parameters are considered while finalizing a design:

- **Strength** The machine member is considered under various stresses which may arise in the part. It has to be safe in all respects.
- **Material selection** Selection of the material depends on many parameters like type of application, weight, durability, temperature conditions, type of environment (corrosive or non corrosive), machinability, weldability, etc.
- **Safe operation** Moving parts have to be specially protected to avoid any unwanted accident. Sharp corners, which could cause injury, are to be avoided.
- **Kinematics** A machine will work satisfactorily only if its moving parts are arranged such that they give the required motion.
- **Cost** The cost of the part has to be suitable, so that it can sustain the competition in the market.
- **Number of items** The design of a machine, required for producing a component, depends on as to how many parts are to be produced. For a small number of items to be produced, one would not like to spend on a machine meant for large production and, hence, its design should be suitable according to production.
- **Aesthetic aspects** While the product is basically designed for its function, the customers are attracted more by its appearance. It has to be to the liking of the people. This aspect changes with time and the type of population, where it is to be used. The parameters which affect the appearance are: shape, surface finish, type of material, colour, etc. The shape of an aeroplane is based on its aerodynamic design so that it offers minimum resistance to the wind. Various surface finishes like Nickel plating on the rims of the wheel of a two wheeler or anodizing on some parts are used. Various colours and colour combinations on the body of the car attract people.
- **Ergonomics aspects** This word is derived from two Greek words: *Ergo*, meaning work, and *nomos*, meaning natural laws. A product is designed so that it causes minimum fatigue to the user and offers maximum possible comfort. For example, shape of an easy chair should provide maximum comfort to the body. Size of parts, like levers, hand wheels, and foot pedals should be such that they are easy to operate with the amount of force which a person can apply without much fatigue. For example, a too big or too small steering wheel of a car will not be comfortable, if its size is much different than the shoulder width of the driver. The size of display instruments should be such that these are easily readable without much strain on the eyes. Proper lighting for night use has to be provided with indicators of contrast colour, for example, instruments on the panel of a car. The size of the letters should be about 1 / 200 times the distance from where they are read to avoid strain to the eyes.
- **Easy maintenance** Every machine requires some maintenance. The design should be such that parts are easily accessible for repair or replacement.

- **Easy lubrication** To decrease friction between the moving parts, lubrication is done. The places where it is needed should be easy accessible.
- **Assembly** Big machines are assembled in small sub-assemblies and then the final assembly is done. The design has to be modular so that each sub-assembly can be easily taken out.
- **Light weight** For portable machines, this is an important consideration. The weight of the machine has to be as minimum as possible, with the usual desired strength.
- **Reliability** A machine has to be reliable enough to provide the type of service for which it is designed.
- **Rigid** The machine should be strong and rigid to bear all loads and vibrations generated in it. This can be done by using rolled sections, welding, etc.
- **Wear resistance** The parts that are prone to wearing should exhibit considerable life before replacement. Selection of suitable materials and lubrication can solve this problem.
- **Use of standard parts** Wherever parts are to be purchased from the market, these have to be adapted to the size of standard parts for easy changeability.
- **Efficiency** It is defined as the ratio of output to input. Losses should be low to achieve maximum efficiency.

1.4 Types of Design

Design is done in many ways. The type of design selected depends on the type of product and requirement.

1. **Empirical design** This type of design is done on the basis of knowledge available for that product for existing practices. The main dimensions are found just by applying empirical formulae and not by strength calculations. These formulae have been tested for years. Generally, only small components can be designed by this method.
2. **Design for strength** Size of the components is calculated by doing stress analysis. All the loads and other service conditions are considered. A factor of safety is assumed to arrive at a safe allowable stress and then the size is found.
3. **Design by evolution** Technology has been in use for the last many years. A safe working design is assumed as the basis and then slight modifications are done in the existing design.
4. **New design** These designs start from scratch, that is, right from conceptual design and across all the stages in design as described in Section 1.2. These designs are also called inventive or creative designs.
5. **Adaptive design** In some fields, the design has been so much tested and proven that there is hardly any major change in the design, for example, bicycle. Slight

PAGE 5 AND 6 IS NOT NOT PRESENT

- Units for the names should not start with upper case, for example, 50 newton and not 50 Newton.

Very large or very small quantities are prefixed with a letter as given in Table 1.2.

Table 1.2 Prefix to Units

Multiplier	10^{12}	10^{9}	10^{6}	10^{3}	10^{-3}	10^{-6}	10^{-9}	10^{-12}
Name	Tera	Giga	Mega	Kilo	Milli	Micro	Nano	Pico
Prefix letter	T	G	M	K	m	μ	n	p

1. **Mass** It is the amount of material contained in a body and does not change with gravitational force. Its unit is kg.
2. **Weight** It is the pull exerted due to gravitational force of earth over a body. Since the value of acceleration due to gravity g varies with altitude, hence weight also varies. Unit of weight is Newton, if mass is in kg and g is in m/s^2. It is equivalent to kgm/s^2.
   Weight = Mass × Acceleration
3. **Density** It is mass per unit volume. Its unit is kg/m^3.
4. **Momentum** It is the product of mass and velocity. Its unit is kgm/s.
   Momentum = Mass × Velocity

5. **Force** As per Newton's second Law of Motion, force is proportional to change of momentum. Thus,

$$\text{Force} = \frac{\text{Mass} \times (\text{Final velocity} - \text{Initial velocity})}{\text{Time}}$$

or Force = Mass × Acceleration

Unit of force is also Newton: $1\text{ N} = 1\text{ kg} \times 1\text{ m/s}^2 = 1\text{ kg m/s}^2$

6. **Couple** Two equal forces F acting parallel to each other in opposite directions give rise to a couple. Its unit is Nm. The distance X between the forces is called arm of couple. Magnitude of the couple T is given by: $T = F \times X$
7. **Torque** Torque T is the product of force and its perpendicular distance from line of axes. Its unit is also Nm. $T = F \times X$
8. **Work** Work W is product of force and displacement X caused by the force. Its unit is also Nm. $W = F \times X$
   For angular displacement, work done is given by: $W = T \times \theta$
   Where, T is the torque, and θ is the angular displacement
9. **Power** It is the rate of doing work. Unit of power is watt.
   Power = Work done / Time taken

If ω is angular speed in radians per second and N is speed in r.p.m., then,

$$P = T \times \frac{\omega}{t} = T \times \frac{2\pi N}{60}$$

10. Energy It is the capacity to do work. Its unit is Nm. It is of two types:

i. **Potential energy** It is the energy $P.E.$ stored in a body for doing work due to its position. It can give work due to its fall.

$P.E.$ = Weight × Height = $W \times h = m \times g \times h$

ii. **Kinetic energy** It is the energy $K.E.$ possessed in a body due to its velocity and mass.

Work done = Force × Distance = Mass × Acceleration × Distance = $m \times a \times s$

Where, a = Acceleration, s = Distance travelled, u = Initial velocity.

From equation $v^2 - u^2 = 2a \times s$,

If u is zero, then, $s = \dfrac{v^2}{2a}$

Hence, $K.E. = m \times a \times s = \dfrac{1}{2} mv^2$

iii. **Strain energy** It is the energy stored in an elastic body when deformed from its natural position. Its unit is also Nm. For example, if a spring with stiffness $s = W/X$ N per unit deformation is deformed through a distance X by a weight W, then strain energy is given by:

Strain energy = Average force × Deformation $= \dfrac{W}{2} \times X = \dfrac{sX^2}{2}$

1.6 Standardization

Standardization, in general, is defined as the process of formulating rules with the cooperation of all concerned for the benefit and promotion for optimum overall economy. Standardization in technology reduces the number of standard sizes, brands, shapes, and properties characterizing manufactured articles. It can be applied to science, engineering, industry, agriculture, construction, and transportation.

Standardization is used in assembly lines and machine tools, construction, agricultural machinery, and in other technological equipments. It also uses identical components and subassemblies to produce identical equipment with regard to use.

Standardization of the brands of various kinds of products and semi-finished goods makes it possible to reduce the variety to a rational number. It shortens the time needed to reset equipment, and increases the number of units in a production run.

1.6.1 Objectives of standardization

Standardization plays an active role in the management of the national economy, in the activities of state bodies, enterprises, and organizations. Its objectives are as follows:

- It eliminates diversity among articles that serve the same purpose and helps to attain a high degree of uniformity in the manufacturing, assembly, and testing of articles.
- It establishes quality and technical requirements for manufactured goods, raw materials, semi-finished products, and assembly components.
- It sets norms, requirements, and methods that govern the design and production of manufactured goods and eliminates multiplicity of varieties, brands, and sizes.
- It seeks to develop standardized units and assembly procedures for industrial products.
- It increases interchangeability, efficiency, and reparability of manufactured articles.
- It ensures uniformity and reliability in measurements, and creates and refines state standards for physical units.
- It establishes uniform systems of documentation and systems for the classification and codification of technical and economic information.
- It establishes the terms and designations used in important areas of science and technology.
- It provides a system of labour safety standards.
- It also sets guidelines for environmental protection for improving the use of natural resources.
- It establishes favourable conditions for foreign trade and cultural, scientific, and technical ties.

1.6.2 Advantages of standardization

Standardization has a significant influence on the rate of development and level of production. When standardization is applied to machines, equipment, and instruments it offers benefits that are derived from larger production runs, lower labour inputs, and increased specialization. The advantages of standardization are:

- Reduction in types of components. For example, a bearing manufacturing company will manufacture only those bearings, which are required by most of the industries. Manufacturing a component on large scale reduces the cost of production. Thus, it brings uniformity and minimizes variety.

- It improves interchangeability and makes repair easy, as worn parts can be easily replaced. Spares available in the market fit the standards; otherwise these may not fit properly.
- Reduces volume of design work and length of the design period substantially.
- Reduces the required assortment of spare parts.
- Shortens the time necessary for creating new equipment.
- Lowers the costs incurred in introducing new products.
- Raises the degree of mechanization and automation in production processes.

- Improves quality, reliability, and durability of products due to the attention given to the technological effectiveness of design.

1.7 Use of Standards in Design

Standards and codes are used for design, testing, erection, etc. Standards set specifications for parts, material, and processes to reduce variety and limit the number of items.

In a design office here are three types of standards:

1. **Company standards** These are used in a particular company or its sister concerns only.
2. **National standards** Every country has framed some standards to be used in that country, for example:

AISI	American Iron and Steel Institute
ASA	American Standard Association
ASTM	American Society for Testing Materials
BIS	Bureau of Indian Standards
DIN	Standards of Germany
IS	Indian standards framed by BIS (Bureau of Indian Standard)
ISI	Indian Standard Institution
SAE	Society of Automotive Engineers

3. **International Standards** There are many organizations in the world who establish standard specifications for different products and materials. International Standards are prepared by International Standards Organization (ISO), for example, ISO 8000 for industries and institutions.

Following standards are used in mechanical design offices:

1. **Standards for materials** These standards are for mechanical properties and chemical composition of different materials (see Chapter 2 on 'Engineering Materials'). For example, IS 210 specifies the grades of grey cast iron; IS 1570 (Part 4) specifies chemical composition of alloy steels.
2. **Standards for standard parts** There are standards for machine parts like bolts, nuts, screws, rivets, bearings, oil seals, belts, chains, keys, etc. For example, **IS** 2494 (Part 1) is for endless V belts and IS 5129 (Part 1) is for the dimension of oil seals.
3. **Standards for limits and tolerances** It is not possible to make a job of exact dimensions. Upper and lower limits of a size, called tolerances, are specified on a production drawing using Indian standard IS 919.
4. **Standards for fits** Two mating parts, like a shaft moving (sliding or rotating) in a hole, are to be provided with a certain clearance, which is called Fit. This could be positive, that is, hole size bigger than shaft, or zero or negative, that is, hole diameter is less than shaft (the shaft is inserted by heating the hole part).
5. **Standards for geometrical tolerances** The part produced may not be of the exact shape as shown in the drawing. Parameters like flatness, squareness, parallelism, circularity, cylindricity, etc., are specified by geometrical tolerances.
6. **Standards for testing** Codes are prepared for testing a finished product to serve the market requirements satisfactorily and safely. For example, a diesel engine is to be tested for a specified time at full load and for some time at overload also. IS 2825 is a code for testing unfired pressure vessels, while IS 807 is for testing cranes.
7. **Standards for drawing** Document SP 46, prepared by BIS, is for practice to be followed for engineering drawings.

1.8 Standard Mechanical Component Designations

A machine generally contains standard components like bolts, nuts, pins, oil seals, bearings, etc. Sometimes, the IS number is also mentioned at the end of the designation to avoid any ambiguity. Table 1.3 gives designation of some standard components.

Table 1.3 Designation of Standard Components

Standard Component	IS Number	Designation	Meaning
Hexagonal bolt	IS 1363–1967	Hex bolt M 10 × 40	Metric threaded hexagonal bolt of diameter 10 mm and length 40 mm.
Hexagonal bolt with nut	IS 1363–1967	Hex bolt M 10 × 40 N	Metric threaded hexagonal bolt of diameter 10 mm and length 40 mm along with nut.
Hexagonal bolt with nut and lock nut	IS 1363–1967	Hex bolt M 10 × 40 NL	Metric threaded hexagonal bolt of diameter 10 mm and length 40 mm along with nut and lock nut.
Castle lock nut	IS 2232–1967	Castle nut M 20	Castle nut with metric threads for 20 mm bolt size.
Plain washers	IS 2016–1967	Machine washer A 20	Washer for 20 mm bolt.

If only one number, M, in between the series is known, the series can be designated as:

$$RN/d\ (\ldots, M, \ldots)$$

Example 1.1

Preferred numbers with given N, $N1$ and $N2$

Find the numbers of R10 series from 10 to 100.

Solution

Given $N = 10, \quad N1 = 10, \quad N2 = 100$

Series Ratio for R10 series is given by: $r = \sqrt[10]{10} = 1.2589$

Since numbers are in geometric progression:

First number $= 10$

Second number $= 10 \times (1.2589)^1 = 12.589 \cong 12.5$

Third number $= 10 \times (1.2589)^2 = 15.84 \cong 16$

Fourth number $= 10 \times (1.2589)^3 = 19.95 \cong 20$

Fifth number $= 10 \times (1.2589)^4 = 25.1 \cong 25$

Sixth number $= 10 \times (1.2589)^5 = 31.62 \cong 32$

Seventh number $= 10 \times (1.2589)^6 = 39.80 \cong 40$

Eighth number $= 10 \times (1.2589)^7 = 50.11 \cong 50$

Ninth number $= 10 \times (1.2589)^8 = 63.08 \cong 63$

Tenth number $= 10 \times (1.2589)^9 = 79.42 \cong 80$

Last and Eleventh Number $= 10 \times (1.2589)^{10} = 99.87 \cong 100$

Example 1.2

Preferred numbers with given *N*, *N*1, *N*2 and *d*

Find the numbers of the series R40/4 (100, …, 400).

