

Engineering Metrology

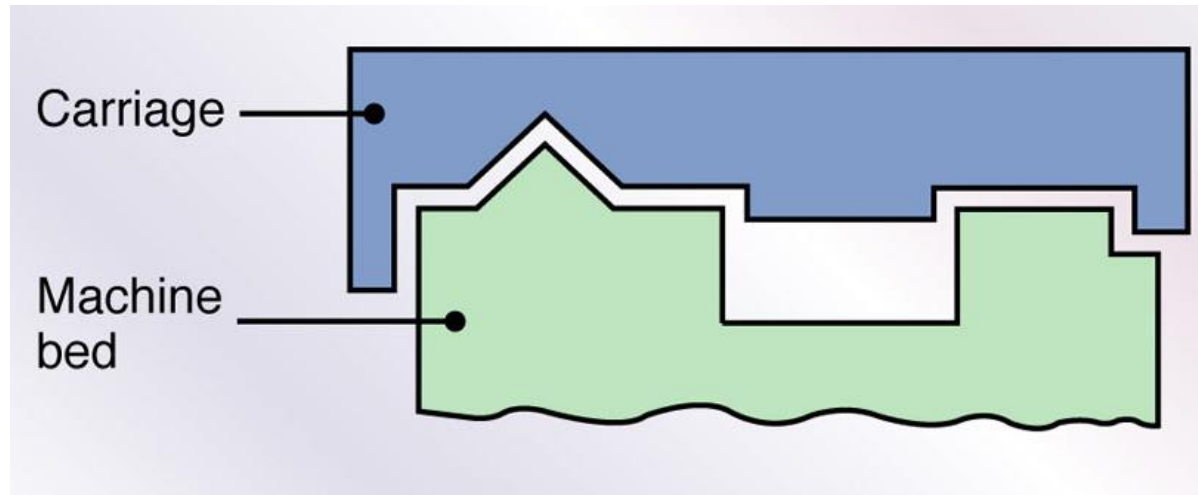


Dr. Sounak K. Choudhury
Mechanical Engineering Department
IIT Kanpur

Dr. Sounak Choudhury
Mechanical Engineering Department
IIT Kanpur



Introduction



Cross-section of a machine-tool slideway.

The width, depth, angles and other dimensions all must be produced and measured accurately for the machine tool to function as expected.

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 designers’ intent and a delivered product.



Accuracy and Precision

Accuracy - the degree to which a measured value agrees with the true value of the quantity of interest

➤ A measurement procedure is accurate when it avoids systematic errors (positive or negative deviations that are consistent from one measurement to the next)

Precision - the degree of repeatability in the measurement Process

➤ Good precision means that random errors in the measurement procedure are minimized



Conventional Measuring Instruments and Gages

- Precision gage blocks
- Measuring instruments for linear dimensions
- Comparative instruments
- Fixed gages
- Angular measurements



Precision Gage Blocks

Standards against which other dimensional measuring instruments and gages are compared

- ❑ Usually square or rectangular blocks
- ❑ Surfaces are finished to be dimensionally accurate and parallel to $\pm$ several millionths of an inch and are polished to a mirror finish
- ❑ Precision gage blocks are available in certain standard sizes or in sets, the latter containing a variety of different sized blocks



Dimensional Metrology Needs

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



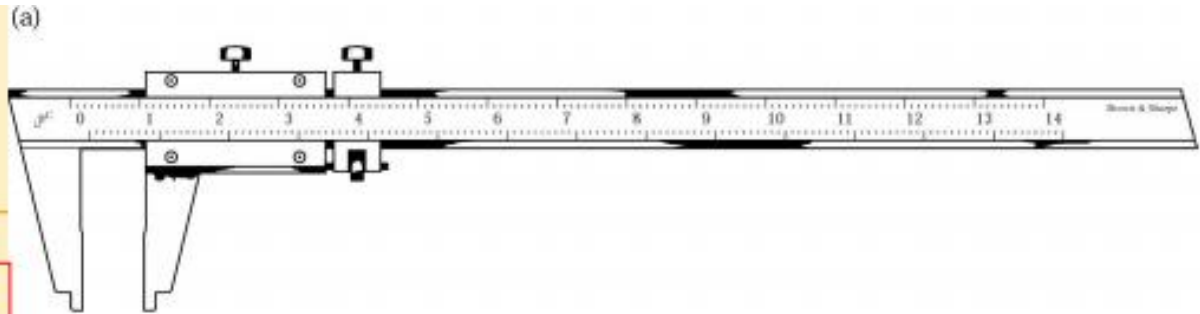
Types of Measurement and Instruments Used

Measurement	Instrument	Sensitivity	
		μm	$\mu\text{in.}$
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



Basic Measurement Devices

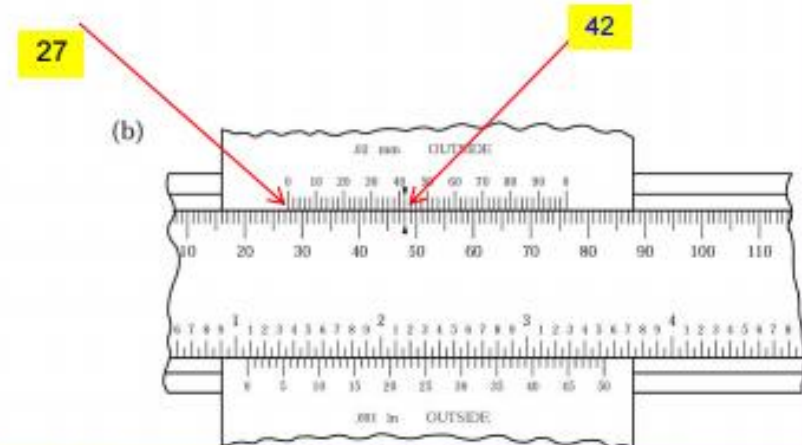
CALIPER AND VERNIER



(a) A caliper gage with a vernier.

(b) A Vernier, reading $27.00 + 0.42 = 27.42$ mm, (or $1.000 + 0.050 + 0.029 = 1.079$ in.)

(c) We arrive at the last measurement as follows: First note that the two UPPER scales pertain to the millimeter units. We next note that the 0 (zero) mark on the upper mm scale has passed the 27 (mm) mark on the lower (mm) scale. Thus, we first record a distance of 27.00 mm.



(e) Finally note that the marks on the two scales coincide at the number 42 (in fact $21 \text{ divisions} \times 0.02 = 0.42$). Each of the 50 graduations on the upper scale indicates 0.02 mm. (Given in this case but you should know how to get it). **0.02 is LEAST Count of the Vernier caliper.**

(f) Thus, the total dimension is **27 mm + 0.42 mm = 27.42 mm.**

Calculation of Least Count of a Vernier Caliper

One small division on main scale = 1 mm

No. of divisions on Vernier scale = 50

50 Vernier scale divisions = 49 divisions on main
scale (or 49 mm)

Each division on Vernier scale = $(49/50)$ mm

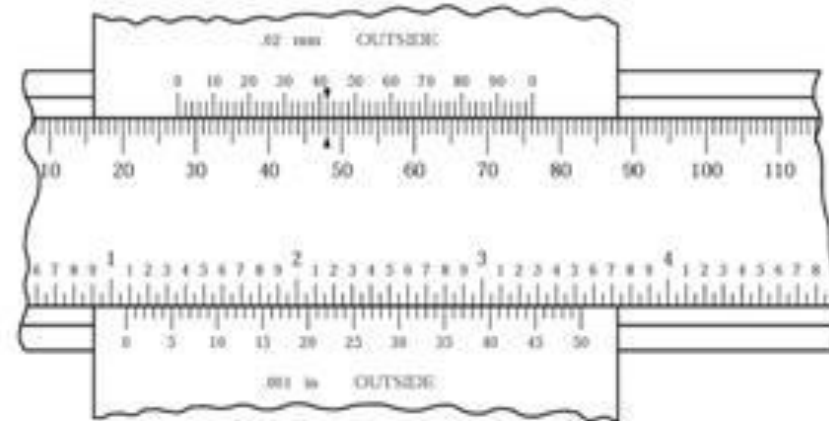
Difference between one main scale division and one

Vernier scale division = $1 - (49/50)$ mm

$$= (50 - 49)/50$$

$$= (1/50) \text{ mm}$$

$$= 0.02 \text{ mm}$$



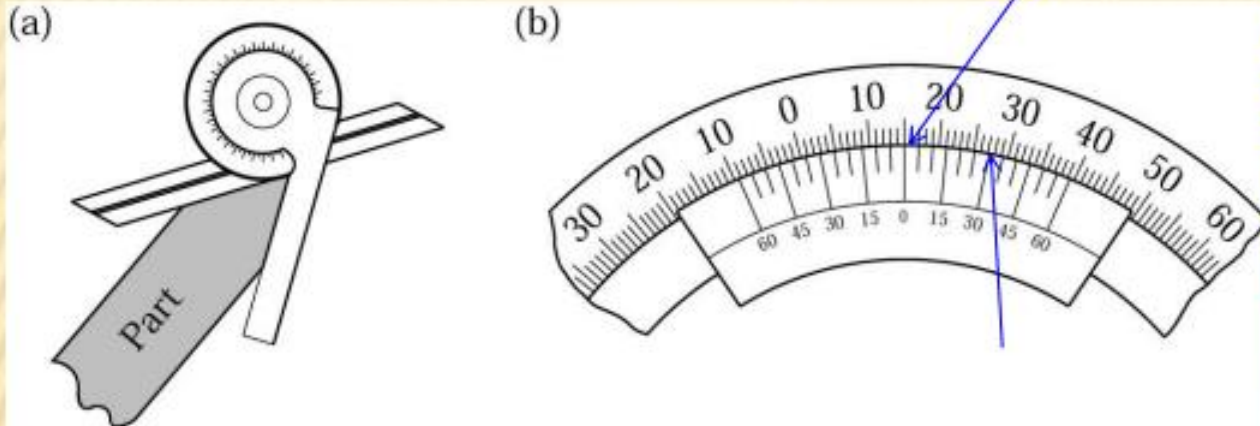
Least Count = 0.02 mm

Analog and Digital Micrometers



(a) A vernier (analog) micrometer. (b) A digital micrometer with a range of 0 to 1 in. (0 to 25 mm) and a resolution of $50\text{ }\mu\text{in.}$ ($1.25\mu\text{m}$). It is generally easier to read dimensions on this instrument compared to the analog micrometer.

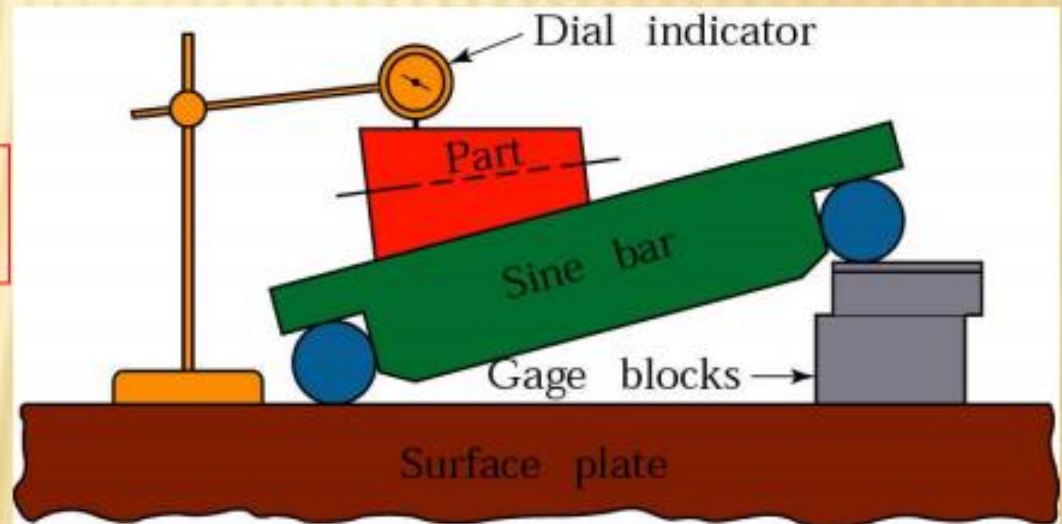
Angle Measuring Instruments



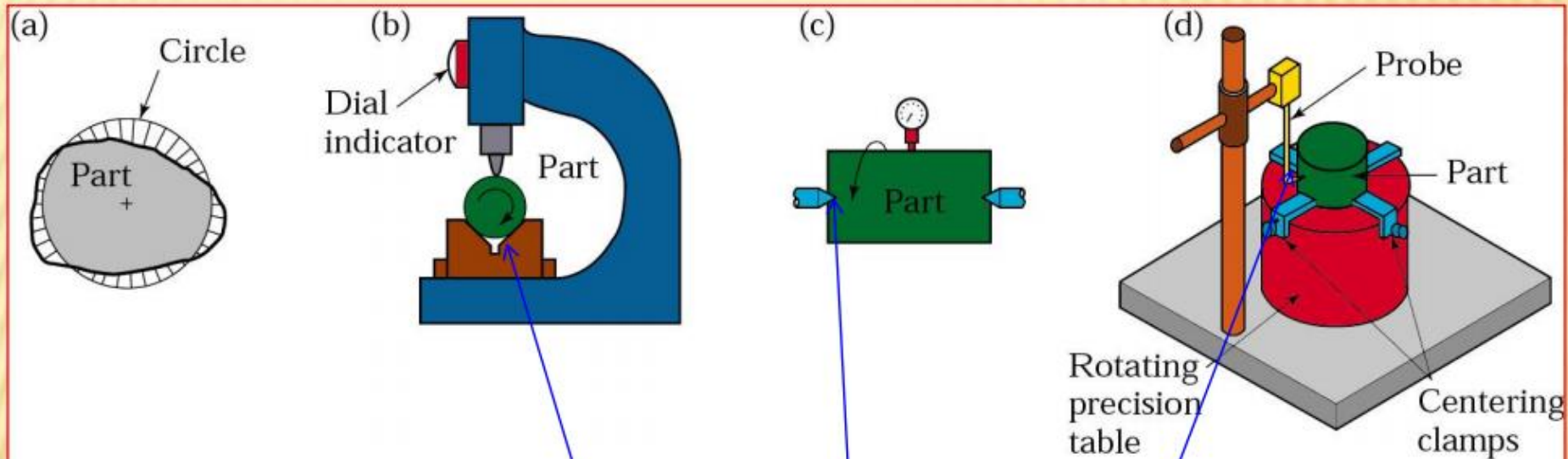
(A) SCHEMATIC ILLUSTRATION OF A BEVEL PROTRACTOR FOR MEASURING ANGLES. (B) VERNIER FOR ANGULAR MEASUREMENT, INDICATING $14^\circ 30'$.

SETUP SHOWING THE USE OF A SINE BAR FOR PRECISION MEASUREMENT OF WORKPIECE ANGLES.

**Gage Block Will Give The Height And Center To Center Distance Is Known In Advance.
You Can Find Angle Of Taper Of The Given Block In The Lab.**



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.



