METROLOGY

ENGINEERING METROLOGY: It's also known as science of measurement or Industrial Inspection.

MEASUREMENT: It's act to determine the property of the object. It includes linear, Angular properties E.g. Length, Width, height, etc…	**INSPECTION:** It's examination of the property of the object w. r. t. Standard. Standard Can be Consumer, Designer, ISO/ BIS…

LINEAR MEASUREMENT: In the 13^{th} conference of International Standard Organization (Around 1980), 1m was standardised. The distance covered by monochromatic light travelling in a vacuum within $1/299{,}792{,}458$ second is called 1 Meter. Sample of 1m is currently been made from Platinum & Iridium alloy in the form of **Tresca Shape**.

OBJECTIVE OF INSPECTION: To perform inspection so that every dimension of component, within acceptable limits, with minimum rejection/ rework, within tolerances within given time within minimum cost can be produce.
But, it's impossible to make anything exact irrespective of methods of manufacturing.

INSPECTION	
ONLINE OR ACTIVE INSPECTION	**OFFLINE OR PASSIVE INSPECTION**
Inspection during Manufacturing.	Inspection after Manufacturing.

Quality depends on 3M (Men, Machine, Material).

Men			Machine			Material	
Skilled	Semi-Skilled	Unskilled	Manual	Semi-Automated	Automated	With impurity	Without impurity

Out of any one reason of above mention reason is enough reason for origin of the subject.
Mathematically, Product is manufactured from Elemental Components (Unit Component). To make Elemental Components Machine is required. Machine is also a product. So, to select one Targeted Value Data as Unit data (Dimension of unit component) from ∞ Number of machines is justified by Normal Distribution theory. Hence, According to Normal Distribution theory (Graph of $\bar{X}$ vs Frequency of occurrence) Targeted Value of machine is not single value it's some range. This range is called as process capability.

$\bar{X}$ = Mean/ Targeted Value	Process Capability= $[-\bar{X}, \bar{X}]$		
$n\sigma$ = Max. Percentage of acceptability	$2\sigma = 68$ %	$4\sigma = 95$ %	$6\sigma = 99.73$ %

2σ & 4σ are used in aerospace application.

ACCURACY	**PRECISION**
Degree of Closeness to the Targeted Value	Repeatability of Closeness to the Targeted Value

BASIC SIZE	**NOMINAL (NORMAL) SIZE**
Any Dimension as Per standard. E.g. 28, 33, etc…	It's Roundup Values of Basic Size. E.g. 25, 32, etc…

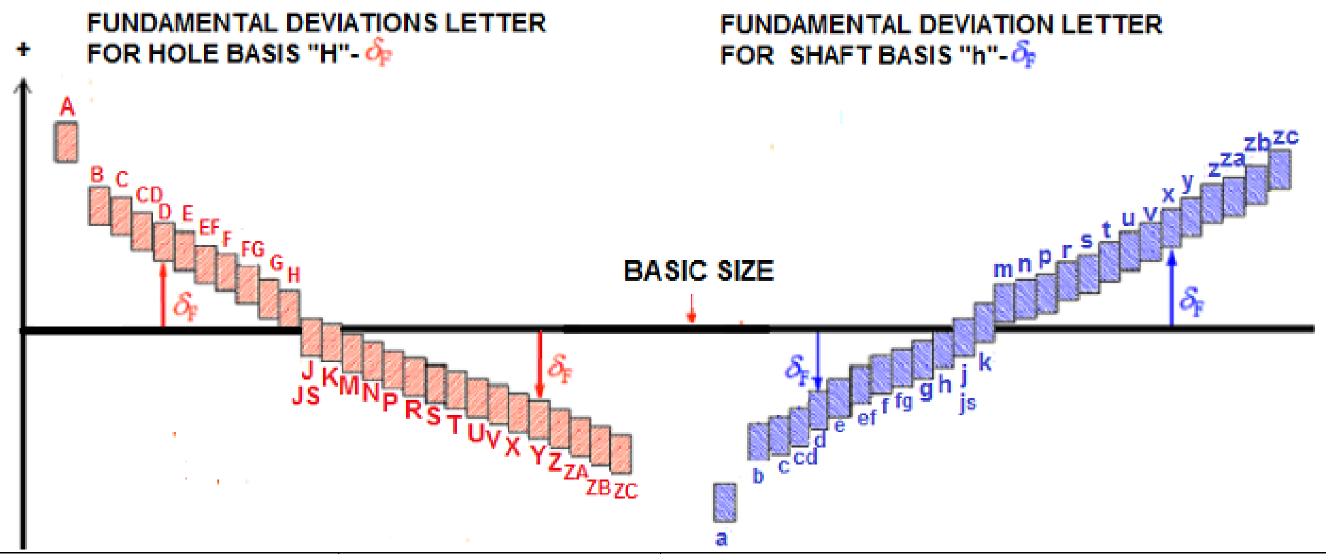
To make the assembly Hole & Shaft Should have Same Basic Size.

