SVCE

Sri Venkateswara College of Engineering

Autonomous - Affiliated to Anna University

ME18501- Metrology and Quality Control (R2018)

V semester

Academic Year 2021-22

Syllabus

UNIT No.	TITLE
I	INTRODUCTION TO METROLOGY & LINEAR MEASUREMENTS
II	ANGULAR AND FORM MEASUREMENTS
III	ADVANCES IN METROLOGY
IV	MEASUREMENT OF PROCESS PARAMETERS
V	QUALITY CONTROL

Text Books

1. Jain R.K "Engineering Metrology", Khanna Publishers, 21 st edition, 2005.

2. Gupta. I.C., "Engineering Metrology", 7th edition, Dhanpatrai Publication, 2012.

UNIT-I
INTRODUCTION TO METROLOGY & LINEAR MEASUREMENTS

Introduction to Metrology – Basics - Need – Precision and Accuracy, Errors in Measurements, Comparators – Mechanical, Electrical & Optical. Interchangeability - limits, fits and tolerances, Limit gauges, Taylor's principle of gauge design. Calibration, Sensitivity, readability & repeatability. Linear measurement - Vernier calipers – Vernier height gauge Vernier depth gauge - Micrometers – Digital calipers - Slip gauges.

Introduction to metrology

Definition

Metrology is the science of measurement.

In broader sense, Metrology is the science and art of precision measurement, testing and evaluation. (Ref:1)

Other Definitions

- It is a field of knowledge concerned with measurements and includes both theoretical and practical problems related to measurement.

- Process of making extremely precise measurement.

- The science concern with the establishment, reproduction and transfer of units of measurements and their standards.

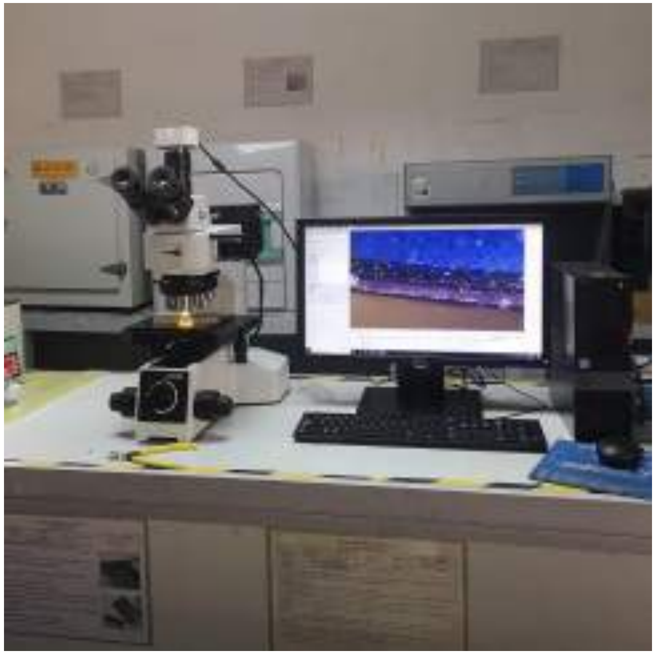
(Ref:3)

Types of Metrology

- Scientific
- Industrial
- Legal

Scientific Metrology

Organization and development of measurement standards and their maintenance at the highest level (Ref:3)

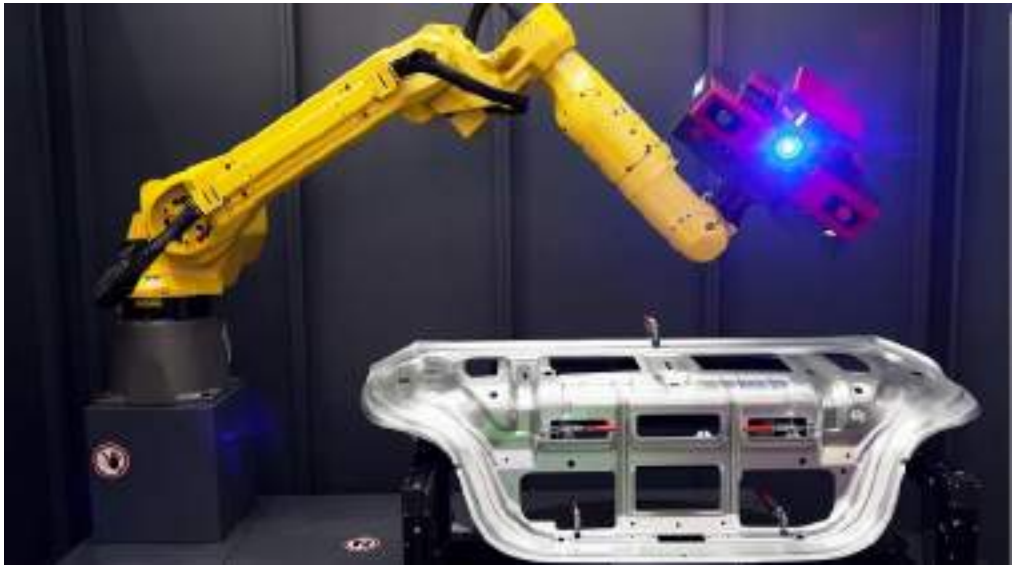


https://www.alibaba.com/product-detail/1000X-6-inch-Large-stage-dark_60658076787.html

Industrial Metrology

Deals with proper functioning of measuring instruments used in industry

(Ref:3)



https://metrology.news/industrial-robots-the-metrology-solution-of-the-future/

Legal metrology

Legal metrology regulate, advise and control the manufacturing and calibration of measuring instruments.

(Ref:3)

Indian emission standards (4-wheel vehicles)

Standard	Reference	Date	Region
India 2000	Euro 1	2000	Nationwide
Bharat Stage II	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003.04	NCR*, 11 cities†
		2005.04	Nationwide
Bharat Stage III	Euro 3	2005.04	NCR*, 11 cities†
		2010.04	Nationwide
Bharat Stage IV	Euro 4	2010.04	NCR*, 13 cities‡
		2015.07	Above plus 29 cities mainly in the states of Haryana, Uttar Pradesh, Rajasthan and Maharastra [3231]
		2015.10	North India plus bordering districts of Rajasthan (9 States) [3232]
		2016.04	Western India plus parts of South and East India (10 States and Territories) [3232]
		2017.04	Nationwide [3232]
Bharat Stage V	Euro 5	n/a [a]	
Bharat Stage VI	Euro 6	2020.04	Nationwide [3827]

* National Capital Region (Delhi)
† Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Secunderabad, Ahmedabad, Pune, Surat, Kanpur and Agra
‡ Above cities plus Solapur and Lucknow. The program was later expanded with the aim of including 50 additional cities by March 2015
[a] Initially proposed in 2015.11 [illegible] but removed from a 2016.02 proposal [illegible] and final BS VI regulation [illegible]

https://dieselnet.com/standards/in/

Metrology is mainly concerned with..

- Establishing the units of measurements, reproducing these units in the form of standards and ensure the uniformity of measurements

- Developing methods of measurement

- Analyse the accuracy of methods of measurement, establishing uncertainty of measurement, researching into the cause of measuring errors

Definition of Measurement

Process or act of obtaining a quantitative comparison between a predefined standard and an unknown magnitude. (Ref:3)

https://willrich.com/which-applications-require-the-use-of-vernier-calipers/

Need for measurements

- Provides fundamental basis for research and development.
- Final stage of any device involving design procedure needs measurement of various quantities related to the performance of the device.
- Measurement is the fundamental element of control process.
- Many operations require measurements for proper performance.
- Measurement helps in the reduction of product cost.

(Ref:3)

Need of Inspection

- Interchangeability of parts (due to mass production)
- To control and restrict the variations within the limits
- Development of precision instruments

(Ref:1)

Metrology Terminologies

Calibration:

The set of operation that establish the relationship between values indicated by instruments and corresponding values given by standards under specified condition

Error:

Measuring instrument output minus true value of the input quantity

Metrology Terminologies

Measurand:

A quantity subject to measurement

Range:

The capacity with in which the instrument is capable of measuring

Response time:

The time which elapses after sudden change of the measured quantity until the instruments gives an indication

Metrology Terminologies

Resolution:

It is the fineness to which an instrument can read

Sensitivity:

The minimum change in value of quantity being measured that an instrument can reliably respond

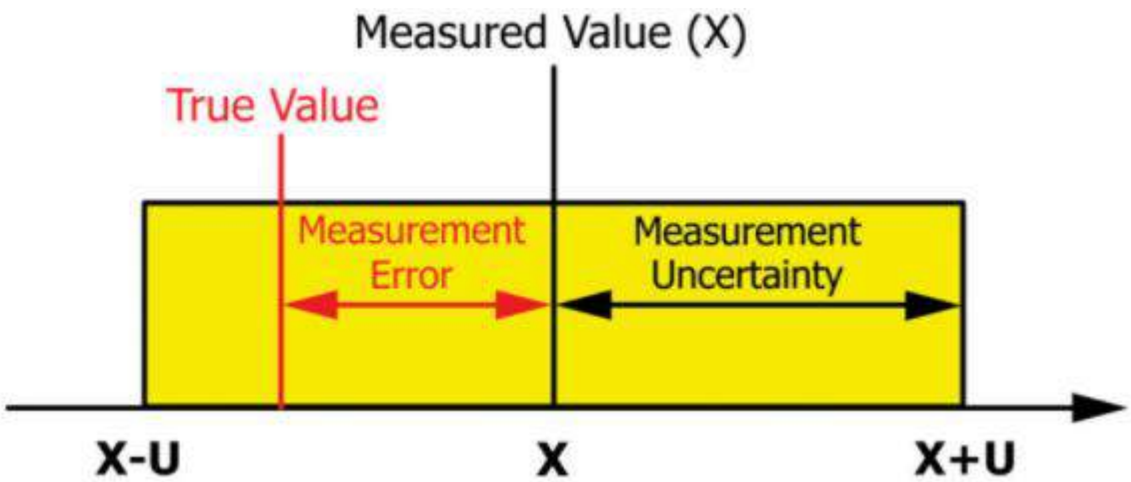
Stability:

The ability of a measuring instrument to constantly maintain its metrological characteristics with time

Metrology Terminologies

Uncertainty:

It is a parameter associated with the results of a measurement that characterizes the dispersion of values that could reasonably be attributed to the Measurand.



HN Metrology Consulting, Inc. (iso-gps.com)

Metrology Terminologies

Standard:

Level of quality or achievement, especially a level that is throughout to be accepted.

Instrument:

Tool or a device that is used to do a particular task.

Environment:

External conditions or surroundings especially those in which people live or work.

Precision and Accuracy

Precision:

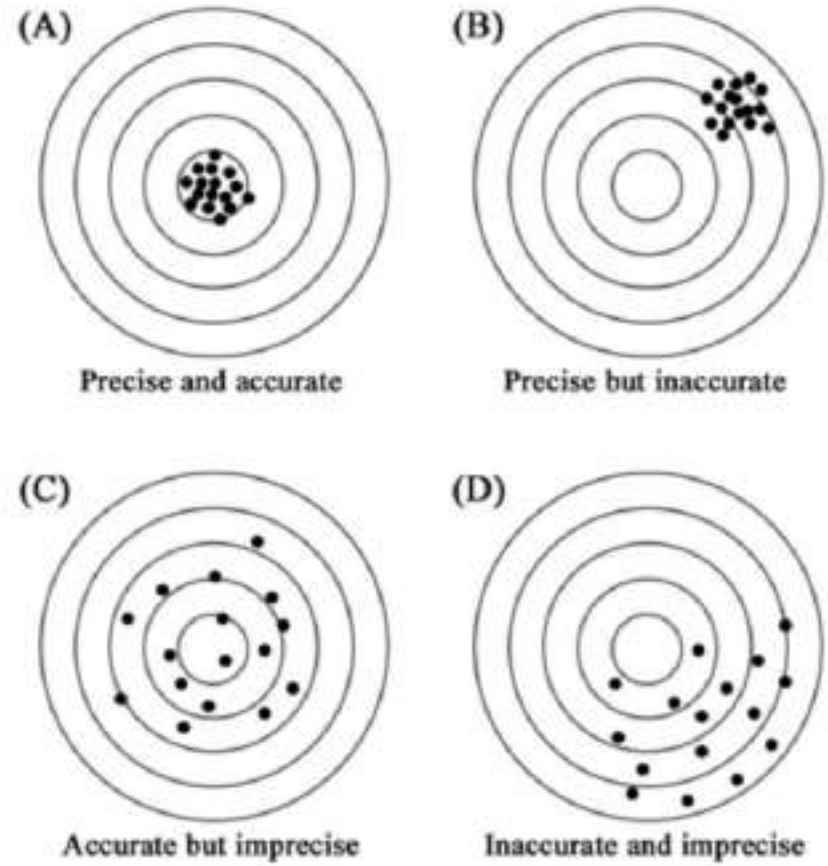
Defined as the repeatability of a measured process.

Accuracy:

Agreement of the result of a measurement with the true value of the measured quantity.

(Ref:1)

Precision and Accuracy



https://nptel.ac.in/content/storage2/courses/102103044/module1/lec1/2.html

Errors in Measurement

Each successive measurement during measuring any measurand will show differences in dimensions

Reasons:

- Instrument error
- Environmental effect
- Human error
- Imperfect datum

(Ref:4)

Controllable errors

- Environmental conditions
- Elastic Deformation
- Deflection errors
- Alignment errors
- Parallax error
- Error due to improper instrument

(Ref:4)

Environmental Error

- Due to effect of variation in the surrounding temperature, pressure and humidity, vibration and shock, electric fields etc.
  - Standard Temperature: 20^oC
  - Allow for temperature stabilization
  - Temperature compensation

$$\text{Error} = l\alpha(t-t_2)$$

$$\text{Error} = l[\alpha_1(t_1-20) - \alpha_2(t_2-20)]$$

- Presence of dirts, Improper datum

(Ref:4)

Elastic deformation

Stylus pressure need to be adjusted

Overhangs should be minimized

Adjust stylus pressure depending on work piece

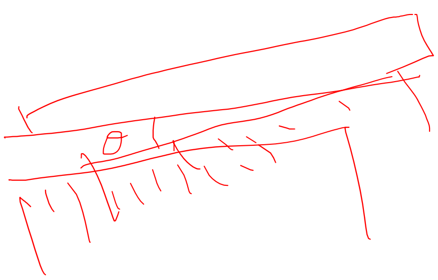
Error due to deflection

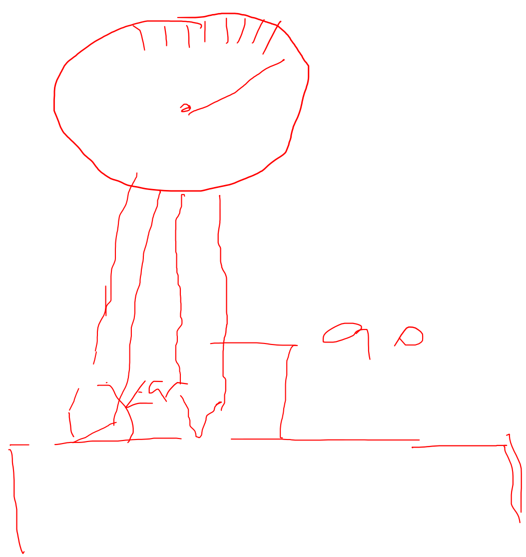
Clamps should be secured properly (for length work piece) and d=0.577L (d- distance between support, L-Length of the work piece)

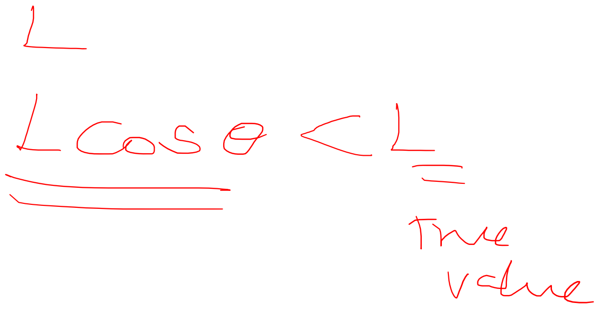
(Ref:4)

Alignment error

Cosine error (due to misalignment)

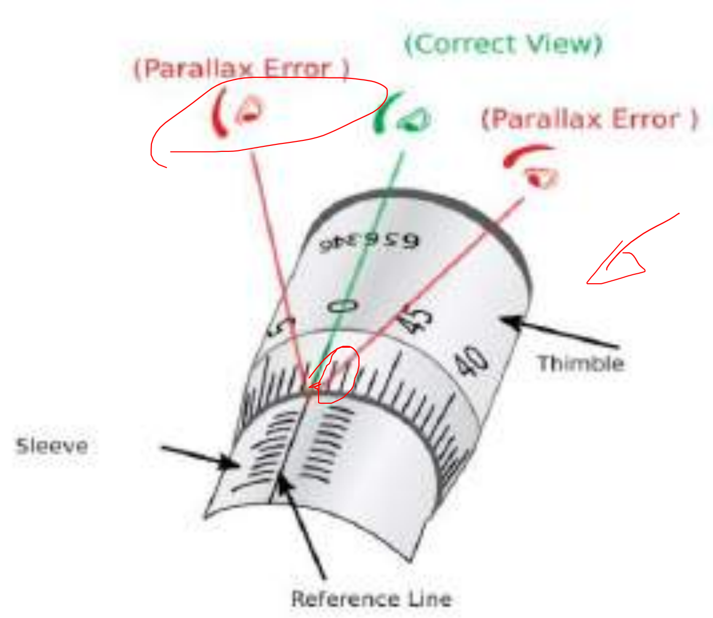






Parallax error

Pointer on a scale is not observed along a line normal to the scale.

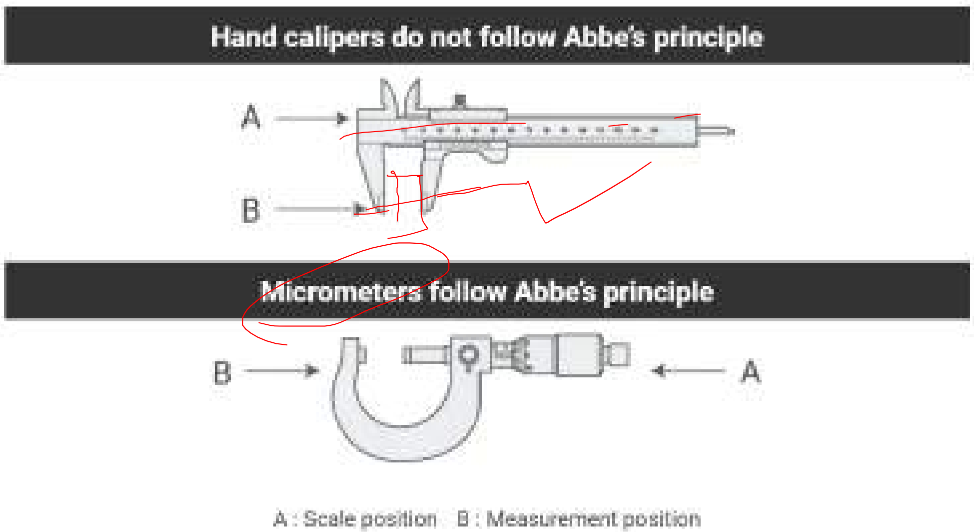


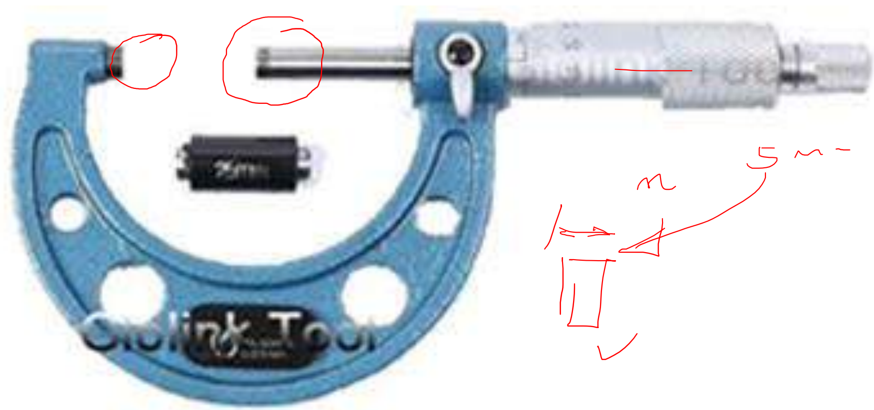
https://www.miniphysics.com/parallax-error-and-zero-error.html

Parallax error

Pointer on a scale is not observed along a line normal to the scale.

- Use Abbe's principle of alignment
- Avoid improper instrument selection
- Error due to wear





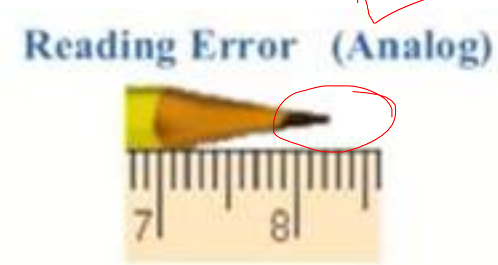
https://www.aliexpress.com/i/32958626937.html

https://www.keyence.com/ss/products/measure-sys/measurement-selection/basic/abbe-principle.jsp

(Ref:4)

Non controllable errors

- Scale error
- Reading error
- Linearity
- Hysteresis
- Repeatability



https://www.youtube.com/watch?v=h72ispCJEeQ

(Ref:4)

Linearity Error and Hysteresis error

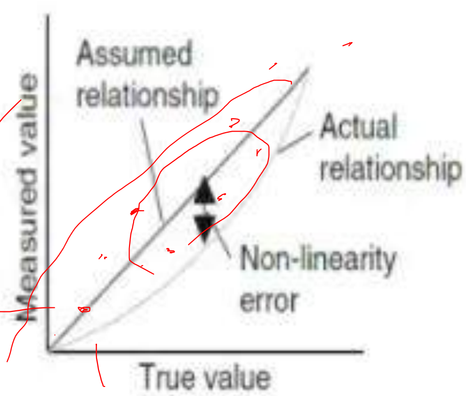
Linearity error:

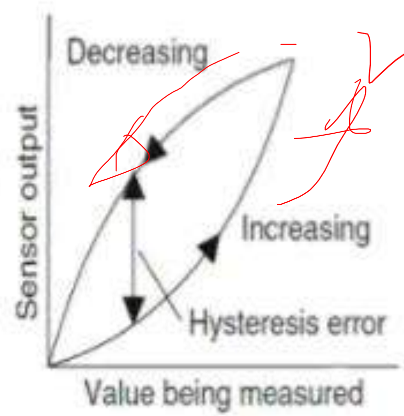
The maximum deviation of the output of a measuring system from a specified straight line

Hysteresis error:

The difference in position between loading and unloading curves

(presence of dry friction, properties of elastic elements, presence of internal stress)





(Ref:4)

Repeatability Error

- Present in every measuring system
- Mean value will mostly away from the true value
- Instrument have to be recalibrated

Meter definition

The French originated the meter in the 1790s as one/ten-millionth of the distance from the equator to the north pole along a meridian through Paris. It is realistically represented by the distance between two marks on an iron bar kept in Paris.

The International Bureau of Weights and Measures, created in 1875, upgraded the bar to one made of 90 percent platinum/10 percent iridium alloy.

In 1960 the meter was redefined as 1,650,763.73 wavelengths of orange-red light, in a vacuum, produced by burning the element krypton (Kr-86).

More recently (1984), the Geneva Conference on Weights and Measures has defined the meter as the distance light travels, in a vacuum, in 1/299,792,458 seconds with time measured by a cesium-133 atomic clock which emits pulses of radiation at very rapid, regular intervals.

The Standard Meter (surveyhistory.org)

Line and End Measurement

When the length being measured is expressed as the distance between two lines, this is referred as **line measurement**

When the length being measured is expressed as the distance between two surfaces, this is referred as **end measurement**

Comparators

- Comparators are Instruments which enable a comparison to be made between the item being measured and a length standard to a high degree of precision

- Comparators only give the dimensional differences between a standard and an unknown quantity

- The procedure is called comparison measurement

Accuracy of comparison measurement depends on

- Accuracy of the standard used for setting the comparator
- Least count of the standard
- Sensitivity of the comparator
- Accuracy of the reading scale

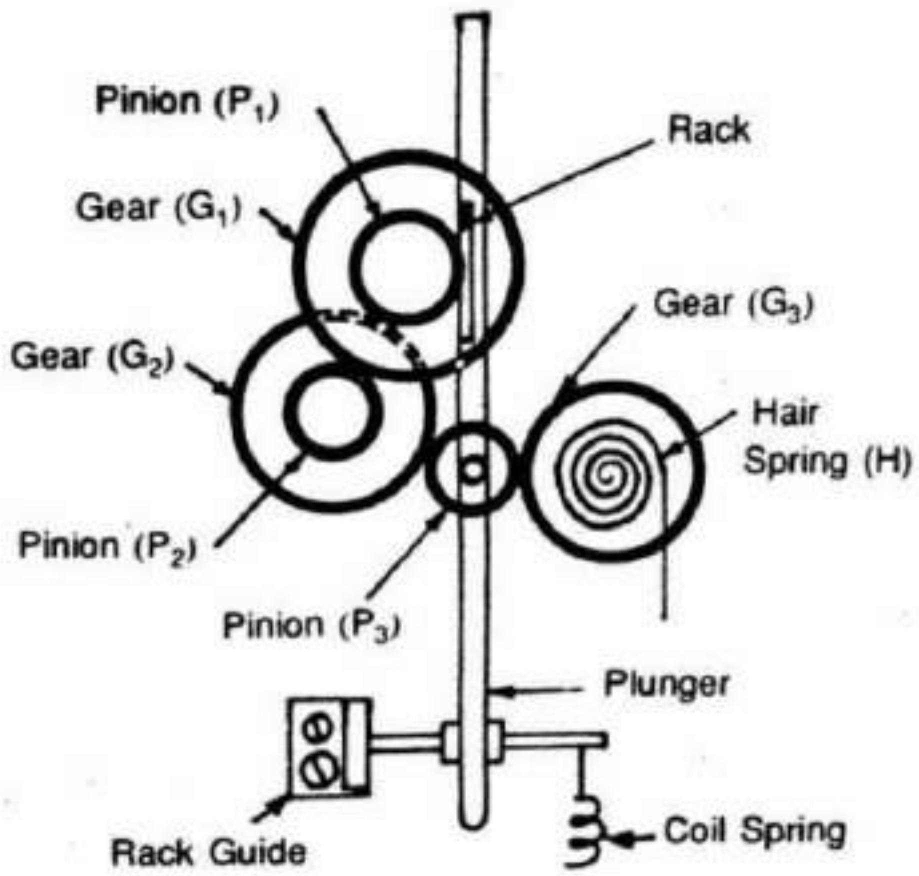
(Ref:3)

Types of comparators

Comparators basically differ in their methods of amplifying and recording the variations. Therefore based on the principle used for amplifying and recording measurements, comparators are broadly classified as follows

- Mechanical
- Optical
- Electrical
- Pneumatic

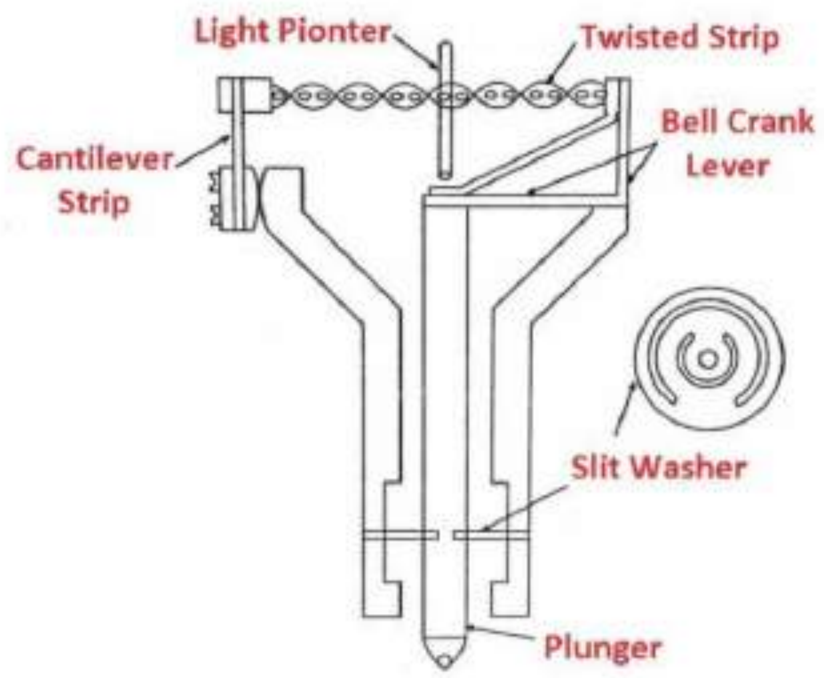
Dial Indicator



https://www.mechanicalpost.site/2020/07/dial-gauge-indicator-construction-and.html

https://in.rsdelivers.com/product/rs-pro/dg-m/rs-pro-plunger-dial-indicator-range-0-10-mm/8412561

Johansson Mikrocator



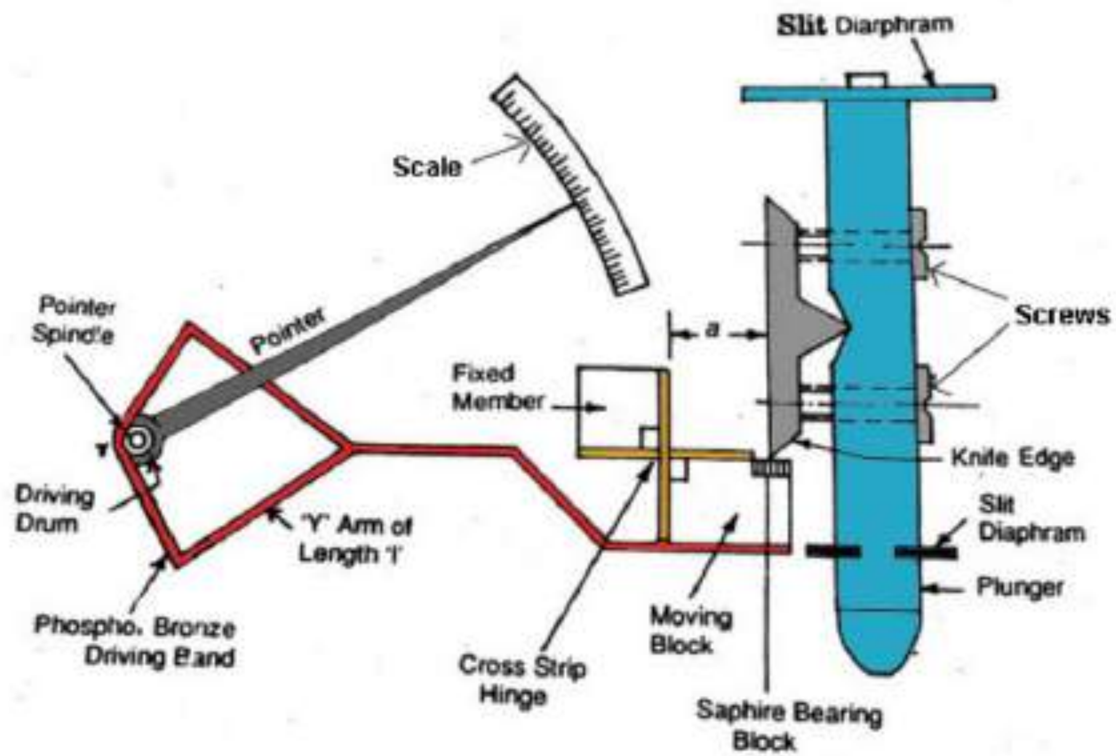
The basic principle was called as Abramson movement

Two halves of thin metal strip, which carries the light pointer, are twisted in opposite directions

$$d\theta/dl \;\alpha\; l/nw^2$$

https://www.theengineerspost.com/mechanical-comparator-types/

Sigma comparator



Magnification = (Y/a) (R/r)

http://www.mechanicalwalkins.com/sigma-comparator-parts-working-advantages-and-disadvantages/

Advantage of Mechanical Comparators

- Inexpensive
- No electricity required
- Usually have linear scale
- Robust and compact
- Easy to handle
- Portable

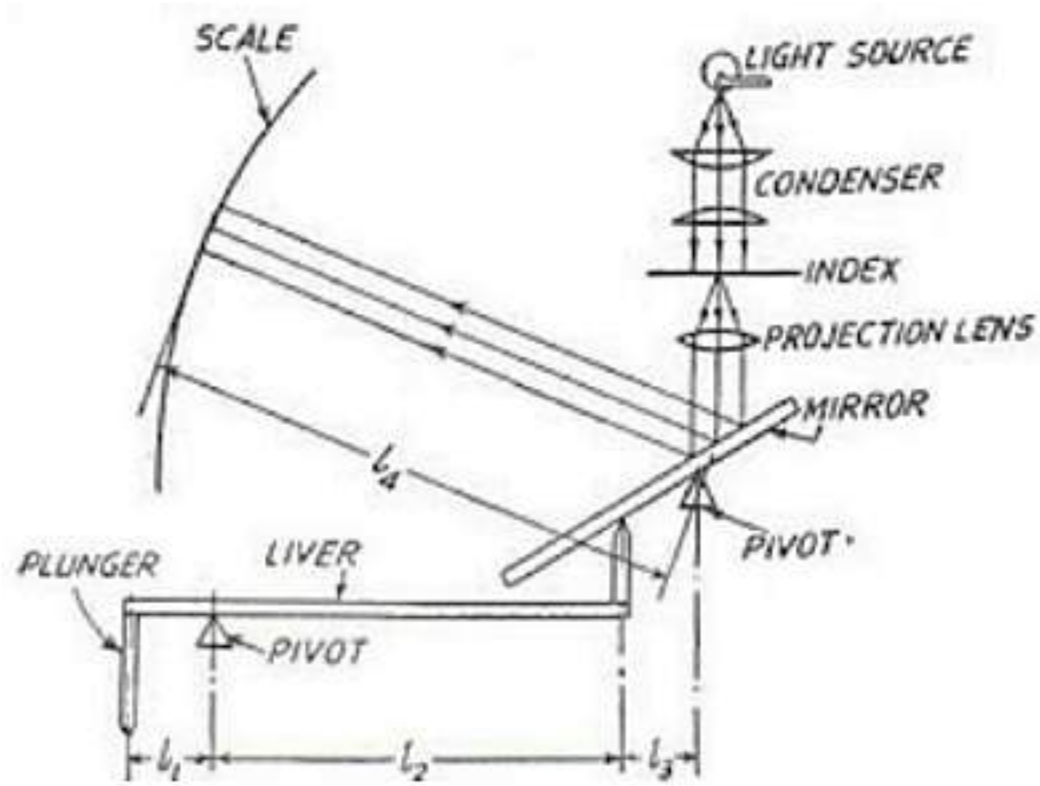
(Ref:1,4)