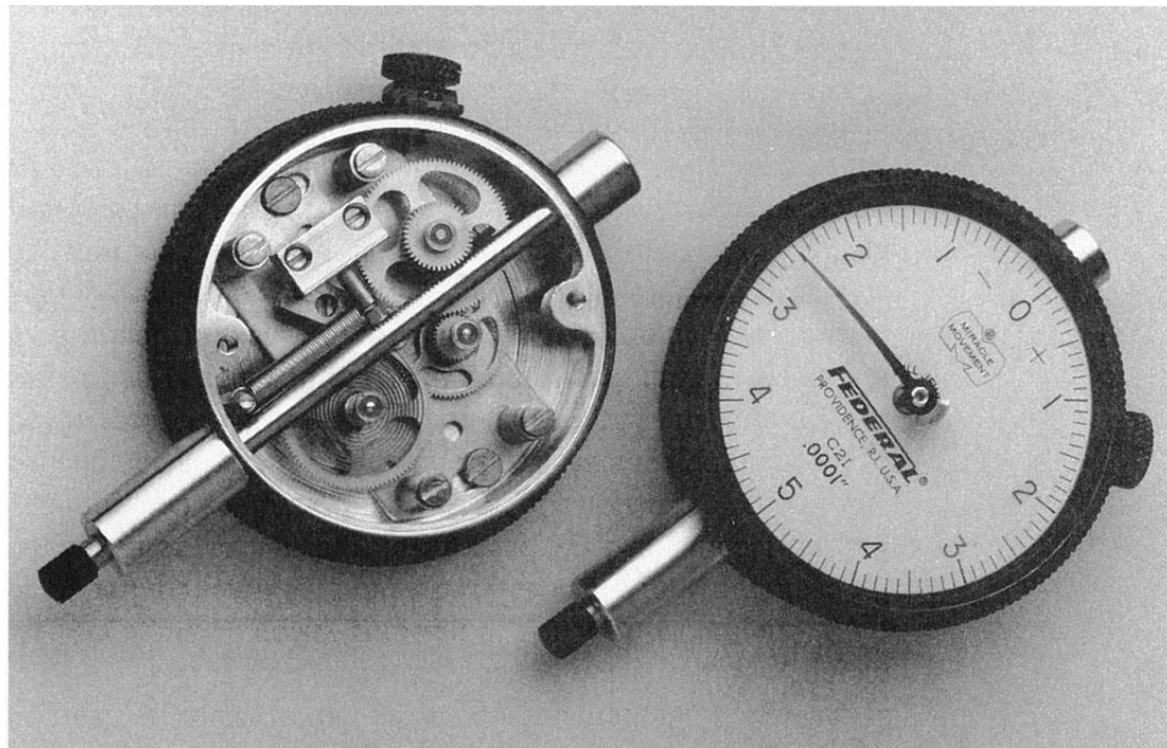
Mechanical Gages: Dial Indicators

- ❑ Mechanical gages are designed to mechanically magnify the deviation to permit observation
- ❑ Most common instrument in this category is the dial indicator, which converts and amplifies the linear movement of a contact pointer into rotation of a dial
- ❑ The dial is graduated in small units such as 0.01 mm or 0.001 inch
- ❑ Applications: measuring straightness, flatness, parallelism, squareness, roundness, and runout



Dial Indicator

Front view shows dial and graduated face; back view shows cover plate removed (photo courtesy of Federal Products Co.)



Roundness and Cylindricity

Roundness, or **circularity**, is the 2D tolerance that controls how closely a cross-section of a cylinder, sphere, or cone is to a mathematically perfect circle.

Consider a cylinder whose purpose is to roll along a flat surface. A small flat on the OD of the cylinder would detract from how smoothly the shaft can roll. The flat spot can even be so large that the shaft cannot roll at all. In this case the flat represents a deviation from a perfect circle that can be measured quite accurately.

Cylindricity is the 3D version of roundness. It assesses how closely an object comes to a perfect cylinder, meaning that it is not only round, but also straight along its axis.

The simplest example that demonstrates the need for cylindricity is a pin which is required to pass completely through a bore with a tight diametral tolerance. The pin may be inspected for diameter and found to be within tolerance. However, if the pin is bent, it may not pass through the bore.



Coaxiality and concentricity

Coaxiality is the tolerance for how closely the axis of one cylinder is to another.

Examples are a shaft having two diameters, or perhaps two bores located on opposite sides of a housing. In either case, the center of one element is expected to be along the same axis as the second element. Since each element is being assessed as an axis, coaxiality is a 3D measurement.

A special case of coaxiality occurs when a part is measured at the same cross-sectional plane, making it a 2D measurement. This special case is called **concentricity** and the most common example is comparing the ID and OD relative to each other on a hollow shaft or tube.

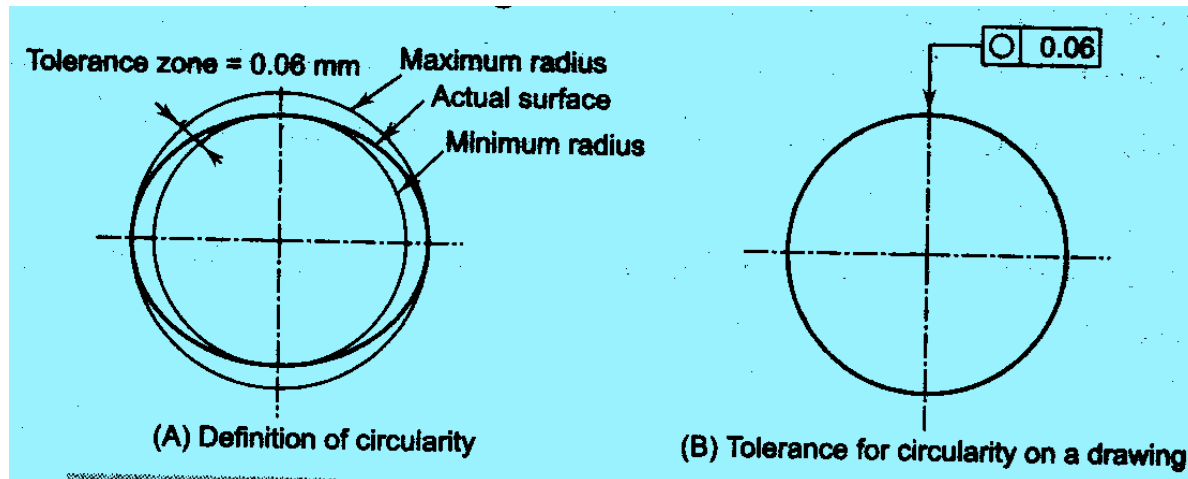
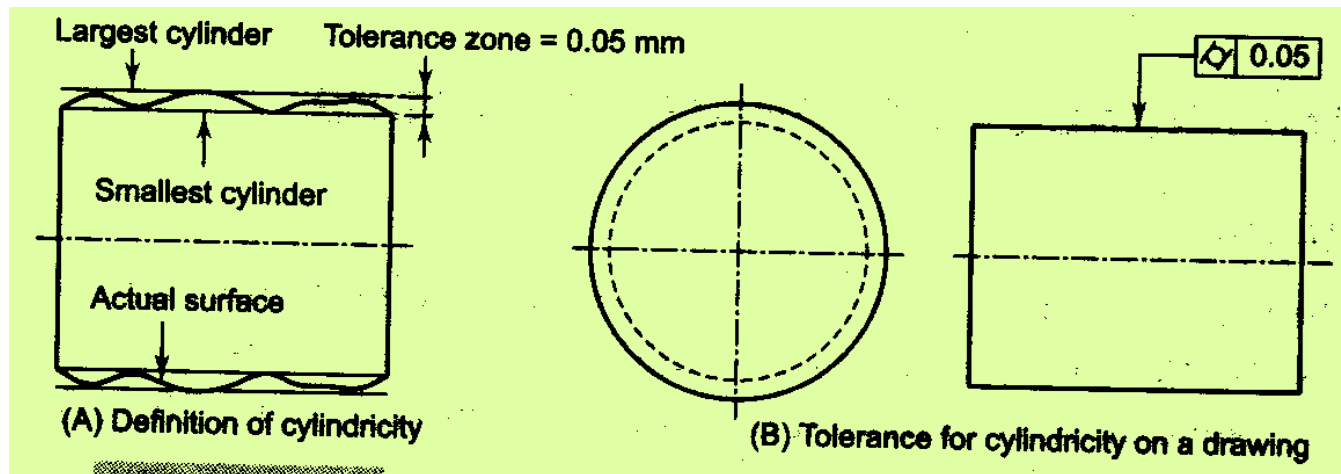


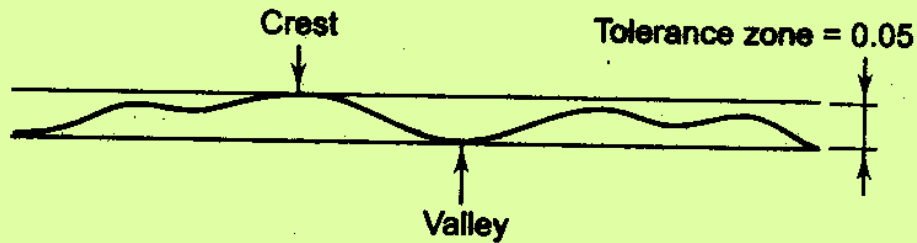
Roundness and Cylindricity

Runout is a 2D measurement that can be either taken in the axial direction or in the radial direction. When measuring in the radial direction, runout combines both roundness and concentricity errors into one composite measurement. If a part is perfectly round, the runout will equal the concentricity and if perfectly concentric the runout will equal the roundness error. Essentially, runout takes into account both the axis offset and the roundness of any object that rotates about an axis.

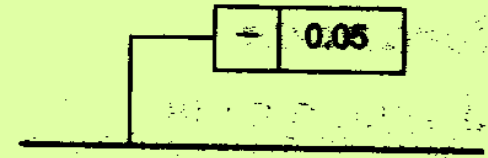
Total Runout is a 3D measurement which takes into account the entire surface of a part. Where runout measures only one cross-section relative to an axis, total runout takes the entire part into consideration, and all variations across the entire surface must fall within a specific tolerance.



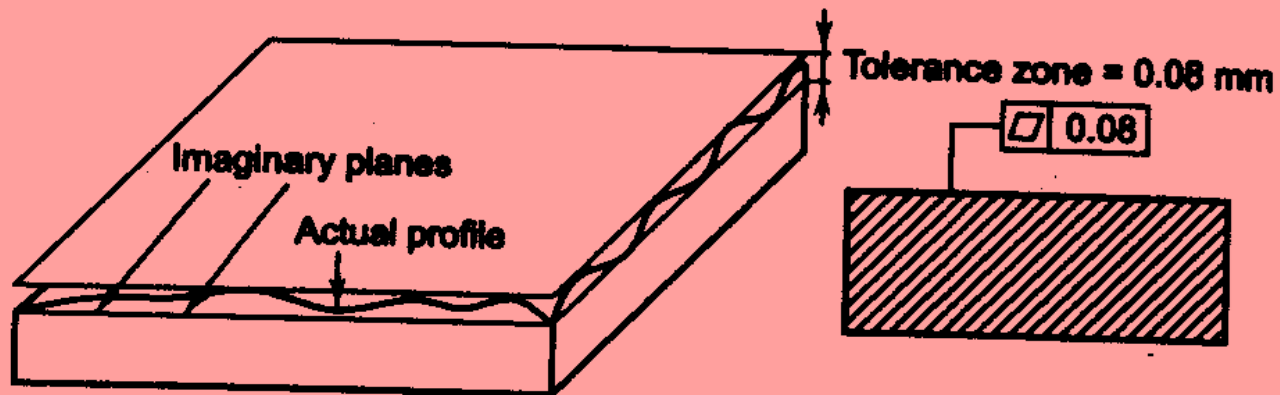




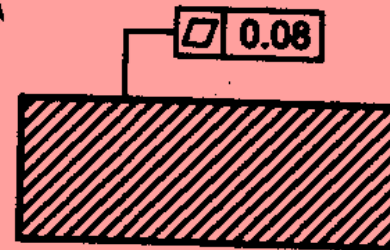
(A) Definition of straightness



(B) Tolerance for straightness on a drawing

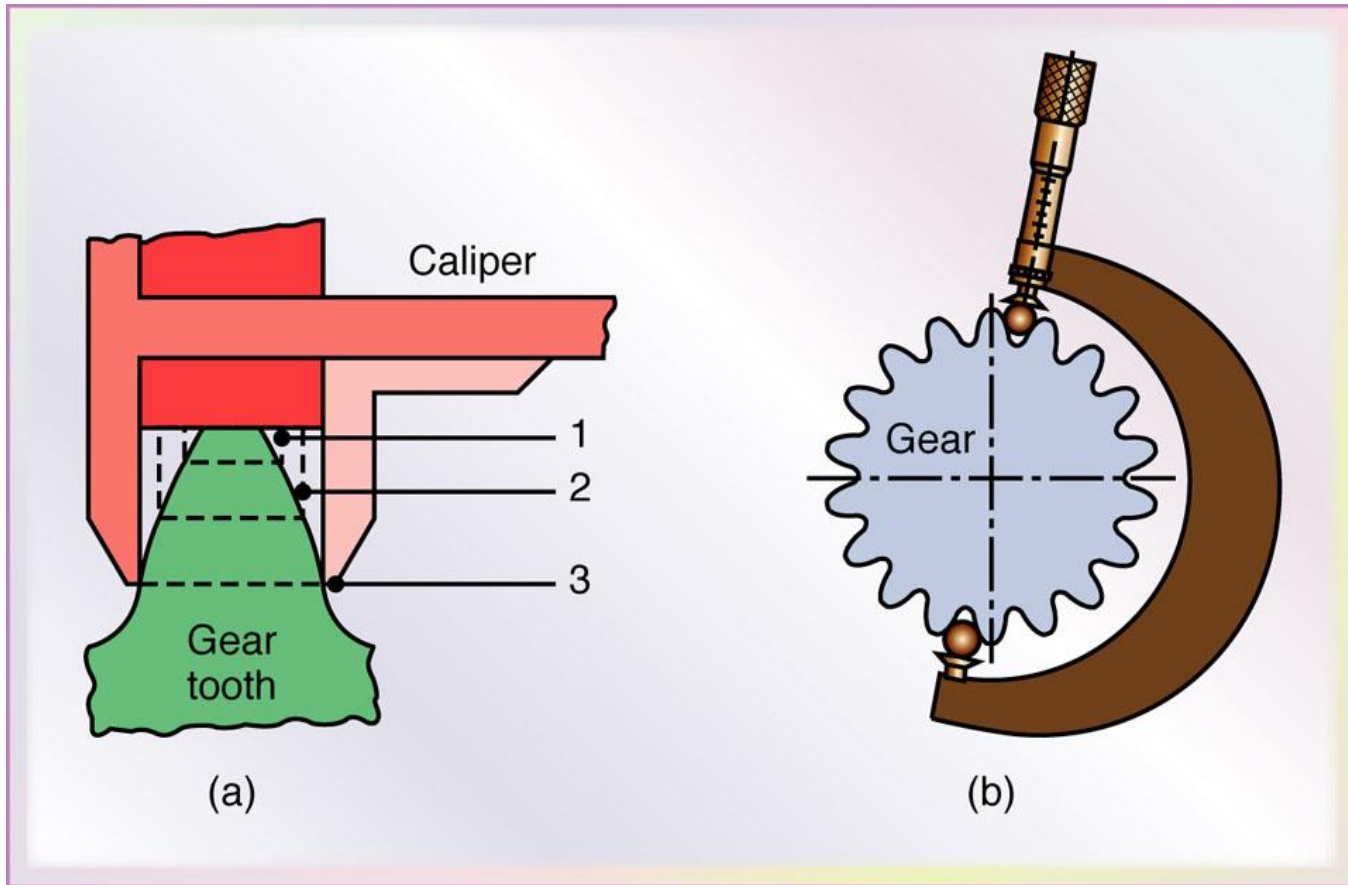


(A) Definition of flatness



(B) Tolerance for flatness on a drawing

Profile Measurement



Measuring gear-tooth thickness and profile with (a) a gear-tooth caliper and (b) balls and a micrometer.

Source: American Gear Manufacturers Association.