Solution

Given $N = 40,\quad d = 4,\quad N1 = 10,\quad N2 = 400$

Series Ratio is: $r = \sqrt[40]{10} = 1.05925$

It is required to have every fourth term, hence Ratio Factor (RF) between two terms is

$= (1.05925)^4 = 1.2589$

First number $= 100$

Second number $= 100 \times 1.2589 = 125.89 \cong 125$

Third number $= 100 \times (1.2589)^2 = 158.489 \cong 160$

Fourth number $= 100 \times (1.2589)^3 = 199.562 \cong 200$

Fifth number $= 100 \times (1.2589)^4 = 255.1188 \cong 255$

Sixth number $= 100 \times (1.2589)^5 = 316.227 \cong 315$

Seventh number $= 100 \times (1.2589)^6 = 398.107 \cong 400$, which is the last number.

Preferred numbers with given *N*, *d* and *M*

Write seven terms of a series given by R40/3 (…, 50, …).

Solution

Given $N = 40,\quad d = 3,\quad M = 50$

R40 series is given as:

1.00	1.06	1.12	1.18	1.25	1.32	1.40	1.50	1.60	1.70	
1.80	1.90	2.00	2.12	2.24	2.36	2.50	2.65	2.80	<u>3.00</u>	
3.15	3.35	<u>3.55</u>	3.75	4.00	<u>4.25</u>	4.50	4.75	<u>5.00</u>	5.30	
5.60	<u>6.00</u>	6.30	6.70	<u>7.10</u>	7.50	8.00	<u>8.50</u>	9.00	9.50	10.00

Every third term on the left side of 5 is: 3.00; 3.55; 4.25 (underlined)

Every third term on right side of 5 is: 6.00; 7.10; 8.50 (underlined)

The term 50 is bigger than the series from 1 to 10 and hence a multiplier of 10 will be used.

So, the required series is: $10 \times (3.00,\ 3.55,\ 4.25,\ 5.00,\ 6.00,\ 7.10,\ 8.50)$
$= 30,\ 35.5,\ 42.5,\ 50,\ 60,\ 71,\ 85$

Example 1.4

Use of preferred numbers

An electric motor is to be produced in six models ranging from 2 KW to 20 KW.

a. Specify the capacities of the motors to be produced.
b. Extend the series up to 80 KW.

Solution

Given $N = 5,\quad N1 = 2,\quad N2 = 20$

Given $N = 5, \quad N1 = 2, \quad N2 = 20$

a. There are only six models, hence series R5 is selected to get six models.

   Models will be in the geometrical progression of the RF r as:

   $2 \times (r)^0, 2 \times (r)^1, 2 \times (r)^2, 2 \times (r)^3, 2 \times (r)^4$, and $2 \times (r)^5$

   The first term is 2 and is given by $2 \times (r)^0$

   The last term is 20 and is given by $2 \times (r)^5$

   From this, $(r)^5 = 20/2 = 10$

   Thus,

$$r = \sqrt[5]{10} = 1.5849$$

   Second model $= 2 \times (1.5849)^1 = 3.1697 \cong 3.2$

   Third model $= 2 \times (1.5849)^2 = 5.0237 \cong 5.0$

   Fourth model $= 2 \times (1.5849)^3 = 7.9621 \cong 8.0$

   Fifth model $= 2 \times (1.5849)^4 = 12.6191 \cong 12.5$

   Sixth model $= 2 \times (1.5849)^5 = 20$

   So, the models will be 2, 3.2, 5.0, 8.0, 12.5 and 20 KW.

b. Next models will also be in the same Geometrical Progression, so just multiply the series by 10 to get: 20, 32, 50, and 80 KW.

Summary

Machine is a device which facilitates in working. There are different types of machines like electric, pneumatic, and hydraulic. This chapter describes mechanical machines.

A machine is just not designed as such, but there are various stages in its design. The process starts from a concept. An idea is conceived for the different parts. A suitable material is selected. The size of each part is calculated for the desired strength required for the working of the machine. A drawing is made for sending to manufacturing section, where it is produced. Then it is tested for the required duties. If satisfactory, it is sent for sale, if not then, the iteration starts again from the design calculations or at the appropriate stage.

While designing, there are many criteria which are to be kept in mind. Material selection is based on the strength and type of environment in which it has to work. If it involves moving links, kinematics is to be considered. The design has to be efficient, light, and at the same time rigid, cost effective, safe, and reliable. If it has many parts, effort should be made to have minimum parts. So far as possible use standard parts available in market. A modular design is preferred to facilitate easy assembly. Provision has to be provided for easy lubrication and easy maintenance. The material has to be wear resistant for machines that have parts that wear out. Aesthetic aspects are also considered to make it attractive to the users.

Design methods are of many types. The method of design given above is for a new design, which is done for strength first. Design by evolution is based on the existing designs and empirical design is done on the basis of knowledge available for that product from existing practices. Adaptive design is used when a design has been so much tested and proved that there is hardly any major change in the design. In a functional design the mechanics part is also considered for its proper working. Process design is done by the production engineers mainly for the tools, machines to be used, processes to be done, surface finishing processes, etc. Industrial design is an effort in styling a product. Now-a-days, with the help of computers, Computer Aided Design (CAD) helps in producing an optimum design.

All physical quantities are measured in units. There are four systems of units which are commonly used and accepted universally. These are: Foot, Pound, Second (FPS), Centimetres, Grams, Seconds (CGS), Meter, Kilogram, Second (MKS), and System International (SI) units. Presently, the SI units are being practiced widely. There are two types of units: Fundamental units for length, mass, time, temperature, etc. Derived units are derived from fundamental units like velocity, acceleration, force, pressure, power, etc.

Standardization, in general, is defined as the process of formulating and applying rules. It is used in technology, assembly lines, brands of various kinds, production processes. etc. Its use eliminates diversity in products, establishes the quality, sets the norms, allows interchangeability, and ensures uniformity and reliability. Its use reduces types of components and improves interchangeability.

Standards are of three types: Company standards used within a particular company; National standards used by different countries such as Bureau of Indian Standards (BIS), Standards of Germany (DIN), Indian standards (IS), (Society of Automotive Engineers (SAE), etc. International Standards are for materials, parts, limits and tolerances, fits (See Chapter 3 for these terms), testing, drawings, etc. Standard mechanical components, like bolts, nuts, washers, rivets, pins, bearings, etc., are designated in a particular format.

When a product is designed for a range of sizes, there can be many different sizes. These are constrained by preferred numbers to minimize the number of different sizes. Roughly, these are equally spaced on a logarithmic scale. The range is covered efficiently if the sizes are in geometrical progression with constant ratio r, also known as Series Ratio. There are four basic series:

Coarse series R5 with $r = \sqrt[5]{10} \cong 1.6$,

Coarse medium series R10 with $r = \sqrt[10]{10} \cong 1.25$.

Medium fine series R20 with $r = \sqrt[20]{10} \cong 1.12$, and

Fine series R40 with $r = \sqrt[40]{10} \cong 1.06$.

Each series is specified by its reserve words like R5, R10, R20 and R40.

Theory Questions

1. What is a machine? What are the various types of machines?
2. Describe the various stages in design.
3. What are the various types of designs?
4. Name the various types of units and describe SI Units.
5. Differentiate between fundamental and derived units by giving examples.
6. What prefixes are used before units?
7. What is the need of standardization? Write its advantages.
8. Name the various Institutions for standardization.
9. Write standard designation codes for some standard mechanical components like bolt, nut, washer, stud, rivet, and ball bearing.
10. What is meant by a preferred number?

10. Preferred numbers vary from:
    (a) 1 to 10
    (b) 10 to 100
    (c) 1 to 1,000
    (d) can be any range, with largest number 10 times the smallest

Answers to multiple choice questions

1. (d) 2. (b) 3. (d) 4. (a) 5. (c) 6. (d) 7. (b) 8. (d) 9. (b) 10. (d)

Design Problems

1. Screw jacks are to be designed in six capacities ranging from 3 kN to 30 kN. Find the capacities.
   [3.0, 4.8, 7.5, 12, 19.2, and 30]
2. Write 11 terms of a series given by R / 40 / 4 (... , 80 , ...)
   [25, 31.5, 40, 50, 63, 80, 100, 112.5, 160, 200, and 250]

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2.1 Introduction

An engineer has to select a suitable material for a machine element to withstand the loads coming on it. A wrong selection may lead to its failure. It has to withstand not only the load, but should possess qualities depending upon many factors like toughness, hardness, life, stiffness, etc. There is a wide range of materials now available, from which a design engineer has to choose according to the requirement of a particular component that performs a specific function.

Table 2.1 Properties of Materials

Property	Definition
Brittleness	Breaks without any appreciable elongation, e.g. glass
Conductivity	Resistance to flow of current
Corrosion resistance	Resistance to corrosion
Creep	Slow and permanent deformation for a part stressed under high temperature
Density	Mass per unit volume; Important for aircraft applications
Ductility	Develop significant permanent deformation before they break
Elasticity	Property to return to its original shape after loads are removed
Fatigue strength	Safe stress under conditions of reversal or varying loads
Hardness	Resistance of material to abrasion or indentation
Machinability	Ease by which a material can be cut on a machine
Magnetic properties	Ability to retain magnetic field
Malleability	Capability to be rolled under pressure
Plasticity	Property to retain the shape permanently when loaded and does not return back
Resilience	Property to absorb energy and resist shocks
Stiffness	Ability to resist bending when loaded; Modulus of elasticity is a measure of stiffness
Strength	Ability to resist loads without breaking
Thermal conductivity	Ability to conduct heat

Property	Definition
Thermal expansion	Increase in length with temperature
Transparency	Ability to allow light to pass
Toughness	Impact strength and ability to withstand shocks
Ultimate strength	Maximum stress at which the material will break in plastic range
Wear	Progressive loss of material due to rubbing of surfaces
Weldability	Ease by which a material can be welded
Yield strength	The maximum safe stress without leading the component to the plastic range

Table 2.2 Physical Properties of Commonly used Metals

Metal	Density (kg/m^3)	Melting point (°C)	Thermal Conductivity (W/m°C)	Coefficient of Linear Expansion (μm/m/°C)
Aluminium	2,700	660	220	23.0
Brass	8,450	950	130	16.7
Bronze	8,730	1,040	67	17.3
Cast iron	7,250	1,300	54.5	9.0
Copper	8,900	1,083	393.5	16.7
Lead	11,400	327	33.5	29.1
Steel	7,850	1,510	50.2	11.1
Zinc	7,200	419	113	33.0

2.3 Classification of Engineering Materials

Engineering materials are broadly classified as metals and non metals. Metals are of two types: Ferrous and Non-ferrous

Amongst ferrous metals, wrought iron (WI) is the purest form of iron (Fe). A little percentage of carbon (C) increases its hardness. Steel up to 0.25 per cent carbon is called low carbon steel. Mild steel is the most commonly used and has carbon between 0.25–0.8 per cent. Items, like tools, etc., are made of high carbon steel with carbon between 0.8–1.5 per cent.

Metals having 2–3 per cent of carbon are called cast iron and those containing carbon between 3–4 per cent are called grey cast iron. Some alloying elements like copper (Cu), chromium (Cr), lead (Pb), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), phosphorus (P), silicon (Si), and sulphur (S) are added to improve the properties of steels and such steels are called alloy steels. Low and medium alloy steels have these constituents less than 10 per cent, while high alloy steels have more than 10 per cent. Classification of ferrous and non-ferrous metals is given below:

- **Metals**
  - Ferrous
    - Wrought iron
    - Carbon steel
      - Low carbon steel
      - Medium carbon steel
      - High carbon steel
    - Cast iron
      - Ductile
      - Grey
      - White
      - Malleable
    - Alloy steel
      - Low alloy
      - Medium alloy
      - High alloy
    - Stainless steel
  - Non-Ferrous
    - Aluminium alloy
    - Copper alloy
    - Miscellaneous metals
- **Non Metals**
  - Plastics
    - Thermo-plastic
    - Thermo-setting
  - Rubber
    - Natural
    - Synthetic
  - Ceramics
  - Wood

2.4 Ferrous Metals

Iron and Iron alloys (called steels) are most commonly used metals. Wrought iron is the purest form of Iron. Mild steel is the most commonly used steel. High carbon steels, alloy steels, and cast irons have high percentage of carbon as shown in Figure 2.1.

Percentage of Carbon ⟶ (Not to scale)

0 0.15 0.45 0.8 1.5 2.3 3 4

Wrought iron	Low carbon steel	Medium carbon steel	High carbon steel	White cast iron	Cast iron	Grey cast iron

Figure 2.1 Percentage of carbon and name of ferrous metals

2.5 Wrought Iron

Wrought iron has a very low percentage of carbon (0.01) and is used for ornamental work, chain links, crane hooks, water, steam pipes, etc. It is a tough, malleable, and ductile material and can be easily forged and welded. It is not suitable for shocks.

Ultimate tensile strength of WI is between 250–500 MPa and the compressive strength about 300 MPa.

2.6 Carbon Steels

Carbon is the main hardening element in steel. If its percentage is more than 0.85, it increases the hardness and tensile strength, but decreases ductility and weldability. Carbon steel has a small amount of carbon along with other alloying elements like Silicon, Manganese, Copper, Sulphur, etc., added to impart certain properties. They can be used for casting, forging, forming, or machining.

Hot rolled carbon steel sheets are made by heating slabs, and then reducing the thickness by passing through a series of rollers. Carbon steel plates of thickness 4–6 mm and width 1,200 mm are produced by directly hot rolling the slabs.

Cold rolled carbon steel sheets are made from hot rolled coils of flats which are pickled and then cold rolled to reduce thickness.

Carbon steel bars are hot rolled from billets in a variety of cross sections like circular, square, etc. Cold finished bars are produced from hot rolled steel by the cold finishing process to achieve a good surface finish. Steel wires are made from hot rolled rods. Steel pipes are made either by welding from hot / cold rolled flats, or seamless pipes by extrusion process. Following are the types of carbon steels:

a. Low carbon steel has a carbon percentage between 0.15–0.45. It is soft, ductile, easily machinable and welded, is not responsive to heat treatment, is not tough, and has a low tensile strength. Low carbon steel is used for chains, rivets, shafts, and pressed steel products. Its tensile strength depends upon the manufacturing method: hot rolled 270 MPa, cold drawn 350 MPa, and annealed 295 MPa.

b. Medium carbon steel has carbon percentage between 0.45–0.8. It is machinable, tough, and strong. It can be heat treated and has higher strength and rigidity than low carbon steel. Medium carbon steel is used for gears, axles, and machine parts. Its tensile strength for hot rolled is 290 MPa, cold drawn 440 MPa, and tempered 435–660 MPa.

c. High carbon steel has carbon percentage between 0.8–1.5. It responds easily to heat treatment. It is very hard and hence used for cutting tools.

