LIMITS, TOLERANCE AND FITS

1- INTRODUCTION

The manufacture of interchangeable parts require precision. Precision is the degree of accuracy to ensure the functioning of a part as intended. However, experience shows that it is impossible to make parts economically to the exact dimensions. This may be due to,

(*i*) inaccuracies of machines and tools,

(*ii*) inaccuracies in setting the work to the tool, and

(*iii*) error in measurement, etc.

The workman, therefore, has to be given some allowable margin so that he can produce a part, the dimensions of which will lie between two acceptable limits, a maximum and a minimum.

The system in which a variation is accepted is called the limit system and the allowable deviations are called tolerances. The relationships between the mating parts are called fits.

The study of limits, tolerances and fits is a must for technologists involved in production. The same must be reflected on production drawing, for guiding the craftsman on the shop floor.

2- LIMITE SYSTEM

Following are some of the terms used in the limit system :

1) **Basic size** It is determined solely from design calculations. If the strength and stiffness requirements need a 50mm diameter shaft, then 50mm is the basic shaft size. If it has to fit into a hole, then 50 mm is the basic size of the hole. Figure 15.1 illustrates the basic size, deviations and tolerances.

2) **Limits** the two extreme permissible sizes between which the actual size is contained are called limits.

The maximum size is called the upper limit and the minimum size is called the lower limit.

3) **Deviation** it is the algebraic difference between a size (actual, maximum, etc.) and the corresponding basic size.

4) **Upper deviation** it is the algebraic difference between the maximum limit of the size and the corresponding basic size.

5) **Lower deviation** it is the algebraic difference between the minimum limit of the size and the corresponding basic size.

6) **Tolerance** The permissible variation of a size is called tolerance. It is the difference between the maximum and minimum permissible limits of the given size. If the variation is provided on one side of the basic size, it is termed as unilateral tolerance. Similarly, if the variation is

provided on both sides of the basic size, it is known as biateral tolerance. It is absolute value without sign.

7) **Allowance** it is the dimensional difference between the maximum material limits of the mating parts, intentionally provided to obtain the desired class of fit. If the allowance is positive, it will result in minimum clearance between the mating parts and if the allowance is negative, it will result in maximum interference.

Here, the two limit dimensions of the shaft are deviating in the negative direction with respect to the basic size and those of the hole in the positive direction. The line corresponding to the basic size is called the zero line or line of zero deviation.

