SNS COLLEGE OF TECHNOLOGY

Coimbatore-35
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DEPARTMENT OF MECHATRONICS ENGINEERING

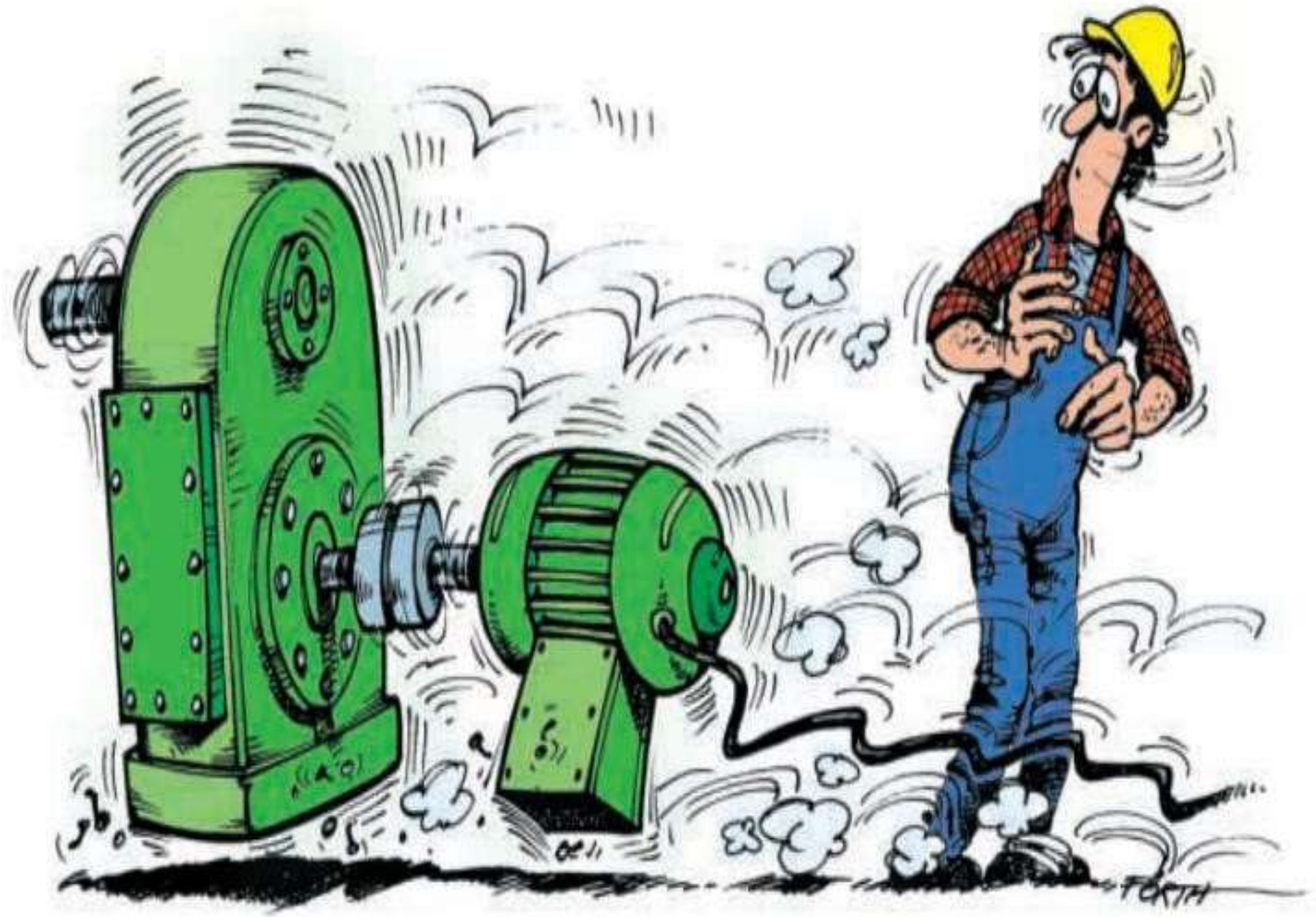
19MCT301– MACHINE DESIGN

III YEAR V SEM

UNIT 1 – INTRODUCTION TO THE DESIGN PROCESS

TOPIC 1 – FACTORS INFLUENCING MACHINE DESIGN

Why Machine Design ?