Mechanical properties of plain carbon steels are given in Table 2.3 and Table 2.5.

Mechanical properties of plain carbon steels are given in Table 2.3 and Table 2.5.

2.6.1 Bureau of Indian Standards designation of steels

Steels are designated as under:

- On the basis of mechanical properties and
- On the basis of chemical composition

2.6.2 Applications of steels

Applications and properties of steel are given in Tables 2.3, 2.4 and 2.5.

Table 2.3 Applications of Plain Carbon Steels (IS 1570 Part I) Designated on the Basis of Mechanical Properties

Material as per IS	Tensile Strength (MPa)	Yield Strength (MPa)	Minimum Percentage Elongation	Applications
Fe290	290	170	27	Cycle, motor cycle, automobile tubes, rivet bars
Fe310	310	180	26	Locomotive carriages, car structures
Fe360	360	220	25	Chemical pressure vessels
Fe410	410	250	23	Bridges, building construction, railway rolling stock
Fe490	490	290	21	Marine engine forgings, machine parts
Fe540	540	320	20	Carriage wagons, bolts, tubes, rail axles
Fe620	620	380	15	Seamless tubes, tramway axles
Fe770	770	460	10	Machine parts for heavy loading
Fe870	870	520	8	Wagon wheels and steel tyres

Table 2.4 Applications of Plain Carbon Steels (IS 1570 Part II) Designated on the Basis of Chemical Composition

Material as per IS	Percentage of Carbon	Percentage of Manganese	Applications
4C2	0.04–0.08	0.2–0.4	Very soft steel used for electrical industry
5C4	0.05–0.1	0.4–0.5	Suitable for cold forming processes like rolling, cold heading, forgings
7C4 10C4 14C6	0.07–0.12 0.10–0.15 0.10–0.18	0.4–0.5 0.4–0.6 0.4–0.7	Cams, light gears, worms, ratchets, chain wheels, spindles, pawls; Suitable for case hardening
15C4	0.15–0.2	0.3–0.6	Lightly stressed parts
15C8 20C8 25C4 25C8	0.1–0.2 0.15–0.25 0.2–0.3 0.2–0.3	0.6–0.9	General purpose steels used for low stressed components
30C8	0.25–0.35	0.6–0.9	Cold formed parts like brake levers, sprockets, tie rods, scooter parts, frames of bicycle, furniture
35C4	0.3–0.4	0.3–0.6	Automobile tubes and fasteners

2.6.3 Selecting a steel

Properties of steels change drastically with the percentage of carbon; hence, selecting a material is important. Guide lines for selecting percentage of carbon are as under:

- Components like car body and deep drawing parts need high ductility which is measured as percentage of elongation. Hence, for such applications low carbon percentage such as 7C4 or 10C4 can be selected.
- If a job is to be fabricated by welding, low carbon steels like 15C8, 20C8 and 25C4 should be selected as these are easily welded.
- For forged components like connecting rod and crank shaft, low and medium carbon steels such as 30C8 or 40C8 should be selected.
- For parts where stresses are high and need strength, toughness, and response to heat treatment to get hard surface, like gears, machine spindles, etc., a high carbon percentage like 40C8, 50C8 or 60C4, etc., should be selected.
- Components like springs, which have to face severe stress and need high strength, carbon steel like 65C6 should be selected.

2.7 Cast Iron

Cast iron is a low cost and easily produced material. Carbon percentage varies from 1.7–4.5 per cent. It can have some traces of other metals like Silicon, Sulphur, Phosphorus, and Manganese. It is brittle and hence cannot be used where shocks are expected. From design considerations, cast iron is still considered as the only choice for certain applications.

Advantages of cast iron

- Easily available in large quantity
- Complex shapes can be produced without increasing the cost
- Offers good compressive strength (about three times than steel)
- Damps down the vibrations, hence the only choice for machine frames and beds
- Wear resistant even under the condition of boundary lubrication
- Easily casted
- Mechanical properties do not change much even up to 350°C
- Not sensitive to notches, while for other material strength decreases with notch
- Strength of cast iron is as under:

Compressive strength	–	400–1,000 MPa
Tensile strength	–	100–200 MPa
Shear strength	–	120 MPa

2.7.4 Effects of impurities on properties of cast iron

Impurities in cast iron change its properties. Elements mentioned below give the name of property which is affected and also the maximum percentage which can be tolerated.

- **Sulphur** makes the cast iron hard, unsound casting, and brittle, therefore its percentage should not be more than 0.1 per cent.
- **Manganese** makes the cast iron hard and white. Manganese controls the harmful effects of S. Its percentage should be less than 0.75 per cent.
- **Phosphorus** increases fluidity and fusibility. The maximum percentage of P is only 1 per cent.
- **Silicon** forms free graphite which makes it soft, free from blow holes, and machinable. The maximum percentage of Si can be up to 4 per cent.

2.8 Alloy Steels

In addition to other alloying elements, carbon is the main constituent in alloy steels. Alloy steel has minimum of 8 per cent of alloying elements like Nickel or Chromium to make it corrosion resistant or provide strength at temperature above 560° C. It is less tough, but more hard. The tensile strength of alloy steel is:

Hot rolled: 335 MPa

Cold drawn: 580 MPa

Tempered: 470 to 800 MPa

2.8.1 Alloy steels designation

Alloy Steel can below, medium, high alloy steel, or tool steel.

a. **Low and medium alloy steels** Total alloying elements are less than 10 per cent for this category. The code is as under:

NN A1 N1 A2 N2 A3 N3

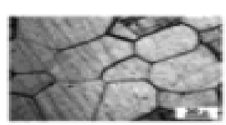
Where, NN A number which is 100 times the average percentage of Carbon;

A1, A2, A3 Chemical symbols for alloying elements 1, 2 and 3, respectively;

N1, N2, N3 Average percentage content of A1, A2 and A3, respectively; are multiplied by a factor, as given in Table 2.10.

Table 2.10 Multiplying Factors of Elements

Chemical Symbol of Elements	Multiplying Factor
Co, Cr, Mn, Ni, Si, and W	4
Al, Be, Cu, Mo, Nb, Pb, Ta, Ti, V, and Zr	10
P and S	100

Alloying Element with Percentage (%)	Properties Imparted	Applications
Phosphorous 0.07–1.2	In large amount it increases strength and hardness, but reduces ductility and toughness; Improves machinability and atmospheric corrosion resistance	Cold forming applications
Silicon 0.2	Increases strength and hardness, but to lesser extent than manganese; It reduces machinability	IC engine valves, springs, heat resistant materials
Silicon-Manganese 1.8–2.2	Used where springiness and elasticity is required	Springs
Sulphur 0.1–0.25	In increased amount it reduces transverse ductility, non-impact toughness, and weldability; It improves machinability	Used for threads, splines, etc.
Vanadium 0.15–0.25 1–5	It gives fine grain structure, increases tensile strength; Maintains strength at high temperatures 	Springs, shafts, gears, axles, and pins Cutting tools, surgical instruments

2.8.3 Applications of alloy steel

Alloy steels are used for saws, drills, knives, razors, tools, and musical strings. Table 2.12 gives some alloy steels as per IS 1570 Part III and their applications.

Table 2.12 Applications of Alloy Steels (IS Designation)

Steel Code	Applications
FREE CUTTING STEELS	
10C8S10	Parts to be cyanided or carbo-nitrided
14C14S14	Used for good machinability and good surface finish
25C12S14	Bolts, studs, heat treated parts of small section requiring more strength than MS
40C10S18	Parts subjected to severe wear, engine shafts, connecting rods, heat treated bolts
11C10S25	Light parts without shock, nuts, and studs
40C15S12	Shafts, heat treated axles, small crank shafts; Not suitable for forgings
ALLOY STEELS	
40Cr1	Gears, connecting rods, stub axles, steering arms, wear resistant plates, earth machines
50Cr1	Spring steel used for helical springs, automobile suspension springs
25Cr3Mo55	Cylinder liners, gears, machine parts, hard surface and wear resistant parts
40Cr1Mo28	Axle shafts, crankshafts, connecting rods, gears, high tensile bolts

Steel Code	Applications
11Mn2	General purpose ductile steel. Used for filler rods, mine car draw gear, couplings
20Mn2 / 27Mn2	Welded structures, crank shafts, shafts, spindles
37Mn2 / 47Mn2	Axles, shafts, crank shafts, connecting rods, tram rails
35Mn2Mo28	General purpose crankshafts, bolts, wheel studs, axles, levers, connecting rods
40Ni3	Refrigerators, compressors, heavy forgings, turbine blades, severe stressed bolts
30Ni4Cr1	Highly stressed gears with high tensile strength
35Ni1Cr60	Heavy vehicle crank shafts, connecting rods, chain parts, clutches, cam shafts
40Ni2Cr1Mo28	Machine parts, collets, spindles, screws, bolts, studs, axles shafts, tappets, arbours
55Si7	Parts subjected to high stress like springs

2.8.4 Guidelines for selecting alloy steel

Each alloying element adds certain properties. Following elements can be selected for imparting the properties mentioned below.

- Silicon adds strength and, hence, parts which are subjected to high stress and need high strength such as springs, silicon steel such as 55Si7 can be selected.
- Nickel increases strength and toughness without losing ductility and, hence, it is good for highly stressed bolts and axles. Therefore, 40Ni3 or 40Ni14 alloy steel can be used.
- Chromium increases hardness and wear resistance. Hence, for components which require hard outside surface with soft inside (like all types of gears), 40Cr1, 40Cr4 is a solution.
- Nickel alloys are used for parts like cams, camshafts, and transmission shafts, which require hardness, toughness, and strength along with ductility. For such parts, Ni-Cr alloy like 35Ni1Cr60 is a solution.

2.9 Stainless Steels

These steels offer high corrosion resistance. These are available in wide range of alloys having Chromium more than 10 per cent and are classified as under:

1. Austenitic stainless steels have 18 per cent Chromium and 8 per cent Nickel, and are known as 18/8 steel. They have high resistance to corrosion, good weldability, high toughness at low temperatures, and excellent ductility.
2. Ferritic stainless steels have 16–20 per cent Chromium and are inferior to Austenitic steels. These are used for press work because of high ductility, but become brittle at low temperature. Ferratic stainless steels have moderate strength and limited weldability.
3. Martensitic stainless steels have 12–18 per cent Chromium and 1–3 per cent Nickel. They have least resistance to corrosion. Martensitic stainless steels are not suitable for cold forming or welding, and offer moderate machinability. Table 2.13 gives the applications of stainless steels.

Table 2.13 Applications of Stainless Steels

Type of Stainless Steel	Applications
Austenitic	Window and door frames, chemical plant tanks, domestic hot water pipe lines, spoons, forks, kitchen utensils, nuts, bolts, screws, rivets, coil and leaf springs
Ferrite	Car silencers, oil burner sleeve, electric cooker, gas and electric cookers, coinage, spoons, forks, knives, domestic Fe soles, driving mirror frames
Martensitic	Tools, turbine parts subjected to high temperature, scales, rulers, knives, kitchen, surgical and dental appliances

2.10 Steels for High Temperatures

Some applications require steel which is supposed to withstand high temperature without losing its strength. Table 2.14 gives a list of such materials and their applications. These are designated as per IS1570 Part V.

Table 2.14 Steels for High Temperature

Material Name	Constituents (%)	Temperature Range (°C)	Application
Low Alloy Steel	0.5 Mo	400–500	Steam plants
Silchrome	C 0.4, Cr 8, Si 3.5	600–800	IC engine valves
Volmax	C 0.5, Cr 8, Si 3.5, Mo 0.5	600–850	Marine engine valves
Ni-Cr-W steel	Ni 13, Cr 13, W 3	700–900	Aero engine valves
Plain Cr steel	Cr 13	700–750	Kitchen utensils
Ferritic Cr steel	Cr 18–30	1,000–1,150	High strength utensils
Austenitic Cr-Ni steel	Cr 18, Ni 8	Up to 1,100	High temperature chemical equipment

2.11 High Speed Steels

High speed steels are used to make cutting tools. They can retain their hardness even when they are heated during the cutting action. They can cut at much higher cutting speed than high carbon steel tools. The most common alloying element is tungsten (W), but other elements like Chromium, V, Molybdenum, cobalt (Co), etc., can also be added.

Tool steels designation is similar to low, medium, and high alloy steels except that letter code XT is put instead of X. Their code is as under:

XT NN A1 P1 A2 P2 A3 P3

Where, NN is 100 times the percentage of Carbon

Commercial Name of Alloy	Alloying Elements and Rest Aluminium	Applications
Hindalium	Mn, Mg, Si and a little Cr	Kitchen utensils
Magnalium	Mg 2–10% Cu 1.75%	Auto and aircraft components
Manganese alloy	Mn 1.25%	Extruded sections, hollow ware, roofing, paneling, tubes
Y alloy	Cu 3.5–4.5% Fe 0.6%, Mn 1.2–1.7% Mg 0.6%, Ni 1.8–2.3% Si 0.6%	High temperature applications like pistons and cylinder heads

Table 2.17 (b) Aluminium Alloys with IS Code and their Applications

IS Code for Aluminium alloys	Applications
IS 2280	Connecting rods
IS 2285	High temperature applications
IS 4652	Pistons and IC engine parts
IS 24345	Heavy duty forgings and structures
IS 24534	Aircraft components
IS 54300	Welded structures, tanks
IS 64430	Roof trusses, deep drawn vessels
IS 74530	Welded pressure vessels

2.14.3 Mechanical properties of aluminium alloys

Properties of an Al alloy (Table 2.18) depend on how it is created, like sand cast or chill cast, and under what conditions, as described below along with the code:

M: As manufactured

T4: Solution treated

T6: Solution and precipitation treated

O: Annealed

W: Solution treated and aged

Table 2.18 Mechanical Properties of Aluminium Alloys

Aluminium Alloy	Condition	Tensile Strength (MPa)		Percentage Elongation	
24,345	M	150		12	
	W	375		8	
24,534	M	190		12	
	W	375		10	
	O	240		12	
54,300	M	265		11	
	O	350		13	
64,430	M	110		12	
	W	185		14	
	O	150		16	
74,530	W	255		9	
Aluminium Alloy	Condition	Sand Cast	Chill Cast	Sand Cast	Chill Cast
2,280	T4	215	265	7	13
2,285	T6	215	280	–	–
2,550	M	-	170	–	–
4,450	M	135	160	2	3
4,600	M	165	190	5	7
4,652	T6	140	–	200	–

2.15 Copper and its Alloys

Copper is a soft, malleable, and ductile material of reddish brown colour with specific gravity of 8.9 and melting point of 1,083° C. Its tensile strength is between 150 – 400 MPa. Copper alloys are designated by the manufacturing method, chemical composition, alloy index, surface finish, and tempering method. Main copper alloys are brass and bronze. These are mainly alloys of Copper, Zn and some other alloying elements as given in Table 2.19. Applications of copper and its alloys are also given in this table.

