

# Course: Machine Design-I: MAC-303

## Unit-I Limits, Fit and Tolerances

### UNIT-I

Introduction: Systematic Design Process (SDP), Basic principles for mechanical design, Use of standards. Manufacturing consideration in design of casting & machining parts.

Dynamic and fluctuating stresses, fatigue failure and endurance limit, design under combined direct & varying stresses. Stress concentration, causes and remedies in design.

Factor of safety and it's affecting factors, Tolerances and fits as per BIS, Materials selection, Designation of steels. Detailed design procedure of Spigot & Socket Cotter joint, Knuckle joint, Pipe joint. Numerical Design Problems.

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## INTRODUCTION

- No two parts can be produced with identical measurements by any manufacturing process.
- In any production process, regardless of how well it is designed or how carefully it is maintained, a certain amount of variation (**natural**) will always exist.

## INTRODUCTION

Variations arises from;

- Improperly adjusted machines
- Operator error
- Tool wear
- Defective raw materials etc.

Such variations are referred as **'assignable causes'** and can be identified and controlled.

## INTRODUCTION

- It is impossible to produce a part to an **exact size or basic size**, some variations, known as **tolerances**, need to be allowed.
- The **permissible level of tolerance** depends on the **functional requirements**, which cannot be compromised.

## INTRODUCTION

- No component can be manufactured precisely to a given dimension; it can only be made to lie between two limits, upper (maximum) and lower (minimum).
- Designer has to suggest these tolerance limits to ensure satisfactory operation.
- The difference between the upper and lower limits is termed *permissive tolerance*.

## INTRODUCTION

### Example

Shaft has to be manufactured to a diameter of  $40 \pm 0.02$  mm.

The shaft has a basic size of 40 mm.

It will be acceptable if its diameter lies between the limits of sizes.

Upper limit of  $40+0.02 = 40.02$  mm

Lower limit of  $40-0.02 = 39.98$  mm.

Then, permissive tolerance is equal to  $40.02 - 39.98 = 0.04$  mm.

## **Need of Limit, Fits and Tolerances**

- Mass Production And Specialization
- Standardization
- Interchangeability

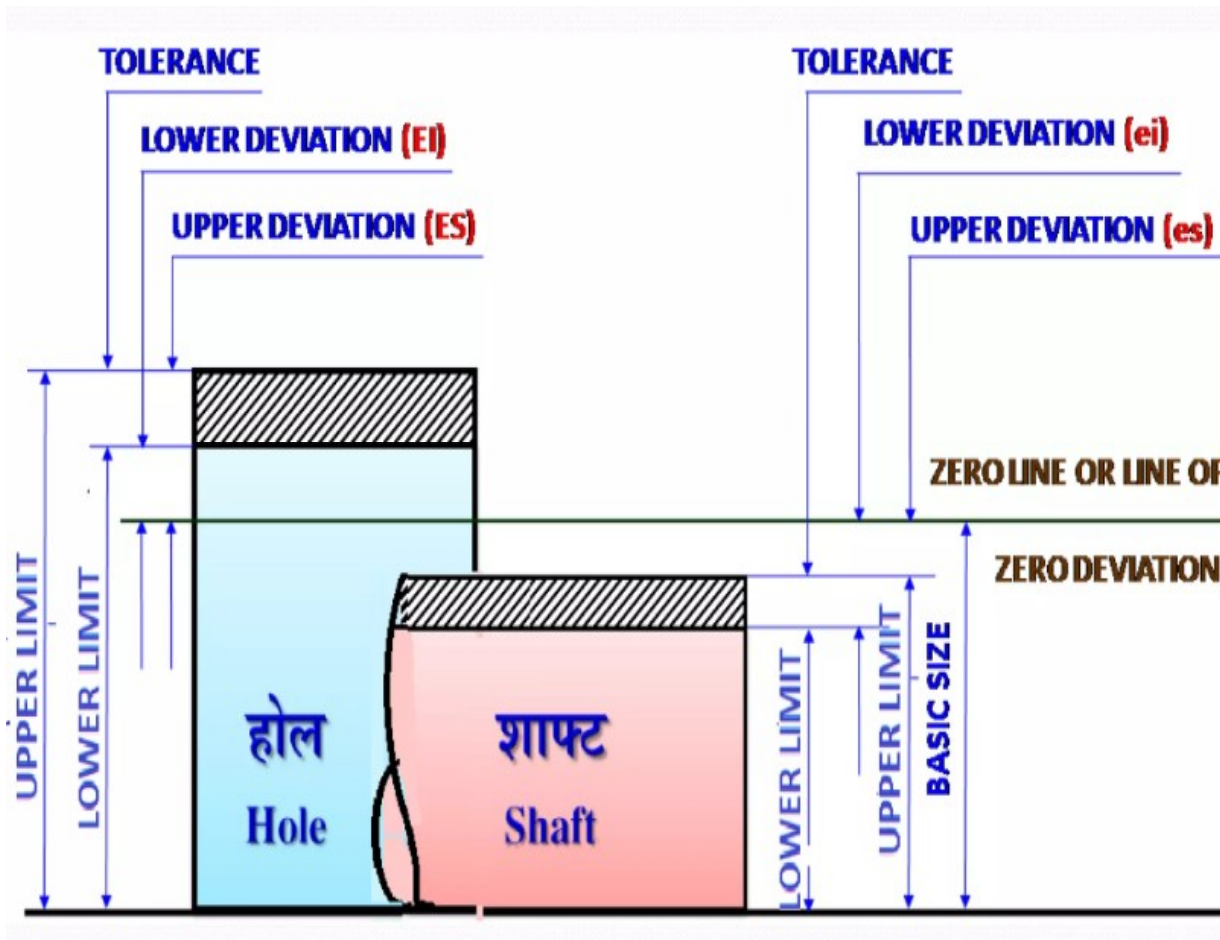
## Tolerances

- To satisfy the ever-increasing demand for accuracy.
- Parts have to be produced with less dimensional variation.
- It is essential for the manufacturer to have an in-depth knowledge of the tolerances to manufacture parts economically, adhere to quality and reliability
- To achieve an increased compatibility between mating parts.

## Tolerances

- The algebraic difference between the upper and lower acceptable dimensions.
- It is an absolute value.
- The basic purpose of providing tolerances is to permit dimensional variations in the manufacture of components, adhering to the performance criterion.

