II.1 A Material

A material is a substance of natural or artificial origin, used for the manufacture of objects, machines, or for the construction of buildings, vehicles, etc.

The designations of materials are subject to standards that maintain the coding used by manufacturers, and more generally by the international community.

II.1.1 Construction Materials

Most materials used in mechanical construction are metallic materials (steel, cast iron, aluminum, copper, etc.) and non-metallic materials (plastics, ceramics, and composites). In the following sections, we will present some mechanical properties of a few metallic materials.

II.2 Criteria for Material Selection

During product design, the designer will choose a material that meets the criteria set forth by the functional specifications.

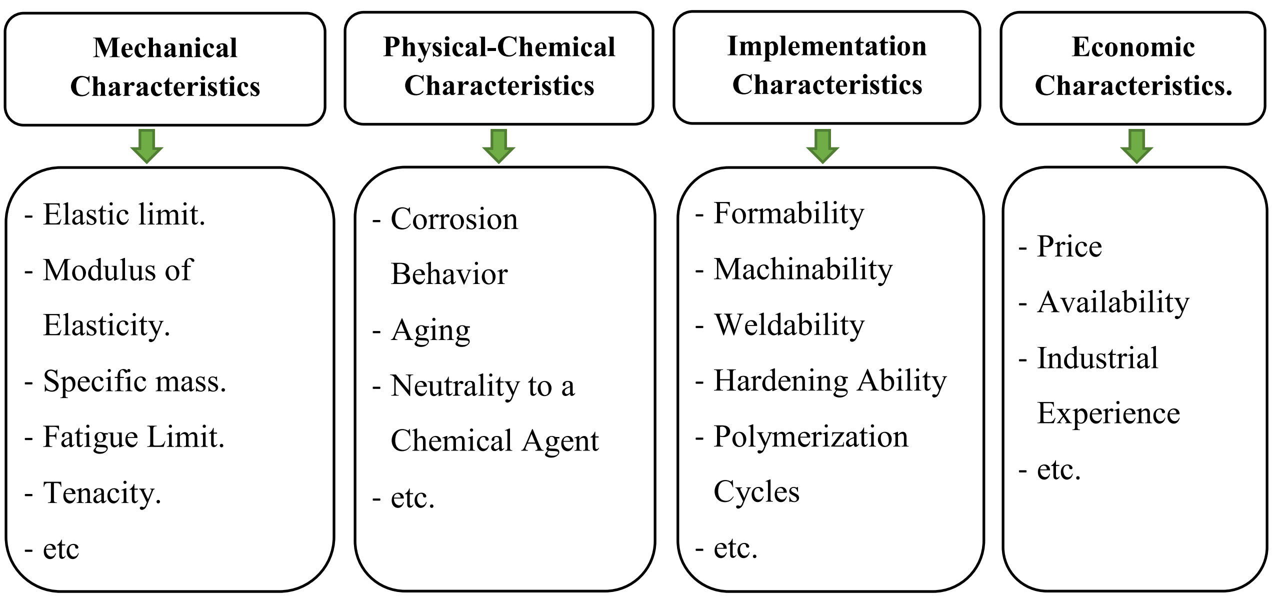


Figure II.1 Criteria for Material Selection

II.3 Strength of Materials and Stresses

II.3.1 Properties of Materials Used in Mechanical Construction

1. Tenacity: This is the resistance to applied forces (deformation and fracture).

2. Elasticity: This is the ability of a material to return to its original shape after the removal of the applied force.

3. Resilience: This is the resistance to fracture and impacts.

4. Endurance: This is the resistance to repeated stresses. It is characterized by the fatigue limit or by the lifespan.

5. Ductility: This is the ability of materials to deform before fracture. It is characterized by the elongation A%, the reduction of area Z%, and resilience in impact tests.

6. Acoustic Resistance: Soundproofing aims to prevent the propagation of sound (through internal or external acoustic insulation), but many materials, referred to as "thermal-acoustic insulation," can serve a triple function—acoustic, phonetic, and thermal (usually consisting of foam or fiber panels).

7. Sealing: Physical sealing concerns the prevention of the passage of a solid, fluid, or gas. In the context of sealing, this passage is referred to as a leak.