TYPES OF ASSEMBLY		
FULL INTERCHANGEABLE	**SELECTIVE**	**MAKE TO SUIT**
No inspection required, randomly picking Hole & Shaft assembly is produced.	Inspection required And Sub lots are prepared according to accuracy. These matching sublots are making assembly.	It's only valid of Job/Unit production. Shaft is made first and hole is reworked (Shaft Based Design).
If a component is failed, only component is replaced. Selective assembly is mostly used in the industries.		If a component is failed, complete assembly is replaced.
It can be Interference or Clearance Joint. Here, Always Hole make first then Shaft.		

LIMIT, FIT, TOLERANCES:
Process Capability is given by the machine manufacturer for particular machine for All the components.
DESIRED TOLERANCES (D.T.): For a group of component Process Capability required by consumer is called D.T.
LIMIT: Permissible range (Maximum to Minimum Size) of a component is called as limit. It denotes as $X_{E_I}^{E_S}$
ECART SUPERIOR OR UPPER LIMIT (E_S): Maximum Permissible Dimension.
ECART INFERIOR OR LOWER LIMIT (E_I): Minimum Permissible Dimension.
FIT DIAGRAM: Graphical Representation of Fits

Width of Tolerance (TW) = Tolerance, Tolerance Zone (TZ), Allowance, Upper Limit (UL), Lower Limit (LL),

FUNDAMENTAL DEVIATION ($\in$): The minimum distance at with the tolerance zone is situated from Basic Size.
As per ISO, there is 25 Types of Fundamental Deviation.



For Holes,	For Shafts,	Fundamental Deviation Representation on Bell Curve,
$A-G \rightarrow \in = LL$ $H \rightarrow \in = 0$ $J-Z \rightarrow \in = UL$	$a-g \rightarrow \in = UL$ $h \rightarrow \in = 0$ $j-z \rightarrow \in = LL$	

HOLE SHAFT DESIGNATION: $SIZE\ HOLE_{IT\ i}\ shaft_{IT\ i}$

For Information, these equations are given. Same way there is complete set of equation.	$\in_D = 16\ D^{0.44}\ \mu m$	$\in_d = -16\ D^{0.44}\ \mu m$
	$\in_F = 5.5\ D^{0.41}\ \mu m$	$\in_f = -5.5\ D^{0.41}\ \mu m$
	$\in_H = 0\ \mu m$	$\in_h = 0\ \mu m$

BASIS OF SYSTEM	
HOLE BASED SYSTEM	**SHAFT BASED SYSTEM**
$HOLE = H$, Shaft Can be anything. E.g. $5H_7h_7$	$HOLE \neq H\ \&\ shaft = h$, Shaft Can be anything.
Widely used in Industries.	Less Preferred in Industries.