Design

The term design can be defined as the formulation of a plan for the satisfaction of human need

Design means to start something new or arrange existing things in a new order to satisfy a recognized need of society.

Classifications of Machine Design

The machine design may be classified as follows :

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

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

3. ***New design.*** This type of design needs lot of research, technical ability and creative thinking. Only those designers who have personal qualities of a sufficiently high order can take up the work of a new design.

The designs, depending upon the methods used, may be classified as follows :

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

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

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

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

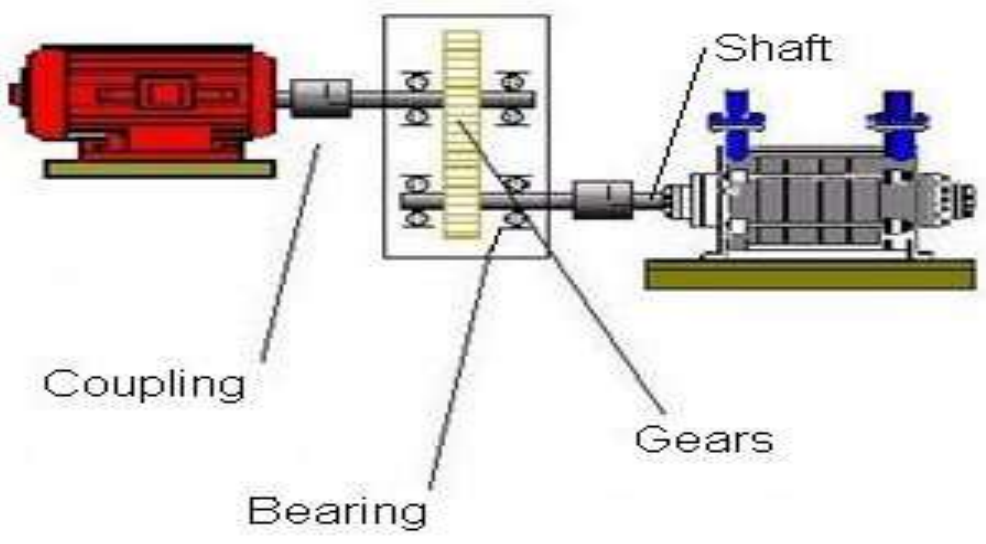
(*e*) ***System design.*** It is the design of any complex mechanical system like a motor car.

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

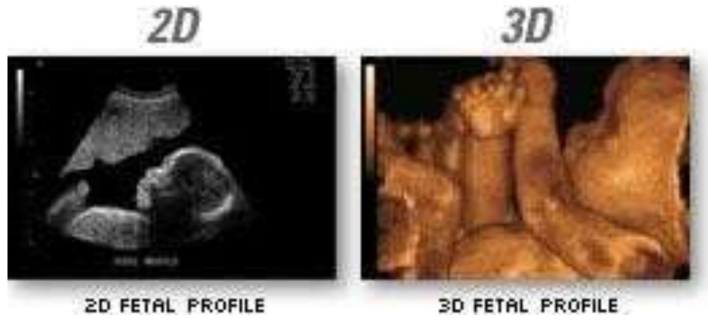
(*g*) ***Computer aided design.*** This type of design depends upon the use of computer systems to assist in the creation, modification, analysis and optimization of a design.

Design of Machine Elements

It can be defined as the selection of material and the values for independent geometrical (elements) parameters so that the element satisfies its functional requirements and undesirable effects and kept within the permissible limits



Adoptive Design



Assessment – 1

Any Other Example of Adoptive Design

Innovative Design

Flying Car

Variant Design (or Modification)

Involves varying the parameters (size, geometry, material properties, control parameters, etc.) of certain aspects of a product to develop a new and more robust design.