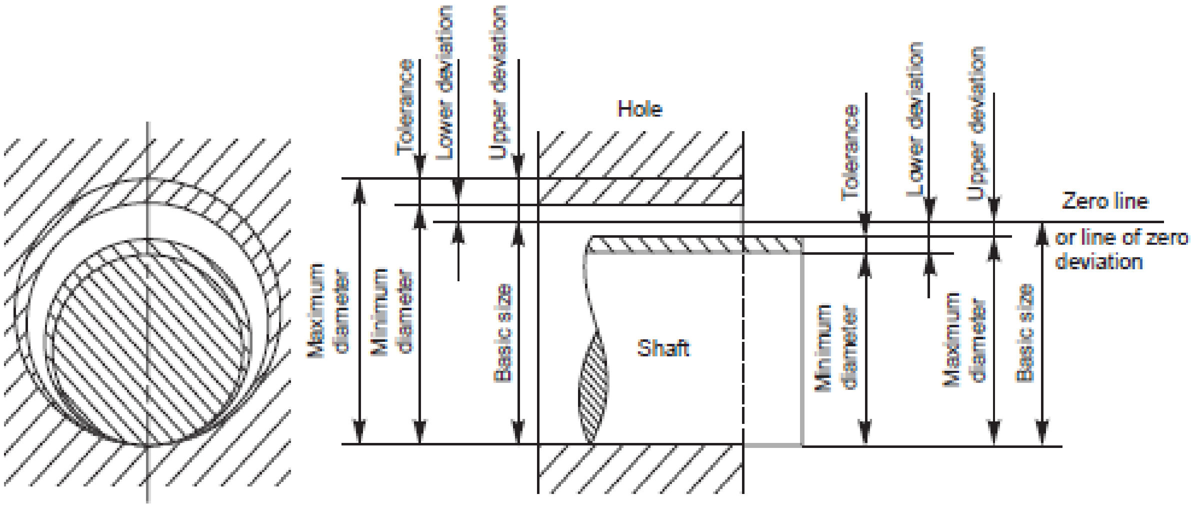
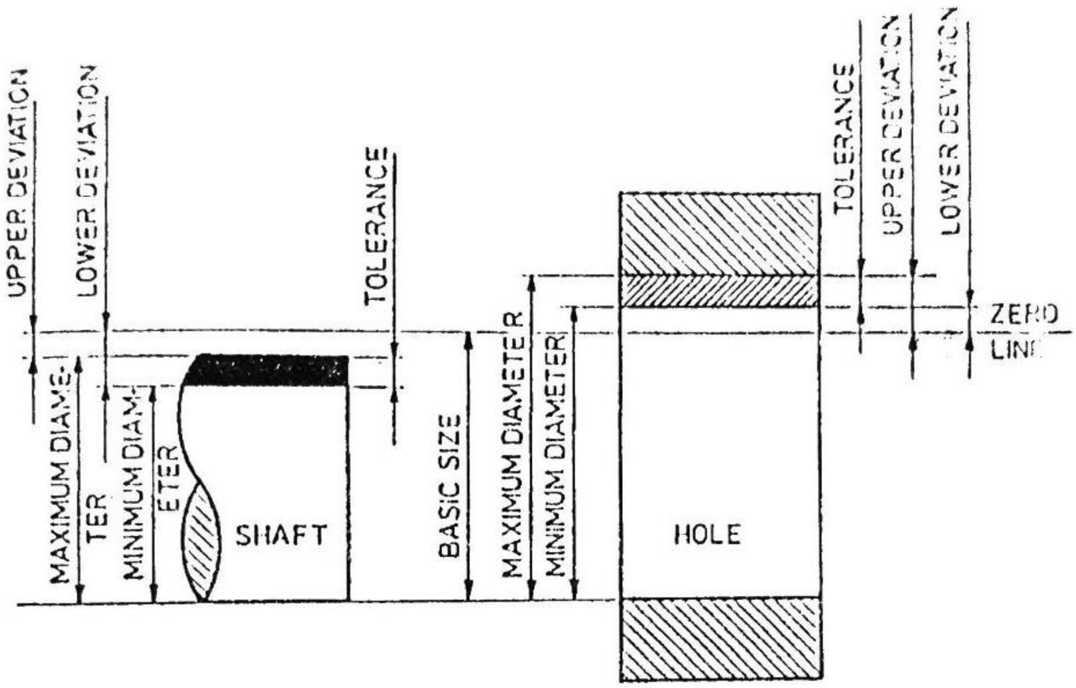
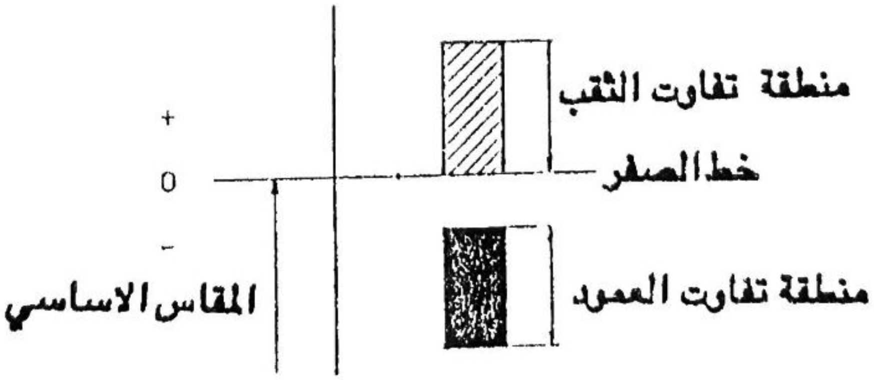


Fig. 1 Diagram illustrating basic size deviations and tolerances



ان الجزء المظلل من الثقب او العمود هو منطقة التفاوتات. ونلاحظ انها مرسومة بمقياس كبير مبالغ فيه وذلك لزيادة التوضيح .

يختصر عادة الشكل اعلاه حيث ترسم فقط منطقة التفاوت لكل من الثقب والعمود وتحذف بقية الخطوط كما في الشكل التالي :



يجب الانتباه بان الانحرافات التي تقع فوق خط الصفر تعتبر موجبة والانحرافات التي تقع تحت خط الصفر تعتبر سالبة .

INSCRIPTION OF LINEAR AND ANGULAR TOLERANCES

INTRODUCTORY NOTE

For uniformity, all the linear dimensions given in this ISO Recommendation are in metric units. It should be understood that inch units could equally well have been used without prejudice to the principles established.

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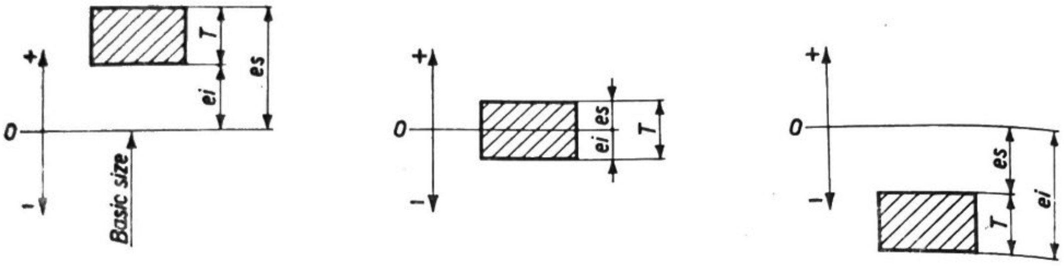
1. DEFINITIONS



T ≐ *Specified tolerance*

O = *Zero line*
Straight line to which the deviations are referred. The zero line is the line when the deviation is nil, and represents the basic size.

es = *Upper deviation of a shaft*
Algebraical difference between the maximum limit of size and the corresponding basic size.

ei = *Lower deviation of a shaft*
Algebraical difference between the minimum limit of size and the corresponding basic size.

