Engineering Metrology

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Outline

Common Metrology Instruments

Common Metrology Instruments

coordinate measuring machine (CMM)

Introduction to Metrology

- Metrology is the science of measurement
- Dimensional metrology is that branch of Metrology which deals with measurement of dimensions of a part or workpiece (lengths, angles, etc.)
- Dimensional measurements at the required level of accuracy are the essential link between the designer's intent and a delivered product.
- The width, depth, angles and other dimensions all must be produced and measured accurately for the machine tool to function as expected.
- **Note:** Metrology is a vast area. In this lecture, the main focus on Dimensional Metrology

Dimensional Metrology Needs

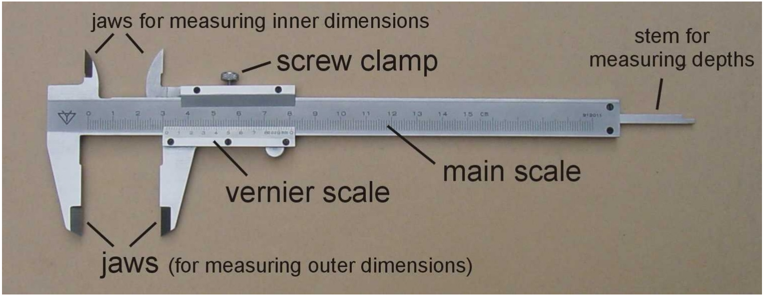
- Linear measurements
- Angular measurements
- Geometric form measurements(Roundness, Straightness, Cylindricity, Flatness etc.)
- Geometric relationships(Parallel, perpendicular,Concentric, runout etc.)
- Controlled surface texture

Types of Measurement and Instruments Used

Measurement	Instrument	Sensitivity	
		μm	μin.
Linear	Steel rule	0.5 mm	1/64 in.
	Vernier caliper	25	1000
	Micrometer, with vernier	2.5	100
	Diffraction grating	1	40
Angle	Bevel protractor, with vernier	5 min	
	Sine bar		
Comparative length	Dial indicator	1	40
	Electronic gage	0.1	4
	Gage blocks	0.05	2
Straightness	Autocollimator	2.5	100
	Transit	0.2 mm/m	0.002 in./ft
	Laser beam	2.5	100
Flatness	Interferometry	0.03	1
Roundness	Dial indicator Circular tracing	0.03	1
Profile	Radius or fillet gage		
	Dial indicator	1	40
	Optical comparator	125	5000
	Coordinate measuring machines	0.25	10
GO-NOT GO	Plug gage		
	Ring gage		
	Snap gage		
Microscopes	Toolmaker's	2.5	100
	Light section	1	40
	Scanning electron	0.001	0.04
	Laser scan	0.1	5

Linear Measurement Devices

- **Vernier Caliper:** It is a visual aid that allows the user to measure more precisely than could be done unaided when reading a uniformly divided straight or circular measurement scale.



Least count: The least count of a measuring instrument is the smallest change in the measured quantity that can be resolved on the instrument's scale

Linear Measurement Devices

Least count of Vernier: It is the difference between the value of one Main scale division and the value of one Vernier scale division. Let the smallest main scale reading, that is the distance between two consecutive graduations (also called its pitch) be S and the distance between two consecutive Vernier scale graduations be V such that the length of (n-1) main scale divisions is equal to n Vernier scale divisions.Then,

the length of (n-1) main scale divisions = the length of n vernier scale division

or, (n-1)S=nV

or, nS-S=nV

or, $S/n = S - V$

or (Pitch)/(Number of Vernier scale divisions) = (Length of one main scale division − Length of one Vernier scale division)

So, S/n and $(S - V)$ are both equal to the least count of vernier scale.

Linear Measurement Devices

Example-1: Ten divisions on the vernier scale coincide with 9 smallest divisions on the main scale (mm), Main scale Reading is 2.6 cm and vernier scale coincides with 7 division of the main scale.
a) Calculate the Least Count(L.C.) of the vernier scale.
b) Calculate the observed reading.

Solution: L.C. = Value of one main scale division - Value of one vernier scale division

L.C. $= 1$ mm$-9/10mm = 0.1mm = 0.01cm$

Observed Reading = Main scale reading + Vernier scale reading

Observed Reading = 2.6 cm + 7 x L.C.