8. Corrosion: The corrosion of a metal is the gradual deterioration of the material caused by a chemical and/or electrochemical reaction with the environment. It is a natural process that converts the metal into a stable chemical form.

9. Specific Load

II.3.2 Mechanical Characteristics of Metallic Materials

The following table shows the main mechanical characteristics of some metallic materials used in mechanical construction.

Material	Elastic limit Re in tension Re(MPa)	Elastic limit in Compression Rec(MPa)	Tensile Strength (MPa)	Young's Modulus (E) (GPa)	Density	Brinell Hardness
Cast Iron C>2%	140 - 680	5*Re	410 - 830	60 - 160	6.8	200 - 300
Steel C<2%	250 - 600	210	400 - 700	210	7.8	120 - 205
Copper	50 - 350	100	210 - 400	120	8.92	90 - 120
Aluminum	20 - 300	65 - 400	70 - 300	76	2.7	65 - 95

Table II.1 Mechanical Properties of Some Metallic Materials

The The elastic limit Re represents a maximum stress that should not be exceeded in practical applications, under penalty of causing the components to deform in a plastic or permanent manner. From Table 1, we notice that the elastic limit Rec in compression of cast iron is five times greater than its elastic limit Re in tension, which means that cast iron is more resistant to compression than to tension.

Another important parameter is the modulus of elasticity or Young's modulus E, which provides an idea of the material's stiffness. It represents the slope of the stress-strain curve in the elastic range and is calculated using the following formula:

$$\boldsymbol{\sigma_e = E.\varepsilon_e}$$

$\boldsymbol{\sigma_e}$ and $\boldsymbol{\varepsilon}$ are respectively the elastic stress and elastic strain. Depending on the amount of carbon present in the steel, it can be classified into several categories:

- If the carbon percentage C < 0.025%, the steel is referred to as extra soft steel.
- If the carbon percentage C < 0.3%, the steel is referred to as soft steel.
- If the carbon percentage is between 0.3% < C < 0.5%, the steel is referred to as medium-hard steel.
- If the carbon percentage C > 0.5%, the steel is referred to as very hard steel with high strength.

II.3.3 Mechanical Characteristics of Materials

1. Tensile Strength Rm = σm: Standard unit MPa [N/mm²]; it is the resistance of a given section to a maximum tensile force. R = F/S

2. Conventional elasticity (Yield) Limit 0.1% or 0.2%: Rp0.1 or Rp0.2

3. Apparent elasticity (Yield) Limit Re: In the tensile curve.

4. Elongation after rupture (at Break) A (unit %): The formulas are found:

$\sigma_e = R_e = F/S$; $\sigma_p = F_p / S$; $\varepsilon = (L - Lo)/Lo$; $A\% = (L - Lo)\ 100 / lo$; $E = \sigma_m / \varepsilon$.

5. Brinell Hardness HB: HB=F/S [daN/mm^2]; avec $S = \pi D/2\ (D - \sqrt{D^2 - d^2})$; avec D=1, 2.5, 5, 10 mm^2 ; $F = 30D^2$.

Rockwell Hardness HRB or HRc ; e=e1-e0 ; HRc=100-e ; HRB=130-e.

Vickers Hardness Hv= F/S =1,8544 . F_{kgf}/d^2 = 0.1891. F_N/d^2.

6. Resilience: (Charpy Test) K=W/S [J/cm^2] ; avec W= P(H-h); P=m.g

K: **Resilience**, represented by the general symbol K, characterizes a material's ability to absorb shocks without breaking. **W**: The energy absorbed by the specimen

II.4 Surface Quality of a Part

II.4.1 Roughness

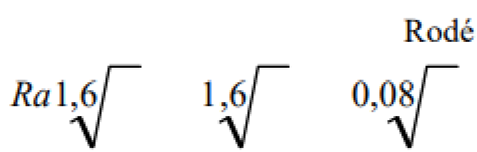
II.4.1 Roughness: It is the characteristic of the surface state of a solid material. It is subject to several technical interpretations.

II.4.2 Roughness Indication

Roughness is symbolized by: $\sqrt{}$

This symbol must be placed on the representative line of the surface or its extension. Inside the symbol, the value in microns of the selected roughness criterion chosen as the admissible limit is written.