In the figures above, the deviations are given for a shaft. For a hole, ES is used for upper deviation and EI for lower deviation.

8) **Design size**

It is that size, from which the limits of size are derived by the application of tolerances. If there is no allowance, the design size is the same as the basic size. If an allowance of 0.05 mm for clearance is applied, say to a shaft of 50 mm diameter, then its design size is (50 – 0.05) = 49.95mm. A tolerance is then applied to this dimension.

9) **Actual size** It is the size obtained after manufacture.

3- TOLERANCE

Great care and judgment must be exercised in deciding the tolerances which may be applied on various dimensions of a component. If tolerances are to be minimum, that is, if the accuracy requirements are severe, the cost of production increases. In fact, the actual specified tolerances dictate the method of manufacture. Hence, maximum possible tolerances must be recommended wherever possible.

Tolerance is denoted by two symbols, a letter symbol and a number symbol, called the grade.

It may be seen from tables that the letter symbols range from **A** to **ZC** for holes and from **a** to **zc** for shafts. The letters **I, L, O, Q, W** and **i, l, o, q, w** have not been used. It is also evident that these letter symbols represent the degree of closeness of the tolerance zone (positive or negative) to the basic size.

Similarly, it can be seen from Tables , that the basic sizes from l mm to 500 mm have been sub-divided into 13 steps or ranges. For each nominal step, there are 18 grades of tolerances, designated as IT 01, IT 0 to IT 1 to IT 16, known as “Fundamental tolerances”.

The fundamental tolerance is a function of the nominal size and its unit is given by the emperical relation, standard tolerance unit, $i = 0.45 \times 3\ D + 0.001\ D$

Where i is in microns and D is the geometrical mean of the limiting values of the basic steps mentioned above, in millimetres. This relation is valid for grades 5 to 16 and nominal sizes from 3 to 500 mm. For grades below 5 and for sizes above 500 mm, there are other empirical relations for which it is advised to refer IS: 1919–1963. Table 15.1A gives the relation between different grades of tolerances and standard tolerance unit i.

FANDEMENTAL DEVIATION

The symbols used for the fundamental deviations for the shaft and hole are as follows :

	Hole	*Shaft*
Upper deviation (E′ cart superior)	ES	es
Lower deviation (E′ cart inferior)	EI	ei

For each letter symbol from **a** to **zc** for shafts and **A** to **ZC** for holes; the magnitude and size of one of the two deviations may be obtained from Table 15.2 or 15.3 and the other deviation is calculated from the following relationship :

Shafts, ei = es – IT

Holes, EI = ES – IT

where IT is fundamental tolerance

NOTE The term ‘shaft’ in this chapter includes all external features (both cylindrical and non-cylindrical) and the term ‘hole’ includes all internal features of any component.

The fundamental deviation for holes are derived from the formulae, corresponding to the shafts, with the following modifications :

(*i*) As a general rule, all the deviations for the types of holes mentioned in (*ii*) and (*iii*) below, are identical with the shaft deviation of the same symbol, *i.e.*, letter and grade but disposed on the other side of the zero line. For example, the lower deviation EI for the hole is equal to the upper deviation *es* of the shaft of the same letter symbol but of opposite sign.

(*ii*) For the holes of sizes above 3 mm and of type N and of grade 9 and above, the upper deviation, ES is 0.

(*iii*) For the holes of size above 3 mm of types J, K, M and N of grades upto and inclusive of 8 and for the types P to ZC of grades upto and inclusive of 7, the upper deviation ES is equal to the lower deviation *ei* of the shaft of same letter symbol but one grade finer (less in number) and of opposite sign, increased by the difference between the tolerances of the two grades in question

Example *Calculate the fundamental deviations for the shaft sizes given below :*

(a) 30 e8 (b) 50 g6 (c) 40 m6.

Solution

fundamental deviation ***(is one of the deviations nearest to the zero line)***

(a) 30 e8 ***from table in page 40***

es=-40 µm ***ei= -73 µm then es is*** *fundamental deviation*

(b) 50 g6 ***from table in page41***

es=-9 ei=-25 ***µm then es is*** *fundamental deviation* *(c) 40 m6* ***<u>from table in page 43</u>***

es=+25   ei=+9 ***µm   then ei is*** *fundamental deviation*

Example *Calculate the fundamental deviations for the hole sizes given below :*

(a) 40 D9 (b) 65 F8.