# Terminology

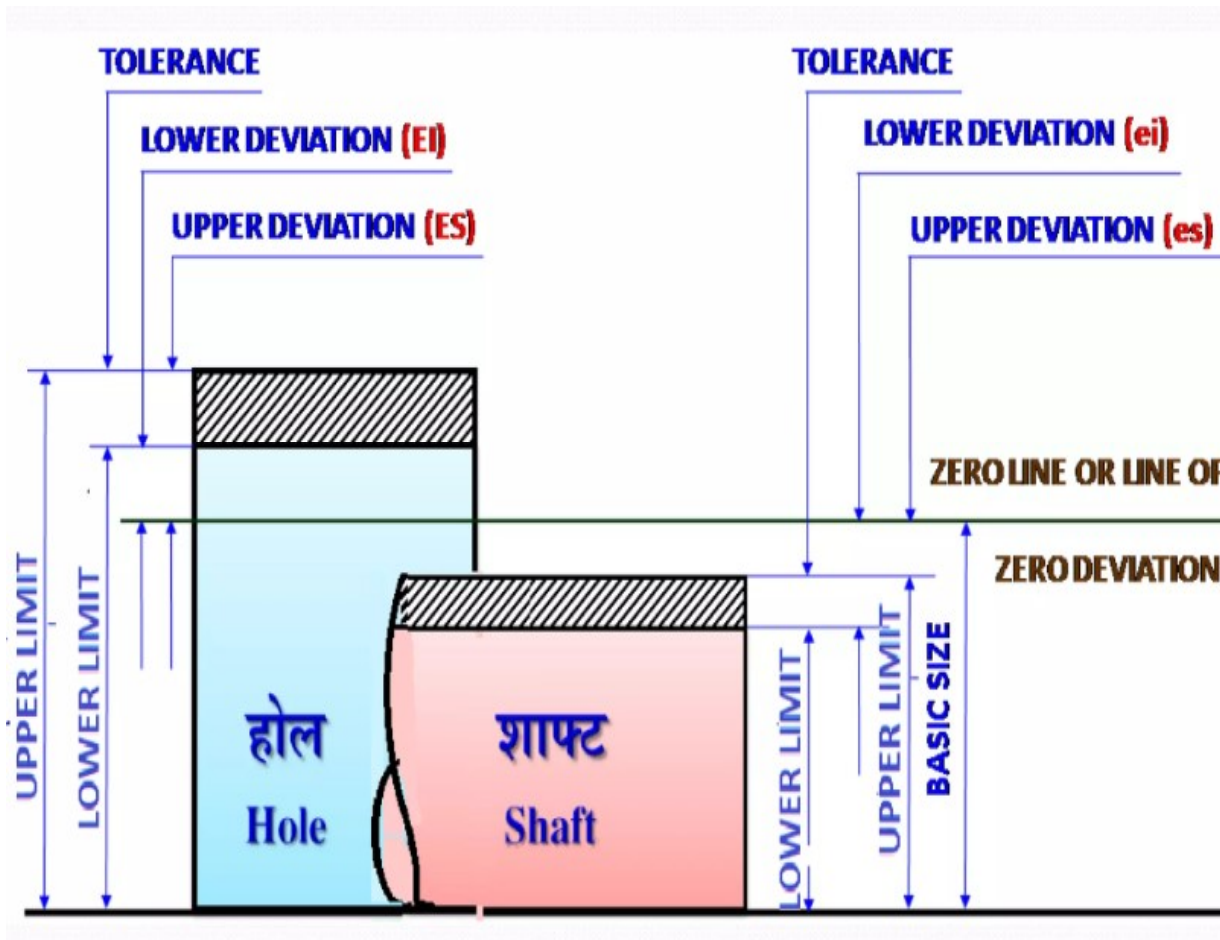


**Basic size:** Size of a part to which all limits of variation (i.e. tolerances) are applied. Basic dimension is theoretical dimension.

**Zero line:** A straight line corresponding to the basic size. The deviations are measured from this line.

**Deviation:** Is the algebraic difference between a size (actual, max. etc.) and the corresponding basic size.

# Terminology



**Upper deviation:** Is the algebraic difference between the maximum size and the basic size.

**Lower deviation:** Is the algebraic difference between the minimum size and the basic size.

**Fundamental deviation:** This is the deviation, either the upper or the lower deviation, which is nearest one to zero line for either a hole or shaft

## General Terminology

- **Actual size:** Size of a part as **found by measurement**
- **Limits of size:** Maximum and minimum permissible sizes for a specific dimension.
- **Tolerance:** Difference between the maximum and minimum limits of size.
- **Allowance:** Difference between maximum material limit of hole and shaft. It is equal to minimum clearance or maximum interference depending on fit.  
**Allowance= Minimum clearance or Maximum Interference**

## Tolerances

### Classification of Tolerance

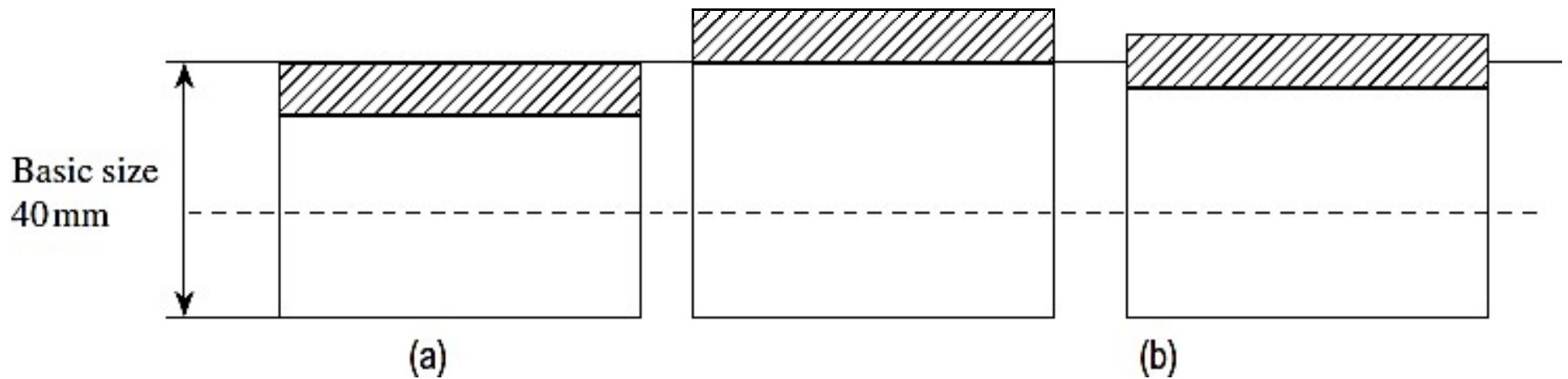
1. Unilateral tolerance
2. Bilateral tolerance