Disadvantages of Mechanical Comparators

- More moving parts than other types (hence friction is more and accuracy is less)
- Sensitive to vibration
- Range of instrument is limited
- Parallax error is possible

(Ref:1)

Optical comparator



Overall magnification of the system = $2(l_2/l_1) * (l_4/l_3)$

(Ref:1)

Advantages of optical Comparators

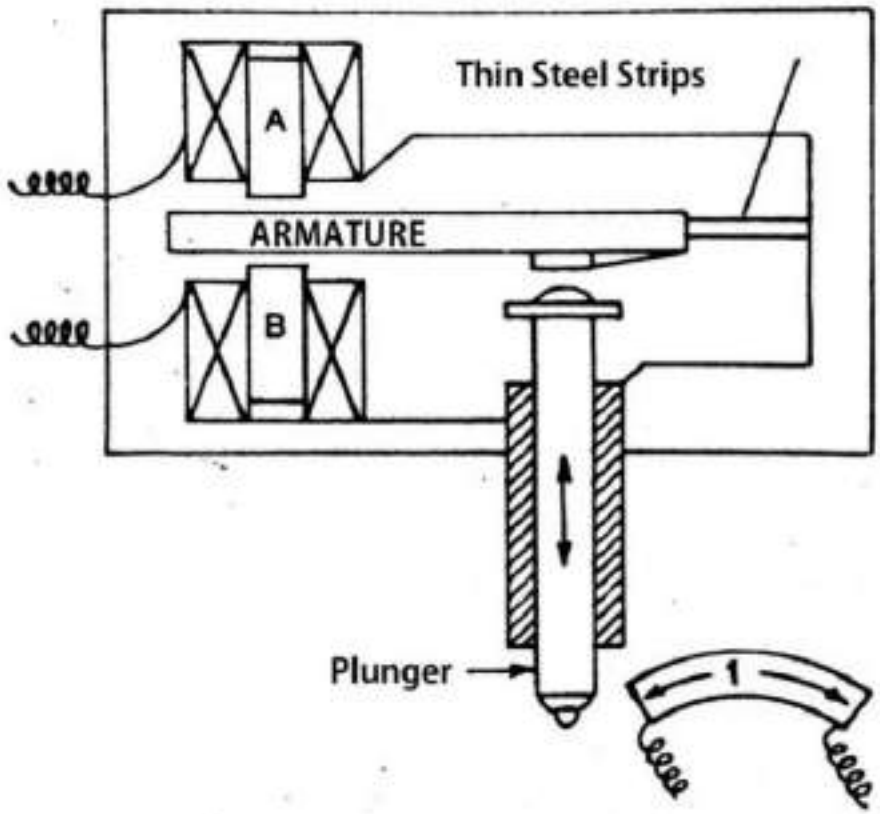
Small number of moving parts hence high accuracy
High range
Very high magnification
Weightless (optical lever)

Disadvantages of optical Comparators

Heat from the lamp may drift the settings
Electric supply necessary
Large and expensive
Darkness necessary
Not convenient for continuous use

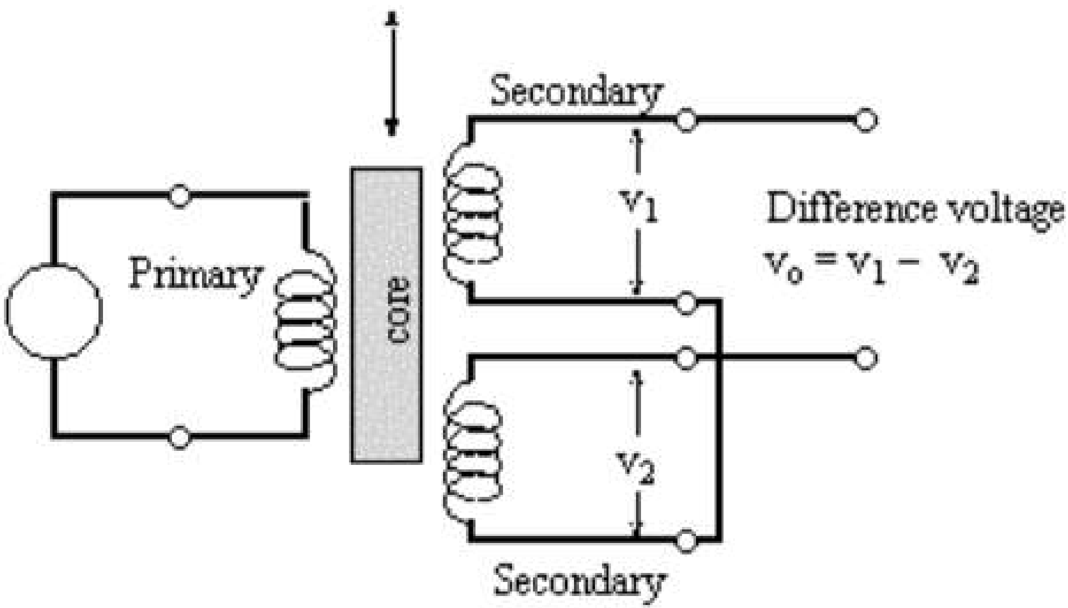
(Ref:1)

Electrical comparator



https://extrudesign.com/electrical-comparators-and-electronic-comparators/

Linearly variable differential transformer



https://instrumentationtools.com/what-is-lvdt/

Advantages of Electrical comparator

- Measuring unit can be remote from display unit
- Less number of moving parts, hence less friction
- Ver high magnification (10000 times)
- Measuring unit can be small and portable

(Ref:4)

Disadvantages of Electrical comparator

- External power needed
- Fluctuation of electric supply affect the results
- Heating of coil
- Expensive

(Ref:4)

Interchangeability

Any component selected at random if assemble correctly with any other mating component that too selected at random is known as interchangeability

- Interchangeability → Mass production
- Standards to be followed for interchangeability

Universal Interchangeability
Local Interchangeability

(Ref:1,3)

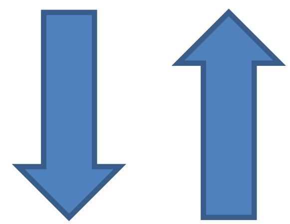
Tolerance

Defined as the total variation permitted in the size of a dimension, and is the algebraic difference between the upper and lower acceptable dimensions

Difference between upper and lower limits is termed as permissive tolerance.

(Ref:3)

Manufacturing cost and work tolerances

Permissive tolerance  Manufacturing cost

(Ref:3)

Classification of tolerance

- Unilateral tolerance
- Bilateral tolerance
- Compound tolerance
- Geometric tolerance

(Ref:3)

Unilateral Tolerance

When the tolerance distribution is only on one side of the basic size, it is known as unilateral tolerance

Employed in drilling process, where dimensions are most likely to deviate in one direction only

(Ref:3)

Bilateral tolerance

Dimensions of the part is allowed to vary on both sides of the basic size but may not be necessarily equally spread on either side of the basic size.

Compound tolerance

When tolerance is determined by established tolerances on more than one dimension, it is known as compound tolerance

(Ref:3)

Geometric tolerance

Defined as the total amount that the dimension of a manufactured part can vary.

Underlines the importance of the shape of a feature against its size.

Further classified into

- Form tolerance
- Orientation tolerance
- Positional tolerance

(Ref:3)

Symbolic representation of geometric tolerances

SYMBOL	GEOMETRIC CHARACTERISTIC
⏥	FLATNESS
—	STRAIGHTNESS
⌭	CYLINDRICITY
○	CIRCULARITY (ROUNDNESS)
⊥	PERPENDICULARITY
//	PARALLELISM
∠	ANGULARITY
⌖	POSITION

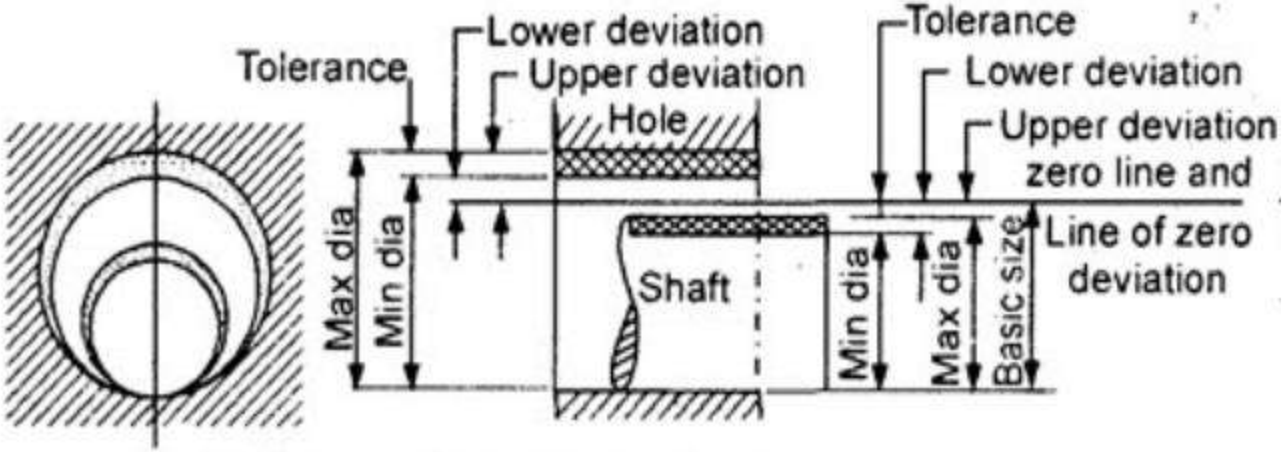


Diagram illustrating basic size deviations and tolerances.

Fits

There is relationship between two mating parts, that are to be assembled, with respect to their dimensions before assembly. This is called fit.

Types:

Clearance fit

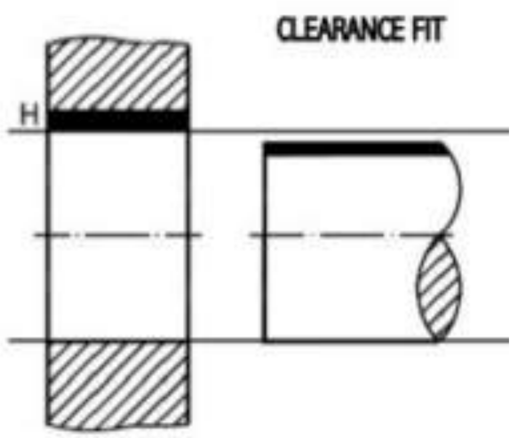
Interference fit

Transition fit

Clearance fit

Largest permissible diameter of the shaft is smaller than the diameter of the smallest hole.

This type of fit always provides clearance



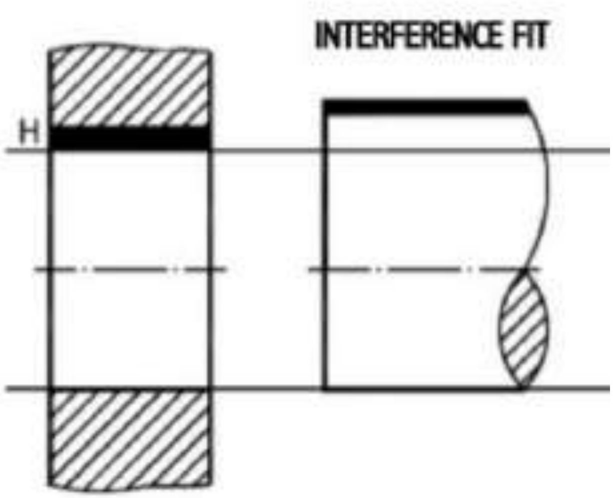
https://mytutorialworld.com/

(Ref:3)

Interference fit

The minimum permissible diameter of the shaft exceeds the maximum allowable diameter of the hole.

Also referred as tight fit.

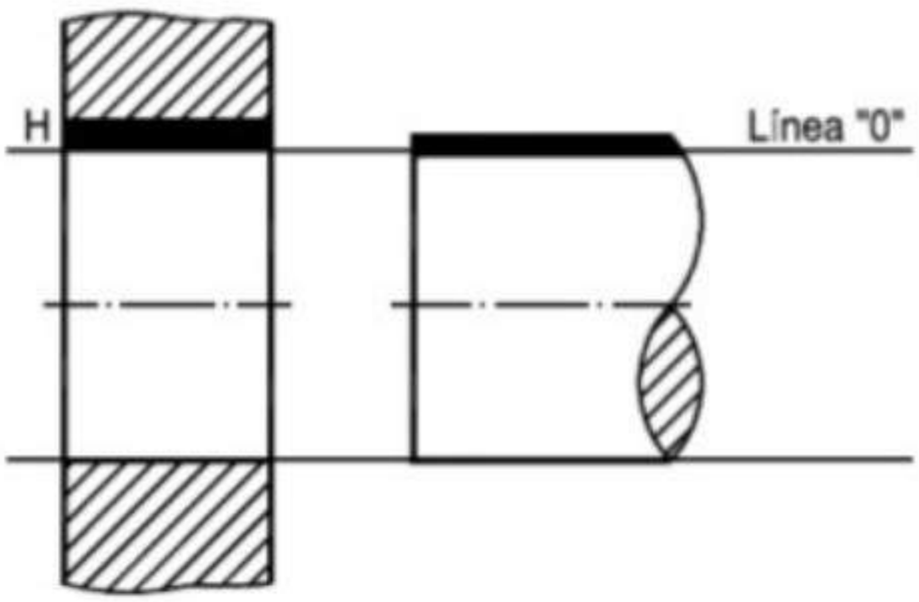


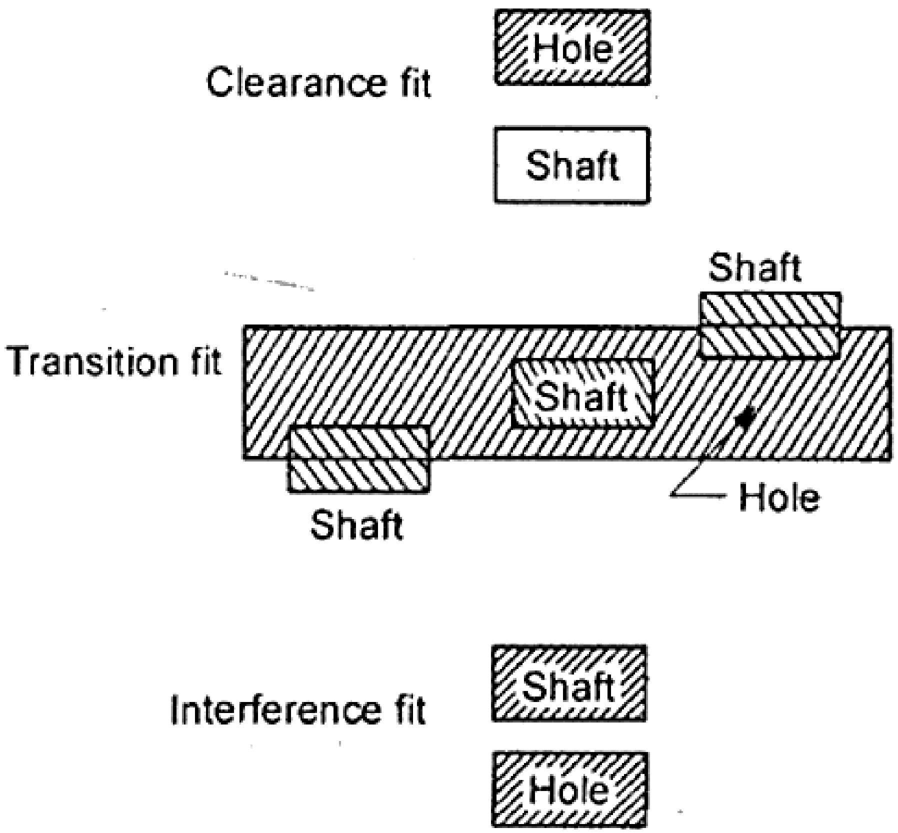
https://mytutorialworld.com/

(Ref:3)

Transition fit

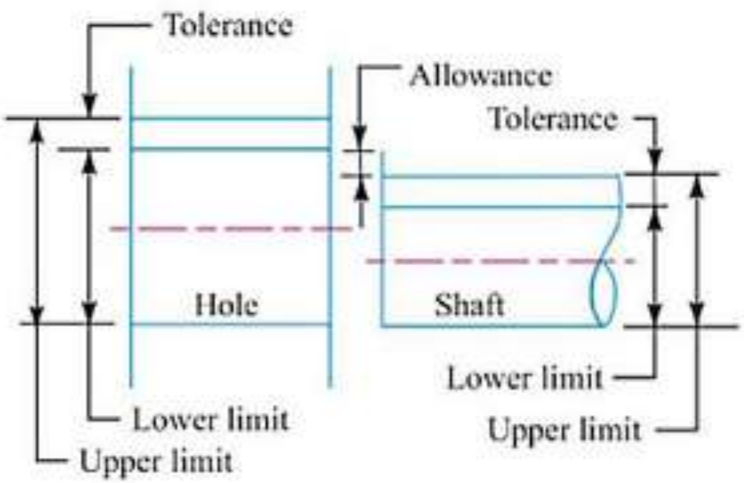
The diameter of the largest permissible hole is greater than the diameter of the smallest shaft and the diameter of the smallest hole is smaller than the diameter Of the largest shaft




Clearance fit
Hole
Shaft
Transition fit
Shaft
Shaft
Shaft
Hole
Interference fit
Shaft
Hole

Allowance

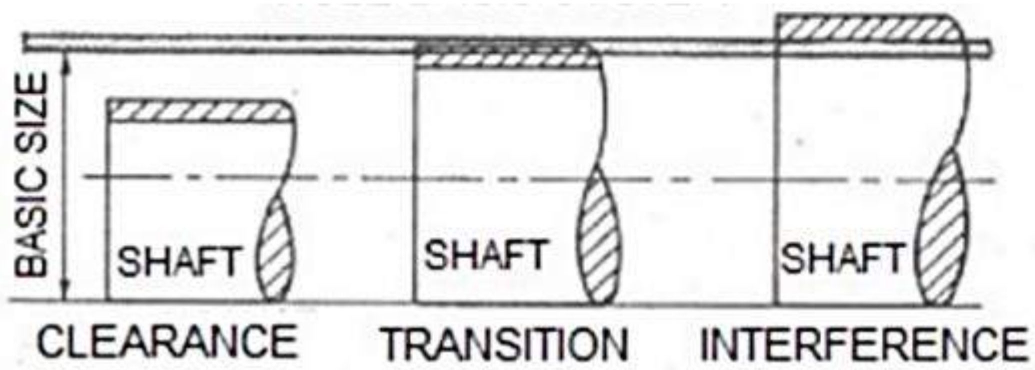
An intentional difference between the maximum material limits of the two mating parts



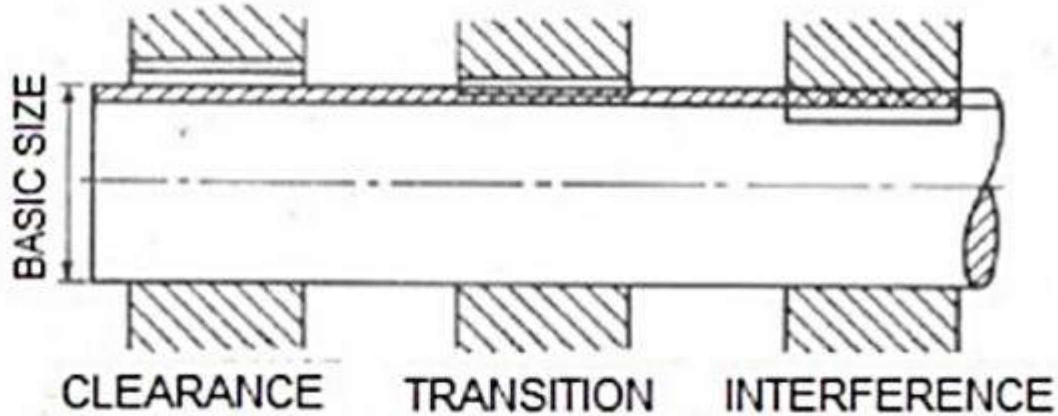
Allowance = Lower limit of hole (LLH) – Higher limit of shaft (HLS)
= LLH - HLS

Allowance can be negative or positive. Positive allowance indicates clearance fit while negative allowance indicates interference fit

Hole and shaft basis system



HOLE BASED SYSTEM
Size of hole is kept constant, shaft size is varied to get different fits.



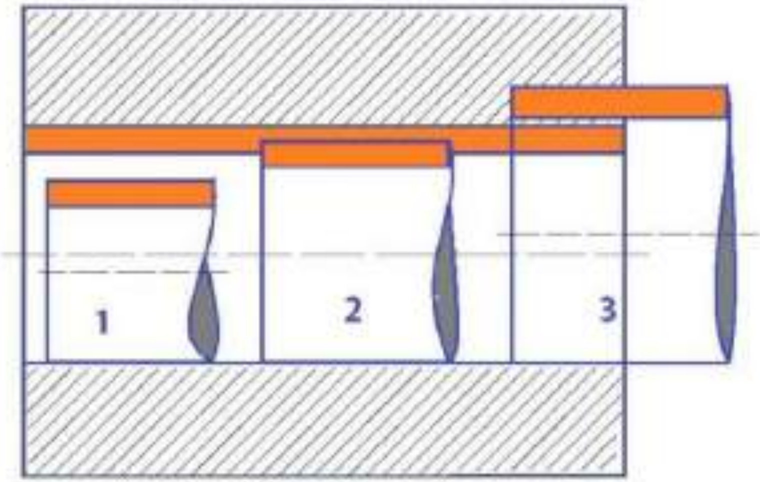
SHAFT BASED SYSTEM
Size of shaft is kept constant, hole size is varied to get different fits.

https://www.rapiddirect.com/blog/types-of-fits/

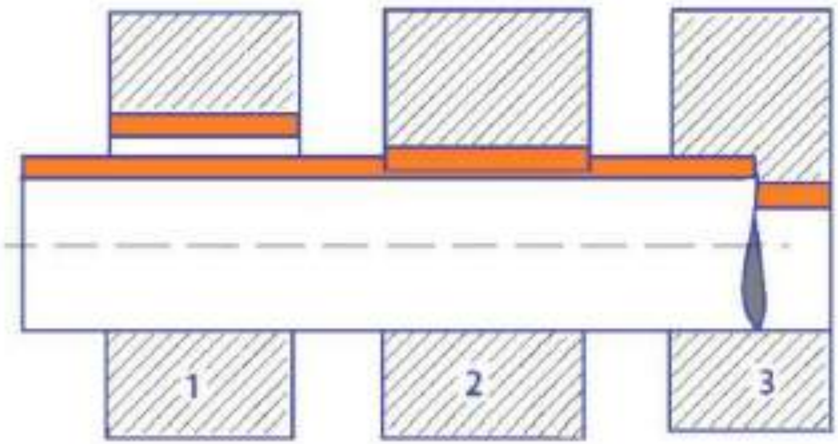
In hole basis system, the fundamental deviation or the lower deviation of the hole is zero, i.e., the lower limit of the hole is the same as the basic size

In shaft basis system, the fundamental deviation or the upper deviation of the shaft is zero, i.e., the higher limit of the shaft is equal to the basic size

(Ref.3)



Hole Basis System



Shaft Basis System

Systems of limits and fits

International organization for standardization specifies the internationally accepted system of limits and fits. Indian standards are in accordance with ISO.

(Ref.3)

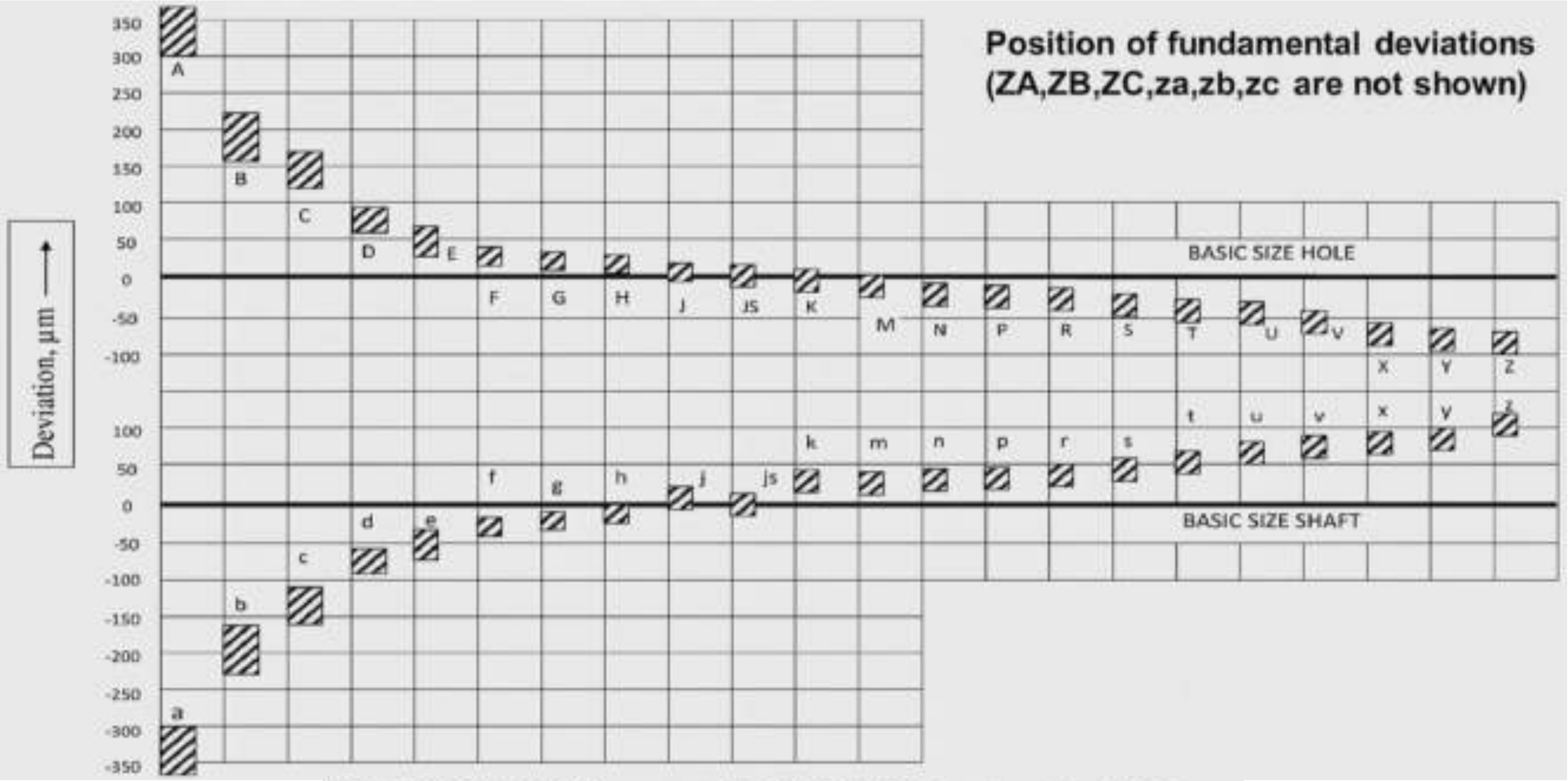
Basic shaft and Basic hole

The shafts and holes that have zero fundamental deviations. The basic hole has zero lower deviation and basic shaft has zero upper deviation

Hole designation: A, B,…, Z, Za, Zb, Zc (Excluding I,L, O, Q, W and adding Js, Za, Zb, Zc) – 25 numbers

Shaft Designation: a, b,…, z, za, zb, zc (Excluding i, l, o, q, w and adding js, za, zb, zc) – 25 numbers

(Ref.4)



LETTER SYMBOLS eg: Ø 30 IT 9 FOR a b c & A B C
Ø 30 IT 7 FOR OTHERS.

