Tolerance and Fits

Chapter 13

Material taken from Mott, 2003, Machine Elements in Mechanical Design.

Tolerances and Fits

- The term tolerances refers to the permissible deviation of a dimension from the specified basic size.
- The proper performance of a machine can depend on the tolerances specified for its parts, particularly those that must fit together for location or for suitable relative motion.

Tolerances and Fits

- The term fit usually refers to the clearances that are permissible between mating parts in a mechanical device that must assemble easily and that must often move relative to each other during normal operation of the device.
- Such fits are usually called running or sliding fits.

Tolerances and Fits

- Fit can also refer to the amount of interference that exists when the inside part should be larger than the outside part.
- Interference fits are used to ensure that mating parts do not move relative to each other.

Factors Affecting Tolerances and Fits

- Consider the plain surface bearings. A critical part of the design is the specification of the diametrical clearance between the journal and the bearing.
- The typical value is just a few thousandths of an inch.
- But some variation must be allowed on both the journal outside diameter and the bearing inside diameter for reasons of economy of manufacture.

Factors Affecting Tolerances and Fits con't

- There will be variation of the actual clearance in production devices, depending on where the individual mating components fall within their own tolerance bands.
- Too small a clearance could cause seizing.
- Conversely, too large a clearance would reduce the precision of the machine and adversely affect the lubrication.

Tolerances, Production Processes, and Costs

- A unilateral tolerance deviates in only one direction from the basic size.
- A bilateral tolerance deviates both above and below the basic size.
- The total tolerance is the difference between the maximum and minimum permissible dimensions.

Tolerances, Production Processes, and Costs con't

- The term allowance refers to an intentional difference between the maximum material limits of mating parts.
- For example, a positive allowance for a hole/shaft pair would define the minimum clearance between mating parts from the largest shaft mating with the smallest hole.
- A negative allowance would result in the shaft being larger than the hole (interference).

Tolerances, Production Processes, and Costs con't

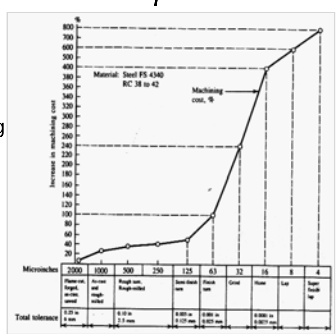
- The term fit refers to the relative looseness (clearance fit) or tightness (interference fit) of mating parts, especially as it affects the motion of the parts or the force between them after assembly.
- Specifying the degree of clearance or interference is one of the tasks of the designer.

Tolerances, Production Processes, and Costs con't

- It is costly to produce components with very small tolerances on dimensions.
- It is the designer's responsibility to set the tolerances at the highest possible level that results in satisfactory operation of the machine.
- The production of part features with small tolerances usually involves finer surface finishes.

Machining Costs Versus Surface Finish Specified

- This shows the general relationship between the surface finish and the relative cost of producing a part.
- The typical total tolerance produced by the processes described is included in the figure.
- The increase in cost is dramatic for the small tolerances and fine finishes.

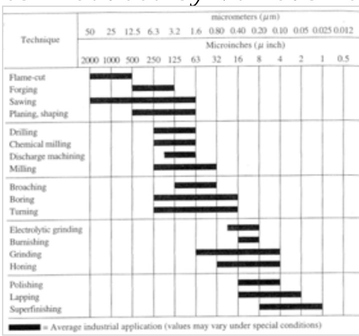


Mott, 2003, Machine Elements in Mechanical Design.

Tolerances, Production Processes, and Costs con't

- The term tolerance grade refers to a set of tolerances that can be produced with an approximately equal production capability.
- The actual total tolerance allowed within each grade depends on the nominal size of the dimension.
- Smaller tolerances can be achieved for smaller dimensions, and vice versa.

Finishes Produced by Various Techniques



Mott, 2003, Machine Elements in Mechanical Design.

