SURFACE ROUGHNESS MEASUREMENT

CONTENTS

Measurement of surface finish

- Basic understanding of surface roughness
- Indication of finish on drawings
- Parameters of surface finish
- Measurement methods: contact and non contact type
- Care of instruments

Why surface finish?

Surface finish, also known a surface texture or surface topography, is the nature of a surface as defined by the characteristics such as **lay, surface roughness, and waviness.**

Surface texture is one of the important factors that **control friction during sliding**.

- To improve look and feel of a product
- Fit between parts
- To control the process that results in the surface needed.

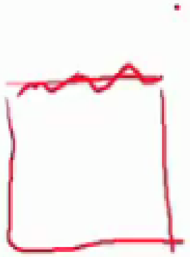
Importance of surface finish

- Surface roughness, is important from the point of view of fundamental problems such as friction and wear, surface contact, lubrication, fatigue strength, and tightness of joints.
- It affects conduction of heat and electrical current, cleanliness, reflectivity of the surface, sealing action.
- It also affects the positional accuracy of mating parts, load-carrying capacity, resistance to corrosion and adhesion of paint and coatings .
- The accuracy and surface-finish requirements for machined parts in modern industry are becoming more and more stringent.

- If the machining imperfections exceed design specifications, the functionality of the product is affected.
- So, it is essential to check whether the design of the work piece complies with the functional requirements
- Hence , it is necessary to check the geometry and the surface characteristics of the work piece

Understanding Surface Texture

- To examine the deviation between points on a surface and other points on the same surface
- Every part's surface is made up of texture and roughness which varies due to manufacturing techniques.
- To understand a component's surface and to control the manufacturing process to the degree required in today's modern world, it is necessary to quantify the surface.
- Surface texture parameters can be grouped into these basic categories: Roughness, Waviness, Spacing, and Hybrid.

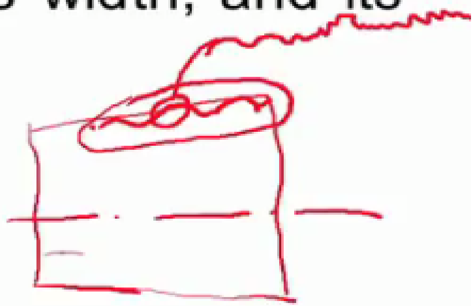


The principal elements of surfaces

Surface: The surface of an object is the boundary which separates that object from another substance. Its shape and extent are usually defined by a drawing or descriptive specifications.

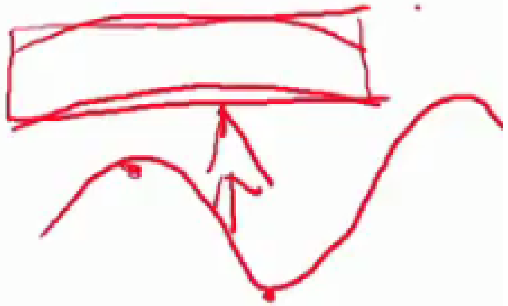
Profile: It is the contour of any specified section through a surface.

Roughness: It is defined as closely spaced, irregular deviations on a scale smaller than that of waviness. Roughness may be superimposed on waviness. Roughness is expressed in terms of its height, its width, and its distance on the surface along which it is measured.



Waviness: It is a recurrent deviation from a flat surface, much like waves on the surface of water. It is measured and described in terms of the space between adjacent crests of the waves (waviness width) and height between the crests and valleys of the waves (waviness height).