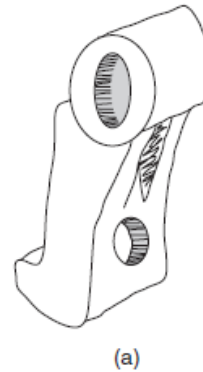
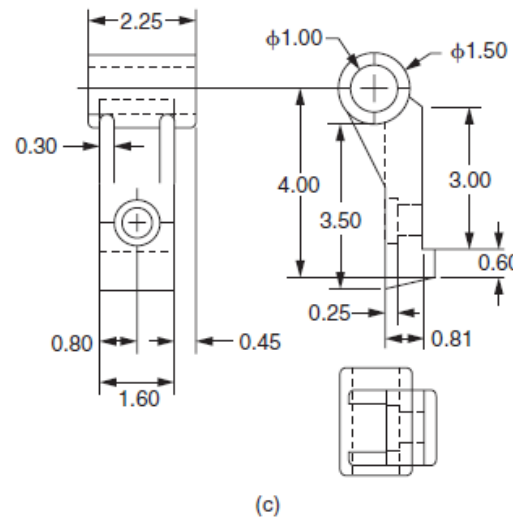
Dr. Sounak Choudhury

Mechanical Engineering Department

IIT Kanpur



Introduction to Tolerances



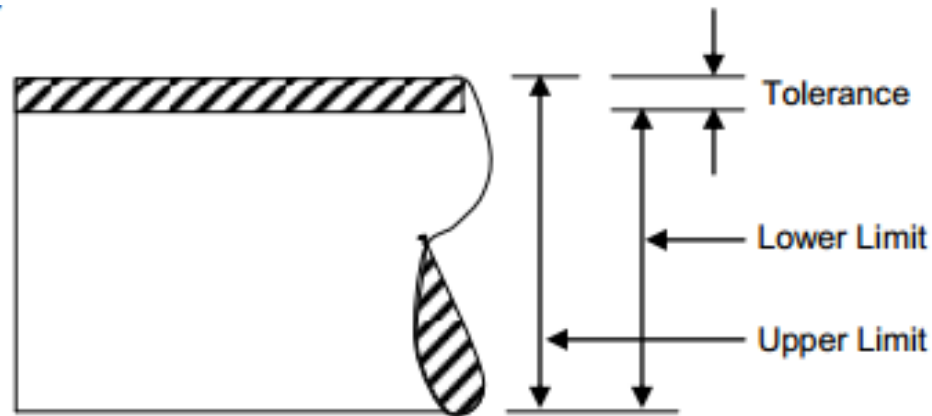
Can more than one or multiple parts be produced with exactly same dimensions?

Why Not?



Tolerance

“the allowable deviation from a standard,
eg: the range of variation permitted in
maintaining a specified dimension in a
machined piece.” (**Webster**)



Tolerance

Tolerances (ANSI Y14.5M-1982):

A tolerance is "the total amount by which a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits"

- Variations occur in any manufacturing process, which are manifested as variations in part size.
- Tolerances are used to define the limits of the allowed variation



Why is it necessary?

- ❑ It is impossible to manufacture a part or component to an exact size or geometry.
- ❑ Since variation from the drawing is inevitable, acceptable degree of variation must be applied.
- ❑ Large variation may affect the functionality of the part.
- ❑ Small variations may affect the economy of the part.



Consequences

- ❑ Cost generally **increases** with **Smaller** (tighter) tolerances.
- ❑ Parts with **Smaller** tolerances often require special methods of manufacture.
- ❑ Parts with **Smaller** tolerances often require greater inspection and call for rejection of parts .



Specification

Tolerance

Dimensional

Geometrical

“ the total amount by which a specified dimension is permitted to Vary”

ANSI (American National Standards Institute)

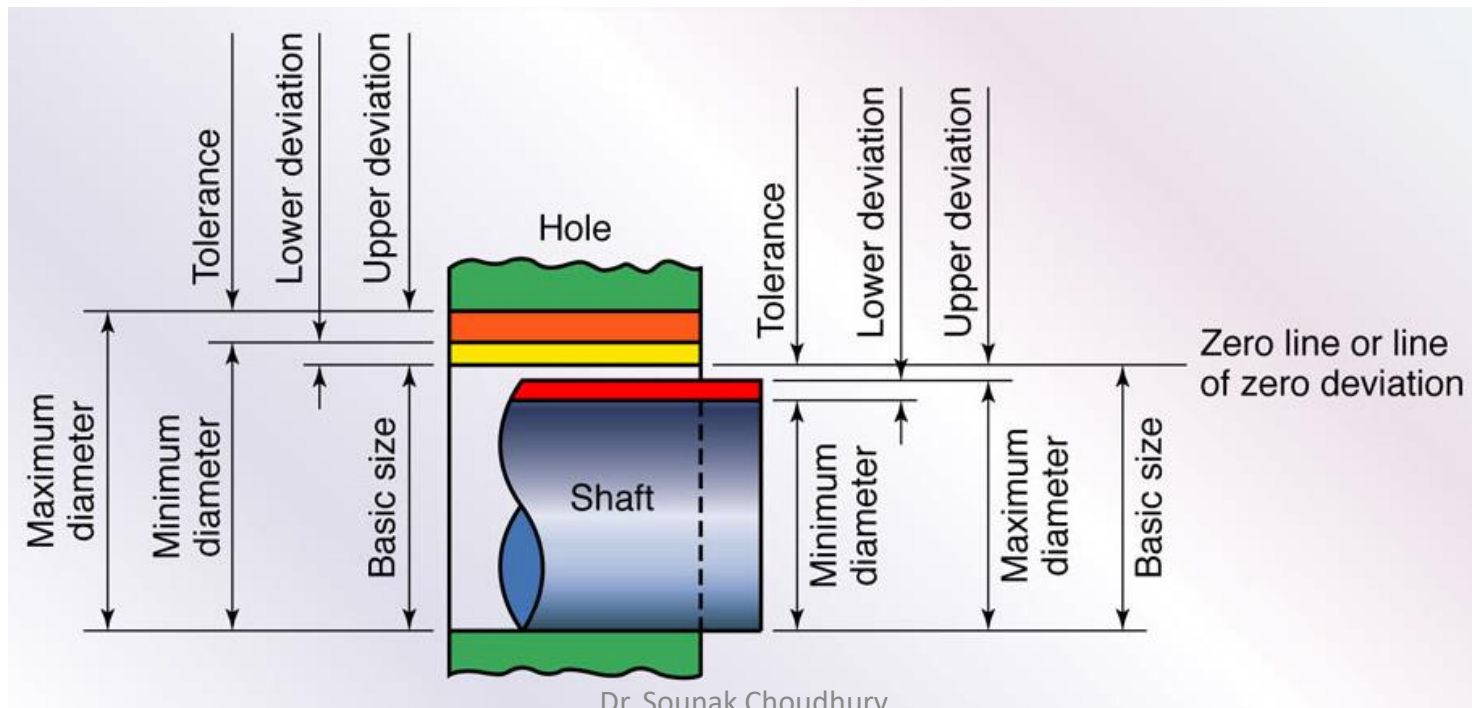


Some Definitions

Basic Size: The size with reference to which the limits of size are fixed.

Actual Size: Actual measured dimension of the part.

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.



Dr. Sounak Choudhury

Mechanical Engineering Department

IIT Kanpur



Some Definitions

Limits of Size: The two extreme permissible sizes of a part between which the actual size should lie.

Maximum Limit of Size: The greater of the two limits of size.

Minimum Limit of Size: The smaller of the two limits of size.

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.

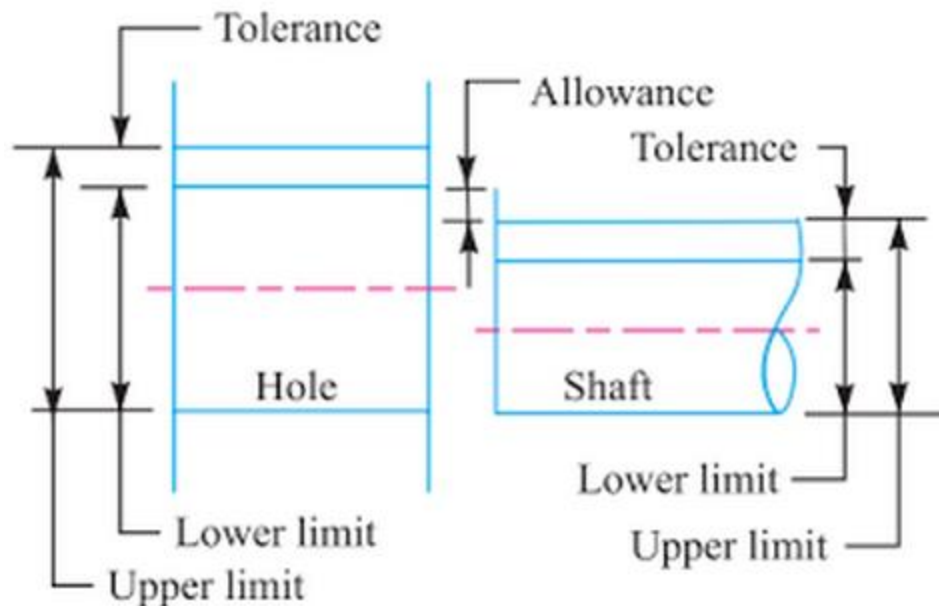


Some Definitions

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.



Some Definitions

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

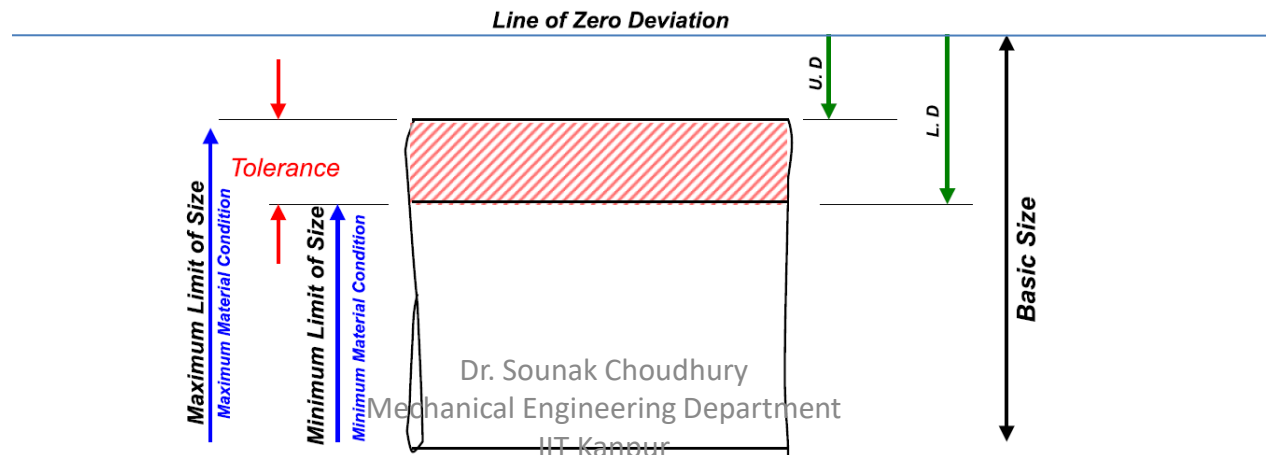
Upper Deviation: It is the algebraic difference between the maximum size and the basic size.

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 .

Shaft



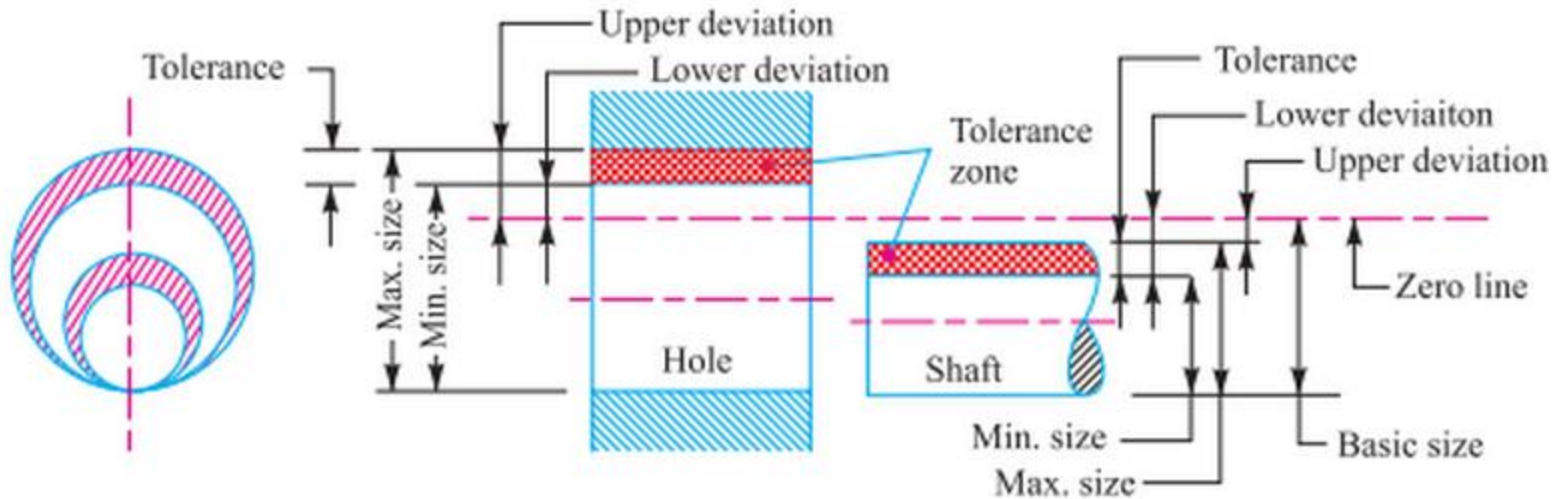
Dr. Sounak Choudhury

Mechanical Engineering Department

IIT Kanpur



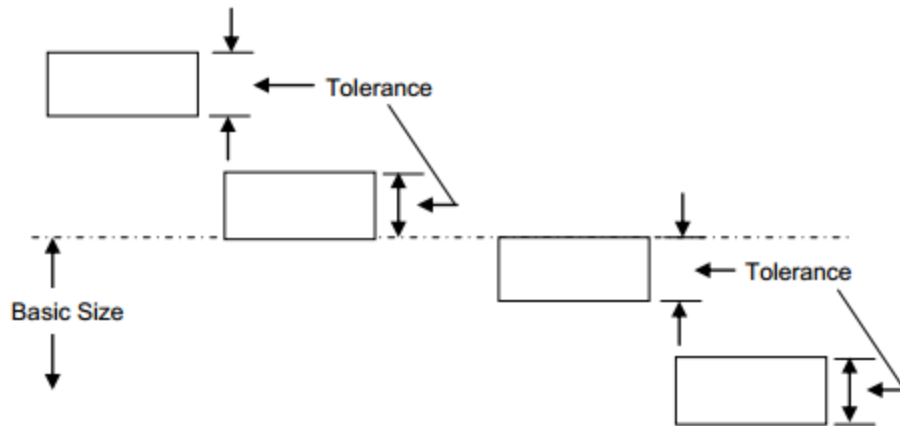
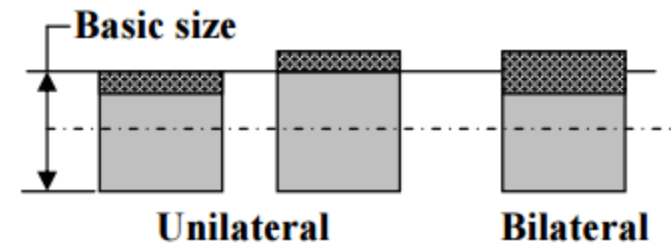
Some Definitions



Specification of DT

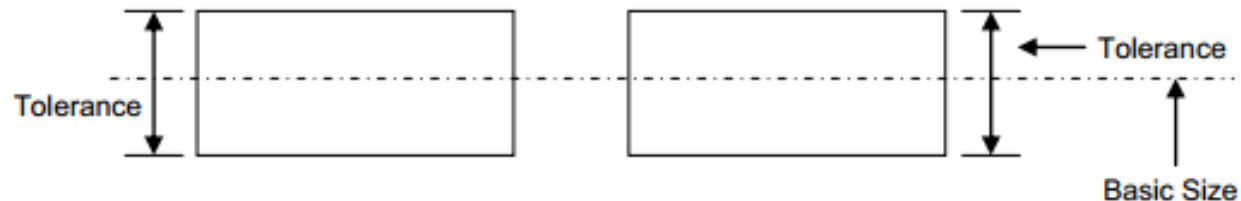
Unilateral Tolerance

In this system, the dimension of a part is allowed to vary only on one side of the basic size, i.e. tolerance lies wholly on one side of the basic size either above or below it.