Table 2.19 Copper, Its Alloys and their Application

Name of Alloy	Percentage of Alloying Elements (%)	Applications
Copper (pure)	Cu 99.95	Wires (due to its high electric conductivity), radiators, condensers
Copper (pure)	Cu 98.85	Chemical plant, deep drawn and spun items

Name of Alloy	Percentage of Alloying Elements (%)	Applications
Brasses		
Brass (Standard)	Cu 65 Zn 35	General cold working alloy
Cartridge brass	Cu 70 Zn 30	Cold rolled sheets, deep drawing, wire drawing, tubes
Gilding metal	Cu 90 Zn 10	Imitation jewelry, decorative works
Gun metal	Cu 88 Zn 2 Sn 10	Boiler fittings, glands, bearings, pump, valve bodies
Monel metal	Cu 30 Fe 1.5 Mn 1.5 Ni 67	High temperature valve seats, chemical engineering equipment
Muntz metal	Cu 60 Zn 40	Hot rolling, extrusion, stamping, condenser, heat exchanger plates
Bronzes		
Bronze	Cu 75–95 Sn 5–25	Wires, rods, sheets, coins
Aluminium bronze	Cu 92–94 Al 6–8	Gears, propellers, pump parts, slide valves, bushes, condenser tubes
Beryllium bronze	Cu 97.8 Be 2.2	Heavy duty switches, bearings, springs, bushes
Manganese bronze	Cu 60 Zn 35 Mn 5	Plungers, bushes, feed pumps, worm gears
Phosphorous bronze	Cu 87–90 Sn 9–10 P 0.1–3	Bearings, worm wheels, gears, pump parts
Silicon bronze	Cu 96 Si 3 Mn 1	Boilers, stoves, tanks
Tin bronze	Cu 89 Zn 11	Bearing bushes, pump bodies

2.16 Tin

Tin is a soft malleable ductile and white shining material. It can be rolled into thin sheets. Tin is used as a protective coating for brass utensils, steel sheets, and foils to keep the moisture away.

2.17 Zinc Alloys

Zinc is a corrosion resistant material. It is used for galvanizing (coating of zinc) iron pipes. Its alloys are used for die casting with considerable strength. The die casting alloy has 4.1 per cent Aluminium, 0.1–1 per cent copper, 0.0–4 per cent Magnesium and rest is all zinc. These alloys are used for auto die casted parts, oil burners, washing machines, refrigerators, and machine casted components.

2.18 Nickel Alloys

Nickel as such has high mechanical strength and corrosion resistance. It is generally used with other metals, which are tabulated in Table 2.20.

Table 2.20 Nickel Alloys and their Application

Name of Alloy	Alloying Elements (%)	Applications
Inconel	Ni 80 Cr 14 Fe 6	Springs for high temperature, exhaust manifolds
Monel metal	Ni 68 Cu 29 Fe 3	Propellers, pump fittings, condenser tubes, turbine blades, food equipment
Nichrome	Ni 65 Cr 15 Fe 20	Heater wires of furnaces, heating elements
Nimonic	Ni 80 Cr 20	Gas turbine engines

2.19 Bearing Materials

A bearing material is supposed to possess the following properties:

- Low coefficient of friction, to reduce friction losses.
- Should not wear, for long life.
- Withstand high pressure occurring due to oil pressure.
- Should have lubrication properties.
- High thermal conductivity, to dissipate heat to atmosphere.
- Non corrosive, so that it is not affected by atmospheric moisture.
- Should be soft, to enable the oil impurities to embed in it.
- Low cost, and easy availability.

Following are the bearing materials that are commonly used:

a. Babbitt is a very popular tin alloy, which is used as a bearing material because of its low coefficient of friction. It is soft and thus absorbs the impurities in it. It has 88 per cent tin, 8 per cent antimony (Sb), and 4 per cent copper.

b. White metal is another bearing material, which has lead and tin. It is used as a lining material for high speed and heavy load bearings.

c. Copper-base alloys are stronger than tin based alloys and are used for bearings under high pressures.

d. Lead-base alloys are also used as bearing materials.

e. Cadmium-base alloys are used for bearings operating at high temperatures.

2.20 Lead

It is a soft metal of greyish colour with specific gravity of 11.36 and melting point of 326° C. It is used to make solder material, lining of acid tanks, coating of electrical cables, and water pipes.

2.21 Non Metals

Non-metal materials are plastics, rubber or wood. Plastics are of two types: Thermoplastics and Thermosetting plastics.

a. **Thermoplastics** These are moulded by softening the material by heat, and then applying pressure to form a permanent hard product. Their applications are listed in Table 2.21

Table 2.21 Applications of Thermoplastics

Thermoplastic	Applications
ABS	Battery casings, helmets, wheels, pipes, radio cases
Acetal Resin	Gears, bearings, threaded fasteners
Acrylics	Combs, bowls, trays, lamp bases, airplane canopies
Cellulosic	Toys, lamp shades, combs, shoe heels, steering wheels, radio cases, pipes, tubes, playing cards, phone handsets, pens
Fluorocarbon	Valve seats, gaskets, coatings, linings, tubing
Nylon	Bristles of brush, tumblers, gears, fishing line, small bearings
Polycarbonate	Aircraft parts, automobiles, gauges, safety glass lenses
Polythene	Tumblers, dishes, bottles, bags, balloons toys, ice cube trays
Polystyrene	Kitchen items, food containers, wall tiles, toys, instrument panels
Polypropylene	Pipe and pipe fittings, wire and cable insulation, packing films sheets
PTFE	Coating on non stick cooking utensils
Vinyl	Rain coats, garment bags, inflatable toys, floor/wall tiles

b. **Thermosetting plastics** These are soft at high temperature and do not become hard with pressure. These plastics become hard when cooled. They can be re-processed any number of times. The applications of thermosetting plastics are listed in Table 2.22.

Table 2.22 Applications of Thermosetting Plastics

Thermoplastic	Applications
Alkyd	Light switches, insulators, mounting cases, as liquid for enamels, lacquers for automobiles and refrigerators
Allyic	Electrical connectors, knobs, coating for plywood, moisture protection
Amino	Tableware, table tops, plywood adhesive, electrical devices.
Casein	Buttons, buckles, beads, knitting needles, toys, adhesives
Epoxy	Protective coating for appliances, cans, drums, gym floors, printed circuits, laminated tools and jigs, liquid storage tanks

Example 2.1

Selecting a material with given parameters

There are four shortlisted materials (Material 1, Material 2, Material 3, Material 4) having the property of ultimate tensile strengths as 800, 850, 1,100, 900, respectively. The cost of these four materials is Rs 50, 70, 90, 80 per unit, respectively. Weightage to Strength is 5 and for Cost is 3. Select a material with maximum points.

Solution

Given $S_{ut1} = 800$ MPa $S_{ut2} = 850$ MPa $S_{ut3} = 1{,}100$ MPa $S_{ut4} = 900$ MPa

Cost 1 = Rs 50 Cost 2 = Rs 70 Cost 3 = Rs 90 Cost 4 = Rs 80

Strength weightage = 5 Cost weightage = 3

There are only two properties, that is, strength and cost. Each is taken one by one for all the four materials.

1. **Strength property**

   a. Calculate *FV*

   Sum of all the values of strength property = 800 + 850 + 1,100 + 900 = 3,650

   FV for Material 1 = 800/3,650 = 0.212

   FV for Material 2 = 850/3,650 = 0.233

   FV for Material 3 = 1,100/3,650 = 0.301

   FV for Material 4 = 900/3,650 = 0.246

   b. Calculate points for strength property = *FV* × Weightage

   Weightage for strength is 5, hence:

   Points for Material 1 = 0.212 × 5 = 1.100

   Points for Material 2 = 0.233 × 5 = 1.165

   Points for Material 3 = 0.301 × 5 = 1.505

   Points for Material 4 = 0.246 × 5 = 1.230

2. **Cost property**

   For cost, the values have to considered inversely because lower the cost, the better it is. Sum of inverse of cost values is:

$$\frac{1}{50}+\frac{1}{70}+\frac{1}{90}+\frac{1}{80} = 0.02 + 0.0143 + 0.0111 + 0.0125 = 0.0579$$

   a. Calculate FV

   FV for Material 1 = 0.02/0.0579 = 0.345

   FV for Material 2 = 0.0143/0.0579 = 0.247

   FV for Material 3 = 0.0111/0.0579 = 0.192

   FV for Material 4 = 0.0125/0.0579 = 0.216

b. Calculate points for cost property = $FV \times$ Weightage

Weightage for cost is 3, hence points for this property are:

Points for Material 1 = $0.345 \times 3 = 1.035$

Points for Material 2 = $0.247 \times 3 = 0.741$

Points for Material 3 = $0.192 \times 3 = 0.576$

Points for Material 4 = $0.216 \times 3 = 0.648$

3. **Make a total of points for all the properties of each material.**

Material 1 = $1.100 + 1.035 = 2.135$

Material 2 = $1.165 + 0.741 = 1.906$

Material 3 = $1.505 + 0.576 = 2.081$

Material 4 = $1.230 + 0.648 = 1.878$

4. **Choose the material with maximum number.**

As Material 1 has the maximum number, that is, 2.135, so this is selected from the short listed materials.

\

Example 2.2

Selecting a material for an application

Select a suitable material for making gears of a small portable machine.

Solution

Step 1 Selection of properties:

Strength, hardness, weight (since the machine is portable, hence, weight has to be less), and cost.

Step 2 Material suitable for gears with their relevant properties are tabulated below (Table 2.24).

Table 2.24 Materials Suitable for Gears and their Properties

Material	Tensile Strength N/mm^2	Hardness (HB)	Density kN/m^3	Cost in Rs/Kg
Cast iron	320	150	72.5	35
Med. carbon steel	500	200	78.5	40
High carbon steel	700	250	78.5	50
Alloy steel	800	260	78.5	60
Phosphorous bronze	200	80	87.3	120

Step 3 Short list the materials. Cast iron is used for big gears, hence dropped from the list.

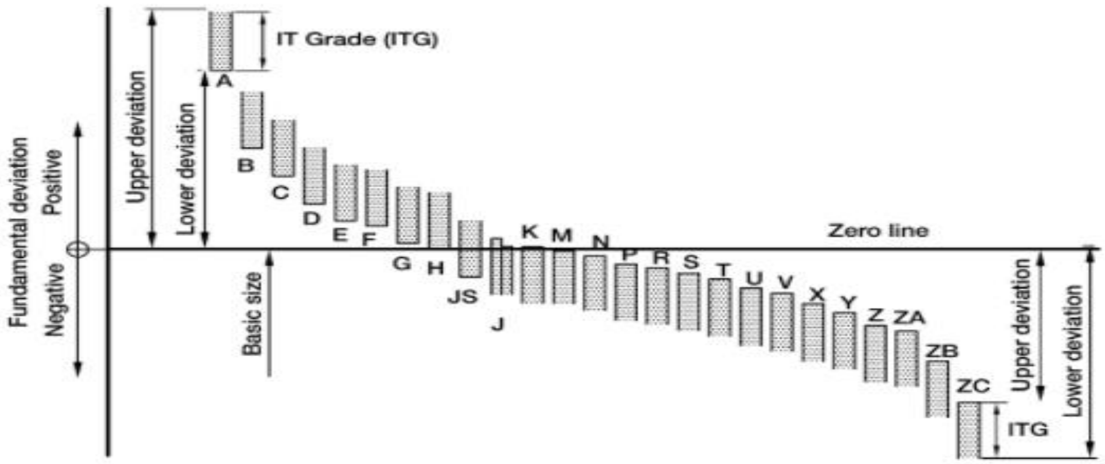


Figure 3.3 Graphical illustrations of tolerance zones for holes

See Figure 3.4 for interpretation of the upper case letter symbols.

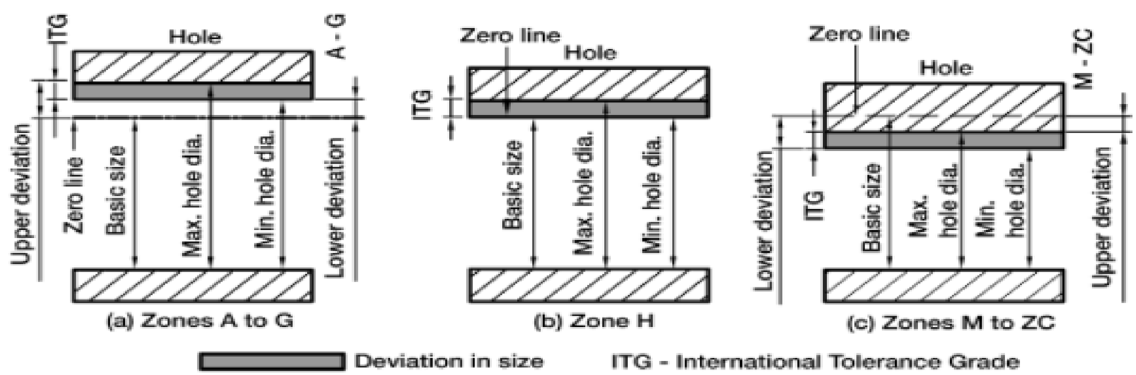


Figure 3.4 Interpretation of upper case letter symbols

3.5.2 Letter symbol for shafts

Figure 3.5 shows the fundamental deviation for the shafts, which is the mirror image of Figure 3.3.

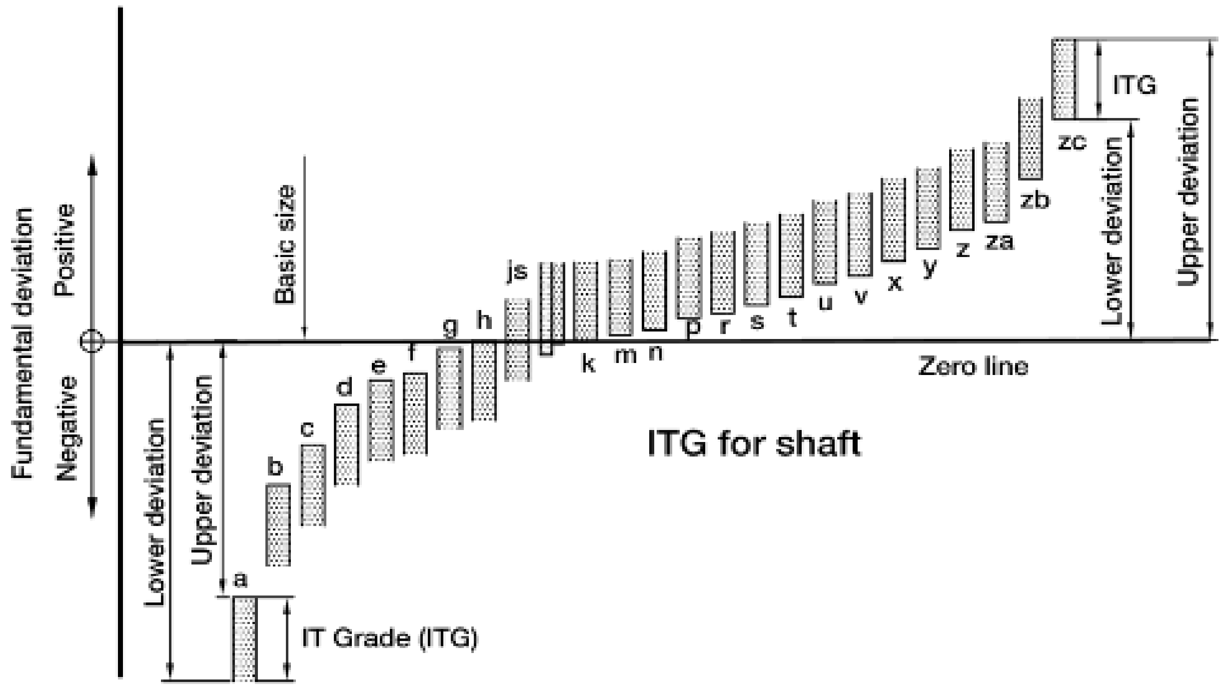


Figure 3.5 Graphical illustrations of tolerance zones for shaft

Interpretations of the different zones are shown in Figure 3.6.