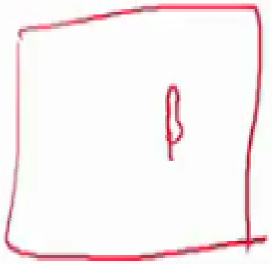
Waviness is caused by,

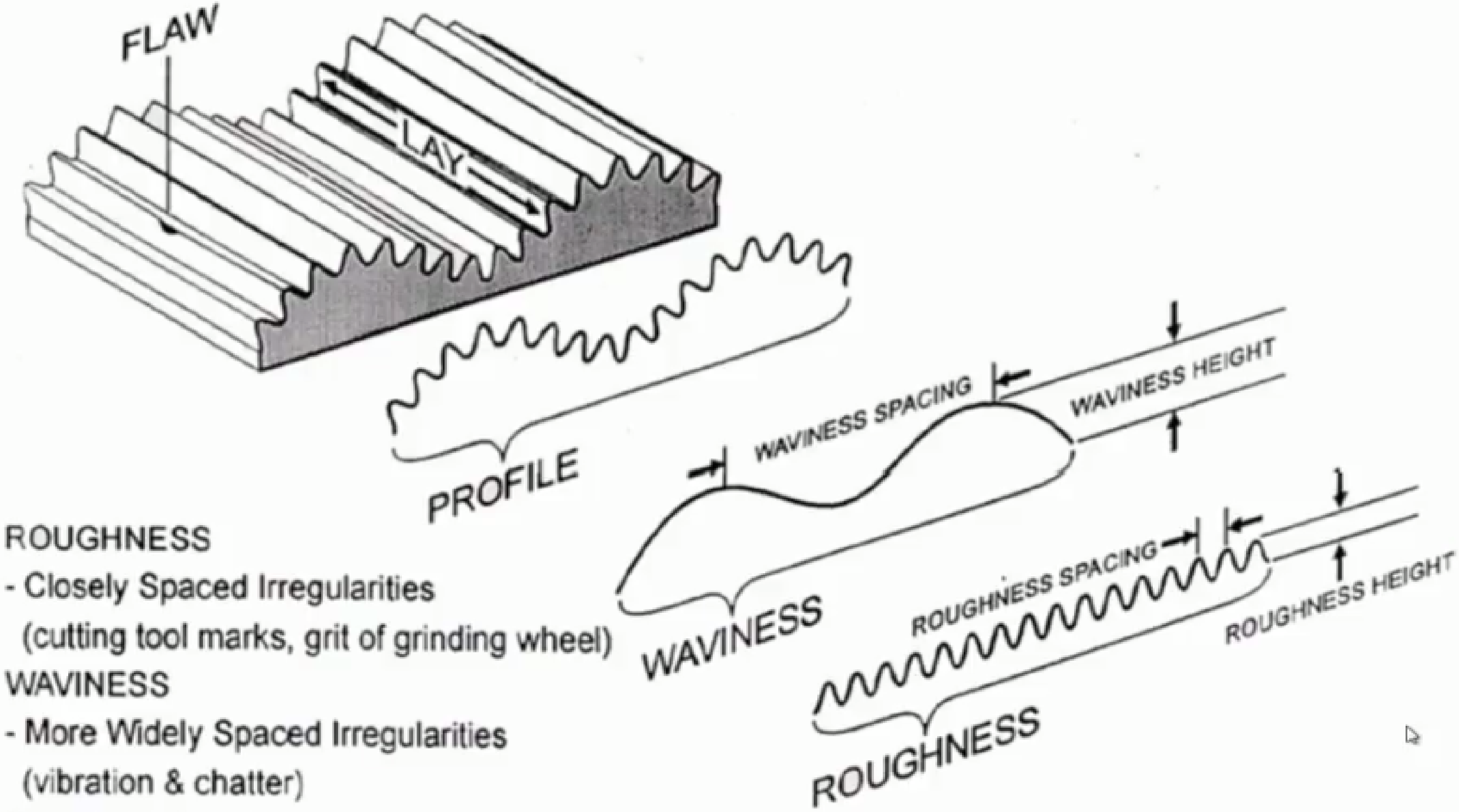


- Deflections of tools, dies, or the work piece,
- Forces or temperature sufficient to cause warping,
- Uneven lubrication,
- Vibration, or
- Any periodic mechanical or thermal variations in the system during manufacturing operations.

Flaws: Flaws, or defects, are random irregularities, such as scratches, cracks, holes, depressions, seams, tears, or inclusions.

Lay: Lay, or directionality, is the direction of the predominant surface pattern and is usually visible to the naked eye.





