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CHAPTER

3

Manufacturing Considerations in Machine Design

3.1 Introduction

In the previous chapter, we have only discussed about the composition, properties and uses of various materials used in Mechanical Engineering. We shall now discuss in this chapter a few of the manufacturing processes, limits and fits, etc.

3.2 Manufacturing Processes

The knowledge of manufacturing processes is of great importance for a design engineer. The following are the various manufacturing processes used in Mechanical Engineering.

1. ***Primary shaping processes.*** The processes used for the preliminary shaping of the machine component are known as primary shaping processes. The common operations used for this process are casting, forging, extruding, rolling, drawing, bending, shearing, spinning, powder metal forming, squeezing, etc.

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2. *Machining processes.* The processes used for giving final shape to the machine component, according to planned dimensions are known as machining processes. The common operations used for this process are turning, planning, shaping, drilling, boring, reaming, sawing, broaching, milling, grinding, hobbing, etc.

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

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

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

To discuss in detail all these processes is beyond the scope of this book, but a few of them which are important from the subject point of view will be discussed in the following pages.

3.3 Casting

It is one of the most important manufacturing process used in Mechanical Engineering. The castings are obtained by remelting of ingots* in a cupola or some other foundry furnace and then pouring this molten metal into metal or sand moulds. The various important casting processes are as follows:

1. *Sand mould casting.* The casting produced by pouring molten metal in sand mould is called sand mould casting. It is particularly used for parts of larger sizes.

2. *Permanent mould casting.* The casting produced by pouring molten metal in a metallic mould is called permanent mould casting. It is used for casting aluminium pistons, electric iron parts, cooking utensils, gears, etc. The permanent mould castings have the following advantages:

1. Shaping the Sand : A wooden pattern cut to the shape of one half of the casting is positioned in an iron box and surrounded by tightly packed moist sand.

2. Ready for the Metal : After the wooden patterns have been removed, the two halves of the mould are clamped together. Molten iron is poured into opening called the runner.

* Most of the metals used in industry are obtained from ores. These ores are subjected to suitable reducing or refining process which gives the metal in a molten form. This molten metal is poured into moulds to give commercial castings, called **ingots.**

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(*a*) It has more favourable fine grained structure.

(*b*) The dimensions may be obtained with close tolerances.

(*c*) The holes up to 6.35 mm diameter may be easily cast with metal cores.

3. ***Slush casting.*** It is a special application of permanent metal mould casting. This method is used for production of hollow castings without the use of cores.

4. ***Die casting.*** The casting produced by forcing molten metal under pressure into a permanent metal mould (known as die) is called die casting. A die is usually made in two halves and when closed it forms a cavity similar to the casting desired. One half of the die that remains stationary is known as ***cover die*** and the other movable half is called ***ejector die.*** The die casting method is mostly used for castings of non-ferrous metals of comparatively low fusion temperature. This process is cheaper and quicker than permanent or sand mould casting. Most of the automobile parts like fuel pump, carburettor bodies, horn, heaters, wipers, brackets, steering wheels, hubs and crank cases are made with this process. Following are the advantages and disadvantages of die casting :

Aluminium die casting component

Advantages

(*a*) The production rate is high, ranging up to 700 castings per hour.

(*b*) It gives better surface smoothness.

(*c*) The dimensions may be obtained within tolerances.

(*d*) The die retains its trueness and life for longer periods. For example, the life of a die for zinc base castings is upto one million castings, for copper base alloys upto 75 000 castings and for aluminium base alloys upto 500 000 castings.

Sand Casting

Investment Casting

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(*e*) It requires less floor area for equivalent production by other casting methods.
(*f*) By die casting, thin and complex shapes can be easily produced.
(*g*) The holes up to 0.8 mm can be cast.

Disadvantages

(*a*) The die casting units are costly.
(*b*) Only non-ferrous alloys are casted more economically.
(*c*) It requires special skill for maintenance and operation of a die casting machine.

5. ***Centrifugal casting.*** The casting produced by a process in which molten metal is poured and allowed to solidify while the mould is kept revolving, is known as centrifugal casting. The metal thus poured is subjected to centrifugal force due to which it flows in the mould cavities. This results in the production of high density castings with promoted directional solidification. The examples of centrifugal castings are pipes, cylinder liners and sleeves, rolls, bushes, bearings, gears, flywheels, gun barrels, piston rings, brake drums, etc.

3.4 Casting Design

An engineer must know how to design the castings so that they can effectively and efficiently render the desired service and can be produced easily and economically. In order to design a casting, the following factors must be taken into consideration :

1. The function to be performed by the casting,
2. Soundness of the casting,
3. Strength of the casting,
4. Ease in its production,
5. Consideration for safety, and
6. Economy in production.

In order to meet these requirements, a design engineer should have a thorough knowledge of production methods including pattern making, moulding, core making, melting and pouring, etc. The best designs will be achieved only when one is able to make a proper selection out of the various available methods. However, a few rules for designing castings are given below to serve as a guide:

1. The sharp corners and frequent use of fillets should be avoided in order to avoid concentration of stresses.
2. All sections in a casting should be designed of uniform thickness, as far as possible. If, however, variation is unavoidable, it should be done gradually.
3. An abrupt change of an extremely thick section into a very thin section should always be avoided.
4. The casting should be designed as simple as possible, but with a good appearance.
5. Large flat surfaces on the casting should be avoided because it is difficult to obtain true surfaces on large castings.
6. In designing a casting, the various allowances must be provided in making a pattern.
7. The ability to withstand contraction stresses of some members of the casting may be improved by providing the curved shapes *e.g.*, the arms of pulleys and wheels.
8. The stiffening members such as webs and ribs used on a casting should be minimum possible in number, as they may give rise to various defects like hot tears and shrinkage, etc.
9. The casting should be designed in such a way that it will require a simpler pattern and its moulding is easier.
10. In order to design cores for casting, due consideration should be given to provide them adequate support in the mould.

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11. The deep and narrow pockets in the casting should invariably be avoided to reduce cleaning costs.

12. The use of metal inserts in the casting should be kept minimum.

13. The markings such as names or numbers, etc., should never be provided on vertical surfaces because they provide a hindrance in the withdrawl of pattern.

14. A tolerance of ± 1.6 mm on small castings (below 300 mm) should be provided. In case more dimensional accuracy is desired, a tolerance of ± 0.8 mm may be provided.

3.5 Forging

It is the process of heating a metal to a desired temperature in order to acquire sufficient plasticity, followed by operations like hammering, bending and pressing, etc. to give it a desired shape. The various forging processes are :

1. Smith forging or hand forging
2. Power forging,
3. Machine forging or upset forging, and
4. Drop forging or stamping

The **smith** or **hand forging** is done by means of hand tools and it is usually employed for small jobs. When the forging is done by means of power hammers, it is then known as ***power forging***. It is used for medium size and large articles requiring very heavy blows. The **machine forging** is done by means of forging machines. The **drop forging** is carried out with the help of drop hammers and is particularly suitable for mass production of identical parts. The forging process has the following advantages :

1. It refines the structure of the metal.
2. It renders the metal stronger by setting the direction of grains.
3. It effects considerable saving in time, labour and material as compared to the production of a similar item by cutting from a solid stock and then shaping it.
4. The reasonable degree of accuracy may be obtained by forging.
5. The forgings may be welded.

It may be noted that wrought iron and various types of steels and steel alloys are the common raw material for forging work. Low carbon steels respond better to forging work than the high carbon steels. The common non-ferrous metals and alloys used in forging work are brass, bronze, copper, aluminium and magnesium alloys. The following table shows the temperature ranges for forging some common metals.

Table 3.1. Temperature ranges for forging.

Material	*Forging temperature (°C)*	*Material*	*Forging temperature (°C)*
Wrought iron	900 – 1300	Stainless steel	940 – 1180
Mild steel	750 – 1300	Aluminium and magnesium alloys	350 – 500
Medium carbon steel	750 – 1250		
High carbon and alloy steel	800 – 1150	Copper, brass and bronze	600 – 950

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3.6 Forging Design

In designing a forging, the following points should always be considered.

1. The forged components should ultimately be able to achieve a radial flow of grains or fibres.
2. The forgings which are likely to carry flash, such as drop and press forgings, should preferably have the parting line in such a way that the same will divide them in two equal halves.
3. The parting line of a forging should lie, as far as possible, in one plane.
4. Sufficient draft on surfaces should be provided to facilitate easy removal of forgings from dies.
5. The sharp corners should always be avoided in order to prevent concentration of stress and to facilitate ease in forging.
6. The pockets and recesses in forgings should be minimum in order to avoid increased die wear.
7. The ribs should not be high and thin.
8. Too thin sections should be avoided to facilitate easy flow of metal.

3.7 Mechanical Working of Metals

The mechanical working of metals is defined as an intentional deformation of metals plastically under the action of externally applied forces.

The mechanical working of metal is described as hot working and cold working depending upon whether the metal is worked above or below the recrystallisation temperature. The metal is subjected to mechanical working for the following purposes :

1. To reduce the original block or ingot into desired shapes,
2. To refine grain size, and
3. To control the direction of flow lines.

3.8 Hot Working

The working of metals above the *recrystallisation temperature is called ***hot working***. This temperature should not be too high to reach the solidus temperature, otherwise the metal will burn and become unsuitable for use. The hot working of metals has the following advantages and disadvantages :

Advantages

1. The porosity of the metal is largely eliminated.
2. The grain structure of the metal is refined.
3. The impurities like slag are squeezed into fibres and distributed throughout the metal.
4. The mechanical properties such as toughness, ductility, percentage elongation, percentage reduction in area, and resistance to shock and vibration are improved due to the refinement of grains.