# Tolerances

## Classification of Tolerance

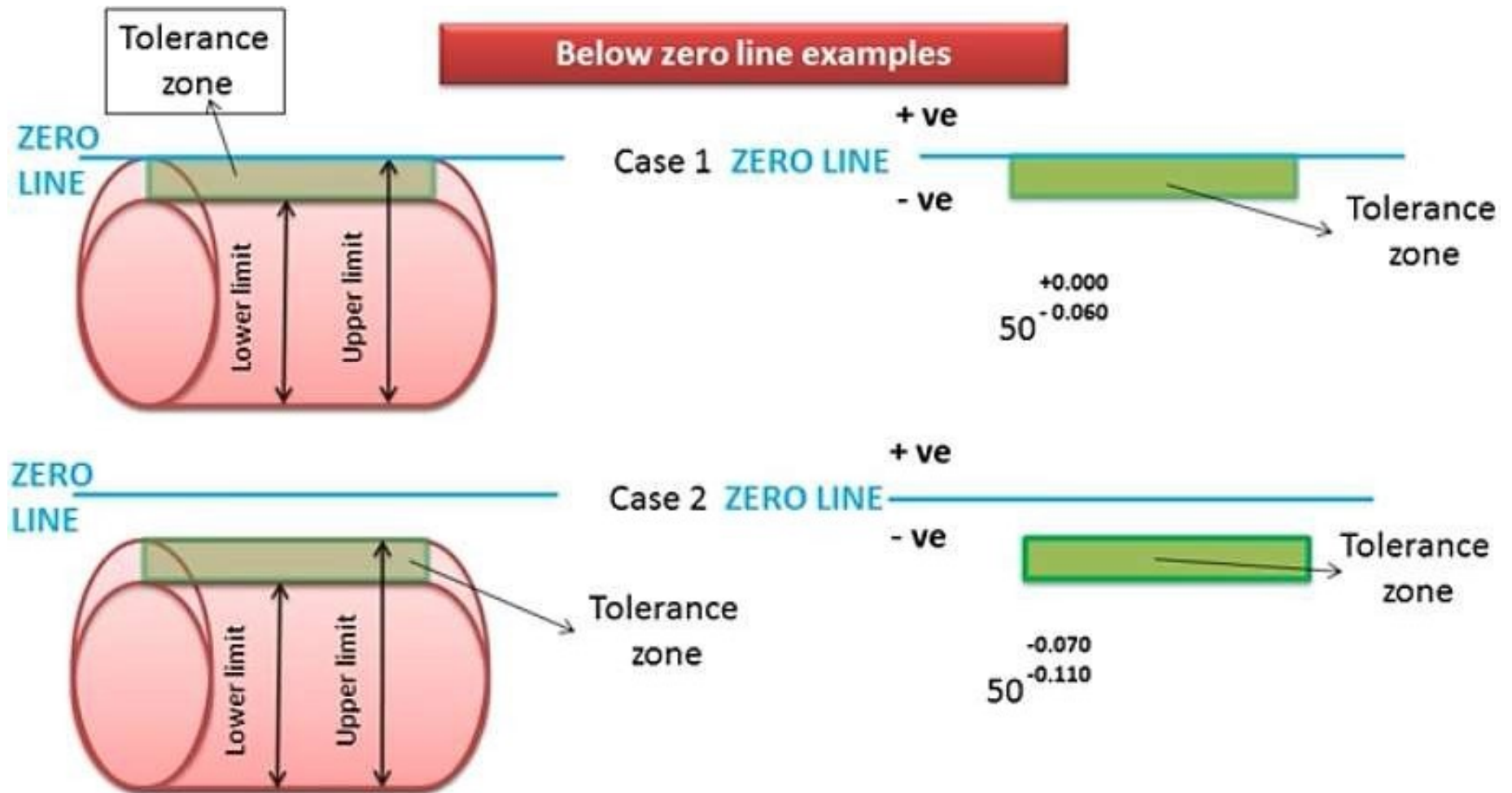
### 1. Unilateral tolerance

- When the tolerance distribution is only on one side of the basic size.  
Either positive or negative, but not both.

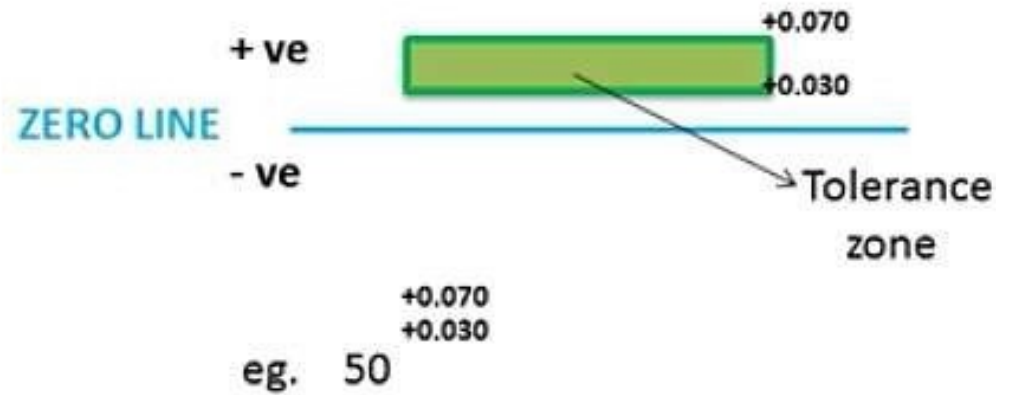
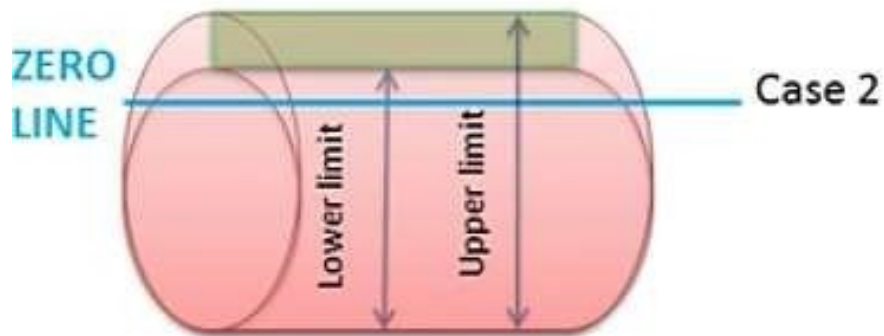
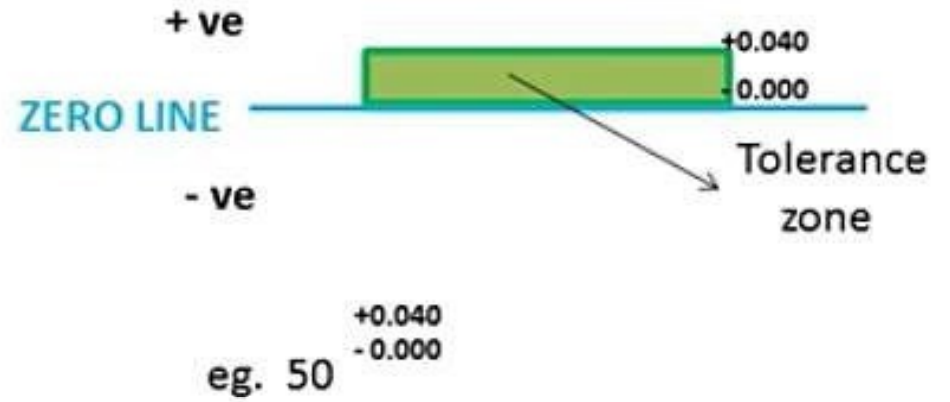
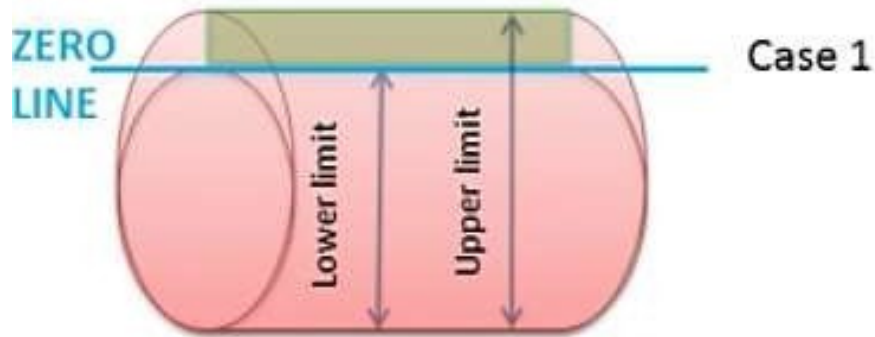