TABLE 13–1 Tolerance grades

Application	Tolerance grades								
Measuring tools	01	0	1	2	3	4	5	6	7
Fits of machined parts	4	5	6	7	8	9	10	11	
Material, as supplied	8	9	10	11	12	13	14		
Rough forms (casting, sawing, forging, etc.)	12	13	14	15	16				

TABLE 13–2 Tolerances for some tolerance grades

	Tolerance grade							
	4	5	6	7	8	9	10	11
Nominal size (in)	Tolerances in thousandths of an inch							
0.24–0.40	0.15	0.25	0.4	0.6	0.9	1.4	2.2	3.5
0.40–0.71	0.20	0.3	0.4	0.7	1.0	1.6	2.8	4.0
0.71–1.19	0.25	0.4	0.5	0.8	1.2	2.0	3.5	5.0
1.19–1.97	0.3	0.4	0.6	1.0	1.6	2.5	4.0	6.0
1.97–3.15	0.3	0.5	0.7	1.2	1.8	3.0	4.5	7.0
3.15–4.73	0.4	0.6	0.9	1.4	2.2	3.5	5.0	9.0
4.73–7.09	0.5	0.7	1.0	1.6	2.5	4.0	6.0	10.0

Mott, 2003, Machine Elements in Mechanical Design.

Preferred Basic Sizes

- The first step in specifying a dimension for a part is to decide on the basic size, that dimension to which the tolerances are applied.
- The analysis for strength, deflection, or performance of the part determines the nominal or minimum size required.
- Unless special conditions exist, the basic size should be chosen from the lists of preferred basic sizes in Table A2-1 for fractional-inch sizes, decimal-inch sizes, and metric sizes from the SI.

Fractional (in)				Decimal (in)			Metric (mm)					
							First	Second	First	Second	First	Second
1/64	0.015 625	5	5.000	0.010	2.00	8.50	1		10		100	
1/32	0.031 25	5¼	5.250	0.012	2.20	9.00		1.1		11		110
1/16	0.0625	5½	5.500	0.016	2.40	9.50	1.2		12		120	
3/32	0.093 75	5¾	5.750	0.020	2.60	10.00		1.4		14		140
1/8	0.1250	6	6.000	0.025	2.80	10.50	1.6		16		160	
5/32	0.156 25	6½	6.500	0.032	3.00	11.00		1.8		18		180
3/16	0.1875	7	7.000	0.040	3.20	11.50	2		20		200	
1/4	0.2500	7½	7.500	0.05	3.40	12.00		2.2		22		220
5/16	0.3125	8	8.000	0.06	3.60	12.50	2.5		25		250	
3/8	0.3750	8½	8.500	0.08	3.80	13.00		2.8		28		280
7/16	0.4375	9	9.000	0.10	4.00	13.50	3		30		300	
1/2	0.5000	9½	9.500	0.12	4.20	14.00		3.5		35		350
9/16	0.5625	10	10.000	0.16	4.40	14.50	4		40		400	
5/8	0.6250	10½	10.500	0.20	4.60	15.00		4.5		45		450
11/16	0.6875	11	11.000	0.24	4.80	15.50	5		50		500	
3/4	0.7500	11½	11.500	0.30	5.00	16.00		5.5		55		550
7/8	0.8750	12	12.000	0.40	5.20	16.50	6		60		600	
1	1.000	12½	12.500	0.50	5.40	17.00		7		70		700
1¼	1.250	13	13.000	0.60	5.60	17.50	8		80		800	
1½	1.500	13½	13.500	0.80	5.80	18.00		9		90		900
1¾	1.750	14	14.000	1.00	6.00	18.50					1000	
2	2.000	14½	14.500	1.20	6.50	19.00						
2¼	2.250	15	15.000	1.40	7.00	19.50						
2½	2.500	15½	15.500	1.60	7.50	20.00						
2¾	2.750	16	16.000	1.80	8.00							
3	3.000	16½	16.500									
3¼	3.250	17	17.000									
3½	3.500	17½	17.500									
3¾	3.750	18	18.000									
4	4.000	18½	18.500									
4¼	4.250	19	19.000									
4½	4.500	19½	19.500									
4¾	4.750	20	20.000									

Mott, 2003, Machine Elements in Mechanical Design.

Clearance Fits

- When there must always be a clearance between mating parts, a clearance fit is specified.
- The designation for standard clearance fits from ANSI Standard B4.1 for members that must move together is the running or sliding clearance fit (RC).
- Within this standard, there are 9 classes, RC1 through RC9, with RC1 providing the smallest clearance, and RC9 the largest.