Disadvantages

1. It requires expensive tools.
2. It produces poor surface finish, due to the rapid oxidation and scale formation on the metal surface.
3. Due to the poor surface finish, close tolerance cannot be maintained.

* The temperature at which the new grains are formed in the metal is known as **recrystallisation temperature.**

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3.9 Hot Working Processes

The various *hot working processes are described as below :

1. *Hot rolling.* The hot rolling process is the most rapid method of converting large sections into desired shapes. It consists of passing the hot ingot through two rolls rotating in opposite directions at the same speed. The space between the rolls is adjusted to conform to the desired thickness of the rolled section. The rolls, thus, squeeze the passing ingot to reduce its cross-section and increase its length. The forming of bars, plates, sheets, rails, angles, I-beam and other structural sections are made by hot rolling.

Hot Rolling : When steel is heated until it glows bright red, it becomes soft enough to form into elabrate shapes.

2. *Hot forging.* It consists of heating the metal to plastic state and then the pressure is applied to form it into desired shapes and sizes. The pressure applied in this is not continuous as for hot rolling, but intermittent. The pressure may be applied by hand hammers, power hammers or by forging machines.

3. *Hot spinning.* It consists of heating the metal to forging temperature and then forming it into the desired shape on a spinning lathe. The parts of circular cross-section which are symmetrical about the axis of rotation, are made by this process.

4. *Hot extrusion.* It consists of pressing a metal inside a chamber to force it out by high pressure through an orifice which is shaped to provide the desired form of the finished part. Most commercial metals and their alloys such as steel, copper, aluminium and nickel are directly extruded at elevated temperatures. The rods, tubes, structural shapes, flooring strips and lead covered cables, etc., are the typical products of extrusion.

5. *Hot drawing or cupping.* It is mostly used for the production of thick walled seamless tubes and cylinders. It is usually performed in two stages. The first stage consists of drawing a cup out of a hot circular plate with the help of a die and punch. The second stage consists of reheating the drawn cup and drawing it further to the desired length having the required wall thickness. The second drawing operation is performed through a number of dies, which are arranged in a descending order of their diameters, so that the reduction of wall thickness is gradual in various stages.

Cold Rolled Steel : Many modern products are made from easily shaped sheet metal.

6. *Hot piercing.* This process is used for the manufacture of seamless tubes. In its operation, the heated cylindrical billets of steel are passed between two conical shaped rolls operating in the same direction. A mandrel is provided between these rolls which assist in piercing and controls the size of the hole, as the billet is forced over it.

* For complete details, please refer to Authors' popular book **'A Text Book of Workshop Technology'.**

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3.10 Cold Working

The working of metals below their recrystallisation temperature is known as ***cold working.*** Most of the cold working processes are performed at room temperature. The cold working distorts the grain structure and does not provide an appreciable reduction in size. It requires much higher pressures than hot working. The extent to which a metal can be cold worked depends upon its ductility. The higher the ductility of the metal, the more it can be cold worked. During cold working, severe stresses known as residual stresses are set up. Since the presence of these stresses is undesirable, therefore, a suitable heat treatment may be employed to neutralise the effect of these stresses. The cold working is usually used as finishing operation, following the shaping of the metal by hot working. It also increases tensile strength, yield strength and hardness of steel but lowers its ductility. The increase in hardness due to cold working is called ***work-hardening.***

In general, cold working produces the following effects :

1. The stresses are set up in the metal which remain in the metal, unless they are removed by subsequent heat treatment.
2. A distortion of the grain structure is created.
3. The strength and hardness of the metal are increased with a corresponding loss in ductility.
4. The recrystalline temperature for steel is increased.
5. The surface finish is improved.
6. The close dimensional tolerance can be maintained.

3.11 Cold Working Processes

The various cold working processes are discussed below:

1. ***Cold rolling.*** It is generally employed for bars of all shapes, rods, sheets and strips, in order to provide a smooth and bright surface finish. It is also used to finish the hot rolled components to close tolerances and improve their toughness and hardness. The hot rolled articles are first immersed in an acid to remove the scale and washed in water, and then dried. This process of cleaning the articles is known as ***pickling.*** These cleaned articles are then passed through rolling mills. The rolling mills are similar to that used in hot rolling.

Gallium arsenide (GaAs) *is now being manufactured as an alternative to silicon for microchips. This combination of elements is a semiconductor like silicon, but is electronically faster and therefore better for microprocessors.*

Note : This picture is given as additional information and is not a direct example of the current chapter.

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2. ***Cold forging.*** The cold forging is also called ***swaging***. During this method of cold working, the metal is allowed to flow in some pre-determined shape according to the design of dies, by a compressive force or impact. It is widely used in forming ductile metals. Following are the three, commonly used cold forging processes :

(*a*) ***Sizing.*** It is the simplest form of cold forging. It is the operation of slightly compressing a forging, casting or steel assembly to obtain close tolerance and a flat surface. The metal is confined only in a vertical direction.

(*b*) ***Cold heading.*** This process is extensively used for making bolts, rivets and other similar headed parts. This is usually done on a cold header machine. Since the cold header is made from unheated material, therefore, the equipment must be able to withstand the high pressures that develop. The rod is fed to the machine where it is cut off and moved into the header die. The operation may be either single or double and upon completion, the part is ejected from the dies.

After making the bolt head, the threads are produced on a thread rolling machine. This is also a cold working process. The process consists of pressing the blank between two rotating rolls which have the thread form cut in their surface.

(*c*) ***Rotary swaging.*** This method is used for reducing the diameter of round bars and tubes by rotating dies which open and close rapidly on the work. The end of rod is tapered or reduced in size by a combination of pressure and impact.

3. ***Cold spinning.*** The process of cold spinning is similar to hot spinning except that the metal is worked at room temperature. The process of cold spinning is best suited for aluminium and other soft metals. The commonly used spun articles out of aluminum and its alloys are processing kettles, cooking utensils, liquid containers, and light reflectors, etc.

4. ***Cold extrusion.*** The principle of cold extrusion is exactly similar to hot extrusion. The most common cold extrusion process is ***impact extrusion***. The operation of cold extrusion is performed with the help of a punch and die. The work material is placed in position into a die and struck from top

Making microchips *demands extreme control over chemical components. The layers of conducting and insulating materials that are laid down on the surface of a silicon chip may be only a few atoms thick yet must perform to the highest specifications. Great care has to be taken in their manufacture (right), and each chip is checked by test probes to ensure it performs correctly.*

Note : This picture is given as additional information and is not a direct example of the current chapter.

by a punch operating at high pressure and speed. The metal flows up along the surface of the punch forming a cup-shaped component. When the punch moves up, compressed air is used to separate the component from the punch. The thickness of the side wall is determined by the amount of clearance between the punch and die. The process of impact extrusion is limited to soft and ductile materials such as lead, tin, aluminium, zinc and some of their alloys. The various items of daily use such as tubes for shaving creams and tooth pastes and such other thin walled products are made by impact extrusion.

5. ***Cold drawing.*** It is generally employed for bars, rods, wires, etc. The important cold drawing processes are as follows:

(*a*) ***Bar or rod drawing.*** In bar drawing, the hot drawn bars or rods from the mills are first pickled, washed and coated to prevent oxidation. A draw bench, is employed for cold drawing. One end of the bar is reduced in diameter by the swaging operation to permit it to enter a drawing die. This end of bar is inserted through the die and gripped by the jaws of the carriage fastened to the chain of the draw bench. The length of bars which can be drawn is limited by the maximum travel of the carriage, which may be from 15 metres to 30 metres. A high surface finish and dimensional accuracy is obtained by cold drawing. The products may be used directly without requiring any machining.

(*b*) ***Wire drawing.*** In wire drawing, the rolled bars from the mills are first pickled, washed and coated to prevent oxidation. They are then passed through several dies of decreasing diameter to provide the desired reduction in size. The dies are usually made of carbide materials.

(*c*) ***Tube drawing***. The tube drawing is similar to bar drawing and in most cases it is accomplished with the use of a draw bench.

6. ***Cold bending.*** The bars, wires, tubes, structural shapes and sheet metal may be bent to many shapes in cold condition through dies. A little consideration will show that when the metal is bend beyond the elastic limit, the inside of the bend will be under compression while the outside will be under tension. The stretching of the metal on the outside makes the stock thinner. Usually, a flat strip of metal is bend by ***roll forming.*** The materials commonly used for roll forming are carbon steel, stainless steel, bronze, copper, brass, zinc and aluminium. Some of its products are metal windows, screen frame parts, bicycle wheel rims, trolley rails, etc. Most of the tubing is now-a-days are roll formed in cold conditions and then welded by resistance welding.

7. ***Cold peening.*** This process is used to improve the fatigue resistance of the metal by setting up compressive stresses in its surface. This is done by blasting or hurling a rain of small shot at high velocity against the surface to be peened. The shot peening is done by air blast or by some mechanical means. As the shot strikes, small indentations are produced, causing a slight plastic flow of the surface metal to a depth of a few hundreds of a centimetre. This stretching of the outer fibres is resisted by those underneath, which tend to return them to their original length, thus producing an outer layer having a compressive stress while those below are in tension. In addition, the surface is slightly hardened and strengthened by the cold working operation.

3.12 Interchangeability

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

It may be noted that when an assembly is made of two parts, the part which enters into the other, is known as ***enveloped surface*** (or **shaft** for cylindrical part) and the other in which one enters is called ***enveloping surface*** (or **hole** for cylindrical part).

Notes: 1. The term ***shaft*** refers not only to the diameter of a circular shaft, but it is also used to designate any external dimension of a part.

2. The term ***hole*** refers not only to the diameter of a circular hole, but it is also used to designate any internal dimension of a part.

3.13 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.