(Ref.4)

Formulae for fundamental deviations for shafts sizes upto 500 mm

UPPER DEVIATION (es)	
Shaft Designation	In Microns (for D in mm)
a	$= -(265 + 1.32D)$ for $D \leq 120$;and $= -3.52D$ for $D > 120$
b	$= -(140 + 0.852D)$; for $D < 160$;And $= -1.82D$ for $D > 160$
c	$= -52D^{0.2}$ for $D \leq 40$ $= -(95 + 0.82)$ for $D > 40$
cd	G.M. of values for c and d
d	$= -16D^{0.44}$
e	$= -11D^{0.41}$
ef	G.M. of values for e and f
f	$= -5.5D^{0.41}$
fg	G.M. of values for f and g
g	$= -2.5D^{0.34}$
h	$= 0$

LOWER DEVIATION (ei)	
Shaft Designation	In microns (for D in mm)
j5 to j8	No formula
js	ITx1/2
k4 to k7	$=+ 0.6 \times \sqrt[3]{D}$
k for Grade ≤ 3 and ≥ 4	$=0$
m	$= +(IT7 - IT6)$
n	$= +5D^{0.34}$
p	$= +IT7 + 0$ to 5
r	= geometric mean of values for p and s
s	$= IT8 + 1$ to 4; for $D \leq 50$ $= +IT7$ to $+0.4D$; for $D > 50$
t	$= +IT7 + 0.63D$
u	$= +IT7$ to $+D$
v	$= +IT1 + 1.2525D$
x	$= +IT7 + 1.62D$
y	$= +IT7 + 2D$
z	$= +IT7 + 2.52D$
za	$= IT8 + 3 + 3.152D$
zb	$= +IT9 + 4D$
zc	$= +IT10 + 4D$

(Ref.4)

	Hole	Shaft
Upper limit	ES	es
Lower limit	EI	ei
Tolerance	ES - EI	es - ei

Grade	Formula
IT01	$(0.008D + 0.3)/1000$
IT0	$(0.012D + 0.5)/1000$
IT1	$(0.02D + 0.8)/1000$
IT2	$(\mathrm{IT1})[7i/(\mathrm{IT1})]^{1/4}$
IT3	$(\mathrm{IT2})^2$
IT4	$(\mathrm{IT2})^3$
IT5	$7i$
IT6	$10i$
IT7	$16i$
IT8	$25i$
IT9	$40i$
IT10	$64i$
IT11	$100i$
IT12	$160i$
IT13	$250i$
IT14	$400i$
IT15	$640i$
IT16	$1000i$

https://www.meadinfo.org/2009/05/international-tolerance-grades-itol-to.html

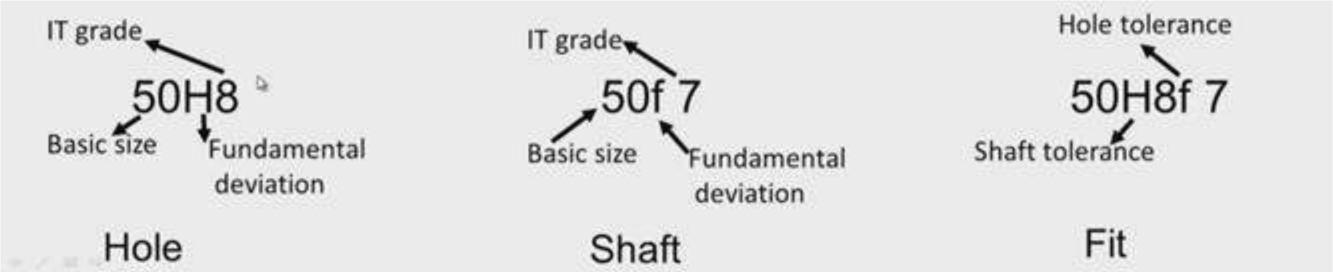
Diameter steps in mm

0-3, 6-10, 18-30, 30-50, 50-80, 80-120, 120-180, 180-250, 250-315, 315-400,400-500

$$D = \sqrt{D_1 D_2}$$

$$i = 0.45 \times \sqrt[3]{D} + 0.001 \times D$$

(Ref.4)



IT grade
50H8
Basic size
Fundamental deviation
Hole
IT grade
50f 7
Basic size
Fundamental deviation
Shaft
Hole tolerance
50H8f 7
Shaft tolerance
Fit

(Ref.4)

Problem

Calculate the limits of tolerance and allowance for a 25 mm shaft and hole pair designated H_8d_9

Geometric mean = D = $\sqrt{18\ X\ 30}$ = 23.2 mm

i = 0.45 $\sqrt[3]{D}$ + 0.001D = 1.3 microns

Hole

For 'H' hole fundamental deviation is zero

For hole quality 8, fundamental tolerance = 25i

Therefore, 25i = 25x1.3 =32.5 microns = 0.0325 mm

Hole limits are, LL = 25 mm and HL = 25+0.0325 = 25.0325 mm = 25.033 mm

Shaft

For 'd' shaft fundamental deviation is $= -16\, D^{0.44}$

$= -16\, (23.2)^{0.44}$

$= -65$ microns $= 0.065$ mm

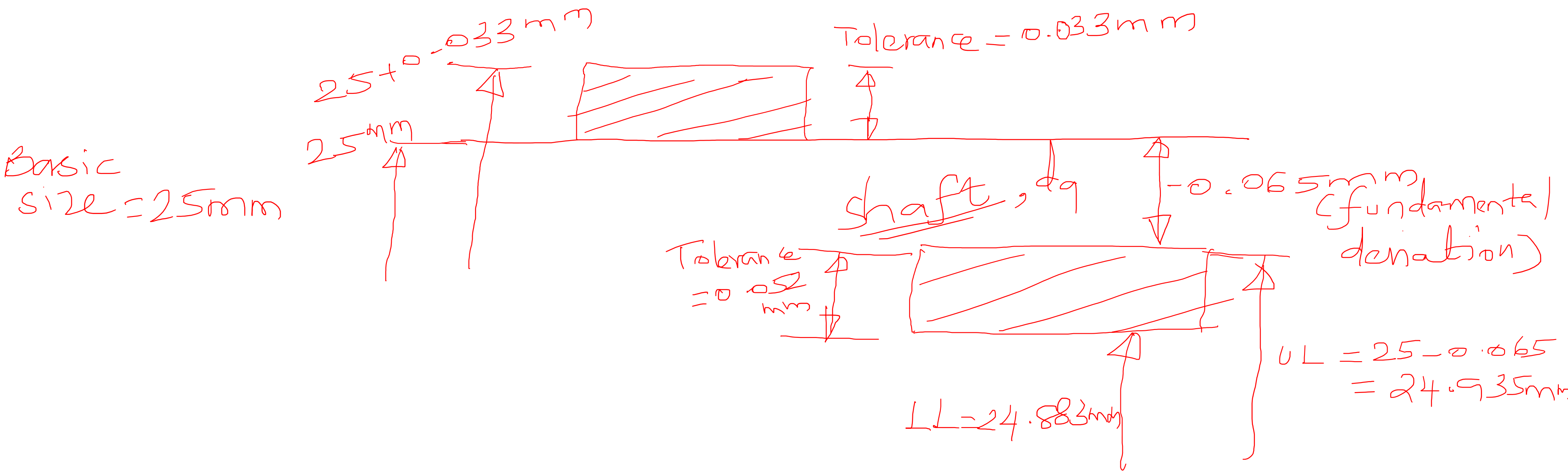
For shaft quality 9, fundamental tolerance = 40i

Therefore, 40i = 40x1.3 = 52 microns = 0.052 mm

Shaft limits are, HL = 25 – 0.065 = 24.935 mm

and LL = 24.935-0.052 = 24.883 mm

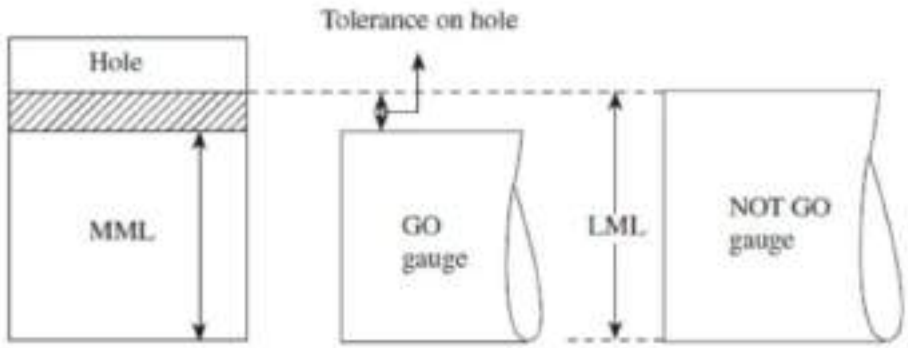
Hole, H8


25+0.033mm
Tolerance = 0.033mm
Basic size = 25mm
25mm
shaft, d9
-0.065mm (fundamental deviation)
Tolerance = 0.052 mm
UL = 25-0.065
= 24.935mm
LL=24.883mm

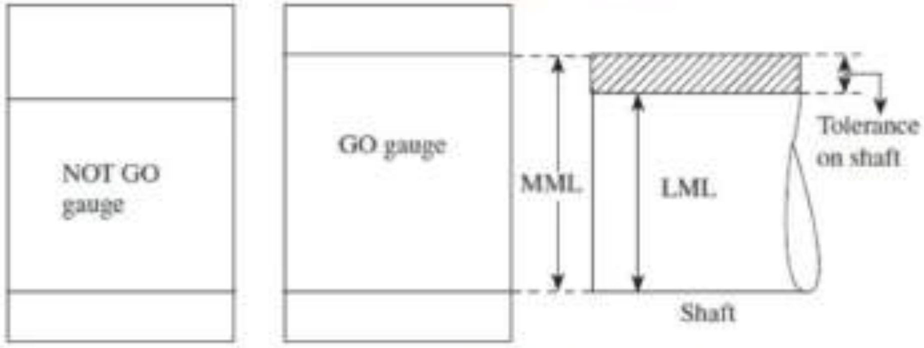
Limit Gauging

- Limit gauges are used to ensure that the components are lie within the permissible limits.
- Limit gauges will nor determine the actual sizes.
- The gauges required to check the dimensions of the components correspond to two sizes (Maximum and Minimum limits).
- These are called Go Gauges and No-go Gauges.

(Ref.3)



Metal limits for hole gauging



Metal limits for shaft gauging

https://www.wikiwand.com/en/Go/no_go_gauge

https://www.indiamart.com/proddetail/

Taylor’s Principle

States that the Go gauge is designed to check maximum metal condition, that is LLH and HLS.

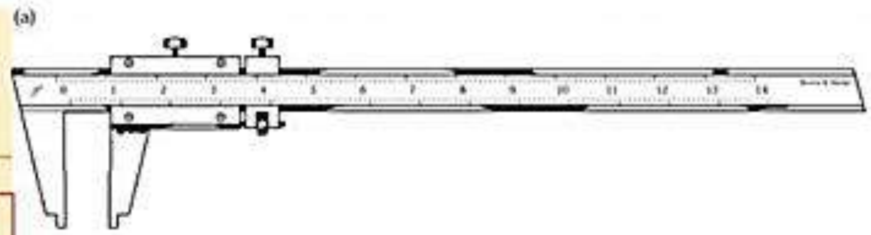
It should also simultaneously check as many related dimensions as possible (roundness, location).

The No-go gauge is designed to check minimum metal condition, that is HLH and LLS. It should check only one dimension at a time.

(Ref.3)

Linear measuring instruments

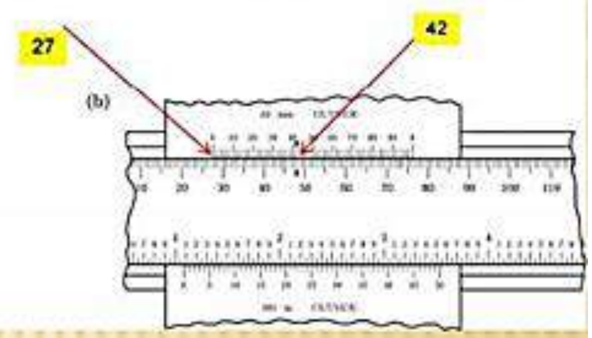
CALIPER AND VERNIER



(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 divisionx0.02=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.**

http://home.iitk.ac.in/~nsinha/Metrology.pdf

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 μin. (1.25μm). It is generally easier to read dimensions on this instrument compared to the analog micrometer.

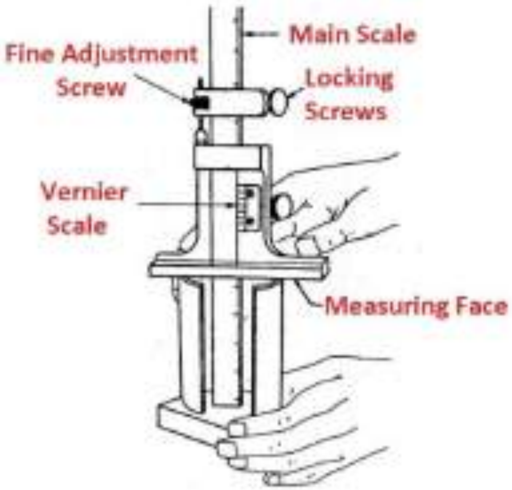
http://home.iitk.ac.in/~nsinha/Metrology.pdf

Vernier Height gauge

https://www.itm.com/

Vernier depth gauge

https://shop.mitutoyo.eu/



www.theengineerspost.com

Slip gauges

(1) Set M 45 (Normal set)			(2) Set M 87 (special set)		
Range (mm)	Steps (mm)	No. of blocks	Range (mm)	Steps (mm)	No. of blocks
1.001 – 1.009	0.001	9	1.001 – 1.009	0.001	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 – 90	10	9
10 – 90	10	9	1.005	—	1

https://www.yourarticlelibrary.com/metrology/

References

1. Jain R.K "Engineering Metrology", Khanna Publishers, 21 st edition, 2005.
2. Gupta. I.C., "Engineering Metrology", 7th edition, Dhanpatrai Publication, 2012.
3. https://nptel.ac.in/courses/112/104/112104250/
4. https://nptel.ac.in/courses/112/106/112106179/

SVCE
Sri Venkateswara College of Engineering
Autonomous - Affiliated to Anna University

ME18501- Metrology and Quality Control (R2018)

V semester
Academic Year 2021-22

UNIT-II
ANGULAR AND FORM MEASUREMENTS

Angular Measurement - Angular measuring instruments – Types – Bevel protractor, Spirit levels, Sine bar – Sine center – Sine table – Angle Dekkor - Autocollimator. Form Measurement - Measurement of surface finish – Surf Tester. Screw thread measurement – Minor diameter & Effective diameter – Two wire method. Gear measurement - Gear terminology - Errors in gears – Pitch & Tooth thickness measurement - Parkinson's gear tester.

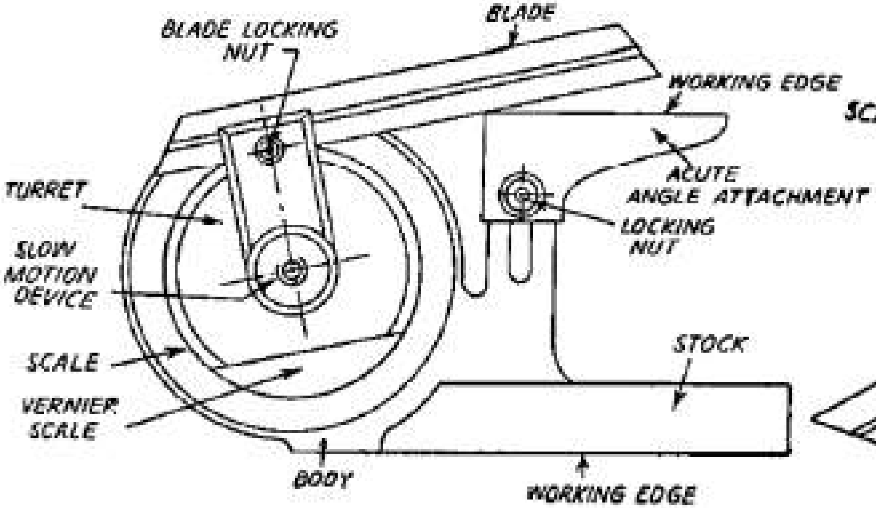
Angle Measuring Instruments types

- Bevel protractor
- Spirit levels
- Sine bar
- Sine center
- Sine table
- Angle Dekkor
- Autocollimator

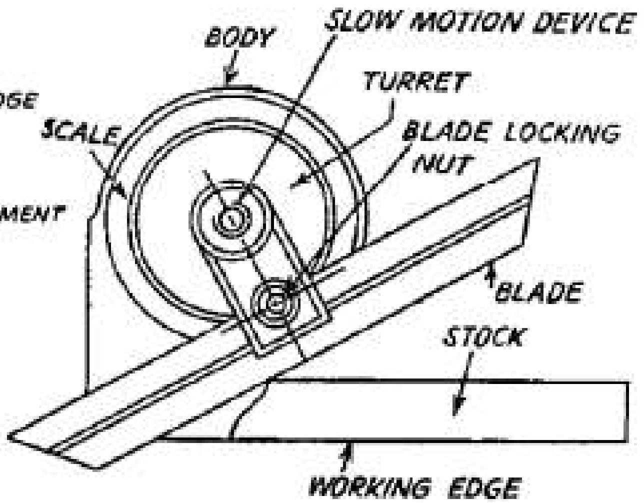
Bevel protractor

Angle – Space between two intersecting Lines or surfaces.

www.craftsmanspace.com/knowledge/vernier-bevel-protractor.html



Mechanical Bevel Protractor with Vernier and acute angle attachment.



Mechanical Bevel Protractor without Vernier and acute angle attachment.

Spirit Level

www.measurementsolutionsinc.com/

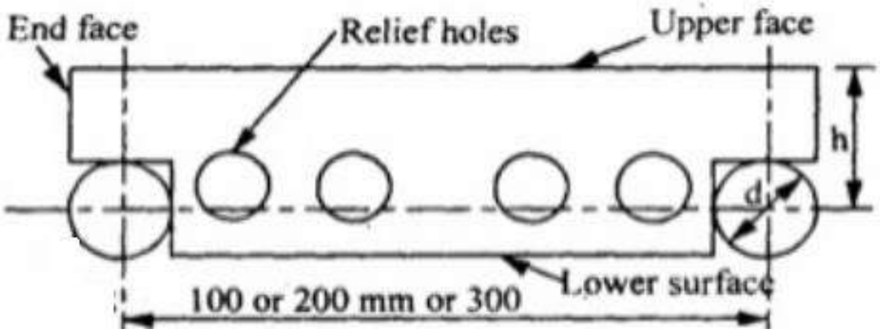
www.leveldevelopments.com/products/vials/plastic-cylindrical-vials/

Angle of tilt $\theta = l/R$

l – Distance by which graduations are separated

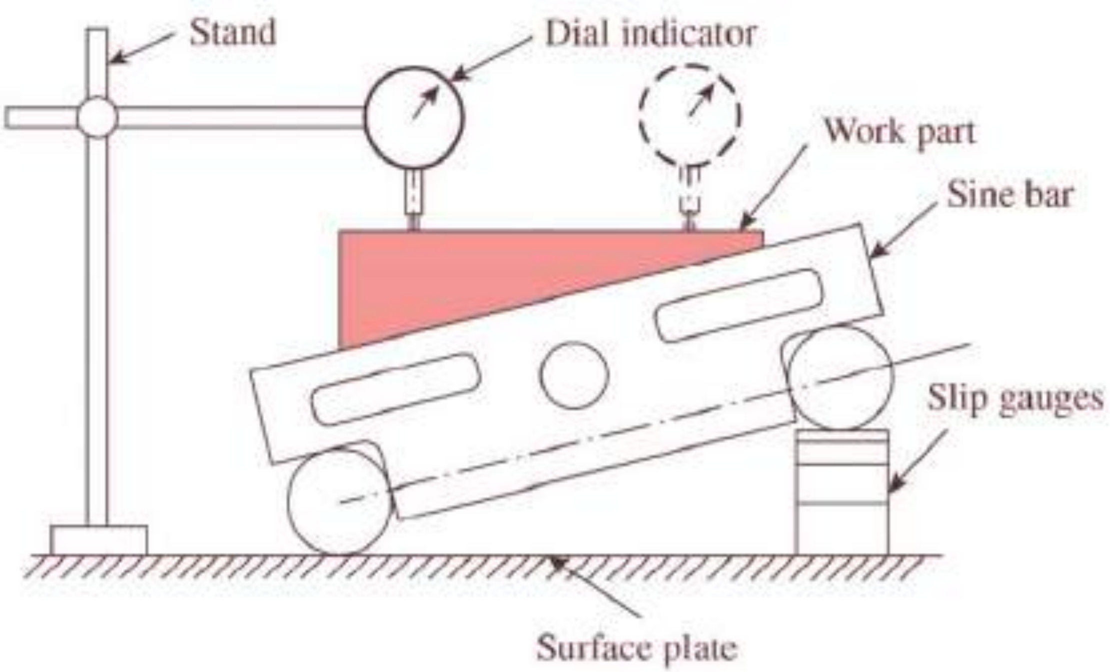
R- Radius of the tube

Sine bar

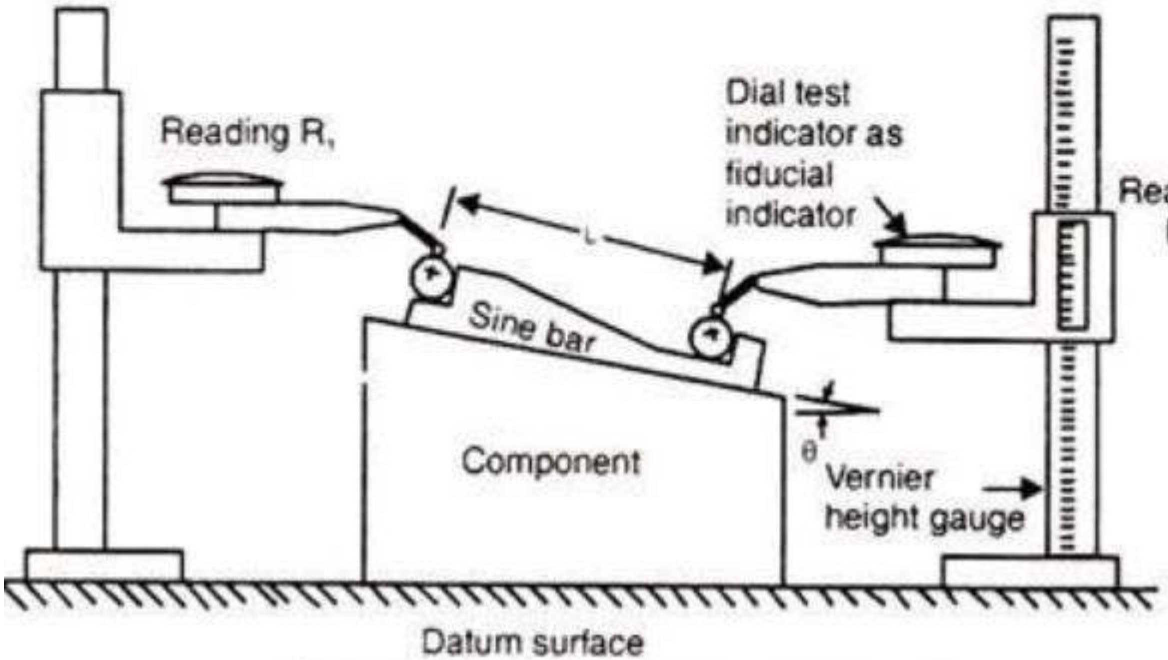


- Made from high carbon, high chromium, corrosion resistant steel.
- Used to measure angles accurately

Principle of sine bar



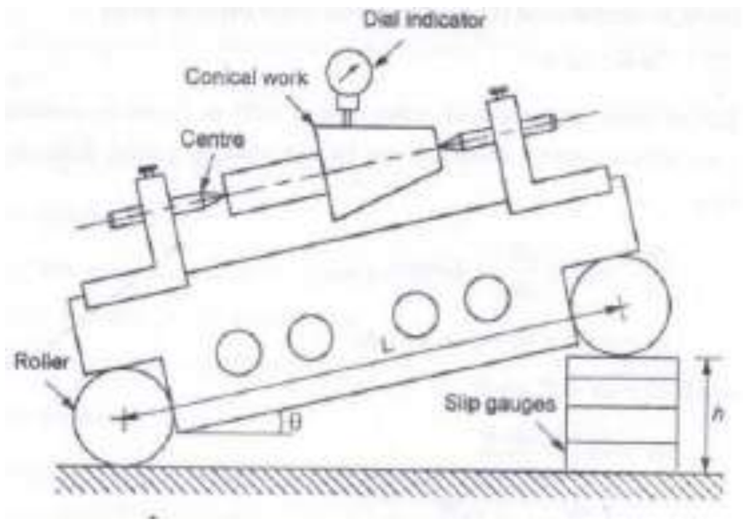
http://site.iugaza.edu.ps/



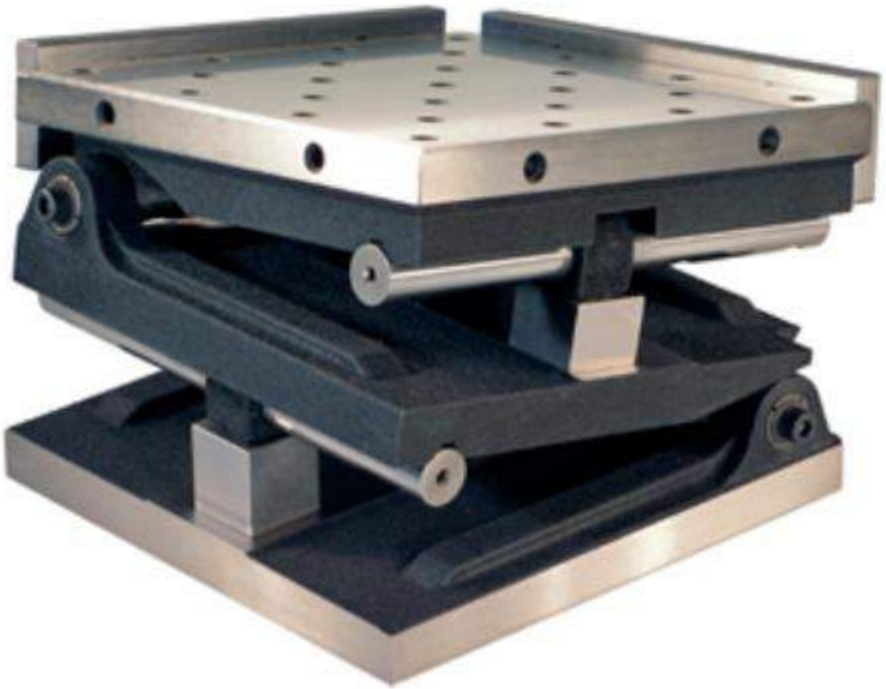
Use of the sine bar (large component).

Sine Center

https://dir.indiamart.com/impcat/sine-center.html



Sine Table

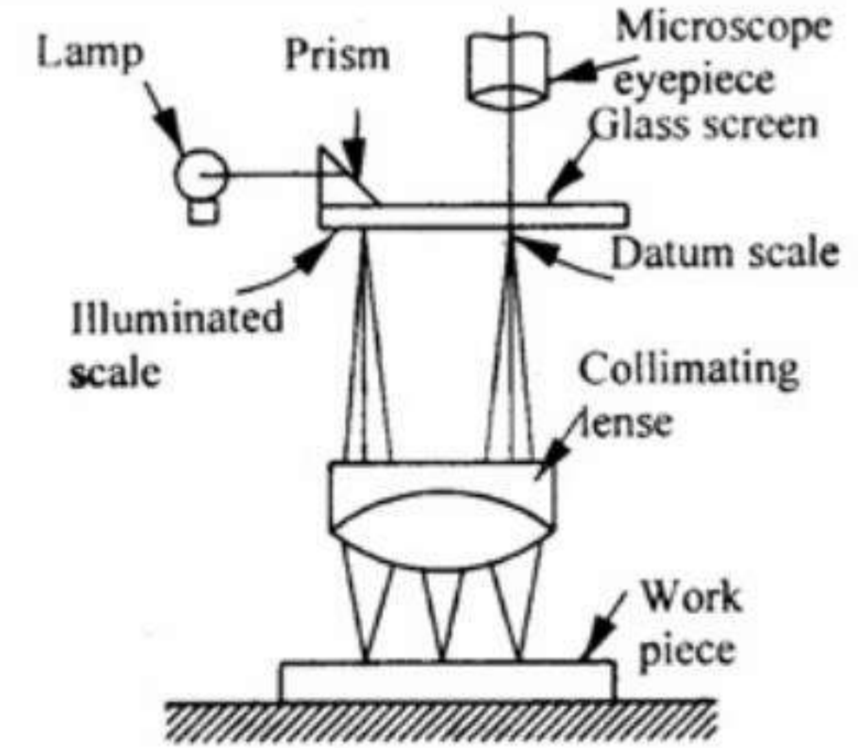


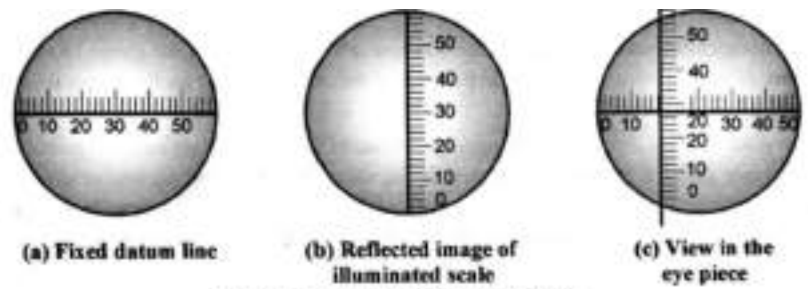
https://www.subtool.com/st/a-sp_master-sine_compound_sine_plates.html

Limitations of sine bar

- Accuracy is limited by measurement of center distance of two precision rollers.
- Devices operating on the sine principle are fairly reliable at angles less than 15^0 but increasingly inaccurate as the angle increases.
- Sine bars become impractical and inaccurate as the angle exceeds 45^0.

Angle dekkor





View in the eyepiece of angle dekkor

Uses of Angle Dekkor

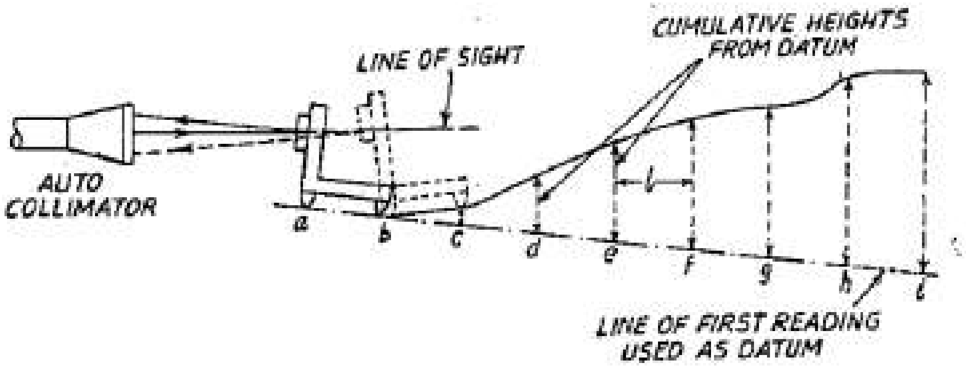
(i) Measuring angle of a component.

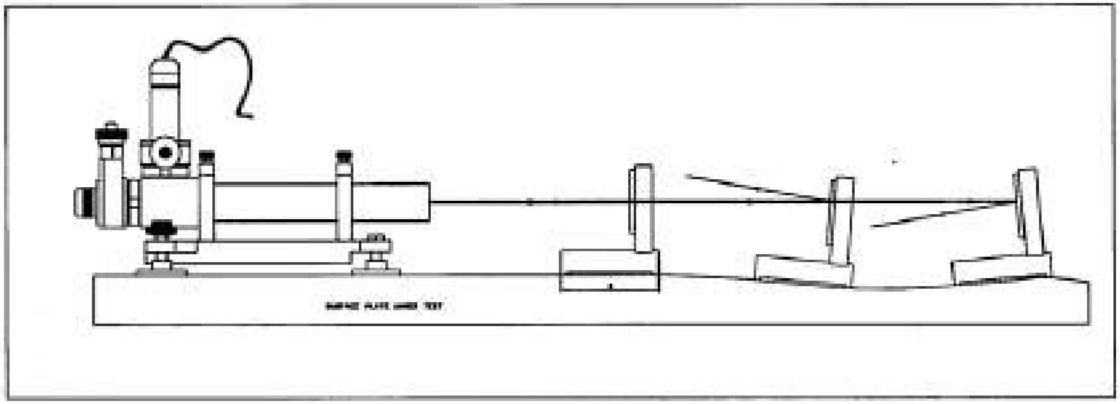
(ii) Checking the slope angle of a V-block.

(iii) To measure the angle of cone or Taper gauge.

https://www.jlabexport.com/angle-dekkor

Auto collimator





Position of the reflector	Position of the reflector (mm)	Micrometer reading (sec)	Difference in reading (sec)	Angular tilt θ (deg)	Level (X) $X = 10*\tan\theta*10^3$ (µm)
1	0				
2	10				
3	20				
4	30				
5	40				

Form measurement -Surface finish

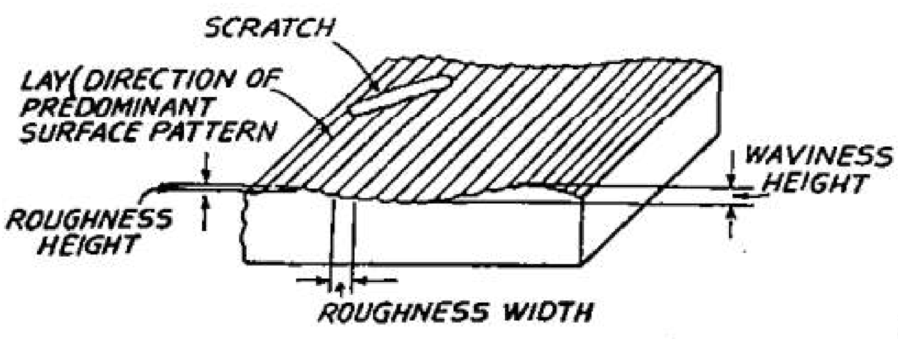
https://mediaserver.responsesource.com/press-release/81679/5618fi1h-performance-superfinish.jpg

https://www.amazon.in/Generic-Brake-Electric-Leather-Scooter/dp/B08263TR4V

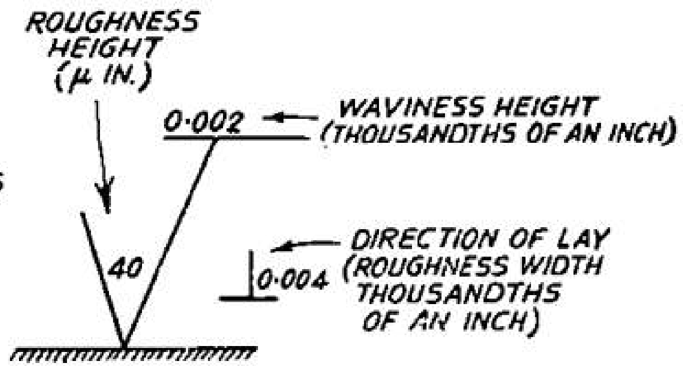
Surface Roughness

Surface roughness is defined as the irregularities which are inherent in the production process.(e.g. cutting tool or abrasive grit). Roughness It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.

https://www.taylor-hobson.com/resource-center/blog/2019/october/what-is-surface-roughness



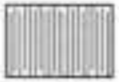
Terms for surface roughness.

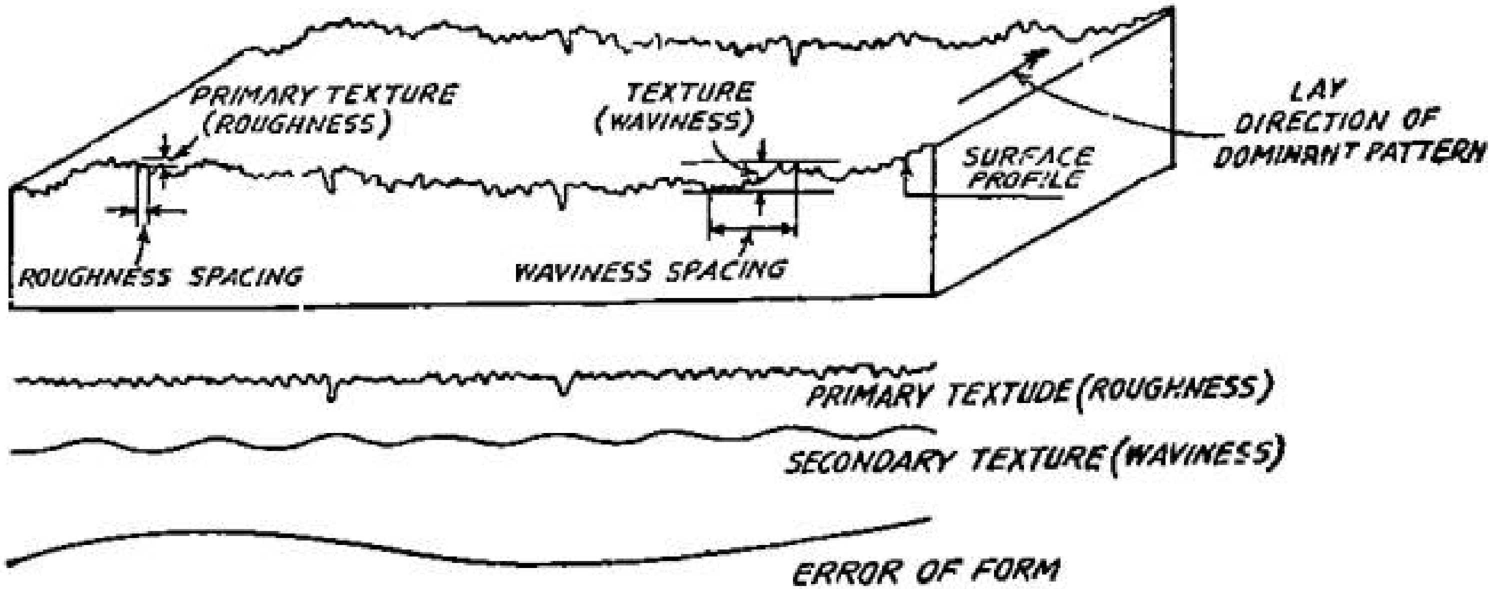


Representation of surface finish.