Observed Reading = 2.6 cm + 7 x 0.01 cm

Observed Reading = 2.67 cm

Linear Measurement Devices

- **Analog and Digital Micrometers:**

(a) A vernier (analog) micrometer(Similar to Vernier caliper). (b) A digital micrometer with a range of 0 to 1 in. (0 to 25 mm) and a resolution of 50 μin. (1.25 μm). It is generally easier to read dimensions on this instrument compared to the analog micrometer

Angle Measuring Instruments

- **Universal Bevel Protractor**
  1) It is an angular measuring instrument capable of measuring angles to within 5 min
  2) The name universal refers to the capacity of the instrument to be adaptable to a great variety of work configurations and angular interrelations.

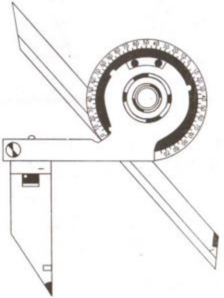


Figure 6.2 : Universal Bevel Protractor

Angle Measuring Instruments

- **Sine Bar**
  1) A sine bar is made up of a hardened steel beam having a flat upper surface.
  2) The bar is mounted on two cylindrical rollers and the axes of the two rollers are parallel to each other.
  3) The accuracy attainable with this instrument is quite high.

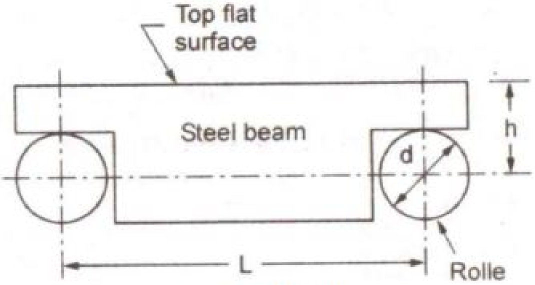


Figure 6.3 : Sine Bar

Angle Measuring Instruments

Use of Sine Bar for Angle Measurement

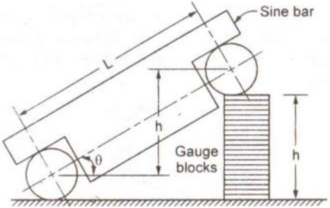


Figure 6.4 : Use of Sine Bar for Angle Measurement

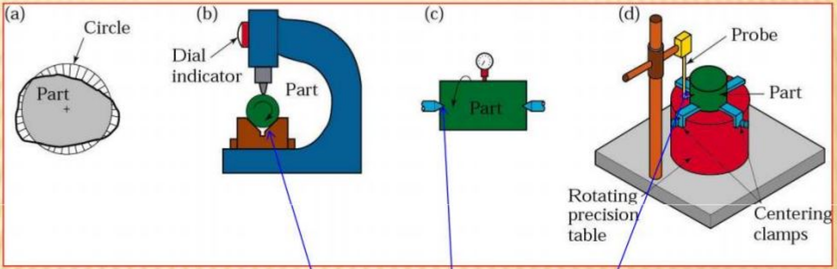
$$sin\theta = \frac{h}{L} \tag{1}$$

For error in angle measurement, differentiating h with respect to θ, we have

$$\frac{d\theta}{dh} = \frac{sec\theta}{L} \tag{2}$$

Therefore, the error in angle measurement $d\theta$, due to an error dh in height h is proportional to secθ.