ROUGHNESS

- Closely Spaced Irregularities
  (cutting tool marks, grit of grinding wheel)

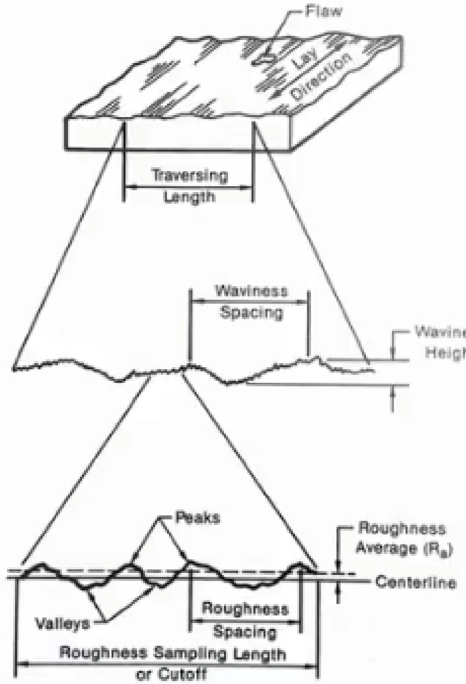
WAVINESS

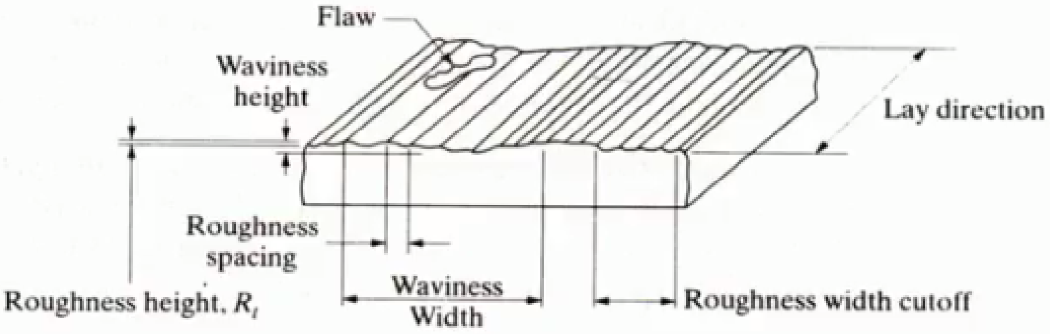
- More Widely Spaced Irregularities
  (vibration & chatter)

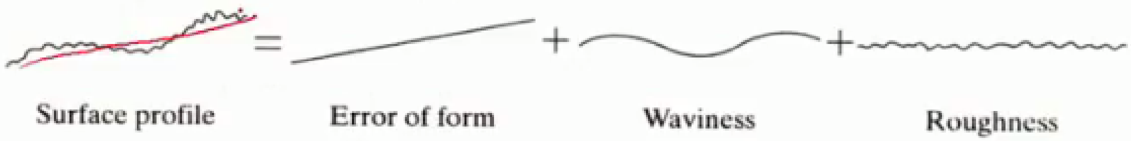
ERROR OF FORM

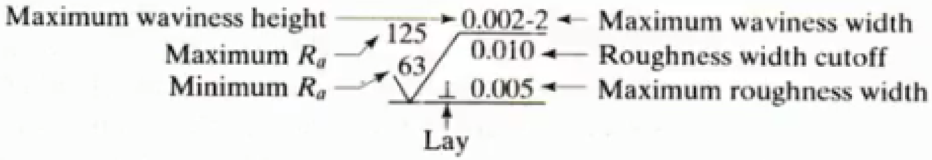
- Long Period or Non-cyclic Deviations
  (errors in ways or spindles, uneven wear)