Bilateral Tolerance

In this system, the dimension of the part is allowed to vary on both the sides of the basic size, i.e. the limits of tolerance lie on either side of the basic size.



Specification of DT

Bilateral

$$20 \pm 0.5$$

$$20^{+0.5}_{-0.5}$$

$$\begin{matrix} 20.05 \\ 19.95 \end{matrix}$$

Unilateral

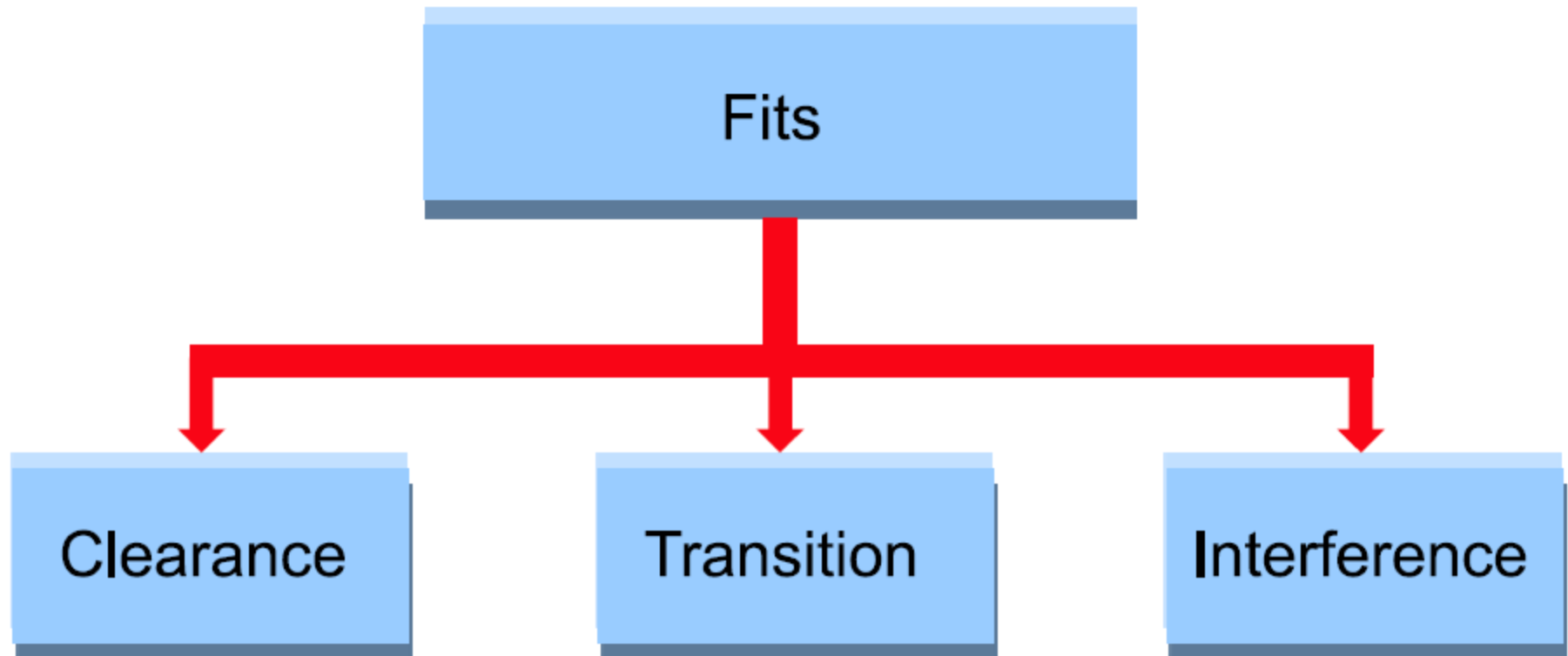
$$20^{+0.5}_0$$

$$\begin{matrix} 20.05 \\ 20.00 \end{matrix}$$



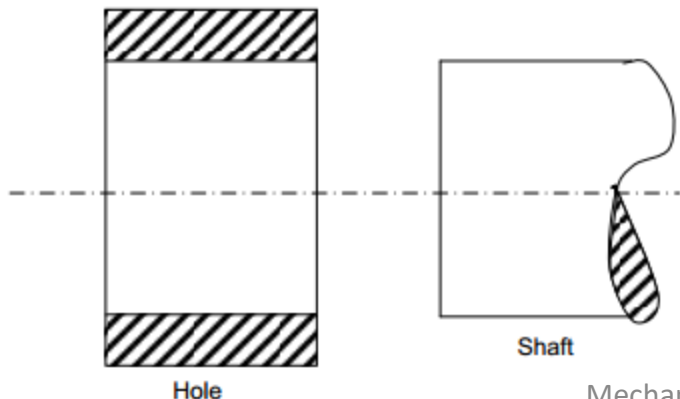
Fit

A fit may be defined as the degree of tightness and looseness between two mating parts.



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.

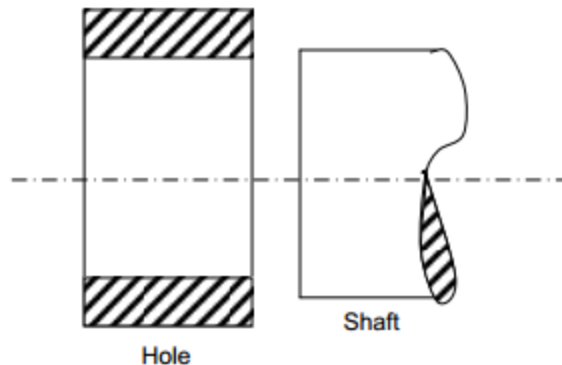
Slide Fit or Medium Fit

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.



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

Interference exists between the high limit of hole and low limit of the 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.

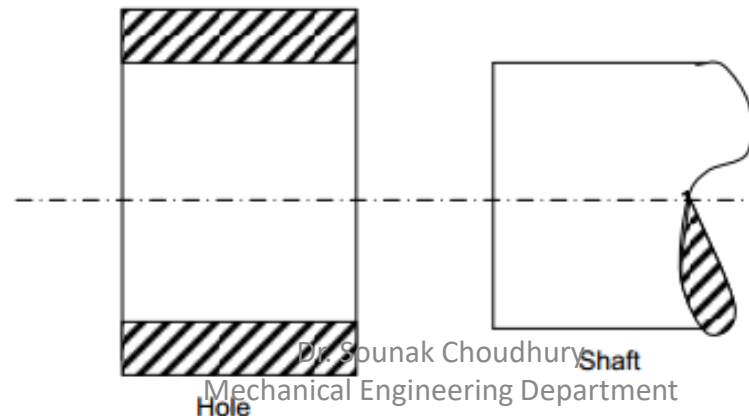
Tight Fit or Force Fit

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 semi-permanent 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.



Dr. Sounak Choudhury

Mechanical Engineering Department

IIT Kanpur



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

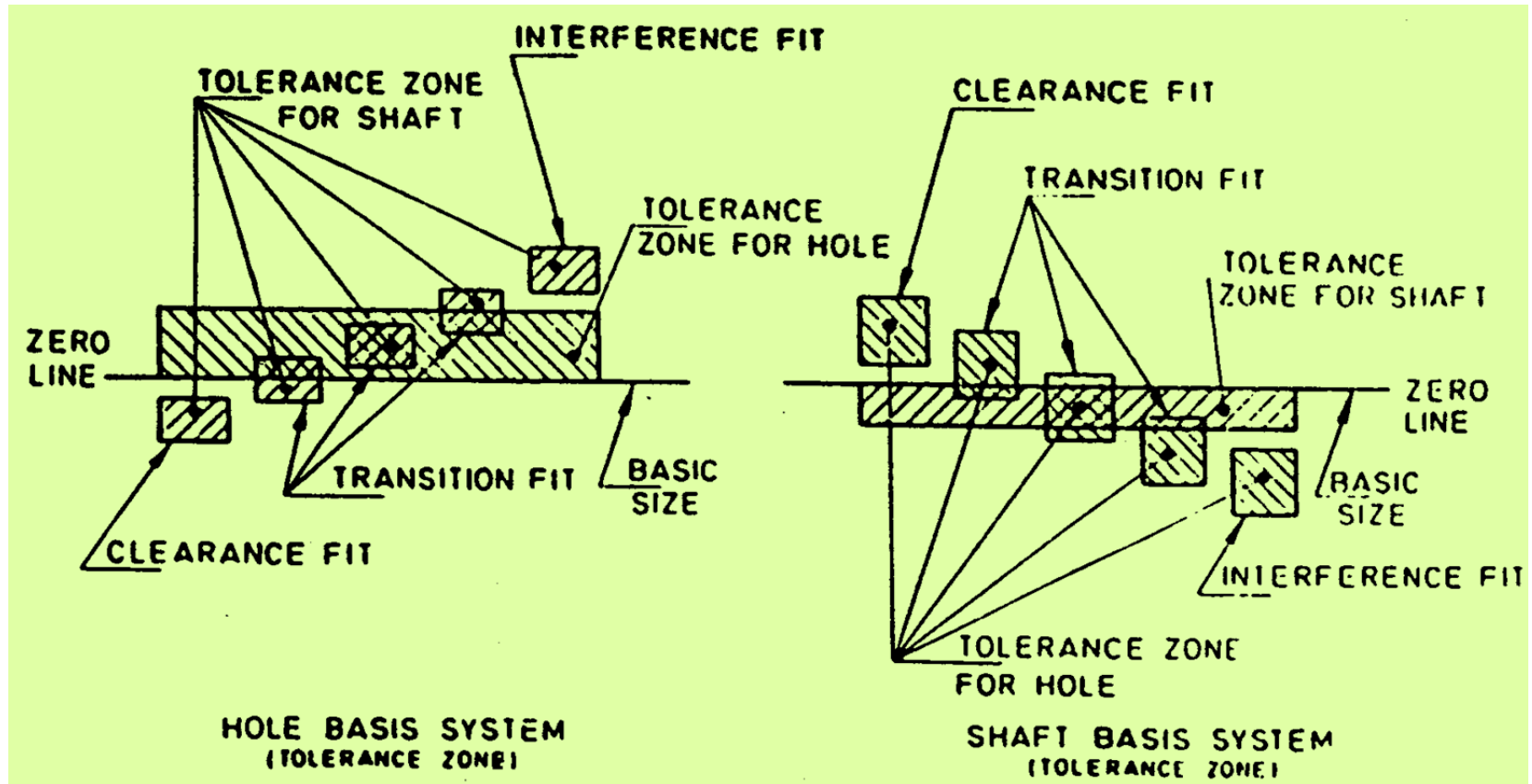
A force fit is used when the two mating parts are to be rigidly fixed so that one cannot move without the other. It either requires high pressure to force the shaft into the hole or the hole to be expanded by heating. It is used in railway wheels, etc.

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.

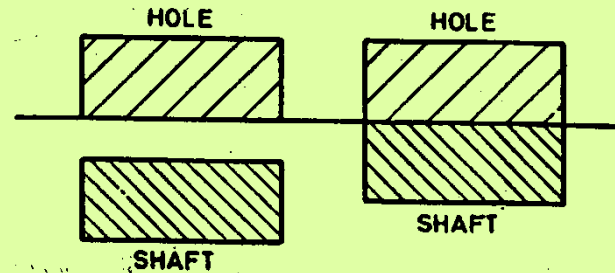


USE HOLE BASIS SYSTEM (why?): min tolerance on hole is 0

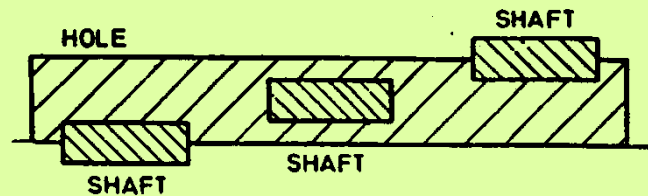


Types of fit: clearance, transition and interference

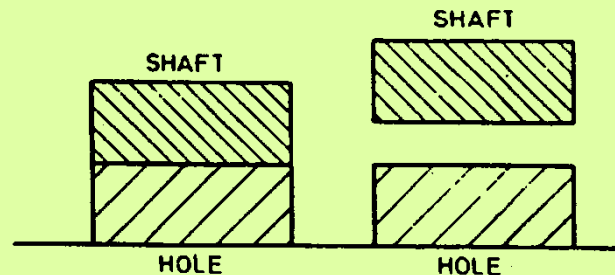
Hole basis
system



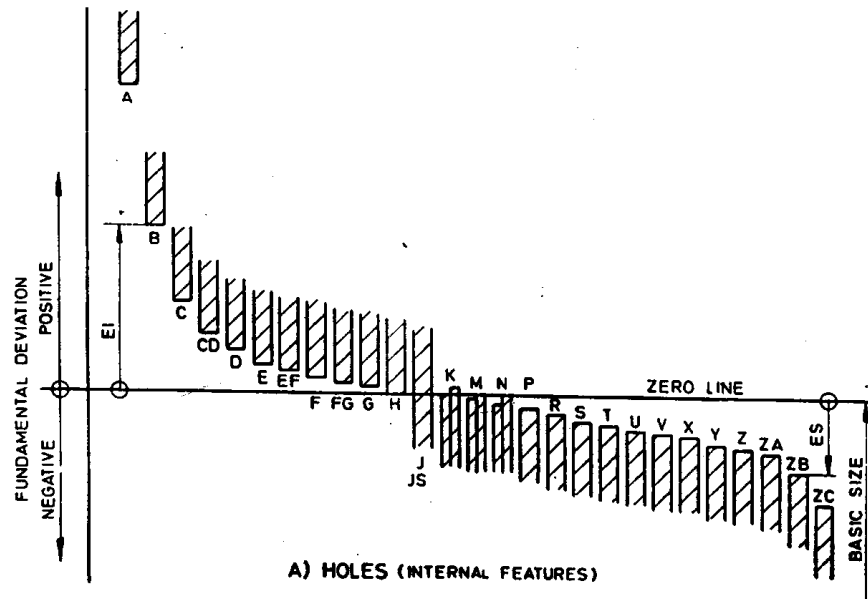
Schematic Representation of
Clearance Fit



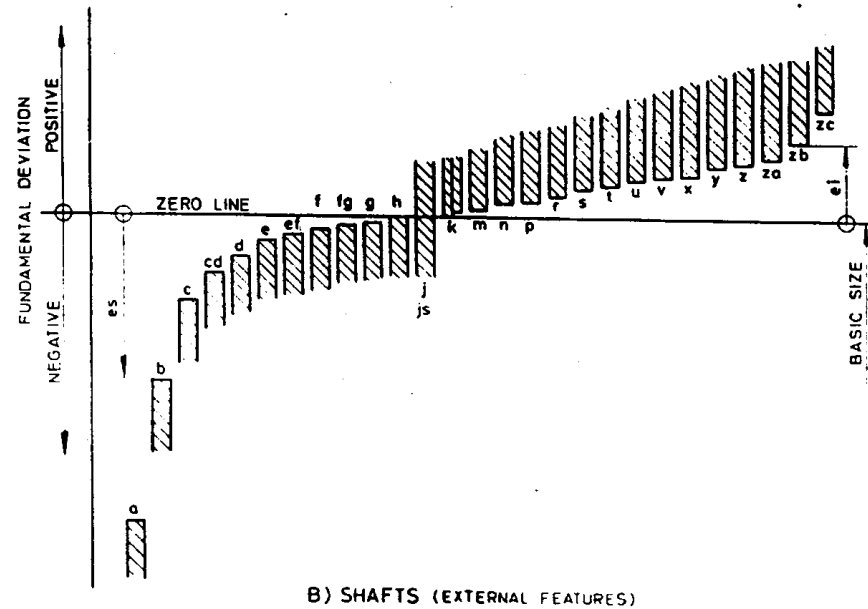
Schematic Representation of
Transition Fit



Schematic Representation of
Interference Fit



H : Lower value of tolerance



h : higher value of tolerance

1 For Holes

Type of Fit	Class of Shaft	With Holes					Remarks
		H6*	H7	H8	H9	H11	
Clearance	$\frac{a}{b}$	—	—	—	—	a11 b11	Large clearance fit and widely used
	c	—	—	—	—	c11	Slack running fit
	d	—	d8*	d8*, d9, d10	d8*, d9, d10	d9	Loose running fit
	e	e7*	e8	e8, e9*			Easy running fit
	f	f6*	f7	f7, f8*			Normal running fit
	g	g5*	g6	—			Close running fit or sliding fit, also spigot and location fit
	h	h5*	h6	h7, h8*, h9*		h11	Precision sliding fit. Also fine spigot and location fit.
Transition	js	js5*	js6	js7*			Push fit for very accurate location with easy assembly and disassembly
	k	k5*	k6	k7*			Light keying fit (true transition) for keyed shafts, non-running locked pins, etc.
	m	m5*	m6*	m7*			Medium keying fit
	n	n5*	n6	n7*			Heavy keying fit (for tight assembly mating surfaces)
Interference	p	p5*	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	r5*	r6	r7*			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 for ferrous parts 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			u7*			Heavy force fit or shrink fit

* Second preference fits.