Tolerances (a) Unilateral (b) Bilateral

# 1. Unilateral tolerance: Below zero line: Negative

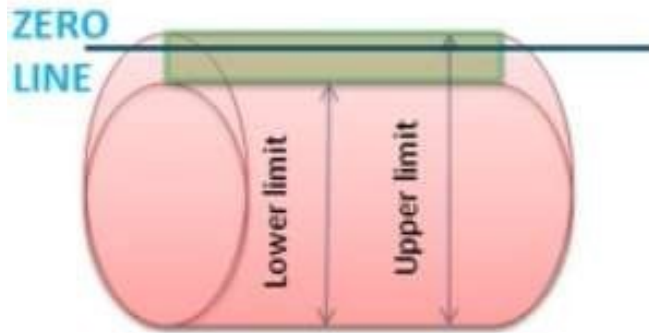


# 1. Unilateral tolerance: **Above zero line:** Positive

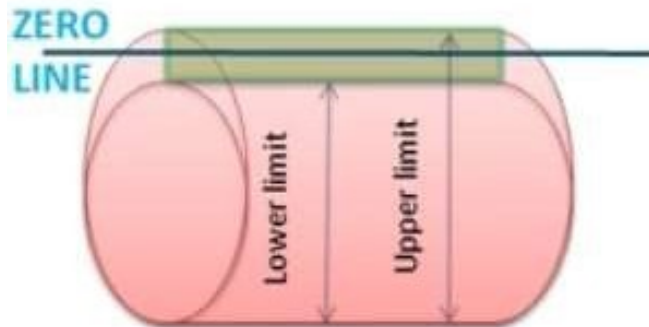
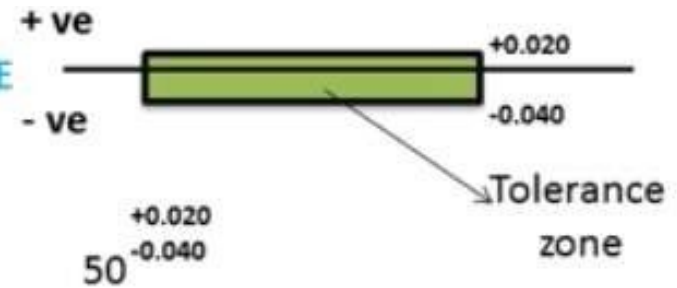


## 2. Bilateral tolerance

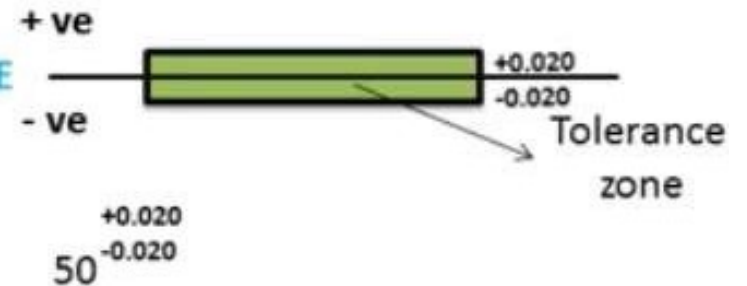
When the tolerance distribution lies on either side of the basic size.



Case 1 ZERO LINE



Case 2 ZERO LINE



- It is not necessary that Zero line will divide the tolerance zone equally on both sides.
- It may be equal or unequal

## MAXIMUM AND MINIMUM METAL CONDITIONS

Consider a shaft having a dimension of  $40 \pm 0.05$  mm and Hole having a dimension of  $45 \pm 0.05$  mm.

### For Shaft

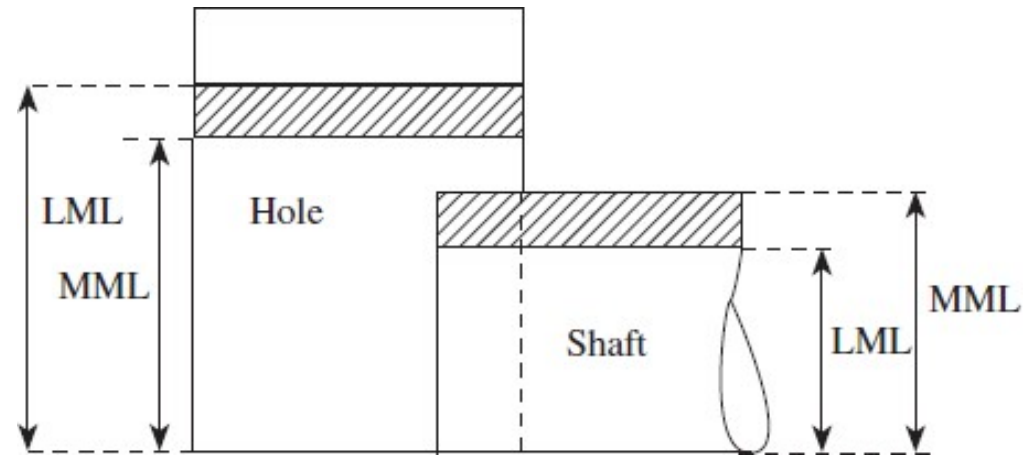
Maximum metal limit (MML) = 40.05 mm

Least metal limit (LML) = 39.95 mm

### For Hole

Maximum metal limit (MML) = 44.95 mm

Least metal limit (LML) = 45.05 mm



# FITS

The Assembly of Two Mating Parts is called Fit.

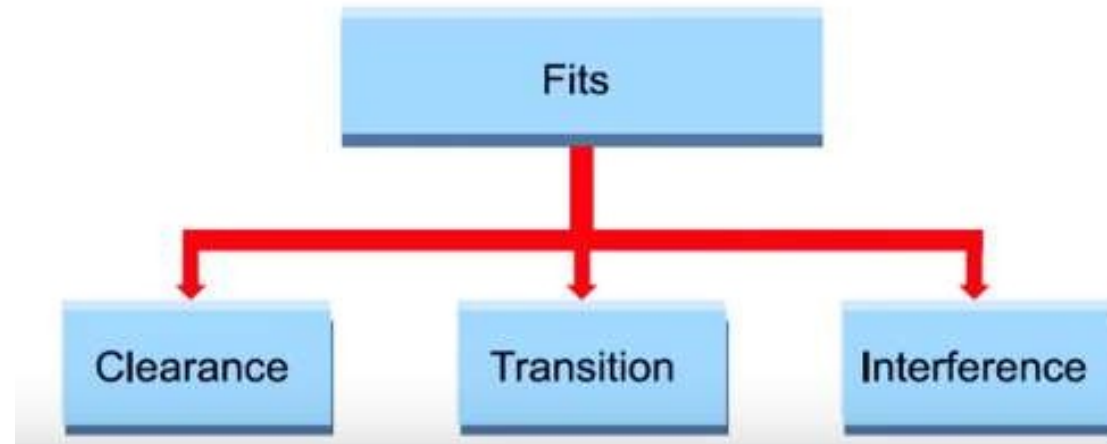
- ❖ **RUNNING FIT:** One part assembled into other so as to allow motion e.g. Shaft in bearing
- ❖ **PUSH FIT :** One part is assembled into other with light hand pressure & no clearance to allow shaft to rotate as in locating plugs.
- ❖ **DRIVING FIT :** One part is assembled into other with hand hammer or medium pressure. Eg pulley fitted on shaft with a key
- ❖ **FORCE FIT:** One part is assembled into other with great pressure e.g. Cart wheels, railway wheels

# FITS

- The degree of tightness and or looseness between the two mating parts.

Three basic types of fits can be identified, depending on the actual limits of the hole or shaft.