(Ref:1)

Types of lay

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.



Terminology for surface roughness.

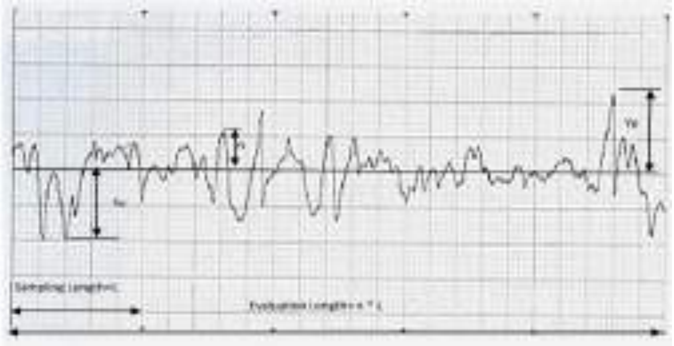
(Ref:1)

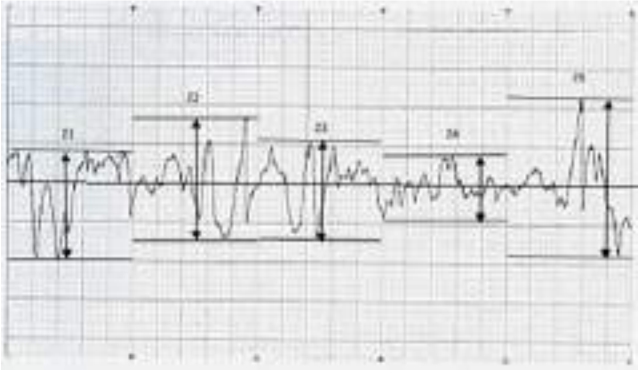
Order of irregularities

Order	Irregularities arise due to...
First	Inaccuracies in machine tool. i.e. straightness in guideways, deformation of work, weight of material etc.
Second	Vibrations in machine. i.e. due to cutting forces
Third	Human errors in machining. i.e. imperfect speed/feed/depth of cut.
Fourth	Rupture of the material during separation from already finished surface of the workpiece.

Form Measurement

Surface roughness tester

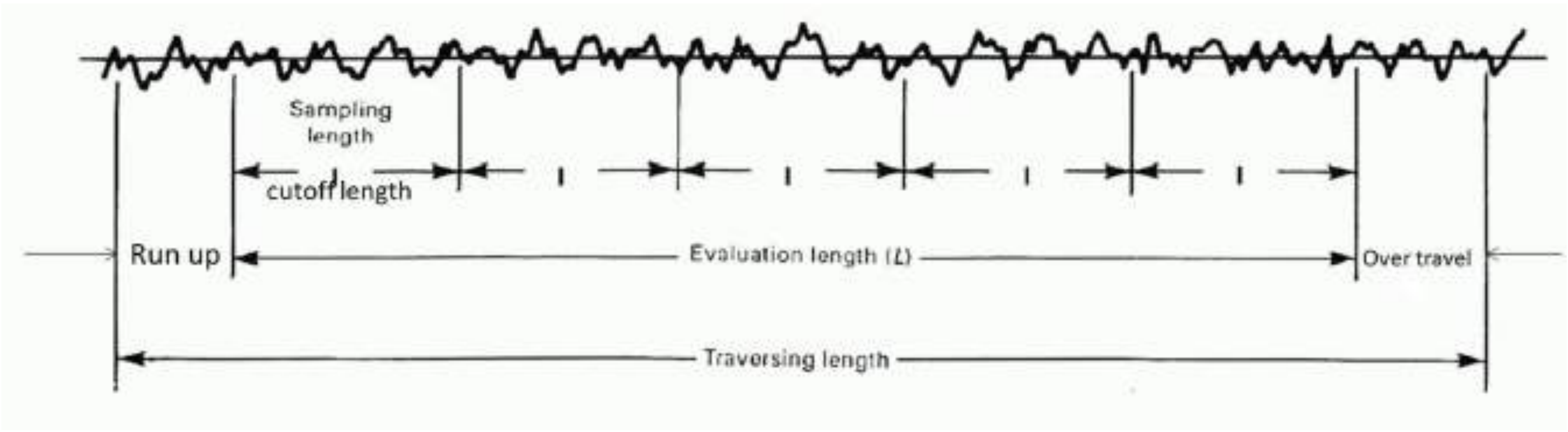




Evaluation length = 1.25 mm
Sampling length = 0.25 mm

Measured surface roughness parameters : R_a, R_t, and R_z

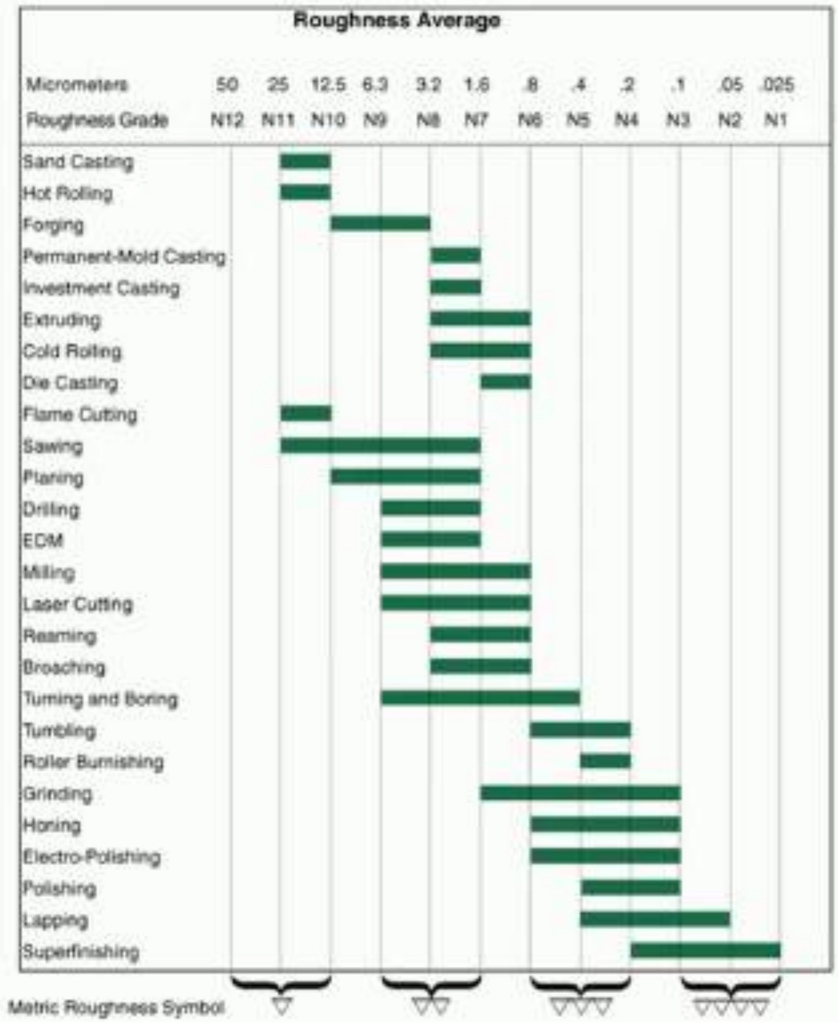
Surface profile measurement lengths



Equivalent surface roughness symbols

Roughness values R_a *µm*	*Roughness grade number*	*Roughness grade symbol*
50	N12	∼
25	N11	▽
12.5	N10	
6.3	N9	▽▽
3.2	N8	
1.6	N7	
0.8	N6	▽▽▽
0.4	N5	
0.2	N4	
0.1	N3	▽▽▽▽
0.05	N2	
0.025	N1	

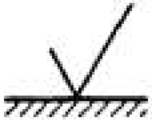
(Ref:4)


Roughness Average
Micrometers 50 25 12.5 6.3 3.2 1.6 .8 .4 .2 .1 .05 .025
Roughness Grade N12 N11 N10 N9 N8 N7 N6 N5 N4 N3 N2 N1
Sand Casting
Hot Rolling
Forging
Permanent-Mold Casting
Investment Casting
Extruding
Cold Rolling
Die Casting
Flame Cutting
Sawing
Planing
Drilling
EDM
Milling
Laser Cutting
Reaming
Broaching
Turning and Boring
Tumbling
Roller Burnishing
Grinding
Honing
Electro-Polishing
Polishing
Lapping
Superfinishing
Metric Roughness Symbol

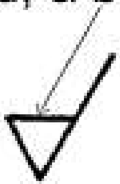
(Ref:4)

INDICATION OF SURFACE TEXTURE

- The **basic symbol** consists of two legs of **unequal** length inclined at approximately **60 degrees** to the line representing the considered surface
- The symbol must be represented by thin line



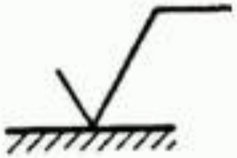
- If the removal of material by **machining** is required, a bar is added to the basic symbol



(Ref:4)

- If the **removal of material is not permitted**, a circle is added to the basic symbol.

- When **special surface characteristics** have to be indicated, a line is added to the longer arm of basic symbol.



(Ref:4)

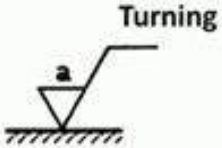
- The value of **roughness** is added to the symbols

a- surface roughness value

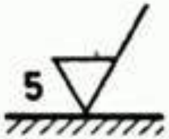
1. Roughness **a** obtained by any production process
2. Roughness **a** obtained by machining
3. Roughness **a** obtained without removal of material

(Ref:4)

- If it is required that the **surface texture** be produced by a **particular production method**, this method is indicated in plain language on the extension of the longer arm of the symbol



- **Indication of machining allowance:** Where it is necessary to specify the value of the machining allowance, this is indicated on the **left of the symbol**. This value shall be expressed in **millimeters**.



(Ref:4)

Symbol		
Removal of Material by machining is		
optional	*obligatory*	*prohibited*
3.2 or N8	3.2 or N8	3.2 or N8
6.3 1.6 or N9 N7	6.3 1.6 or N9 N7	6.3 1.6 or N9 N7

(Ref:4)

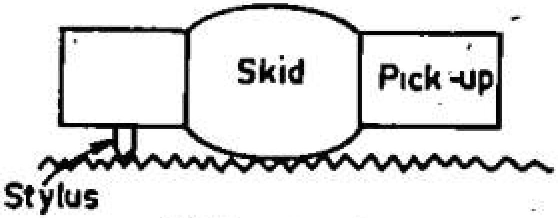
Methods of measuring surface finish

- Comparison methods
- Direct instrument measurements

  -Profilometer

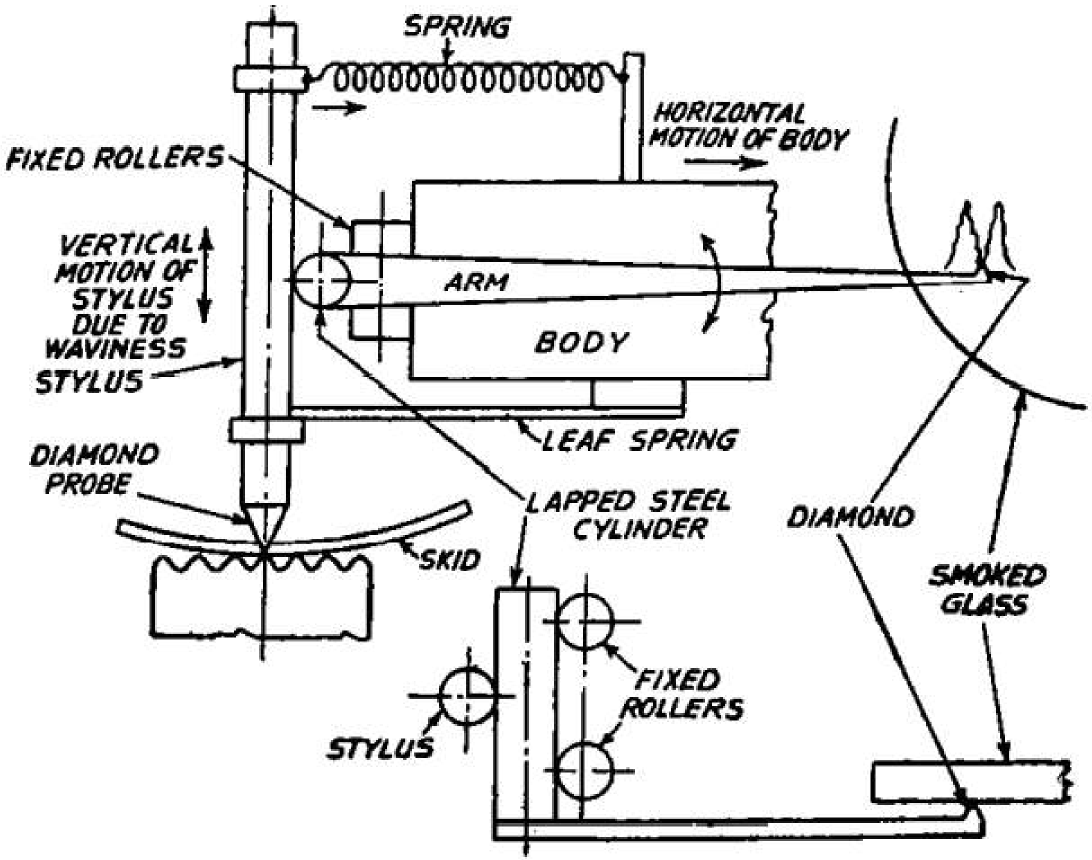
  -Tomlinson surface meter

  -Taylor-Hobson Talysurf



Skid and stylus.

(Ref:4)



Tomlinson Surface Meter.

(Ref:4)

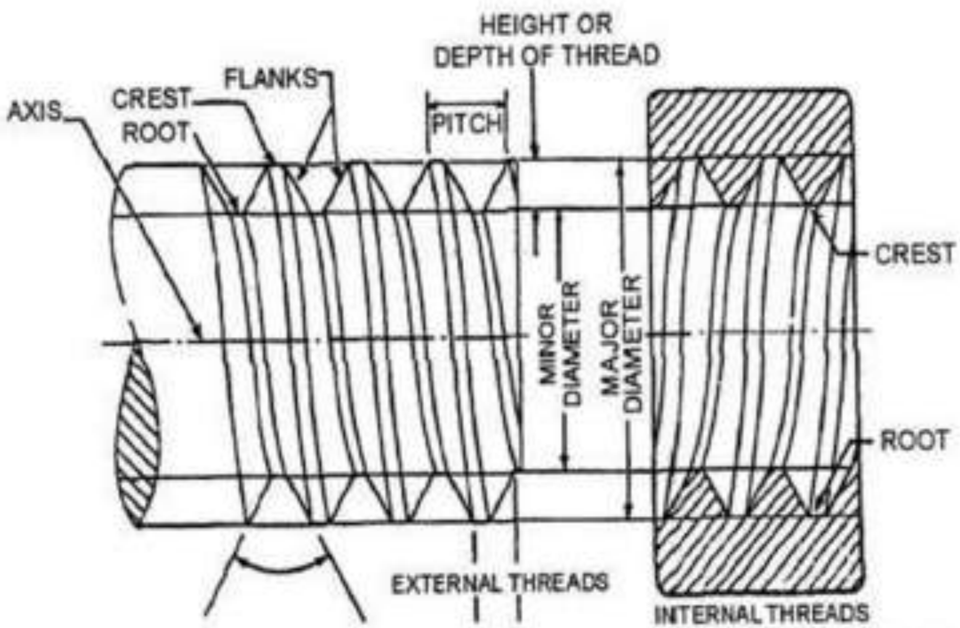
Reasons for controlling surface texture

- To improve service life
- To improve fatigue resistance
- To reduce wear
- To have close dimensional tolerance
- To reduce corrosion

(Ref. 5)

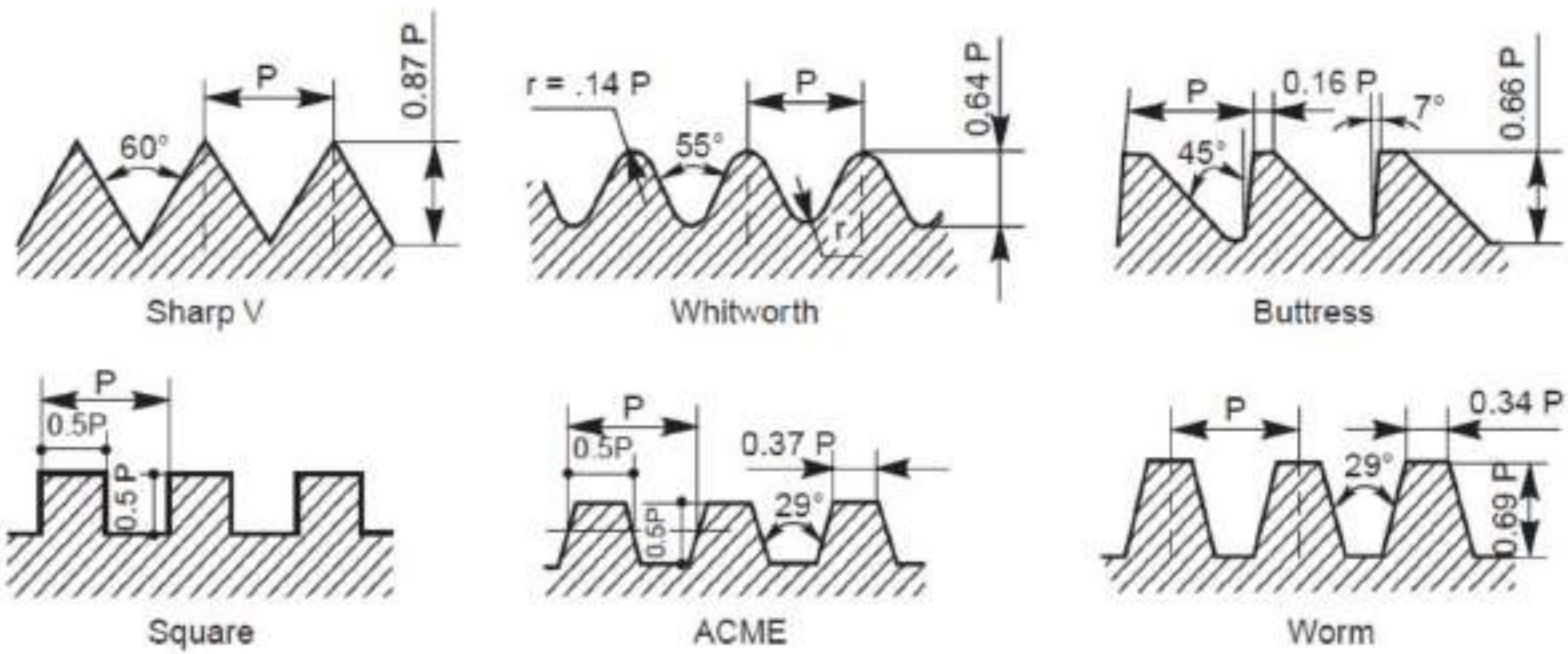
Screw thread measurement

Screw threads are employed to fasten two components with the help of nuts or two transmit power and motion (Lead screw)



http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2476

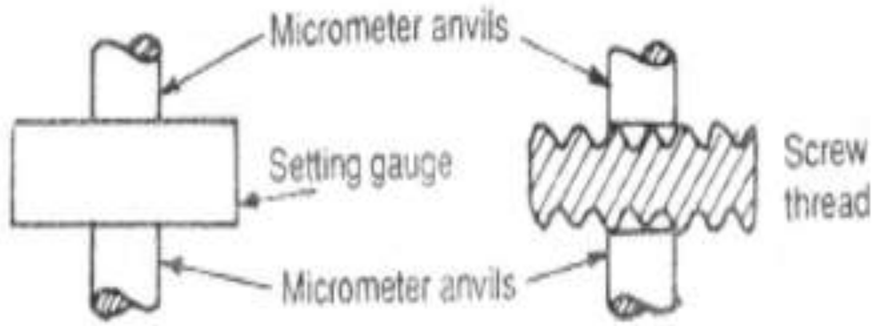
(Ref. 5)



P
0.87 P
60°
Sharp V
r = .14 P
P
0.64 P
55°
r
Whitworth
P
0.16 P
7°
0.66 P
45°
Buttress
P
0.5P
0.5 P
Square
P
0.5P
0.37 P
29°
0.5P
ACME
P
0.34 P
29°
0.69 P
Worm

Floating carriage micrometer

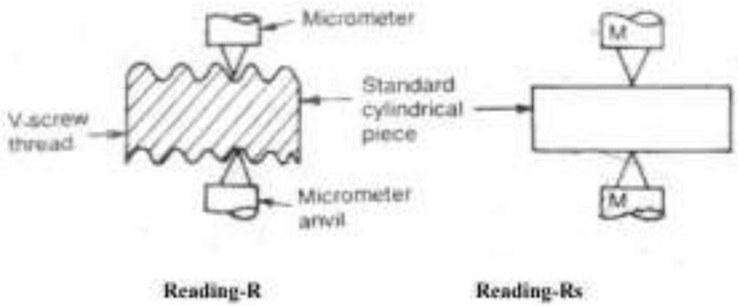
Measurement of Major Diameter (D1):



Reading –Rs **Reading-R**

Major Diameter = D + (R-Rs)

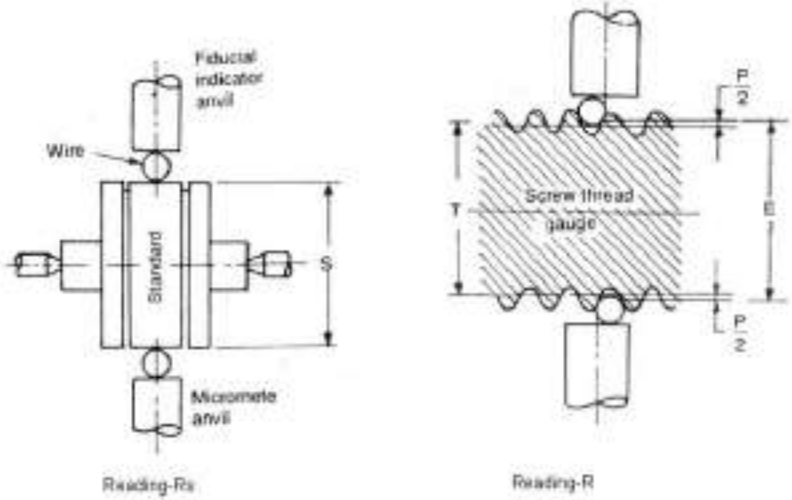
Measurement of Core or Minor Diameter (D2):



Minor Diameter (E) = D + (R-Rs)

Minor Diameter (T) = M.D – (2*0.6495 P)

Measurement of Effective Diamete (D_2):



Effective Diameter (E) = D + (R-Rs)+Pvalue
Effective Diameter (T) = M.D – (0.6495 P)

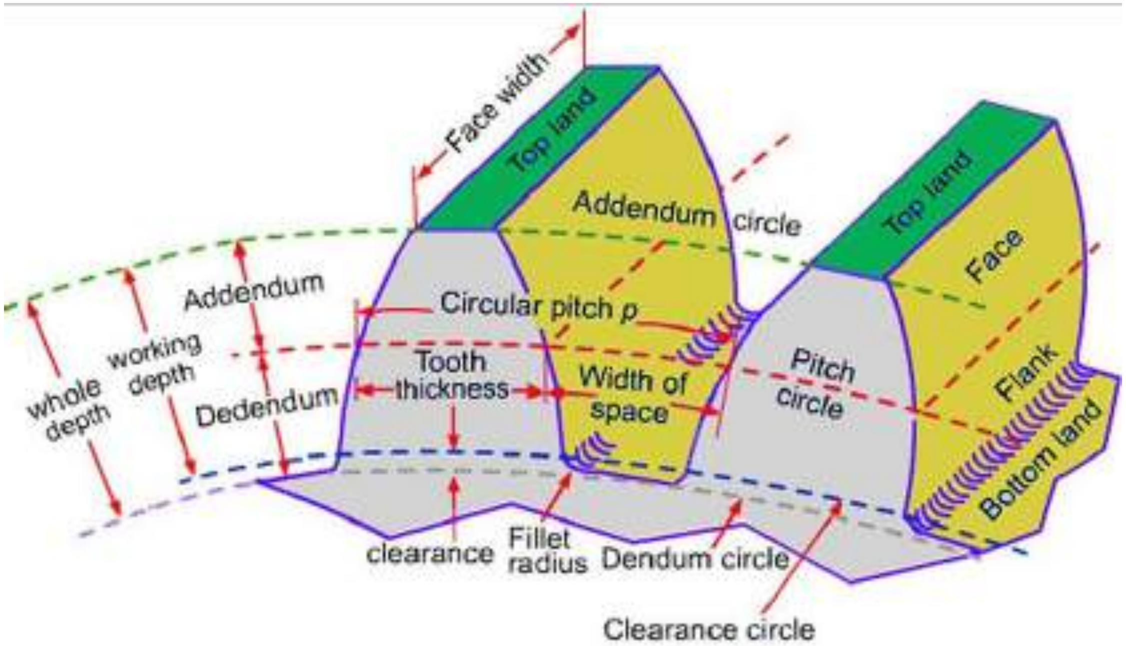
Prism selection chart

	Suitable for Screws		
Designating Size	Unified Whitworth Threads Per Inch.	Metric Pitch in mm.	B.A. Number
A	40	0.5 to 1.25	9 to 12
B	40 to 28	1.5 to 2.25	3 to 8
C	26 to 14	2.5 to 4.00	0 to 2
D	12 to 4	4.5 to 6.00	--

Chart for wire selection to measure effective diameter

[illegible]	ISO metric Pitches (in mm)	
	Pitch P	[illegible]
1	2	3
0.17	0.25	0.047
	0.30	0.090
[illegible]	-	-
[illegible]	0.35	[illegible]
[illegible]	0.40	[illegible]
[illegible]	0.45	[illegible]
	0.50	0.143
[illegible]	[illegible]	0.165
	-	-
[illegible]	-	-
	-	-
0.455	0.70	0.151
	0.75	[illegible]
	0.80	[illegible]
[illegible]	0.90	0.249
	-	-
[illegible]	1.00	0.246
[illegible]	1.25	0.358
	-	-
	-	-
	-	-
0.895	1.50	[illegible]
	-	-
1.10	1.75	0.418
	-	-
	-	-
[illegible]	2.00	0.382
	-	-
[illegible]	2.50	0.515
	-	-
[illegible]	3.00	[illegible]
	3.50	[illegible]
2.55	4.00	[illegible]
	4.50	[illegible]
[illegible]	5.00	[illegible]
	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
	-	-
[illegible]	-	-

Gear tooth terminology



en.wikiversity.org/wiki/Gears

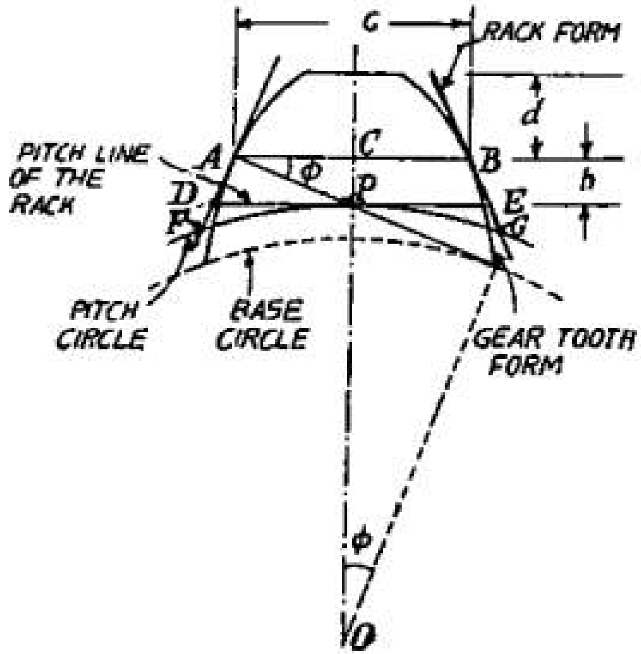
Module (m) = **D/ (T+2)**

Chordal width (W) = **mT sin [90/T]**

Chordal Addendum (H) = **m+mT/2 [1-cos (90/T)]**

Where D- Outside Diameter of Gear in 'mm'
T- Number of teeth on the gear to be tested

Constant cord method

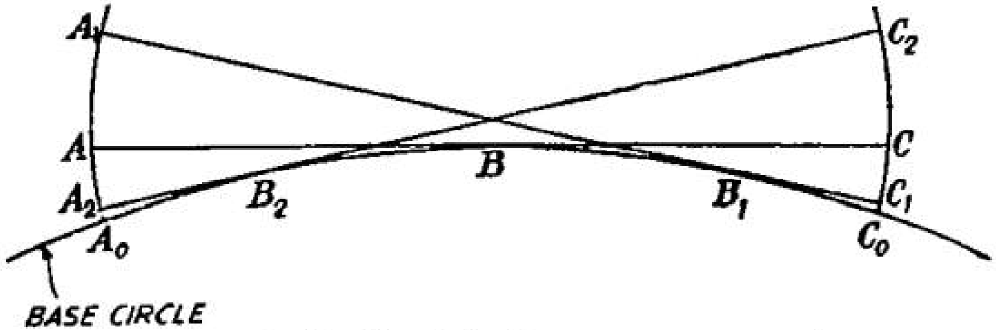


$$c = \text{constant chord} = 2AC = (\pi/2)\, m \cos^2 \phi$$

$$d = m\left(1 - \frac{\pi}{4}\cos\phi \sin\phi\right)$$

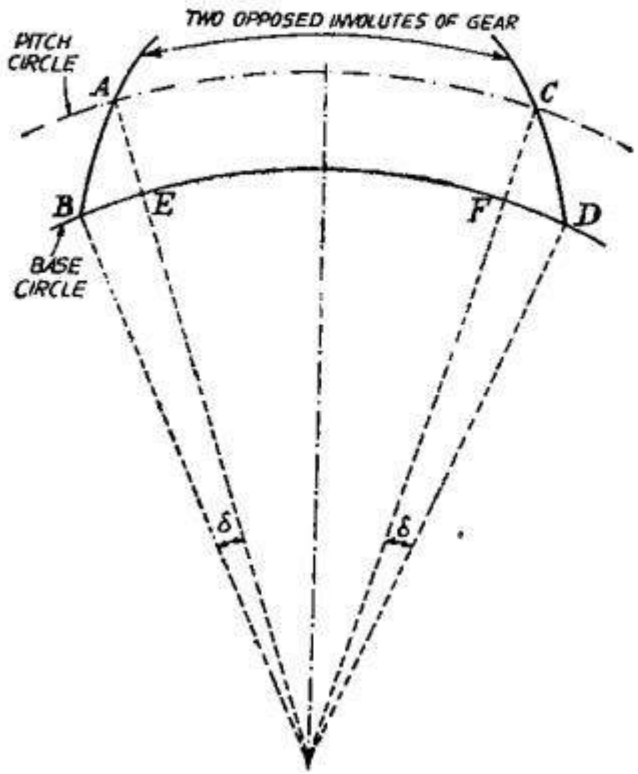
(Ref. 1)

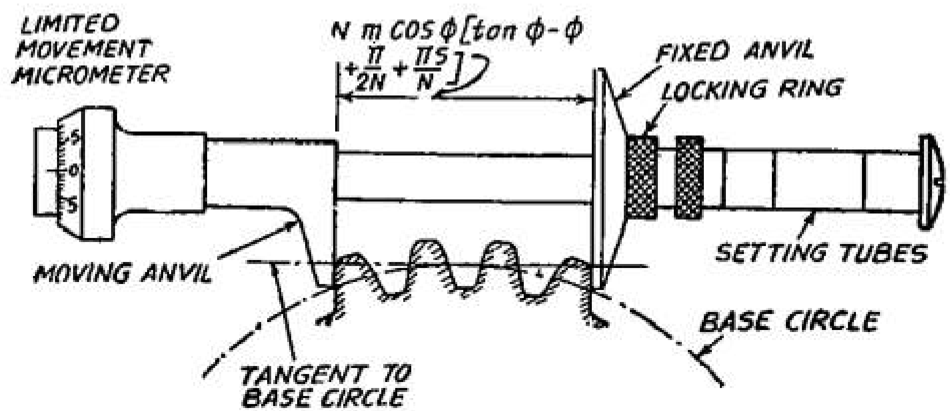
Base Tangent Method



Generation of pair of involutes by a common generator.