99

Nominal Size Range mm

	e6	e8	e12	e16	e20	e24	e28	e32	e36	e40	e44	e48	e52	e56	e60	e64	e68	e72	e76	e80	e84	e88	e92	e96	e100	e104	e108	e112	e116	e120	e124	e128	e132	e136	e140	e144	e148	e152	e156	e160	e164	e168	e172	e176	e180	e184	e188	e192	e196	e200	e204	e208	e212	e216	e220	e224	e228	e232	e236	e240	e244	e248	e252	e256	e260	e264	e268	e272	e276	e280	e284	e288	e292	e296	e300	e304	e308	e312	e316	e320	e324	e328	e332	e336	e340	e344	e348	e352	e356	e360	e364	e368	e372	e376	e380	e384	e388	e392	e396	e400	e404	e408	e412	e416	e420	e424	e428	e432	e436	e440	e444	e448	e452	e456	e460	e464	e468	e472	e476	e480	e484	e488	e492	e496	e500	e504	e508	e512	e516	e520	e524	e528	e532	e536	e540	e544	e548	e552	e556	e560	e564	e568	e572	e576	e580	e584	e588	e592	e596	e600	e604	e608	e612	e616	e620	e624	e628	e632	e636	e640	e644	e648	e652	e656	e660	e664	e668	e672	e676	e680	e684	e688	e692	e696	e700	e704	e708	e712	e716	e720	e724	e728	e732	e736	e740	e744	e748	e752	e756	e760	e764	e768	e772	e776	e780	e784	e788	e792	e796	e800	e804	e808	e812	e816	e820	e824	e828	e832	e836	e840	e844	e848	e852	e856	e860	e864	e868	e872	e876	e880	e884	e888	e892	e896	e900	e904	e908	e912	e916	e920	e924	e928	e932	e936	e940	e944	e948	e952	e956	e960	e964	e968	e972	e976	e980	e984	e988	e992	e996	e1000	e1004	e1008	e1012	e1016	e1020	e1024	e1028	e1032	e1036	e1040	e1044	e1048	e1052	e1056	e1060	e1064	e1068	e1072	e1076	e1080	e1084	e1088	e1092	e1096	e1100	e1104	e1108	e1112	e1116	e1120	e1124	e1128	e1132	e1136	e1140	e1144	e1148	e1152	e1156	e1160	e1164	e1168	e1172	e1176	e1180	e1184	e1188	e1192	e1196	e1200	e1204	e1208	e1212	e1216	e1220	e1224	e1228	e1232	e1236	e1240	e1244	e1248	e1252	e1256	e1260	e1264	e1268	e1272	e1276	e1280	e1284	e1288	e1292	e1296	e1300	e1304	e1308	e1312	e1316	e1320	e1324	e1328	e1332	e1336	e1340	e1344	e1348	e1352	e1356	e1360	e1364	e1368	e1372	e1376	e1380	e1384	e1388	e1392	e1396	e1400	e1404	e1408	e1412	e1416	e1420	e1424	e1428	e1432	e1436	e1440	e1444	e1448	e1452	e1456	e1460	e1464	e1468	e1472	e1476	e1480	e1484	e1488	e1492	e1496	e1500	e1504	e1508	e1512	e1516	e1520	e1524	e1528	e1532	e1536	e1540	e1544	e1548	e1552	e1556	e1560	e1564	e1568	e1572	e1576	e1580	e1584	e1588	e1592	e1596	e1600	e1604	e1608	e1612	e1616	e1620	e1624	e1628	e1632	e1636	e1640	e1644	e1648	e1652	e1656	e1660	e1664	e1668	e1672	e1676	e1680	e1684	e1688	e1692	e1696	e1700	e1704	e1708	e1712	e1716	e1720	e1724	e1728	e1732	e1736	e1740	e1744	e1748	e1752	e1756	e1760	e1764	e1768	e1772	e1776	e1780	e1784	e1788	e1792	e1796	e1800	e1804	e1808	e1812	e1816	e1820	e1824	e1828	e1832	e1836	e1840	e1844	e1848	e1852	e1856	e1860	e1864	e1868	e1872	e1876	e1880	e1884	e1888	e1892	e1896	e1900	e1904	e1908	e1912	e1916	e1920	e1924	e1928	e1932	e1936	e1940	e1944	e1948	e1952	e1956	e1960	e1964	e1968	e1972	e1976	e1980	e1984	e1988	e1992	e1996	e2000	e2004	e2008	e2012	e2016	e2020	e2024	e2028	e2032	e2036	e2040	e2044	e2048	e2052	e2056	e2060	e2064	e2068	e2072	e2076	e2080	e2084	e2088	e2092	e2096	e2100	e2104	e2108	e2112	e2116	e2120	e2124	e2128	e2132	e2136	e2140	e2144	e2148	e2152	e2156	e2160	e2164	e2168	e2172	e2176	e2180	e2184	e2188	e2192	e2196	e2200	e2204	e2208	e2212	e2216	e2220	e2224	e2228	e2232	e2236	e2240	e2244	e2248	e2252	e2256	e2260	e2264	e2268	e2272	e2276	e2280	e2284	e2288	e2292	e2296	e2300	e2304	e2308	e2312	e2316	e2320	e2324	e2328	e2332	e2336	e2340	e2344	e2348	e2352	e2356	e2360	e2364	e2368	e2372	e2376	e2380	e2384	e2388	e2392	e2396	e2400	e2404	e2408	e2412	e2416	e2420	e2424	e2428	e2432	e2436	e2440	e2444	e2448	e2452	e2456	e2460	e2464	e2468	e2472	e2476	e2480	e2484	e2488	e2492	e2496	e2500	e2504	e2508	e2512	e2516	e2520	e2524	e2528	e2532	e2536	e2540	e2544	e2548	e2552	e2556	e2560	e2564	e2568	e2572	e2576	e2580	e2584	e2588	e2592	e2596	e2600	e2604	e2608	e2612	e2616	e2620	e2624	e2628	e2632	e2636	e2640	e2644	e2648	e2652	e2656	e2660	e2664	e2668	e2672	e2676	e2680	e2684	e2688	e2692	e2696	e2700	e2704	e2708	e2712	e2716	e2720	e2724	e2728	e2732	e2736	e2740	e2744	e2748	e2752	e2756	e2760	e2764	e2768	e2772	e2776	e2780	e2784	e2788	e2792	e2796	e2800	e2804	e2808	e2812	e2816	e2820	e2824	e2828	e2832	e2836	e2840	e2844	e2848	e2852	e2856	e2860	e2864	e2868	e2872	e2876	e2880	e2884	e2888	e2892	e2896	e2900	e2904	e2908	e2912	e2916	e2920	e2924	e2928	e2932	e2936	e2940	e2944	e2948	e2952	e2956	e2960	e2964	e2968	e2972	e2976	e2980	e2984	e2988	e2992	e2996	e3000	e3004	e3008	e3012	e3016	e3020	e3024	e3028	e3032	e3036	e3040	e3044	e3048	e3052	e3056	e3060	e3064	e3068	e3072	e3076	e3080	e3084	e3088	e3092	e3096	e3100	e3104	e3108	e3112	e3116	e3120	e3124	e3128	e3132	e3136	e3140	e3144	e3148	e3152	e3156	e3160	e3164	e3168	e3172	e3176	e3180	e3184	e3188	e3192	e3196	e3200	e3204	e3208	e3212	e3216	e3220	e3224	e3228	e3232	e3236	e3240	e3244	e3248	e3252	e3256	e3260	e3264	e3268	e3272	e3276	e3280	e3284	e3288	e3292	e3296	e3300	e3304	e3308	e3312	e3316	e3320	e3324	e3328	e3332	e3336	e3340	e3344	e3348	e3352	e3356	e3360	e3364	e3368	e3372	e3376	e3380	e3384	e3388	e3392	e3396	e3400	e3404	e3408	e3412	e3416	e3420	e3424	e3428	e3432	e3436	e3440	e3444	e3448	e3452	e3456	e3460	e3464	e3468	e3472	e3476	e3480	e3484	e3488	e3492	e3496	e3500	e3504	e3508	e3512	e3516	e3520	e3524	e3528	e3532	e3536	e3540	e3544	e3548	e3552	e3556	e3560	e3564	e3568	e3572	e3576	e3580	e3584	e3588	e3592	e3596	e3600	e3604	e3608	e3612	e3616	e3620	e3624	e3628	e3632	e3636	e3640	e3644	e3648	e3652	e3656	e3660	e3664	e3668	e3672	e3676	e3680	e3684	e3688	e3692	e3696	e3700	e3704	e3708	e3712	e3716	e3720	e3724	e3728	e3732	e3736	e3740	e3744	e3748	e3752	e3756	e3760	e3764	e3768	e3772	e3776	e3780	e3784	e3788	e3792	e3796	e3800	e3804	e3808	e3812	e3816	e3820	e3824	e3828	e3832	e3836	e3840	e3844	e3848	e3852	e3856	e3860	e3864	e3868	e3872	e3876	e3880	e3884	e3888	e3892	e3896	e3900	e3904	e3908	e3912	e3916	e3920	e3924	e3928	e3932	e3936	e3940	e3944	e3948	e3952	e3956	e3960	e3964	e3968	e3972	e3976	e3980	e3984	e3988	e3992	e3996	e4000	e4004	e4008	e4012	e4016	e4020	e4024	e4028	e4032	e4036	e4040	e4044	e4048	e4052	e4056	e4060	e4064	e4068	e4072	e4076	e4080	e4084	e4088	e4092	e4096	e4100	e4104	e4108	e4112	e4116	e4120	e4124	e4128	e4132	e4136	e4140	e4144	e4148	e4152	e4156	e4160	e4164	e4168	e4172	e4176	e4180	e4184	e4188	e4192	e4196	e4200	e4204	e4208	e4212	e4216	e4220	e4224	e4228	e4232	e4236	e4240	e4244	e4248	e4252	e4256	e4260	e4264	e4268	e4272	e4276	e4280	e4284	e4288	e4292	e4296	e4300	e4304	e4308	e4312	e4316	e4320	e4324	e4328	e4332	e4336	e4340	e4344	e4348	e4352	e4356	e4360	e4364	e4368	e4372	e4376	e4380	e4384	e4388	e4392	e4396	e4400	e4404	e4408	e4412	e4416	e4420	e4424	e4428	e4432	e4436	e4440	e4444	e4448	e4452	e4456	e4460	e4464	e4468	e4472	e4476	e4480	e4484	e4488	e4492	e4496	e4500	e4504	e4508	e4512	e4516	e4520	e4524	e4528	e4532	e4536	e4540	e4544	e4548	e4552	e4556	e4560	e4564	e4568	e4572	e4576	e4580	e4584	e4588	e4592	e4596	e4600	e4604	e4608	e4612	e4616	e4620	e4624	e4628	e4632	e4636	e4640	e4644	e4648	e4652	e4656	e4660	e4664	e4668	e4672	e4676	e4680	e4684	e4688	e4692	e4696	e4700	e4704	e4708	e4712	e4716	e4720	e4724	e4728	e4732	e4736	e4740	e4744	e4748	e4752	e4756	e4760	e4764	e4768	e4772	e4776	e4780	e4784	e4788	e4792	e4796	e4800	e4804	e4808	e4812	e4816	e4820	e4824	e4828	e4832	e4836	e4840	e4844	e4848	e4852	e4856	e4860	e4864	e4868	e4872	e4876	e4880	e4884	e4888	e4892	e4896	e4900	e4904	e4908	e4912	e4916	e4920	e4924	e4928	e4932	e4936	e4940	e4944	e4948	e4952	e4956	e4960	e4964	e4968	e4972	e4976	e4980	e4984	e4988	e4992	e4996	e5000	e5004	e5008	e5012	e5016	e5020	e5024	e5028	e5032	e5036	e5040	e5044	e5048	e5052	e5056	e5060	e5064	e5068	e5072	e5076	e5080	e5084	e5088	e5092	e5096	e5100	e5104	e5108	e5112	e5116	e5120	e5124	e5128	e5132	e5136	e5140	e5144	e5148	e5152	e5156	e5160	e5164	e5168	e5172	e5176	e5180	e5184	e5188	e5192	e5196	e5200	e5204	e5208	e5212	e5216	e5220	e5224	e5228	e5232	e5236	e5240	e5244	e5248	e5252	e5256	e5260	e5264	e5268	e5272	e5276	e5280	e5284	e5288	e5292	e5296	e5300	e5304	e5308	e5312	e5316	e5320	e5324	e5328	e5332	e5336	e5340	e5344	e5348	e5352	e5356	e5360	e5364	e5368	e5372	e5376	e5380	e5384	e5388	e5392	e5396	e5400	e5404	e5408	e5412	e5416	e5420	e5424	e5428	e5432	e5436	e5440	e5444	e5448	e5452	e5456	e5460	e5464	e5468	e5472	e5476	e5480	e5484	e5488	e5492	e5496	e5500	e5504	e5508	e5512	e5516	e5520	e5524	e5528	e5532	e5536	e5540	e5544	e5548	e5552	e5556	e5560	e5564	e5568	e5572	e5576	e5580	e5584	e5588	e5592	e5596	e5600	e5604	e5608	e5612	e5616	e5620	e5624
--	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Geometrical tolerances