1. Clearance fit
2. Interference fit
3. Transition fit

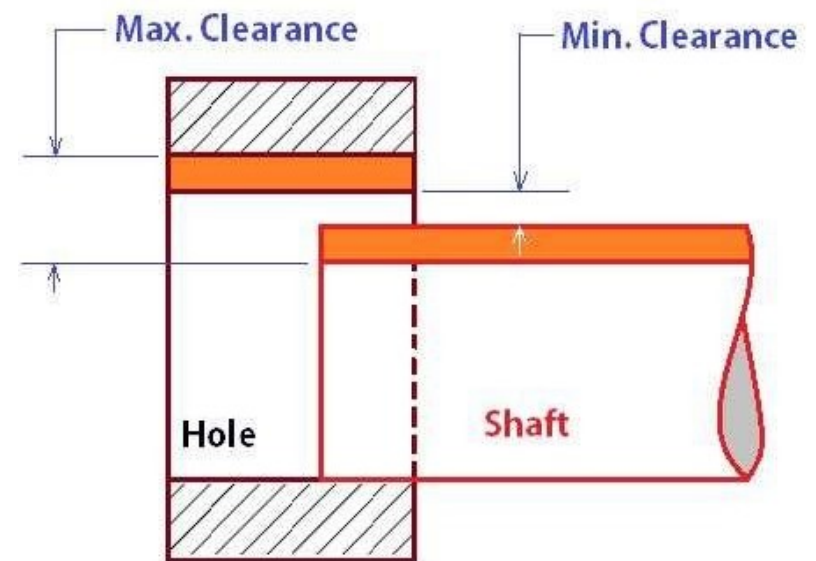


# FITS

1. Clearance fit Upper limit of shaft is less than the lower limit of the hole.

Tolerance zones never meet

Max. C = UL of hole - LL of shaft  
Min. C = LL of hole - UL of shaft

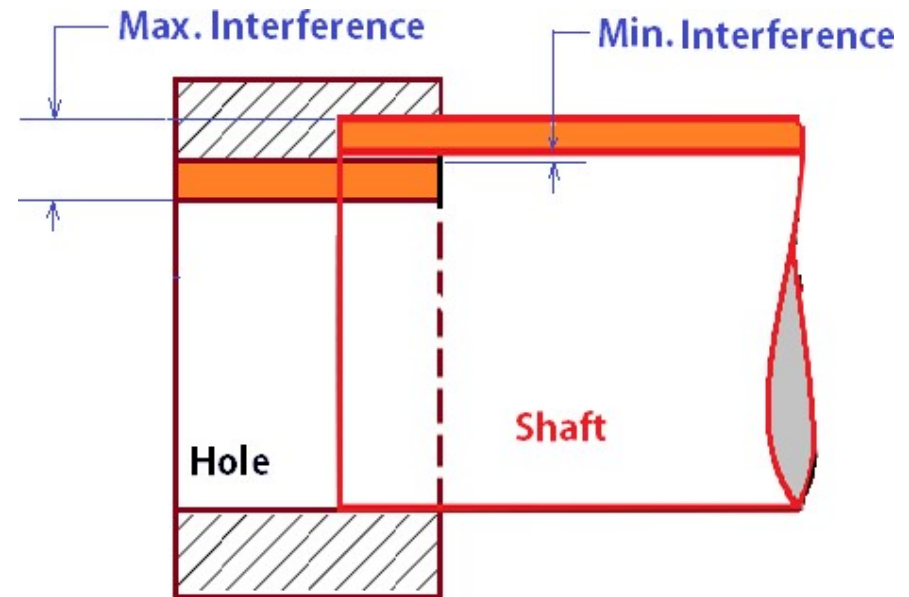
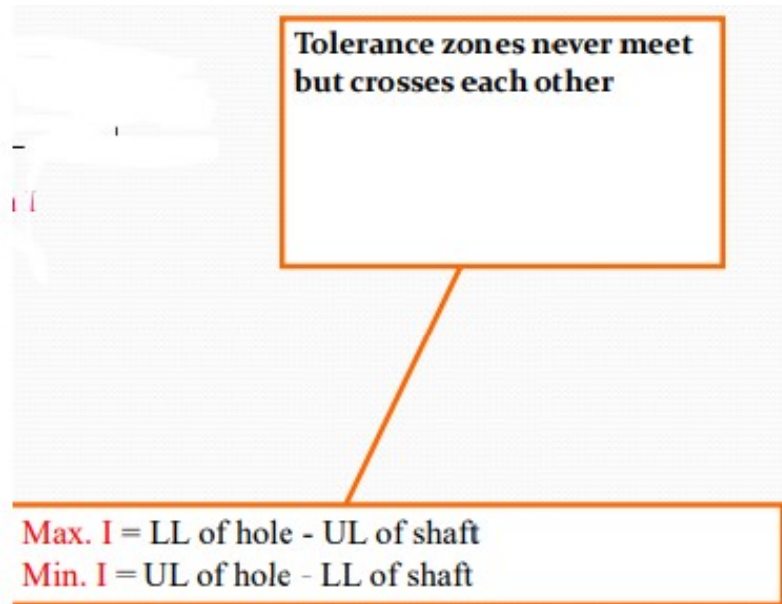


The clearance fits may be slide fit, easy sliding fit, running fit, slack running fit and loose running fit.

E.g.: Shaft rotating in a bush

## FITS

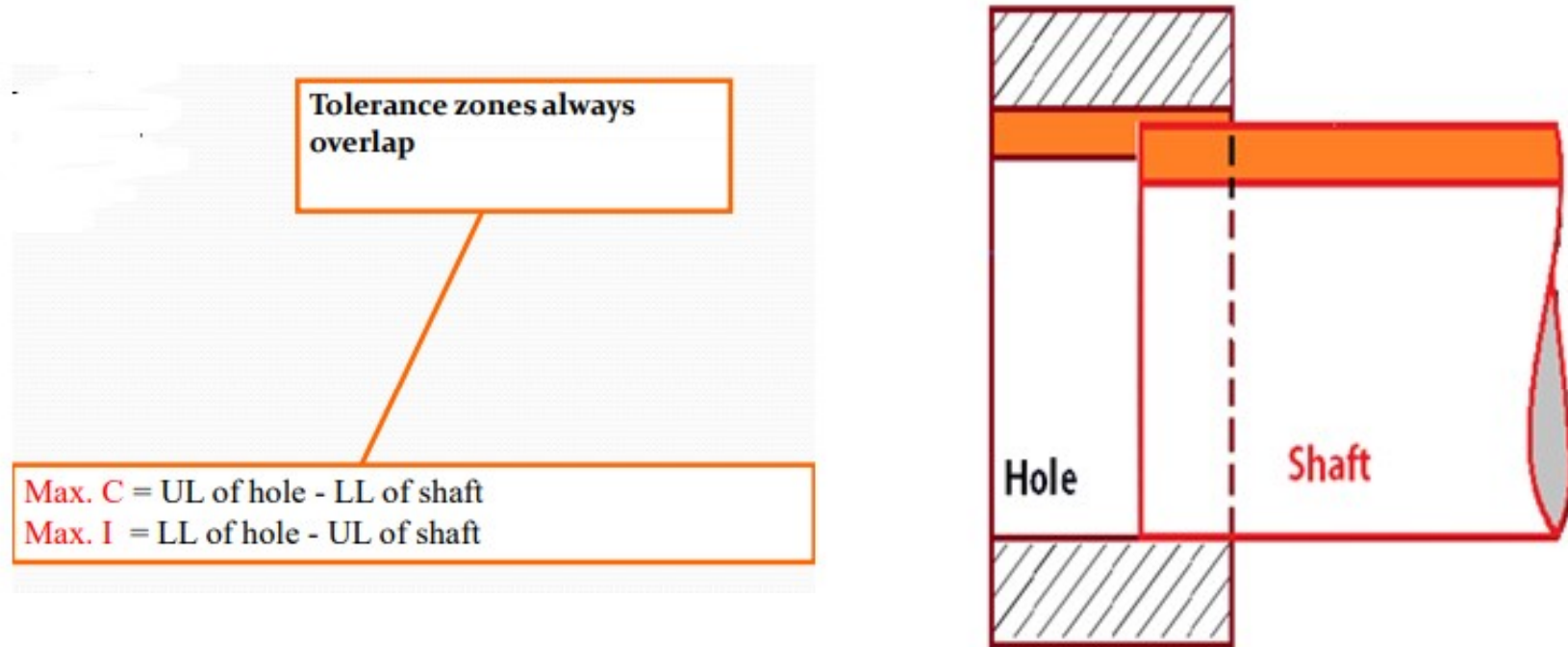
### 2. Interference fit      Upper limit of the hole is less than the lower limit of shaft.