Examples:



II.4.3 Main Parameters Related to the Mean Line

The parameters are defined over an evaluation length (1) that includes 'n' base lengths. For example, five base lengths l (Fig II.2).

Arithmetic mean Deviation of the Profile Ra

Ra is equal to the arithmetic mean, calculated over the base length, of the absolute value of the ordinate z at each point of the profile and the OX axis.

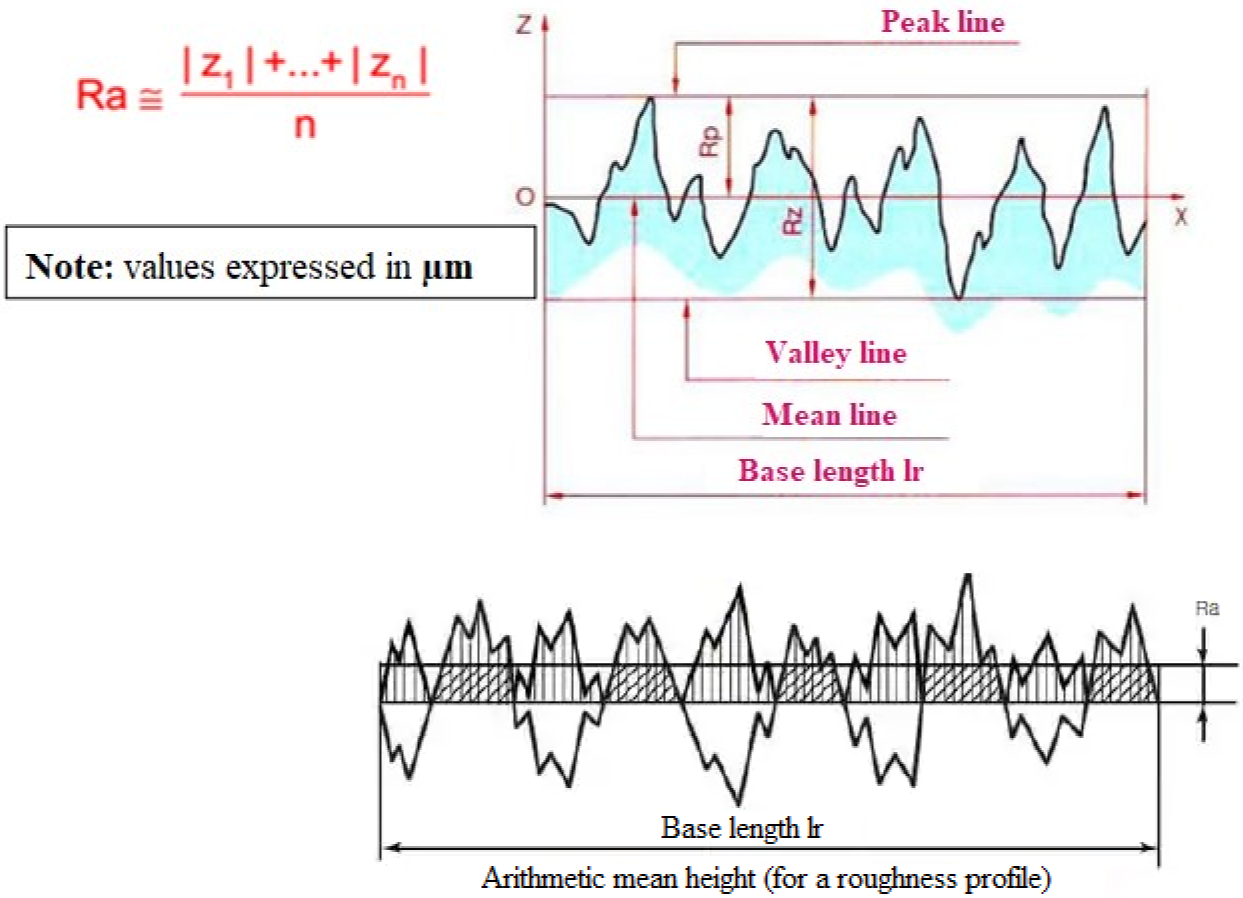


Figure II.2: Roughness measurement parameter Ra.

Maximum profile height Rz: It is the distance between the peak line and the valley line.