TYPES OF TOLERANCES	
UNILATERAL TOLERANCE ZONE	**BILATERAL TOLERANCE ZONE**
$HOLE = A-G\ or\ shaft = j-z$ $HOLE = J-Z\ or\ shaft = a-g$	$HOLE = J_S\ \&\ shaft = j_s$ It's easy to read for worker. E.g. Equally Bilateral tolerance 25 ± 0.5

We can shift basic size line. And be careful while considering upper and lower limits.

FIT: It's defined as relationship between hole and shaft before assembly.

For hole-based system, 1. Clearance/ Loose Running/ Free Fit: Tolerance zone of shaft is below the tolerance zone of hole, $LL_H > UL_S$ $Min\ Clearance = LL_H - UL_S$ | $Max\ Clearance = UL_H - LL_S$ 2. Interference/ Press Fit: Tolerance zone of shaft is above the tolerance zone of hole, $UL_H < LL_S$. $Min\ Interference = LL_S - UL_H$ | $Max\ Interference = UL_H - LL_S$ E.g. Flywheel & Shaft, Bush & hub, Ball bearing & shaft 3. Transition Fit: Tolerance zone of shaft and the tolerance zone of hole are overlapped. E.g. Coupling ring & shaft. $Max\ Clearance, Min\ Clearance, Max\ Interference, Min\ Interference$ Can be found according to the situation of the tolerance zone.		

MATERIAL LIMIT: Material required to get the size of Hole & Shaft.

MAXIMUM MATERIAL LIMIT		**MINIMUM MATERIAL LIMIT**	
For Hole, LL.	For Shaft, UL.	For Hole, UL.	For Shaft, LL.

During Machining object's material limit changes E.g. From Maximum Material limit to Minimum Material Limit.

ALLOWANCE: It's the difference between maximum material limit of hole and shaft.

For Clearance Fit, $Allowance = Min\ Clearance$	For Interference Fir, $Allowance = Max\ Interference$

NOTE: Allowance signifies quality of fit.

PLATTING/ COATING/ ELECTROPLATING: During Platting object's material limit changes E.g. From Minimum Material limit to Maximum Material Limit. Platting is adding material which having tolerance zone.

SHAFT	HOLE
$UL_{After} = UL_{befor} + 2\ UL_{Platting}$ $LL_{After} = LL_{befor} + 2\ LL_{Platting}$	$UL_{After} = UL_{befor} - 2\ LL_{Platting}$ $LL_{After} = LL_{befor} - 2\ UL_{Platting}$

WIDTH OF TOLERANCE: ISO introduced the graph of Initial Tolerance $(i)(in\ \mu m)$ vs Dimension Range $(D)(0 - 500m)$. ISO Dimension Ranges $(D\ in\ mm)$,

Above – Up to & Included $(in\ mm)$		Above – Up to & Included $(in\ mm)$	
D_1	D_2	D_1	D_2
0	3	80	120
3	6	120	180
6	10	180	250
10	18	250	315
18	30	315	400
30	50	400	500
50	80		

Dimension Range

$$D\ (in\ mm) = \sqrt{D_1 D_2}$$

$$i = 0.45\sqrt[3]{D} + 0.001D\ (in\ \mu m)$$

As per ISO there is 16(old)/18(new) **Grades of tolerances** in Modified/ 5-Step Preferred Series & GP,

$IT01$ $0.3 + 0.008D$	$IT0$ $0.5 + 0.012D$	$IT1$ i	$IT2$ $1.6i$	$IT3$ $2.5i$
$IT4$ $4i$	$IT5$ $\mathbf{7i}$	$IT6$ $10i$	$IT7$ $16i$	$IT8$ $25i$
$IT9$ $40i$	$IT10$ $64i$	$IT11$ $100i$	$IT12$ $160i$	$IT13$ $250i$
$IT14$ $400i$	$IT15$ $640i$	$IT16$ $1000i$		

ISO introduced Grades of tolerances. It's used to classify the type of industry.