- The interference fits may be shrink fit, heavy drive fit and light drive fit.
- Shaft need additional force to fit into the hole.

### 3. Transition fit

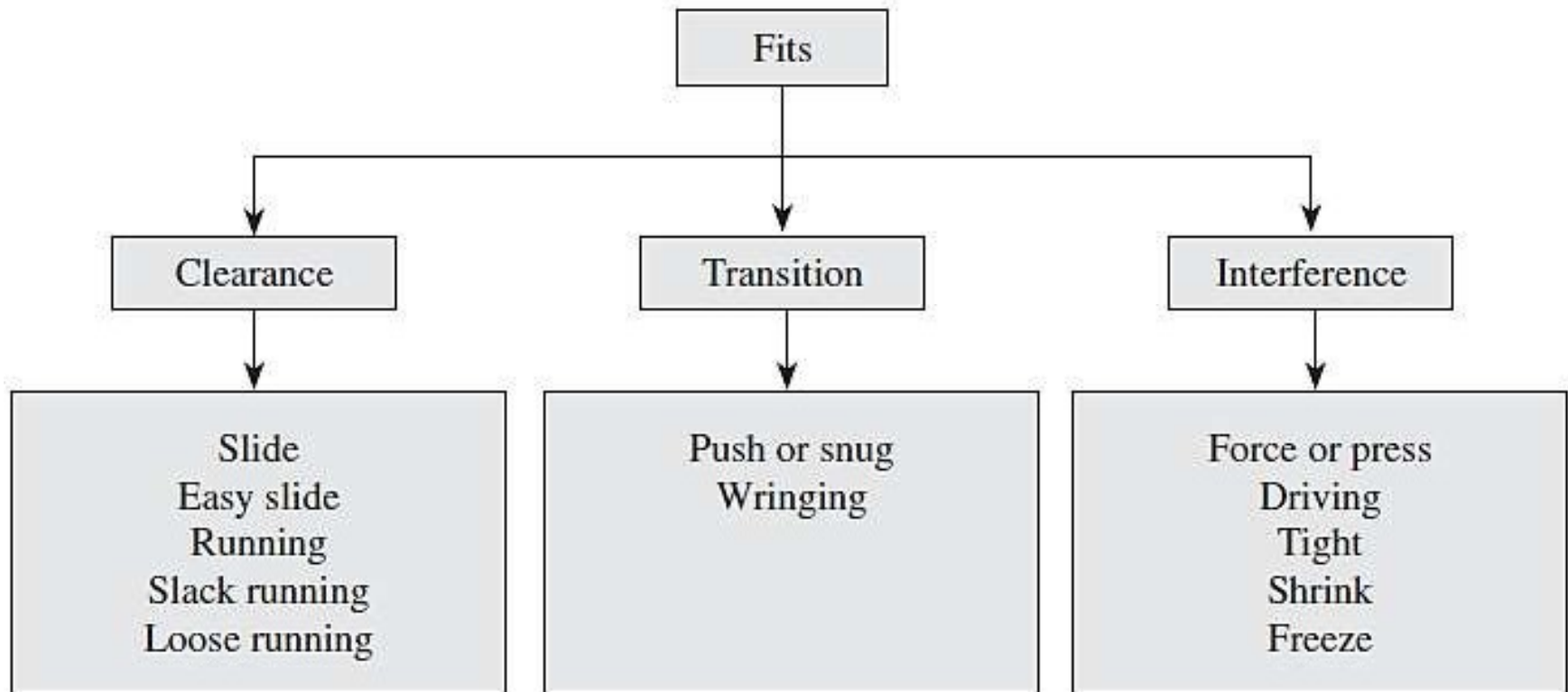
Dia. of the largest permissible hole is greater than the dia. of the smallest shaft.



- The transition fits may be tight fit and push fit, wringing fit (Gear, pulley on shaft), press fit.

# FITS

## Detailed classification of Fits



# FITS

## Applications

Description of fit	Class of fit	Application area
<i>Clearance fit</i>		
Slide	H7/h6	Sealing rings, bearing covers, movable gears in change gear trains, clutches, etc.
Easy slide	H7/g7	Lathe spindle, spigots, piston, and slide valves
Running	H8/f8	Lubricated bearings (with oil or grease), pumps and smaller motors, gear boxes, shaft pulleys, etc.
Slack running	H8/c11	Oil seals with metal housings, multi-spline shafts, etc.
Loose running	H8/d9	Loose pulleys, loose bearings with low revolution, etc.

# FITS

## Applications

### *Interference fit*

Force or press	H8/r6	Crankpins, car wheel axles, bearing bushes in castings, etc.
Driving	H7/s6	Plug or shaft slightly larger than the hole
Tight	H7/p6	Stepped pulleys on the drive shaft of a conveyor
Shrink	H7/u6, H8/u7	Bronze crowns on worm wheel hubs, couplings, gear wheels, and assembly of piston pin in IC engine piston
Freeze	H7/u6, H8/u7	Insertion of exhaust valve seat inserts in engine cylinder blocks and insertion of brass bushes in various assemblies

# FITS

## Application of Fits

<i>Transition fit</i>		
Push or snug	H7/k6	Pulleys and inner ring of ball bearings on shafts
Wringing	H7/n6	Gears of machine tools

## Tolerance symbols

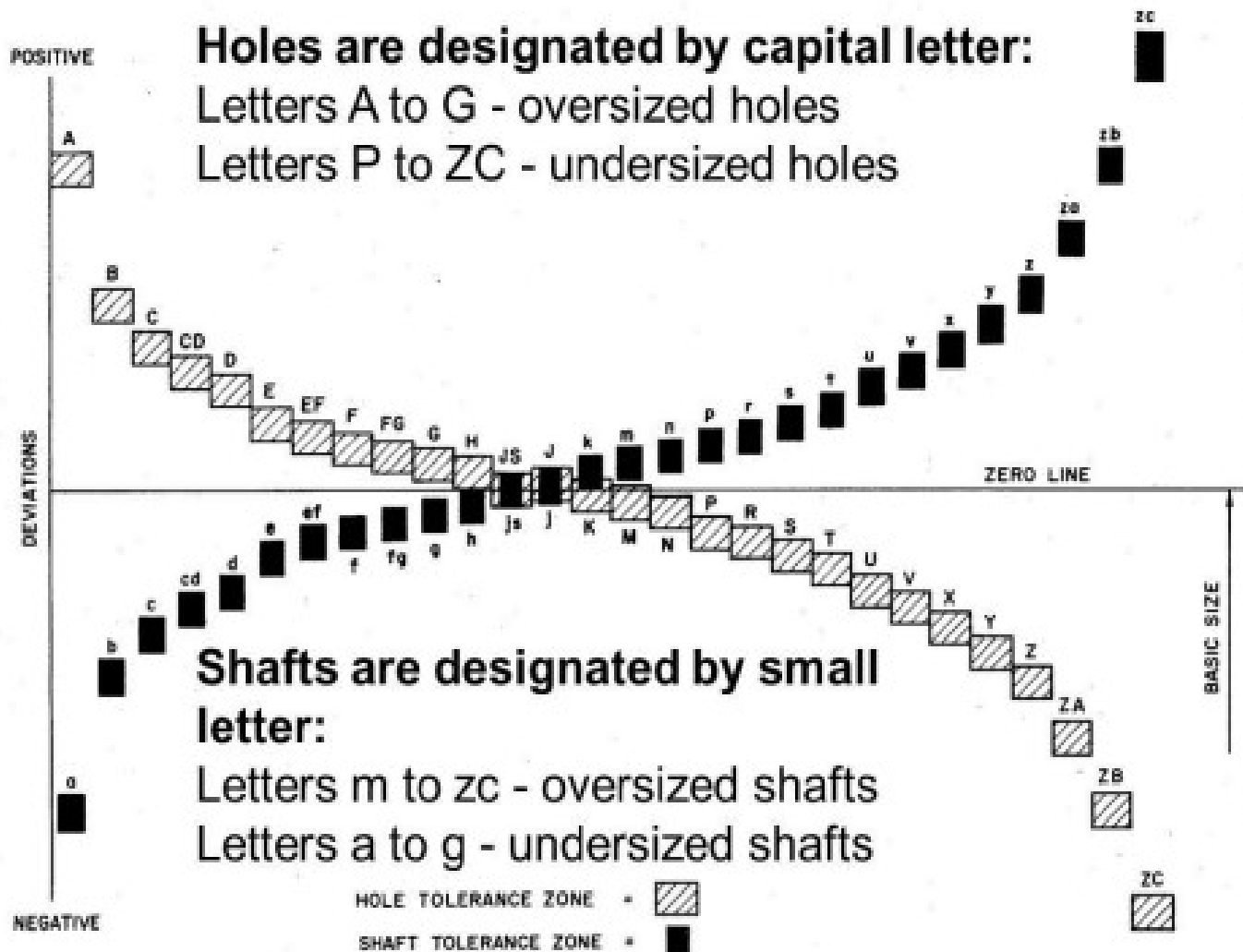
- **Fundamental Deviation:** Deviation either the upper or lower deviation, nearest to the zero line. (provides the position of the tolerance zone).