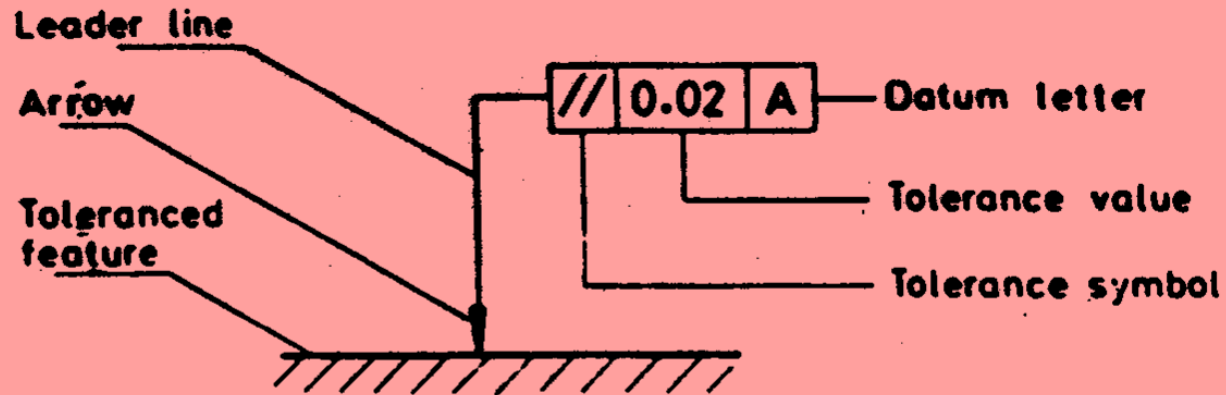
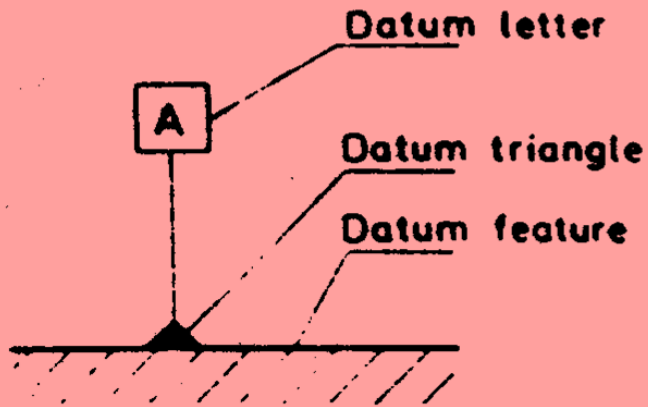
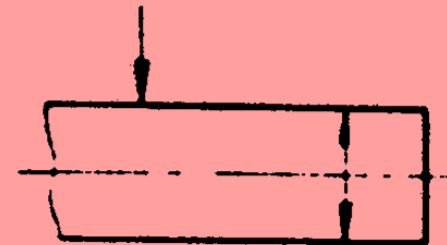
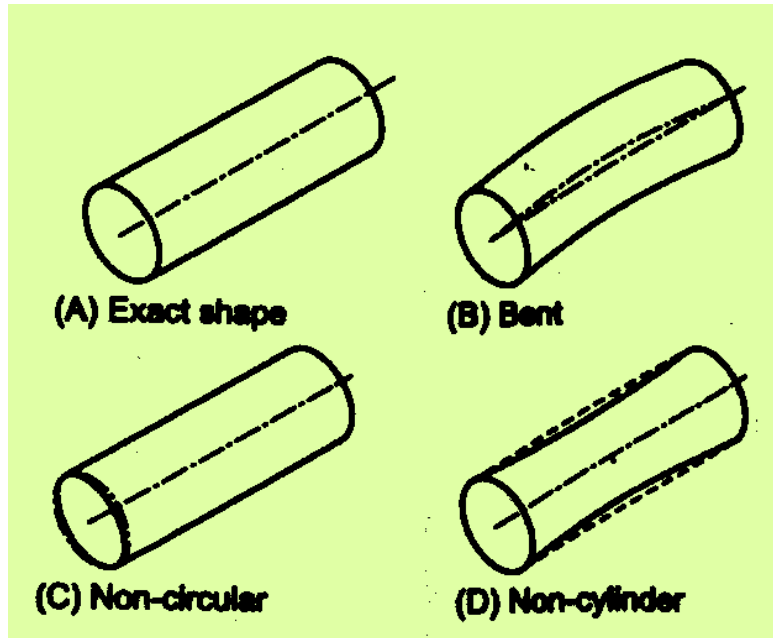
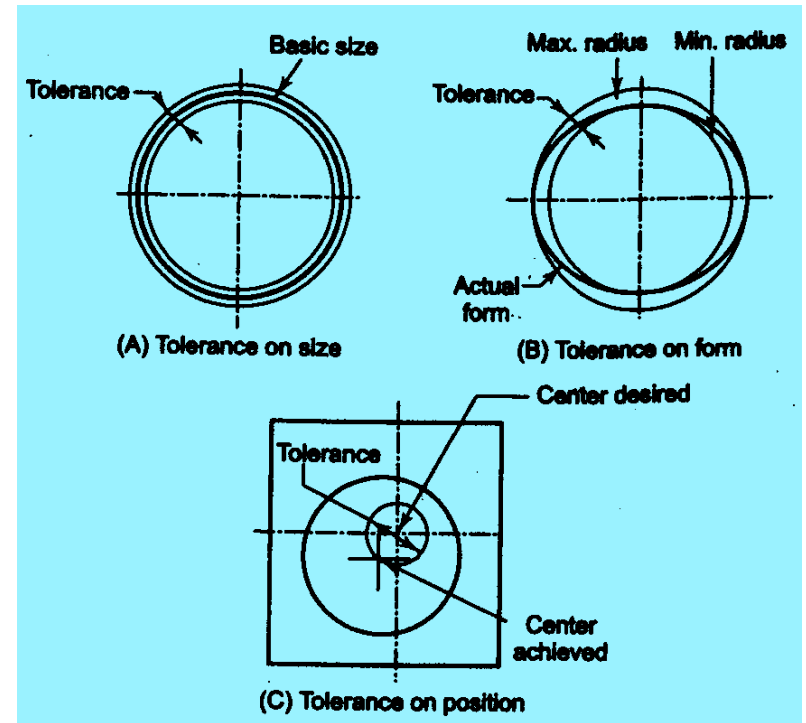


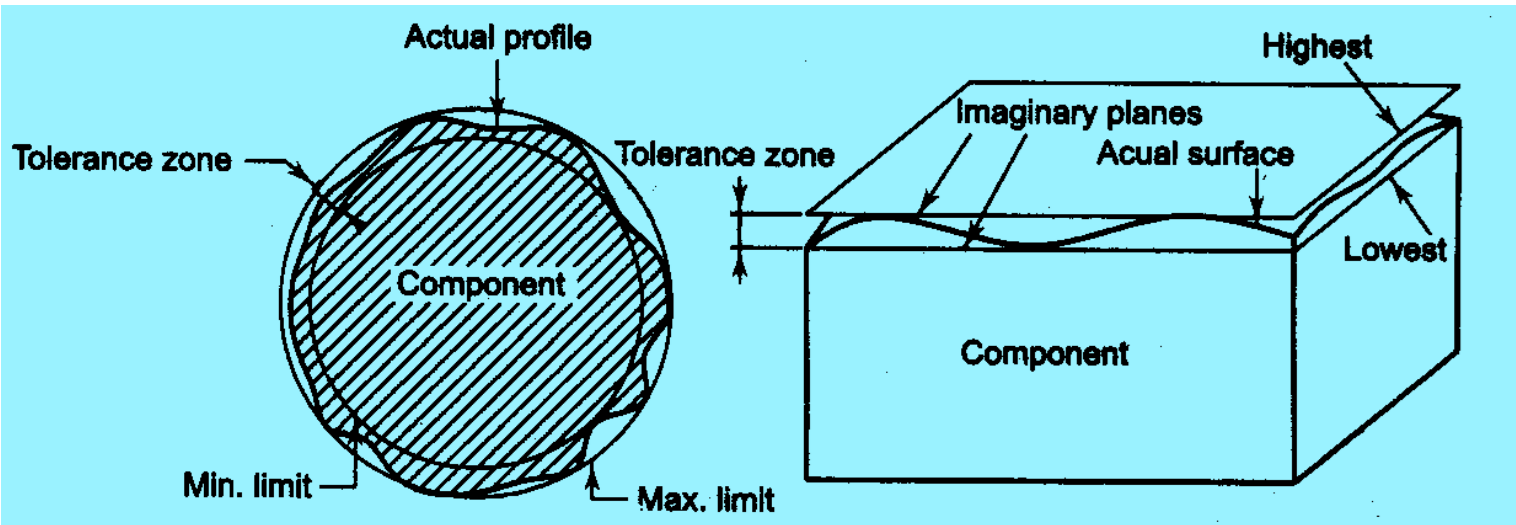
FIG.18.1

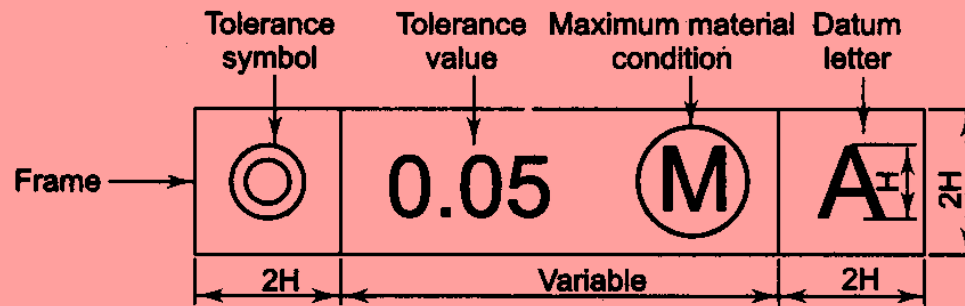


Refers to the
generating line
or the surface

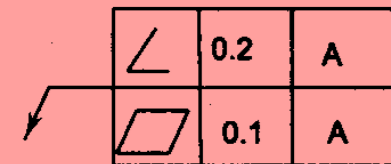




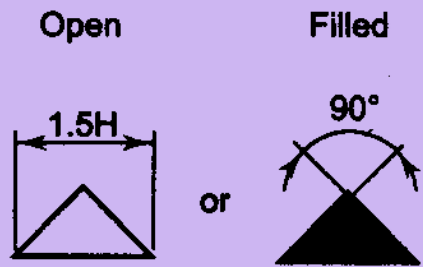




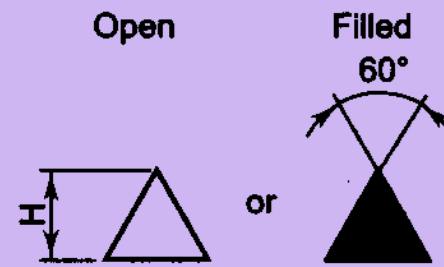
(A) Single frame



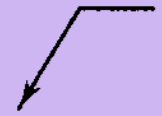
(B) Multiple frames



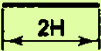
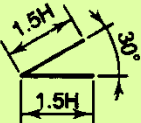
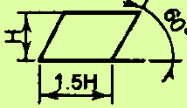
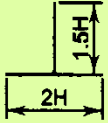
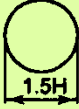
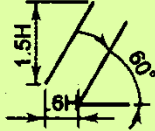
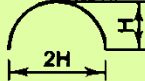
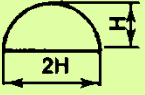
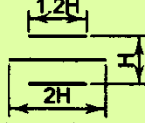
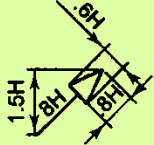
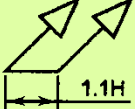
(A) ASME and BIS

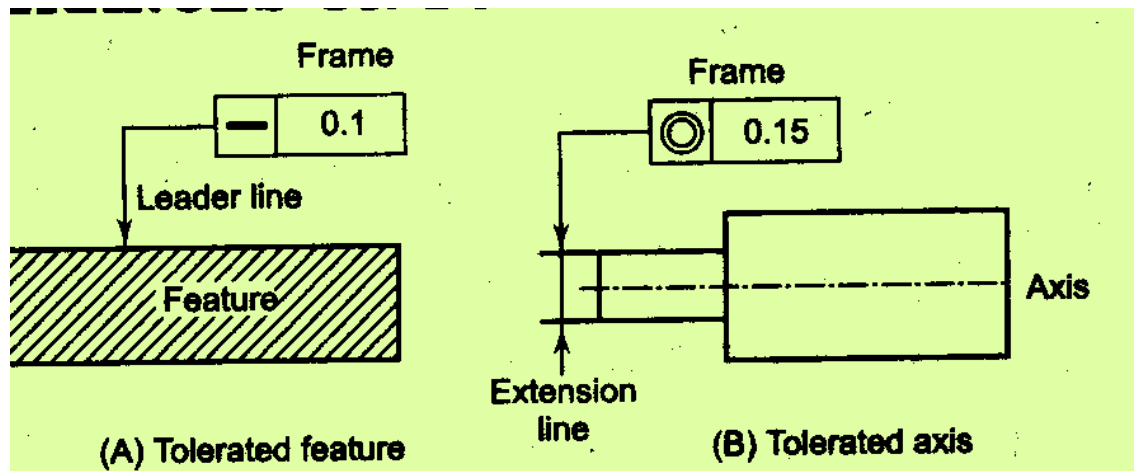
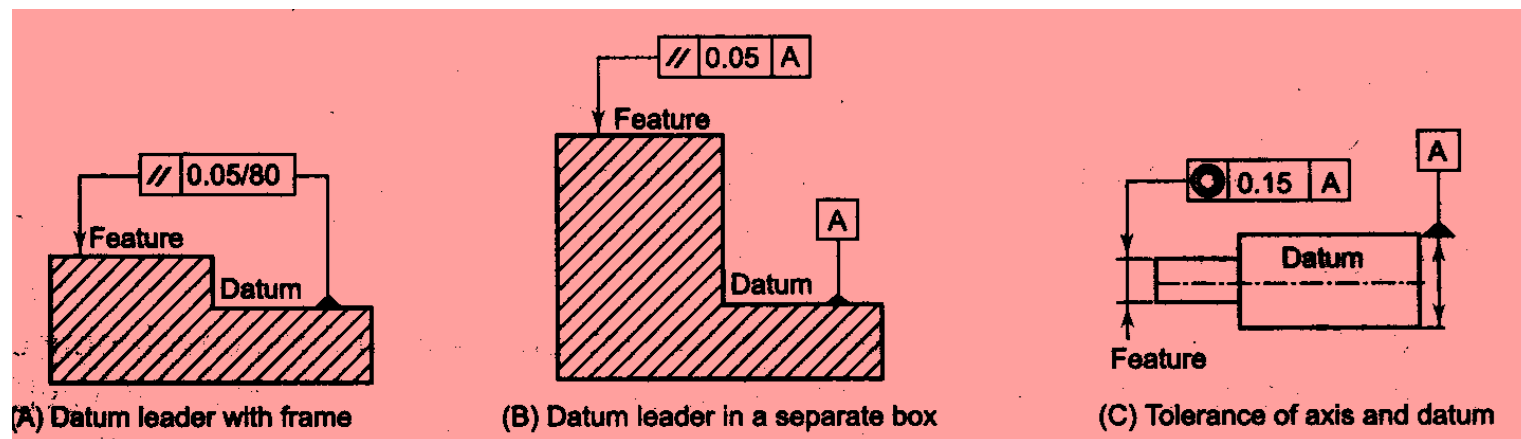