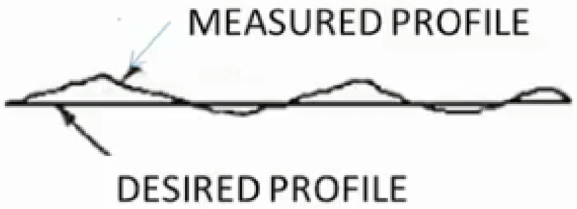
Surface roughness terminology



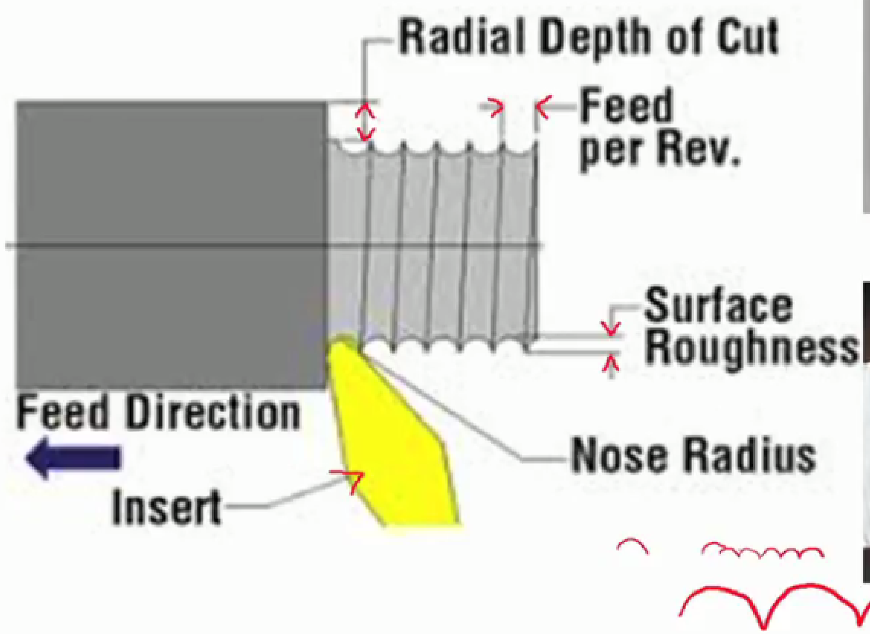


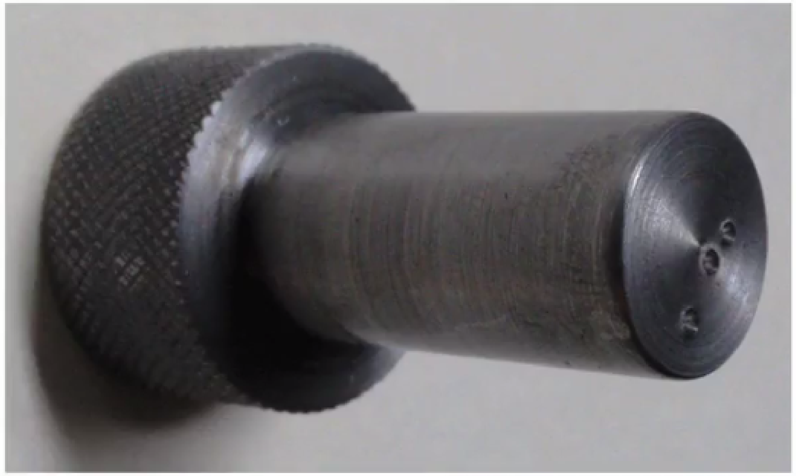






Turning operation





SURFACE ROUGHNESS IN MACHINING

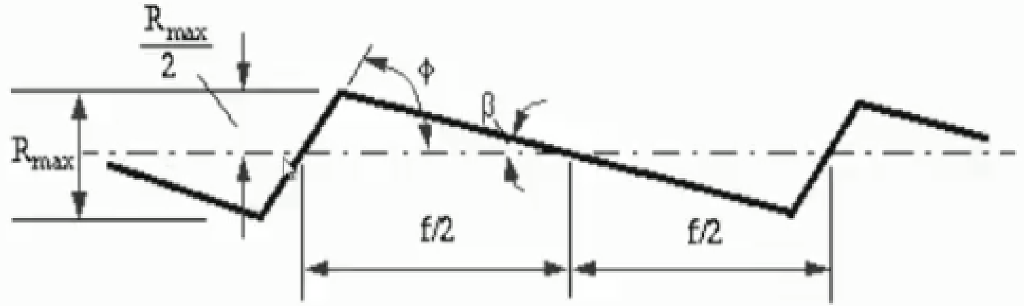
The resultant roughness produced by a machining process is a combination of two quantities:

a. Ideal roughness

b. Natural roughness

Ideal roughness: Ideal surface roughness is a function of feed and geometry of the tool. It represents the best possible finish which can be obtained for a given tool shape and feed**. It can be achieved only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely**

Idealized model of surface roughness



Natural roughness: Factors contributing to natural roughness are the **occurrence of built-up edge and vibration of the machine tool**.