<u>Solution</u>

(a) 40 D9 ***<u>from data book table in page 45</u>***

*ES=142   EI=****+80µm   then 80 is*** *fundamental deviation*

(b) 65 F8 ***<u>from DATA BOOK table in page 46</u>***

ES=+76   EI= ***+ 30 µm   then 30 is*** *fundamental deviation*

3- Methods of placing Limit dimensions (

There are three methods used in industries for placing limit dimensions or tolerancing individual dimensions.

Method 1

In this method, the tolerance dimension is given by its basic value, followed by a symbol, comprising of both a letter and a numeral. The following are the equivalent values of the terms given in Fig.4 :

$$\phi\, 25H7 = \phi\, 25^{+0.021}_{+0.000}$$

$$10H10 = 10^{+0.058}_{+0.000}$$

$$40C11 = 40^{+0.280}_{+0.120}$$

$$10h9 = 10^{-0.000}_{-0.036}$$

$$\phi\, 25h9 = \phi\, 25^{-0.000}_{-0.052}$$

$$\phi\, 40h11 = \phi\, 40^{-0.000}_{-0.160}$$

The terms φ 25*H*7, 10*H*10 and 40*C*11 refer to holes, since the terms involve capital letter symbols. The capital letter '*H*' signifies that the lower deviation is zero and the number symbol 7 signifies the grade, the value of which is 21 microns (Tables of data book) which in turn is equal to the upper deviation.

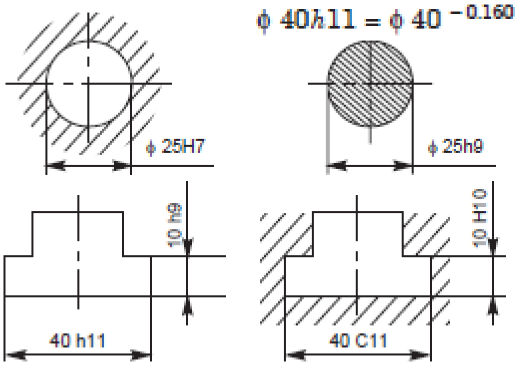
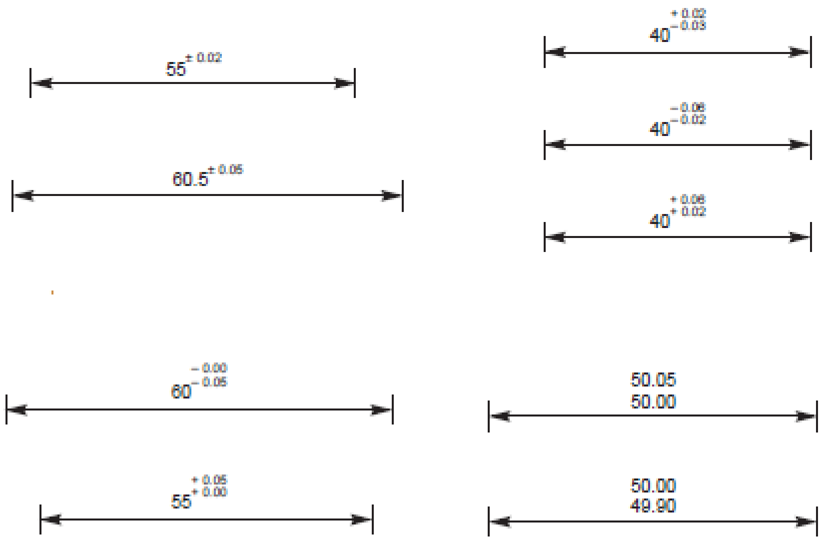


Fig. .4 Toleranced dimensions for internal and external features

The terms φ40*H*11 and 10*h*9 refer to shafts features, since the terms involve lower case letters.

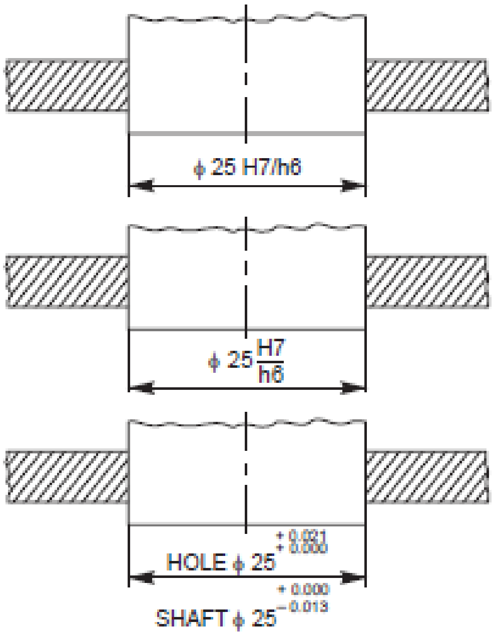
Method 2

In this method, the basic size and the tolerance values are indicated above the dimension line; the tolerance values being in a size smaller than that of the basic size and the lower deviation value being indicated in line with the basic size.