(B) ISO

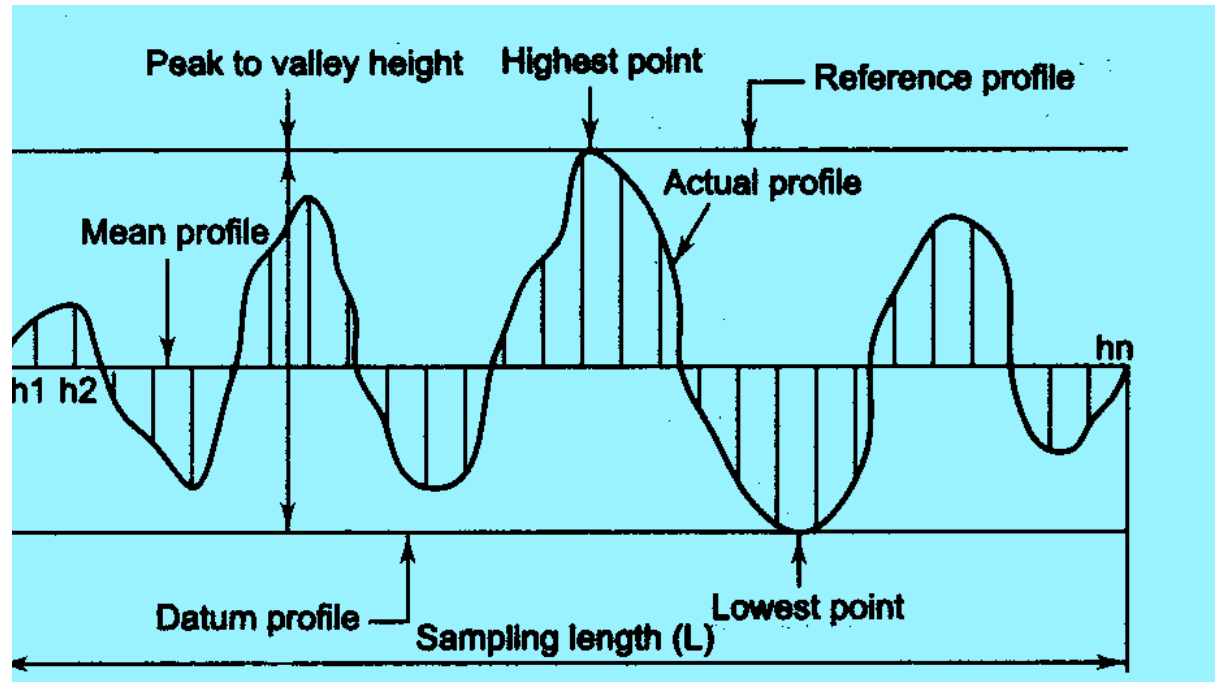


(C) ANSI

(A) Single feature symbols		(B) Related feature symbols	
Tolerance/symbol	Proportions	Tolerance/symbol	Proportions
Straightness 		Angularity 	
Flatness 		Perpendicularity 	
Circularity 		Parallelism 	
Cylindricity 		Concentricity 	
Profile of line 		Position 	
Profile of surface 		Symmetry 	
(C) Runout			
Run out 		Total run out 	



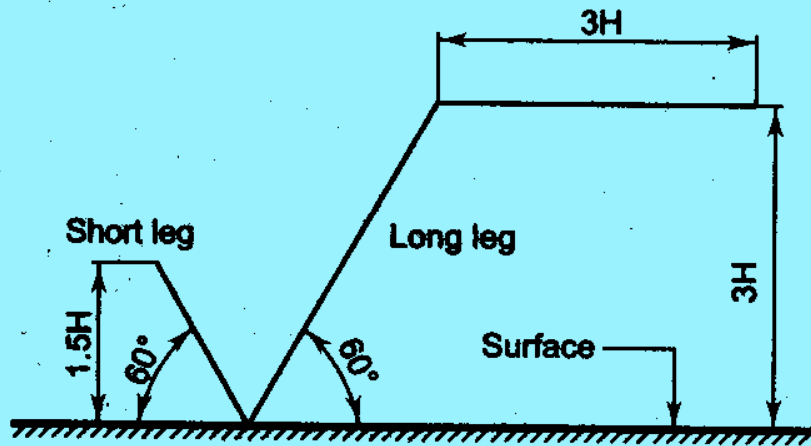
SURFACE FINISH



<i>S.No.</i>	<i>Process</i>	<i>Minimum- Maximum</i>	<i>Average application range Minimum-Maximum</i>
1	Gas cutting	6.3-100	12.5-25
2	Sand casting	6.3-50	12.5-25
3	Hot rolling	6.3-50	12.5-25
4	Sawing	1.6-25	1.6-12.5
5	Planing	1.6-25	1.6-12.5
6	Shaping	1.6-25	1.6-12.5
7	Forging	1.6-25	3.2-12.5
8	Turning	0.32-25	0.4-6.3
9	Milling	0.32-25	0.8-6.3
10	Filing	0.25-25	3.2-6.3
11	Drilling	1.6-20	1.6-6.3
12	Boring	0.2-25	0.4-6.3
13	Chemical milling	0.8-12.5	1.6-6.3
14	Electric discharge machining	0.8-12.5	1.6-6.3
15	Electron beam	0.2- 6.3	0.8-6.3
16	Laser	0.2-6.3	0.8-6.3

(Contd.)

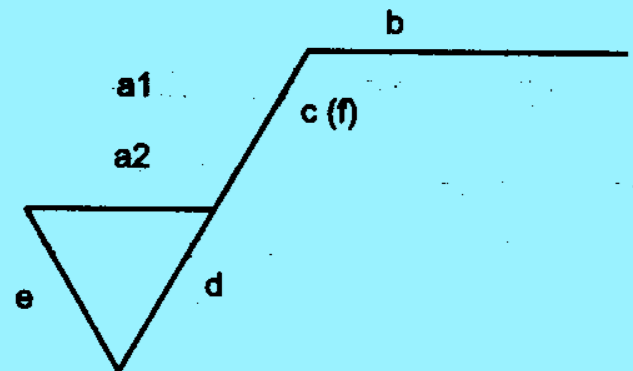




(A) Basic symbol with proportions

Where:

- a1 – Maximum permissible roughness
- b – Production method
- d – Direction of lay
- f – Roughness criterion other than Ra



(B) Symbol with locations of specifications

- a2 – Minimum permissible roughness
- c – Sampling length
- e – Machining allowance

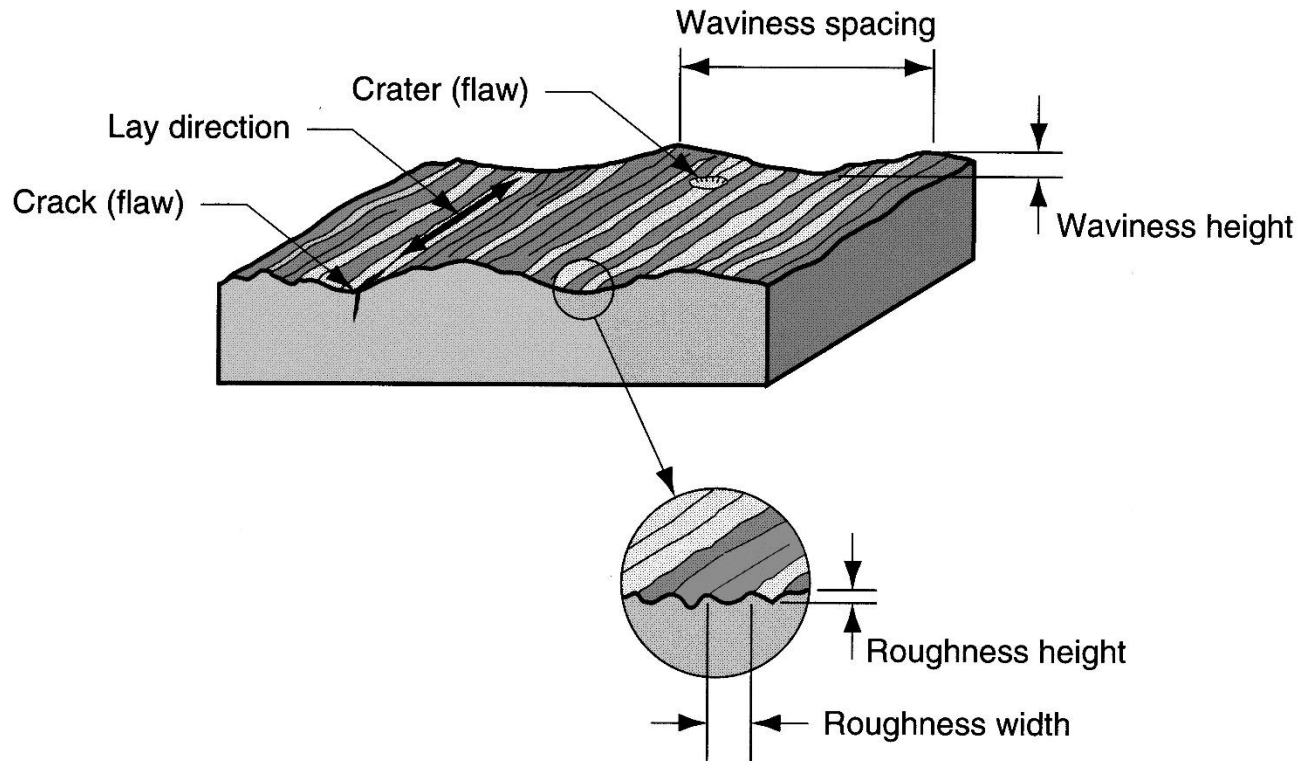
Table 20.1 Roughness symbols and their meaning

No.	Roughness symbol	Meaning
A		Basic symbol without any specifications
B		Material removal prohibited
C		Machining required
D		Machining required. Maximum roughness is 'a'
E		Surface roughness should lie between a1 and a2.
F		Sampling length 'c' specified
G		Direction of lay 'd' specified as perpendicular
H		Machining allowance 'e' specified
I		Machining operation 'b' specified as milling
J		Treatment is indicated as chrome plating
K		Roughness criterion other than Ra in parentheses
L		A note for same roughness all over as 'a'
M		Named symbol X has same specifications as given on right hand side after equal to sign

<i>Roughness values—Ra in microns</i>	<i>Roughness grade number</i>	<i>Roughness grade symbol</i>
50	N12	~
25 12.5	N11 N10	▽
6.3 3.2 1.6	N9 N8 N7	▽▽
0.8 0.4 0.2	N6 N5 N4	▽▽▽
0.1 0.05 0.025	N3 N2 N1	▽▽▽▽

Surface Texture

Repetitive and/or random deviations from the nominal surface of an object



Surface texture features

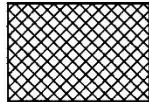
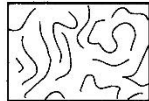
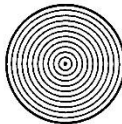
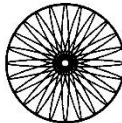
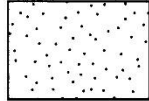
Four Elements of Surface Texture

1. *Roughness* - small, finely-spaced deviations from nominal surface determined by material characteristics and process that formed the surface
2. *Waviness* - deviations of much larger spacing; they occur due to work deflection, vibration, heat treatment, and similar factors
 - Roughness is superimposed on waviness



3. *Lay* - predominant direction or pattern of the surface texture

Possible lays of a surface

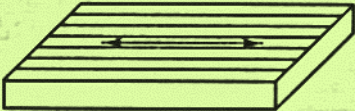
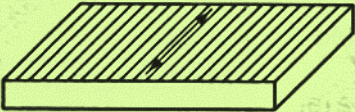
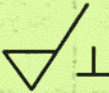
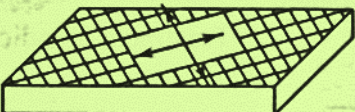
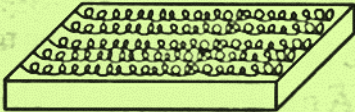
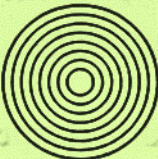
Lay symbol	Surface pattern	Description
=		Lay is parallel to line representing surface to which symbol is applied.
⊥		Lay is perpendicular to line representing surface to which symbol is applied.
X		Lay is angular in both directions to line representing surface to which symbol is applied.
M		Lay is multidirectional.
C		Lay is circular relative to center of surface to which symbol is applied.
R		Lay is approximately radial relative to the center of the surface to which symbol is applied.
P		Lay is particulate, nondirectional, or protuberant.

4. *Flaws* - irregularities that occur occasionally on the surface

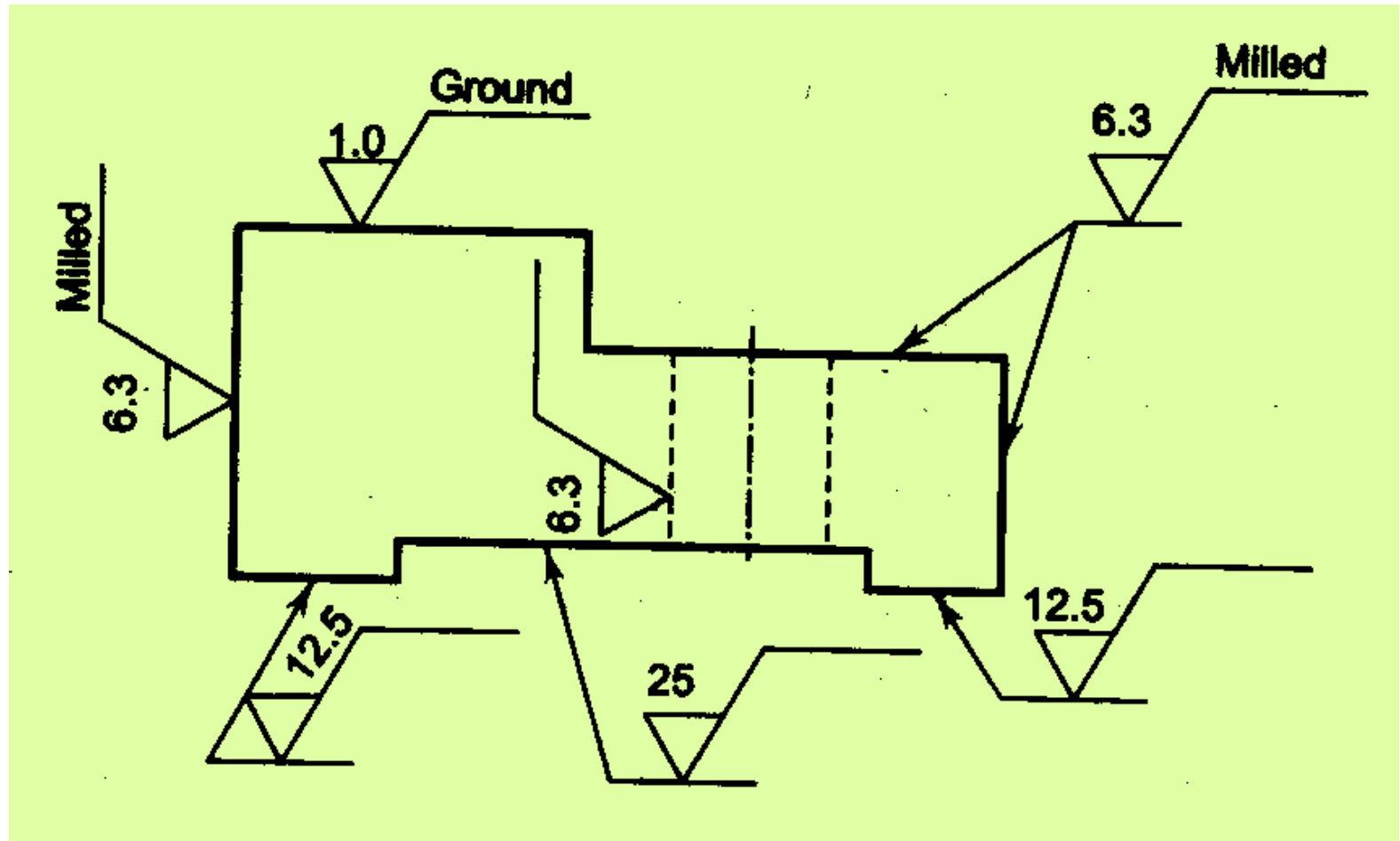
- Includes cracks, scratches, inclusions, and similar defects in the surface
- Although some flaws relate to surface texture, they also affect surface integrity