Factors tending to reduce chip-tool friction and factors reducing the built-up edge would give improved surface finish.

- For a sharp tool without nose radius, the maximum height of unevenness is given by: $R_{max} = f / (\cot\varphi \cot\beta)$
- Where, f is feed rate, φ is major cutting edge angle and β is the minor cutting edge angle.
- The surface roughness value is given by, $Ra = Rmax/4$
- Practical cutting tools are usually provided with a rounded corner
- The roughness value is closely related to the feed and corner radius by the following expression:

$R_a = (0.0321 f^2)/r$, where r is the corner radius.

FACTORS AFFECTING THE SURFACE FINISH

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

A) The machining variables which include

a) Cutting speed

b) Feed, and

c) Depth of cut.

B) The tool geometry

Some geometric factors which affect achieved surface finish include:

a) Nose radius

b) Rake angle

c) Side cutting edge angle, and

d) Cutting edge.

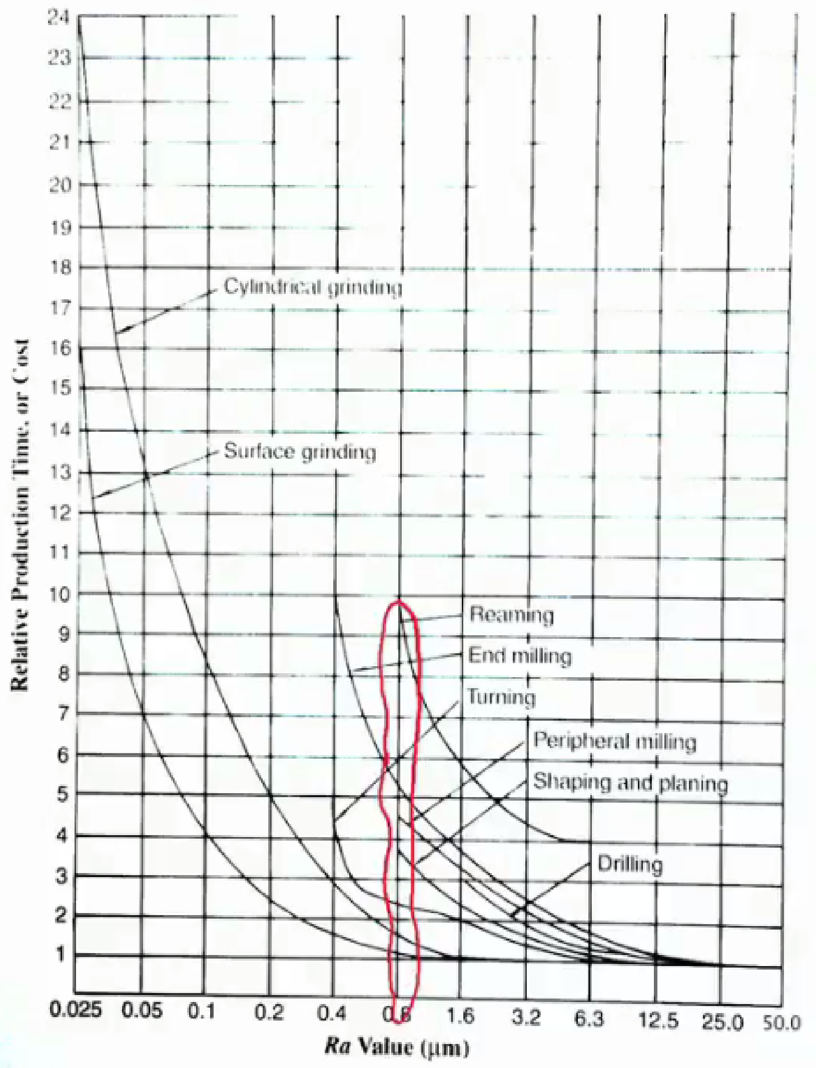
C) Work piece and tool material combination and their mechanical properties

D) Quality and type of the machine tool used,

E) Auxiliary tooling, and lubricant used, and

F) Vibrations between the work piece, machine tool and cutting tool.