(Ref. 1)



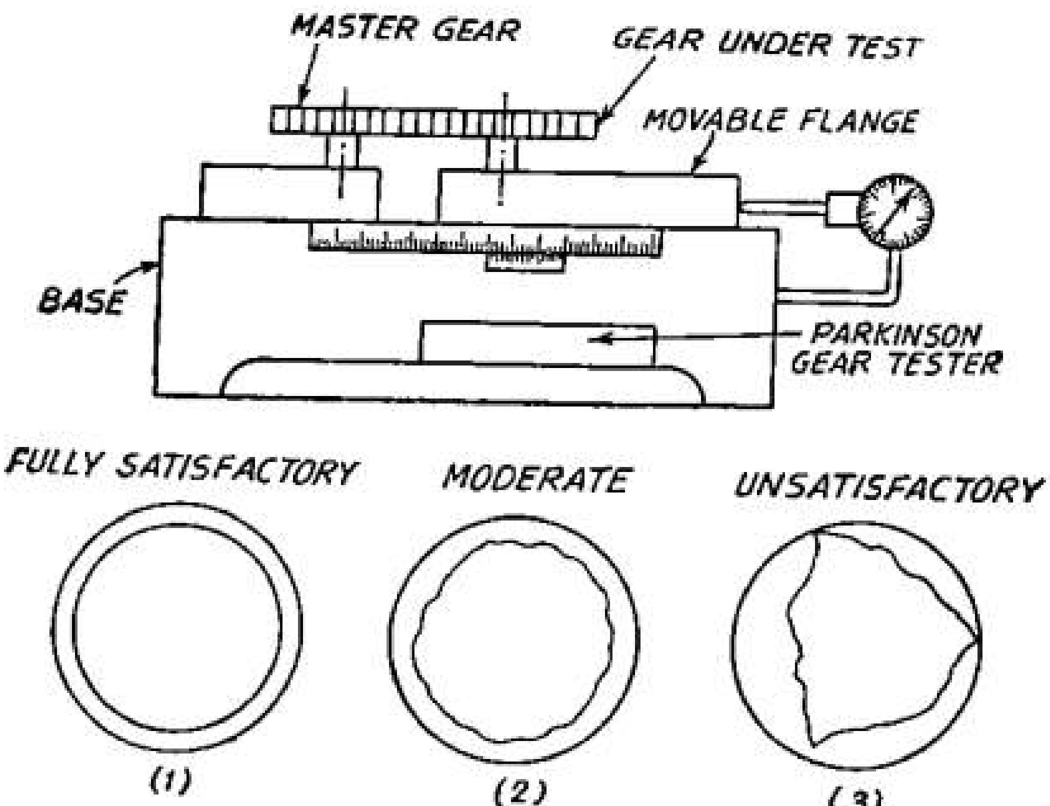


'David Brown' Base Tangent Comparator.

$$Nm \cos\phi \left[\tan\phi - \phi - \frac{\pi}{2N} + \frac{\pi S}{N} \right]$$

(Ref. 1)

Parkinson gear tester



(Ref. 1)

Sources of errors in gear manufacturing

Errors in Reproducing method

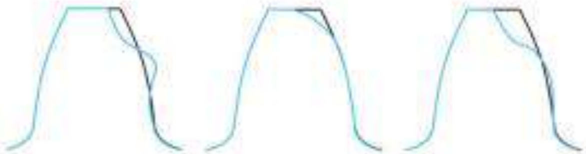
1. Incorrect profile on the cutting tool
2. Incorrect positioning the tool in relation to the work
3. Incorrect indexing of the blank

Errors in Generation method

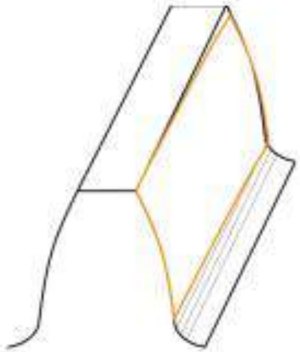
1. Errors in the manufacturing of the cutting tool
2. Errors in positioning the tool in relation to the work
3. Errors in relative motion of the tool and blank

(Ref. 1)

Gear Errors



(a) Profile errors, characterised by a deviation from the nominal profile. These increase noise.

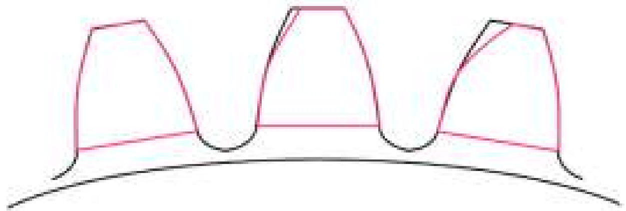


(b) Lead errors, a linear deviation along the face of the tooth. This affects load-carrying capacity.

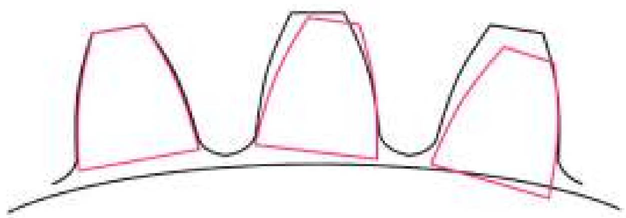
Form Error

(Ref. 6)

Gear Errors



(a) Pitch error, the difference between nominal angular location and actual measured location. This affects motion transfer.



(b) Runout, radial displacement of gear teeth which is cumulative across teeth. This affects motion transfer.

Position Error

(Ref. 6)

References

1. Jain R.K “Engineering Metrology”, Khanna Publishers, 21 st edition, 2005.
2. Gupta. I.C., “Engineering Metrology”, 7th edition, Dhanpatrai Publication, 2012.
3. https://nptel.ac.in/courses/112/104/112104250/
4. https://nptel.ac.in/courses/112/106/112106179/
5. Mahajan. M, “Metrology”, Dhanpat rai & Co, 2012.
6. L.L. Alhadeff ⇑ , T. Slatter“A straightforward and low-cost pre-inspection measurement method for small gears”, Manufacturing Letters, 2020, 23, pp. 23-28

SVCE

Sri Venkateswara College of Engineering

Autonomous - Affiliated to Anna University

ME18501- Metrology and Quality Control (R2018)

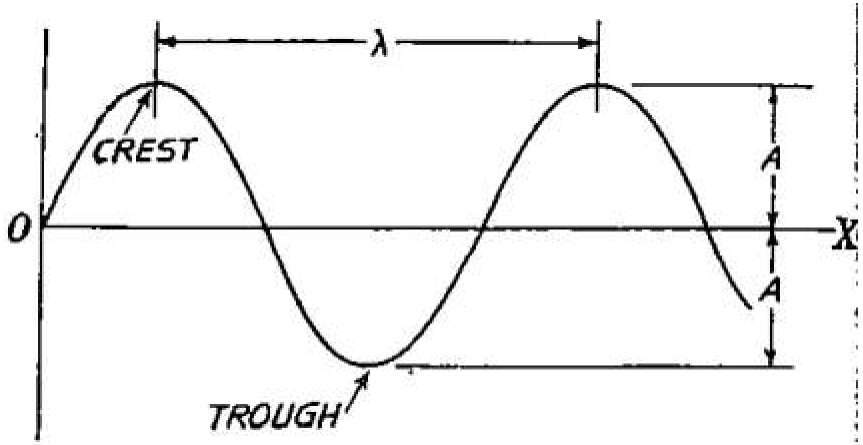
V semester

Academic Year 2021-22

UNIT-III
ADVANCES IN METROLOGY

Interferometry – Types of Interferometers – Michelson interferometer – NPL flatness interferometer. Laser metrology - Basic concept of lasers - Advantages of Laser – Laser Interferometers – Types – DC and AC lasers interferometer – Applications. Coordinate Measuring Machines - Types of construction – Probes. CNC CMM, Machine vision system – Image acquisition & Image processing.

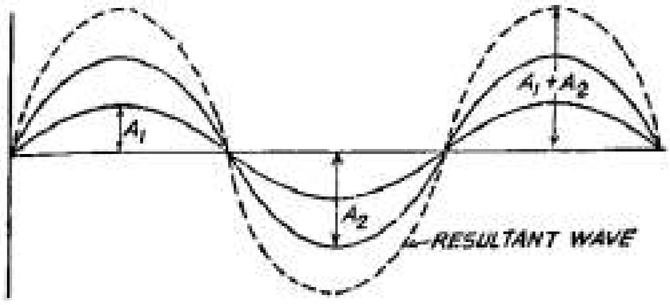
Interferometry



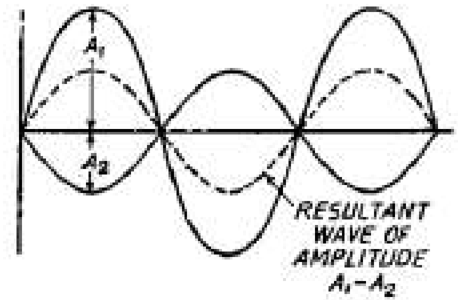
Nature of light.

(Ref. 1)

Interferometry



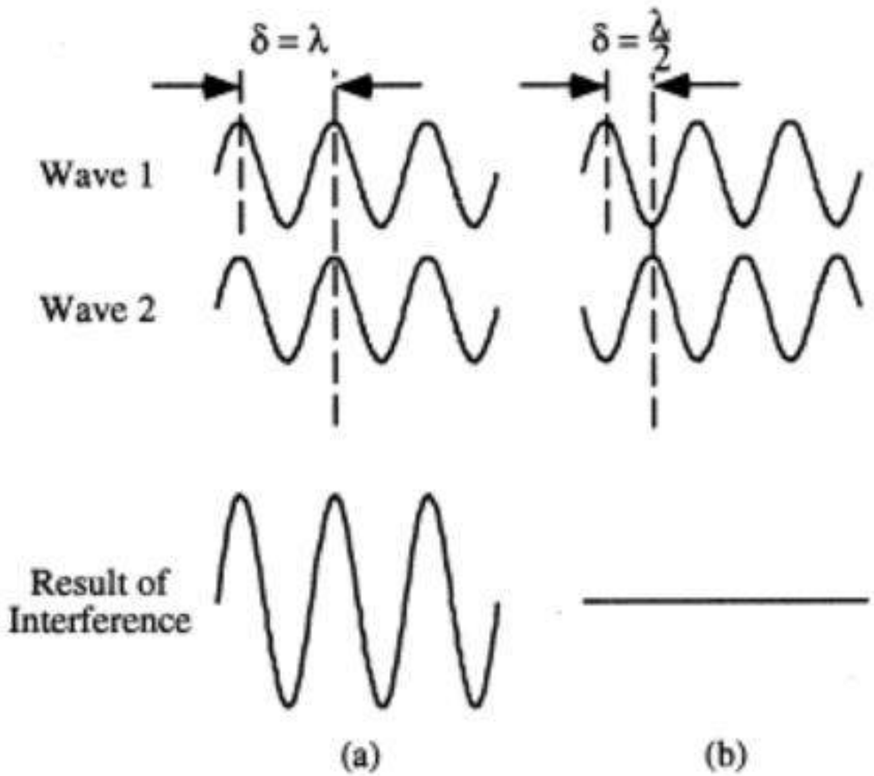
Effect of combining two rays in same phase.



Effect of Combining two rays out of phase by λ/2.

When two light waves superimpose, then the resultant amplitude (or intensity) in the region of superposition is different than the amplitude (or intensity) of individual waves. This modification in the distribution of intensity in the region of superposition is Called interference. (Ref. 4)

(Ref. 1)



https://www.rpi.edu/dept/phys/ScIT/InformationStorage/intdiff/intdiff.html

Interferometry

Conditions for interference to occur:

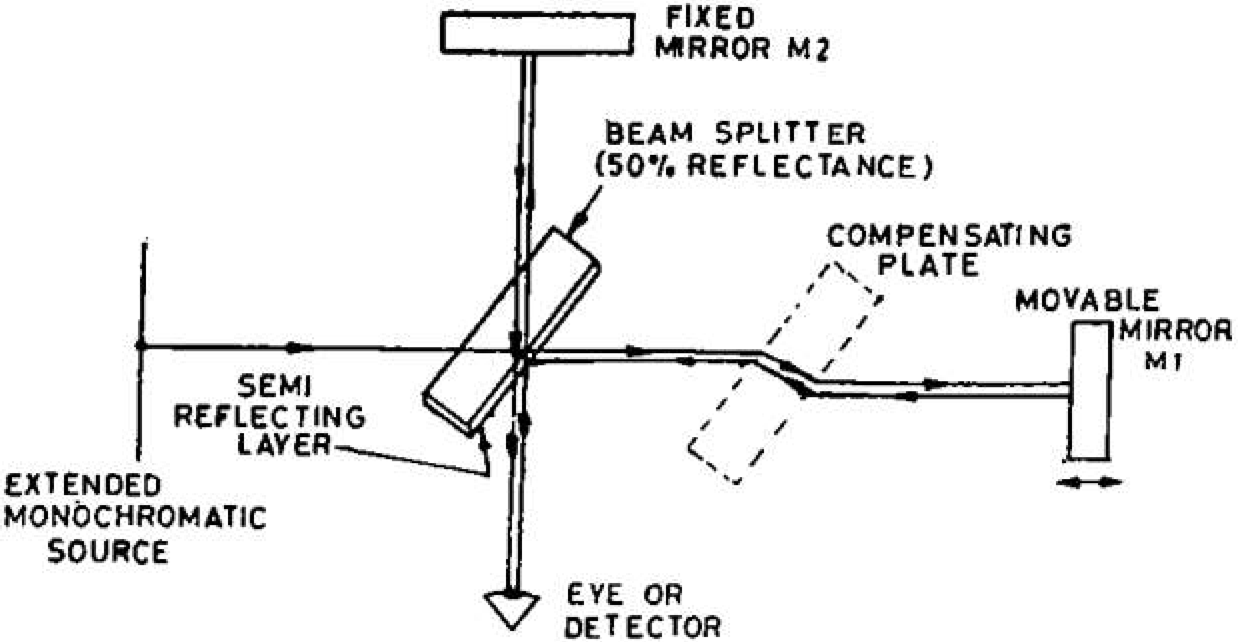
1. Light rays are obtained by division from a single source
2. Rays before being combined at the eye must travel paths whose length differ by an odd number of half wavelengths

(Ref. 1)

Light sources

- Mercury
- Cadmium
- Krypton
- Thallium
- Sodium
- Helium
- Neon

Michelson Interferometer

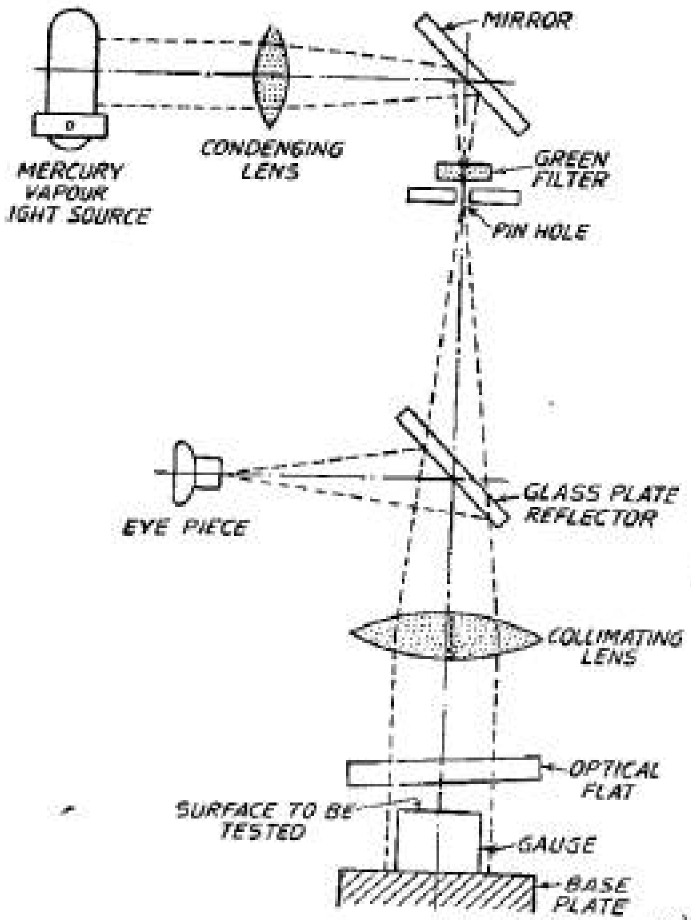


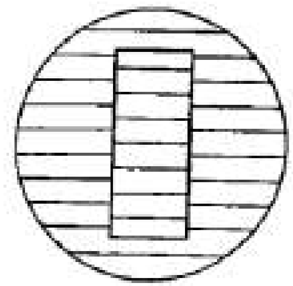
(Ref. 1)

Sophistications to improve Michelson's basic apparatus

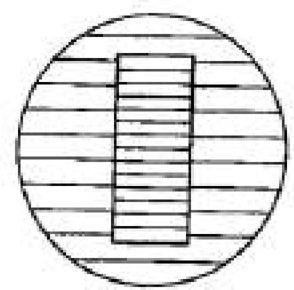
- Use of laser light source (for long distances)
- Replacement of mirrors by cube-corner reflectors
- Replacement of eyepiece by photo cells

NPL Flatness Interferometer





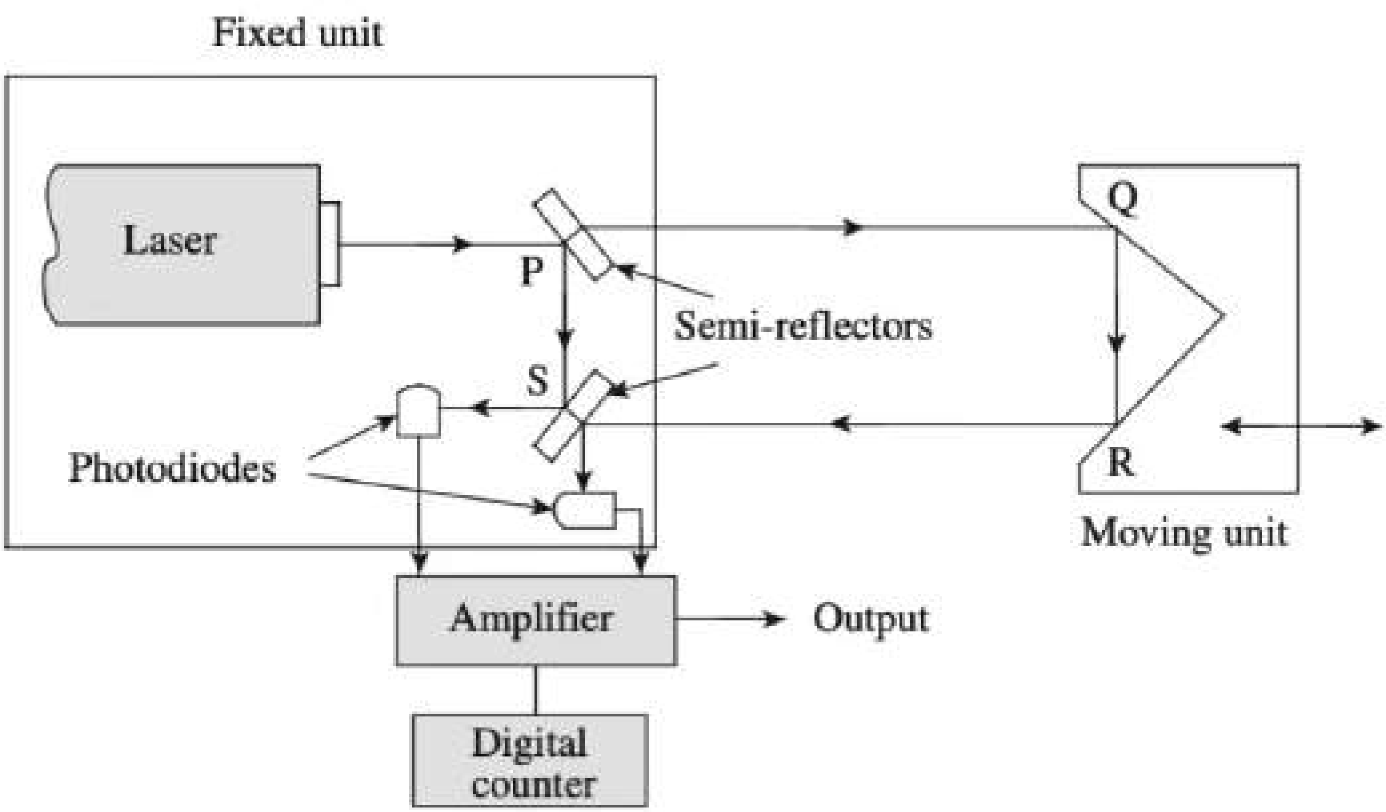
(a) Gauge face flat and parallel to base plate.



(b) Gauge face flat but not parallel to base plate.

(Ref. 1)

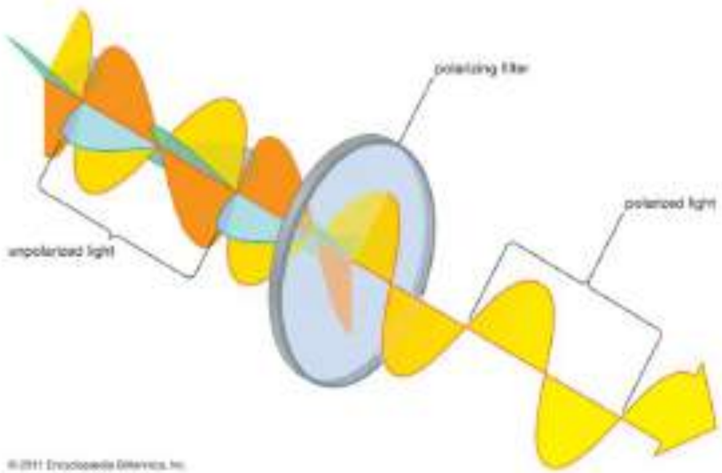
Laser Interferometer

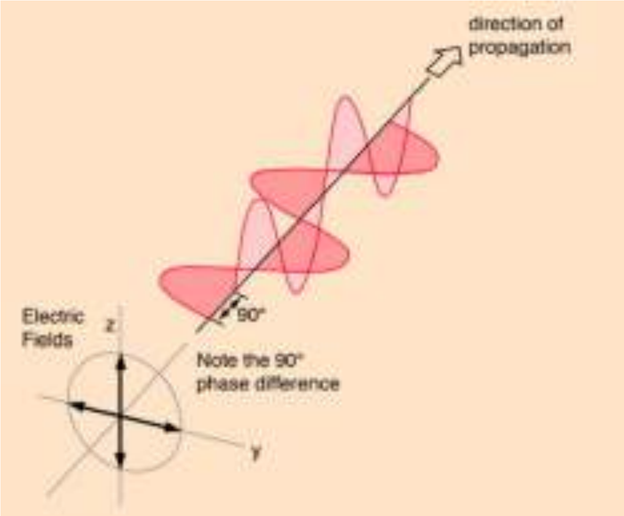


https://extrudesign.com/

(Ref. 4)

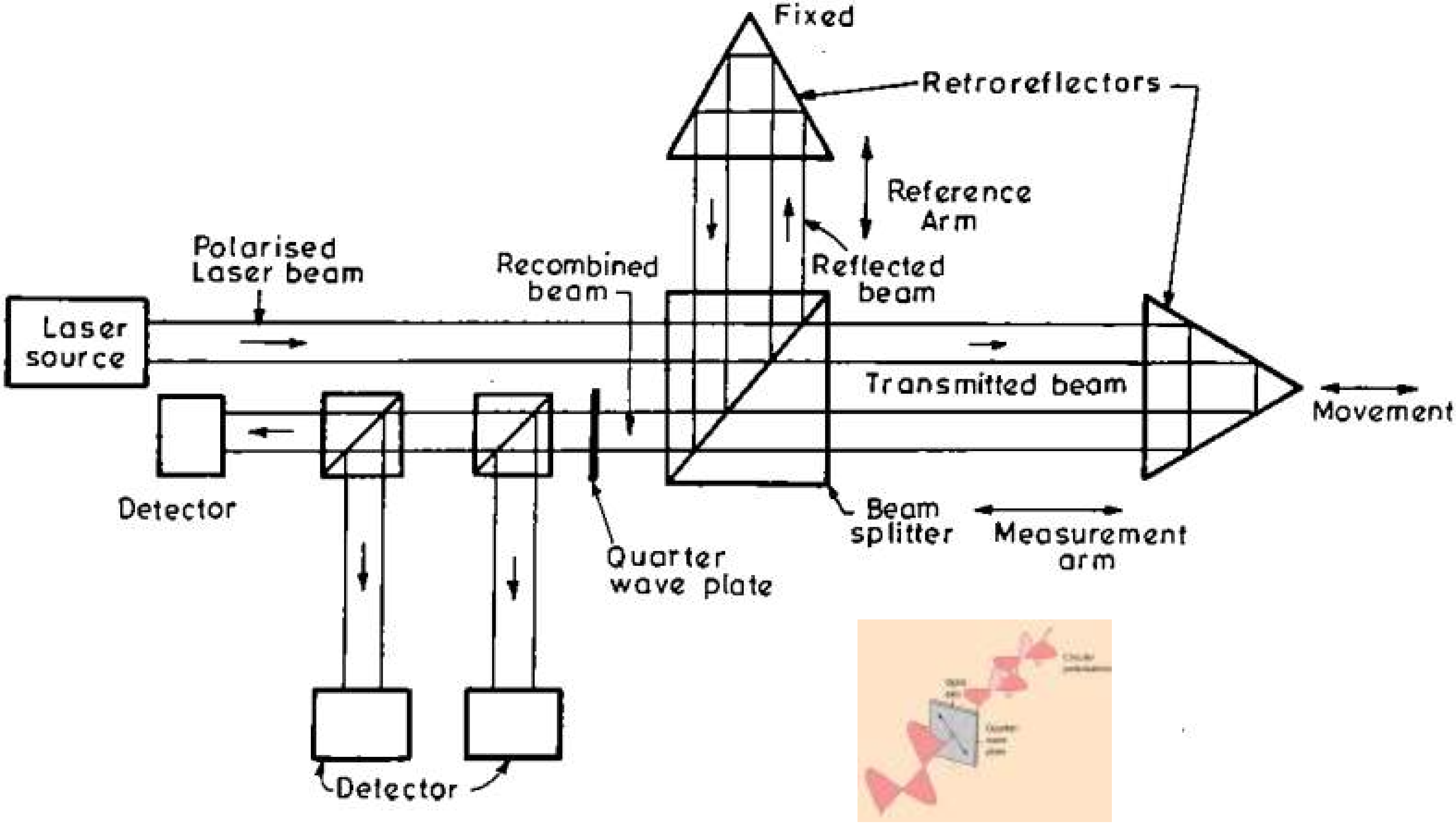
Polarization





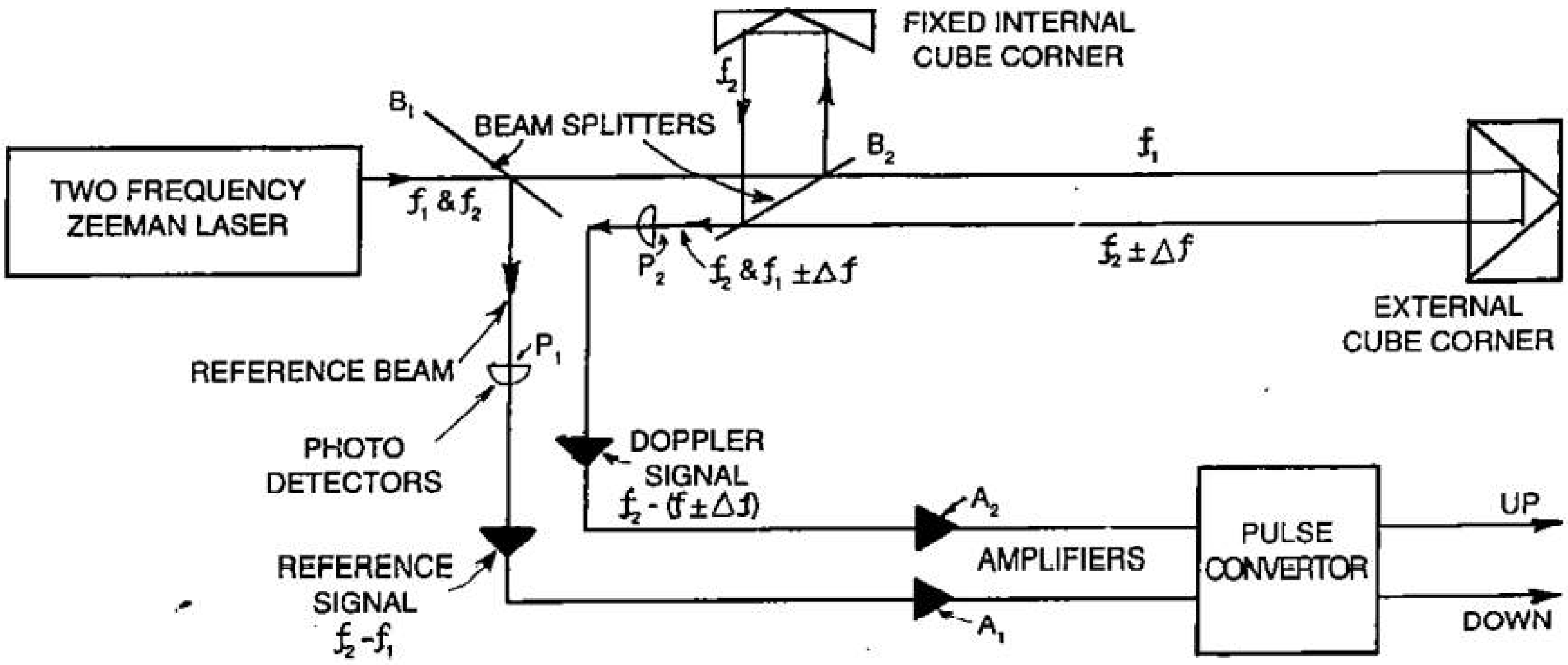
http://hyperphysics.phyastr.gsu.edu/hbase/phyopt/polclas.html

DC Interferometer



http://hyperphysics.phyastr.gsu.edu/hbase/phyopt/polclas.html

AC Interferometer



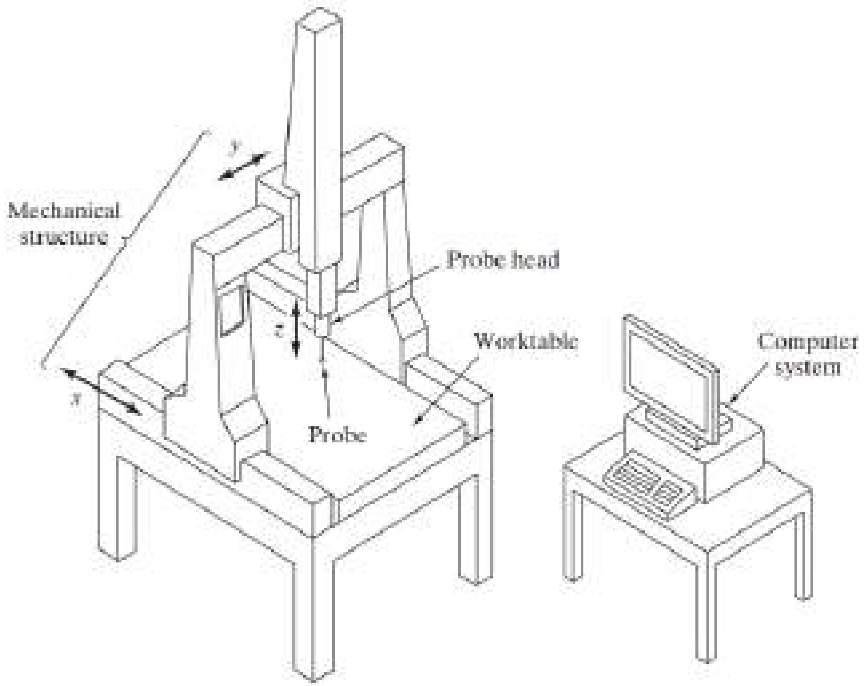
Applications of Laser

- Distance measurement
- Velocity measurement
- Profile and surface position measurement
- Measurement of product dimension
- Measurement of surface finish

Coordinate measuring machine

Coordinate metrology is concerned with measuring the actual shape and dimensions of an object and comparing these results with the desired shape and dimensions, as might be specified on a part drawing.

A coordinate measuring machine (CMM) is an electromechanical system designed to perform coordinate metrology. It has a contact probe that can be positioned in three dimensions to the surfaces of a work part.