Bolts and Nuts

Factors Influencing Machine Design

Following are the general considerations in designing a machine component :

1. *Type of load and stresses caused by the load*
2. *Motion of the parts or kinematics of the machine*
3. *Selection of materials*
4. *Form and size of the parts*
5. *Frictional resistance and lubrication*
6. *Convenient and economical features*
7. *Use of standard parts.*
8. *Safety of operation*
9. *Workshop facilities.*
10. *Number of machines to be manufactured.*
11. *Cost of construction*
12. *Assembling*

Factors Influencing Machine Design

- Strength Vibrations
- Thermal considerations
- Lubrication
- Maintenance
- Flexibility
- Size and Shape
- Stiffness
- Noise
- Reliability
- Safety

Design Process

- Recognition of need
- Definition of Problem
- Synthesis
- Analysis and optimization
- Evaluation
- Presentation

General Procedure in Machine Design

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

1. *Recognition of need.* First of all, make a complete statement of the problem, indicating the need, aim or purpose for which the machine is to be designed.

2. *Synthesis (Mechanisms).* Select the possible mechanism or group of mechanisms which will give the desired motion.

3. *Analysis of forces.* Find the forces acting on each member of the machine and the energy transmitted by each member.

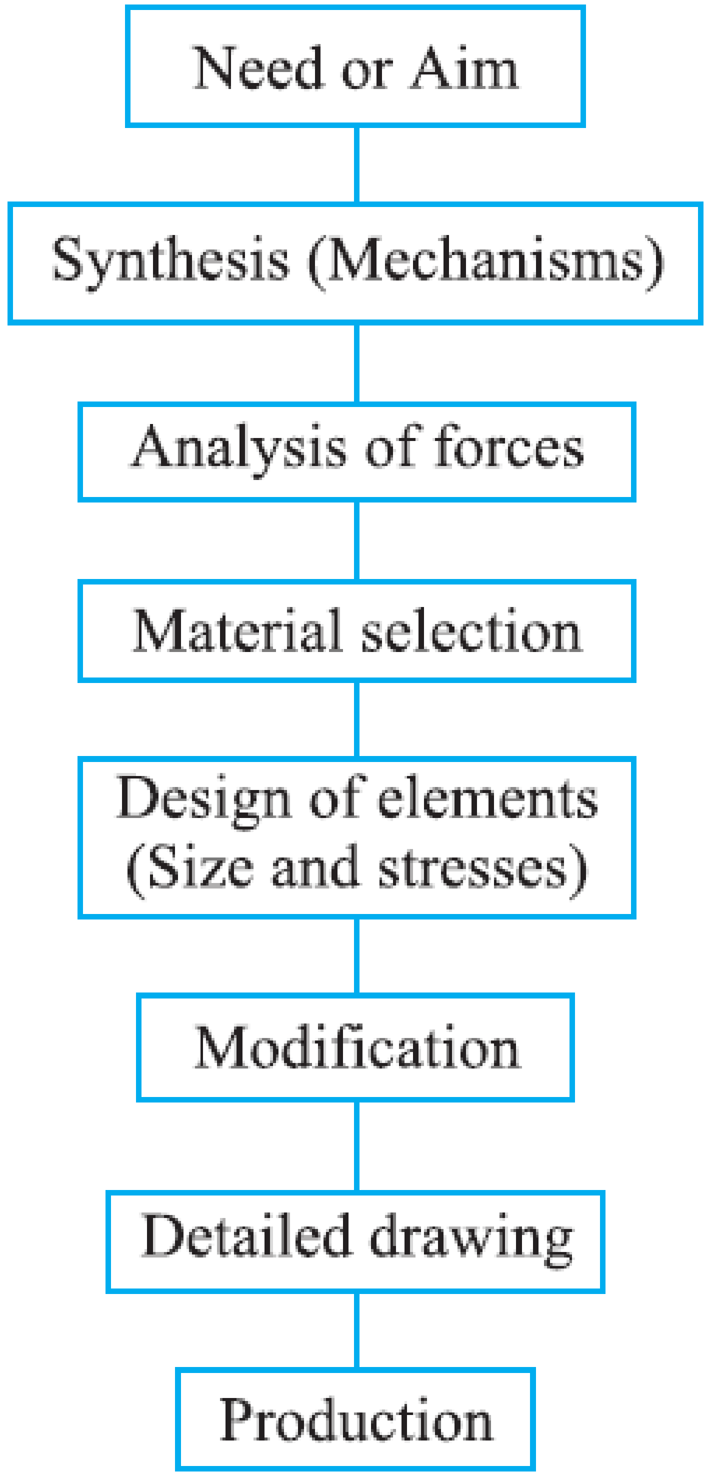
4. *Material selection.* Select the material best suited for each member of the machine.