Method 3

In this method, the maximum and minimum sizes are directly indicated above the dimension line. When assembled parts are dimensioned, the fit is indicated by the basic size common to both the components, followed by the hole tolerance symbol first and then by th shaft tolerance symbol (*e.g.*, φ 25 H7/*h*6, etc., in Fig. 15.9).



2.4 Limits of size

Limits of size may also be indicated according to Figure 6.

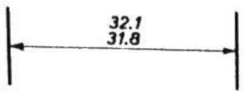


Fig. 6

2.5 Limits of size in one direction

If a dimension needs to be limited in one direction only, this should be indicated by adding «min.» or «max.» to the dimension (Fig. 7).

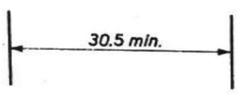
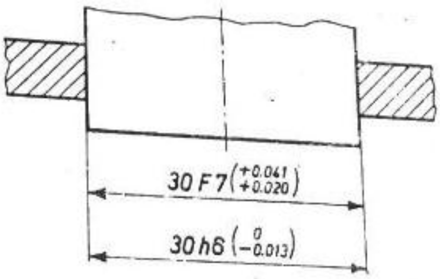


Fig. 7

If it is necessary to specify also the numerical values of the deviations, they should be written in parentheses as shown in Figure 13.



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(a) the basic size,
(b) the tolerance symbol,

(c) if it is necessary to express them, the values of the deviations, in parentheses (Fig. 2).

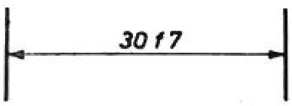


Fig. 1

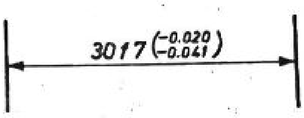


Fig. 2

2.2 Tolerances shown in figures

The components of the toleranced dimension are entered in the following order (Fig. 3):

(a) the basic size,
(b) the values of the deviations.

If one of the two deviations is nil, this should be expressed by the figure 0 (Fig. 4).

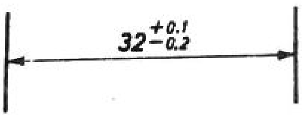


Fig. 3

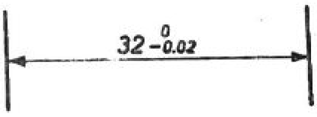


Fig. 4

2.3 Symmetrically disposed tolerance

If the tolerance is disposed symmetrically to the basic size, the value of the deviations should be written once only, preceded by the sign ± (Fig. 5).

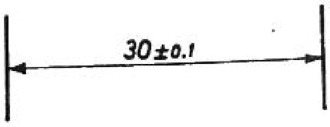


Fig. 5

• See ISO/R 286, *ISO System of limits and fits, Part I: General, tolerances and deviations.*

4. FITS

The relation between two mating parts is known as a fit. Depending upon the actual limits of the hole or shaft sizes, fits may be classified as clearance fit, transition fit and interference fit.

4.1 Clearance fit

It is a fit that gives a clearance between the two mating parts.

4.1.1 Minimum Clearance

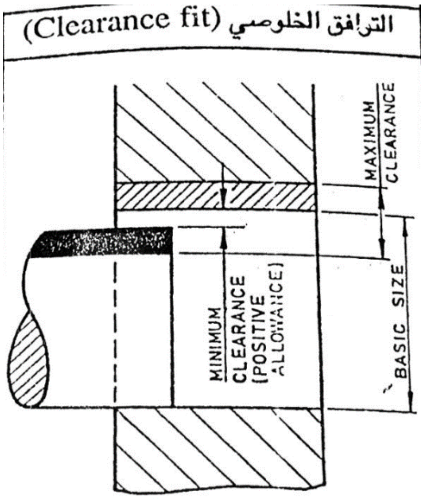
It is the difference between the minimum size of the *hole* and the maximum size of the *shaft* in a clearance fit.

4.1.2 Maximum Clearance

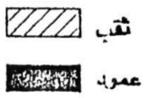
It is the difference between the maximum size of the *hole* and the minimum size of the *shaft* in a clearance or transition fit.

The fit between the shaft and hole in Fig. 15.10 is a clearance fit that permits a minimum

clearance (allowance) value of 29.95 – 29.90 = + 0.05 mm and a maximum clearance of + 0.15 mm.



يمكن اختصار الشكل اعلاه كما يلي :



نلاحظ من الرسم بان منطقة تفاوت الثقب تقع فوق منطقة تفاوت العـمود وان هناك دائما خلوص بين الجزئين .