Maximum peak height Rp: It is the distance between the peak line and the average (mean) line.

Maximum peak Rp

Maximum peak observed over the analyzed length. If a Cartesian coordinate system is established with the x-axis aligned with the central line of the surface to be measured, the maximum peak, read on the y-axis, can also be noted as **Rp = ymax** (see diagram below).

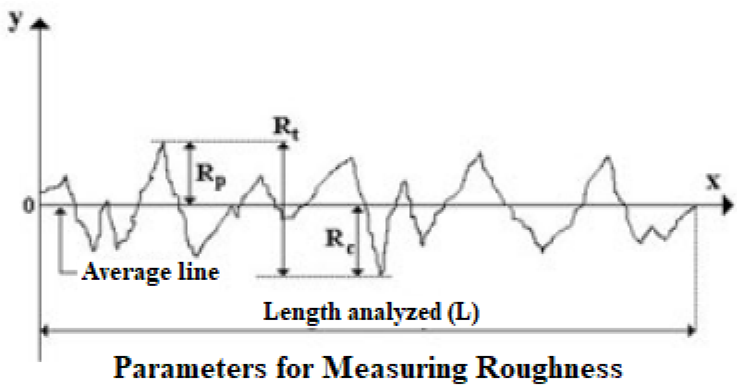


Figure II.3 : Parameters for Measuring Roughness Rp

Maximum Depth Rc

Maximum depth observed over the analyzed length (see diagram below). Rc: Rc = | ymin |

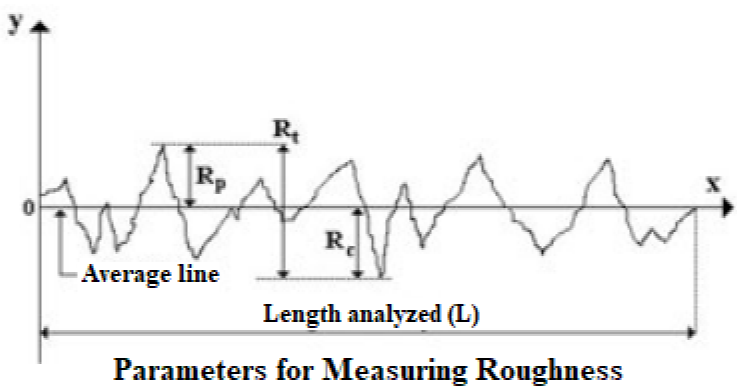


Figure II.4 : Parameters for Measuring Roughness Rc

Total Roughness Rt

Total roughness: It corresponds to the sum of the maximum peak and the maximum depth observed over the analyzed length. Rt = Rp + Rc (see diagram below).

II.5 Tolerance and Fit

II.5.1 Tolerance

Due to the inevitable imprecision of manufacturing processes, a part cannot be made precisely to a predetermined dimension. To serve its purpose, it is sufficient that it falls within two acceptable limits, the difference of which constitutes the tolerance (Fig II.5). We find:

Nominal dimension (Basic saiz): this is the dimension indicated on the drawing common to the **shaft** and the **hole (bore)**.

Limit dimensions: maximum and minimum between which the actual dimension must fall.

Deviation: algebraic difference between a dimension (actual, maximum, or minimum) and the corresponding nominal dimension.

II.5.2 Fit

It results from the difference before assembly between the dimensions of two parts intended to be assembled. We find:

Clearance fit: the tolerance zone of the bore is entirely above the tolerance zone of the shaft.

Interference fit: the tolerance zone of the bore is below that of the shaft (thus inverted).

Transition fit: sometimes clearance, sometimes interference. That is, we find opposite signs for the maximum and minimum. Example: $C_{max} > 0$ and $C_{min} < 0$ or vice versa;

Note: The calculation for clearance is: **Maxi clearance = Maxi size of hole - Mini size of shaft**

= Higher limit of hole - Lower limit of shaft

= HLH – LLS

= (BS + ES) – (BS – ei)

Mini clearance = Mini size of hole - Maxi size of shaft

= **Lower limit of hole - Higher limit of shaft**

= LLH – HLS

= (BS + EI) – (BS – es)

The calculation for **interference** is: I_{max} **= es-EI and** I_{min} **=ei-ES**