5. *Design of elements (Size and Stresses).* Find the size of each member of the machine by considering the force acting on the member and the permissible stresses for the material used. It should be kept in mind that each member should not deflect or deform than the permissible limit.

6. *Modification.* Modify the size of the member to agree with the past experience and judgment to facilitate manufacture. The modification may also be necessary by consideration of manufacturing to reduce overall cost.

7. *Detailed drawing.* Draw the detailed drawing of each component and the assembly of the machine with complete specification for the manufacturing processes suggested.

8. *Production.* The component, as per the drawing, is manufactured in the workshop.



Selection of Materials for Engineering Purposes

The selection of a proper material, for engineering purposes, is one of the most difficult problem for the designer. The best material is one which serve the desired objective at the minimum cost. The following factors should be considered while selecting the material :

1. Availability of the materials,
2. Suitability of the materials for the working conditions in service, and
3. The cost of the materials.

Physical Properties of Metals

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

Mechanical Properties of Metals

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(a) Brinell hardness test,

(b) Rockwell hardness test,

(c) Vickers hardness (also called Diamond Pyramid) test, and

(d) Shore scleroscope.

According to Indian standard, IS : 1570 (Part II/Sec I)-1979 (Reaffirmed 1991), the carbon steels are designated in the following order :

(*a*) Figure indicating 100 times the average percentage of carbon content,
(*b*) Letter ‘C’, and
(*c*) Figure indicating 10 times the average percentage of manganese content. The figure after multiplying shall be rounded off to the nearest integer.

For example 20C8 means a carbon steel containing 0.15 to 0.25 per cent (0.2 per cent on an average) carbon and 0.60 to 0.90 per cent (0.75 per cent rounded off to 0.8 per cent on an average) manganese.

According to Indian standard, IS : 1762 (Part I)-1974 (Reaffirmed 1993), the high alloy steels (*i.e.* stainless steel and heat resisting steel) are designated in the following order:

1. Letter ‘X’.
2. Figure indicating 100 times the percentage of carbon content.
3. Chemical symbol for alloying elements each followed by a figure for its average percentage content rounded off to the nearest integer.
4. Chemical symbol to indicate specially added element to allow the desired properties.

For example, X 10 Cr 18 Ni 9 means alloy steel with average carbon 0.10 per cent, chromium 18 per cent and nickel 9 per cent.

According to Indian standard, IS : 1762 (Part I)-1974 (Reaffirmed 1993), the high speed tool steels are designated in the following order :

1. Letter ‘XT’.
2. Figure indicating 100 times the percentage of carbon content.
3. Chemical symbol for alloying elements each followed by the figure for its average percentage content rounded off to the nearest integer, and
4. Chemical symbol to indicate specially added element to attain the desired properties.

For example, XT 75 W 18 Cr 4 V 1 means a tool steel with average carbon content 0.75 per cent, tungsten 18 per cent, chromium 4 per cent and vanadium 1 per cent.

Illustration (i) 40 Cr 14

This means:

1. Average carbon content is $\left(\frac{40}{100}\right)$ = 0.4% it means, it can vary from say, 0.3% to 0.5%.
2. Chromium is the principal alloying element with $\left(\frac{14}{100}\right)$ = 0.14%. It means, it can vary from say 0.13% - 0.15%

Illustration (ii) An alloy steel of the following composition is to be designated

Carbon = 0.13 to 0.17%

Silicon = 0.1 to 0.4%

Chromium = 0.5 to 0.8%

Manganese = 0.4 to 0.5%

Here, carbon varies from 0.13 to 0.17. $\therefore$ Average % of $C = 0.15$.