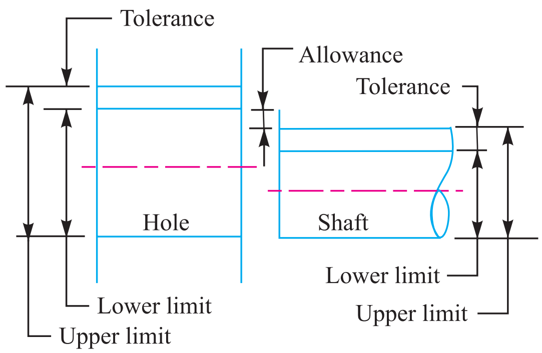


Fig. 3.1. Limits of sizes.

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. 3.1. 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, *e.g.* $20^{+0.000}_{-0.004}$, 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.

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

Fig. 3.2. Method of assigning tolerances.

When the tolerance is allowed on both sides of the nominal size, *e.g.* $20^{+0.002}_{-0.002}$, 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. 3.2 (*a*) and (*b*) respectively.

7. ***Tolerance zone.*** It is the zone between the maximum and minimum limit size, as shown in Fig. 3.3.

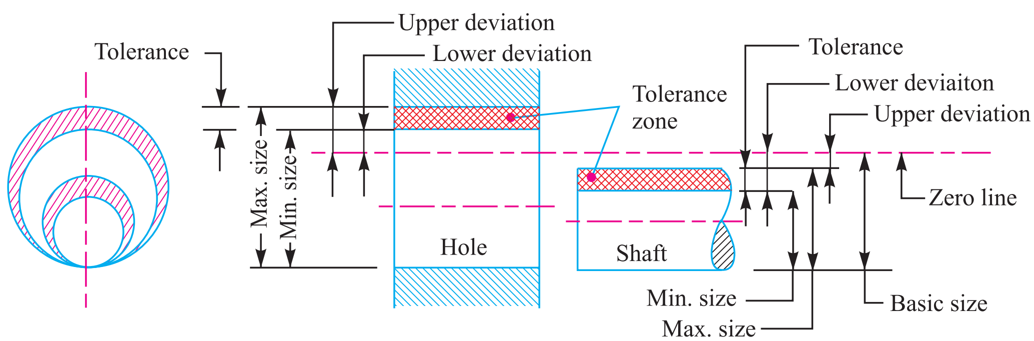


Fig. 3.3. Tolerance zone.

8. ***Zero line.*** It is a straight line corresponding to the basic size. The deviations are measured from this line. The positive and negative deviations are shown above and below the zero line respectively.

9. ***Upper deviation.*** It is the algebraic difference between the maximum size and the basic size. The upper deviation of a hole is represented by a symbol *ES* (Ecart Superior) and of a shaft, it is represented by *es*.

10. ***Lower deviation.*** It is the algebraic difference between the minimum size and the basic size. The lower deviation of a hole is represented by a symbol *EI* (Ecart Inferior) and of a shaft, it is represented by *ei*.

11. ***Actual deviation.*** It is the algebraic difference between an actual size and the corresponding basic size.

12. ***Mean deviation.*** It is the arithmetical mean between the upper and lower deviations.

13. ***Fundamental deviation.*** It is one of the two deviations which is conventionally chosen to define the position of the tolerance zone in relation to zero line, as shown in Fig. 3.4.

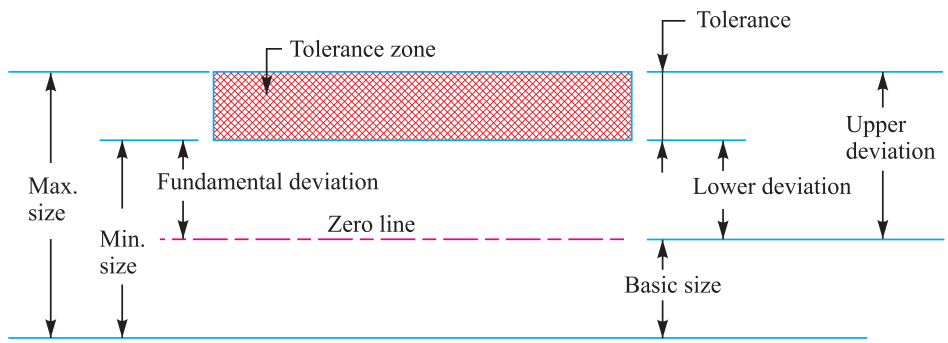


Fig. 3.4. Fundamental deviation.

3.14 Fits

The degree of tightness or looseness between the two mating parts is known as a *fit* of the parts. The nature of fit is characterised by the presence and size of clearance and interference.

The ***clearance*** is the amount by which the actual size of the shaft is less than the actual size of the mating hole in an assembly as shown in Fig. 3.5 (*a*). In other words, the clearance is the difference between the sizes of the hole and the shaft before assembly. The difference must be ***positive.***

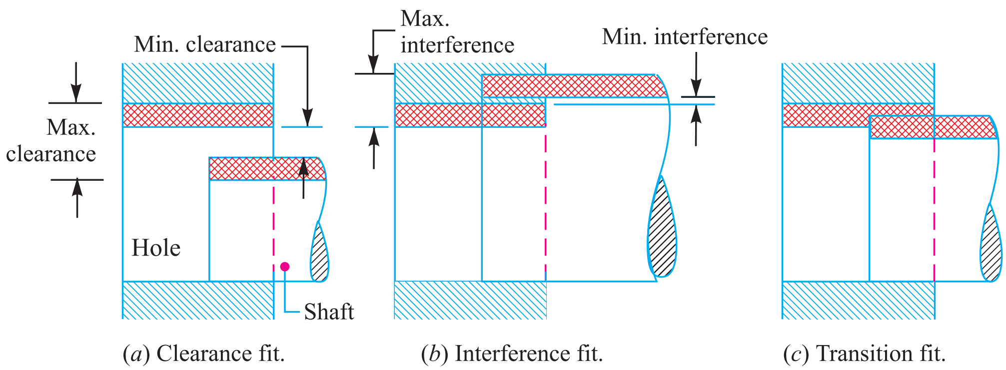


Fig. 3.5. Types of fits.

The ***interference*** is the amount by which the actual size of a shaft is larger than the actual finished size of the mating hole in an assembly as shown in Fig. 3.5 (*b*). In other words, the interference is the arithmetical difference between the sizes of the hole and the shaft, before assembly. The difference must be ***negative.***

3.15 Types of Fits

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

1. *Clearance fit.* In this type of fit, the size limits for mating parts are so selected that clearance between them always occur, as shown in Fig. 3.5 (*a*). It may be noted that in a clearance fit, the tolerance zone of the hole is entirely above the tolerance zone of the shaft.

In a clearance fit, the difference between the minimum size of the hole and the maximum size of the shaft is known as ***minimum clearance*** whereas the difference between the maximum size of the hole and minimum size of the shaft is called ***maximum clearance*** as shown in Fig. 3.5 (*a*).

A Jet Engine : *In a jet engine, fuel is mixed with air, compressed, burnt, and exhausted in one smooth, continuous process. There are no pistons shuttling back and forth to slow it down.*

Note : This picture is given as additional information and is not a direct example of the current chapter.

The clearance fits may be slide fit, easy sliding fit, running fit, slack running fit and loose running fit.

2. *Interference fit.* In this type of fit, the size limits for the mating parts are so selected that interference between them always occur, as shown in Fig. 3.5 (*b*). It may be noted that in an interference fit, the tolerance zone of the hole is entirely below the tolerance zone of the shaft.

In an interference fit, the difference between the maximum size of the hole and the minimum size of the shaft is known as ***minimum interference,*** whereas the difference between the minimum size of the hole and the maximum size of the shaft is called ***maximum interference,*** as shown in Fig. 3.5 (*b*).

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

3. *Transition fit.* In this type of fit, the size limits for the mating parts are so selected that either a clearance or interference may occur depending upon the actual size of the mating parts, as shown in Fig. 3.5 (*c*). It may be noted that in a transition fit, the tolerance zones of hole and shaft overlap.

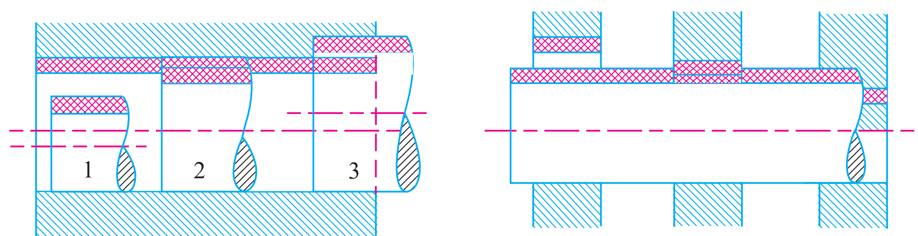
The transition fits may be force fit, tight fit and push fit.

3.16 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. 3.6 (*a*), then the limit system is said to be on a hole basis.

2. *Shaft basis system.* When the shaft is kept as a constant member (*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. 3.6 (*b*), then the limit system is said to be on a shaft basis.

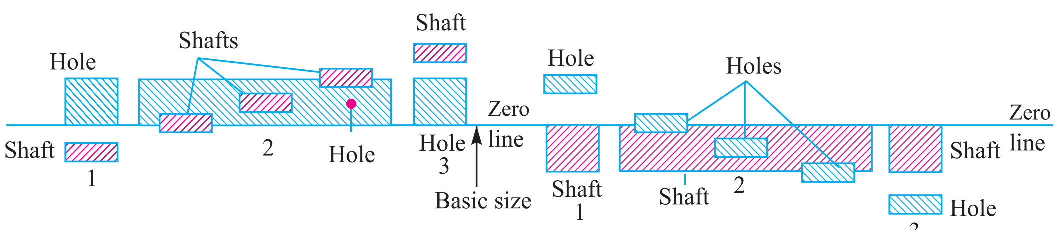


1. Clearance fit. 2. Transition fit. 3. Interference fit.

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

Fig. 3.6. Bases of limit system.