Precision Industries	Application of Precision Industries	General Eng. Industry	Heavy Industry
Manufacturing of Measurement instruments is under Precision Industries. Least Count is very small	Classification of component and decides acceptability in Application of precision industry. E.g. inspection in the industries.	All Industries where mass production is carried out is known as General Eng. Industry.	Manufacturing of machines is done in heavy industries. Least Count is very large.
$IT01 - IT4$	$IT5 - IT9$	$IT10 - IT14$	$IT15 - IT16$

TOLERANCE SINK (ACCUMULATION OF TOLERANCES):

$Tolerance\ Sink, f_{-}^{+} = a_{-}^{+} - (b_{-}^{+} + c_{-}^{+} + d_{-}^{+} + e_{-}^{+})$	$f^{+} = a^{+} - (b_{-} + c_{-} + d_{-} + e_{-})$ $f_{-} = a_{-} - (b^{+} + c^{+} + d^{+} + e^{+})$	
$Tolerance\ Sink, f_{-}^{+} = a_{-}^{+} \cdot b_{-}^{+}$	$f_{-} = a_{-} \cdot b_{-}$	$f^{+} = a^{+} \cdot b^{+}$
$Tolerance\ Sink, H_{-}^{+} = R_{-}^{+} \cdot \sin\theta_{-}^{+}$ $B_{-}^{+} = R_{-}^{+} \cdot \cos\theta_{-}^{+}$	$H^{+} = R^{+} \cdot \sin\theta^{+}$ $B^{+} = R^{+} \cdot \cos\theta_{-}$	$H_{-} = R_{-} \cdot \sin\theta_{-}$ $B_{-} = R_{-} \cdot \sin\theta^{+}$

LIMIT GAUGES			
HOLE		SHAFT	
PLUG GAUGE		RING GAUGE	
GO GAUGE	NO-GO GAUGE	GO GAUGE	NO-GO GAUGE

TAYLORS DESIGN:

Go Gauge: It's made for Maximum Material Limit.	No-Go Gauge: It's made for Minimum Material Limit.

Based on necessary evil phenomenon all gauges are provided with gauge tolerances. If Go gauges provided with extra gauge tolerance (due to wearing in use) is called **wear tolerance.**

DESIGN OF LIMIT GAUGES:

3 TYPES OF DESIGN		
WORKSHOP/ MACHINE LOCATION/ MANUFACTURING GAUGES	**INSPECTION GAUGES**	**ISO OR GENERAL GAUGES**
It takes workshop peoples' mindset in consideration.	It takes Quality department peoples' mindset in consideration.	It takes in consideration of all aspects.
Gauge Tolerances towards each other.	Gauge Tolerances away from each other.	GO: Workshop, NO-GO: Inspection

As per standard,

Gauge Tolerance = 10% of Workpiece Tolerance	Wear Tolerance = 10% of Gauge Tolerance

Rule: No Problem of rejecting acceptable component but should not accept even single reject able component.

- No single accepted component should be rejected For the Inspection Gauge Design.

NOTE: Wear Tolerance is added to the Go gauge only when the workpiece tolerance is grater then 0.1 mm.

VIOLATION OF TAYLOR'S DESIGN:

Go Gauge: It's made in full form. (1)	No-Go Gauge: It's made in individual dimension. (n)

FULL FORM: It's made up of solid with more than the length of hole to measure throughout the hole.

INDIVIDUAL DIMENSION: Use separate gauge for each dimension.

1. Instead of making Go gauge as full form, it's made as hollow or cut ring.
2. Instead of making No-Go gauge as disk, it's made as sheet.
3. Instead of using separate No-Go gauge for each dimension, it's made for multiple dimension.
4. Both Go & No-Go Gauges are mounted on single handle (E.g. Snap Gauge).

GAUGE MATERIALS:

1. Mild Steel: All properties present except Corrosiveness, hardness & machinability.
2. En-24: It's Stainless Steel used in Eng. Industries. All properties present except Coefficient of thermal expansion.
3. Invar/ Elinvar: It's alloy of Cr, Ni. It has very less thermal expansion.
4. Glass: Very popular in Precision industry.