Among the other alloying elements, chromium is largest in composition with average % being 0.65 $\left\{(ie.)\left(\frac{0.5+0.8}{2}\right)=0.65\right\}$. Since it is less than 1% it is shown by an underline.

$\therefore$ The designation will be 15 *Cr* <u>65</u>

Illustration (iii)

35 Mn 2 Mo <u>45</u>

Average % of carbon = 0.35

Manganese is the principal alloying element with average 2%. Average % of Molybdenum is 0.45%

Illustration (iv)

40 Ni 2 Cr 1 Mo 28

Meaning:

Average % of carbon = 0.4%

Average % of Nickel = 2%

Average % of Chromium = 1%

Average % of Molybdenum 28%

Important Terms used in Limit System

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

1. *Nominal size.* It is the size of a part specified in the drawing as a matter of convenience.

2. *Basic size.* It is the size of a part to which all limits of variation (*i.e.* tolerances) are applied to arrive at final dimensioning of the mating parts. The nominal or basic size of a part is often the same.

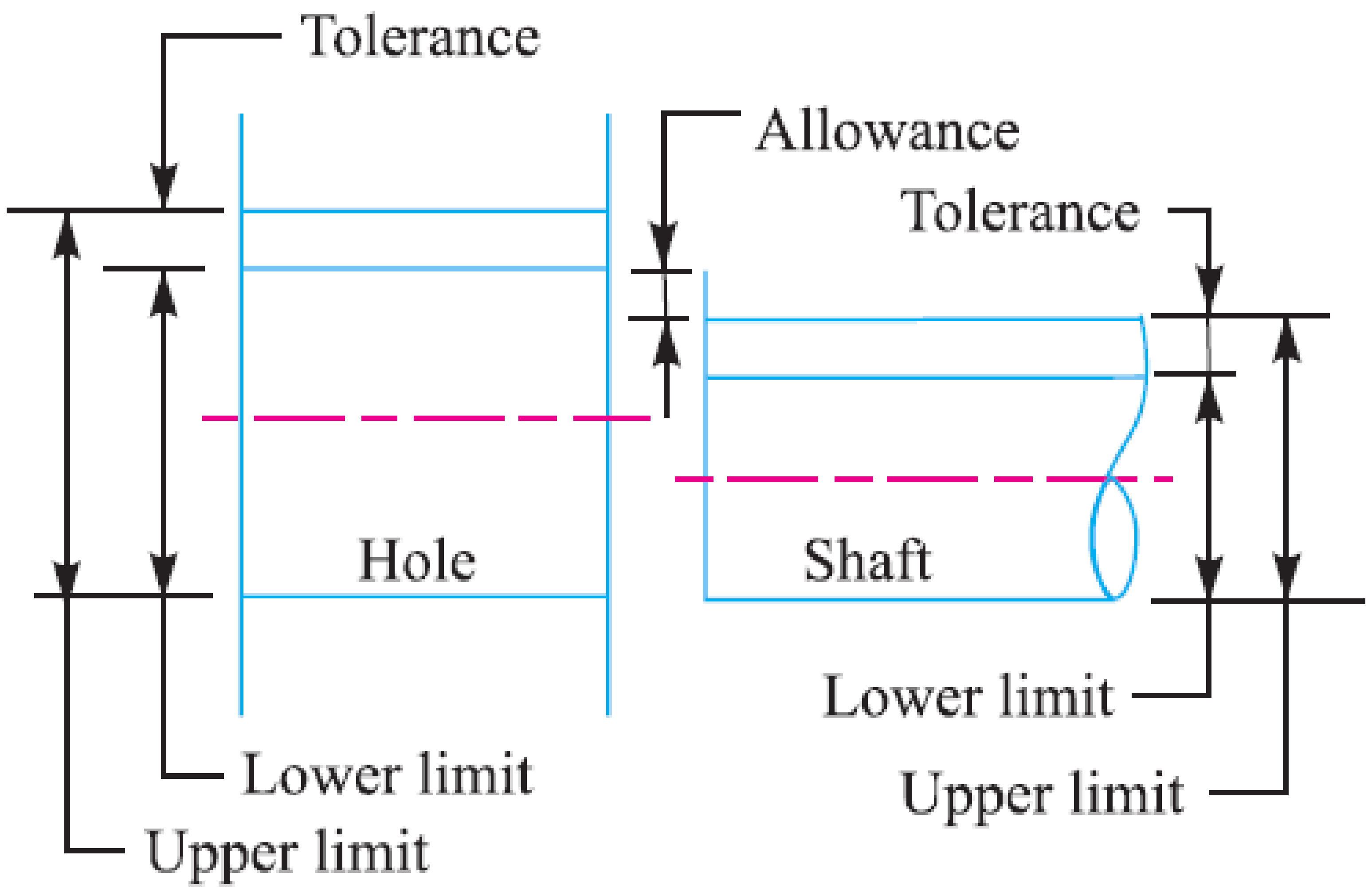
3. *Actual size.* It is the actual measured dimension of the part. The difference between the basic size and the actual size should not exceed a certain limit, otherwise it will interfere with the interchangeability of the mating parts.