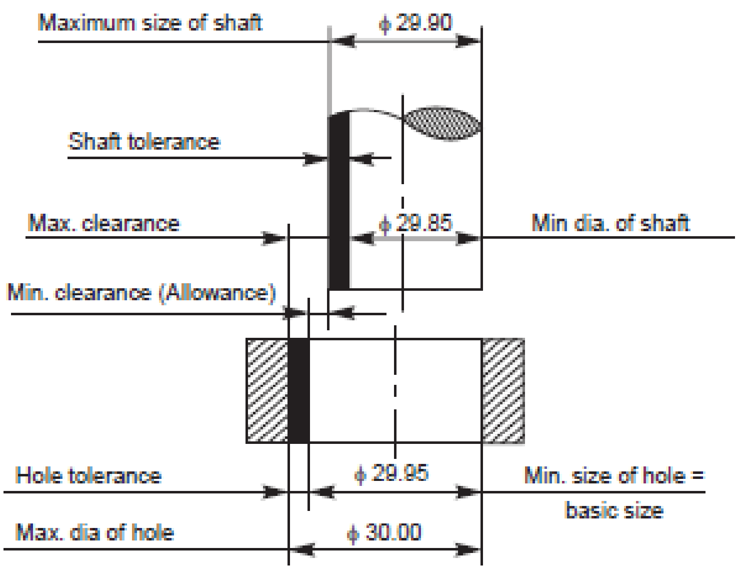


Fig. 15.10 Clearance fit

4.2 Transition Fit

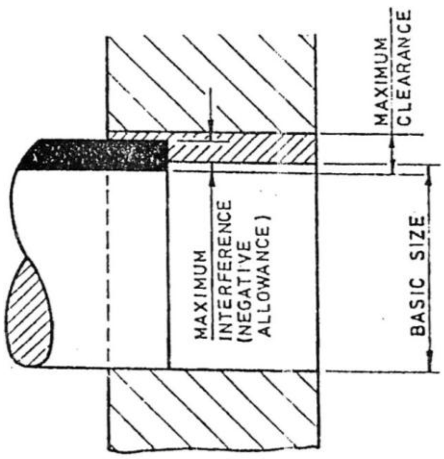
This fit may result in either an interference or a clearance, depending upon the actual values of the tolerance of individual parts. The shaft in Fig. 15.11 may be either smaller or larger

than the hole and still be within the prescribed tolerances. It results in a clearance fit, when

shaft diameter is 29.95 and hole diameter is 30.05 (+ 0.10 mm) and interference fit, when shaft

diameter is 30.00 and hole diameter 29.95 (– 0.05 mm).

(Transition fit) التوافق الانتقالي



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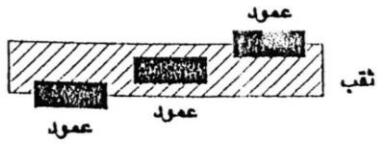


نلاحظ من الرسم بان منطقتي تفاوت الثقب والعمود متداخلتين . ممكن هذه الحالة ان تنتج خلوص أو تداخل بين الجزئين .

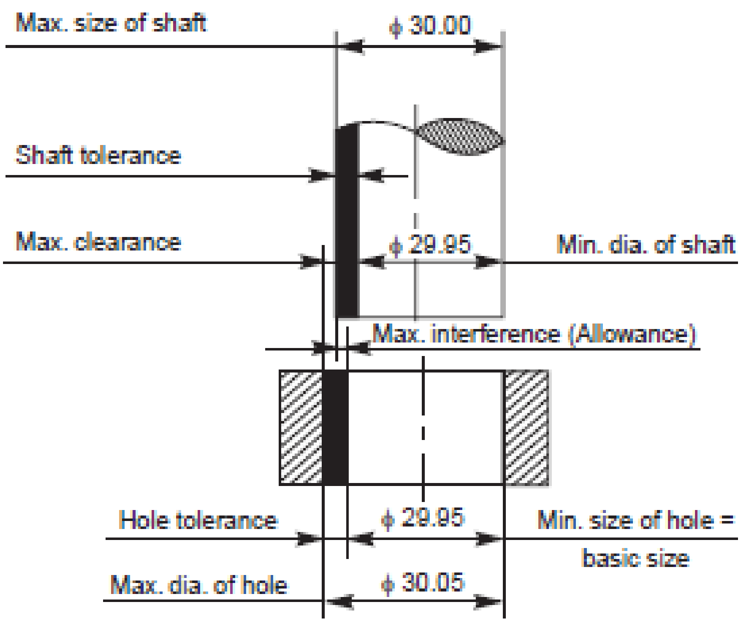
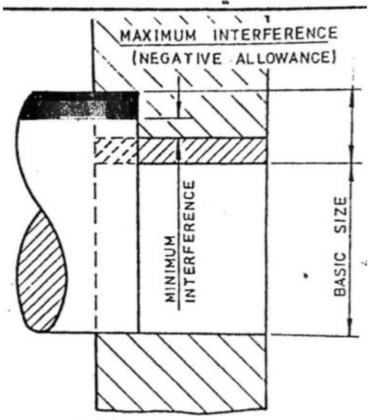


Fig. 15.11 Transition fit

4.3 Interference Fit

If the difference between the hole and shaft sizes is negative before assembly; an interference fit is obtained.