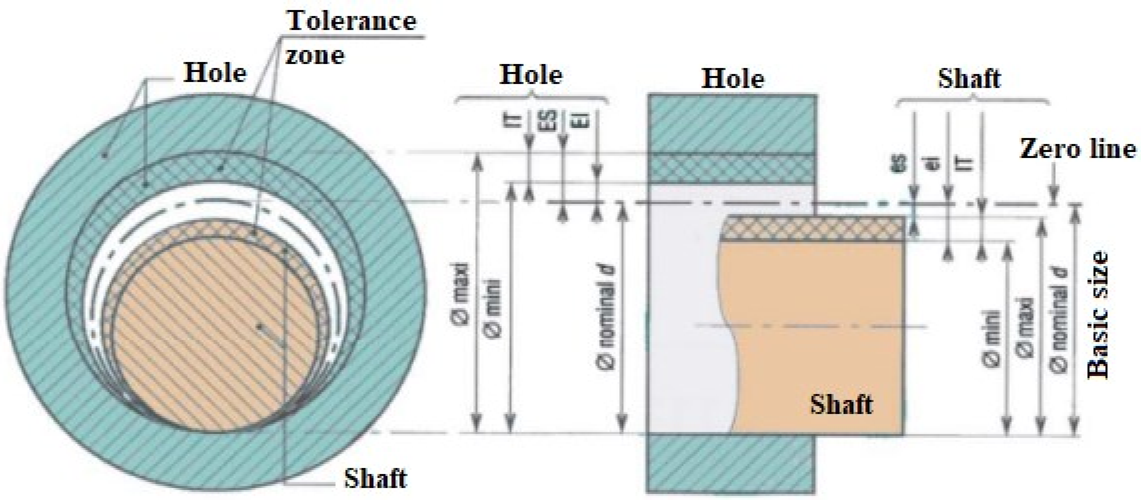


Fig II.5 Tolerance and Fit

Tolerance Quality: It is the numerical value in "microns" of the IT (the tolerance interval). The ISO system provides thirteen tolerance grades for nominal dimensions ranging from 1 to 500 mm. Each of these grades is divided into eighteen qualities marked by the numbers 01 to 16 (the most commonly used values are from 5 to 11).

Tolerance position: The position of the tolerance interval is determined by a letter (sometimes two) relative to the nominal dimension. Uppercase for bores (Holes), lowercase for shafts (Fig. II.6) for specific positions, we find:

Normal bore (Hole) is at H → Ei = 0; JS → ES = EI

Normal shaft is at h → es = 0; js → es = ei

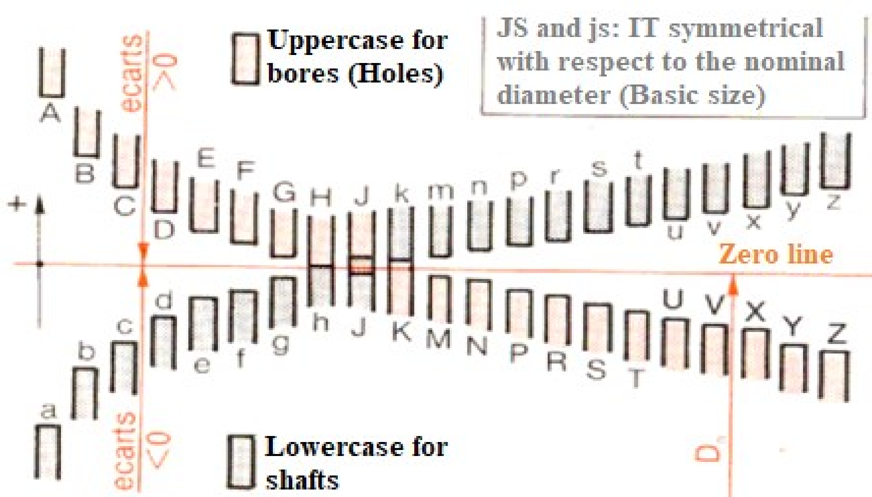


Fig II.6 Relative Position of IT

Fit

It refers to the assembly of a shaft and a hole (Fig II.7). To reduce tooling (drills, reamers), one limits the use to one of the following two systems:

1. **Normal Bore System** (preferably used). The position of the IT of the bore (Hole) is fixed by the letter H (Ei=0), allowing for clearance or interference by varying the position of the IT of the shaft.
2. **Normal Shaft System**; used when the shaft is "commercialized" (bearings, drawn bars or tubes, etc.), delivered with a tolerance position h (es=0). The desired fit is achieved by varying the position of the IT of the bore.