Clearance Fits con’t

- <u>RC1 (close sliding fit):</u> Accurate location of parts that must assemble without perceptible play.
- <u>RC2 (sliding fit):</u> Parts that will move and turn easily but are not intended to run freely. Parts may seize with small temperature changes, especially in the larger sizes.

Clearance Fits con't

- RC3 (precision running fit): Precision parts operating at slow speeds and light loads that must run freely. Changes in temperature may cause difficulties.
- RC4 (close running fit): Accurate location with minimum play for use under moderate loads and speeds. A good choice for accurate machinery.

Clearance Fits con't

- RC5 (medium running fit): Accurate machine parts for higher speeds and/or loads than RC4.
- RC6 (medium running fit): Similar to RC5 for applications in which larger clearance is desired.

Clearance Fits con't

- RC7 (free running fit): Reliable relative motion under wide temperature variations in applications where accuracy is not critical.
- RC8 (loose running fit): Permits large clearances, allowing the use of parts with commercial, "as received" tolerances.

Clearance Fits con't

- <u>RC9 (loose running fit):</u> Similar to RC8, with approximately 50% larger clearances.

Clearance Fits con't

- The complete standard ANSI B4.1 lists the tolerances on the mating parts and the resulting limits of clearances for all 9 classes and for sizes from 0 to 200 in.
- The next table is abstracted from the standard.
- Let RC2 represent the precision fits (RC1, RC2, RC3); let RC5 represent the accurate, reliable running fits (RC4 to RC7); and let RC8 represent the loose fits (RC8, RC9).

Clearance Fits con't

- The numbers on the table are in thousandths of an inch.
- A clearance of 2.8 from the table means a difference in size between the inside and outside parts of 0.0028 in.
- The tolerances on the hole and the shaft are to be applied to the basic size to determine the limits of size for that dimension.

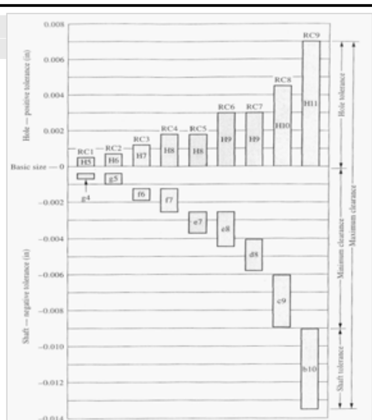
TABLE 13–3 Clearance fits (RC)

Nominal size range (in) Over To	Class RC2 Limits of clearance	Class RC2 Standard limits Hole	Class RC2 Standard limits Shaft	Class RC5 Limits of clearance	Class RC5 Standard limits Hole	Class RC5 Standard limits Shaft	Class RC8 Limits of clearance	Class RC8 Standard limits Hole	Class RC8 Standard limits Shaft
0–0.12	0.1 0.55	+0.25 0	−0.1 −0.3	0.6 1.6	+0.6 −0	−0.6 −1.0	2.5 5.1	+1.6 0	−2.5 −3.5
0.12–0.24	0.15 0.65	+0.3 0	−0.15 −0.35	0.8 2.0	+0.7 −0	−0.8 −1.3	2.8 5.8	+1.8 0	−2.8 −4.0
0.24–0.40	0.2 0.85	+0.4 0	−0.2 −0.45	1.0 2.5	+0.9 −0	−1.0 −1.6	3.0 6.6	+2.2 0	−3.0 −4.4
0.40–0.71	0.25 0.95	+0.4 0	−0.25 −0.55	1.2 2.9	+1.0 −0	−1.2 −1.9	3.5 7.9	+2.8 0	−3.5 −5.1

Mott, 2003, Machine Elements in Mechanical Design.

Clearance Fits con't

- The next figure shows a graphical display of the tolerances and fits for all nine RC classes when applied to a shaft/hole combination in which the basic size is 2.000 in and the basic hole system is used.
- Note that such a diagram shows the total tolerance on both the shaft and the hole, as well as the dramatic range of clearances provided by the 9 classes within the RC system.
- The tolerance for the hole always starts at the basic size, while the shaft tolerance is offset below the basic size to provide for the minimum clearance (smallest hole combined with the largest shaft).



Mott, 2003, Machine Elements in Mechanical Design.