Symbols for directions of surface lay

<i>Direction of lay</i>	<i>Graphical interpretation</i>	<i>Symbol</i>	<i>Indication</i>
Parallel to plane of projection of the view in which symbol is used		=	
Perpendicular to plane of projection of the view in which symbol is used		⊥	
Crossed in two slant directions relative to plane of projection of the view in which symbol is used		×	
Multi-directional		M	
Approximately circular relative to the center of the surface to which the symbol is applied		C	
Approximately radial relative to the center of the surface to which the symbol is applied		R	

An Example



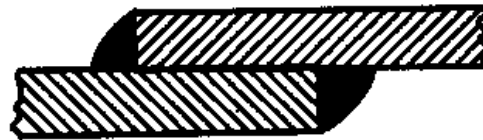
WELDED JOINTS



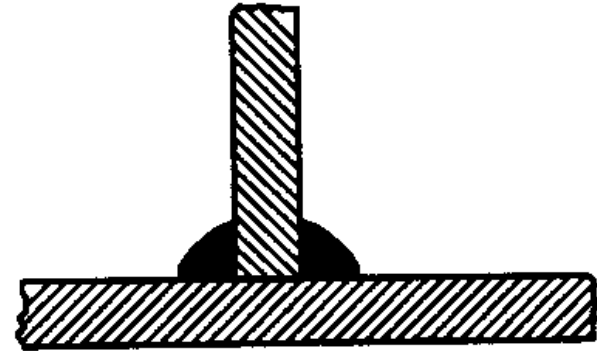
or
Butt joint



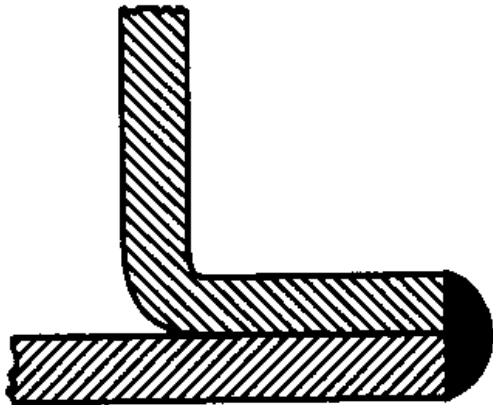
Butt joint (Bead)



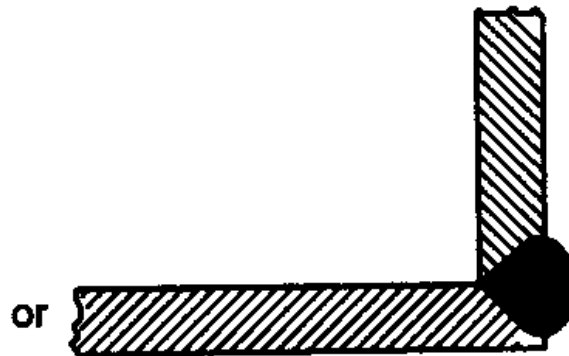
Lap joint



T joint



Edge joint



or

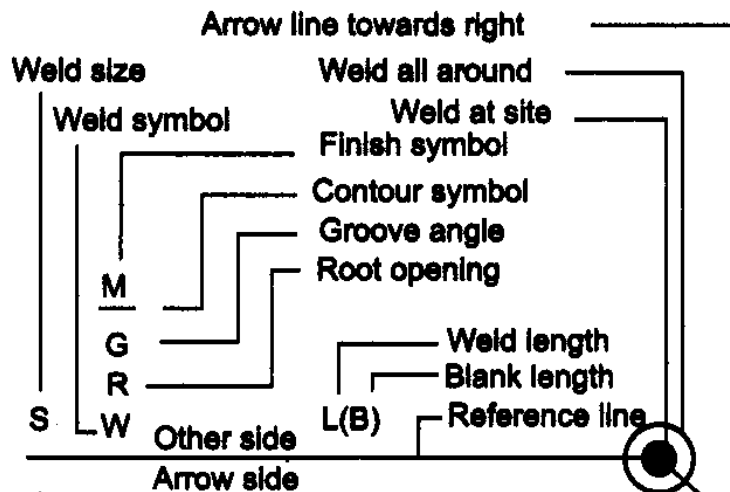
Edge joint



or

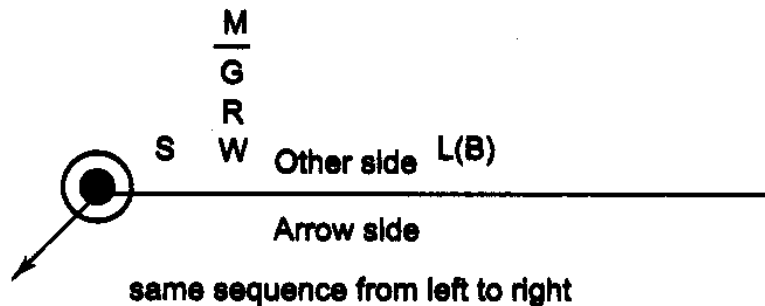
Edge joint

Figure 10.1 Welded joints (a) Butt joint (b) Lap joint (c) T joint (d) Edge joint

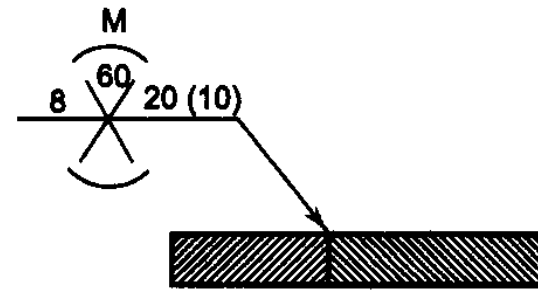


Elements of this area remain in same sequence from left to right even for arrow towards left

(A) Arrow towards right

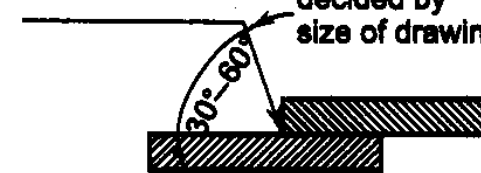


(B) Arrow towards left

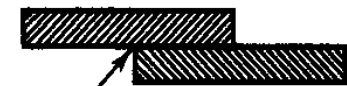


(C) Example

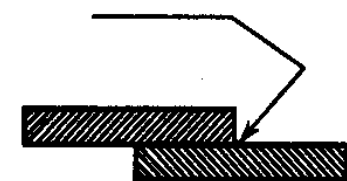
Length of arrow decided by size of drawing



(D) Arrow downwards towards right



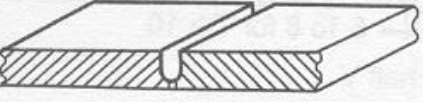
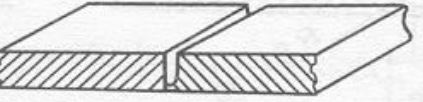
(E) Arrow upwards towards right



(F) Bent arrow



(G) More than one reference lines

NAME OF JOINT	SHAPE OF JOINT	SYMBOL
SQUARE BUTT WELD		
BACK WELD		⌒
SINGLE HALF V WELD		√
DOUBLE V WELD		X
SINGLE U WELD		U
DOUBLE U WELD		∞
SINGLE J WELD		J

Surface Roughness and Surface Finish

Surface roughness - a measurable characteristic based on roughness deviations

Surface finish - a more subjective term denoting smoothness and general quality of a surface

- In popular usage, surface finish is often used as a synonym for surface roughness
- Both terms are within the scope of surface texture



Surface Roughness

Average of vertical deviations from nominal surface over a specified surface length

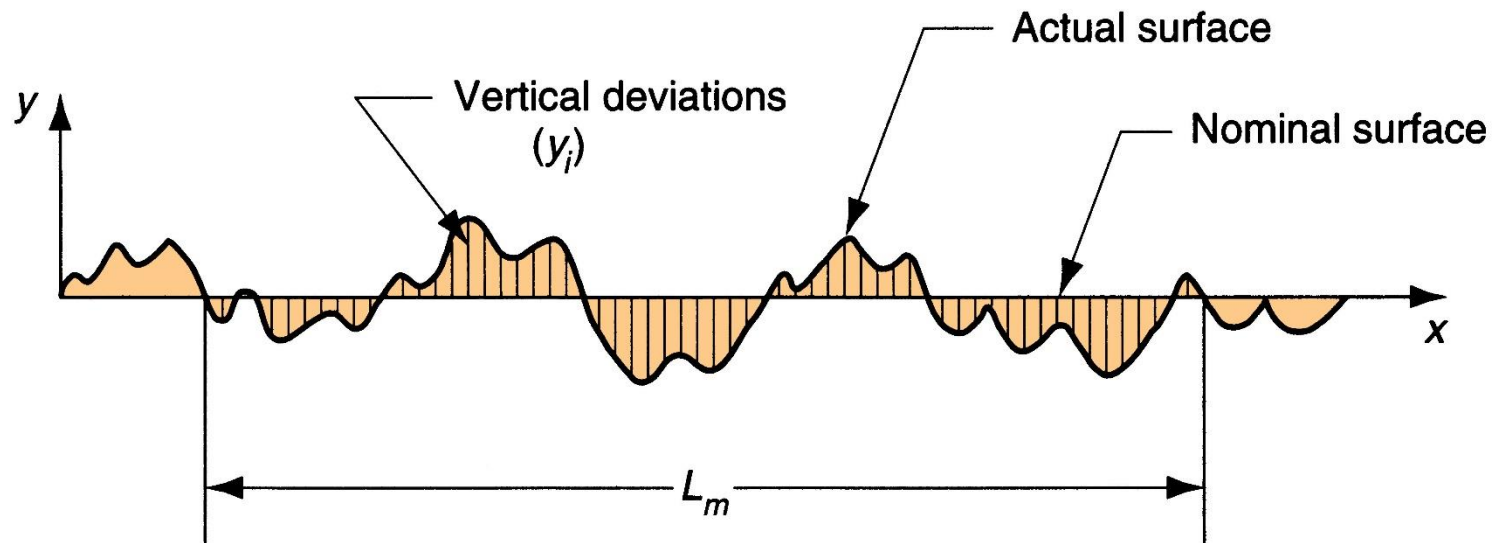


Figure 5.5 - Deviations from nominal surface used in the two definitions of surface roughness

Surface Roughness Equation

Arithmetic average (AA) is generally used, based on absolute values of deviations, and is referred to as *average roughness*

$$R_a = \frac{1}{L_m} \int_0^{L_m} |y| dx$$

where R_a = average roughness; y = vertical deviation from nominal surface (absolute value); and L_m = specified distance over which the surface deviations are measured



An Alternative Surface Roughness Equation

Approximation of previous equation is perhaps easier to comprehend:

$$R_a = \sum_{i=1}^n \frac{|y_i|}{n}$$

where R_a has the same meaning as above; y_i = vertical deviations (absolute value) identified by subscript i ; and n = number of deviations included in L_m



Cutoff Length

- A problem with the R_a computation is that waviness may get included
- To deal with this problem, a parameter called the *cutoff length* is used as a filter to separate waviness from roughness deviations
- Cutoff length is a sampling distance along the surface. A sampling distance shorter than the waviness width eliminates waviness deviations and only includes roughness deviations



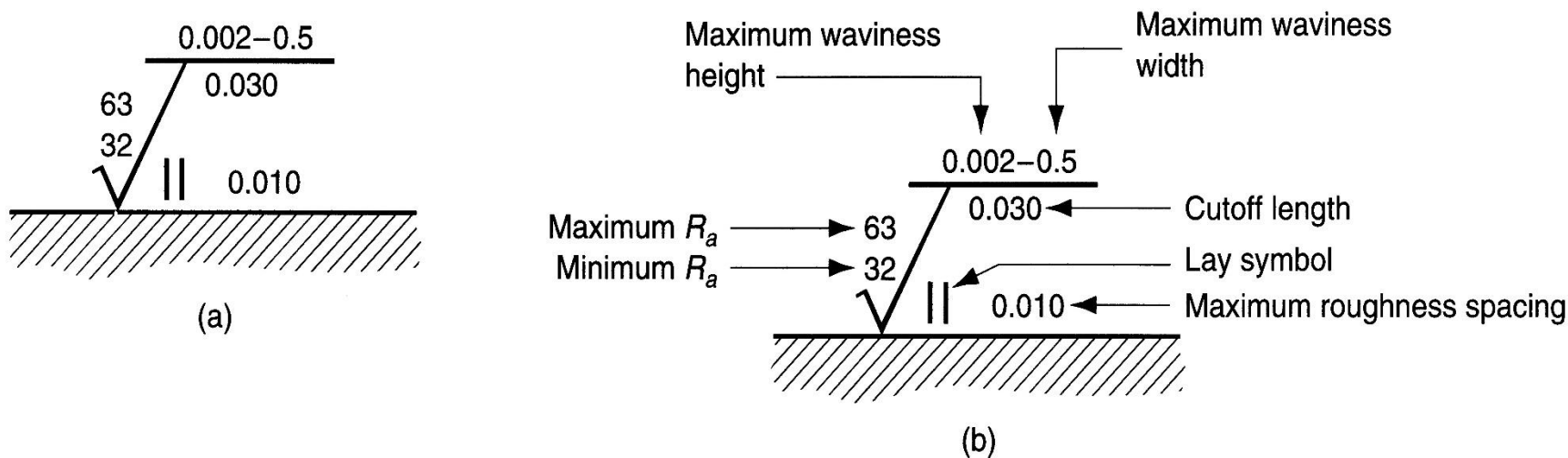


Figure 5.6 - Surface texture symbols in engineering drawings:

(a) the symbol, and (b) symbol with identification labels

Values of R_a are given in microinches; units for other measures are given in inches

Designers do not always specify all of the parameters on engineering drawings

Surface Integrity

- Surface texture alone does not completely describe a surface
- There may be metallurgical changes in the altered layer beneath the surface that can have a significant effect on a material's mechanical properties
- *Surface integrity* is the study and control of this subsurface layer and the changes in it that occur during processing which may influence the performance of the finished part or product



Surface Changes Caused by Processing

- Surface changes are caused by the application of various forms of energy during processing
 - Example: Mechanical energy is the most common form in manufacturing. Processes include metal forming (e.g., forging, extrusion), press working, and machining
 - Although primary function is to change geometry of workpart, mechanical energy can also cause residual stresses, work hardening, and cracks in the surface layers



Surface Changes Caused by Mechanical Energy

- Residual stresses in subsurface layer
- Cracks - microscopic and macroscopic
- Laps, folds, or seams
- Voids or inclusions introduced mechanically
- Hardness variations (e.g., work hardening)



Surface Changes Caused by Thermal Energy

- Metallurgical changes (recrystallization, grain size changes, phase changes at surface)
- Redeposited or re-solidified material (e.g., welding or casting)
- Heat-affected zone in welding (includes some of the metallurgical changes listed above)
- Hardness changes



Surface Changes Caused by Chemical Energy

- Intergranular attack
- Chemical contamination
- Absorption of certain elements such as H and Cl in metal surface
- Corrosion, pitting, and etching
- Dissolving of microconstituents
- Alloy depletion and resulting hardness changes



Surface Changes Caused by Electrical Energy

- Changes in conductivity and/or magnetism
- Craters resulting from short circuits during certain electrical processing techniques