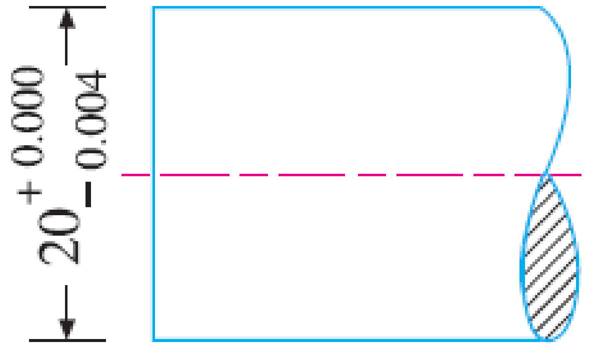
4. *Limits of sizes.* There are two extreme permissible sizes for a dimension of the part as shown in Fig.. The largest permissible size for a dimension of the part is called ***upper*** or ***high*** or ***maximum limit,*** whereas the smallest size of the part is known as ***lower*** or ***minimum limit.***

5. *Allowance.* It is the difference between the basic dimensions of the mating parts. The allowance may be ***positive*** or ***negative***. When the shaft size is less than the hole size, then the allowance is ***positive*** and when the shaft size is greater than the hole size, then the allowance is ***negative.***

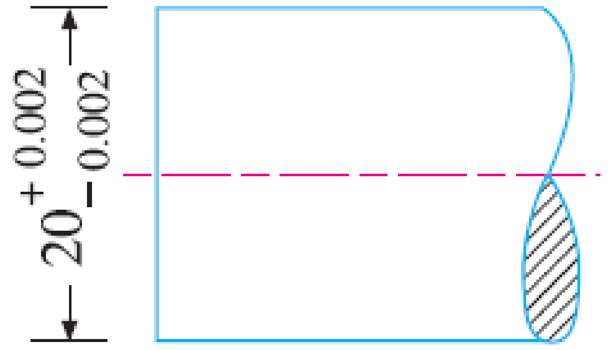
6. *Tolerance.* It is the difference between the upper limit and lower limit of a dimension. In other words, it is the maximum permissible variation in a dimension. The tolerance may be ***unilateral*** or ***bilateral.*** When all the tolerance is allowed on one side of the nominal size, then it is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

When the tolerance is allowed on both sides of the nominal size, then it is said to be ***bilateral system of tolerance.*** In this case + 0.002 is the upper limit and – 0.002 is the lower limit. The method of assigning unilateral and bilateral tolerance is shown in Fig.