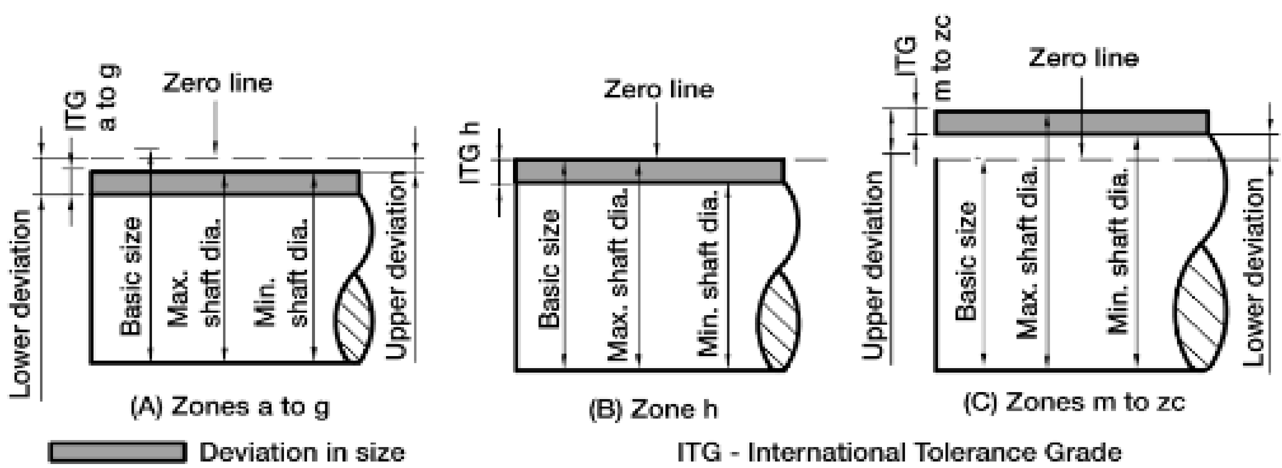


Figure 3.6 Interpretation of lower case letter symbols

3.5.2 Letter symbol for shafts

Figure 3.5 shows the fundamental deviation for the shafts, which is the mirror image of Figure 3.3.

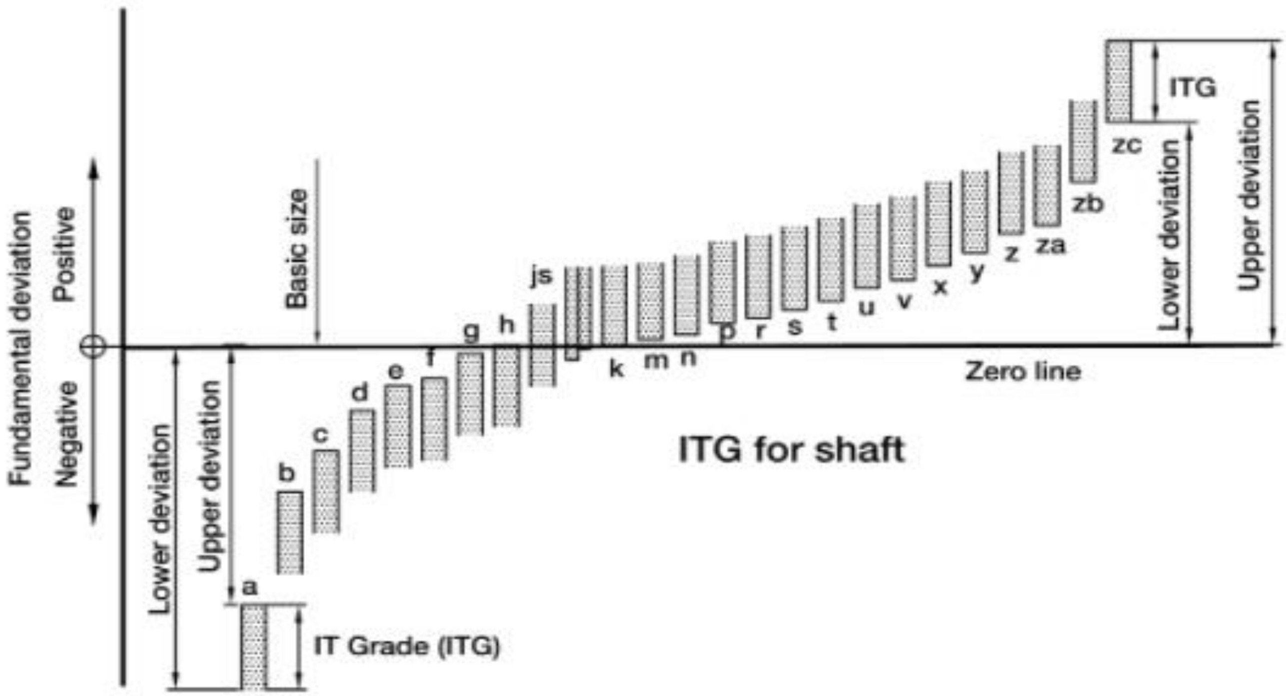


Figure 3.5 Graphical illustrations of tolerance zones for shaft

Interpretations of the different zones are shown in Figure 3.6.

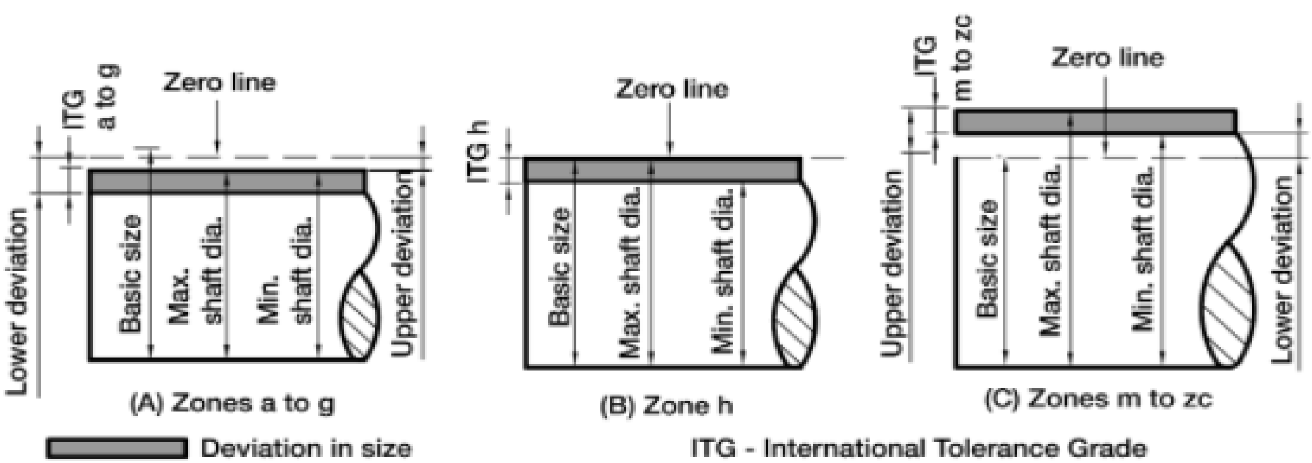


Figure 3.6 Interpretation of lower case letter symbols

Fundamental deviation of holes and shafts is given in Tables 3.5 and 3.6, respectively.

<u>63 TO 68 NOT AVAILABLE</u>

Example 3.5

Size calculation from fundamental deviations

Calculate maximum and minimum sizes of the shafts for the following fundamental tolerances:

a. 40d6 b. 80h8

Solution

The relevant portions of tables 3.2 and 3.6 are being reproduced here for easy reference. Refer Figure 3.5 also.

Values from Table 3.1

Case	Basic size	Range	IT Grade (ITG)	Tolerance value
(a)	40	30 – 50	6	16
(b)	80	50 – 80	8	46

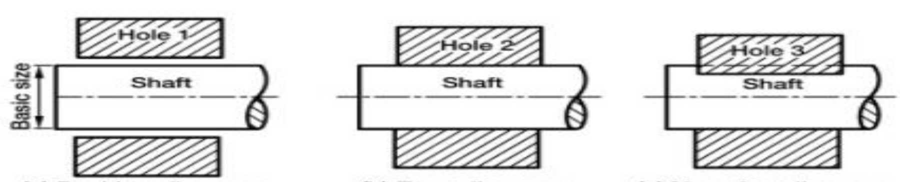
Values from Table 3.6

Case	Basic size	Range	Tolerance zone	Tolerance (μ)	Upper or lower
(a)	40	40 – 50	d	– 80	Upper
(b)	80	50 – 80	h	0	Upper

a. 40d6

From Table 3.6, under tolerance zone d, the upper deviation value for basic size 40 mm is – 80 μ, that is, – 0.080 mm. Hence, maximum size is 39.92 mm.
From Table 3.2, for basic size 40 mm, under IT grade 6, the tolerance value is 16 μ, that is, 0.016 mm.
Hence, minimum size is: = 39.92 – 0.016 = 39.904 mm

70 NOT AVAILABLE



(a) Positive allowance (b) Zero allowance (c) Negative allowance

Figure 3.10 Shaft basis of fits

3.9 Specifying a Fit

A fit is specified by two fundamental tolerance grades on hole and shaft, separated by a dash. The first tolerance is on hole and the second tolerance is of shaft. If fit is on the hole basis, tolerance grade H is specified for hole. For example:

H6 – d7 H6 is the tolerance zone for the hole and d7 is the tolerance zone for the shaft.

If fit is to be specified on shaft basis, tolerance h is specified for the shaft. The same fit (H6 – d7 on hole basis) can be specified on shaft basis as under:

D7 – h6 D7 is the tolerance zone for the hole and h6 is the tolerance zone for the shaft.

3.10 Types of Fits

Moving or rotating parts require a definite amount of clearance between the stationary and moving parts. There are three main types of fits as given below:

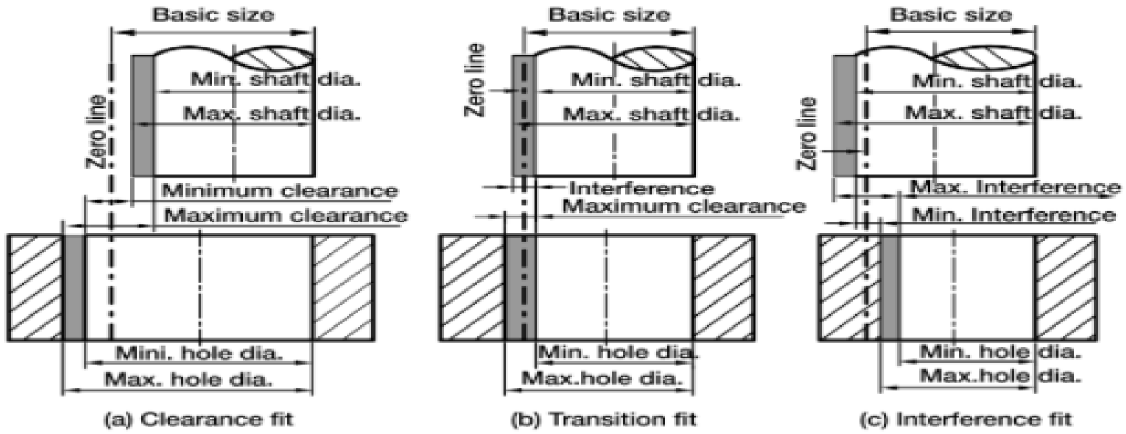


Figure 3.11 Types of fits

3. Describe tolerances with at least six associated terms.
4. How is fundamental deviation specified? Differentiate between symbols A and a, H and h.
5. What is an IT grade? How many grades are there and how are these specified?
6. What are the various methods of specifying tolerances? Describe by examples.
7. Differentiate between the hole and shaft basis system of fits.
8. What is meant by the term fit? What are the various types of fits? Give examples of each type.
9. Differentiate between tolerance, limit, and fit.
10. Suggest suitable fits for the following applications:
    a. Bush fixed in a housing. b. Locating snug.
    c. Key in the key way of a pulley dismantled frequently.
    d. Ball bearing on a shaft e. Flywheel shrunk fit over a shaft.
11. Name the dimensions A, B. . . . F for a shaft shown in Figure 3.P1.