Measuring Roundness



(A) SCHEMATIC ILLUSTRATION OF "OUT OF ROUNDNESS" (EXAGGERATED). MEASURING ROUNDNESS USING

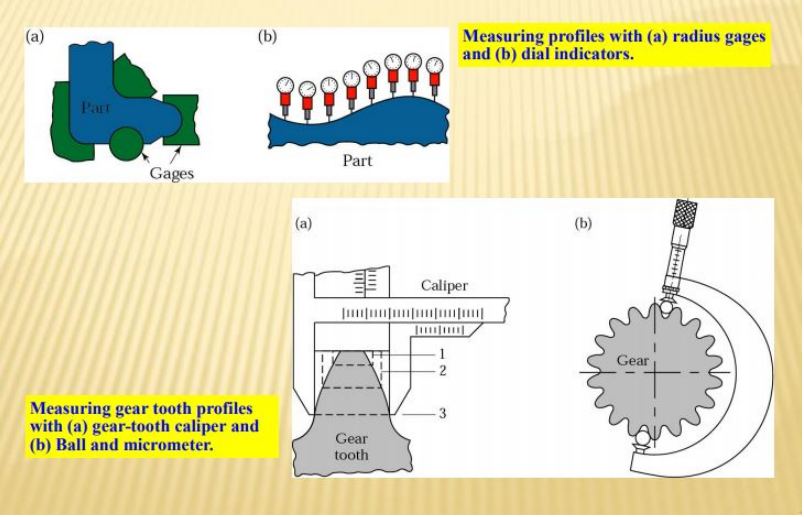
(B) V-BLOCK AND DIAL INDICATOR,

(C) PART SUPPORTED ON CENTERS AND ROTATED, AND

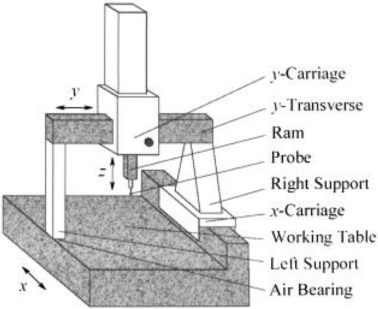
(D) CIRCULAR TRACING, WITH PART BEING ROTATED ON A VERTICAL AXIS.

***(E) SOURCE:* AFTER F. T. FARAGO.**

Measuring Profiles



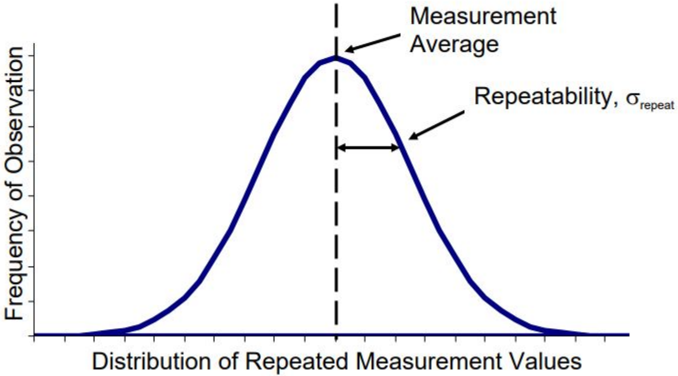
coordinate measuring machine (CMM)



- It is a device for measuring the physical geometrical characteristics of an object.
- Measurements are defined by a probe attached to the third moving axis of this machine.
- Probes may be mechanical, optical, laser, or white light, among others.

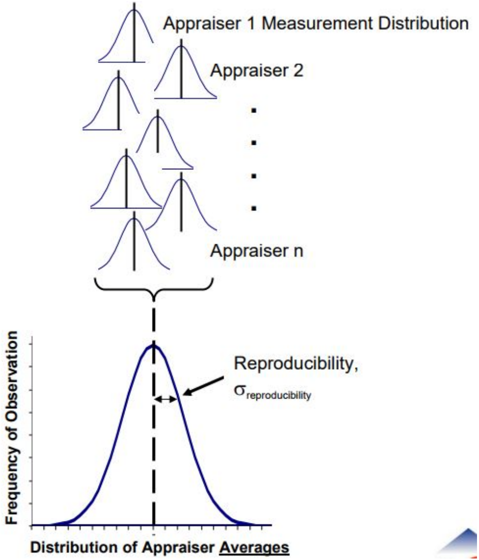
Repeatability

- Repeatability is the consistency of a single appraiser to measure the same part multiple times with the same measurement system.
- it is related to the standard deviation of the measured values.



Reproducibility

Reproducibility is the consistency of different appraisers in measuring the same part with the same measurement system; it is related to standard deviation of the distribution of appraiser averages



Measurement Error

- Measurement Error is the statistical summing of the error generated by Repeatibility (the variation within an appraiser) and Reproducibility (the variation between appraisers)

$$\sigma_{error} = \sqrt{\sigma^2_{repeatability} + \sigma^2_{reproducibility}} \quad (3)$$