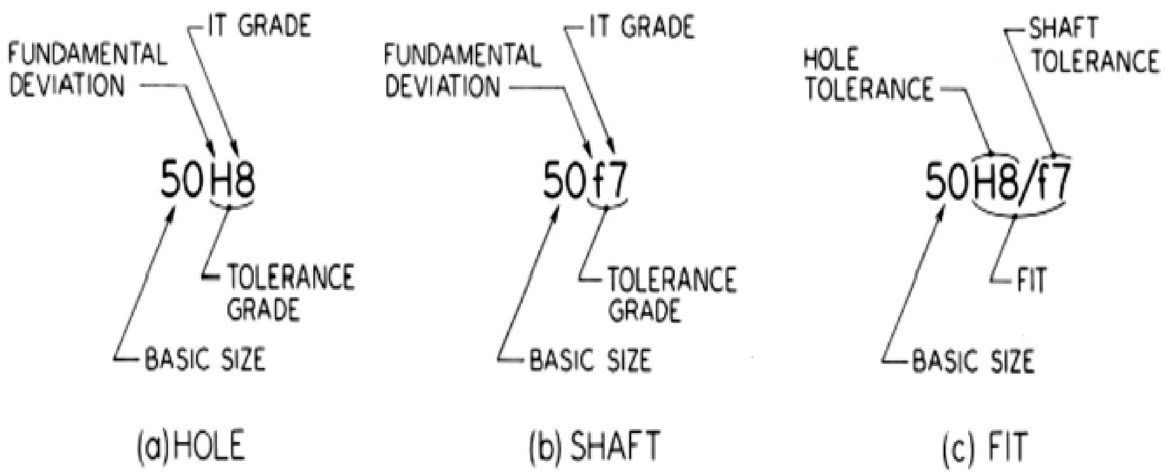
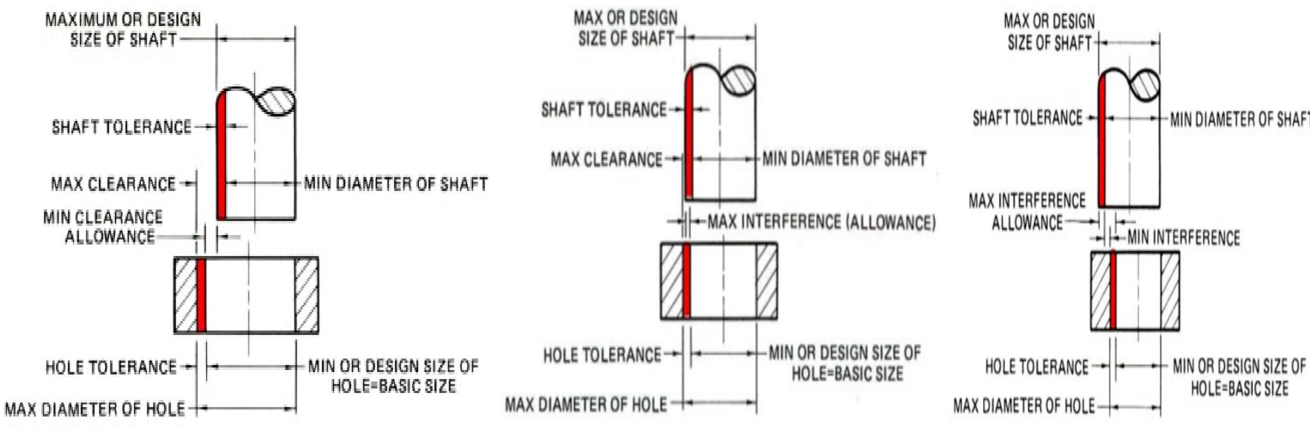


Fig II.7 Application of definitions of symbols to holes and shafts

- **Allowance**

Translate this text into French. An allowance is the intentional difference between the maximum material limits, that is, LLH and HLS (minimum clearance or maximum interference) of the two mating parts. It is the prescribed difference between the dimensions of the mating parts to obtain the desired type of fit. Allowance may be positive or negative. Positive allowance indicates a clearance fit, and an interference fit is indicated by a negative allowance.