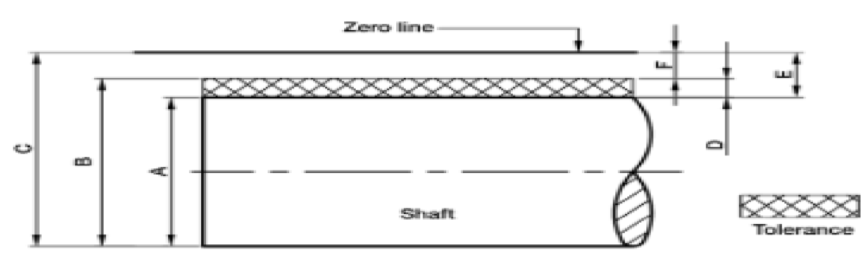


Figure 3.P1

12. Describe the various methods used to check tolerances in a mass production environment.

Multiple Choice Questions

Tick the correct answer

1. Deviation is:
   (a) difference between maximum and minimum size
   (b) same as tolerance
   (c) difference between basic and actual size
   (d) difference between limits
2. An allowance is the difference between:
   (a) upper and lower deviation (b) basic and actual size
   (c) maximum limit of mating parts (d) basic size of hole and actual size of shaft

3. Fundamental tolerance is given by:
   (a) a number symbol (b) a letter symbol
   (c) a three digit number
   (d) both by a letter symbol and a number symbol
4. Lower case letter for tolerances are used for:
   (a) shaft (b) journal
   (c) hole (d) both for hole and shaft
5. Letter JS in the fundamental tolerance denotes a value on both + and – sides as:
   (a) zero (b) 2 IT (c) 0.75 IT (d) IT / 2
6. Type of fit is decided by:
   (a) difference in maximum shaft diameter and maximum hole size
   (b) difference in maximum shaft diameter and minimum hole size
   (c) the application
   (d) manufacturing method
7. Type fit used for a slide journal bearing is:
   (a) H8 – e8 (b) H6 – j8 (c) H8 – b7 (d) H5 – h5

Answers to multiple choice questions

1. (b) 2. (c) 3. (d) 4. (b) 5. (d) 6. (c) 7. (a)

Design Problems

1. Calculate maximum and minimum sizes of the shafts for the following fundamental tolerances:
   (a) 50c7 (b) 70h9 (c) 90p6
   [(a) 49.870 mm, 49.845 mm (b) 70.000 mm, 69.926 mm (c) 90.059 mm, 90.037 mm]
2. Calculate maximum and minimum sizes of the holes for the following fundamental tolerances:
   (a) 45G7 (b) 80J7 (c) 120ZC6
   [(a) 45.034 mm, 45.009 mm (b) 80.042 mm, 80.012 mm (c) 119.332 mm, 119.310 mm]
3. A hole of 50 mm has tolerance as C10. Calculate its maximum and minimum sizes.
   [50.23 mm, 50.13 mm]
4. A shaft of 80 mm has tolerance as b9. Calculate its maximum and minimum sizes.
   [70.800 mm, 78.726 mm]
5. A shaft of diameter 30 mm rotates at medium speed in a sleeve bearing. Specify the following:
   a. Type of fit required.
   b. Maximum and minimum shaft diameters.
   c. Maximum and minimum inside diameter of sleeve.

5 ANS A

6. Calculate maximum and minimum size of holes having fundamental tolerances as:

   (a) 40C10 (b) 60N9 (c) 120Z

   [(a) 40.22 mm, 40.12 mm (b) 59.980 mm, 58.906 mm (c) 119.690 mm, 119.668 mm]

7. Calculate limits of the shaft diameter having fundamental tolerance as:

   (a) 50d9 (b) 70g8 (c) 80s9

   [(a) $50^{-0.08}_{-0.142}$ (b) $70^{-0.0010}_{-0.056}$ (c) $80^{0.133}_{0.059}$]

8. Find maximum and minimum clearance for different fits for the following sizes:

   (a) 50 H11 – c11 (b) 60 H7 – k6 (c) 70 H7 – s6

   [(a) 0.045 mm, 0.13 mm (b) 0.028 mm, – 0.021 mm (c) – 0.29 mm, – 0.72 mm]

9. A stepped block is shown in Figure 3.P2. Evaluate tolerance for size A and B.

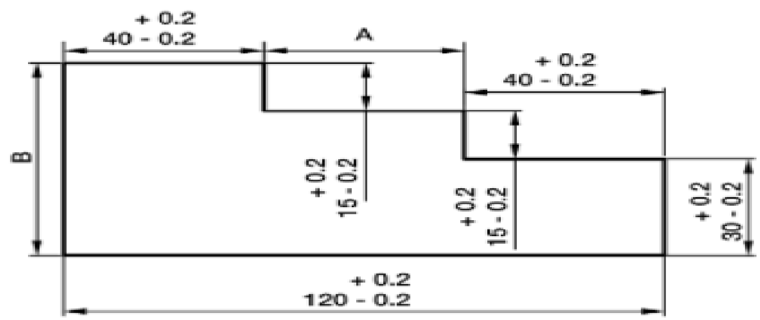


Figure 3.P2 A stepped block

[$A = \pm$ 0.6 mm, $B = \pm$ 0.6 mm]

10. A stepped shaft shown in Figure 3.P3 is to be produced in large quantity. Specify suitable tolerances for the 50 mm end and overall length. [0.075 mm and 0.09 mm]

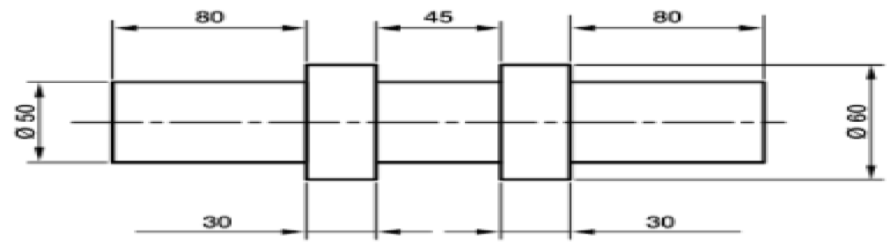


Figure 3.P3 A stepped shaft

11. Draw Figure 3. P4 and put the tolerances by the method indicated in the table below. Also calculate the tolerances for the dimensions X and Y.

Process	Type of Work	Production Rate	Cost	Tolerances IT Grades	Surface Roughness (μ)
CNC machines	Repeated accurate jobs	Depends on complexity of the job; tool changes	High	IT 5 – IT 7	0.8 – 3.2
Rapid Prototyping	For development work only	Very slow	High	IT 5 – IT 7	3.2 – 12.5

4.4 Shaping Processes

Shaping processes involve heating of a material to its melting point and then pouring it into a cavity of the same shape as the component. If the cavity is made in sand boxes called mould, it is called Sand casting. Making a mould is time consuming and hence suitable only for small number of items to be produced.

If the number of components to be made is large, Die casting is used, in which the mould is made of metals having a melting point higher than the melting point of the material to be poured.

4.4.1 Sand casting

Sand casting needs a pattern of the same shape as the component. For a small number of castings, the pattern is generally made of wood that ensures some pattern allowances. The pattern is made slightly bigger than the component because the metal shrinks when cooled. This allowance is called shrinkage allowance. If some surfaces are to be machined, machining allowance of the order of 3 mm is given. When the pattern is taken out of the mould, its vertical surfaces may damage the mould. Hence, for easy removal of the pattern from the mould, a taper of the order of 1 mm for every 100 mm depth is given to the vertical surfaces. This is called Draft allowance.

Sand casting is done for ferrous and non-ferrous materials. Surface quality and tolerances are poor. It is suitable for small and big jobs rather than mass production. Sand casting is relatively cheaper in comparison to the material removal process. If the numbers of parts to be produced are more, then the pattern may be of Al. The pattern drawing should be inclusive of all pattern allowances like shrinkage allowance, draft allowance, and machining allowance. Following are the salient points for sand castings.

- Any metal can be casted.
- Castings give a rough surface. Where they come in contact with other parts the surfaces are machined; otherwise, they are left un-machined.
- Sand casting is used when the size of the casting is large (may be in tens / hundreds of kilograms).
- Castings are rigid and strong, hence suitable for machine frames.

c. **Uniform section** A uniformly thick casting surface cools uniformly and is an important requirement for getting a sound casting. Uniform cooling leads to stress-free and distortion-free casting. Thus, while designing all the sections should be kept uniform, as far as possible.

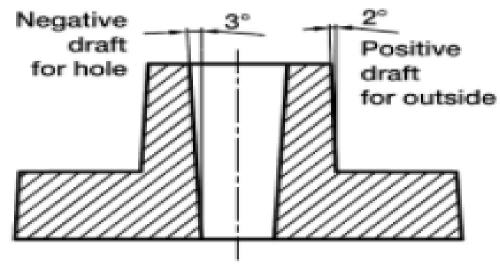


Figure 4.2 Drafts

d. **Gradual change in section** In case it is not possible to maintain a uniform thickness in any area of the casting design, then a gradual, rather than an abrupt, change is made. A uniform section is the best. If at all a change in cross section is required, it should be gradual or with a fillet to avoid stress concentration (Figure 4.3).

Figure 4.3 Gradual changes in section

e. **Avoid tensile stresses** Castings are good in compression. Tensile loads (Chapter 6) should be avoided for castings (Figure 4.4), where tensile stresses are avoided just by orienting a component properly.

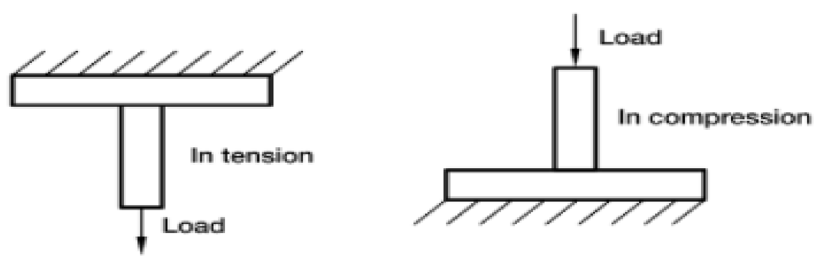


Figure 4.4 Avoiding tensions

f. **Reduce tensile stresses** If tensile load is unavoidable, a rib or a tie rod can be provided to support it (Figure 4.5).

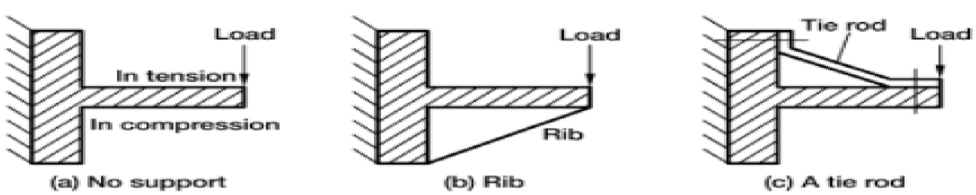


Figure 4.5 Reducing tensions

- Figure 4.11(b) shows an inclined parting line. Due to inclined parting, it results in a side thrust, which tries to displace the dies and, hence, to resist this force, some area or dowel pins, etc. are provided.
- If the parting line cannot be on a single plane, then it is a good practice to use symmetry of the design to minimize the side thrust forces. Shapes with doubly inclined lines balance such forces [Figure 4.11(c)].
- Using two components as mirror image of each other, as shown in Figure 4.11(d), can also cancel such forces.

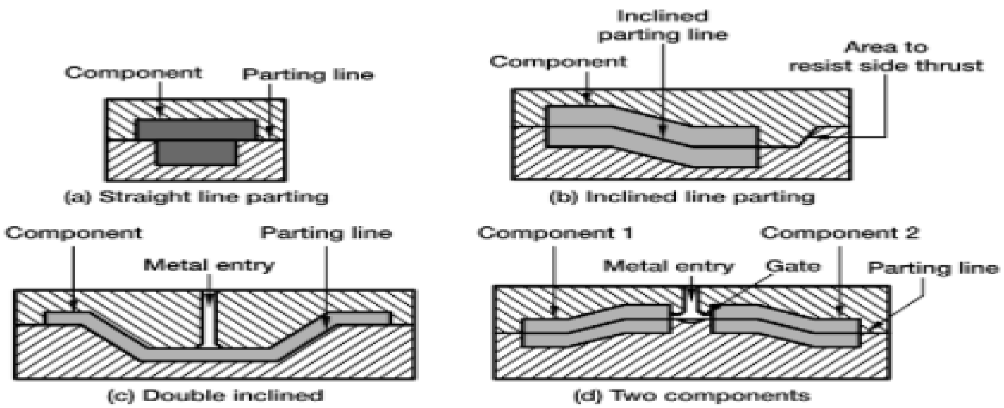


Figure 4.11 Shape and position of parting line in dies

b. **Draft allowances** This type of allowance is given for easy removal of the component from the die (Figure 4.12). Generally, all forged surfaces that lie parallel to the die motion are tapered. This taper also helps the flow into the deeper die cavities. Outside surfaces are inclined at an angle equal to the draft angle of about 6°, while inside surfaces are given a negative draft of about 9°. The incline is more than the outside as these surfaces contract when cooled and grip the surface of the die.

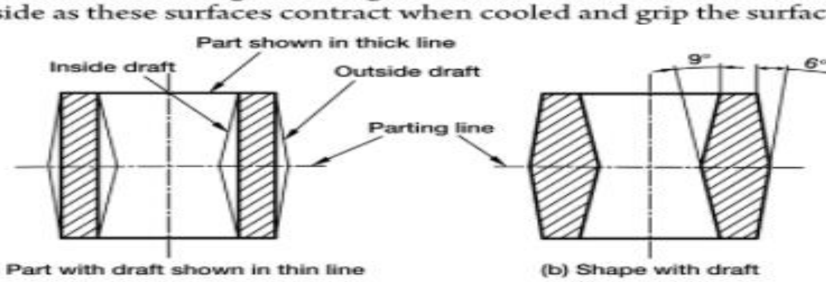


Figure 4.12 Draft angles for steel forgings

Low-draft and no-draft forging can be used for metals like Al and brass. This is done when the reduction or elimination of a draft yields significant benefits in machining, etc. Recommended draft angles are tabulated in Table 4.6.

Table 4.6 Draft Angles in Degrees for Forging Dies

Material	Draft Angle
Aluminium	0 – 2
Brass and Copper base alloys	0 – 3
Steel	5 – 7
Stainless steel	5 – 8

c. **Undercuts** As in most forming processes, use of undercuts should be avoided as these make the removal of the part difficult, if not impossible, and cutting the fibre makes the part weak.

d. **Fillets** Generous fillets and radii should be provided to aid in material flow. Sharp corners increase stress concentrations in the forgings, as well as make the dies weak. The value of fillet radius depends on the protrusion. Recommended minimum and maximum radii are given in Table 4. 7.

Table 4.7 Fillet or Corner Radius in mm for Forgings

Height of Protrusion	Fillet Radius	
	Minimum	Maximum
13	1.5	5
25	3	6
50	5	10
100	6	10
400	22	50

e. **Ribs** Ribs should not be high or narrow, as they offer difficulty for the material to flow. The ratio of rib height, *H*, to thickness, *T*, in general, should not exceed 6:1.

(Figure 4.13). As a general rule, the rib thickness should be equal to or less than the part thickness to avoid process defects. Deep recesses are easier to forge with spherical bottoms.

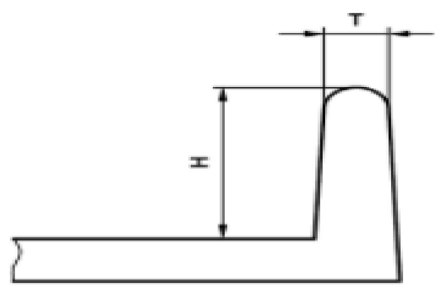


Figure 4.13 Rib height and thickness

f. **Tolerances in forgings** Following are the tolerances adapted in forgings:

- Dimension tolerances are usually positive and approximately 0.3 per cent of the dimension, rounded off to the next higher 0.5 mm.