Clearance Fits con't

- The maximum clearance combines the largest hole with the smallest shaft.
- The codes within the tolerance bars refer to the tolerance grades.
- The capital H combined with a tolerance grade number is used for the hole in the basic hole system for which there is no fundamental deviation from the basic size.

Clearance Fits con't

- The lowercase letters in the shaft tolerance bars indicates the minimum clearance between the basic hole size and the fundamental shaft size.
- Then the tolerance is added to the fundamental deviation.
- The size of the tolerance is indicated by the number.

A shaft carrying an idler sheave for a belt drive system is to have a nominal size of 2.00 in. The sheave must rotate reliably on the shaft, but with the smoothness characteristic of accurate machinery. Specify the limits of size for the shaft and the sheave bore, and list the limits of clearance that will result. Use the basic hole system.

An RC5 fit should be satisfactory in this application. From Table 13–3, the hole tolerance limits are +1.8 and −0. The sheave hole then should be within the following limits:

Sheave Hole

$$2.0000 + 0.0018 = 2.0018 \text{ in} \quad \text{(largest)}$$
$$2.0000 - 0.0000 = 2.0000 \text{ in} \quad \text{(smallest)}$$

Notice that the smallest hole is the basic size.

The shaft tolerance limits are −2.5 and −3.7. The resulting size limits are as follows:

Shaft Diameter

$$2.0000 - 0.0025 = 1.9975 \text{ in} \quad \text{(largest)}$$
$$2.0000 - 0.0037 = 1.9963 \text{ in} \quad \text{(smallest)}$$

Mott, 2003, Machine Elements in Mechanical Design.

Figure 13–5 illustrates these results.

Combining the smallest shaft with the largest hole gives the largest clearance. Conversely, combining the largest shaft with the smallest hole gives the smallest clearance. Therefore, the limits of clearance are

$$2.0018 - 1.9963 = 0.0055 \text{ in} \quad \text{(largest)}$$
$$2.0000 - 1.9975 = 0.0025 \text{ in} \quad \text{(smallest)}$$

These values check with the limits of clearance in Table 13–3. Notice that the total tolerance for the shaft is 0.0012 in, and for the hole 0.0018 in, both relatively small values.

Mott, 2003, Machine Elements in Mechanical Design.

Interference Fits

- Interference fits are those in which the inside member is larger than the outside member, requiring the application of force during assembly.
- There is some deformation of the parts after assembly, and a pressure exists at the mating surfaces.

Interference Fits con't

- Force fits are designed to provide a controlled pressure between mating parts throughout the range of sizes for a given class.
- They are used where forces or torques are transmitted through the joint.
- Instead of being assembled through the application of force, similar fits are obtained by shrink fitting, in which one member is heated to expand it while the other remains cool.

Interference Fits con't

- Locations interference fits are used for location only.
- There is no movement between parts after assembly, but there is no special requirement for the resulting pressure between mating parts.

Force Fits (FN)

- FN1 (light drive fit): Only light pressure required to assemble mating parts. Used for fragile parts and where no large forces must be transmitted across the joint.
- FN2 (medium drive fit): General-purpose class used frequently for steel parts of moderate cross section.

Force Fits (FN) con't

- FN3 (heavy drive fit): Used for heavy steel parts.
- FN4 (force fit): Used for high-strength assemblies where high resulting pressures are required.
- FN5 (force fit): Similar to FN4 for higher pressures.

Force Fits (FN)

- The use of shrink fit methods is desirable in most cases of interference fits and is virtually required in the heavier cases and larger-size parts.
- The temperature increase required to produce a given expansion for assembly can be computed from the basic definition of the coefficient of thermal expansion:
  - **$\delta = \alpha L(\Delta t)$**
  - Where δ = total deformation desired (in or mm)
  - α = coefficient of thermal expansion (in/in*°F or mm/mm*°C)
  - L = nominal length of member being heated (in or mm)
  - Δt = temperature difference (°F or °C)