It may be positive, negative, or zero.

- **Upper deviation:** Designated as 'ES' for a Hole and as 'es' for a shaft.
- **Lower deviation:** Designated as 'EI' for a Hole and as 'ei' for a shaft.

## Tolerance symbols

- First eight designations from A (a) to H (h) for holes (shafts) are used for clearance fit
- Designations, JS (js) to ZC (zc) for holes (shafts), are used for interference or transition fits



'H' is used for holes and 'h' is used for shafts whose fundamental deviation is zero.

## Tolerance symbols

Used to specify the tolerance and fits for mating components.

Example: Consider the designation **40 H7/d9**

- Basic size of the shaft and hole = 40 mm.
- Nature of fit for the hole basis system is designated by H
- Fundamental deviation of the hole is zero.
- Tolerance grade: IT7.
- The shaft has a d-type fit, the fundamental deviation has a negative value.
- IT9 tolerance grade.

Fundamental deviation for shafts and holes of sizes from above 500 to 3150 mm

Shafts			Holes			Formula for deviations in $\mu\text{m}$
Type	Fundamental deviation	Sign	Type	Fundamental deviation	Sign	(for $D$ in mm)
d	es	-	D	EI	+	$16D^{0.44}$
e	es	-	E	EI	+	$11D^{0.41}$
f	es	-	F	EI	+	$5.5D^{0.41}$
g	es	-	G	EI	+	$2.5D^{0.34}$
h	es	No sign	H	EI	No sign	0
js	ei	-	JS	ES	+	$0.5IT\pi$
k	ei	-	K	ES	-	0
m	ei	+	M	ES	-	$0.024D + 12.6$
n	ei	+	N	ES	-	$0.04D + 21$
P	ei	+	P	ES	-	$0.072D + 37.8$
r	ei	+	R	ES	-	Geometric mean of the values for p and s or P and S
s	ei	+	S	ES	-	$IT7 + 0.4D$
t	ei	+	T	ES	-	$IT7 + 0.63D$
u	ei	+	U	ES	-	$IT7 + D$

## Tolerance Grade

- BIS: 18 grades of fundamental tolerances are available.
- Designated by the letters **IT** followed by a number.
- ISO/BIS: IT01, IT0, and **IT1 to IT16**.
- Tolerance values corresponding to grades **IT5 – IT16** are determined using the standard tolerance unit ( $i$ , in  $\mu\text{m}$ )

## Tolerance Grade

Standard Tolerance unit,  $i = 0.453 \sqrt[3]{D} + 0.001D$  microns

- $D$  = diameter of the part in mm.
- $0.001D$  = Linear factor counteracts the effect of measuring inaccuracies.
- Value of tolerance unit ' $i$ ' is obtained for sizes up to 500 mm.
- $D$  is the geometric mean of the lower and upper diameters.
- $D = \sqrt{D_{\max} \times D_{\min}}$

## Tolerance Grade

$$D = \sqrt{D_{\max} \times D_{\min}}$$

The various steps specified for the diameter steps are as follows:

- 1–3, 3–6, 6–10, 10–18, 18–30, 30–50, 50–80, 80–120
- 120–180, 180–250, 250–315, 315–400, 400–500
- 500–630, 630–800, and 800–1000 mm.

## Tolerance Grade

### Standard tolerance units

Tolerance grade	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Standard tolerance unit ( <i>i</i> )	10	16	25	40	64	100	160	250	400	640	1000

## Tolerances grades for applications

Fundamental tolerance	Applications
IT01–IT4	For production of gauges, plug gauges, and measuring instruments
IT5–IT7	For fits in precision engineering applications such as ball bearings, grinding, fine boring, high-quality turning, and broaching
IT8–IT11	For general engineering, namely turning, boring, milling, planning, rolling, extrusion, drilling, and precision tube drawing
IT12–IT14	For sheet metal working or press working
IT15–IT16	For processes such as casting, stamping, rubber moulding, general cutting work, and flame cutting

## Hole Basis and Shaft Basis Systems

- To obtain the desired class of fits, either the size of the hole or the size of the shaft must vary.

Two types of systems are used to represent three basic types of fits, clearance, interference, and transition fits.

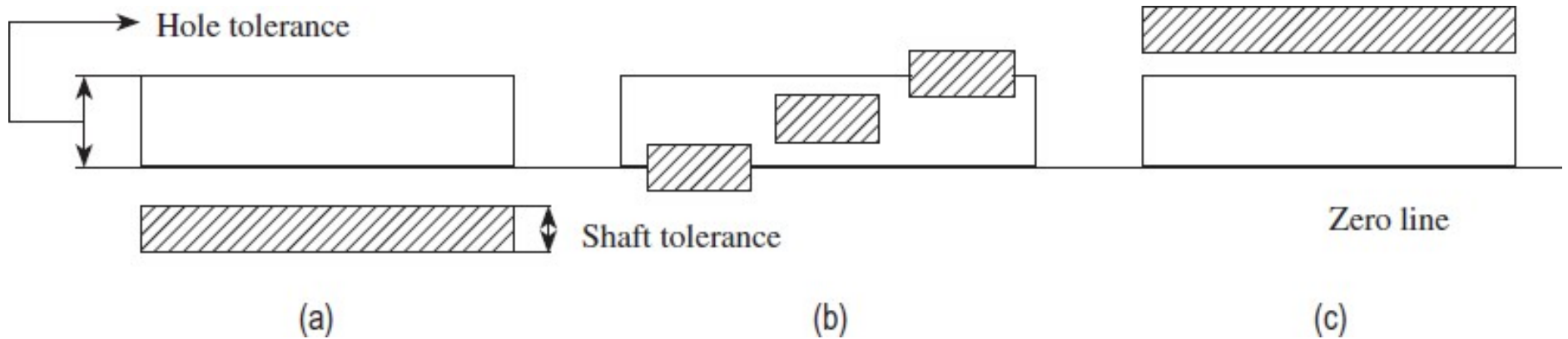
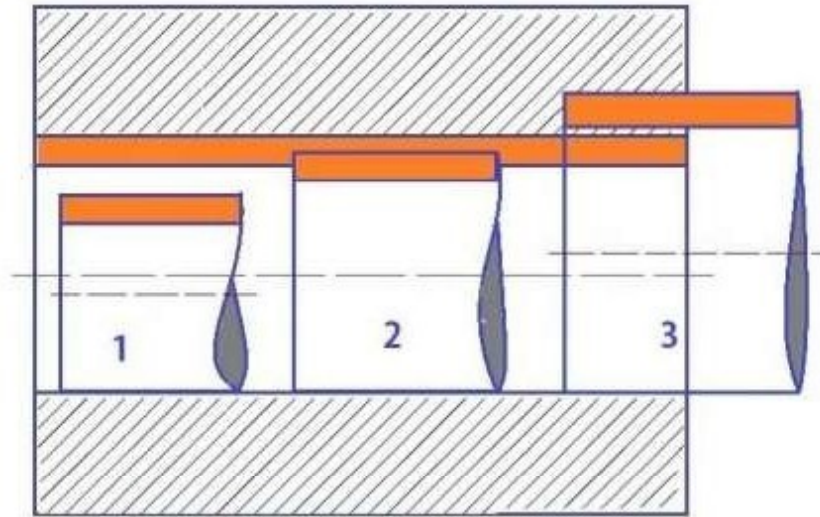
(a) Hole basis system