Radial drilling machine

Planning machine

Slotting machine

Table 4.10 Machines for Material Removal

S. No.	Name of Machine	Type of Work
1	Lathe	Cylindrical/taper turning, thread cutting, drilling, boring, knurling, grooving, etc.
2	Shaper	Short flat surfaces of average surface finish, inclined surfaces, grooves, etc.
3	Horizontal milling	Flat surfaces of good quality, grooves, gears, splines
4	Vertical milling	Profile milling of any contour, die making, surface milling
5	Drilling machine	Holes from 20 mm to 50 mm on big radial drill machines
6	Slotting machine	Key ways
7	Broaching machine	Key ways, splines
8	Hobbing machine	Gear cutting
9	Planning machine	Making long flat surfaces and long grooves like lathe beds

4.7.1 Design considerations in machining

Processes like casting or forging give the required shape. But to get the required size, a geometric shape with close tolerances and good surface finish machining is required. Cost of manufacture can be reduced by proper planning of machining operations. Following points should be kept in mind for machining processes:

- Geometric construction should be as far as possible straight or circular as any other geometry requires special tools and fixtures.
- Tolerances specified on drawing should be adequate: neither more nor less. Close tolerances increase the cost of manufacture.
- For machining parts, sufficient gripping area should be available for gripping the part.
- Runout clearance (undercut) near a shoulder should be provided for threads or grinding, etc.

- Amount of machining should be the minimum to reduce cost.
- Provide location for holding and fixing job in jigs or fixtures, if required.
- Avoid sharp corners to avoid stress concentration. Provide fillets or chamfers in place of corners.
- For drilling, surface should be normal to the axis of hole.

4.8 Jigs

Interchangeability of parts in mass production is a prime requirement for assembly. To produce identical parts, jigs are used for guiding tools while manufacturing. Jigs not only increase the speed of production and accuracy, but also reduce production cost and time. Jigs perform two functions:

- Support and hold a job securely and
- Guide for the location of a cutting tool.

The jig is drawn in continuous lines, while the job is usually shown by chain-dotted lines for differentiation purpose. The type of jig required for each job depends on its shape and hence has to be suitably designed and details are to be given on the production drawing.

The jig facilitates in locating the centers quickly and exactly. Sometimes, if the surface is inclined, it is not possible to drill a hole without a suitable jig. Figure 4.18 shows a jig for drilling an inclined hole in a circular rod. If the rod is not properly secured, it may rotate and the hole may not be at the desired location.

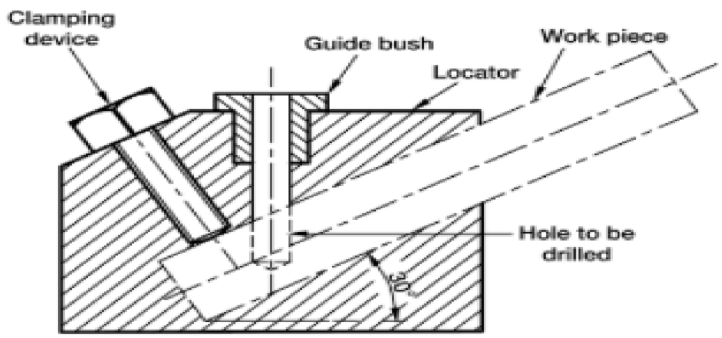


Figure 4.18 A jig for drilling an inclined hole

4.9 Fixtures

Fixture is a device to locate and hold the work securely in a definite position. It only holds the work and does not guide any tool. Generally, it is fitted on the machine. Fixtures are drawn by chain-dotted lines in the drawing as shown in Figure 4.19. The fixture shown is to bore a hole of a bearing block.

furnace and cooled in still air away from any draft. This results in tough steel with fine grain structure and gives a good surface finish on machining.

e. **Carburizing** In this process only the surface of the work piece is hardened. It is a thermo-chemical process. Carburizing is so called because the work piece is exposed to gases containing carbon-like carbon-di-oxide or methane. If nitrogen (N) is also added in the carbon environment then it is called carbo-nitriding. It is done in three steps:

i. Heat the work piece in an environment of gases of Carbon/Nitrogen. Depth of hardness depends on the temperature, time of exposure, and type of steel.

ii. The work piece is quenched in oil or water.

iii. Temper the work piece to reduce high stresses in the surface, which increases its sensitivity to crack while surface grinding.

4.13 Surface Finishing Processes

When the surface smoothness required is more than what conventional machines can give, grinding machines are used. Machines used for surface finishing are given in Table 4.11. The roughness, in microns obtainable with different processes is given in Table 4.12.

Table 4.11 Machines for Surface Finishing

S. No.	Name of Machine	Type of Work
1	Surface grinder	To make flat smooth surfaces
2	Cylindrical grinder	To make smooth cylindrical surfaces
3	Center-less grinder	For high production jobs of circular cross section
4	Internal grinder	Used to grind internal holes
5	Honing	Roughness varies between 0.025μ and 0.4μ, e.g. cylinder liners
6	Lapping	Gives surface finish better than honing

Table 4.12 Roughness in μ with Different Processes (from rough to fine)

S. No.	Process	Min. – Max.	S. No.	Process	Min. – Max.
1	Sand casting	6.3 – 50	11	Extruding	0.4 – 12.5
2	Hot rolling	6.3 – 50	12	Reaming	0.4 – 3.2
3	Planning	1.6 – 25	13	Broaching	0.4 – 3.2
4	Shaping	1.6 – 25	14	Hobbing	0.4 – 3.2
5	Forging	1.6 – 25	15	Die casting	0.4 – 3.2
6	Turning	0.32 – 25	16	Cyl. grinding	0.05 – 12.5
7	Milling	0.32 – 25	17	Surface grinding	0.05 – 12.5
8	Drilling	1.6 – 20	18	Honing	0.02 – 0.8
9	Boring	0.2 – 25	19	Polishing	0.05 – 1.6
10	E.D M.	0.8 – 12.5	20	Lapping	0.1 – 0.8

For specifying a suitable roughness depending on the application, Table 4.13 can be used as a guide line.

Table 4.13 Applications and Suggested Roughness (in microns)

Applications	Roughness
Low grade roughness from sand casting, flame cutting, chipping, rough forging; suitable for un-machined surfaces and is rarely specified	25
Surface resulting from heavy machine cuts, coarse feeds in turning, shaping, milling, boring	12.5
Used for unfinished clean operations; resulting from coarse ground surfaces, rough file, commercial turning	6.3
Roughest surface that can be used for parts subjected to loads, vibrations, high stresses; medium commercial machine finish on lathe, milling, shaper; Die casting, extrusion, and rolled surfaces	3.2
Good machining finish with high speed and fine feed turning; used for close fits; not suitable for high speed shafts having vibrations	1.6
High grade finish by machine tools like center-less, cylindrical, and surface grinding machines; suitable for parts under high stress concentration; cost is high	0.8
High quality surface by grinding, honing, lapping especially where smoothness is very important; suitable for high speed shafts where lubrication is not dependable	0.4
Fine surface produced by honing, lapping, buffing; suitable for hydraulic cylinders	0.2

and high speed shafts where lubrication is not dependable	
Costly surface produced by honing, lapping, buffing; suitable for instrument work, chrome plated piston rods	0.1
Costliest surface produced by super finishing' used for fine and sensitive instruments, gauge blocks	0.05 and 0.025

4.14 Design for Assembly

The aim of Design for Assembly (DFA) is to simplify a product so that the cost of assembly is reduced. However, consequences of applying DFA usually include improved quality, reliability, reduction in production equipment and part inventory. These secondary benefits

GATE

7. Explain expendable pattern casting process with schematic illustration and applications. [GATE 2015]

8. Explain the salient design principles of milling fixtures. [GATE 2015]

9. Explain the principles of the electro-chemical machining process with the help of a diagram. [GATE 2015]

10. The process of reheating martensitic steel to reduce its brittleness without any significant loss in its hardness is:

    (a) Normalizing (b) annealing (c) quenching (d) tempering

    [Ans. (a)] [GATE 2014]

11. The hot tearing in a metal casting is due to:

    (a) high fluidity (b) high melt temperature

    (c) wide range of solidification temperature (d) low coefficient of thermal expansion

    [Ans. (c)] [GATE 2014]

12. Match the heat treatment processes (Group A) and their associated effects on properties (Group B) of medium carbon steel.

Group A	Group B
P. Tempering	I. Strengthening and grain refinement
Q. Quenching	II. Inducing toughness
R. Annealing	III. Hardening
S. Normalizing	IV. Softening

(a) P - III Q-IV, R-II, S-I (b) P - II Q-III, R-IV, S-I

(c) P - III Q-II, R-IV, S-I (d) P - II Q-III, R-I, S-IV

[Ans. (b)] [GATE 2014]

13. In a rolling process, the state of stress of the material undergoing deformation is:

    (a) Pure compression (b) Pure shear

    (c) Compression and shear (d) Tension and shear

    [Ans. (c)] [GATE 2013]

14. Match the correct pairs:

Processes	**Characteristics/ Application**
P. Friction welding	1. Non-consumable electrode
Q. Gas metal arc welding	2. Joining of thick plates
R. Tungsten inert gas welding	3. Consumable electrode wire
S. Electro slag welding	4. Joining of cylindrical dissimilar materials

Example 5.2

Elongation with axial pull and weight

A lift carries a load of 5 kN and hangs vertically from a steel wire of diameter 5 mm and length 20 m. Find the elongation of wire, considering the weight of the wire, having density 7.8×10^4 N/ m^3. Assume $E = 2 \times 10^5$ MPa.

Solution

Given $P = 5$ KN $\quad D = 5$ mm $\quad L = 20$ m $\quad \rho = 7.8 \times 10^4$ N/m^3 $\quad E = 2 \times 10^5$ MPa

$$\text{Area of wire} = \frac{\pi d^2}{4} = \frac{\pi \times 5^2}{4} = 19.625 \text{ mm}^2 = 19.625 \times 10^{-6} \text{ m}^2$$

$$\text{Volume of wire} = \text{Area} \times \text{Length} = 19.625 \times 10^{-6} \times 20 = 0.3925 \times 10^{-3} \text{ m}^3$$

$$\text{Weight of the wire} = \text{Volume} \times \text{density} = 0.3925 \times 10^{-3} \times 7.8 \times 10^4 = 30.615 \text{ N}$$

Total elongation of wire δl is equal to the elongation due to load W of lift plus elongation due to the weight of wire W_w acting at CG of the wire (i.e. middle of the length).

$$\text{Elongation due to load of lift} = \frac{W \times L}{A \times E} = \frac{5 \times 10^3 \times 20{,}000}{19.625 \times 2 \times 10^5} = 25.4 \text{ mm}$$

$$\text{Elongation due to weight of wire} = \frac{W_w \times 0.5L}{A \times E} = \frac{30.615 \times 10{,}000}{19.625 \times 2 \times 10^5} = 0.078 \text{ mm}$$

$$\text{Total elongation of wire} = 25.4 + 0.078 = 25.478 \text{ mm}$$

Example 5.3

Size for a given load in axial pull with limited elongation

A mild steel bar of length 2 m is pulled by a load of 200 kN. The percentage of elongation is not to exceed 0.05%. Assuming $E = 2 \times 10^5$ MPa, find:

a. Bar diameter.

b. What maximum load it can take, if there is no restriction on elongation? Take $S_{ut} = 360$ MPa

Solution

Given $L = 2$ m $\quad P = 200$ kN $\quad \delta L \times 100/L = 0.05 \quad E = 2 \times 10^5$ MPa $\quad S_{ut} = 360$ MPa

$$\frac{\delta L}{L} = \frac{0.05}{100} \quad \text{Therefore, } \delta L = 2{,}000 \times 0.0005 = 1 \text{ mm}$$

a. $$\delta L = \frac{P \times L}{A \times E} \quad \text{Or,} \quad = \frac{W \times L}{A \times E} = \frac{5 \times 10^3 \times 20{,}000}{19.625 \times 2 \times 10^5} = 25.4 \text{ mm}$$

$$\text{Therefore, diameter } d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 2{,}000}{3.14}} = 50.5 \text{ mm}$$

b. Maximum load = Area × Ultimate stress = 2,000 × 360 = 720 × 10^3 N = 720 kN

Example 5.4

Size for axial pull in a rectangular bar for a given load

A tensile load of 60 kN is applied to a rectangular flat having length 500 mm and uniform thickness as 25% of its width. Find the following assuming yield stress 250 MPa, ultimate stress 400 MPa, $FOS = 3$, and $E = 2 \times 10^5$ MPa:

a. Find the cross section of the flat.

b. For this section, what will be the elongation, when it fails?

Solution

Given Load = 60 kN $\quad T/W = 0.25 \quad S_{ut} = 400$ MPa $\quad S_{yt} = 250$ MPa

$L = 500$ mm $\quad FOS = 3 \quad E = 2 \times 10^5$ MPa

a. Safe tensile stress

$$\sigma_{yt} = \frac{S_{yt}}{FOS} = \frac{250}{3} = 83.3 \text{ N/mm}^2$$

Area of flat = width × thickness = $W \times 0.25\, W = 0.25\, W^2$

$$\sigma_{yt} = \frac{\text{Load}}{\text{Area}} \quad \text{Putting the values:}$$

$$83.3 = \frac{60 \times 10^3}{0.25\, W^2} \quad \text{Or,} \quad W = 53.67 \text{ mm}$$

Thickness $T = 0.25 \times W = 13.4$ mm

Area of flat = $0.25\ W^2 = 0.25 \times (53.67)^2 = 720.3\ \text{mm}^2$

The load, when it fails $P = S_{ut} \times A = 400 \times 720.3 = 288{,}000\ \text{N} = 288\ \text{kN}$

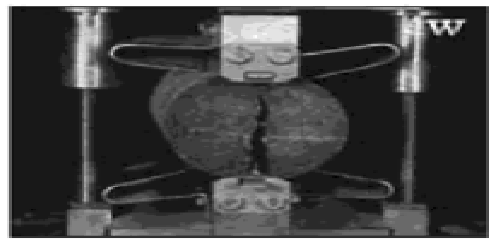
$$E = \frac{P \times L}{A \times \delta L} \qquad \text{Or,} \quad \delta L = \frac{PL}{AE} = \frac{288 \times 10^3 \times 500}{720.3 \times 2 \times 10^5} = 1\ \text{mm}$$

5.10 Compressive Stresses

If a body is compressed [Figure 5.1 (b)] by two equal and opposite forces as shown in Picture below for compression failure, then compressive stress is developed. It is given as:

$$\sigma_c = \frac{P}{A} \tag{5.10}$$

Where, P = Axial force (N), A = Area of cross section (mm)



If a component, on which compressive load is applied, is short, that is, the length to diameter ratio (L/D) is less than 80, then the above equation holds good, but if the length is such that L/D ratio is greater than 80, it tends to buckle and the analysis has to be done taking into account the buckling of a long rod (Section 5.11).