Table 13-4 Force and Shrink Fits

Nominal size range (in)	Class FN1			Class FN2			Class FN3			Class FN4			Class FN5		
	Limits of interference	Standard limits		Limits of interference	Standard limits		Limits of interference	Standard limits		Limits of interference	Standard limits		Limits of interference	Standard limits	
Over To		Hole	Shaft		Hole	Shaft		Hole	Shaft		Hole	Shaft		Hole	Shaft
0–0.12	0.05 0.5	+0.25 −0	+0.5 +0.3	0.2 0.85	+0.4 −0	+0.85 +0.6				0.3 0.95	+0.4 −0	+0.95 +0.7	0.3 1.3	+0.6 −0	+1.3 +0.9
0.12–0.24	0.1 0.6	+0.3 −0	+0.6 +0.4	0.2 1.0	+0.5 −0	+1.0 +0.7				0.4 1.2	+0.5 −0	+1.2 +0.9	0.5 1.7	+0.7 −0	+1.7 +1.2
0.24–0.40	0.1 0.75	+0.4 −0	+0.75 +0.5	0.4 1.4	+0.6 −0	+1.4 +1.0				0.6 1.6	+0.6 −0	+1.6 +1.2	0.5 2.0	+0.9 −0	+2.0 +1.4
0.40–0.56	0.1 0.8	+0.4 −0	+0.8 +0.5	0.5 1.6	+0.7 −0	+1.6 +1.2				0.7 1.8	+0.7 −0	+1.8 +1.4	0.6 2.3	+1.0 −0	+2.3 +1.6
0.56–0.71	0.2 0.9	+0.4 −0	+0.9 +0.6	0.5 1.6	+0.7 −0	+1.6 +1.2				0.7 1.8	+0.7 −0	+1.8 +1.4	0.8 2.5	+1.0 −0	+2.5 +1.8

Mott, 2003, Machine Elements in Mechanical Design.

Force Fits (FN) con't

- For cylindrical parts, L is the diameter and δ is the diameter change required.
- The next table gives the values for α for several materials.

TABLE 13–5 Coefficient of thermal expansion

Material	Coefficient of thermal expansion, α: in/in·°F	Coefficient of thermal expansion, α: mm/mm·°C
Steel:		
AISI 1020	6.5×10^{-6}	11.7×10^{-6}
AISI 1050	6.1×10^{-6}	11.0×10^{-6}
AISI 4140	6.2×10^{-6}	11.2×10^{-6}
Stainless steel:		
AISI 301	9.4×10^{-6}	16.9×10^{-6}
AISI 430	5.8×10^{-6}	10.4×10^{-6}
Aluminum:		
2014	12.8×10^{-6}	23.0×10^{-6}
6061	13.0×10^{-6}	23.4×10^{-6}
Bronze:	10.0×10^{-6}	18.0×10^{-6}

Mott, 2003, Machine Elements in Mechanical Design.

Stresses for Force Fits

- When force fits are used to secure mechanical parts, the interference creates a pressure acting at the mating surfaces.
- The pressure causes stresses in each part.
- Under heavy force fits, or even lighter fits in fragile parts, the stresses developed can be great enough to yield ductile materials.
- A permanent set results, which normally destroys the usefulness of the assembly.
- With brittle materials such as cast iron, actual fracture may result.

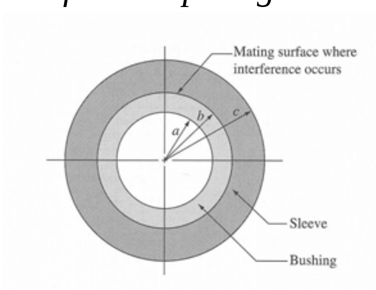
Stresses for Force Fits con't

- The stress analysis applicable to force fits is related to the analysis of thick-walled cylinders.
- The outer member expands under the influence of the pressure at the mating surface, with the tangential tensile stress developed being a maximum at the mating surface.

Stresses for Force Fits con't

- The inner member contracts because of the pressure and is subjected to a tangential compressive stress along with the radial compressive stress equal to the pressure.

Procedure for Computing Stresses



Mott, 2003, Machine Elements in Mechanical Design.