Allowance = Maximum metal condition of hole - Maximum metal condition of shaft



(A) CLEARANCE FIT (B) TRANSITION FIT (C) INTERFERENCE FIT

Example 1 The following limits are specified in a limit system, to give a clearance fit between a hole and a shaft:

Hole = $\mathbf{25^{+0.03}_{0.000}}$ and shaft = $\mathbf{25^{-0.006}_{-0.020}}$

Determine the following:

a) Basic size

b) Tolerances on shaft and hole

c) Maximum and minimum clearances.

d) Determination of allowance

Example 2 For the following hole and shaft assembly, determine

(a) hole and shaft tolerance

(b) type of fit.

Hole = $\mathbf{20^{+0.025}_{+0.000}}$ and shaft = $\mathbf{20^{+0.080}_{+0.005}}$

ISO Tolerances for Shafts (ISO 286-2)																				
Nominal Shaft Sizes (mm)																				
over	3	6	10	18	30	40	50	65	80	100	120	140	160	180	200	225	250	280	315	355
inc.	6	10	18	30	40	50	65	80	100	120	140	160	180	200	225	250	280	315	355	400
micrometres																				
a12	-270 -390	-280 -430	-290 -470	-300 -510	-310 -560	-320 -570	-340 -640	-360 -660	-380 -730	-410 -760	-460 -860	-520 -920	-580 -980	-660 -1120	-740 -1200	-820 -1280	-920 -1440	-1050 -1570	-1200 -1770	-1350 -1920
d6	-30 -38	-40 -49	-50 -61	-65 -78	-80 -96		-100 -119		-120 -142		-145 -170			-170 -199			-190 -222		-210 -246	
e6	-20 -28	-25 -34	-32 -43	-40 -53	-50 -66		-60 -79		-72 -94		-85 -110			-100 -129			-110 -142		-125 -161	
e13	-20 -200	-25 -245	-32 -302	-40 -370	-50 -440		-60 -520		-72 -612		-85 -715			-100 -820			-110 -920		-125 -1015	
f5	-10 -15	-13 -19	-16 -24	-20 -29	-25 -36		-30 -43		-36 -51		-43 -61			-50 -70			-56 -79		-62 -87	
f6	-10 -18	-13 -22	-16 -27	-20 -33	-25 -41		-30 -49		-36 -58		-43 -68			-50 -79			-56 -88		-62 -98	
f7	-10 -22	-13 -28	-16 -34	-20 -41	-25 -50		-30 -60		-36 -71		-43 -83			-50 -96			-56 -108		-62 -119	
g5	-4 -9	-5 -11	-6 -14	-7 -16	-9 -20		-10 -23		-12 -27		-14 -32			-15 -35			-17 -40		-18 -43	
g6	-4 -12	-5 -14	-6 -17	-7 -20	-9 -25		-10 -29		-12 -34		-14 -39			-15 -44			-17 -49		-18 -54	
g7	-4 -16	-5 -20	-6 -24	-7 -28	-9 -34		-10 -40		-12 -47		-14 -54			-15 -61			-17 -69		-18 -75	
h4	-0 -4	-0 -4	-0 -5	-0 -6	-0 -7		-0 -8		-0 -10		-0 -12			-0 -14			-0 -16		-0 -18	
h5	-0 -5	-0 -6	-0 -8	-0 -9	-0 -11		-0 -13		-0 -15		-0 -18			-0 -20			-0 -23		-0 -25	
h6	-0 -8	-0 -9	-0 -11	-0 -13	-0 -16		-0 -19		-0 -22		-0 -25			-0 -29			-0 -32		-0 -36	
h7	-0 -12	-0 -15	-0 -18	-0 -21	-0 -25		-0 -30		-0 -35		-0 -40			-0 -46			-0 -52		-0 -57	
h8	-0 -18	-0 -22	-0 -27	-0 -33	-0 -39		-0 -46		-0 -54		-0 -63			-0 -72			-0 -81		-0 -89	
h9	-0 -30	-0 -36	-0 -43	-0 -52	-0 -62		-0 -74		-0 -87		-0 -100			-0 -115			-0 -130		-0 -140	
h10	-0 -48	-0 -58	-0 -70	-0 -84	-0 -100		-0 -120		-0 -140		-0 -160			-0 -185			-0 -210		-0 -230	