PROPERTIES:

1. High Hardness.
2. Good Machinability.
3. Low Coefficient of thermal expansion.
4. It should be chemically inert.
5. Less Weight.
6. Less Cost.
7. Less Corrosiveness.

SLIP GAUGES: It's rectangular block of specific height with high surface finished.

WRINGING: It's method of joining slip gauge to create height by initially sliding one gauge over other than rotated.

NORMAL SET (M45)			SPECIAL SET (M87 OR M88)		
Range	**Step**	**No.**	**Range**	**Step**	**No.**
$1.001 - 1.009$	0.009	9	$1.001 - 1.009$	0.009	9
$1.01 - 1.09$	0.01	9	$1.01 - 1.49$	0.01	49
$1.1 - 1.9$	0.1	9	$0.5 - 9.5$	0.5	19
$1 - 9$	1	9	$10 - 100$	10	10
$10 - 90$	10	9	1.0005		1
Total		45	Total		87 Old, 88 New

Always Use minimum number of slip height to build height. Use subtraction method to count the number of slip gauge.

FEELER GAUGE: It's linear measurement instrument to measure small gap. E.g. Measurement of Spark plug gap.

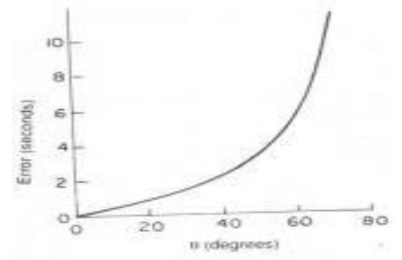
ANGULAR MEASUREMENT:

1. **ANGLE GAUGE OR ANGLE BLOCK:** It's direct contact & direct measuring instrument. 1 Set (13 Piece)

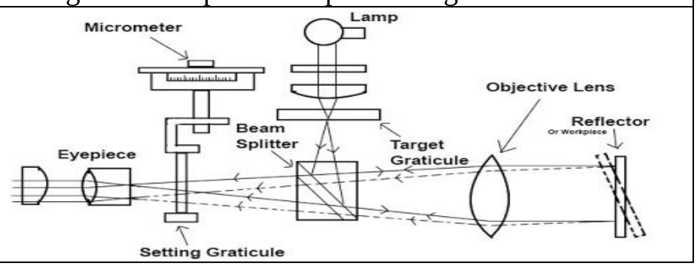
Degree: $1°, 3°, 27°, 41°$ Minute: $1', 3', 9', 27'$ Second: $3'', 6'', 18'', 30''$	Use subtraction method to calculate the number of Angle gauge required. By joining any surface of the angle gauge to another face of different angle block we can get different values angles. Light is used for checking and dark room is required.

Limitation: Workpiece should have good surface finish because angle gauge directly in contact with surface.

2. **SINE BAR:** It's direct contact & indirect measuring instrument. **Allen Screws** are used to tighten the same diameter rollers. Holes are mad to reduce the weight of the sine bar. It's made up of High Cr & C Alloy. Height/ Depth Gauge, Micrometre, slip gauges may be used along with sine bar for measurement of the angle.

For Accurate measurement, 1. Standard Centre distance between rollers required. 2. Two rollers must have same diameter. 3. Flatness of top & bottom surface of the main body. 4. Parallelism of axis of roller.	L = Centre distance between 2 Rollers, D = Diameter of Rollers, h = Height of Slip Gauge, $\sin\theta = \frac{h}{L} \Rightarrow d\theta = \tan\theta\left(\frac{dh}{h} - \frac{dL}{L}\right) \propto \tan\theta$ From the above equation we can say that sine bar is used to measure angle only up to $45°$ Because of increasing in error drastically.	