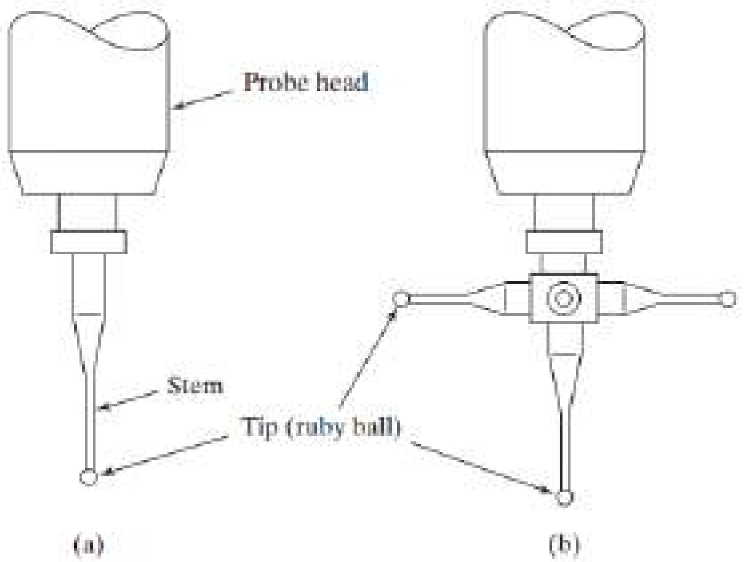
Coordinate measuring machine

Components

Probe head and probe to contact the work part surfaces

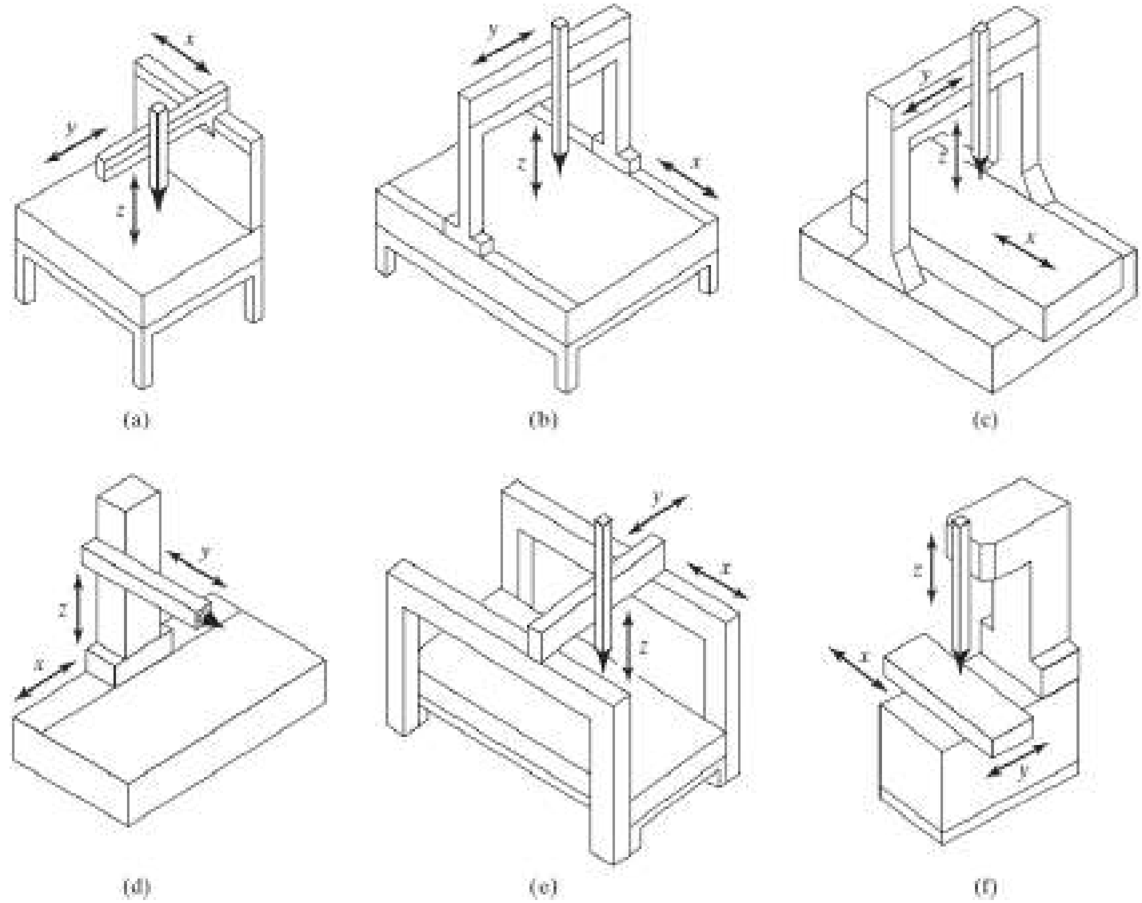
Mechanical structure that provides motion of the probe in three Cartesian axes and displacement transducers to measure the coordinate values of each axis

PROBE



Contact probe configurations: (a) single tip and (b) multiple tips.

- Ruby ball (aluminium oxide)
- Trigger Mechanisms
- Displacement transducer & CMM controller
- Radius compensation



Six types of CMM construction: (a) cantilever, (b) moving bridge, (c) fixed bridge, (d) horizontal arm (moving ram type), (e) gantry, and (f) column.

CMM

Advantages of CMM

- Wide variety of parts can be inspected
- Reduced inspection cycle time
- Flexibility (Minimum change over time)
- Reduced operator errors
- Greater accuracy and precision
- Avoidance of multiple setup

Applications of CMM

- Offline and online inspection
- Calibration of Gauges and fixtures
- Measurement of geometric features requires multiple contact point
- Complex part geometry

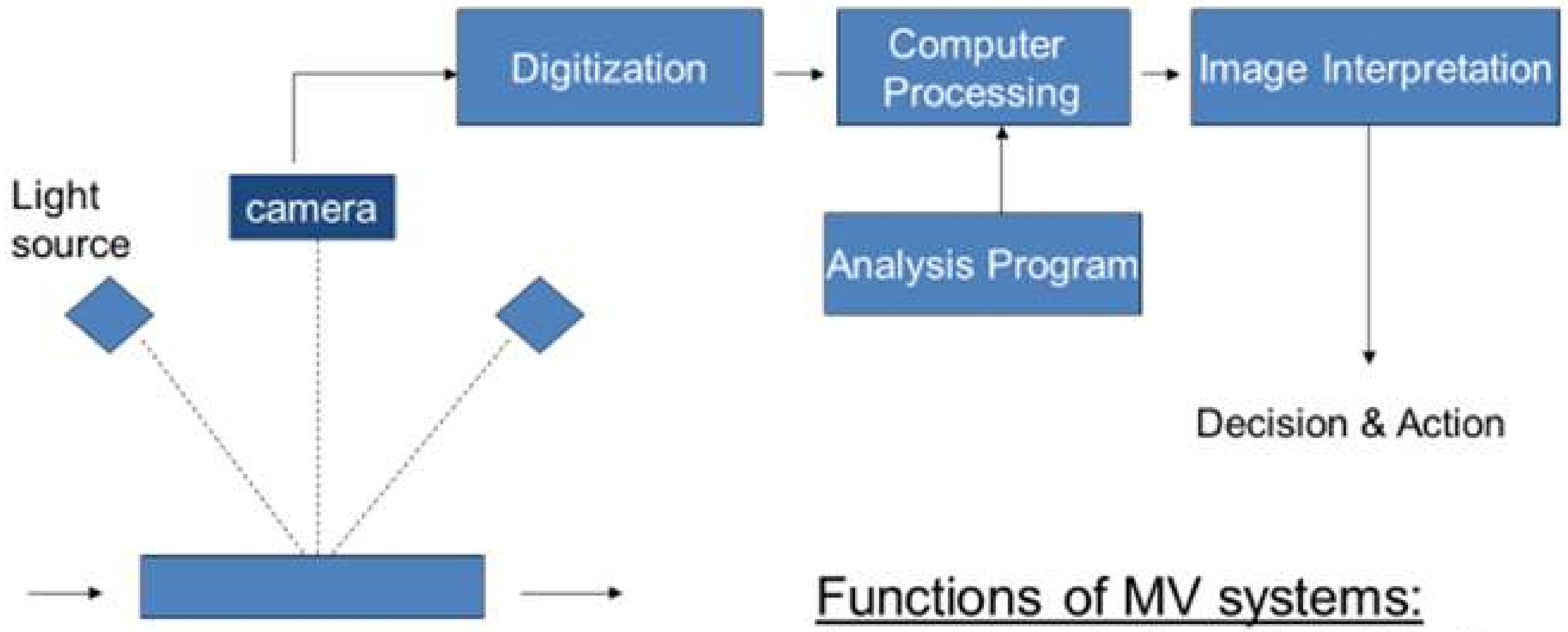
Machine vision

- MV is the acquisition of image data, followed by the processing & interpretation of these data by computer for some useful application.

Classification:

2D & 3D systems.

Machine vision



<u>Functions of MV systems:</u>

Image acquisition & digitization

Image processing & Analysis

Interpretation

Image Acquisition & Digitization

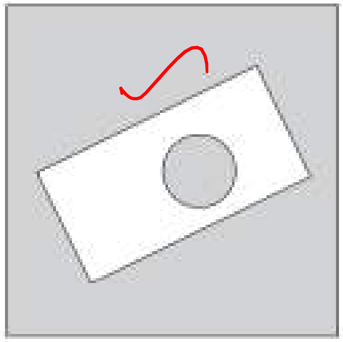
Image is obtained by dividing the viewing area into a matrix of discrete picture elements (pixels), in which each element has a value that is proportional to the light intensity of that portion.

Intensity value is converted into equivalent digital value by an ADC.

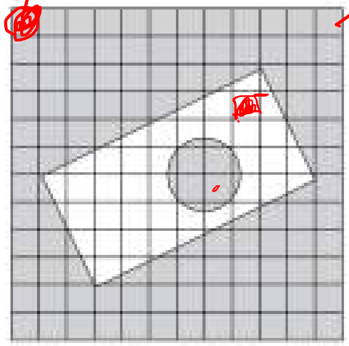
Types of digitization

- Binary vision system
- Gray scale system

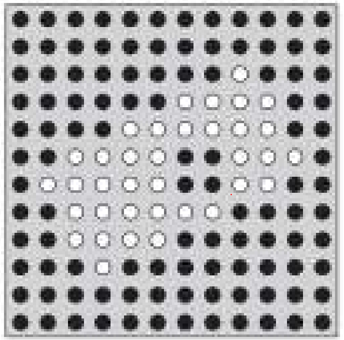
Binary image



(a)



(b)



(c)

Grey scale image

Digital cameras

- Operate by focusing the image onto a 2-D array of very small, finely spaced photosensitive elements using conventional optical lenses

- Image sensors

  - CCD (Charge-coupled Device)

  - CMOS (Complementary metal-oxide semiconductor)

Advantages of CMOS based cameras are high speed operation, low cost and lower power consumption

Illumination

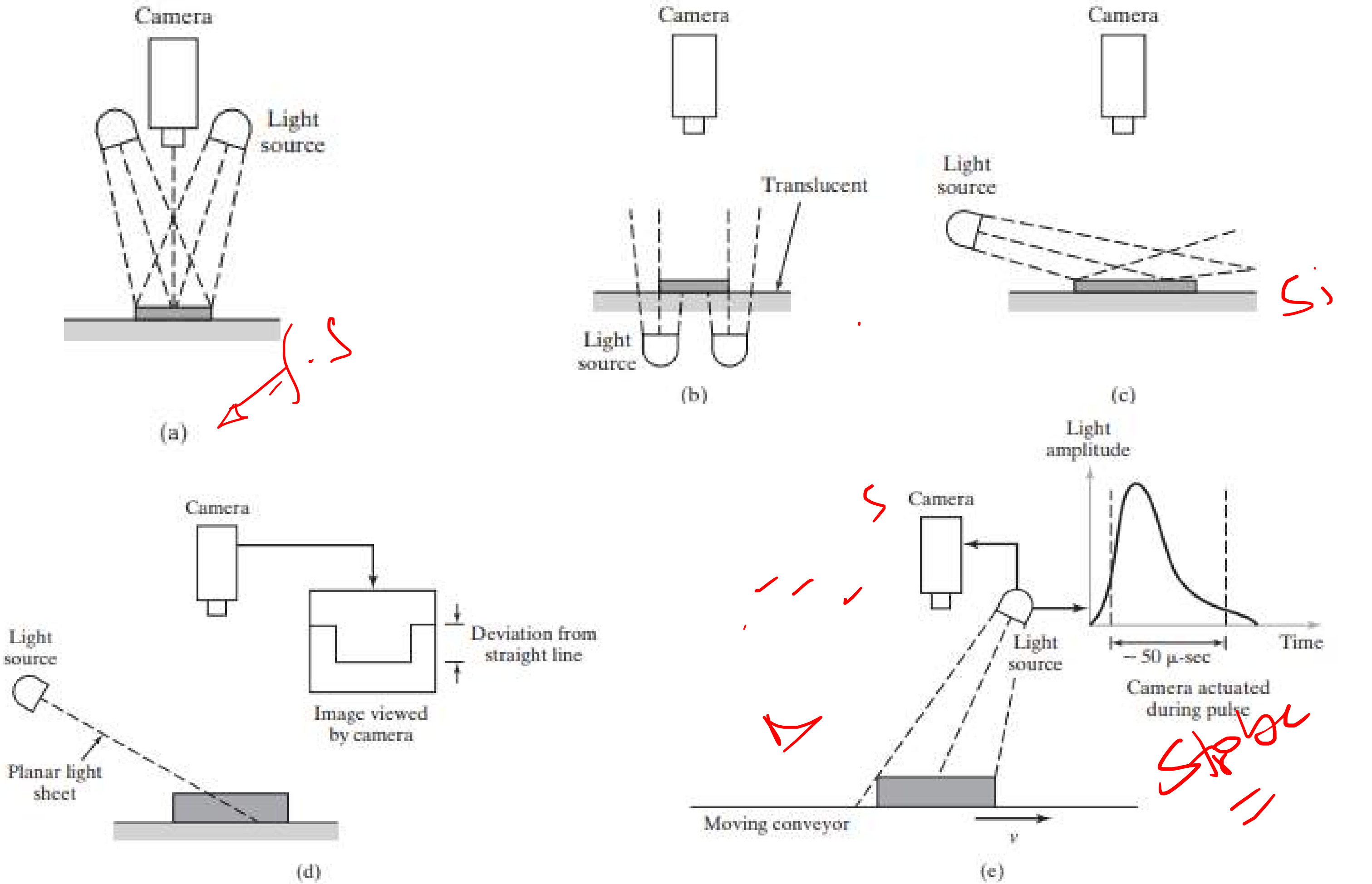


Image processing and analysis

- Thresholding
- Edge detection
- Feature extraction

Interpretation

- Template matching
- Feature weighting

Applications

- Inspection (Dimensional measurement, Dimensional gaging, Detection of surface flaws & defects)

- Identification (verification of presence of components, hole location)

- Visual guidance and control (teamed with a robot or similar machine to control the movement of the machine)

References

1. Jain R.K "Engineering Metrology", Khanna Publishers, 21 st edition, 2005.
2. Gupta. I.C., "Engineering Metrology", 7th edition, Dhanpatrai Publication, 2012.
3. https://nptel.ac.in/courses/112/104/112104250/
4. https://nptel.ac.in/courses/112/106/112106179/
5. Mahajan. M, "Metrology", Dhanpat rai & Co, 2012.

SVCE
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ME18501- Metrology and Quality Control (R2018)

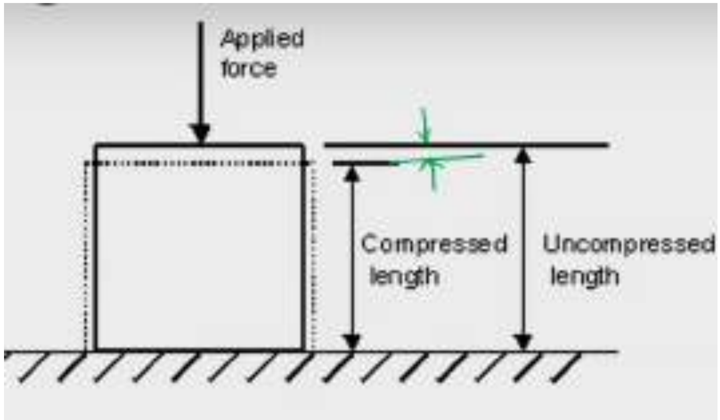
V semester
Academic Year 2021-22

UNIT-IV
MEASUREMENT OF PROCESS PARAMETERS

Measurement of Force Load cells Hydraulic & Pneumatic load cells LVDT. Basics of Torque & Power measurement. Flow measurement Differential pressure flow meter, Magnetic flow meter Ultrasonic flow meter. Temperature measurement – Thermocouples Radiation pyrometer Infrared temperature sensor.

Force load cell

Elastic devices that can be used for measurement of force through indirect methods through use of secondary transducers are load cells.



Primary transducer – An elastic member

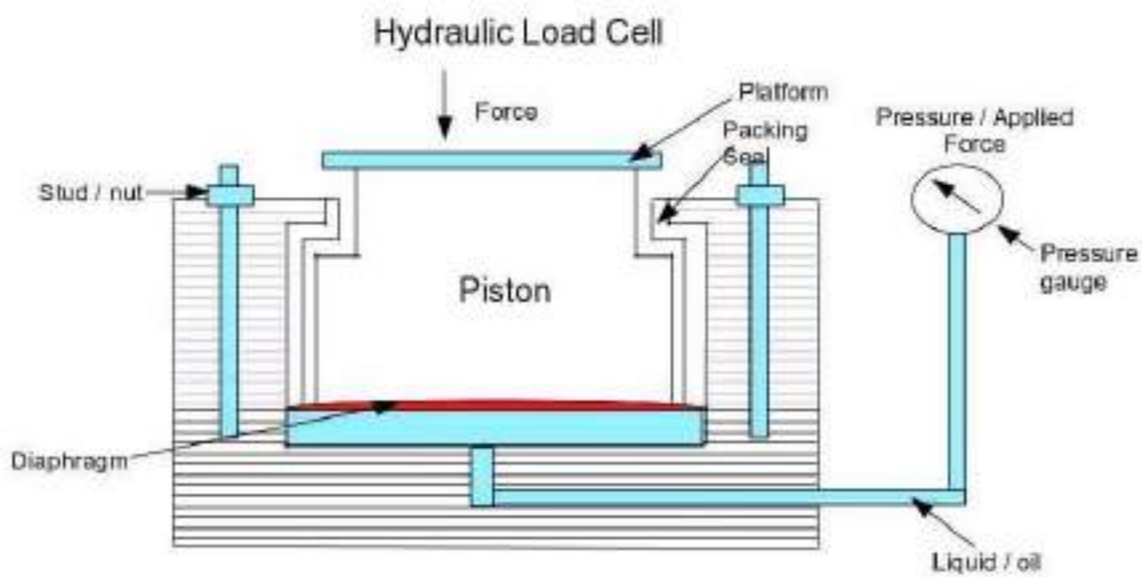
Secondary transducer – A strain gauge

Ref. 1

Factors considered in the design of load cell

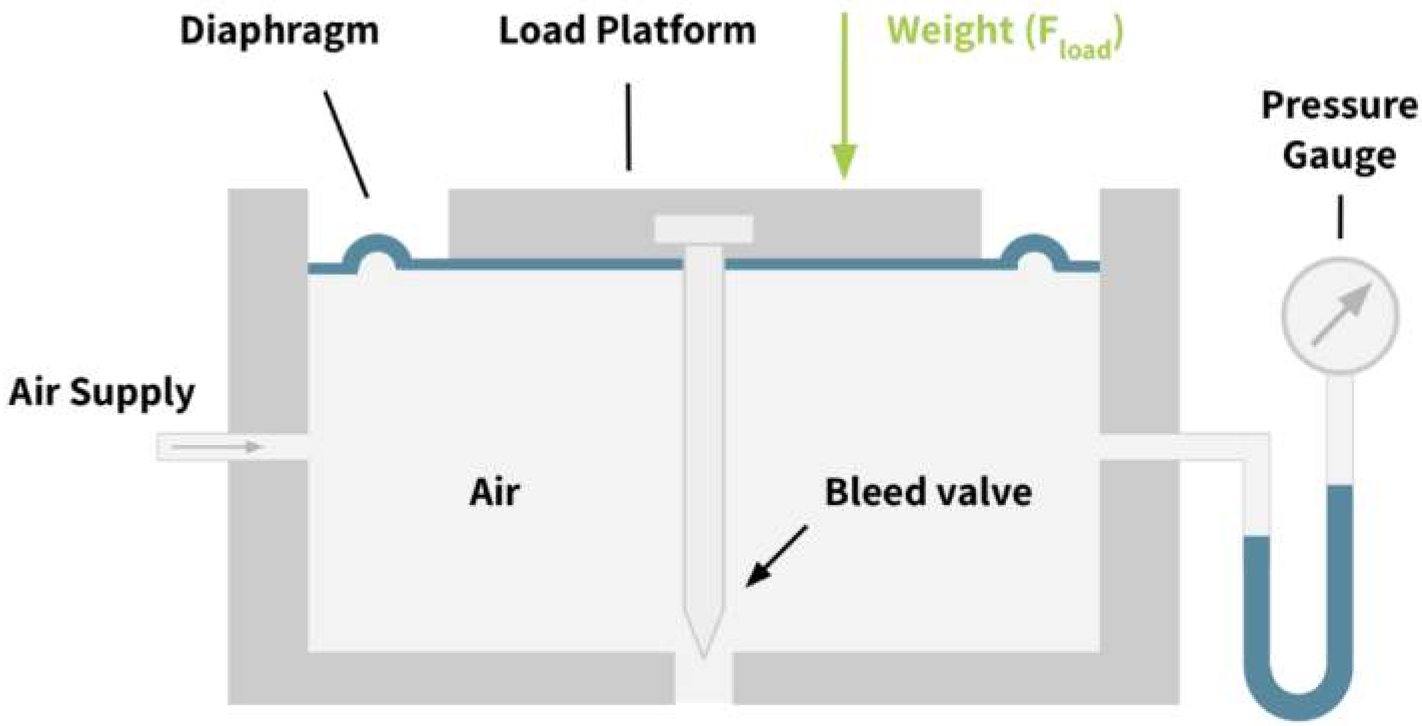
- Stiffness of the elastic member (K=F/y)
  - *Sensitivity*
  - *Response time*
  - *Stress maintained within elastic limit*
- Positioning of gauges
- Provision for temperature compensation (due to temperature sensitivity issues)

Hydraulic and Pneumatic load cells



https://instrumentationtools.com/hydraulic-load-cell-principle/

Pneumatic load cell



https://tacunasystems.com/knowledge-base/an-overview-of-load-cells/

Measurement of torque

- Torque is obtained by measuring force at a distance

  $T = Fr$ **Nm**

- Torque is often associated with the determination of power

  Power

  $P = T\omega$ **W** $(\omega = 2\pi n \ \text{rad/s})$

Measurement of torque of rotation shaft

- The methods of measurement of torque involve

  Powe source

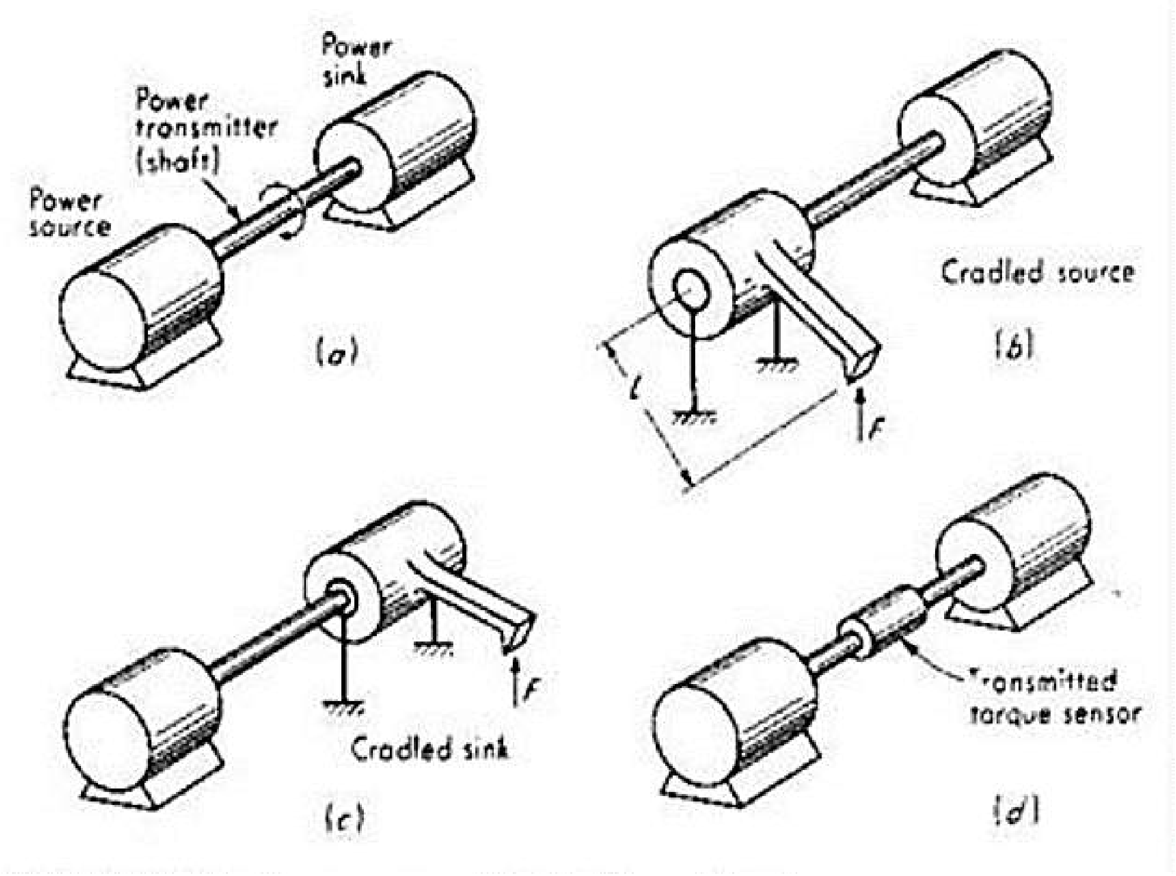
  Power sink

  Power transmitter

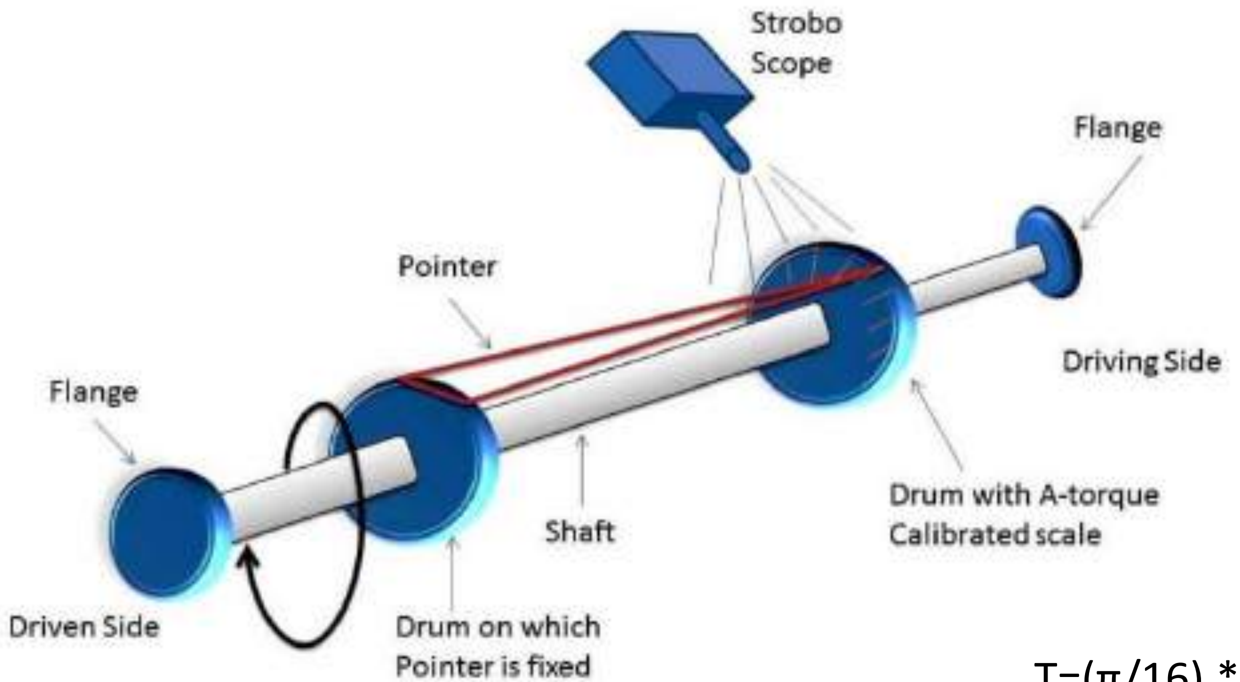
Methods:

1. Torque reaction methods
2. Torque measuring methods using strain sensors

Torque reaction methods



Stroboscopic method



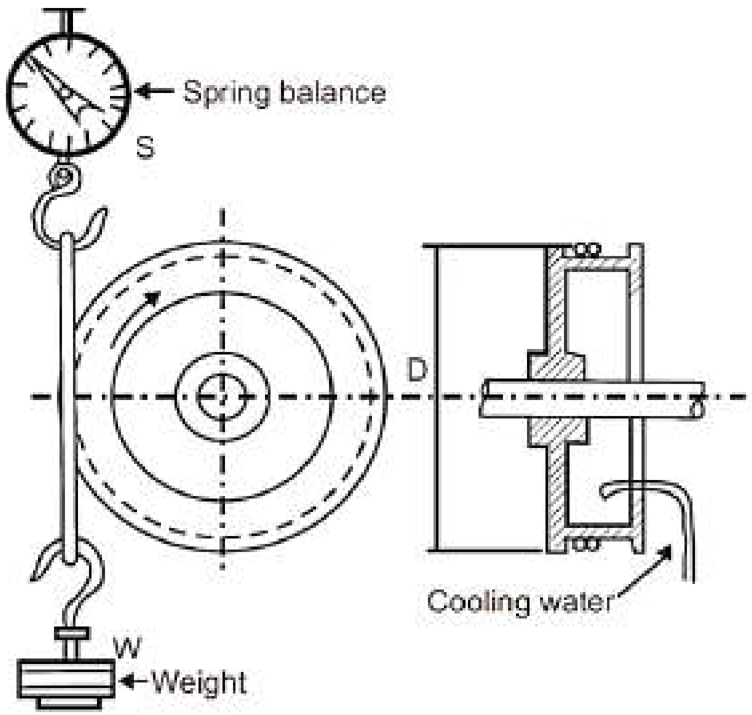
$$T=(\pi/16) * G * d^3 * \theta$$

https://instrumentationtools.com/mechanical-torsion-meter-principle/

Power measurement

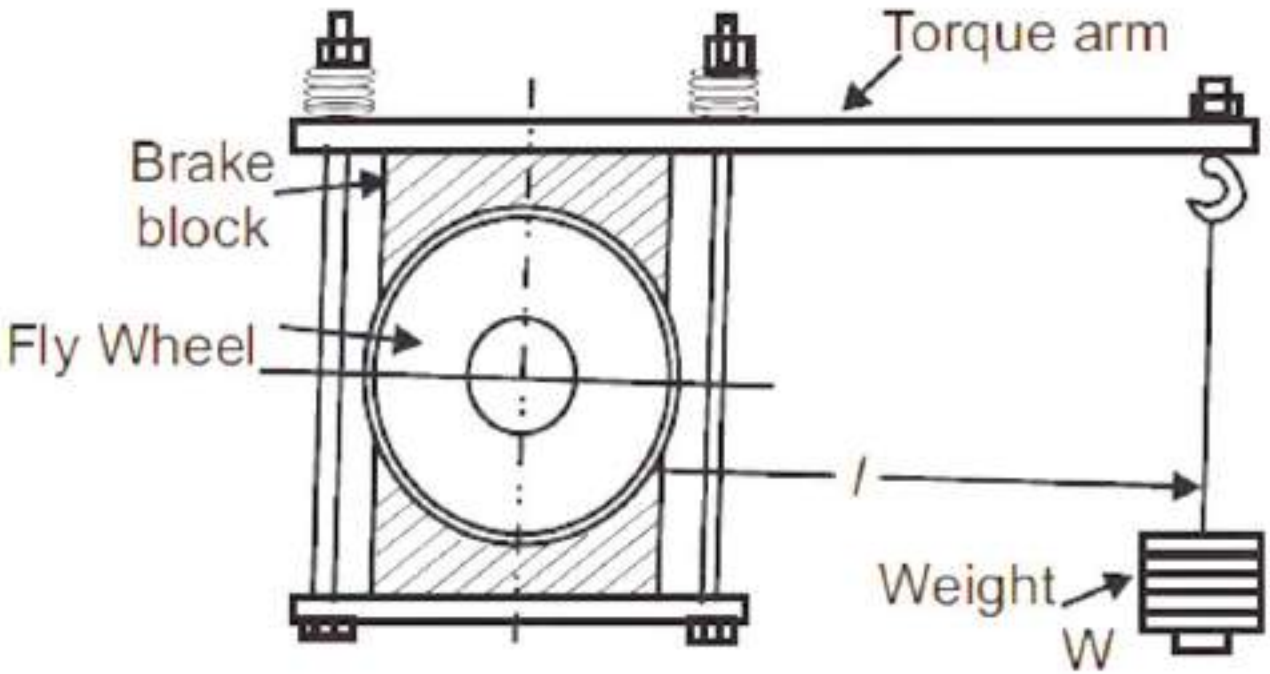
- Power is defined as rate of doing work
- Simultaneous measurement of torque and shaft speed is required to determine power delivered
- Machines used for this are called as dynamometers, which are classified as
    1. Absorption dynamometers
    2. Transmission dynamometers
    3. Driving dynamometers