The hole basis and shaft basis system may also be shown as in Fig. 3.7, with respect to the zero line.



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

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

Fig. 3.7. Bases of limit system.

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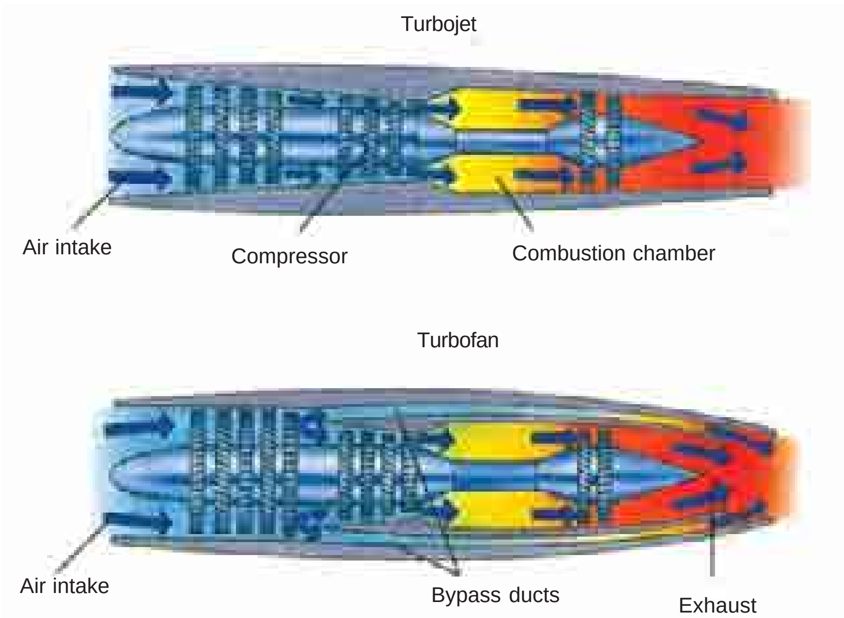
It may be noted that from the manufacturing point of view, a hole basis system is always preferred. This is because the holes are usually produced and finished by standard tooling like drill, reamers, etc., whose size is not adjustable easily. On the other hand, the size of the shaft (which is to go into the hole) can be easily adjusted and is obtained by turning or grinding operations.



Turbofan engines are quieter and more efficient than simple turbojet engines. Turbofans drive air around the combustion engine as well as through it.

Note : This picture is given as additional information and is not a direct example of the current chapter.

3.17 Indian Standard System of Limits and Fits

According to Indian standard [IS : 919 (Part I)-1993], the system of limits and fits comprises 18 grades of fundamental tolerances *i.e.* grades of accuracy of manufacture and 25 types of fundamental deviations indicated by letter symbols for both holes and shafts (capital letter *A* to *ZC* for holes and small letters *a* to *zc* for shafts) in diameter steps ranging from 1 to 500 mm. A unilateral hole basis system is recommended but if necessary a unilateral or bilateral shaft basis system may also be used. The 18 tolerance grades are designated as IT 01, IT 0 and IT 1 to IT 16. These are called ***standard tolerances***. The standard tolerances for grades IT 5 to IT 7 are determined in terms of standard tolerance unit (i) in microns, where

i (microns) = $0.45\sqrt[3]{D} + 0.001\,D$, where D is the size or geometric mean diameter in mm.

The following table shows the relative magnitude for grades between IT 5 and IT 16.

Table 3.2. Relative magnitude of tolerance grades.

Tolerance grade	IT 5	IT 6	IT 7	IT 8	IT 9	IT 10	IT 11	IT 12	IT 13	IT 14	IT 15	IT 16
Magnitude	7 *i*	10 *i*	16 *i*	25 *i*	40 *i*	64 *i*	100 *i*	160 *i*	250 *i*	400 *i*	640 *i*	1000 *i*

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The values of standard tolerances corresponding to grades IT 01, IT 0 and IT 1 are as given below:

For IT 01, i (microns) $= 0.3 + 0.008\ D$,

For IT 0, i (microns) $= 0.5 + 0.012\ D$, and

For IT 1, i (microns) $= 0.8 + 0.020\ D$,

where D is the size or geometric mean diameter in mm.

The tolerance values of grades IT 2 to IT 4 are scaled approximately geometrically between IT 1 and IT 5. The fundamental tolerances of grades IT 01, IT 0 and IT 1 to IT 16 for diameter steps ranging from 1 to 500 mm are given in Table 3.3. The manufacturing processes capable of producing the particular IT grades of work are shown in Table 3.4.

The alphabetical representation of fundamental deviations for basic shaft and basic hole system is shown in Fig. 3.8.

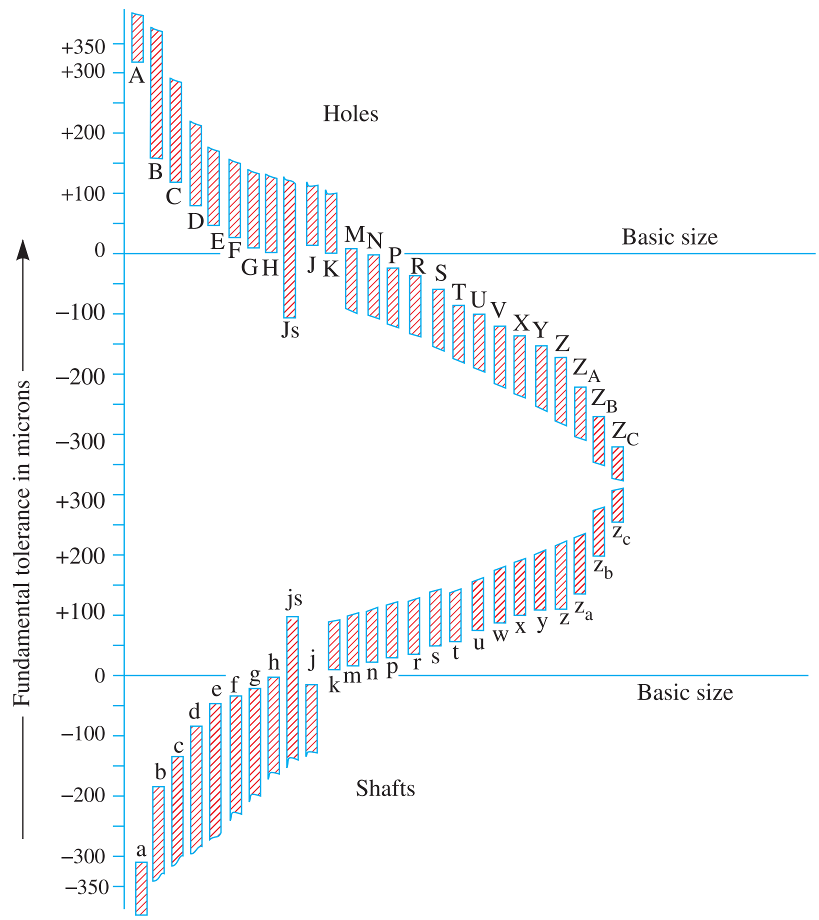

Fig. 3.8. Fundamental deviations for shafts and holes.

Table 3.3. Fundamental tolerances of grades IT01, IT0 and IT1 to IT16, according to IS : 919 (Part I) – 1993.

Basic size (Diameter steps) in mm		*Standard tolerance grades, in micron (1 micron = 0.001 mm)*																	
		IT01	IT0	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Over To and inc.	1 3	0.3	0.5	0.8	1.2	2	3	4	6	10	14	25	40	60	100	140	250	400	600
Over To and inc.	3 6	0.4	0.6	1	1.5	2.5	4	5	8	12	18	30	48	75	120	180	300	480	750
Over To and inc.	6 10	0.4	0.6	1	1.5	2.5	4	6	9	15	22	36	58	90	150	220	360	580	900
Over To and inc.	10 18	0.5	0.8	1.2	2	3	5	8	11	18	27	43	70	110	180	270	430	700	1100
Over To and inc.	18 30	0.6	1	1.5	2.5	4	6	9	13	21	33	52	84	130	210	330	520	840	1300
Over To and inc.	30 50	0.6	1	1.5	2.5	4	7	11	16	25	39	62	100	160	250	390	620	1000	1600
Over To and inc.	50 80	0.8	1.2	2	3	5	8	13	19	30	46	74	120	190	300	460	740	1200	1900
Over To and inc.	80 120	1	1.5	2.5	4	6	10	15	22	35	54	87	140	220	350	540	870	1400	2200
Over To and inc.	120 180	1.2	2	3.5	5	8	12	18	25	40	63	100	160	250	400	630	1000	1600	2500
Over To and inc.	180 250	2	3	4.5	7	10	14	20	29	46	72	115	185	290	460	720	1150	1850	2900
Over To and inc.	250 315	2.5	4	6	8	12	16	23	32	52	81	130	210	320	520	810	1300	2100	3200
Over To and inc.	315 400	3	5	7	9	13	18	25	36	57	89	140	230	360	570	890	1400	2300	3800
Over To and inc.	400 500	4	6	8	10	15	20	27	40	63	97	155	250	400	630	970	1550	2500	4000

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Table 3.4. Manufacturing processes and IT grades produced.