Procedure for Computing Stresses

1. Determine the amount of interference from the design of the parts.
2. Compute the pressure at the mating surface from this equation if both members are from the same material:

$$\mathbf{p} = \frac{\mathbf{E}\delta}{\mathbf{b}}\left[\frac{(\mathbf{c}^2-\mathbf{b}^2)(\mathbf{b}^2-\mathbf{a}^2)}{2\mathbf{b}^2(\mathbf{c}^2-\mathbf{a}^2)}\right]$$

Procedure for Computing Stresses

2. Con't: if they are of different materials use:

$$\mathbf{p} = \frac{\delta}{\mathbf{b}\left[\frac{1}{\mathbf{E_o}}\left(\frac{\mathbf{c}^2+\mathbf{b}^2}{\mathbf{c}^2-\mathbf{b}^2}+\mathbf{v_o}\right)+\frac{1}{\mathbf{E_i}}\left(\frac{\mathbf{b}^2+\mathbf{a}^2}{\mathbf{b}^2-\mathbf{a}^2}-\mathbf{v_i}\right)\right]}$$

- Where p = pressure at the mating surface
- δ = total diametral interference
- E = modulus of elasticity of each member if same
- E_o = modulus of elasticity of outer member
- E_i = modulus of elasticity of inner member
- V_o = Poisson's ratio of outer member
- V_i = Poisson's ratio of inner member

Procedure for Computing Stresses

3. Compute the tensile stress in the outer member from:

$$\sigma_o = \mathbf{p}\left(\frac{\mathbf{c}^2+\mathbf{b}^2}{\mathbf{c}^2-\mathbf{b}^2}\right)$$

4. Compute the compressive stress in the inner member from:

$$\sigma_i = -\mathbf{p}\left(\frac{\mathbf{b}^2+\mathbf{a}^2}{\mathbf{b}^2-\mathbf{a}^2}\right)$$

Procedure for Computing Stresses

5. If desired the increase in diameter of the inner and outer member due to the tensile stresses can be computed. The equation for the outer member is given.

$$\delta_o = \frac{2bp}{E_o}\left[\left(\frac{c^2+b^2}{c^2-b^2}\right)+\upsilon_o\right]$$

Problem 13–2 A bronze bushing is to be installed into a steel sleeve as indicated in Figure 13–6. The bushing has an inside diameter of 2.000 in and a nominal outside diameter of 2.500 in. The steel sleeve has a nominal inside diameter of 2.500 in and an outside diameter of 3.500 in.

1. Specify the limits of size for the outside diameter of the bushing and the inside diameter of the sleeve in order to obtain a heavy drive fit, FN3. Determine the limits of interference that would result.
2. For the maximum interference from 1, compute the pressure that would be developed between the bushing and the sleeve, the stress in the bushing and the sleeve, and the deformation of the bushing and the sleeve. Use $E = 30 \times 10^6$ psi for the steel and $E = 17 \times 10^6$ for the bronze. Use $v = 0.27$ for both materials.

Solution For 1, from Table 13–4, for a part size of 2.50 in at the mating surface, the tolerance limits on the hole in the outer member are +1.2 and −0. Applying these limits to the basic size gives the dimension limits for the hole in the steel sleeve:

2.5012 in
2.5000 in

For the bronze insert, the tolerance limits are +3.2 and +2.5. Then the size limits for the outside diameter of the bushing are

2.5032 in
2.5025 in

The limits of interference would be 0.0013 to 0.0032 in.

For 2, the maximum pressure would be produced by the maximum interference, 0.0032 in. Then, using $a = 1.00$ in, $b = 1.25$ in, $c = 1.75$ in, $E_o = 30 \times 10^6$ psi, $E_i = 17 \times 10^6$ psi, and $v_o = v_i = 0.27$ from Equation (13–3),

$$p = \frac{\delta}{b\left[\frac{1}{E_o}\left(\frac{c^2 + b^2}{c^2 - b^2} + v_o\right) + \frac{1}{E_i}\left(\frac{b^2 + a^2}{b^2 - a^2} - v_i\right)\right]}$$

$$p = \frac{0.0032}{(1.25)\left[\frac{1}{30 \times 10^6}\left(\frac{1.75^2 + 1.25^2}{1.75^2 - 1.25^2} + 0.27\right) + \frac{1}{17 \times 10^6}\left(\frac{1.25^2 + 1.00^2}{1.25^2 - 1.00^2} - 0.27\right)\right]}$$

$$p = 7034 \text{ psi}$$

The tensile stress in the steel sleeve is

$$\sigma_o = p\left(\frac{c^2 + b^2}{c^2 - b^2}\right) = 7034\left(\frac{1.75^2 + 1.25^2}{1.75^2 - 1.25^2}\right) = 21\,692 \text{ psi}$$