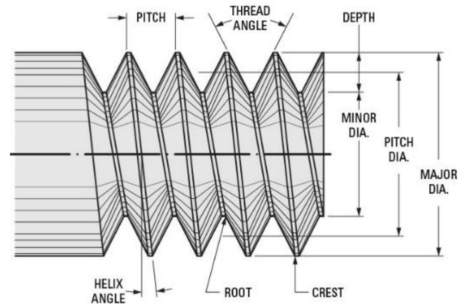
3. **AUTO-COLLIMATOR:** It's indirect contact & indirect measuring instrument. It's used to find the flatness/ Straightness/ Angle measurement.

Flatness: Departure of Plane in given surface.	Straightness: Departure of point in a given direction.
It has convex lance which has constant focal length. Reflector is moving over the surface which is required to check. Simultaneously the light source emits light on reflector. The deviation in rejector waves are received on screen and deviation in reflected waves gives angle of inclination in that direction. $x = 2f\ \delta\theta$	

4. **CLINOMETER:** It's simple protector attached with mass using rope. It used for measuring very large angles & heights.
5. **PRECISION BALL MEASUREMENT:** It's used when making a contact is difficult to measure angle. It's also known as **Taper & Internal Diameter** Measurement.

For Cone, $$\sin\frac{\theta}{2} = \frac{d_2 - d_1}{2(h_1 - h_2) - (d_2 - d_1)}$$	For Dovetail, $$\tan\frac{\theta}{2} = \frac{d_2 - d_1}{(L_1 - L_2) - (d_2 - d_1)}$$

SCREW THREAD MEASUREMENT:

By using **Flat Ended Micrometre**, Major Diameter can be found. By using **Pointed Anvil Micrometre**, Minor Diameter can be found. By using **Pitch Gauge**, Pitch & Thread Angle of the Bolt can be found. Pitch gauge is used only for single start thread. To measure Pitch in any number of starts thread **Pitch measurement machine** is used. To measure Thread angle, Wires/ Rollers/ Spherical Balls are used.	$2\theta =$ Thread/ Flank/ Included Angle, $\theta =$ Half Thread Angle, $M =$ Major Diameter, $m =$ Minor Diameter, $D_e =$ PCD of Thread, $P =$ Pitch of the Thread, $L = nP =$ Lead, $n =$ No. of Starts,	

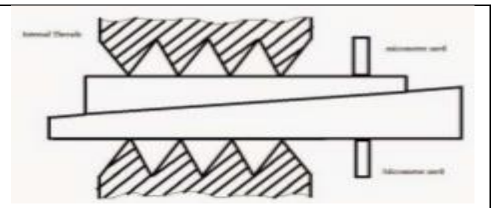
Wires are used for external thread. Rollers are used when rack and pinion arrangement is present. Spherical Ball is used for Gears. All of these are used with Flat ended Micrometre.

For Wires in Half Thread angle measurement, $$\sin\theta = \frac{d_2 - d_1}{(M_2 - M_1) - (d_2 - d_1)}$$	Methods for measurement of PCD or Effective Diameter, 1. 2 Wire method (Used for Small Pitch), 2. 3 Wire method (Used for Large Pitch)

Best Size wire is the diameter of wire which makes point contact exactly on pitch line ($D_w =$ Best Size Wire Dia.)

To Find Best Size Wire Diameter, $$\cos\theta = \frac{P}{2D_w}, From\ Geometry$$	**ABBE'S PRINCIPLE:** • Point Contact gives accuracy. • Always use Horizontal & Vertical Planes in measurement.
$$PCD = X - \left(D_w + \frac{P}{2}\tan\theta\right) = X - D_w(1 + \sin\theta)$$ $$PCD = T + \left(D_w - \frac{P}{2}\tan\theta\right) = T + D_w(1 - \sin\theta)$$ $$= T + D_w(1 - \operatorname{cosec}\theta) + \frac{P}{2}\cot\theta$$	$X =$ Over Micrometre Reading, $T =$ Under Micrometre Reading, $$T = X - 2D_w$$ **NOTE:** For ISO or Metric Thread, $2\theta = 60°$, $M16 \times 2$ Where, $P = 2$

OPTICAL PROJECTOR: It's non-contact type measuring instrument. It's simply scaling a projection of actual object and measurement is done on the screen.