Rope brake dynamometer



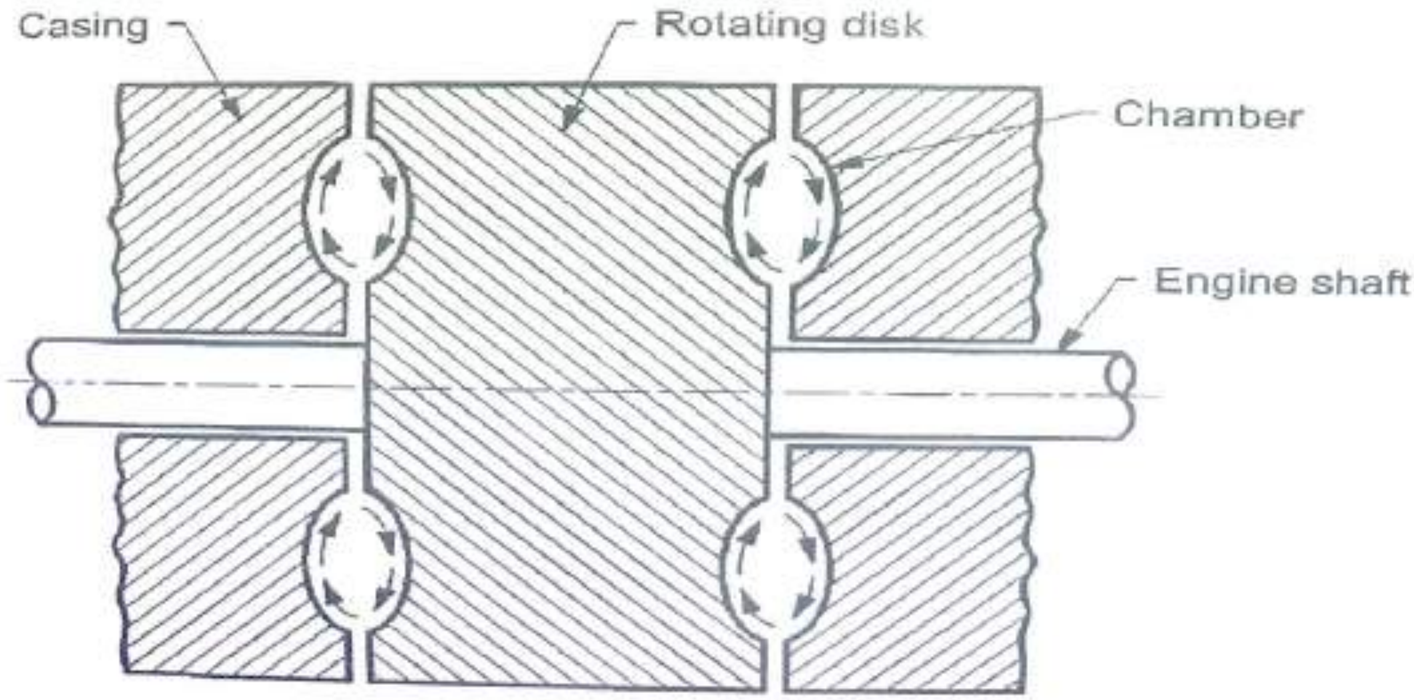
Brake power = $\pi DN (W-S)/60$

Prony brake dynamometer

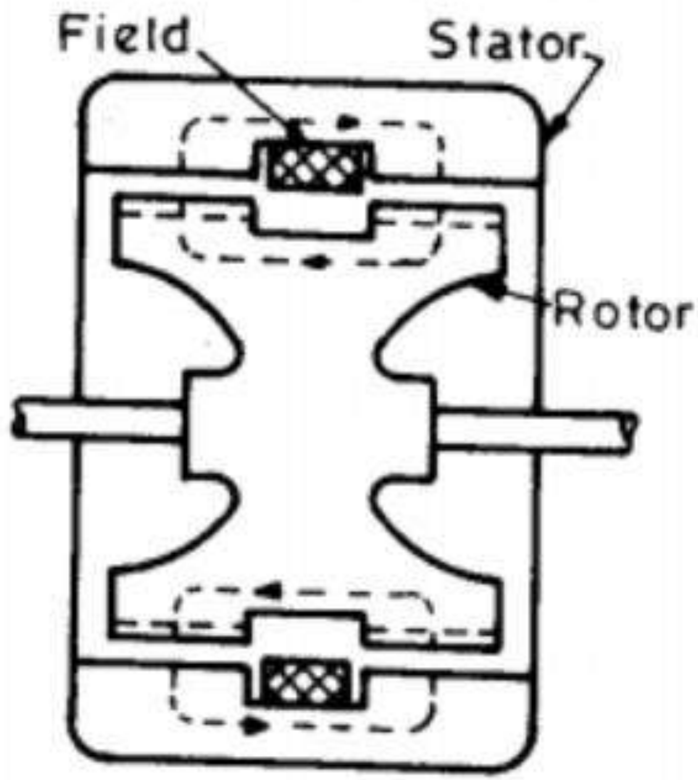


Brake power = $2\pi NT = 2\pi N\,(W \times l)$

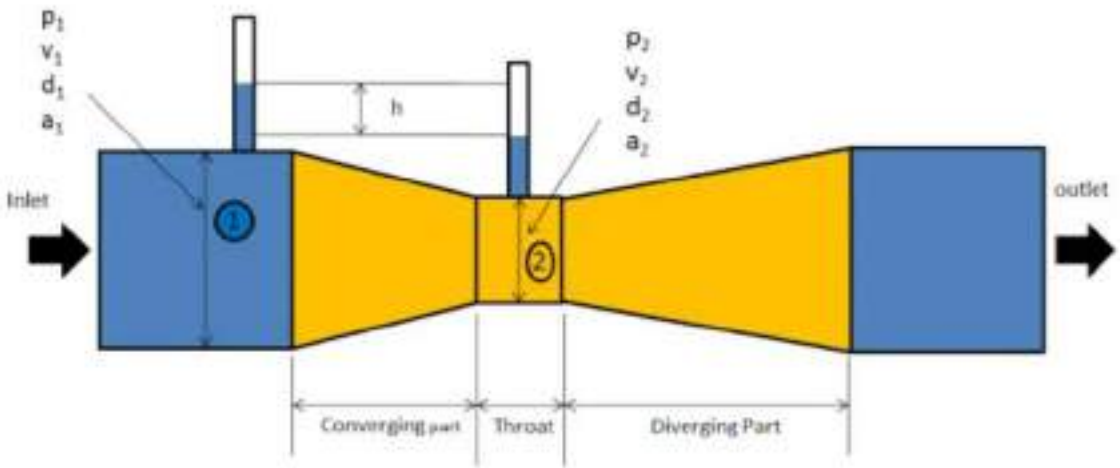
Hydraulic dynamometer



Eddy current dynamometer



Flow measurement

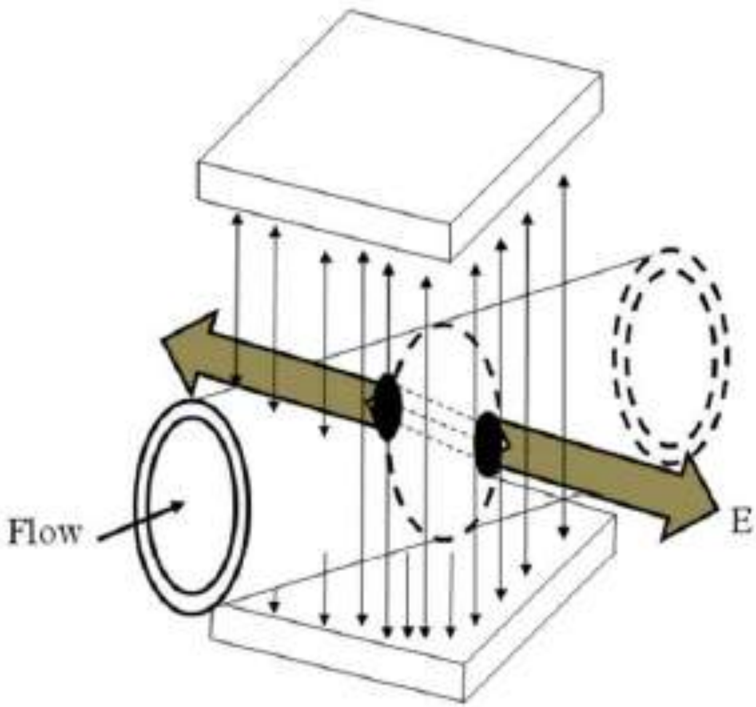


Venturimeter

$$Q_{act} = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

mechanicalbooster.com/2016/06/venturimeter-principle-construction-working-diagram.html

Electromagnetic flow meter



EMF = BLV

Where, B is the magnetic flux density (gauss), L is the length of the conductor and V is the velocity of the conductor

Source: NPTEL

Advantages and limitations of Electromagnetic flow meter

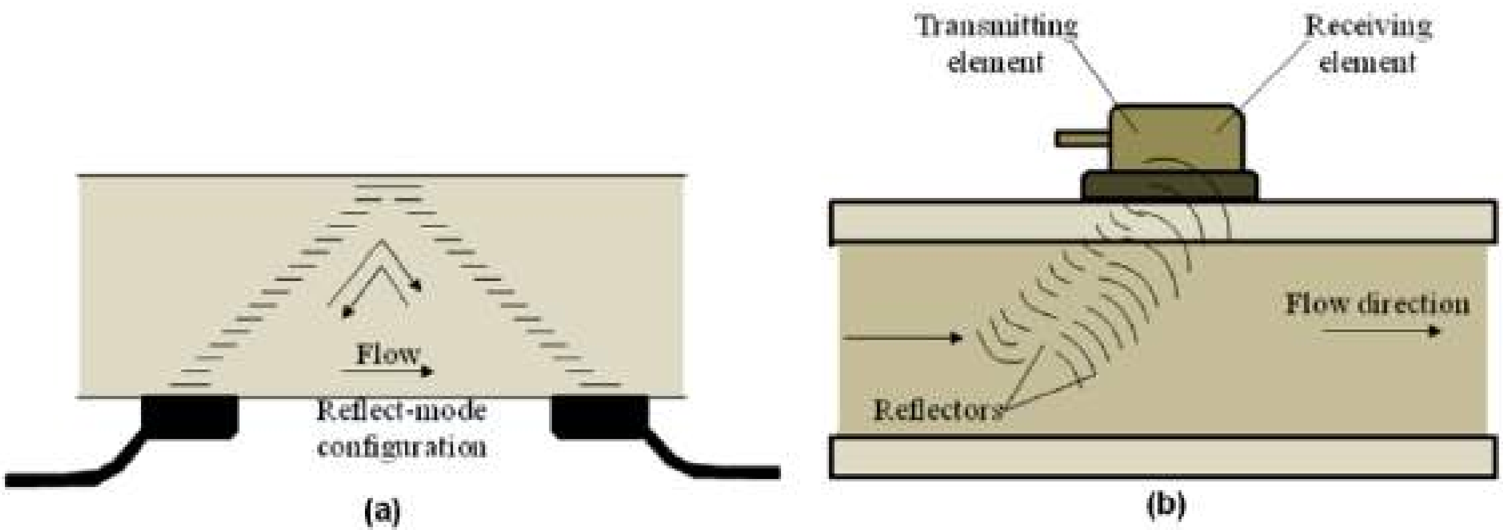
Advantages

- Linear response
- Low sensitivity to upstream conditions
- No moving parts
- Suitable for slurries

Limitations

- Fluid media must be electrically conductive
- Need proper power source

Ultrasonic flow meter



Transit time

Frequency shift

V= K l(Δ(t)); K is a constant

Source: NPTEL

Advantages and limitations of ultrasonic flow meter

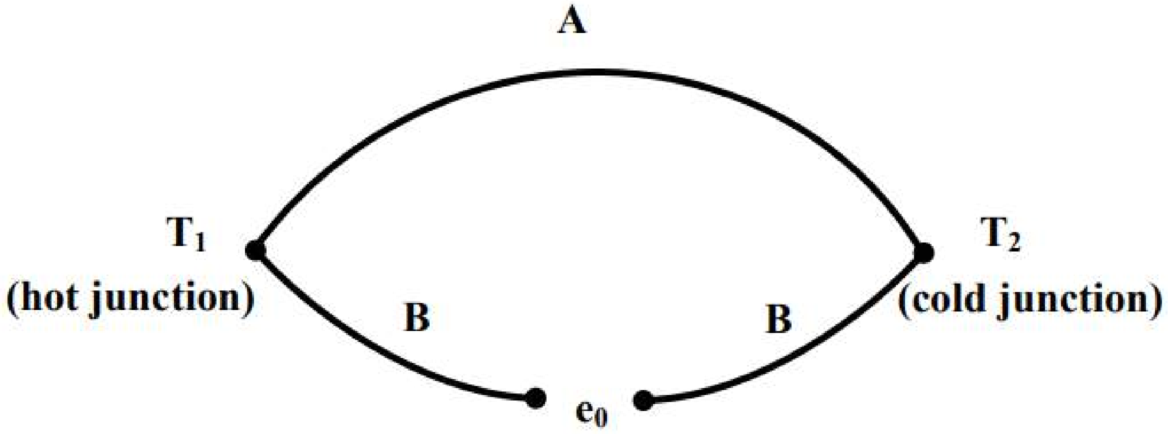
Advantages

- Applicable to both liquids and gases
- Can be installed for wide range of pipes
- No head loss

Limitations

- Sensitivity to velocity profiles
- Not applicable to granular pipe materials

Temperature Measurement



$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$

where T_1 and T_2 are hot and cold junction temperatures in K.

C_1 and C_2 are constants depending upon the materials.

For Copper/ Constantan thermocouple, C_1=62.1 and C_2=0.045.

Source: NPTEL

Advantages and limitations of thermocouple

Advantages

- Rugged and readings are consistent
- Can measure wide range of temperature
- Characteristics are almost linear
- No power source required
- Inexpensive
- Can be Installed easily

Limitation

- Low sensitivity
- Calibration required because of the presence of non-linearity
- Not for precise measurement

Source: NPTEL

(Ref.2)

Radiation pyrometry

Black body radiation

- A body at higher temperatures emits electromagnetic radiation.
- The rate at which energy is emitted depends on surface temperature and surface conditions.
- The thermal radiation from a body is composed of wavelengths forming an energy distribution.
- The total emissive power of a black body (e_b) at a particular temperature is

$$e_b = \int_0^{\lambda} e_{b\lambda}\, d\lambda$$

Planck's distribution law

$$e_{b\lambda} = \frac{2\,\pi\,h\,a^2\,\lambda^{-5}}{\exp\left[\frac{ch}{K_B\,\lambda T}\right]-1}$$

h – Planck's constant
a- Velocity of light
λ– Wavelength
T-absolute temperature
K_B- Boltzmann constant
(1.380649×10−23 J·K−1)

Total emissive power of a black body is $e_b = \sigma T^4$ W/m^2

σ = Stefan's Boltzmann constant $5.67 \times 10^{-8} Wm^{-2}K^{-4}$

Radiation from real surfaces

$e = \varepsilon e_b$

$$e_\lambda = \frac{2\,\epsilon\,\pi\, h a^2\, \lambda^{-5}}{\exp\left[\frac{ch}{K_B\,\lambda T}\right] - 1}$$

(Monochromatic emissive power of a real source)

h – Planck's constant
a- Velocity of light
λ– Wavelength
T-absolute temperature
K_B- Boltzmann constant (1.380649×10−23 J·K−1)

Total emissive power of a real surface is $e_b = \sigma\,\varepsilon\,T^4$ W/m^2

- Emissivity of metals decreases with increasing wavelength
- Roughness increases emissivity

Principles of radiation pyrometer

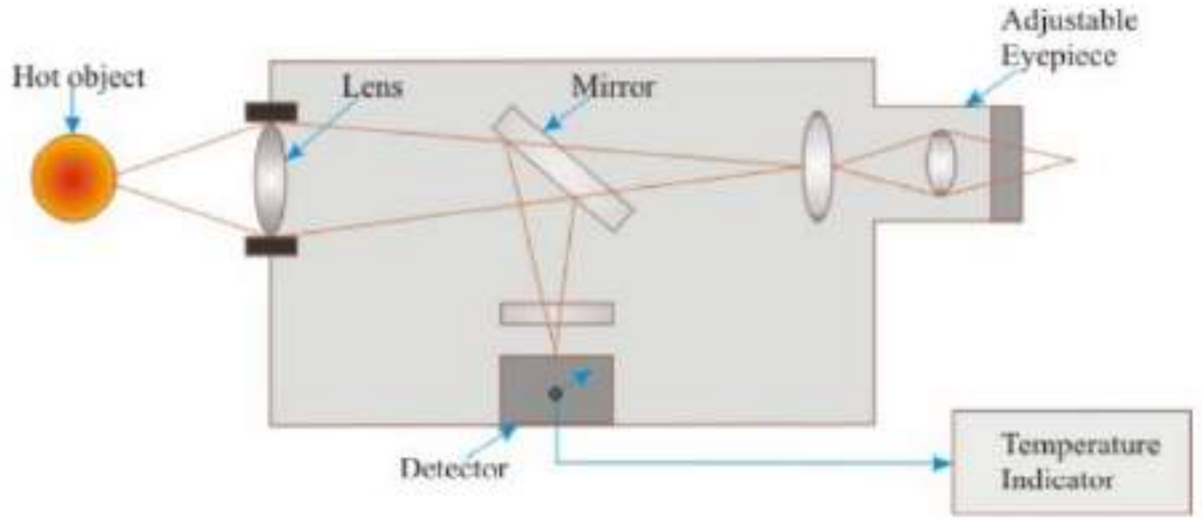
- Temperature measurement is based on the measurement of radiation either directly by a sensor or by comparing with the radiation of a body of known temperature.
- The radiation pyrometer is a non contact type of temperature measurement.
- The wavelength region having high intensity is between 0.1 to 10µm.

  0.1 is the ultraviolet region,

  0.4 to 0.7 is the visible region

  0.7 onwards is the infrared region.
- With the increase in temperature, radiation intensity is stronger toward shorter wavelengths.
- The temperature measurement by radiation pyrometer is limited within 0.5 to 8µm wave length region.

Total radiation pyrometer



- Semiconductors to sense the radiation are materials of Si, PbS, indium, antimonides etc.
- Gases CO_2, H_2O like and dust should not obstruct the path of radiation. The dust particles scatter the radiation, whereas CO and water vapor selectivity absorbs radiation

Material for windows	Transmissivity
Glasses like quartz, Pyrex, ruby etc.	Good in ultraviolet and visible region of wavelength but are opaque to infrared. Glass windows are useful for wavelengths lower than 2.5μm. Beyond wavelength of 2.5μm , transmissivity decreases drastically.
Barium fluoride and zinc sulphide	They have 60 – 80% transmissivity in the infrared and visible region.
Calcium fluoride	It has a very good transmissivity in visible and infrared region.

Advantages and Limitations of radiation pyrometer

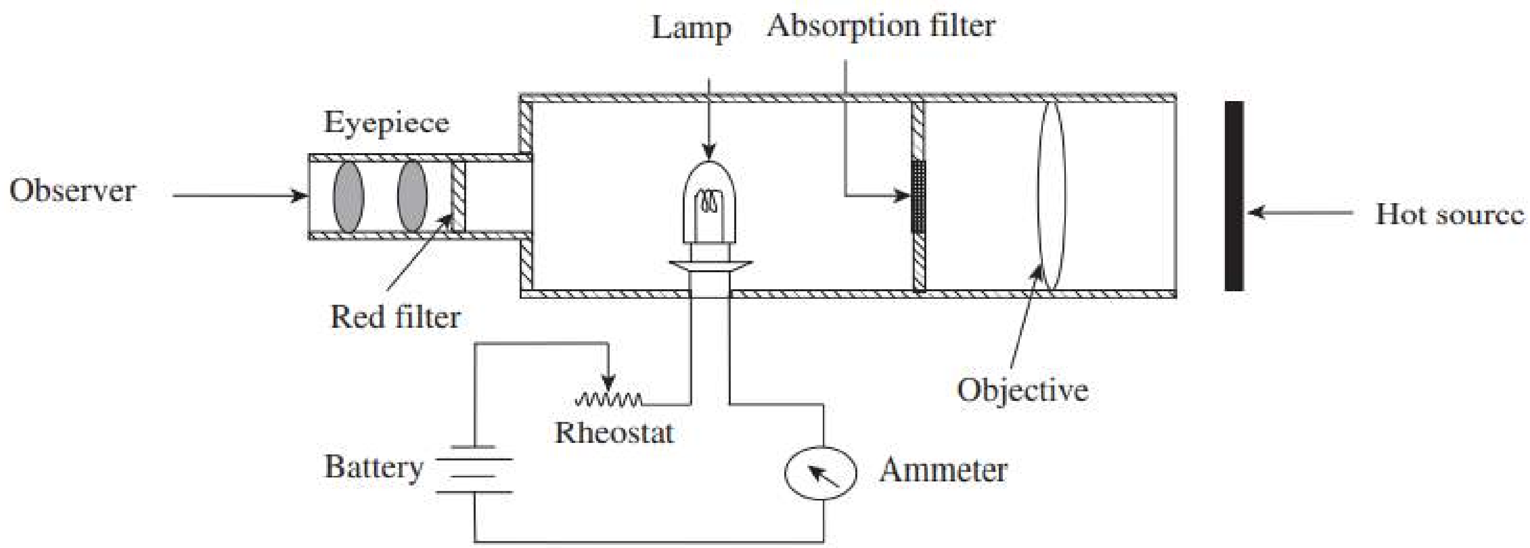
Advantages

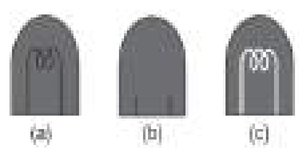
- It is a non-contact-type device.
- It gives a very quick response.
- High-temperature measurement can be accomplished

Limitations

- Availability of optical materials limit on the wavelengths that can be measured
- The surface of the hot object should be clean. It should not be oxidized. Scale formation does not allow to measure radiation
- Emissivity correction is required. Change in emissivity with temperature need to be considered

Optical Pyrometer (Disappearing filament type)





Disappearing filament principle (a) Current passing though the filament is low (b) Current passing though the filament is exact (c) Current passing though the filament is high

(Ref.2)

Advantages of Optical Pyrometer

- They are simple in construction and portable.
- Optical pyrometers are flexible and easy to operate.
- They provide very high accuracy of up to ±5 °C.
- Since they are non-contact-type sensors, they are used for a variety of applications.
- They can be used for remote-sensing applications, since the distance between the source and the pyrometer does not affect the temperature measurement.
- Optical pyrometers can be employed for both temperature measurement and for measuring wavelengths that are less than 0.65µm.

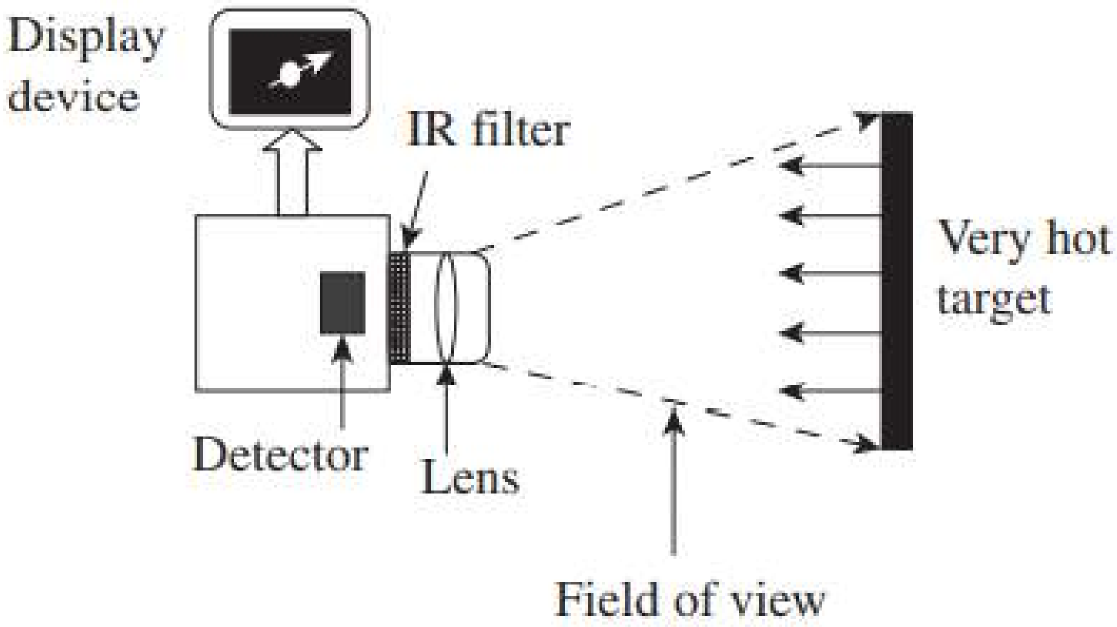
(Ref.2)

Limitations of Optical Pyrometer

- Optical pyrometers can be employed for measurement only if the minimum temperature is around 700°C, since it is based on intensity of light.
- Temperature measurement at short intervals is not possible.
- Emissivity errors may affect measurement.
- Optical pyrometers are used for the measurement of clean gases only.

(Ref.2)

Infrared temperature sensors (Infrared thermometer)



(Ref.2)

Advantages and limitations of IR thermometers

Advantages

- Facilitates the measurement of temperatures of moving objects.
- Useful in situations where objects are placed in vacuum or in a controlled atmosphere, or the distance between the source of the temperature and the instrument of measurement is large.
- Helpful when the objects are in inaccessible areas/ hazardous conditions, wherein non-contact measurement is the only option available for determining temperature.

Limitations

- Ambient conditions such as temperature variations and percentage of CO_2 (since it absorbs infrared radiations) in the atmosphere affect accuracy.

(Ref.2)

1. https://nptel.ac.in/noc/courses/noc19/SEM1/noc19-me03/
2. L. Krishnamurthy & N.V. Raghavendra, “Engineering Metrology and Measurements”, Oxford university press.

SVCE

Sri Venkateswara College of Engineering

Autonomous - Affiliated to Anna University

ME18501- Metrology and Quality Control (R2018)

V semester

Academic Year 2021-22

UNIT-V

QUALITY CONTROL

Quality – Definitions - Meaning of quality of product & services - Quality of conformance & Quality of performance. ISO 9000 Series & other standards, necessity of ISO certification. Statistical Quality Control – Meaning and importance of SQC, Control charts for variables – X & R charts, Acceptance Sampling.

Definition of Quality

Quality may be defined in several ways as,

- The component is said to possess good quality, if it works well in the equipment, for which, it is meant. Thus, quality is defined as
    1. “fitness for purpose.” (Juran, 1974)
    2. “conformance to requirements or specifications.” (Crosby, 1979)
- Quality is a distinguishing feature or grade of product in appearance, performance, life, reliability, taste, odour, maintainability etc.
- Quality is a degree, to which, a specified product manufactured by a company is preferred by consumers over competing products of equivalent grade, but manufactured by other companies.

(Ref:1)

Garvin, in 1984 divides the definition of quality into five major categories—namely,

- transcendent
- product-based
- user-based
- manufacturing-based and value-based

(Ref:1)

Eight attributes to define product quality

Performance
Features
Reliability
Conformance
Durability
Serviceability
Aesthetics
Perceived quality

(Ref:1)

Quality of service

- From the customers' perspective, service is the combination of the customers experience and their perception of the outcome of the service.

- The term service quality (Johnston and Clark, 2008) is often used to mean different aspect. Some may use the term to mean how the customer is treated overall. This may be more accurately called “quality of service.”

(Ref:1)

Quality Characteristics

- Variables
- Attributes

Driving force - Customers

Does Quality has a time dimension?

“Need and preference of customer changes with time, the level of quality or degree of customer satisfaction also changes.”

(Ref:1)

- Internal Customer
- External Customer

Quality of Conformance

Quality of conformance is concerned with, how well; the manufactured product conforms to the 'quality of design'.

Quality of conformance is basically meeting the standards defined in the design phase after the product is manufactured or while the service is delivered.

Quality of design is defined as, "the quality specified by design engineer, on behalf of customer".

(Ref:1)

Factors Governing Quality of Design

- Types of customers in the market.
- Intended life, environmental condition, reliability, improvement in continuity of service.
- Specific requirements such as strength, fatigue resistance, life, interchangeability of manufactured items.
- Economical considerations with Profit to company.

(Ref:1)

Factors Governing Quality of Conformance

- Raw materials, machines, tools, measuring instruments should be capable of producing finished parts having adequate standards. In addition, they should be maintained properly.
- Appropriate process selection and adequate process control.
- Trained and experienced operators.
- Effective inspection programme.
- Feedbacks of internal inspection as well as customers should be analysed for taking corrective action.
- Proper care should be taken in transportation, shipment and storage of finished products or goods.

Quality of Performance

Quality of performance is concerned with, ‘how well the manufactured product gives its performance’.

Factors Governing Quality of Performance:
(i) Quality of design, and (ii) Quality of conformance.

Even if, the quality of design is best, the product may give poor performance due to lack of conformance control.

Similarly, if quality of conformance is best, the finished product may not perform well, because quality of design specified before actual manufacturing is not correct.

“Best possible quality of design and good quality of conformance, together will ensure excellent quality of performance.”

If quality of performance of product is not good, then it leads to

(i) Increase in consumer complaints,

(ii)Increase in consumers' claims for replacement within specified warranty period, against damaged product.

(iii)Increase in number of calls from consumers for repairing and servicing of product.

International Organization for Standardization (ISO)& Standards

International Organization for Standardization (ISO) is an independent, non-governmental international organization with a membership of 165 National Standard Bodies. ISO published its 9000 series of standards in 1987.

The ISO 9000 standard **specifies the guidelines for maintaining a quality system**.

The ISO standard mainly **addresses operational aspects and organizational aspects such as responsibilities, reporting**, etc.

ISO 9000 **specifies a set of guidelines for repeatable and high quality product development**.

It is important to realize that ISO 9000 standard is a **set of guidelines for the production process and is not directly concerned about the product itself**.

(Ref: 5,6)

ISO standards?

Formula that describes the best way of doing something.

It could be about making a product, managing a process, delivering a service or supplying materials – standards cover a huge range of activities.

(Ref: 5)

Necessity for ISO Certification

- Confidence of customers in an organization increases when organization qualifies for ISO certification. This is especially true in the international market.

- ISO certification makes the development process focused, efficient, and cost effective.

- ISO certification points out the weak points of an organization and recommends remedial action.

- ISO sets the basic framework for the development of an optimal process and Total Quality Management (TQM).

Types of ISO standards

- Quality management standards (ISO 9001:2015)
- Environmental management standards (ISO 14001:2015)
- Health and safety standards (ISO 45000)
- Energy management standards (ISO 50001)
- Food safety standards (ISO 22000)
- IT security standards (ISO/IEC 27001:2013)

(Ref: 5)

ISO 9000 quality standards

The ISO 9000 series of standards is based on the premise that if a proper process is followed for production, then good quality products are bound to follow automatically.

ISO 9000:2015 – Specify Fundamentals and vocabulary

ISO 9001:2015 – Specify requirements for quality management system

ISO 9004:2018 – Provides guidelines and self assessment tools to review

(Ref: 5)

ISO 9000:2015 – Specify Fundamentals and vocabulary (Extract)

3.1.1

top management

person or group of people who directs and controls an **organization** (3.2.1) at the highest level

Note 1 to entry: Top management has the power to delegate authority and provide resources within the organization.

Note 2 to entry: If the scope of the **management system** (3.5.3) covers only part of an organization, then top management refers to those who direct and control that part of the organization.

Note 3 to entry: This constitutes one of the common terms and core definitions for ISO management system standards given in Annex SL of the Consolidated ISO Supplement to the ISO/IEC Directives, Part 1.

3.1.2

quality management system consultant

person who assists the **organization** (3.2.1) on **quality management system realization** (3.4.3), giving advice or **information** (3.8.2)

Note 1 to entry: The quality management system consultant can also assist in realizing parts of a **quality management system** (3.5.4).

Note 2 to entry: ISO 10019:2005 provides guidance on how to distinguish a competent quality management system consultant from one who is not competent.

[SOURCE:ISO 10019:2005, 3.2, modified]

3.1.3

involvement

taking part in an activity, event or situation

Scope of ISO9000 standards

- Organizations seeking sustained success through the implementation of a quality management system
- Customers seeking confidence in an organization's ability to consistently provide products and services conforming to their requirements
- Organizations seeking confidence in their supply chain that product and service requirements will be met
- Organizations and interested parties seeking to improve communication through a common understanding of the vocabulary used in quality management
- Organizations performing conformity assessments against the requirements of ISO 9001
- Providers of training, assessment or advice in quality management
- Developers of related standards.