S.No.	*Manufacturing process*	*IT grade produced*	*S.No.*	*Manufacturing process*	*IT grade produced*
1.	Lapping	4 and 5	9.	Extrusion	8 to 10
2.	Honing	4 and 5	10	Boring	8 to 13
3.	Cylindrical grinding	5 to 7	11.	Milling	10 to 13
4.	Surface grinding	5 to 8	12.	Planing and shaping	10 to 13
5.	Broaching	5 to 8	13.	Drilling	10 to 13
6.	Reaming	6 to 10	14.	Die casting	12 to 14
7.	Turning	7 to 13	15.	Sand casting	14 to 16
8.	Hot rolling	8 to 10	16.	Forging	14 to 16

For hole, *H* stands for a dimension whose lower deviation refers to the basic size. The hole *H* for which the lower deviation is zero is called a ***basic hole.*** Similarly, for shafts, *h* stands for a dimension whose upper deviation refers to the basic size. The shaft *h* for which the upper deviation is zero is called a ***basic shaft.***

This view along the deck of a liquefied natural gas (LNG) carrier shows the tops of its large, insulated steel tanks. The tanks contain liquefied gas at-162°C.

A fit is designated by its basic size followed by symbols representing the limits of each of its two components, the hole being quoted first. For example, 100 *H*6/*g*5 means basic size is 100 mm and the tolerance grade for the hole is 6 and for the shaft is 5. Some of the fits commonly used in engineering practice, for holes and shafts are shown in Tables 3.5 and 3.6 respectively according to IS : 2709 – 1982 (Reaffirmed 1993).

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Table 3.5. Commonly used fits for holes according to IS : 2709 – 1982 (Reaffirmed 1993).

Type of fit	*Class of shaft*	*With holes* H6	H7	H8	H11	*Remarks and uses*
Clearance fit	*a*	—	—	—	*a*11	Large clearance fit and widely used.
	b	—	—	—	*b*11	
	c	—	*c*8	**c* 9	*c* 11	Slack running fit.
	d	—	*d*8	**d* 8 *d* 9, *d*10	*d* 11	Loose running fit—used for plummer block bearings and loose pulleys.
	e	*e*7	*e*8	**e* 8-*e* 9	—	Easy running fit—used for properly lubricated bearings requiring appreciable clearance. In the finer grades, it may be used on large electric motor and turbogenerator bearings according to the working condition.
	f	**f* 6	*f* 7	**f* 8	—	Normal running fit—widely used for grease lubricated or oil lubricated bearings where no substantial temperature differences are encountered—Typical applications are gear box shaft bearings and the bearings of small electric motors, pumps, etc.
	g	**g* 5	**g* 6	*g* 7	—	Close running fit or sliding fit—Also fine spigot and location fit—used for bearings for accurate link work and for piston and slide valves.
	h	**h* 5	**h* 6	**h* 7–*h* 8	**h*11	Precision sliding fit. Also fine spigot and location fit—widely used for non-running parts.
Transition fit	*j*	**j*5	**j*6	**j*7	—	Push fit for very accurate location with easy assembly and dismantling—Typical applications are coupling, spigots and recesses, gear rings clamped to steel hubs, etc.
	k	**k* 5	**k* 6	*k* 7	—	True transition fit (light keying fit)—used for keyed shaft, non-running locked pins, etc.
	m	**m* 5	**m* 6	*m* 7	—	Medium keying fit.
	n	*n* 5	**n* 6	*n*7	—	Heavy keying fit—used for tight assembly of mating parts.

* Second preference fits.

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Type of fit	Class of shaft	With holes H6	H7	H8	H11	Remarks and uses
Interference fit	p	p5	*p6	—	—	Light press fit with easy dismantling for non-ferrous parts. Standard press fit with easy dismantling for ferrous and non-ferrous parts assembly.
	r	r5	*r6	—	—	Medium drive fit with easy dismantling for ferrous parts assembly. Light drive fit with easy dismantling for non-ferrous parts assembly.
	s	s5	*s6	s7	—	Heavy drive fit on ferrous parts for permanent or semi-permanent assembly. Standard press fit for non-ferrous parts.
	t	t5	t6	*t7	—	Force fit on ferrous parts for permanent assembly.
	u	u5	u6	*u7	—	Heavy force fit or shrink fit.
	v, x	—	—	—	—	Very large interference fits — not recommended for use
	y, z	—	—	—	—	

Table 3.6. Commonly used fits for shafts according to IS : 2709 – 1982 (Reaffirmed 1993).

Type of fit	Class of hole	With shafts *h5	h6	h7	*h8	h9	h11	Remarks and uses
Clearance fit	A	—	—	—	—	—	A11	Large clearance fit and widely used.
	B	—	—	—	—	—	B11	
	C	—	—	—	—	—	C11	Slack running fit.
	D	—	*D9	—	D10	D10	*D11	Loose running fit.
	E	—	*E8	—	E8*	E9	—	Easy running fit.
	F	—	*F7	—	F8	*F8	—	Normal running fit.
	G	*G6	G7	—	—	—	—	Close running fit or sliding fit, also spigot and location fit.
	H	*H6	H7	H8	H8	H8, H9	H11	Precision sliding fit. Also fine spigot and location fit.
	Js	*Js6	Js7	*Js8	—	—	—	Push fit for very accurate location with easy assembly and disassembly.

* Second preference fits.

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Type of fit	Class of hole	With shafts						Remarks and uses
		*h5	h6	h7	*h8	h9	h11	
Transition fit	K	*K6	K7	*K8	—	—	—	Light keying fit (true transition) for keyed shafts, non-running locked pins, etc.
	M	*M6	*M7	*M8	—	—	—	Medium keying fit.
	N	*N6	N7	*N8	—	—	—	Heavy keying fit (for tight assembly of mating surfaces).
Interference fit	P	*P6	P7	—	—	—	—	Light press fit with easy dismantling for non-ferrous parts. Standard press fit with easy dismantling for ferrous and non-ferrous parts assembly.
	R	*R6	R7	—	—	—	—	Medium drive fit with easy dismantling for ferrous parts assembly. Light drive fit with easy dismantling for non-ferrous parts assembly.
	S	*S6	S7	—	—	—	—	Heavy drive fit for ferrous parts permanent or semi- permanent assembly, standard press fit for non-ferrous parts.
	T	*T6	T7	—	—	—	—	Force fit on ferrous parts for permanent assembly.

3.18 Calculation of Fundamental Deviation for Shafts

We have already discussed that for holes, the upper deviation is denoted by *ES* and the lower deviation by *EI*. Similarly for shafts, the upper deviation is represented by *es* and the lower deviation by *ei*. According to Indian standards, for each letter symbol, the magnitude and sign for one of the two deviations (*i.e.* either upper or lower deviation), which is known as fundamental deviation, have been determined by means of formulae given in Table 3.7. The other deviation may be calculated by using the absolute value of the standard tolerance (*IT*) from the following relation:

$$ei = es - IT \quad \text{or} \quad es = ei + IT$$

It may be noted for shafts *a* to *h*, the upper deviations (*es*) are considered whereas for shafts *j* to *Zc*, the lower deviation (*ei*) is to be considered.

Computer simulation of stresses on a jet engine blades.

* Second preference fits.

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The fundamental deviation for Indian standard shafts for diameter steps from 1 to 200 mm may be taken directly from Table 3.10 (page 76).

Table 3.7. Formulae for fundamental shaft deviations.

Upper deviation (es)		*Lower deviation (ei)*	
Shaft designation	*In microns (for D in mm)*	*Shaft designation*	*In microns (for D in mm)*
a	= – (265 + 1.3 *D*)	*J* 5 to *j* 8	No formula
	for $D \leq 120$	*k* 4 to *k* 7	$= + 0.6 \sqrt[3]{D}$
	= – 3.5 *D*		
	for $D > 120$	*k* for grades	= 0
		≤ 3 and ≤ 8	
b	= – (140 + 0.85 *D*)	*m*	= + (*IT* 7 – *IT* 6)
	for $D \leq 160$		
	= – 1.8 *D*	*n*	$= + 5\,(D)^{0.34}$
	for $D > 160$	*p*	= + *IT* 7 + 0 to 5
c	$= -52\,(D)^{0.2}$	*r*	= Geometric mean of values of *ei*
	for $D \leq 40$		for shaft *p* and *s*
	= – (95 + 0.8 *D*)	*s*	= + (*IT* 8 + 1 to 4) for $D \leq 50$
	for $D > 40$		= + (*IT* 7 + 0.4 *D*) for $D > 50$
d	$= -16\,(D)^{0.44}$	*t*	= + (*IT* 7 + 0.63 *D*)
e	$= -11\,(D)^{0.41}$	*u*	= + (*IT* 7 + *D*)
f	$= -5.5\,(D)^{0.41}$	*v*	= + (*IT* 7 + 1.25 *D*)
		x	= + (*IT* 7 + 1.6 *D*)
g	$= -2.5\,(D)^{0.34}$	*y*	= + (*IT* 7 + 2 *D*)
		z	= + (*IT* 7 + 2.5 *D*)
h	= 0	*za*	= + (*IT* 8 + 3.15 *D*)
		zb	= + (*IT* 9 + 4 *D*)
		zc	= + (*IT* 10 + 5 *D*)

For *js*, the two deviations are equal to ± *IT*/2.

3.19 Calculation of Fundamental Deviation for Holes

The fundamental deviation for holes for those of the corresponding shafts, are derived by using the rule as given in Table 3.8.

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Table 3.8. Rules for fundamental deviation for holes.

All deviation except those below			*General rule* Hole limits are identical with the shaft limits of the same symbol (letter and grade) but disposed on the other side of the zero line. *EI* = Upper deviation *es* of the shaft of the same letter symbol but of opposite sign.
For sizes above 3 mm	*N*	9 and coarser grades	*ES* = 0
	J, K, M and *N*	Upto grade 8 inclusive	*Special rule* *ES* = Lower deviation *ei* of the shaft of the same letter symbol but one grade finer and of opposite sign increased by the difference between the tolerances of the two grades in question.
	P to *ZC*	upto grade 7 inclusive	

The fundamental deviation for Indian standard holes for diameter steps from 1 to 200 mm may be taken directly from the following table.