MEASUREMENTS IN NUT: 1. **Sliding Bar** is used for the Minor Diameter measurement. 2. **Wax** is used for the Major Diameter, Pitch measurement. $$M + m + 2\ Flank\ Height$$ PCD Measurement using ball, $\cos\theta = P/2D_w$, $D_w = BS\ Ball\ Diameter$ $$PCD = \boldsymbol{Y} + D_w(1 + \sin\theta), Where\ Y = Inside\ Sliding\ Bar\ Height$$	

CONDITION TO MAKE ASSEMBLY BETWEEN NUT & BOLT:

1. PCD Should be same.
2. Pitch Must be Same.
3. $M_{nut} \geq M_{bolt}$
4. $m_{nut} \geq m_{bolt}$

Rework always should be performed on **Nut.** Virtual Effective Diameter is the diameter after rework on Nut.

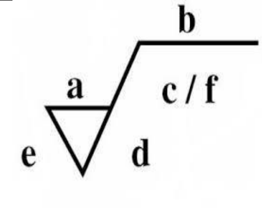
$V.E.D.(in\ mm) = D_e + V.C.$	Virtual Change, $V.C. = \delta P\cot\theta + 0.0131P(\delta\theta_1 + \delta\theta_2)$
$\delta P =$ Error in Pitch (P) measurement, $\theta_1 =$ Right Hand half Thread Angle, $\theta_2 =$ Left Hand half Thread Angle,	$\delta\theta_1 =$ Error in Right Hand half Thread Angle in Degree, $\delta\theta_2 =$ Error in Left Hand half Thread Angle in Degree, **NOTE:** $\delta\theta_1, \delta\theta_2$ are not given, $V.C. = \delta P\cot\theta$

SURFACE FINISH:

Lay: It's the pattern generated on the surface by continuous feed motion.
Flaw: It's defect generated on the surface due to impurities present in the material. E.g. Faylite: $Fe + SiO_3 \rightarrow FeSiO_3$
Sampling Length: It's Length of workpiece considered for the surface measurement.
Surface Texture: It's combination of lay & flows or Waviness & roughness w. r. t. given sampling length is called surface texture.

Primary Texture or Waviness: It's Large wavelength fluctional over the sampling length. It's majorly due to Machine vibration or some misalignment which remains same throughout the length.
Secondary Texture or Roughness: It's Small wavelength fluctional over the sampling length. It's majorly due to tool vibration or wearing of tool.

LAY MARKS ORIENTATION	SYMBOL	OPERATION
Parallel to the axis of workpiece	$=$	Shaping/ Planning
Perpendicular to the axis of workpiece	$\perp$	Turning, Shaping, Planning
Intersecting each other	$\times$	Knurling
Multidirectional Lay	M	Grinding
Circular Lay	C	Facing
Radial Lay	R	Slotting Operation

<table>
<tr><th colspan="4">REPRESENTATION OF SURFACE FINISH</th></tr>
<tr><th colspan="2">I.S.O. FOR REPRESENTATION</th><th colspan="2">INDIAN STANDARD</th></tr>
<tr><td rowspan="6">$e =$ Machining Allowance
$a =$ Value of Central Line Average ($Ra\ in\ \mu m$)
$d =$ Symbol of Lay,
$c/f =$ Sampling Length ($in\ mm$)
$b =$ Production Method</td><td rowspan="6">
</td><th>Symbol</th><th>Centre line average Value</th></tr>
<tr><td>∇∇∇∇</td><td>$< 0.25\ \mu m$</td></tr>
<tr><td>∇∇∇</td><td>$1.6 - 0.25\ \mu m$</td></tr>
<tr><td>∇∇</td><td>$8 - 1.6\ \mu m$</td></tr>
<tr><td>∇</td><td>$25 - 8\ \mu m$</td></tr>
<tr><td>$\sim$</td><td>$> 25\ \mu m$</td></tr>
</table>

DATUM REFERENCE FOR SURFACE FINISH MEASUREMENT:

1. **M-SYSTEM:** Area above the mean line is the same as area below the mean line.
2. **E-SYSTEM:** By rolling small ball or sphere over the surface the envelope line is generated by capturing movement of centre of ball. Shifting this envelope line in such a way that area in both the side remain the same. By this system waviness can be eliminated. It's advanced system.