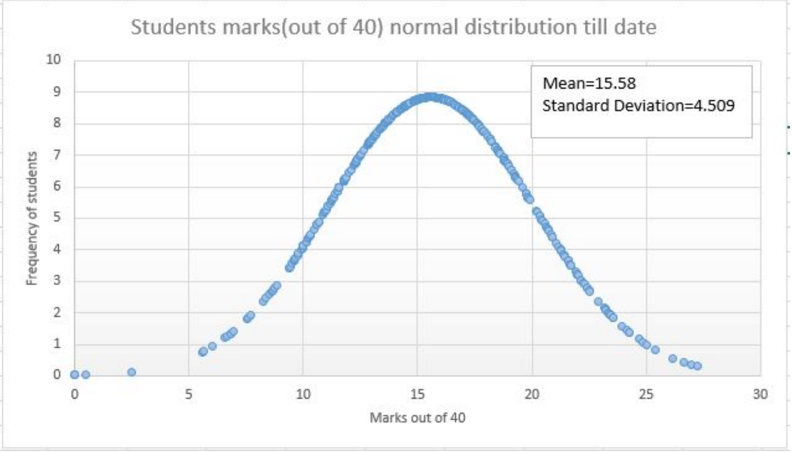
where $\sigma_{repeatability}$ and $\sigma_{reproducibility}$ are the standard deviations of the measured values in repeatability and reproducibility.
The formula for standard deviation is

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \quad (4)$$

where x_i is the measured value and $\bar{x}$ is the mean value and N is the number of observations in the sample

Example of Standard Deviation

- Here, if we calculate the standard deviation of your marks then x_i is the individual's marks and $\bar{x}$ is the mean of class marks and N is the number of students.
- This normal distribution includes your real marks (Mid-sem+Quiz+Lab exercise+lab Reports+Drawing)



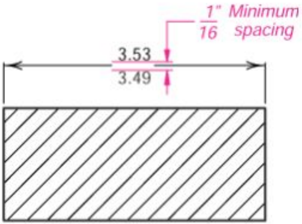
Introduction to Engineering Tolerance

- **Definition:** The allowable deviation from a standard.
- Tolerance is the total amount a dimension may vary and is the difference between the upper (maximum) and lower (minimum) limits.
- Types of Tolerance: Dimensional and Geometrical
- Allowance for a specific variation in the size of part is called Dimensional Tolerance.
- Allowance for a specific variation in the geometry of part is called Geometrical Tolerance.
- Tolerances are used to control the amount of variation inherent in all manufactured parts.
- One of the great advantages of using tolerances is that it allows for interchangeable parts, thus permitting the replacement of individual parts.

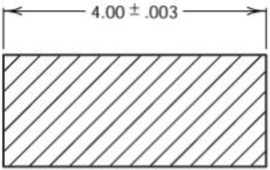
Tolerance in relation to Cost

- Cost generally increases with smaller tolerance
  -Small tolerances cause an exponential increase in cost
  -Therefore your duty as an engineer have to consider : **Do you need ϕ1.0001cm or is 1.01cm good enough?**
- Parts with small tolerances often require special methods of manufacturing.
- Parts with small tolerances often require greater inspection and call for the rejection of parts $\rightarrow$ Greater Quality Inspection $\rightarrow$ Greater cost.
- Do not specify a smaller tolerance than is necessary!