The compressive stress in the bronze bushing is

$$\sigma_i = -p\left(\frac{b^2 + a^2}{b^2 - a^2}\right) = -7034\left(\frac{1.25^2 + 1.00^2}{1.25^2 - 1.00^2}\right) = -32\,050 \text{ psi}$$

The increase in the diameter of the sleeve is

$$\delta_o = \frac{2bp}{E_o}\left[\frac{c^2 + b^2}{c^2 - b^2} + v_o\right]$$

$$\delta_o = \frac{2(1.25)(7034)}{30 \times 10^6}\left[\frac{1.75^2 + 1.25^2}{1.75^2 - 1.25^2} + 0.27\right] = 0.00\,196 \text{ in}$$

The decrease in the diameter of the bushing is

$$\delta_i = -\frac{2bp}{E_i}\left[\frac{b^2 + a^2}{b^2 - a^2} - v_i\right]$$

$$\delta_i = \frac{2(1.25)(7034)}{17 \times 10^6}\left[\frac{1.25^2 + 1.00^2}{1.25^2 - 1.00^2} + 0.27\right] = 0.00\,444 \text{ in}$$

Note that the sum of δ_o and δ_i equals 0.0064, the total interference, δ.

General Tolerancing Methods

- The tolerances must ensure that the component fulfills its function.
- But it should also be as large as practical to permit economical manufacture.
- This pair of conflicting principles must be dealt with.

General Tolerancing Methods

- Special attention should be paid to the features of a component that mate with other components and with which they must operate reliably or with which they must be accurately loaded.
- The fit of the inner races of the bearings on the shafts is an example of such features.

General Tolerancing Methods

- Where no other component mates with certain features of a given component, the tolerances should be as large as practical so that they can be produced with basic machining, molding, or casting processes without the need for subsequent finishing.

General Tolerancing Methods

- It is often recommended that blanket tolerances be given for such dimensions and that the precision with which the basic size is stated on the drawing implies a certain tolerance.
- For decimal dimensions in US Customary units, a note similar to the following is given:

DIMENSIONS IN inches. TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE STATED.

XX.X = ±0.050
XX.XX = ±0.010
XX.XXX = ±0.005
XX.XXXX = ±0.0005
ANGLES: ±0.50°

where X represents a specified digit

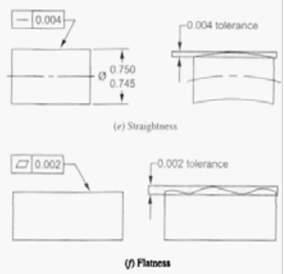
Mott, 2003, Machine Elements in Mechanical Design.

General Tolerancing Methods

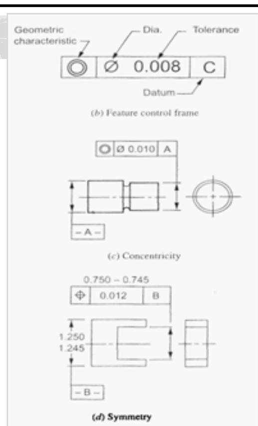
- For example, if a given dimension has a basic size of 2.5 inches, the dimension can be stated on the drawing in any of 4 ways with different interpretations.
  - 2.5 means 2.5 ± 0.050 or limits of 2.550 to 2.450 in
  - 2.50 means 2.50 ± 0.010 or limits of 2.510 to 2.490 in
  - 2.500 means 2.500 ± 0.005 or limits of 2.505 to 2.495 in
  - 2.5000 means 2.5000 ± 0.0005 or limits of 2.5005 to 2.4995 in

Any other desired tolerance must be specified on the dimension.

Tolerance	Characteristic	Symbol
Form	Straightness	—
	Flatness	▱
	Circularity	○
	Cylindricity	⌭
Profile	Profile of a line	⌒
	Profile of a surface	⌓
Orientation	Angularity	∠
	Perpendicularity	⊥
	Parallelism	//
Location	Position/symmetry	⌖
	Concentricity	◎
Runout	Circular runout	↗
	Total runout	⌰



Mott, 2003, Machine Elements in Mechanical Design.



Mott, 2003, Machine Elements in Mechanical Design.