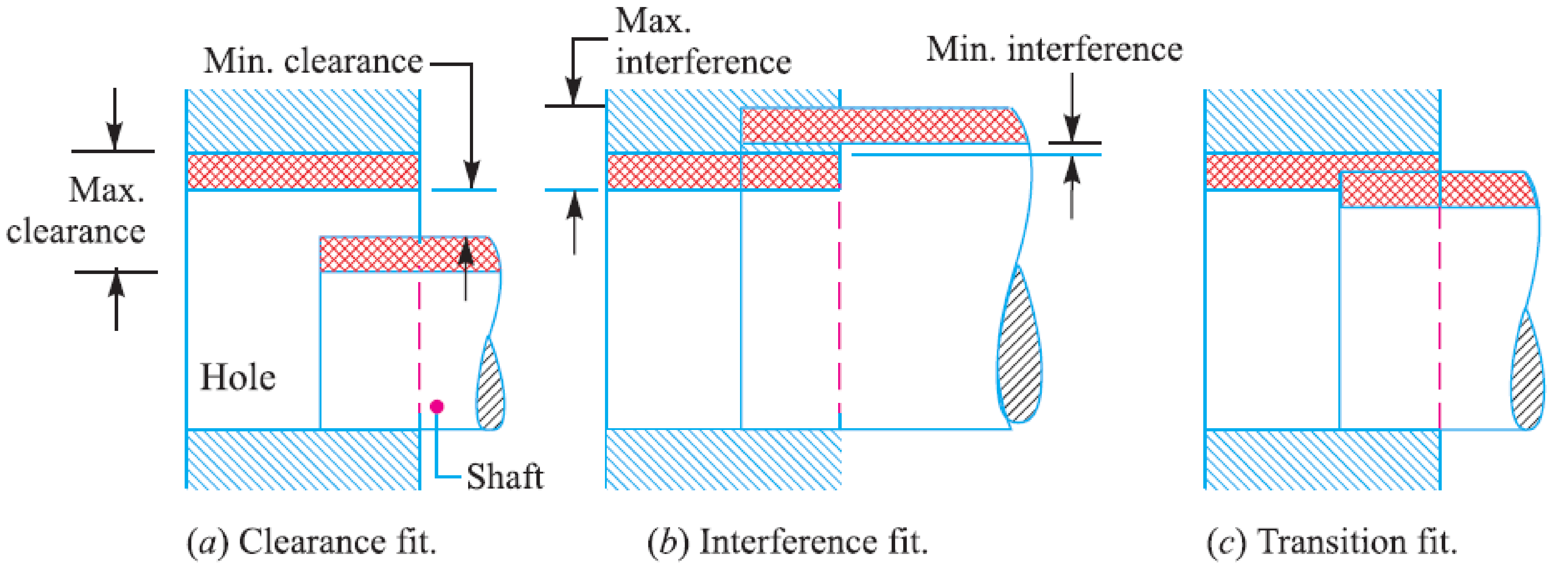


(*a*) Unilateral tolerance.



(*b*) Bilateral tolerance.

Types of Fits



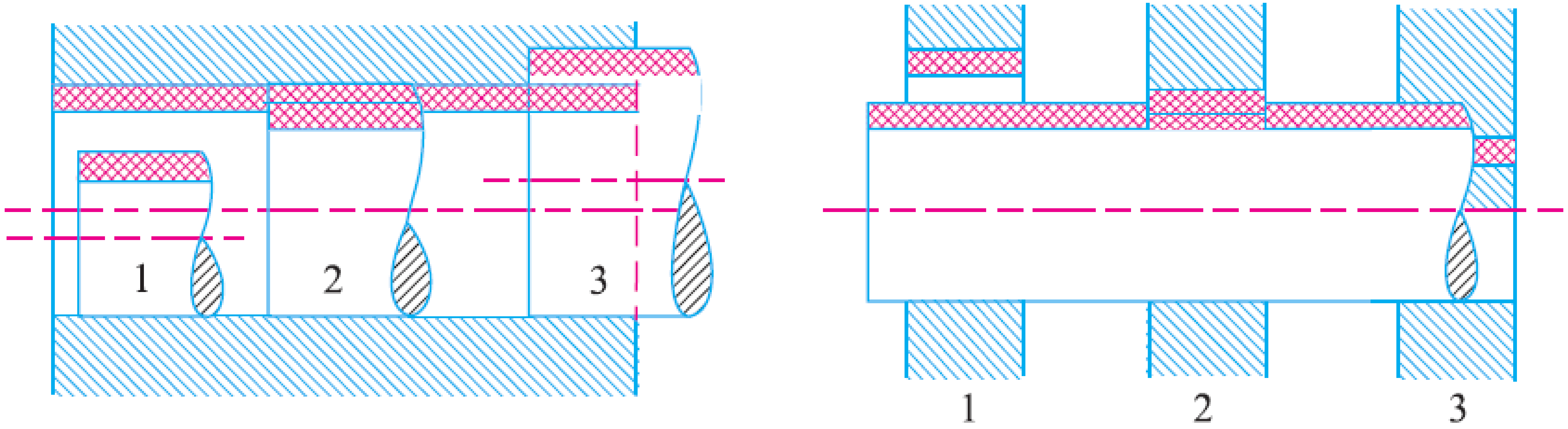
- The clearance fits may be slide fit, easy sliding fit, running fit, slack running fit and loose running fit
- The interference fits may be shrink fit, heavy drive fit and light drive fit
- The transition fits may be force fit, tight fit and push fit