(Tnterference fit) التوافق التداخلي



4.3.1 **Minimum Interference**

It is the magnitude of the difference (negative) between the maximum size of the *hole* and the minimum size of the *shaft* in an interference fit before assembly.

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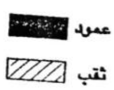


4.3.2 **Maximum Interference**

It is the magnitude of the difference between the minimum size of the *hole* and the maximum size of the *shaft* in an interference or a transition fit before assembly.

نلاحظ من الرسم بان منطقة تفاوت الثقب تقع تحت منطقة تفاوت العمود وان هناك دائما تداخل بين الجزئين .

The shaft in Fig. 15.12 is larger than the hole, so it requires a press fit, which has an effect similar to welding of two parts. The value of minimum interference is 30.25 – 30.30 = – 0.05 mm and maximum interference is 30.15 – 30.40 = – 0.25 mm.

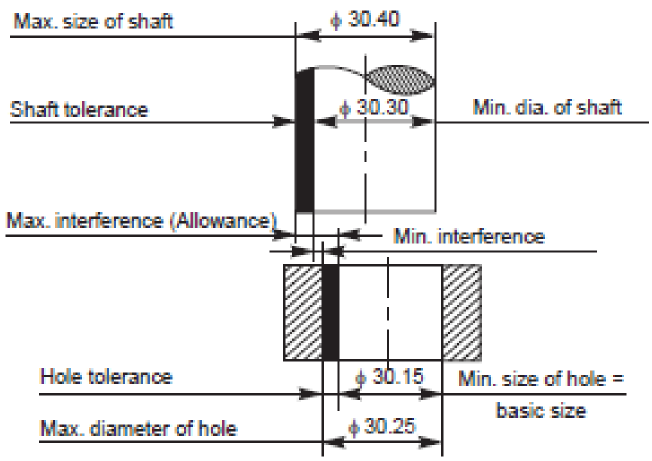
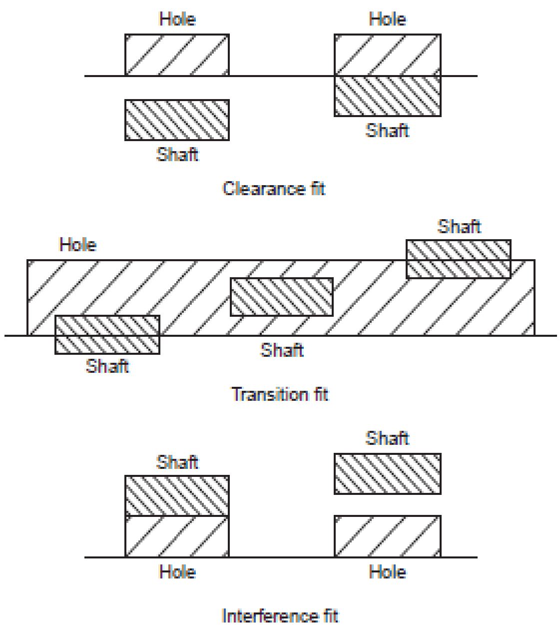
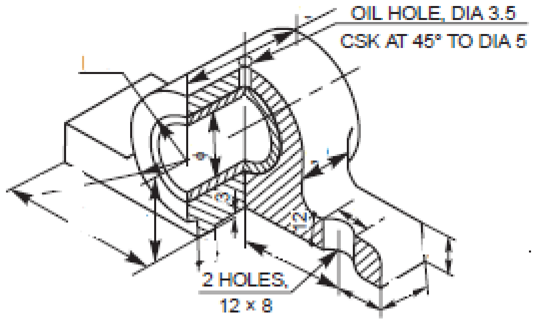


Fig. 15.12 Interference fit

shows the conventional representation of these three classes of fits.





Example *A journal bearing consists of a bronze bush of diameter 100 mm fitted into housing and a steel shaft of 50 mm diameter, running in the bush, with oil as lubricant. Determine the working dimensions of (a) bore of the housing ,* H7/p6, *(b) bush ,* H7/f7 *and (c) shaft. Calculate the maximum and minimum interference or clearance.*

Solution *Step 1:* Select the nature of assembly or fit based on the function. Referring to Tables the fits to be employed are selected as below:

(*a*) for the bush and housing, H7/p6 (interference fit),
(*b*) for the shaft and bush, H7/f 7 (normal running fit).