Quality Management Principles

The seven quality management principles are:

QMP 1 – Customer focus

QMP 2 – Leadership

QMP 3 – Engagement of people

QMP 4 – Process approach

QMP 5 – Improvement

QMP 6 – Evidence-based decision making

QMP 7 – Relationship management

Customer focus

- Increased customer value
- Increased customer satisfaction
- Improved customer loyalty
- Enhanced repeat business
- Enhanced reputation of the organization
- Expanded customer base
- Increased revenue and market share

(Ref: 5)

Leadership

- Increased effectiveness and efficiency in meeting the organization’s quality objectives
- Better coordination of the organization’s processes
- Improved communication between levels and functions of the organization
- Development and improvement of the capability of the organization and its people to deliver desired results

Engagement of People

- Improved understanding of the organization's quality objectives by people in the organization and increased motivation to achieve them
- Enhanced involvement of people in improvement activities
- Enhanced personal development, initiatives and creativity
- Enhanced people satisfaction
- Enhanced trust and collaboration throughout the organization
- Increased attention to shared values and culture throughout the organization

Process approach

- Enhanced ability to focus effort on key processes and opportunities for improvement
- Consistent and predictable outcomes through a system of aligned processes
- Optimized performance through effective process management, efficient use of resources, and reduced cross-functional barriers
- Enabling the organization to provide confidence to interested parties as to its consistency, effectiveness and efficiency

Improvement

- Improved process performance, organizational capabilities and customer satisfaction
- Enhanced focus on root-cause investigation and determination, followed by prevention and corrective actions
- Enhanced ability to anticipate and react to internal and external risks and opportunities
- Enhanced consideration of both incremental and breakthrough improvement
- Improved use of learning for improvement
- Enhanced drive for innovation

Evidence-based decision making

- Improved decision-making processes
- Improved assessment of process performance and ability to achieve objectives
- Improved operational effectiveness and efficiency
- Increased ability to review, challenge and change opinions and decisions
- Increased ability to demonstrate the effectiveness of past decisions

Relationship management

- Enhanced performance of the organization and its interested parties through responding to the opportunities and constraints related to each interested party
- Common understanding of goals and values among interested parties
- Increased capability to create value for interested parties by sharing resources and competence and managing quality-related risks
- A well-managed supply chain that provides a stable flow of goods and services

ISO9000 series

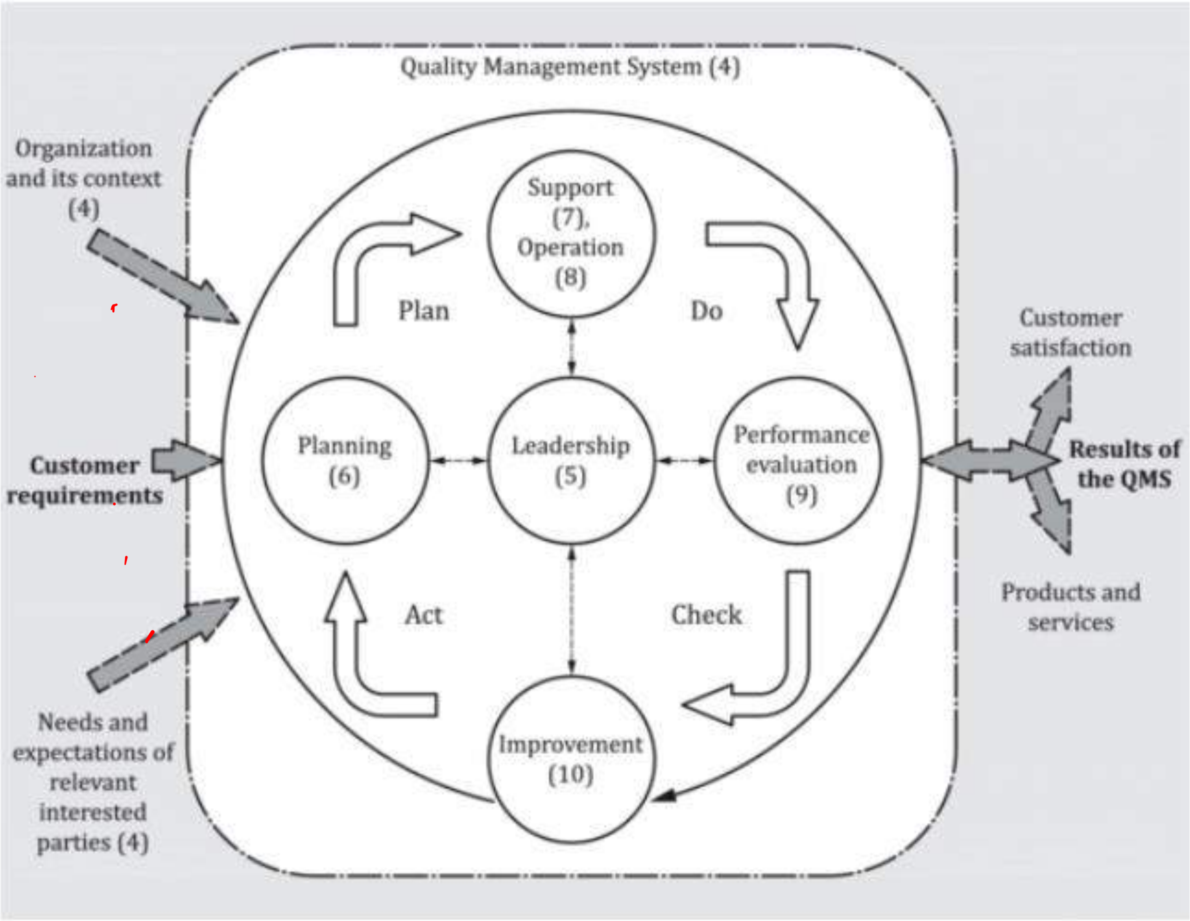
- There are 10 sections (clauses) in ISO 9001.
- Sections 4-10 contain requirements that are auditable.
- To successfully implement ISO 9001:2015 Any organization must satisfy the requirements within clauses 4-10 along with meeting customer and applicable statutory and regulatory requirements.

(Ref: 7)

Sections of ISO9001

- Scope
- Normative References
- Terms and Definitions
- Context of the Organization
- Leadership
- Planning
- Support
- Operation
- Performance Evaluation
- Improvement

Plan-Do-Check-Act (PDCA) cycle



(Ref: 5)

Section 4: Context of the Organization

1. Thoughtfully align your business objectives and intent with the QMS.

2. Determine
   i. External and internal issues
   ii. Needs and expectations of interested parties
   iii. Quality management system scope

(Ref: 7)

Section 5: Leadership

Top management must

1. Demonstrate leadership and commitment
2. Establish and communicate a quality policy
3. Ensure responsibilities and authorities are assigned, communicated and understood

Section 6: Planning

Address

1. Organizational risks
2. Opportunities
3. Changes and quality objectives

(Ref: 7)

Section 7: Support

1. Providing resources
2. Ensures employees are competent and aware
3. Provides documented information to support the quality management system

(Ref: 7)

Section 8: Operation

Covers the **plan and control processes** needed to meet the requirements for products and services (design and development, external providers, production and service provision, release of products and services, nonconforming outputs).

(Ref: 7)

Section 9: Performance Evaluation

ISO 9001 requires your organization's QMS to **monitor, measure, analyze, and evaluate** your quality management system.

(Ref: 7)

Section 10: Improvement

1. Select opportunities for improvement
2. Take action against nonconformities
3. Implement corrective actions as necessary
4. Continually improve your quality management system

(Ref: 7)

Statistical Quality Control

- Refers to the use of statistical methods in the monitoring and maintaining of the quality of products and services

- Categories of SQC
  - Statistical Process Control
  - Descriptive Statistics
  - Acceptance Sampling

(Ref: 8)

Statistical Process Control

- Collect data from the process and compare to control limits
- Analyse and find reasons for deviations if any.

SPC Techniques

1. Control Charts
2. Histograms
3. Run Charts
4. Pareto charts
5. Cause and effect diagram
6. Flow diagram
7. Scatter diagram

(Ref: 8)

Chance and Assignable causes of Quality variation

- Inherent or natural variability (Background noise)

  - Unavoidable causes (Chance causes)

“A process that is operating only with chance causes of variation present is said to be in a statistical control”

- Other variabilities from three sources

  -Improperly adjusted machines

  -Operator errors

  -Defective raw materials

  } **Assignable causes**

“A process that is operating in the presence of assignable causes is said to be out of control”

(Ref: 9)

Control Charts

- Used to monitor, control and improve process performance over time by studying variations and its sources.

- Types of control charts:

Control charts by variables (X-bar and R charts)

Control charts by attributes (P and C charts)

(Ref: 8)

X bar chart

- To monitor changes in the mean of a process

R chart

- To monitor the dispersion or variability of the process

(Ref: 8)

Statistical Basis of the chart

Suppose that a quality characteristic is normally distributed with mean **μ** and standard deviation **σ** where both are known.

If $x_1, x_2, \ldots x_n$ is a sample of size n then the average of the sample is

$\bar{x} = (x_1+x_2+\ldots x_n)/n$

If there are 'm' such samples then the grand average is

$\bar{\bar{x}} = (\bar{x}_1+\bar{x}_2+\ldots\bar{x}_m)/m$

(Ref: 9)

- If $x_1, x_2, \ldots. x_n$ is a sample of size n then the Range of the sample is

$R = x_{max} - x_{min}$

If $R_1, R_2, \ldots R_m$ are the ranges of the 'm' samples, then

$\bar{R} = (R_1 + R_2 + \ldots R_m)/m$

(Ref: 9)

X bar chart

Upper control Limit = UCL = $\bar{\bar{x}} + \frac{3\bar{R}}{d_2\sqrt{n}} = \bar{\bar{x}} + A_2 \bar{R}$

Lower control Limit = LCL = $\bar{\bar{x}} - \frac{3\bar{R}}{d_2\sqrt{n}} = \bar{\bar{x}} - A_2 \bar{R}$

R Chart

Upper control Limit = UCL = $D_4 \bar{R}$

Lower control Limit = LCL = $D_3 \bar{R}$

(Ref: 9)

Factors useful in the Construction of Control Charts

	Chart for Averages			*Chart for standard deviations*					*Chart for Ranges*						
	Factors for Control Limits			*Factors for: Central Line*	*Factors for: Control Limits*				*Factors for Central Line*		*Factors for Control Limits*				
n	A	A_2	A_3	c_4	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	0	3.267	0	2.606	1.128	0.8862	0.852	0	3.686	0	3.266
3	1.732	1.023	1.954	0.8862	0	2.568	0	2.276	1.693	0.5908	0.888	0	4.357	0	2.574
4	1.500	0.729	1.628	0.9213	0	2.266	0	2.088	2.059	0.4857	0.879	0	4.697	0	2.281
5	1.342	0.577	1.427	0.9400	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.003
7	1.134	0.419	1.182	0.9594	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.206	5.203	0.076	1.924
8	1.061	0.373	1.099	0.9650	0.185	1.815	0.179	1.751	2.847	0.3512	0.819	0.389	5.306	0.137	1.863
9	1.000	0.337	1.032	0.9693	0.239	1.761	0.232	1.707	2.970	0.3367	0.807	0.548	5.392	0.184	1.816
10	0.949	0.308	0.975	0.9727	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.688	5.467	0.223	1.777
11	0.905	0.285	0.927	0.9754	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.813	5.533	0.256	1.744
12	0.866	0.266	0.886	0.9776	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.924	5.593	0.284	1.716
13	0.832	0.249	0.850	0.9794	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.026	5.646	0.307	1.693
14	0.802	0.235	0.817	0.9810	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.119	5.695	0.328	1.672
15	0.775	0.223	0.789	0.9823	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.204	5.739	0.347	1.653
16	0.750	0.212	0.763	0.9835	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.283	5.781	0.363	1.637
17	0.728	0.203	0.739	0.9845	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.357	5.819	0.378	1.622
18	0.707	0.194	0.718	0.9854	0.482	1.518	0.475	1.496	3.640	0.2747	0.738	1.425	5.855	0.392	1.608
19	0.688	0.187	0.698	0.9862	0.497	1.503	0.490	1.483	3.689	0.2711	0.733	1.490	5.888	0.404	1.596
20	0.671	0.180	0.680	0.9869	0.510	1.490	0.504	1.470	3.735	0.2677	0.728	1.550	5.920	0.415	1.585
21	0.655	0.173	0.663	0.9876	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.607	5.950	0.425	1.575
22	0.640	0.167	0.647	0.9882	0.534	1.466	0.528	1.448	3.819	0.2618	0.719	1.661	5.978	0.435	1.565
23	0.626	0.162	0.633	0.9887	0.545	1.455	0.539	1.438	3.858	0.2592	0.715	1.712	6.004	0.444	1.556
24	0.612	0.157	0.619	0.9892	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.761	6.030	0.452	1.548
25	0.600	0.153	0.606	0.9896	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.807	6.055	0.460	1.540
Over 25	$3/\sqrt{n}$	$3/d_2\sqrt{n}$	---	---	*	**	---	---	---	---	---	---	---	---	---

Selection of quality characteristics

- Give priority to those characteristics that cause more nonconfirming items and that increases costs

(Ref: 10)

Selection of samples

Maximize difference between samples

Minimize difference within the samples

Lots from which samples are chosen should be homogeneous

Sample Size

Normally between 4 and 10

(Ref: 10)

Frequency of sampling

Depends on the cost of obtaining information to the cost of not detecting the nonconforming items

Type of Measuring Instruments

(Ref: 10)

In semiconductor manufacturing, a manufacturer wish to establish statistical control of the flow width of the wafers using $\bar{x}$ and R charts. Twenty-five samples, each of size five wafers, have been taken. The interval of time between samples or subgroups is one hour. The flow width measurement data (in x microns) from these samples are shown in Table. Draw the $\bar{x}$ and R charts and check whether the process is in control or not.

(Ref: 9)

Sample Number	Wafers						
	1	2	3	4	5	$\bar{x}_i$	R_i
1	1.3235	1.4128	1.6744	1.4573	1.6914	1.5119	0.3679
2	1.4314	1.3592	1.6075	1.4666	1.6109	1.4951	0.2517
3	1.4284	1.4871	1.4932	1.4324	1.5674	1.4817	0.1390
4	1.5028	1.6352	1.3841	1.2831	1.5507	1.4712	0.3521
5	1.5604	1.2735	1.5265	1.4363	1.6441	1.4882	0.3706
6	1.5955	1.5451	1.3574	1.3281	1.4198	1.4492	0.2674
7	1.6274	1.5064	1.8366	1.4177	1.5144	1.5805	0.4189
8	1.4190	1.4303	1.6637	1.6067	1.5519	1.5343	0.2447
9	1.3884	1.7277	1.5355	1.5176	1.3688	1.5076	0.3589
10	1.4039	1.6697	1.5089	1.4627	1.5220	1.5134	0.2658
11	1.4158	1.7667	1.4278	1.5928	1.4181	1.5242	0.3509
12	1.5821	1.3355	1.5777	1.3908	1.7559	1.5284	0.4204
13	1.2856	1.4106	1.4447	1.6398	1.1928	1.3947	0.4470
14	1.4951	1.4036	1.5893	1.6458	1.4969	1.5261	0.2422
15	1.3589	1.2863	1.5996	1.2497	1.5471	1.4083	0.3499
16	1.5747	1.5301	1.5171	1.1839	1.8662	1.5344	0.6823
17	1.3680	1.7269	1.3957	1.5014	1.4449	1.4874	0.3589
18	1.4163	1.3864	1.3057	1.6210	1.5573	1.4573	0.3153
19	1.5796	1.4185	1.6541	1.5116	1.7247	1.5777	0.3062
20	1.7106	1.4412	1.2361	1.3820	1.7601	1.5060	0.5240
21	1.4371	1.5051	1.3485	1.5670	1.4880	1.4691	0.2185
22	1.4738	1.5936	1.6583	1.4973	1.4720	1.5390	0.1863
23	1.5917	1.4333	1.5551	1.5295	1.6866	1.5592	0.2533
24	1.6399	1.5243	1.5705	1.5563	1.5530	1.5688	0.1156
25	1.5797	1.3663	1.6240	1.3732	1.6887	1.5264	0.3224
						$\Sigma\bar{x}_i = 37.6400$	$\Sigma R_i = 8.1302$
						$\bar{\bar{x}} = 1.5056$	$\bar{R} = 0.32521$

(Ref: 9)

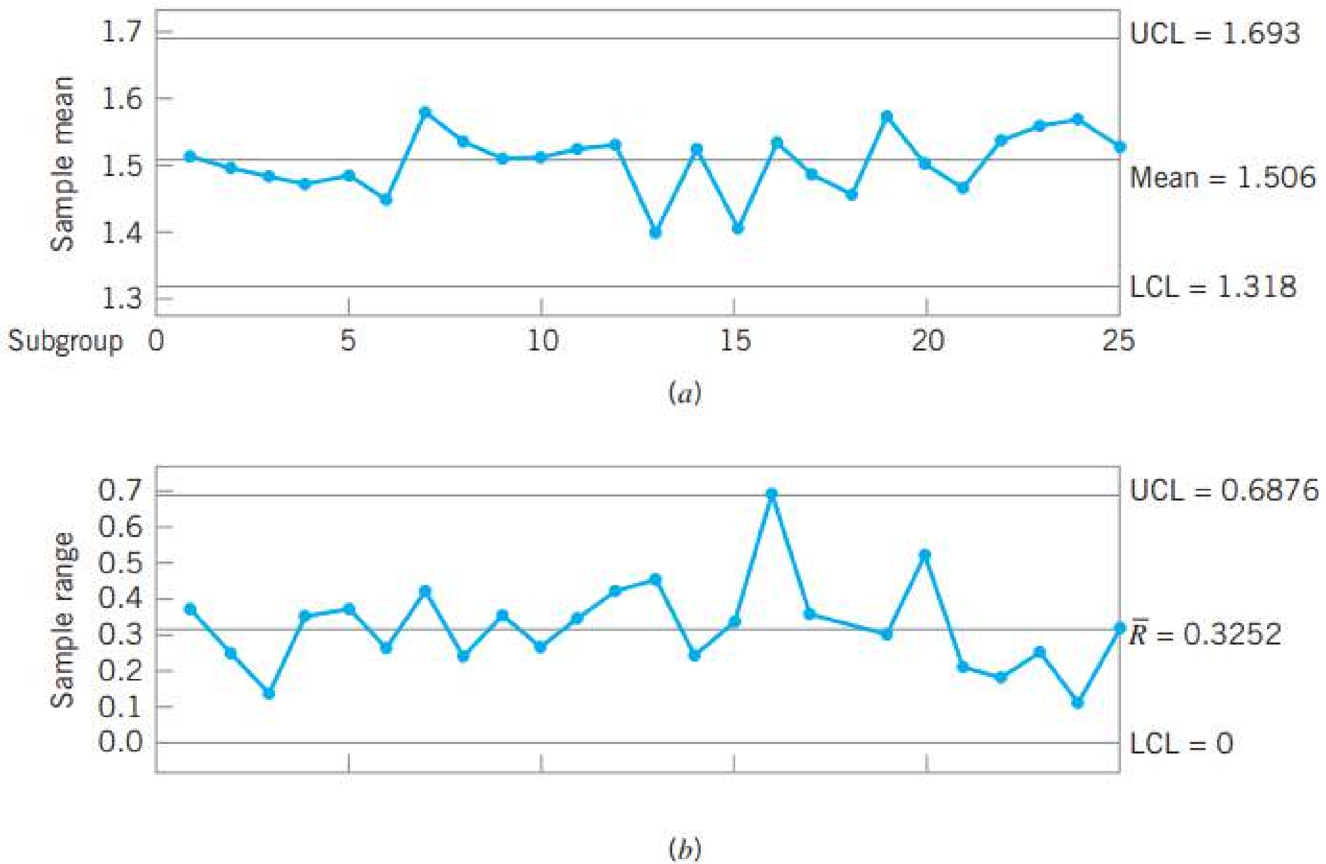
$$\overline{R} = \frac{\sum_{i=1}^{25} R_i}{25} = \frac{8.1302}{25} = 0.32521$$

$$\overline{\overline{x}} = \frac{\sum_{i=1}^{25} \overline{x}_i}{25} = \frac{37.6400}{25} = 1.5056$$

$$\text{LCL} = \overline{R} D_3 = 0.32521(0) = 0$$
$$\text{UCL} = \overline{R} D_4 = 0.32521(2.114) = 0.68749$$

$$\text{LCL} = \overline{\overline{x}} - A_2 \overline{R} = 1.5056 - (0.577)(0.32521) = 1.31795$$
$$\text{UCL} = \overline{\overline{x}} + A_2 \overline{R} = 1.5056 + (0.577)(0.32521) = 1.69325$$

(Ref: 9)

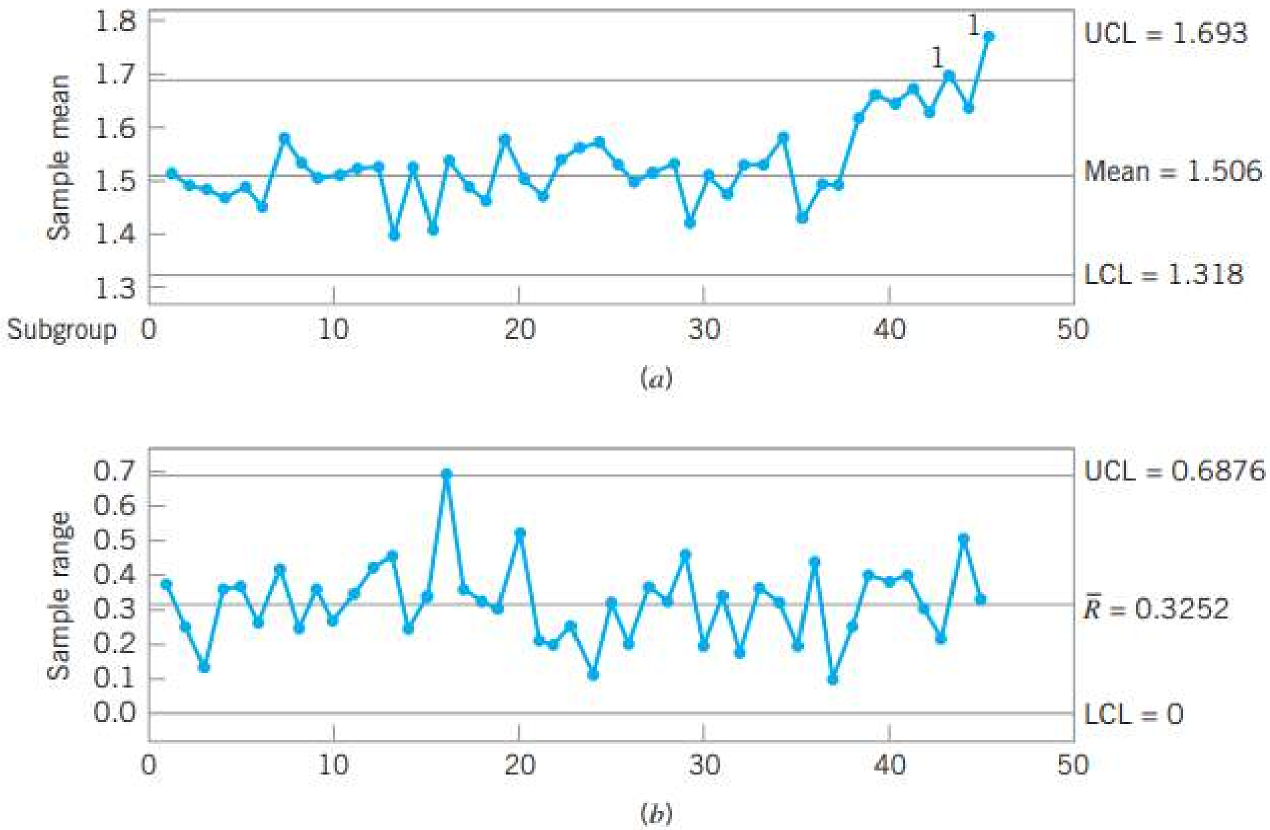


Sample mean
1.7
1.6
1.5
1.4
1.3
UCL = 1.693
Mean = 1.506
LCL = 1.318
Subgroup 0 5 10 15 20 25
(a)
Sample range
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
UCL = 0.6876
$\bar{R}$ = 0.3252
LCL = 0
(b)

(Ref: 9)

Sample Number	Wafers						
	1	2	3	4	5	$\bar{x}_i$	R_i
26	1.4483	1.5458	1.4538	1.4303	1.6206	1.4998	0.1903
27	1.5435	1.6899	1.5830	1.3358	1.4187	1.5142	0.3541
28	1.5175	1.3446	1.4723	1.6657	1.6661	1.5332	0.3215
29	1.5454	1.0931	1.4072	1.5039	1.5264	1.4152	0.4523
30	1.4418	1.5059	1.5124	1.4620	1.6263	1.5097	0.1845
31	1.4301	1.2725	1.5945	1.5397	1.5252	1.4724	0.3220
32	1.4981	1.4506	1.6174	1.5837	1.4962	1.5292	0.1668
33	1.3009	1.5060	1.6231	1.5831	1.6454	1.5317	0.3445
34	1.4132	1.4603	1.5808	1.7111	1.7313	1.5793	0.3181
35	1.3817	1.3135	1.4953	1.4894	1.4596	1.4279	0.1818
36	1.5765	1.7014	1.4026	1.2773	1.4541	1.4824	0.4241
37	1.4936	1.4373	1.5139	1.4808	1.5293	1.4910	0.0920
38	1.5729	1.6738	1.5048	1.5651	1.7473	1.6128	0.2425
39	1.8089	1.5513	1.8250	1.4389	1.6558	1.6560	0.3861
40	1.6236	1.5393	1.6738	1.8698	1.5036	1.6420	0.3662
41	1.4120	1.7931	1.7345	1.6391	1.7791	1.6716	0.3811
42	1.7372	1.5663	1.4910	1.7809	1.5504	1.6252	0.2899
43	1.5971	1.7394	1.6832	1.6677	1.7974	1.6970	0.2003
44	1.4295	1.6536	1.9134	1.7272	1.4370	1.6321	0.4839
45	1.6217	1.8220	1.7915	1.6744	1.9404	1.7700	0.3187

(Ref: 9)


Sample mean
1.8
1.7
1.6
1.5
1.4
1.3
Subgroup
0
10
20
30
40
50
UCL = 1.693
Mean = 1.506
LCL = 1.318
(a)
Sample range
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
UCL = 0.6876
$\bar{R}$ = 0.3252
LCL = 0
(b)

(Ref: 9)

Acceptance sampling

A procedure for sentencing incoming batches without doing 100% inspection

Why not 100% inspection?

- Expensive
- Not possible when products are to be destroyed to test
- Inspection handling itself will induce defects
- Inspection become tedious

Advantages of sampling inspection

- Lower cost
- Less staff
- Less risk of handling damages
- Less time

(Ref: 10)

Disadvantages of sampling inspection

- Risk of rejecting good lot **(Producer's risk)** and accepting poor lot **(Consumer's risk)**
- Less information about the product compared to 100% inspection
- Selection and adoption of sampling plan require more time

(Ref: 10)

Application points for acceptance sampling

- Raw materials and purchased parts
- Finished parts
- Before a costly operation
- Before an irreversible process

Acceptance plan

- Set of procedures for inspecting incoming materials or finished goods

- Identifies

  Type of sample

  Sample size (n)

  Criteria (c) - to accept or reject lot

- Producer and consumer must negotiate

Single sampling plan

N=Lot size

n= sample size

c= acceptance number

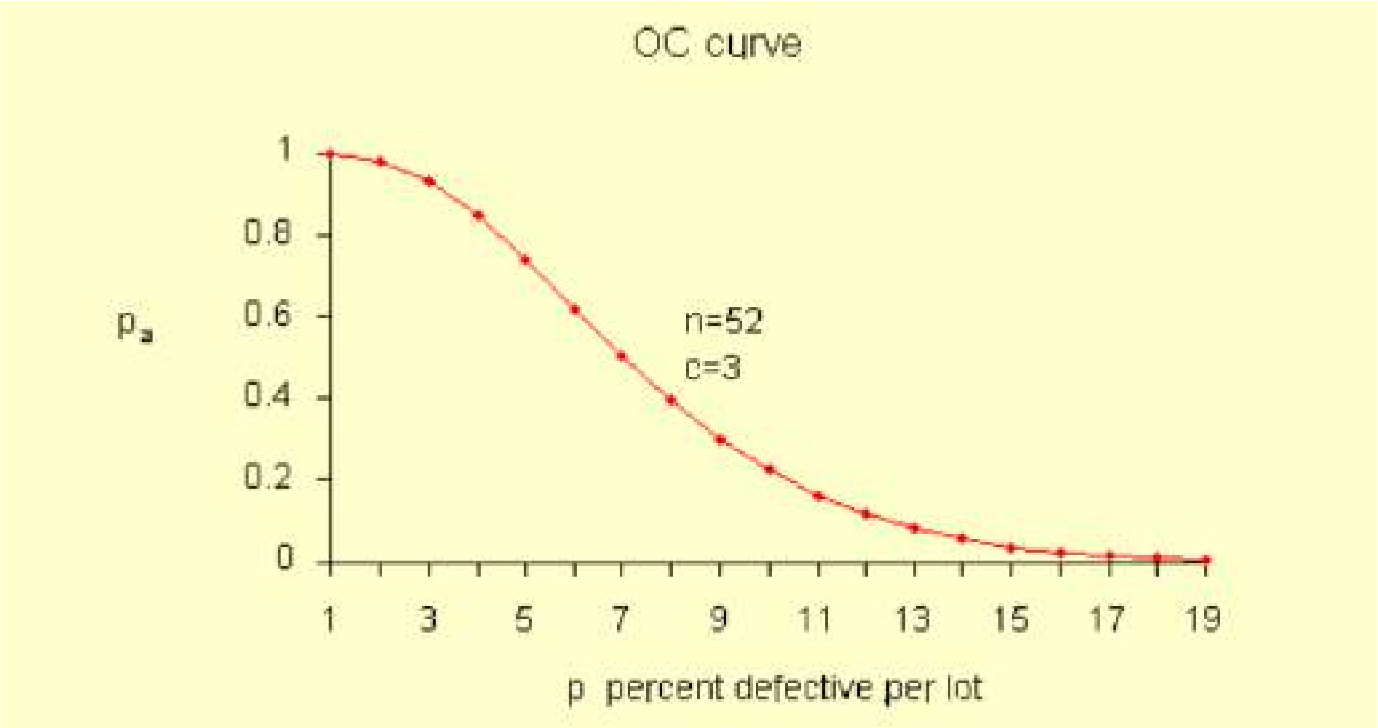
d = number of defective items in the sample

If d<=c, accept; else reject the lot

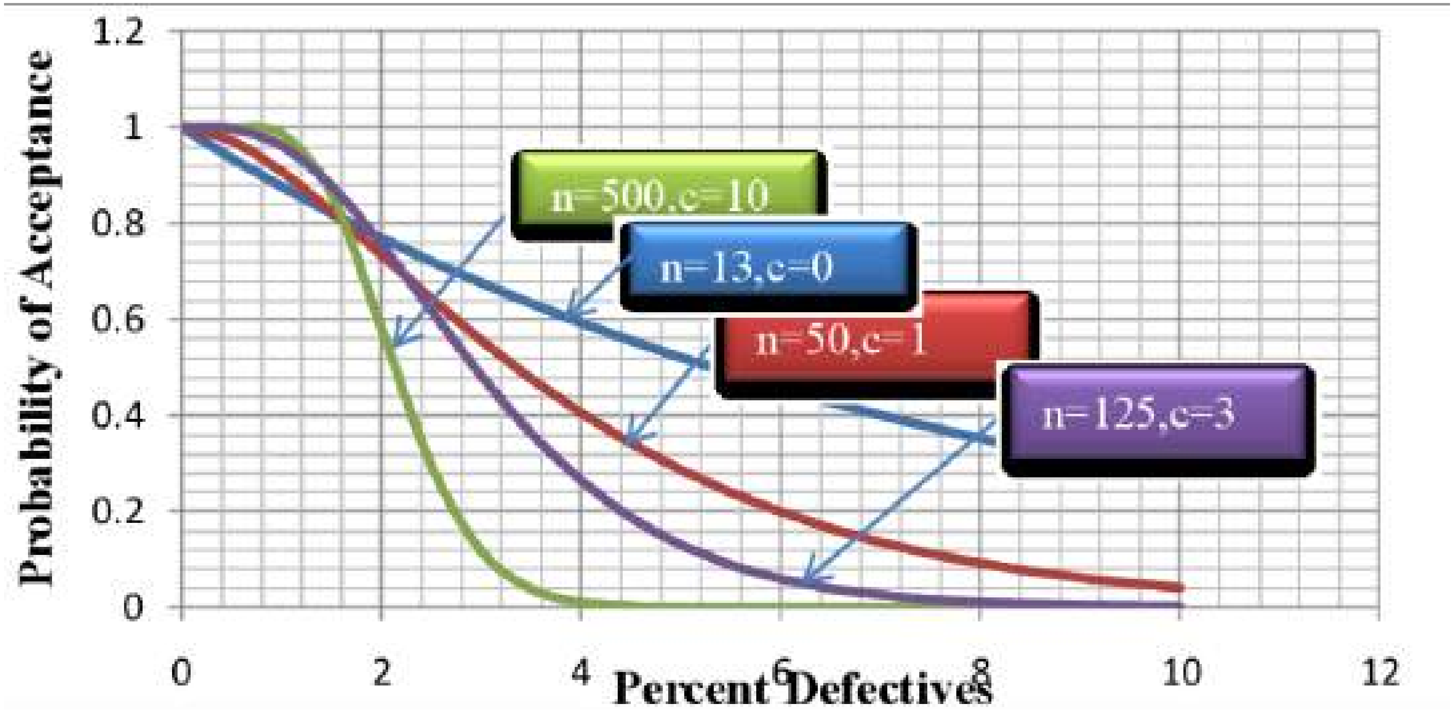
Sampling Errors

- Type I (α Error or Producer's Risk)
- Type II (β Error or Consumer's Risk)

		The Truth (Based on Entire Population)	
		Nothing Is There (H_0 Is True)	Something Is There (H_0 Is False)
Your Conclusion (Based on Your Sample)	I Don't See Anything (Nonsignificant)	Right!	Wrong (Type II Error)
	I See Something (Significant)	Wrong (Type I Error)	Right!



OC curve
1
0.8
0.6
0.4
0.2
0
p_a
n=52
c=3
1
3
5
7
9
11
13
15
17
19
p percent defective per lot



Probability of Acceptance
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
Percent Defectives
n=500,c=10
n=13,c=0
n=50,c=1
n=125,c=3

Draw the X and R chart for the following diameter measurements (Class room exercise)

Sample Number	Observations		
1	74.030	74.002	74.019
2	73.995	73.992	74.001
3	73.988	74.024	74.021
4	74.002	73.996	73.993
5	73.992	74.007	74.015
6	74.009	73.994	73.997
7	73.995	74.006	73.994
8	73.985	74.003	73.993
9	74.008	73.995	74.009
10	73.998	74.000	73.990
11	73.994	73.998	73.994
12	74.004	74.000	74.007
13	73.983	74.002	73.998
14	74.006	73.967	73.994
15	74.012	74.014	73.998
16	74.000	73.984	74.005
17	73.994	74.012	73.986
18	74.006	74.010	74.018
19	73.984	74.002	74.003
20	74.000	74.010	74.013
21	73.982	74.001	74.015
22	74.004	73.999	73.990
23	74.010	73.989	73.990
24	74.015	74.008	73.993
25	73.982	73.984	73.995

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