Basis of Limit System

The following are two bases of limit system:

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

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



1. Clearance fit. 2. Transition fit. 3. Interference fit.

(*a*) Hole basis system. (*b*) Shaft basis system.

Example: *Calculate the tolerances, fundamental deviations and limits of sizes for the shaft designated as 40 H8 / f7.*

Solution. Given: Shaft designation = 40 *H*8 / *f* 7

The shaft designation 40 *H*8 / *f* 7 means that the basic size is 40 mm and the tolerance grade for the hole is 8 (*i.e.* *I T* 8) and for the shaft is 7 (*i.e.* *I T* 7).

Tolerances

Since 40 mm lies in the diameter steps of 30 to 50 mm, therefore the geometric mean diameter,

$$D = \sqrt{30 \times 50} = 38.73 \text{ mm}$$

We know that standard tolerance unit,

$$i = 0.45\sqrt[3]{D} + 0.001\,D$$

$$= 0.45\sqrt[3]{38.73} + 0.001 \times 38.73$$

$$= 0.45 \times 3.38 + 0.03873 = 1.559\,73 \quad \text{or} \quad 1.56 \text{ microns}$$

$$= 1.56 \times 0.001 = 0.001\,56 \text{ mm} \qquad \ldots(\because 1 \text{ micron} = 0.001 \text{ mm})$$

we find that standard tolerance for the hole of grade 8 ($IT8$)
= 25 i = 25 × 0.001 56 = 0.039 mm **Ans.**
and standard tolerance for the shaft of grade 7 ($IT7$)
= 16 i = 16 × 0.001 56 = 0.025 mm **Ans.**

Limits of sizes

We know that lower limit for hole
= Basic size = 40 mm **Ans.**

Upper limit for hole = Lower limit for hole + Tolerance for hole
= 40 + 0.039 = 40.039 mm **Ans.**

Upper limit for shaft = Lower limit for hole or Basic size – Fundamental deviation (upper deviation)
= 40 – 0.025 = 39.975 mm **Ans.**

and lower limit for shaft = Upper limit for shaft – Tolerance for shaft
= 39.975 – 0.025 = 39.95 mm **Ans.**

Preferred Numbers

When a machine is to be made in several sizes with different powers or capacities, it is necessary to decide what capacities will cover a certain range efficiently with minimum number of sizes. It has been shown by experience that a certain range can be covered efficiently when it follows a geometrical progression with a constant ratio. The preferred numbers are the conventionally rounded off values derived from geometric series including the integral powers of 10 and having as common ratio of the following factors:

$$\sqrt[5]{10},\ \sqrt[10]{10},\ \sqrt[20]{10} \text{ and } \sqrt[40]{10}$$

These ratios are approximately equal to 1.58, 1.26, 1.12 and 1.06. The series of preferred numbers are designated as *R5, R10, R20 and R40 respectively. These four series are called ***basic series*****.** The other series called ***derived series*** may be obtained by simply multiplying or dividing the basic sizes by 10, 100, etc. The preferred numbers in the series R5 are 1, 1.6, 2.5, 4.0 and 6.3