Dimensional Tolerance representation

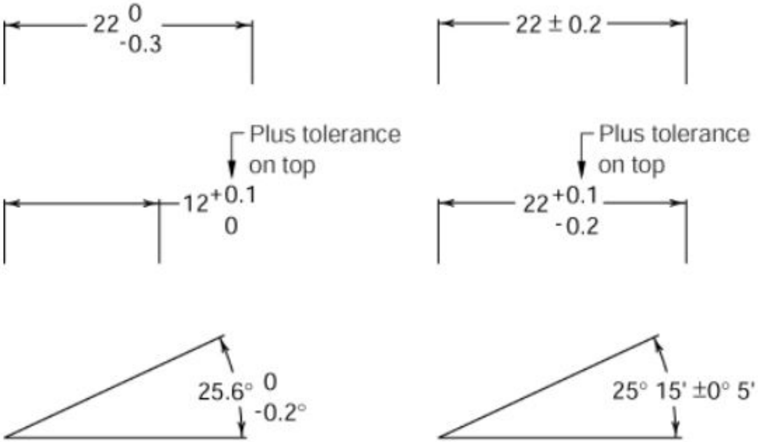


(A) Direct limits



(B) Tolerance values

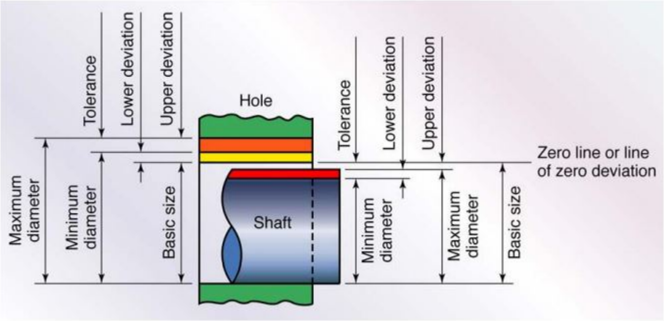
Dimensional Tolerance representation



(A) Unilateral tolerancing

(B) Bilateral tolerancing

Important Terms in Tolerancing



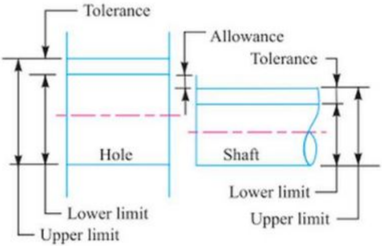
- **Shaft:** A term used by convention to designate all external features of a part, including those which are not cylindrical.
- **Hole:** A term used by convention to designate all internal features of a part, including those which are not cylindrical.

Important Terms in Tolerancing

- **Basic Size:** the nominal diameter of the shaft (or bolt) and the hole. This is, in general, the same for both components.
- **Actual Size:** the measured size of the finished part after machining.
- **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.
- **Limits of Size:** The term limits of size referred to the two extreme permissible sizes for a dimension of a part(hole or shaft), between which the actual size should lie.
- **Maximum Limit of Size:** The greater of the two limits of size of a part(Hole or shaft).

Important Terms in Tolerancing

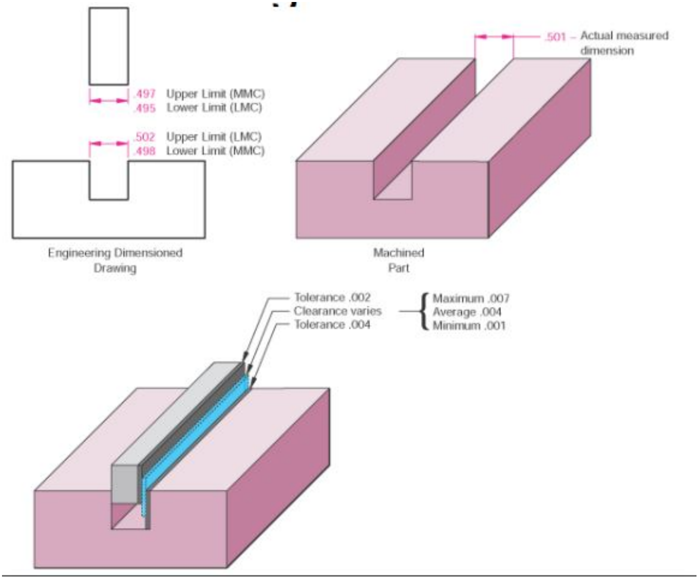
- **Minimum Limit of Size:** The smaller of the two limits of size of a part(Hole or shaft).
- **Allowance:** It is the difference between the basic dimensions of the mating parts.
  When the shaft size is less than the hole size, then the allowance is positive and when the shaft size is greater than the hole size, then the allowance is negative.
- **Tolerance:** It is the difference between the upper limit and lower limit of a dimension.



Important Terms in Tolerancing

- **Tolerance Zone:** It is the zone between the maximum and minimum limit size.
- **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.
- **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.