(b) Shaft basis system.

## Hole Basis systems

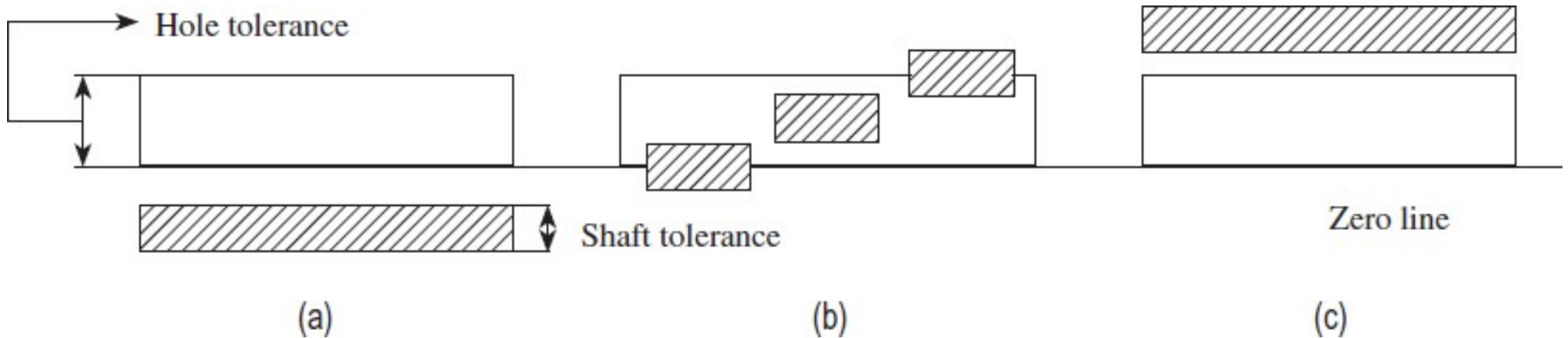
- The size of the hole is kept constant and the shaft size is varied to give various types of fits.
- Lower deviation of the hole is zero, i.e. the lower limit of the hole is same as the basic size.
- Two limits of the shaft and the higher dimension of the hole are varied to obtain the desired type of fit.

## Hole Basis systems



**(a) Clearance fit (b) Transition fit (c) Interference fit**

## Hole Basis systems



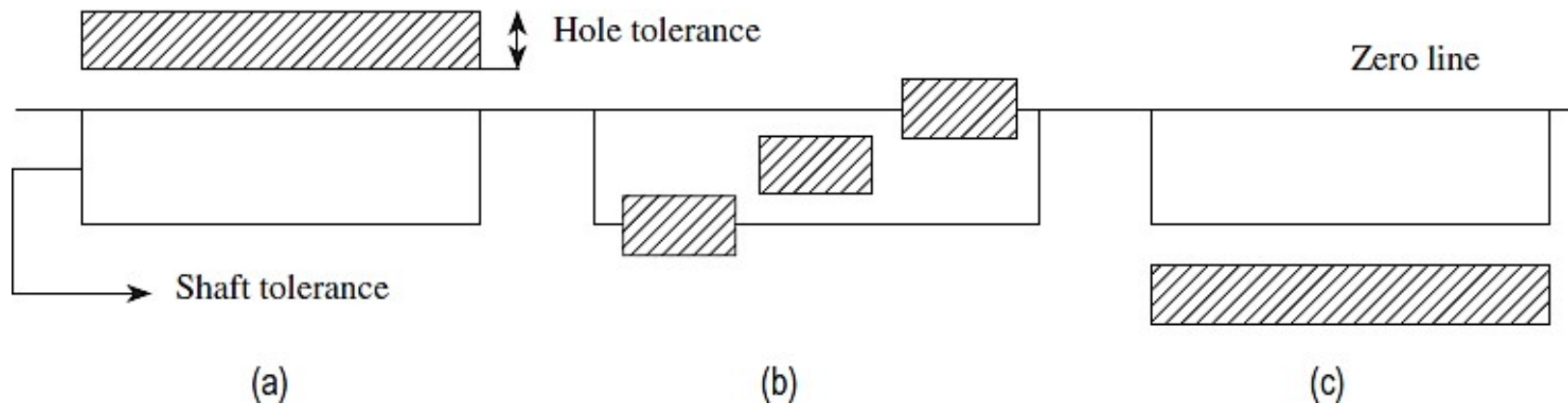
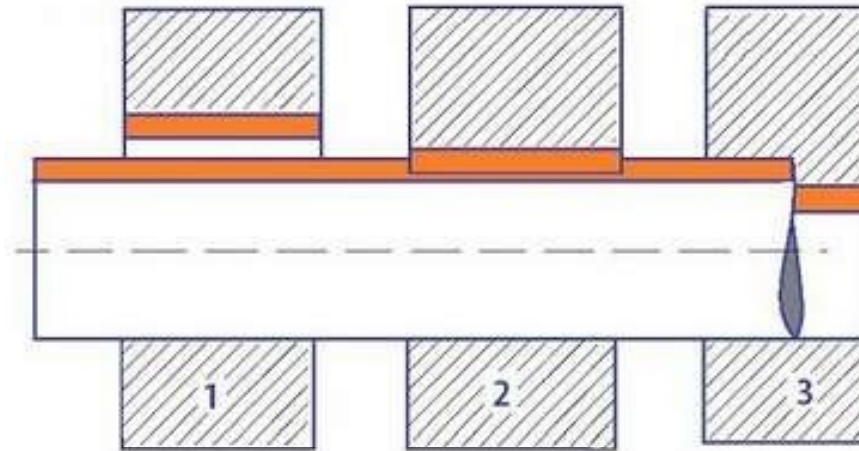
This system is widely adopted in industries, easier to manufacture shafts of varying sizes to the required tolerances.

Standard-size plug gauges are used to check hole sizes accurately.

## Shaft Basis systems

- The size of the shaft is kept constant and the hole size is varied to obtain various types of fits.
- Fundamental deviation or the upper deviation of the shaft is zero.
- System is not preferred in industries, as it requires more number of standard-size tools, like reamers, broaches, and gauges, increases manufacturing and inspection costs.

## Shaft Basis systems



(a) Clearance fit (b) Transition fit (c) Interference fit