Table 3.9. Indian standard 'H' Hole
Limits for H5 to H13 over the range 1 to 200 mm as per IS : 919 (Part II) -1993.

Diameter steps in mm		*Deviations in micron (1 micron = 0.001 mm)*									
		H5	H6	H7	H8	H9	H10	H11	H12	H13	H5 – H13
Over	To	High +	High +	High +	High +	High +	High +	High +	High +	High +	Low
1	3	5	7	9	14	25	40	60	90	140	0
3	6	5	8	12	18	30	48	75	120	180	0
6	10	6	9	15	22	36	58	90	150	220	0
10 14	14 18	8	11	18	27	43	70	110	180	270	0
18 24	24 30	9	13	21	33	52	84	130	210	330	0
30 40	40 50	11	16	25	39	62	100	160	250	460	0
50 65	65 80	13	19	30	46	74	120	190	300	390	0
80 100	100 120	15	22	35	54	87	140	220	350	540	0
120 140	140 160	18	25	40	63	100	160	250	400	630	0
160 180	180 200	20	29	46	72	115	185	290	460	720	0

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Table 3.10. Indian standard shafts for common use as per IS : 919 (Part II)–1993.

Shaft	*Limit*	*Values of deviations in microns for diameter steps 1 to 200 mm (1 micron = 0.001 mm)*																
		1 to 3	3 to 6	6 to 10	10 to 14	14 to 18	18 to 24	24 to 30	30 to 40	40 to 50	50 to 65	65 to 80	80 to 100	100 to 120	120 to 140	140 to 160	160 to 180	180 to 200
*s*6	High+	22	37	32	39	39	48	48	59	59	72	78	93	101	117	125	133	151
*s*7	High+	24	31	38	46	46	56	66	68	68	83	89	106	114	132	140	148	168
*s*6 & *s*7	Low+	15	19	23	28	28	35	35	43	43	53	59	71	79	92	100	108	122
*p*9	High+	16	20	24	29	29	35	35	42	42	51	51	59	59	68	68	68	79
	Low+	9	12	15	18	18	22	22	26	26	32	32	37	37	43	43	43	50
*k*6	High+	—	—	10	12	12	15	15	18	18	21	21	25	25	28	28	28	33
*k*7	High+	—	—	16	19	19	23	23	27	27	32	32	38	38	43	43	43	50
*k*6 & *k*7	Low+	—	—	1	1	1	2	2	2	2	2	2	3	3	3	3	3	4
	High+	7	9	10	12	12	13	13	15	15	18	18	20	20	22	22	22	25
	Low–	2	3	5	6	6	8	8	10	10	12	12	15	15	18	18	18	21
*h*6	High–	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Shaft	Limit	Values of deviations in microns for diameter steps 1 to 200 mm (1 micron = 0.001 mm)																
		1 to 3	3 to 6	6 to 10	10 to 14	14 to 18	18 to 24	24 to 30	30 to 40	40 to 50	50 to 65	65 to 80	80 to 100	100 to 120	120 to 140	140 to 160	160 to 180	180 to 200
h7	High–	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h6	Low–	7	8	9	11	11	13	13	16	16	19	19	22	22	25	25	26	29
&		&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&
h7		9	12	15	18	18	21	21	25	25	30	30	35	35	40	40	40	46
g 6	High–	3	4	5	6	6	7	7	9	9	10	10	12	12	14	14	14	15
	Low–	10	12	14	17	17	20	20	25	25	29	29	34	34	39	39	39	44
f 7	High–	7	10	13	16	16	20	20	25	25	30	30	36	36	43	43	43	50
f 8	High–	7	10	13	16	16	20	20	25	25	30	30	36	36	43	43	43	50
f 7	Low–	16	22	28	34	34	41	41	50	50	60	60	71	71	83	83	83	96
&		&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&
f 8		21	28	35	43	43	53	53	64	64	76	76	90	90	106	106	106	122
e 8	High–	14	20	25	32	32	40	40	50	50	60	60	72	72	85	85	85	100
e 9	High–	14	20	25	32	32	40	40	50	50	60	60	72	72	85	85	85	100
e 8	Low–	28	38	47	59	58	73	73	89	89	106	106	126	126	148	148	148	172
&		&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&
e 9		39	50	61	75	75	92	92	112	112	134	134	158	158	185	185	185	215
d 9	High–	20	30	40	50	50	65	65	80	80	100	100	120	120	145	145	145	170
	Low–	45	60	76	93	93	117	117	142	142	174	174	207	207	245	245	245	285
c 9	High–	60	70	80	95	95	110	110	120	130	140	150	170	180	200	210	230	240
	Low–	85	100	116	138	138	162	162	182	192	214	224	257	267	300	310	330	355
b 9	High–	140	140	150	150	150	160	160	170	180	190	200	220	240	260	280	310	340
	Low–	165	170	186	193	193	212	212	232	242	264	274	307	327	360	380	410	545

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Example 3.1. *The dimensions of the mating parts, according to basic hole system, are given as follows :*

Hole : 25.00 mm *Shaft : 24.97 mm*

25.02 mm *24.95 mm*

Find the hole tolerance, shaft tolerance and allowance.

Solution. Given : Lower limit of hole = 25 mm ; Upper limit of hole = 25.02 mm ; Upper limit of shaft = 24.97 mm ; Lower limit of shaft = 24.95 mm

Hole tolerance

We know that hole tolerance

= Upper limit of hole – Lower limit of hole

= 25.02 – 25 = 0.02 mm **Ans.**

Shaft tolerance

We know that shaft tolerance

= Upper limit of shaft – Lower limit of shaft

= 24.97 – 24.95 = 0.02 mm **Ans.**

Allowance

We know that allowance

= Lower limit of hole – Upper limit of shaft

= 25.00 – 24.97 = 0.03 mm **Ans.**

Example 3.2. *Calculate the tolerances, fundamental deviations and limits of sizes for the shaft designated as 40 H8 / f7.*

Solution. Given: Shaft designation = 40 $H8$ / f 7

The shaft designation 40 $H8$ / f 7 means that the basic size is 40 mm and the tolerance grade for the hole is 8 (*i.e.* $IT\,8$) and for the shaft is 7 (*i.e.* $IT\,7$).

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,

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

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

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

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

From Table 3.2, we find that standard tolerance for the hole of grade 8 ($IT\,8$)

$= 25\,i = 25 \times 0.001\,56 = 0.039$ mm **Ans.**

and standard tolerance for the shaft of grade 7 ($IT\,7$)

$= 16\,i = 16 \times 0.001\,56 = 0.025$ mm **Ans.**

Note : The value of $IT\,8$ and $IT\,7$ may be directly seen from Table 3.3.

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Fundamental deviation

We know that fundamental deviation (lower deviation) for hole *H*,

$$EI = 0$$

From Table 3.7, we find that fundamental deviation (upper deviation) for shaft *f*,

$$es = -5.5\,(D)^{0.41}$$
$$= -5.5\,(38.73)^{0.41} = -24.63 \text{ or } -25 \text{ microns}$$
$$= -25 \times 0.001 = -0.025 \text{ mm}$$ **Ans.**

∴ Fundamental deviation (lower deviation) for shaft *f*,

$$ei = es - IT = -0.025 - 0.025 = -0.050 \text{ mm}$$ **Ans.**

The –ve sign indicates that fundamental deviation lies below the zero line.

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) ...(∵ Shaft *f* lies below the zero line)

= 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.**

Example 3.3. *Give the dimensions for the hole and shaft for the following:*

(*a*) *A 12 mm electric motor sleeve bearing;*

(*b*) *A medium force fit on a 200 mm shaft; and*

(*c*) *A 50 mm sleeve bearing on the elevating mechanism of a road grader.*

Solution.

(a) Dimensions for the hole and shaft for a 12 mm electric motor sleeve bearing

From Table 3.5, we find that for an electric motor sleeve bearing, a shaft *e* 8 should be used with *H* 8 hole.

Since 12 mm size lies in the diameter steps of 10 to 18 mm, therefore the geometric mean diameter,

$$D = \sqrt{10 \times 18} = 13.4 \text{ mm}$$

We know that standard tolerance unit,

$$i = 0.45\,\sqrt[3]{D} + 0.001\,D$$
$$= 0.45\,\sqrt[3]{13.4} + 0.001 \times 13.4 = 1.07 + 0.0134 = 1.0834 \text{ microns}$$

∴ *Standard tolerance for shaft and hole of grade 8 (*IT* 8)

= 25 *i* ...(From Table 3.2)

= 25 × 1.0834 = 27 microns

= 27 × 0.001 = 0.027 mm ...(∵ 1 micron = 0.001 mm)

From Table 3.7, we find that upper deviation for shaft '*e*',

$$es = -11(D)^{0.41} = -11\,(13.4)^{0.41} = -32 \text{ microns}$$
$$= -32 \times 0.001 = -0.032 \text{ mm}$$

* The tolerance values may be taken directly from Table 3.3.

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We know that lower deviation for shaft '*e*',

$$ei = es - IT = -0.032 - 0.027 = -0.059 \text{ mm}$$

∴ Dimensions for the hole (*H* 8)

$$= 12^{+0.027}_{+0.000}$$ **Ans.**

and dimension for the shaft (*e* 8)

$$= 12^{-0.032}_{-0.059}$$ **Ans.**

(b) Dimensions for the hole and shaft for a medium force fit on a 200 mm shaft

From Table 3.5, we find that shaft *r* 6 with hole *H* 7 gives the desired fit.