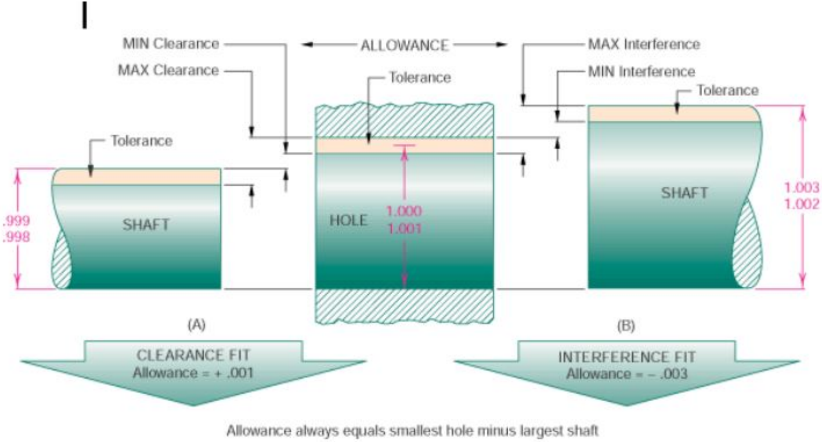
Tolerancing Example



Fit Types

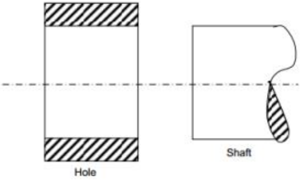
- **Clearance fit** occurs when two toleranced mating parts will always leave a space or clearance when assembled.
- **Interference fit** occurs when two toleranced mating parts will always interfere when assembled.
- **Transition fit** occurs when two toleranced mating parts will sometimes be an interference fit and sometimes be a clearance fit when assembled.

Example of Fits



Clearance Fit

- In clearance fit, an air space or clearance exists between the shaft and hole
- Such fits give loose joint.
- A clearance fit has positive allowance, i.e. there is minimum positive clearance between high limit of the shaft and low limit of the hole.
- Allows rotation or sliding between the mating parts.



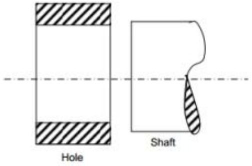
- *Clearance = Hole - Shaft*
- *Hole - Shaft > 0*
- *Hole > Shaft*

Types of Clearance Fit

- **Loose Fit:** It is used between those mating parts where no precision is required. It provides minimum allowance and is used on loose pulleys, agricultural machineries etc.
- **Running Fit:** For a running fit, the dimension of shaft should be smaller enough to maintain a film of oil for lubrication. It is used in bearing pair etc.
- **Slide Fit or Medium Fit:** It is used on those mating parts where great precision is required. It provides medium allowance and is used in tool slides, slide valve, automobile parts, etc.

Interference Fit

- A negative difference between diameter of the hole and the shaft is called interference.
- In such cases, the diameter of the shaft is always larger than the hole diameter.
- It used for components where motion, power has to be transmitted.
- Interference exists between the high limit of hole and low limit of the shaft.



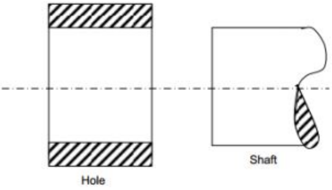
- *Interference = (- Clearance)*
- *Hole - Shaft < 0*
- *Hole < Shaft*

Types of Interference Fit

- **Shrink Fit or Heavy Force Fit:** It refers to maximum negative allowance. In assembly of the hole and the shaft, the hole is expanded by heating and then rapidly cooled in its position. It is used in fitting of rims etc.
- **Medium Force Fit:** These fits have medium negative allowance.Considerable pressure is required to assemble the hole and the shaft. It is used in car wheels, armature of dynamos etc.
- **Tight Fit or Force Fit:** One part can be assembled into the other with a hand hammer or by light pressure. A slight negative allowance exists between two mating parts (more than wringing fit). It gives a semipermanent fit and is used on a keyed pulley and shaft, rocker arm, etc.

Transition Fit

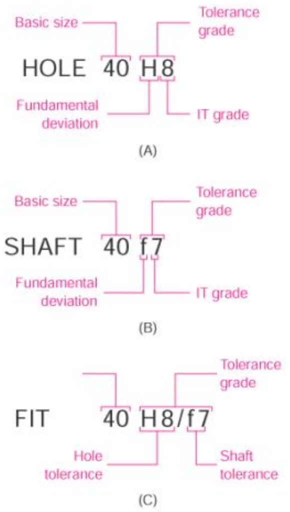
- It may result in either clearance fit or interference fit depending on the actual value of the individual tolerances of the mating components.
- Transition fits are a compromise between clearance and interference fits.
- They are used for applications where accurate location is important but either a small amount of clearance or interference is permissible.



Types of Transition Fit

- **Push Fit or Snug Fit:** It refers to zero allowance and a light pressure is required in assembling the hole and the shaft. The moving parts show least vibration with this type of fit.
- **Force Fit or Shrink Fit:** A force fit is used when the two mating parts are to be rigidly fixed so that one cannot move without the other. It either requires high pressure to force the shaft into the hole or the hole to be expanded by heating. It is used in railway wheels, etc.
- **Wringing Fit:** A slight negative allowance exists between two mating parts in wringing fit. It requires pressure to force the shaft into the hole and gives a light assembly. It is used in fixing keys, pins, etc.