Table II.2 ISO Tolerances for Shafts (ISO 286-2

ISO Tolerances for Holes (ISO 286-2)																				
Nominal hole sizes (mm)																				
over	3	6	10	18	30	40	50	65	80	100	120	140	160	180	200	225	250	280	315	355
inc.	6	10	18	30	40	50	65	80	100	120	140	160	180	200	225	250	280	315	355	400
micrometres																				
E6	+28 +20	+34 +25	+43 +32	+53 +40	+66 +50		+79 + 60		+94 +72		+110 +85			+129 +100			+142 +110		+161 +125	
E7	+32 +20	+40 +25	+50 +32	+61 +40	+75 +50		+90 + 60		+107 +72		+125 +85			+146 +100			+162 +110		+185 +125	
E11	+95 +20	+115 +25	+142 +32	+170 +40	+210 +50		+250 + 60		+292 +72		+335 +85			+390 +100			+430 +110		+485 +125	
E12	+140 +20	+175 +25	+212 +32	+250 +40	+300 +50		+360 + 60		+422 +72		+485 +85			+560 +100			+630 +110		+695 +125	
E13	+200 +20	+245 +25	+302 +32	+370 +40	+440 +50		+520 + 60		+612 +72		+715 +85			+820 +100			+920 +110		+1 015 +125	
F6	+18 +10	+22 +13	+27 +16	+33 +20	+41 +2		+49 + 30		+58 +36		+68 43			+79 +50			+88 +56		+98 +62	
F7	+22 +10	+28 +13	+34 +16	+41 +20	+50 +25		+60 + 30		+71 +36		+83 43			+96 +50			+108 +56		+119 +62	
F8	+28 +10	+35 +13	+43 +16	+53 +20	+64 +25		+76 + 30		+90 +36		+106 43			+122 +50			+137 +56		+151 +62	
G6	+12 +4	+14 +5	+17 +6	+20 +7	+25 +9		+29 +10		+34 + 12		+39 +14			+44 +15			+49 +17		+54 +18	
G7	+16 +4	+20 +5	+24 +6	+28 +7	+34 +9		+40 +10		+47 + 12		+54 +14			+61 +15			+69 +17		+75 +18	
G8	+22 +4	+27 +5	+33 +6	+40 +7	+48 +9		+56 +10		+66 + 12		+77 +14			+87 +15			+98 +17		+107 +18	
H6	+8 0	+9 0	+11 0	+13 0	+16 0		+19 0		+22 0		+25 0			+29 0			+32 0		+36 0	
H7	+12 0	+15 0	+18 0	+21 0	+25 0		+30 0		+35 0		+40 0			+46 0			+52 0		+57 0	
H8	+18 0	+22 0	+27 0	+33 0	+39 0		+46 0		+54 0		+63 0			+72 0			+81 0		+89 0	
H9	+30 0	+36 0	+43 0	+52 0	+62 0		+74 0		+87 0		+100 0			+115 0			+130 0		+140 0	
H10	+48 0	+58 0	+70 0	+84 0	+100 0		+120 0		+140 0		+160 0			+185 0			+210 0		+230 0	
H11	+75 0	+90 0	+110 0	+130 0	+160 0		+190 0		+220 0		+250 0			+290 0			+320 0		+360 0	
J6	+5 -3	+5 -4	+6 -5	+8 -5	+10 -6		+13 -6		+16 -6		+18 -7			+22 -7			+25 -7		+29 -7	
J7	+6 -6	+8 -7	+10 -8	+12 -9	+14 -11		+18 -12		+22 -13		+26 -14			+30 -16			+36 -16		+39 -18	
J8	+10 -8	+12 -10	+15 -12	+20 -13	+24 -15		+28 -18		+34 -20		+41 -22			+47 -25			+55 -26		+60 -29	

Table II.3 ISO Tolerances for Holes (ISO 286-2)