SURFACE FINISH MEASUREMENT:

1. **MAXIMUM PEAK TO VALLEY HEIGHT (H_{max} or R_t):**

For successive or consecutive pick and welly first identify the pick and welly. After that find maximum pick & minimum welly. Difference between them will give R_t.

For Turning,

From Geometry, $\tan\psi + \cot\psi_1 = \frac{f}{H_{max}}$	For 90° V-Tool, $\psi_1 = \psi$ $H_{max}(in\ \mu m) = \frac{f}{2}$	Practically Round nose Tool is used, $H_{max}(in\ \mu m) = f^2/8R$	$\psi =$ Side Cutting Edge Angle, $\psi_1 =$ End Cutting Edge Angle, H_{max} is independent of DOC.

2. **CENTRELINE AVERAGE VALUE (C.L.A.) (R_a):**

$R_a(in\ \mu m) = \frac{y_1 + y_2 + y_3 + \cdots + y_n}{n}$	For Turning, $R_a = H_{max}/4$ $\tan\psi + \cot\psi_1 = f/H_{max}$	For Shaping, $R_a = H_{max}/2$

For Small Portion if there is small deviation in surface roughness, $H_{max} > R_a$. But in actual case except that surface there may be chance that sample is good throughout the length.

AREA BASED:

<table>
<tr><td colspan="2">Magnification indicates the dimension corresponds to the square box having same area as surface roughness curve bound with mean value.</td><td>$HM =$ Horizontal Magnification,
$VM =$ Vertical Magnification,</td></tr>
<tr><td>$R_a(in\ \mu m) = \frac{\sum A}{L} \cdot \frac{1}{VM} \cdot \frac{1000}{HM}$</td><td>$\sum A = \sum A_{above} + \sum A_{below}$</td><td></td></tr>
</table>

<table>
<tr><td>3. ROOT MEAN SQUARE VALUE (RMS) (R_g or R_s):</td><td>4. 10 POINT VALUE (R_z): Average over definite Value.</td></tr>
<tr><td>$R_s(in\ \mu m) = \sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + \cdots + y_n^2}{n}} = 1.1\ R_a$</td><td>$R_z(in\ \mu m) = \frac{\sum_1^5 P_i - \sum_1^5 V_i}{5}$
$V_i =$ Top 5 welly | $P_i =$ Top 5 pick</td></tr>
</table>

After Grinding on one surface, $R_a < R_z < R_s < R_t\ or\ H_{max}$

5. **FORM FACTOR (K):**

Draw the box whose top is max pick and root is maximum welly.	$K = A_{metal}/A_{total}$ & $0 \le K \le 1$

INTERNATIONAL ROUGHNESS GRADES:

R_a	N	$N_{-25\%}^{+50\%}$
0.025	N_1	$0.02 - 0.04$
0.05	N_2	$0.04 - 0.08$
0.1	N_3	$0.08 - 0.15$
0.2	N_4	$0.15 - 0.3$
0.4	N_5	$0.3 - 0.6$
0.8	N_6	$0.6 - 1.2$
1.6	N_7	$1.2 - 2.4$
3.2	N_8	$2.4 - 4.8$
6.3	N_9	$4.8 - 9.6$
12.5	N_{10}	$9.6 - 18.75$
25.0	N_{11}	$18.75 - 37.5$
0.5	N_{12}	$37.5 - 75.0$