Specifications of Tolerancing

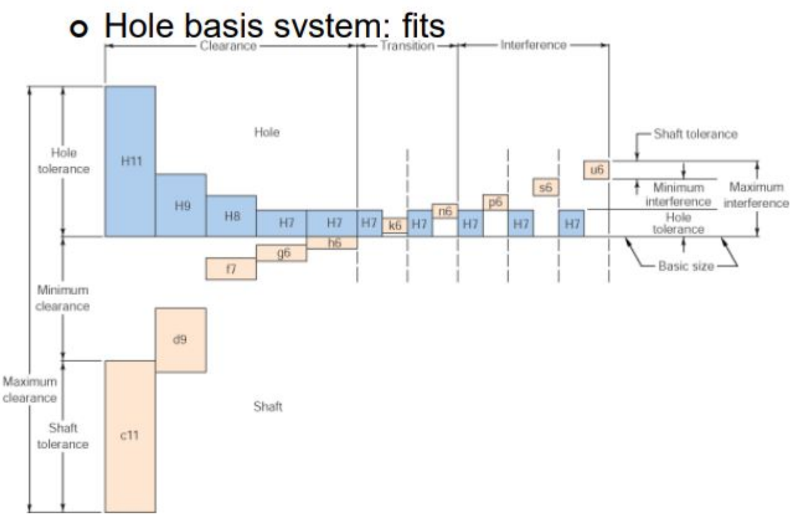


where IT represents International tolerance

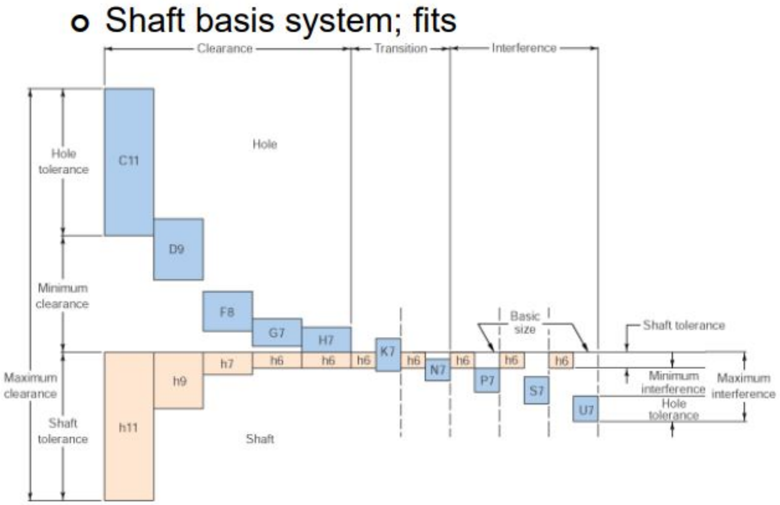
Standard Hole Basis Table

BASIC SIZE		LOOSE RUNNING			FREE RUNNING			CLOSE RUNNING			SLIDING			LOCATIONAL CLEARANCE		
		Hole H11	Shaft c11	Fit	Hole H9	Shaft d9	Fit	Hole H8	Shaft f7	Fit	Hole H7	Shaft g6	Fit	Hole H7	Shaft h6	Fit
40	MAX	40.160	39.880	0.440	40.062	39.920	0.204	40.039	39.975	0.029	40.025	39.991	0.050	40.025	40.000	0.041
	MIN	40.000	39.720	0.120	40.000	39.858	0.060	40.000	39.950	0.025	40.000	39.975	0.009	40.000	39.984	0.000
50	MAX	50.160	49.870	0.450	50.062	49.920	0.204	50.039	49.975	0.089	50.025	49.991	0.050	50.025	50.000	0.041
	MIN	50.000	49.710	0.130	50.000	49.858	0.080	50.000	49.950	0.025	50.000	49.975	0.009	50.000	49.984	0.000
60	MAX	60.190	59.860	0.520	60.074	59.900	0.248	60.046	59.970	0.106	60.030	59.990	0.059	60.030	60.000	0.049
	MIN	60.000	59.670	0.140	60.000	59.826	0.100	60.000	59.940	0.030	60.000	59.971	0.010	60.000	59.981	0.000
80	MAX	80.190	79.550	0.530	80.074	79.900	0.248	80.046	79.970	0.106	80.030	79.990	0.059	80.030	80.000	0.049
	MIN	80.000	79.660	0.150	80.000	79.826	0.100	80.000	79.940	0.030	80.000	79.971	0.010	80.000	79.981	0.000
100	MAX	100.220	99.830	0.610	100.087	99.880	0.294	100.054	99.964	0.125	100.035	99.988	0.069	100.035	100.000	0.057
	MIN	100.000	99.610	0.170	100.000	99.793	0.120	100.000	99.929	0.036	100.000	99.966	0.012	100.000	99.978	0.000
120	MAX	120.220	119.820	0.620	120.087	119.880	0.294	120.054	119.964	0.125	120.035	119.988	0.069	120.035	120.000	0.057
	MIN	120.000	119.600	0.180	120.000	119.793	0.120	120.000	119.929	0.036	120.000	119.966	0.012	120.000	119.978	0.000