Step 2: Obtain the fundamental deviations based on the type of hole/shaft and thus the respective sizes. From Tables,

(a)

(*1*) for a hole of type H7 (housing), dimension of the housing bore = 100 mm ,pag.46 in data book

lower deviation, EI = 0.000
upper deviation, ES = +35 µm = +0.035 mm
Hence, dimension of the housing bore = $100^{+0.00}_{+0.037}$

(*2*) for a shaft of type *p6* (bush), dimension of the bush = 100 mm ,pag.43 in data book

lower deviation, *ei* = +37 µm = + 0.037mm
upper deviation, *es* =+59 µm = 0.059 mm
Hence, the outside size of the bush =$100_{+.037}^{+0.059}$

(b)

(*1*) for a hole of type H7 (bush), dimension of the bush = 50 mm ,pag.47 in data book

lower deviation, EI = 0.000

upper deviation, ES = 0.025 mm
Hence, the bore of the bush = 50 $0.000_{0.00}^{+0.025}$.

(*2*) for a shaft of type *f* 7, dimension of the shaft = 50 mm ,pag.41 in data book

upper deviations, *es* = – 0.025
lower deviation, *ei* = – 0.05 mm
Hence, shaft dimension is = $50_{-0.025}^{0.050}$

Step 4: Calculate the interference/clearance
(*a*) between the bush and housing :
Maximum interference = 100.00 – 100.059 = – 0.059 mm
Minimum interference = 100.035 – 100.037 = – 0.002 mm

(*b*) between the bush and shaft :
Maximum clearance = 50.025 – 49.050 = + 0.075 mm
Minimum clearance = 50.000 – 49.075 = + 0.025 mm

5.Hole bases and shaft basis system

In working out limit dimensions for the three classes of fits; two systems are in use, *viz.*, the hole basis system and shaft basis system.

5.1 Hole Basis system

In this system, the size of the shaft is obtained by subtracting the allowance from the basic size of the hole. This gives the design size of the shaft. Tolerances are then applied to each part separately. In this system, the lower deviation of the hole is zero. The letter symbol for this situation is '*H*'. The hole basis system is preferred in most cases, since standard tools like drills, reamers, broaches, etc., are used for making a hole.

5.2 Shaft Basis system

In this system, the size of the hole is obtained by adding the allowance to the basic size of the shaft. This gives the design size for the hole. Tolerances are then applied to each part. In this system, the upper deviation of the shaft is zero. The letter symbol for this situation is '*h*'. The shaft basis system is preferred by (*i*) industries using semi-finished shafting as raw materials, *e.g.*, textile industries, where spindles of same size are used as cold-finished shafting and (*ii*)when several parts having different fits but one nominal size is required on a single shaft.

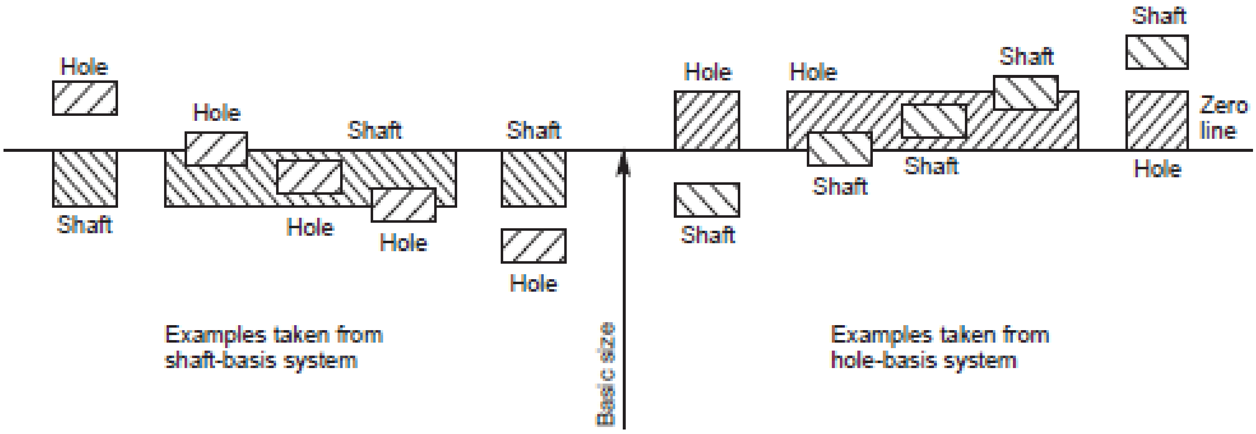


Fig. 15.14 Examples illustrating shaft basis and hole basis systems

HOME WORK

1. Calculate the maximum and minimum limits for both the shaft and hole in the following; using the tables for tolerances and name the type of fit obtained:

(*a*) 45H8/d7 (*b*) 180H7/n6 (*c*) 120H7/s6

(*d*) 40G7/h6 (*e*) 35 C11/h10

2. A schematic representation of basic size and its deviations are given in Fig. below Calculate the following in each case for a shaft of 50 mm basic size:

(*a*) Upper deviation (*b*) Lower deviation (*c*) Tolerance

(*d*) Upper limit size (*e*) Lower limit size