Since 200 mm lies in the diameter steps of 180 mm to 250 mm, therefore the geometric mean diameter,

$$D = \sqrt{180 \times 250} = 212 \text{ mm}$$

We know that standard tolerance unit,

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

$$= 0.45 \sqrt[3]{212} + 0.001 \times 212 = 2.68 + 0.212 = 2.892 \text{ microns}$$

∴ Standard tolerance for the shaft of grade 6 (*IT*6) from Table 3.2

$$= 10\, i = 10 \times 2.892 = 28.92 \text{ microns}$$

$$= 28.92 \times 0.001 = 0.02892 \text{ or } 0.029 \text{ mm}$$

and standard tolerance for the hole of grade 7 (*IT* 7)

$$= 16\, i = 16 \times 2.892 = 46 \text{ microns}$$

$$= 46 \times 0.001 = 0.046 \text{ mm}$$

We know that lower deviation for shaft '*r*' from Table 3.7

$$ei = \frac{1}{2}\left[(IT\,7 + 0.4\,D) + (IT\,7 + 0 \text{ to } 5)\right]$$

$$= \frac{1}{2}\left[(46 + 0.4 \times 212) + (46 + 3)\right] = 90 \text{ microns}$$

$$= 90 \times 0.001 = 0.09 \text{ mm}$$

and upper deviation for the shaft *r*,

$$es = ei + IT = 0.09 + 0.029 = 0.119 \text{ mm}$$

∴ Dimension for the hole *H* 7

$$= 200^{+0.046}_{+0.00}$$ **Ans.**

and dimension for the shaft *r* 6

$$= 200^{+0.119}_{+0.09}$$ **Ans.**

(c) Dimensions for the hole and shaft for a 50 mm sleeve bearing on the elevating mechanism of a road grader

From Table 3.5, we find that for a sleeve bearing, a loose running fit will be suitable and a shaft *d* 9 should be used with hole *H* 8.

Since 50 mm size lies in the diameter steps of 30 to 50 mm or 50 to 80 mm, therefore the geometric mean diameter,

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

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We know that standard tolerance unit,

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

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

$$= 1.522 + 0.03873 = 1.56073 \quad \text{or} \quad 1.56 \text{ microns}$$

∴ Standard tolerance for the shaft of grade 9 (*IT* 9) from Table 3.2

$$= 40\ i = 40 \times 1.56 = 62.4 \text{ microns}$$

$$= 62.4 \times 0.001 = 0.0624 \quad \text{or} \quad 0.062 \text{ mm}$$

and standard tolerance for the hole of grade 8 (*IT* 8)

$$= 25\ i = 25 \times 1.56 = 39 \text{ microns}$$

$$= 39 \times 0.001 = 0.039 \text{ mm}$$

We know that upper deviation for the shaft *d*, from Table 3.7

$$es = -16\ (D)^{0.44} = -16\ (38.73)^{0.44} = -80 \text{ microns}$$

$$= -80 \times 0.001 = -0.08 \text{ mm}$$

and lower deviation for the shaft *d*,

$$ei = es - IT = -0.08 - 0.062 = -0.142 \text{ mm}$$

∴ Dimension for the hole *H* 8

$$= 50^{+0.039}_{+0.000}$$ **Ans.**

and dimension for the shaft *d* 9

$$= 50^{-0.08}_{-0.142}$$ **Ans.**

Example 3.4. *A journal of nominal or basic size of 75 mm runs in a bearing with close running fit. Find the limits of shaft and bearing. What is the maximum and minimum clearance?*

Solution. Given: Nominal or basic size = 75 mm

From Table 3.5, we find that the close running fit is represented by *H* 8/*g* 7, *i.e.* a shaft *g* 7 should be used with *H* 8 hole.

Since 75 mm lies in the diameter steps of 50 to 80 mm, therefore the geometric mean diameter,

$$D = \sqrt{50 \times 80} = 63 \text{ mm}$$

We know that standard tolerance unit,

$$i = 0.45\ \sqrt[3]{D} + 0.001\ D = 0.45\ \sqrt[3]{63} + 0.001 \times 63$$

$$= 1.79 + 0.063 = 1.853 \text{ micron}$$

$$= 1.853 \times 0.001 = 0.001\ 853 \text{ mm}$$

∴ Standard tolerance for hole '*H*' of grade 8 (*IT* 8)

$$= 25\ i = 25 \times 0.001\ 853 = 0.046 \text{ mm}$$

and standard tolerance for shaft '*g*' of grade 7 (*IT* 7)

$$= 16\ i = 16 \times 0.001\ 853 = 0.03 \text{ mm}$$

From Table 3.7, we find that upper deviation for shaft *g*,

$$es = -2.5\ (D)^{0.34} = -2.5\ (63)^{0.34} = -10 \text{ micron}$$

$$= -10 \times 0.001 = -0.01 \text{ mm}$$

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∴ Lower deviation for shaft g,

$$ei = es - IT = -0.01 - 0.03 = -0.04 \text{ mm}$$

We know that lower limit for hole

= Basic size = 75 mm

Upper limit for hole = Lower limit for hole + Tolerance for hole

= 75 + 0.046 = 75.046 mm

Upper limit for shaft = Lower limit for hole – Upper deviation for shaft

...(∵ Shaft g lies below zero line)

= 75 – 0.01 = 74.99 mm

and lower limit for shaft = Upper limit for shaft – Tolerance for shaft

= 74.99 – 0.03 = 74.96 mm

We know that maximum clearance

= Upper limit for hole – Lower limit for shaft

= 75.046 – 74.96 = 0.086 mm **Ans.**

and minimum clearance = Lower limit for hole – Upper limit for shaft

= 75 – 74.99 = 0.01 mm **Ans.**

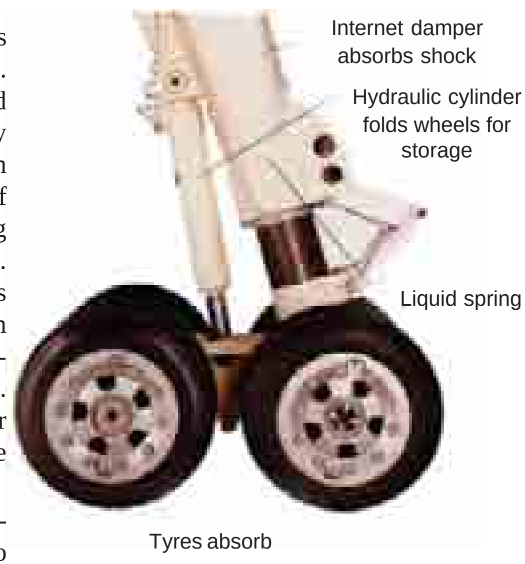
3.20 Surface Roughness and its Measurement

A little consideration will show that surfaces produced by different machining operations (*e.g.* turning, milling, shaping, planing, grinding and superfinishing) are of different characteristics. They show marked variations when compared with each other. The variation is judged by the degree of smoothness. A surface produced by superfinishing is the smoothest, while that by planing is the roughest. In the assembly of two mating parts, it becomes absolutely necessary to describe the surface finish in quantitative terms which is measure of micro-irregularities of the surface and expressed in microns. In order to prevent stress concentrations and proper functioning, it may be necessary to avoid or to have certain surface roughness.

There are many ways of expressing the surface roughness numerically, but the following two methods are commonly used :

1. Centre line average method (briefly known as CLA method), and
2. Root mean square method (briefly known as RMS method).

The ***centre line average method*** is defined as the average value of the ordinates between the surface and the mean line, measured on both sides of it. According to Indian standards, the surface finish is measured in terms of 'CLA' value and it is denoted by *Ra*.



Landing Gear : *When an aircraft comes in to land, it has to lose a lot of energy in a very short time. the landing gear deals with this and prevents disaster. First, mechanical or liquid springs absorb energy rapidly by being compressed. As the springs relax, this energy will be released again, but in a slow controlled manner in a damper-the second energy absorber. Finally, the tyres absorb energy, getting hot in the process.*

$$\text{CLA value or } Ra \text{ (in microns)} = \frac{y_1 + y_2 + y_3 + ... \, y_n}{n}$$

where, $y_1, y_2, ...y_n$ are the ordinates measured on both sides of the mean line and n are the number of ordinates.

The ***root mean square method*** is defined as the square root of the arithmetic mean of the squares of the ordinates. Mathematically,

$$\text{R.M.S. value (in microns)} = \sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + ... \, y_n^2}{n}}$$

According to Indian standards, following symbols are used to denote the various degrees of surface roughness :

Symbol	Surface roughness (*Ra*) in microns
∇	8 to 25
∇ ∇	1.6 to 8
∇ ∇ ∇	0.025 to 1.6
∇ ∇ ∇ ∇	Less than 0.025

The following table shows the range of surface roughness that can be produced by various manufacturing processes.

Table 3.11. Range of surface roughness.

S.No.	*Manufacturing process*	*Surface roughness in microns*	*S.No.*	*Manufacturing process*	*Surface roughness in microns*
1.	Lapping	0.012 to 0.016	9	Extrusion	0.16 to 5
2.	Honing	0.025 to 0.40	10.	Boring	0.40 to 6.3
3.	Cylindrical grinding	0.063 to 5	11.	Milling	0.32 to 25
4.	Surface grinding	0.063 to 5	12.	Planing and shaping	1.6 to 25
5.	Broaching	0.40 to 3.2	13.	Drilling	1.6 to 20
6.	Reaming	0.40 to 3.2	14.	Sand casting	5 to 50
7.	Turning	0.32 to 25	15.	Die casting	0.80 to 3.20
8.	Hot rolling	2.5 to 50	16.	Forging	1.60 to 2.5

3.21 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. Table 3.12 shows basic series of preferred numbers according to IS : 1076 (Part I) – 1985 (Reaffirmed 1990).