When a compressive load is applied, its length decreases and cross section increases. The ratio of decrease in length to the original length is called compressive strain and is given by:

$$\varepsilon_c = \frac{\delta L}{L} \qquad \text{Where,} \quad \delta L \text{ is change in length and } L \text{ is original length}$$

Example 5.5

Compressive load on various sections

Find the maximum compressive load the members shown below in Figure 5.S1 can take? Assume the members to be short in order to neglect the buckling effect.

a. A pipe of outside diameter 30 mm and inside diameter 25 mm with ultimate compressive strength 360 MPa.
b. A hollow rectangular cast iron pipe of exterior 40 × 30 mm, wall thickness 5 mm, and ultimate compressive strength 260 MPa.
c. H-section with outside dimensions along X axis 40 mm and along Y axis 30 mm, uniform wall thickness of 5 mm, and ultimate compressive strength 450 MPa.

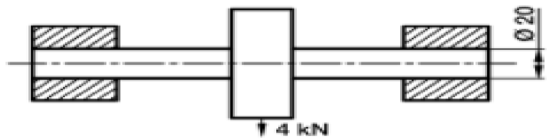


Figure 5.52 A shaft supported on bearings

There are two bearings, hence force on each bearing $P = \frac{4}{2} = 2\text{ kN} = 2{,}000\text{ N}$

Bearing area $= L \times d = 20\,L$

$$\sigma_b = \frac{\text{Load}}{\text{Area}} \qquad \text{Putting the values:} \quad 4 = \frac{2{,}000}{20\,L} \qquad \text{Or,} \quad L = 16.7\text{ mm}$$

5.13 Shear Stresses

When a body is pulled by two equal and opposite forces at right angles to the axis of the resisting body (e.g. a rivet in Figure 5.7), the stress developed in the resisting body is called shear stress. For example, a rivet shears off at the common surface of the two plates. The resisting area, which is the cross sectional area of the rivet, is given by:

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

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

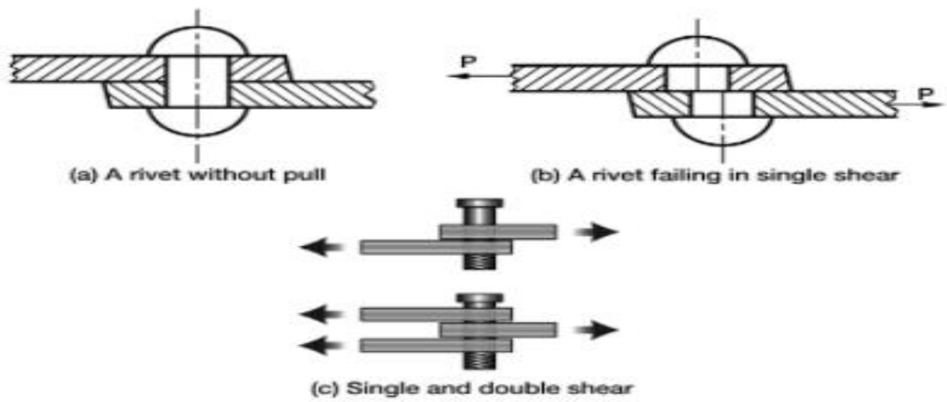


Figure 5.7 A rivet in shear

Safe shear stress τ is defined as, $\tau = \frac{\text{Shear strength}}{FOS} = \frac{S_s}{FOS}$

Pages 135 to 143 are not shown in this preview.

$$\frac{\sigma^2 LA}{2E} = W\left(h + \frac{\sigma L}{E}\right)$$

Writing this equation in the form of a quadratic equation:

$$\sigma^2 \frac{LA}{2E} - \sigma \frac{WL}{E} - Wh = 0$$

There will be two roots of this equation. Taking the positive sign for the maximum stress:

$$\sigma = \frac{W}{A} + \frac{W}{A}\sqrt{1 + \frac{2hEA}{WL}} \tag{5.29}$$

The terms can be rearranged for stress with shock and with initial velocity ($v = \sqrt{2gh}$) with a free fall from height h.

The first term $\left(\frac{W}{A}\right)$ is the stress, which exists if the load is applied gradually without any shock.

If h is equal to zero, that is, load is applied with shock but without any initial velocity, then the stress becomes:

$$\sigma = \frac{W}{A} + \frac{W}{A} = \frac{2W}{A} \tag{5.30}$$

That is, stress is doubled with shock.

Shock factor is defined as under:

$$K_{shock} = \frac{\text{Stress produced by impact}}{\text{Stress produced by same load applied gradually}}$$

Value of shock factor can be calculated by the following equation:

$$K_{shock} = 1 + \sqrt{1 + \frac{2h}{y}} \tag{5.31}$$

Where, h = Height of free fall of load to produce velocity for impact

y = Deformation under same static load

If height h and deformation y are not known, the values of the shock factor can be assumed suitably from Table 5.5.

Table 5.5 Shock Factor

Type of Shock Load	Impact Stress	K_{shock}
Static or gradually applied loads	1	1
Minor shocks	1–1.5	0.7–1
Heavy shocks	1.5–2	0.5–0.7

Example 5.16

Impact stress due to fall from height

A weight of 2 kN falls through a height of 100 mm which slides over a bar of 20 mm diameter and length 2 m. Assuming E as 200 GPa, find the stress and deflection of the bar and its elongation due to impact load.

Solution

Given $W = 2$ kN $\quad d = 20$ mm $\quad L = 2{,}000$ mm $\quad h = 100$ mm $\quad E = 200$ GPa

Area $A = 0.785\, d^2 = 0.785 \times 20^2 = 314\ \text{mm}^2$

$$\sigma = \frac{W}{A} + \frac{W}{A}\sqrt{1 + \frac{2hEA}{WL}}$$

Putting the values in this equation, $\dfrac{W}{A} = \dfrac{2{,}000}{314} = 6.37$

$$\sigma = 6.37 + 6.37\sqrt{1 + \frac{2 \times 100 \times 200{,}000 \times 314}{2{,}000 \times 2{,}000}} = 6.37 + (6.37 \times 56) = 363.4\ \text{MPa}$$

$$\delta = \frac{\sigma L}{E} = \frac{363 \times 2{,}000}{200{,}000} = 3.63\ \text{mm}$$

Example 5.17

Size with impact load

Find the rod diameter of length 1 m, if a load of 1 kN falls through a height of 100 mm, assuming safe tensile stress as 200 MPa and $E = 210$ GPa. Also calculate the elongation of the rod.

Solution

Given $W = 1$ kN $\quad L = 1{,}000$ mm $\quad h = 100$ mm $\quad E = 210$ GPa $\quad \sigma = 200$ MPa

From Equation (5.31): $\sigma = \dfrac{W}{A} + \dfrac{W}{A}\sqrt{1 + \dfrac{2hEA}{WL}}$

Putting the values: $200 = \dfrac{1{,}000}{A} + \dfrac{1{,}000}{A}\sqrt{1 + \dfrac{2 \times 100 \times 210{,}000 \times A}{1{,}000 \times 1{,}000}}$

Or, $0.2A = 1 + \sqrt{1 + 42A}$

(a) Normal stress is zero in the z-direction
(b) Normal stress is tensile in the z-direction
(c) Normal stress is compressive in the z-direction
(d) Normal stress varies in the z-direction

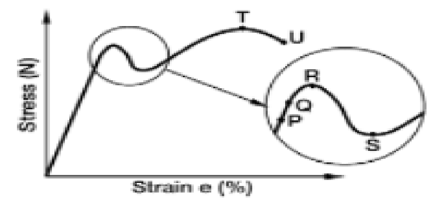
[Ans. (a)][GATE 2014]

14. A rectangular hole of size 100 mm × 50 mm is to be made on a 5 mm thick sheet of steel having ultimate tensile strength and shear strength of 500 MPa and 300 MPa, respectively. The hole is made by punching process. Neglecting the effect of clearance, the punching force(in kN) is:

(a) 300 (b) 450 (c) 600 (d) 750

[Ans. (b)][GATE 2014]

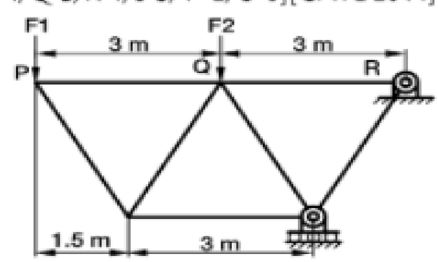
15. The stress-strain curve for mild steel is shown in the figure below. Choose the correct option referring to both, the figure and table.



Point on Graph	Description of the Point
P	1. Upper yield point
Q	2. Ultimate tensile strength
R	3. Proportionality limit
S	4. Elastic limit
T	5. Lower yield point
U	6. Failure

[Ans. P-4, Q-3, R-1, S-5, T- 2, U-6][GATE 2014]

16. For the truss shown in the figure, the force F1 and F2 are 9 kN and 3 kN, respectively. The force in kN in the member QS is__________.

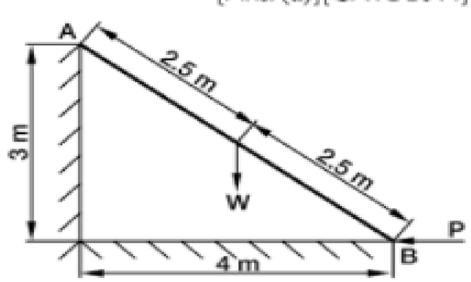


(a) 11.25 tension
(b) 11.25 compression
(c) 13.5 tension
(d) 13.5 compression

[Ans. (a)][GATE 2014]

17. A ladder AB of length 5 m and weight (W) 600 N is resting against a wall. Assuming frictionless contact at floor (B) and the wall (A), the magnitude of force P (in Newton) required to maintain equilibrium of the ladder is __________

[Ans. P = 400 N][GATE 2014]



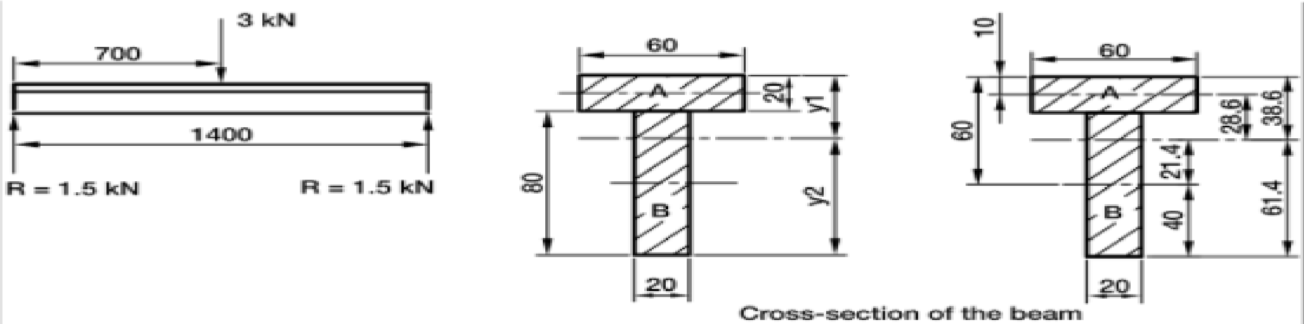


Figure 6.51 An asymmetrical beam

b. Moment of area of Section A about its own centroid axis A:

$$I_A = \frac{bh^3}{12} = \frac{60 \times 20^3}{12} = 4 \times 10^4 \text{ mm}^4$$

Moment of area of Section B about its own centroid axis B:

$$I_B = \frac{20 \times 80^3}{12} = 8.53 \times 10^5 \text{ mm}^4$$

Using Parallel Axis theorem for both the sections (Equation 6.5), $I_n = I_c + Ad^2$

Moment of area of Section A about centroid axis of T-section:

For Section A, distance $d = 38.6 - 10 = 28.6$

$$I_{nA} = (4 \times 10^4) + (1{,}200 \times 28.6^2) = 1.02 \times 10^6 \text{ mm}^4$$

Moment of area of Section B about centroid axis of T-section

For Section B, distance $d = y2 - 40 = 61.4 - 40 = 21.4$ mm

For Section B, distance $d = y2 - 40 = 61.4 - 40 = 21.4$ mm

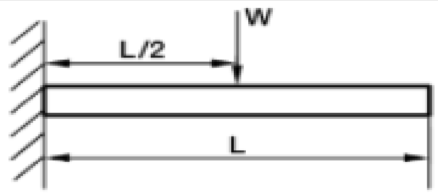
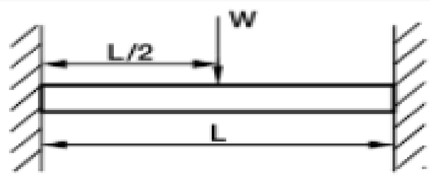
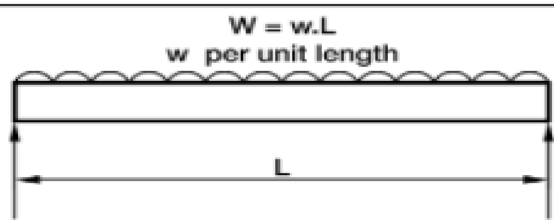
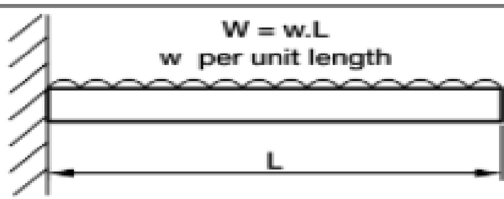
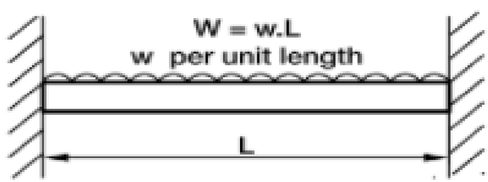
$$I_{nB} = (8.53 \times 10^5) + (1{,}600 \times 21.4^2) = 1.58 \times 10^6 \text{ mm}^4$$

Total moment of area of the T-section, $I_{xx} = I_n = 2.60 \times 10^6 \text{ mm}^4$

Using Equation (6.1) for bending moment $\sigma = \dfrac{M}{I} \times y$

For the stress at the top fibre, $\sigma = \dfrac{1.05 \times 10^6}{1.02 \times 10^6} \times 38.6 = 39.73 \text{MPa}$

c. For the stress at the bottom fibre, $\sigma = \dfrac{1.05 \times 10^6}{2.606 \times 10^6} \times 61.4 = 24.73 \text{MPa}$

Type of Load and Support	Maximum Bending Moment	Shear Force	Maximum Deflection
	$\frac{3WL}{16}$	$\frac{11W}{16}$	$\frac{7WL^3}{786EI}$
	$\frac{WL}{8}$	$\frac{W}{2}$	$\frac{WL^3}{192EI}$
	$\frac{WL}{8}$	$\frac{W}{2}$	$\frac{5WL^3}{384EI}$
	$\frac{WL}{2}$	W	$\frac{WL^3}{8EI}$
	$\frac{WL}{24}$	$\frac{W}{2}$	$\frac{WL^3}{384EI}$