160	MAX	160.250	159.790	0.710	160.100	159.855	0.345	160.063	159.957	0.146	160.040	159.986	0.078	160.040	160.000	0.065
	MIN	160.000	159.540	0.210	160.000	159.755	0.145	160.000	159.917	0.043	160.000	159.961	0.014	160.000	159.975	0.000
200	MAX	200.290	199.760	0.820	200.115	199.830	0.400	200.072	199.950	0.168	200.046	199.985	0.040	200.046	200.000	0.075
	MIN	200.000	199.470	0.240	200.000	199.715	0.170	200.000	199.904	0.050	200.000	199.956	0.015	200.000	199.971	0.000
250	MAX	250.290	249.720	0.860	250.115	249.830	0.400	250.072	249.950	0.168	250.046	249.985	0.090	250.046	250.000	0.075
	MIN	250.000	249.430	0.280	250.000	249.715	0.170	250.000	249.904	0.050	250.000	249.956	0.015	250.000	249.971	0.000
300	MAX	300.320	299.670	0.970	300.130	299.810	0.450	300.081	299.944	0.189	300.052	299.983	0.101	300.052	300.000	0.084
	MIN	300.000	299.350	0.330	300.000	299.680	0.190	300.000	299.892	0.056	300.000	299.951	0.017	300.000	299.968	0.000
400	MAX	400.360	399.600	1.120	400.140	399.790	0.490	400.089	399.938	0.208	400.057	399.982	0.111	400.057	400.000	0.093
	MIN	400.000	399.240	0.400	400.000	399.650	0.210	400.000	399.881	0.062	400.000	399.946	0.018	400.000	399.964	0.000
500	MAX	500.400	499.520	1.280	500.155	499.770	0.540	500.097	499.932	0.228	500.063	499.980	0.123	500.063	500.000	0.103
	MIN	500.000	499.120	0.480	500.000	499.615	0.230	500.000	499.869	0.068	500.000	499.940	0.020	500.000	499.960	0.000

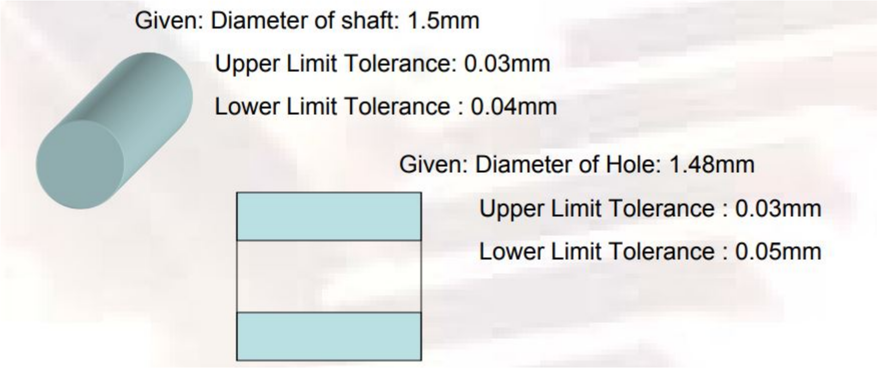
Hole Basis System; Fits



Shaft Basis System; Fits



Example



- **Answer:** Allowance: -0.1mm
  Clearance: 0.05mm
  Type of Fit: Transition Fit
  Solve it!

Thank You