* The symbol R is used as a tribute to Captain Charles Renard, the first man to use preferred numbers.

Notes : 1. The standard sizes (in mm) for wrought metal products are shown in Table 3.13 according to IS : 1136 – 1990. The standard G.P. series used correspond to R10, R20 and R40.

2. The hoisting capacities (in tonnes) of cranes are in R10 series, while the hydraulic cylinder diameters are in R40 series and hydraulic cylinder capacities are in R5 series.

3. The basic thickness of sheet metals and diameter of wires are based on R10, R20 and R40 series. Wire diameter of helical springs are in R20 series.

Table 3.12. Preferred numbers of the basic series, according to IS : 1076 (Part I)–1985 (Reaffirmed 1990).

Basic series	*Preferred numbers*
R5	1.00, 1.60, 2.50, 4.00, 6.30, 10.00
R10	1.00, 1.25, 1.60, 2.00, 2.50, 3.15, 4.00, 5.00, 6.30, 8.00, 10.00
R20	1.00, 1.12, 1.25, 1.40, 1.60, 1.80, 2.00, 2.24, 2.50, 2.80, 3.15, 3.55, 4.00, 4.50, 5.00, 5.60, 6.30, 7.10, 8.00, 9.00, 10.00
R40	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, 3.00, 3.15, 3.35, 3.55, 3.75, 4.00, 4.25, 4.50, 4.75, 5.00, 5.30, 5.60, 6.00, 6.30, 6.70, 7.10, 7.50, 8.00, 8.50, 9.00, 9.50, 10.00

Table 3.13. Preferred sizes for wrought metal products according to IS : 1136 – 1990.

Size range	*Preferred sizes (mm)*
0.01 – 0.10 mm	0.02, 0.025, 0.030, 0.04, 0.05, 0.06, 0.08 and 0.10
0.10 – 1 mm	0.10, 0.11, 0.12, 0.14, 0.16, 0.18, 0.20, 0.22, 0.25, 0.28, 0.30, 0.32, 0.35, 0.36, 0.40, 0.45, 0.50, 0.55, 0.60, 0.63, 0.70, 0.80, 0.90 and 1
1 – 10 mm	1, 1.1, 1.2, 1.4, 1.5, 1.6, 1.8, 2.22, 2.5, 2.8, 3, 3.2, 3.5, 3.6, 4, 4.5, 5, 5.5, 5.6, 6, 6.3, 7, 8, 9 and 10
10 – 100 mm	10 to 25 (in steps of 1 mm), 28, 30, 32, 34, 35, 36, 38, 40, 42, 44, 45, 46, 48,50, 52, 53, 55, 56, 58, 60, 62, 63, 65, 67, 68, 70, 71, 72, 75, 78, 80, 82, 85, 88, 90, 92, 95, 98 and 100
100 – 1000 mm	100 to 200 (in steps of 5 mm), 200 to 310 (in steps of 10 mm), 315, 320, 330, 340, 350, 355, 360, 370, 375, 380 to 500 (in steps of 10 mm), 520, 530,550, 560, 580, 600, 630, 650, 670, 700, 710 and 750 – 1000 (in steps of 50 mm)
1000 – 10 000 mm	1000, 1100, 1200, 1250, 1400, 1500, 1600, 1800, 2000, 2200, 2500, 2800, 3000, 3200, 3500, 3600, 4000, 4500, 5000, 5500, 5600, 6000, 6300, 7000, 7100, 8000, 9000 and 10 000

EXERCISES

1. A journal of basic size of 75 mm rotates in a bearing. The tolerance for both the shaft and bearing is 0.075 mm and the required allowance is 0.10 mm. Find the dimensions of the shaft and the bearing bore. **[Ans. For shaft : 74.90 mm, 74.825 mm ; For hole : 75.075 mm, 75 mm]**
2. A medium force fit on a 75 mm shaft requires a hole tolerance and shaft tolerance each equal to 0.225 mm and average interference of 0.0375 mm. Find the hole and shaft dimensions.
[Ans. 75 mm, 75.225 mm ; 75.2625 mm, 75.4875 mm]

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3. Calculate the tolerances, fundamental deviations and limits of size for hole and shaft in the following cases of fits :

   (*a*) 25 *H* 8 / *d* 9; and (*b*) 60 *H* 7 / *m* 6

   [Ans. (*a*) 0.033 mm, 0.052 mm; 0, – 0.064 mm, – 0.116 mm; 25 mm, 25.033 mm, 24.936 mm, 24.884 mm (*b*) 0.03 mm, 0.019 mm; 0.011 mm, – 0.008 mm; 60 mm, 60.03 mm, 59.989 mm, 59.97 mm]

4. Find the extreme diameters of shaft and hole for a transition fit *H*7/*n*6, if the nominal or basic diameter is 12 mm. What is the value of clearance and interference?

   [Ans. 12.023 mm, 12.018 mm; 0.006 mm, – 0.023 mm]

5. A gear has to be shrunk on a shaft of basic size 120 mm. An interference fit *H*7/*u*6 is being selected. Determine the minimum and maximum diameter of the shaft and interference.

   [Ans. 120.144 mm, 120.166 mm; 0.109 mm, 0.166 mm]

QUESTIONS

1. Enumerate the various manufacturing methods of machine parts which a designer should know.
2. Explain briefly the different casting processes.
3. Write a brief note on the design of castings?
4. State and illustrate two principal design rules for casting design.
5. List the main advantages of forged components.
6. What are the salient features used in the design of forgings? Explain.
7. What do you understand by 'hot working' and 'cold working' processes? Explain with examples.
8. State the advantages and disadvantages of hot working of metals. Discuss any two hot working processes.
9. What do you understand by cold working of metals? Describe briefly the various cold working processes.
10. What are fits and tolerances? How are they designated?
11. What do you understand by the nominal size and basic size?
12. Write short notes on the following :

    (*a*) Interchangeability; (*b*) Tolerance; (*c*) Allowance; and (*d*) Fits.
13. What is the difference in the type of assembly generally used in running fits and interference fits?
14. State briefly unilateral system of tolerances covering the points of definition, application and advantages over the bilateral system.
15. What is meant by 'hole basis system' and 'shaft basis system'? Which one is preferred and why?
16. Discuss the Indian standard system of limits and fits.
17. What are the commonly used fits according to Indian standards?
18. What do you understand by preferred numbers? Explain fully.

OBJECTIVE TYPE QUESTIONS

1. The castings produced by forcing molten metal under pressure into a permanent metal mould is known as

   (*a*) permanent mould casting (*b*) slush casting
   (*c*) die casting (*d*) centrifugal casting
2. The metal is subjected to mechanical working for

   (*a*) refining grain size (*b*) reducing original block into desired shape
   (*c*) controlling the direction of flow lines (*d*) all of these

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3. The temperature at which the new grains are formed in the metal is called
   (*a*) lower critical temperature (*b*) upper critical temperature
   (*c*) eutectic temperature (*d*) recrystallisation temperature
4. The hot working of metals is carried out
   (*a*) at the recrystallisation temperature (*b*) below the recrystallisation temperature
   (*c*) above the recrystallisation temperature (*d*) at any temperature
5. During hot working of metals
   (*a*) porosity of the metal is largely eliminated
   (*b*) grain structure of the metal is refined
   (*c*) mechanical properties are improved due to refinement of grains
   (*d*) all of the above
6. The parts of circular cross-section which are symmetrical about the axis of rotation are made by
   (*a*) hot forging (*b*) hot spinning
   (*c*) hot extrusion (*d*) hot drawing
7. The cold working of metals is carried out .... the recrystallisation temperature.
   (*a*) above (*b*) below
8. The process extensively used for making bolts and nuts is
   (*a*) hot piercing (*b*) extrusion
   (*c*) cold peening (*d*) cold heading
9. In a unilateral system of tolerance, the tolerance is allowed on
   (*a*) one side of the actual size (*b*) one side of the nominal size
   (*c*) both sides of the actual size (*d*) both sides of the nominal size
10. The algebraic difference between the maximum limit and the basic size is called
   (*a*) actual deviation (*b*) upper deviation
   (*c*) lower deviation (*d*) fundamental deviation
11. A basic shaft is one whose
   (*a*) lower deviation is zero (*b*) upper deviation is zero
   (*c*) lower and upper deviations are zero (*d*) none of these
12. A basic hole is one whose
   (*a*) lower deviation is zero (*b*) upper deviation is zero
   (*c*) lower and upper deviations are zero (*d*) none of these
13. According to Indian standard specifications, 100 $H\,6\,/\,g\,5$ means that the
   (*a*) actual size is 100 mm
   (*b*) basic size is 100 mm
   (*c*) difference between the actual size and basic size is 100 mm
   (*d*) none of the above
14. According to Indian standards, total number of tolerance grades are
   (*a*) 8 (*b*) 12
   (*c*) 18 (*d*) 20
15. According to Indian standard specification, 100 $H6/g5$ means that
   (*a*) tolerance grade for the hole is 6 and for the shaft is 5
   (*b*) tolerance grade for the shaft is 6 and for the hole is 5
   (*c*) tolerance grade for the shaft is 4 to 8 and for the hole is 3 to 7
   (*d*) tolerance grade for the hole is 4 to 8 and for the shaft is 3 to 7

ANSWERS

1. (*c*)	**2.** (*d*)	**3.** (*d*)	**4.** (*c*)	**5.** (*d*)
6. (*b*)	**7.** (*b*)	**8.** (*d*)	**9.** (*b*)	**10.** (*b*)
11. (*b*)	**12.** (*a*)	**13.** (*b*)	**14.** (*c*)	**15.** (*a*)