Relative production cost or time necessary to produce surface finish by different processes

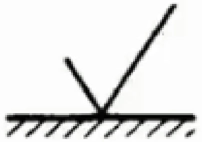


Surface roughness values for common production processes

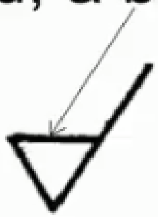
Plain glass cutting by hot air jet, Ra < 1 µm
(E.S. Prakash , 2000)

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

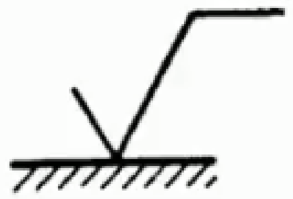


- If the removal of material by **machining** is required, a bar is added to the basic symbol

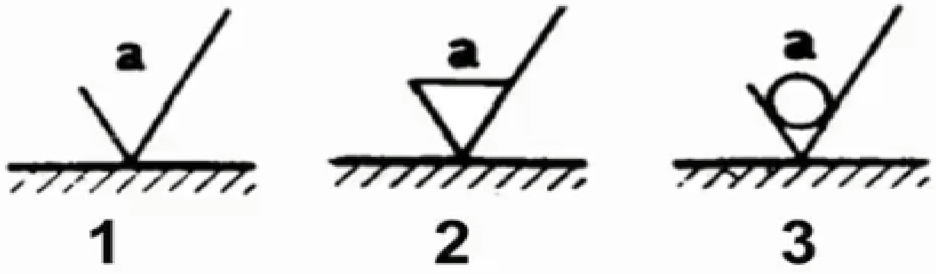


- If the **removal of material is not permitted**, a circle is added to the basic symbol.

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



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

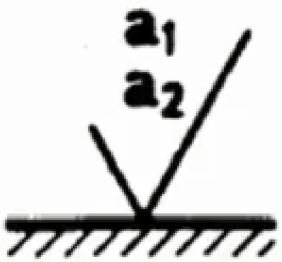


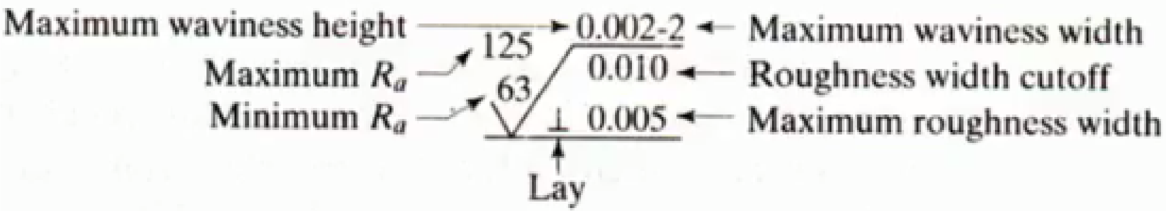
a- surface roughness value

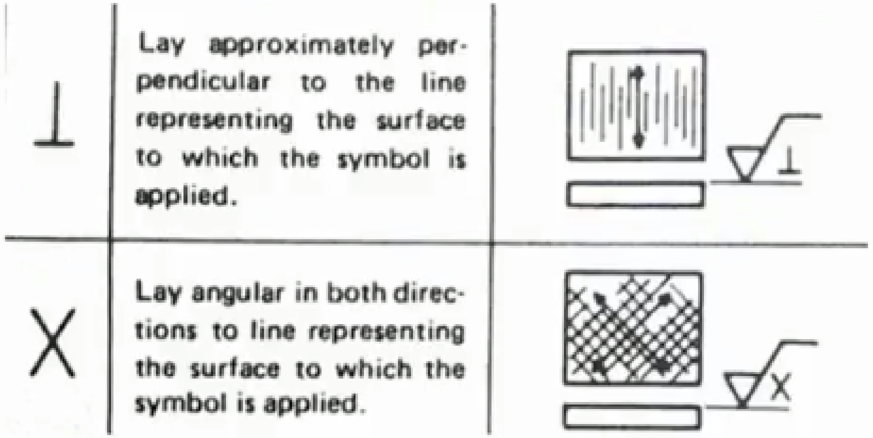
1. Roughness **a** obtained by any production process
2. Roughness **a** obtained by machining
3. Roughness **a** obtained without removal of material

- If it is necessary to impose maximum and minimum limits of surface roughness, both values are indicated

Maximum limit (a_1) ; minimum limit (a_2)

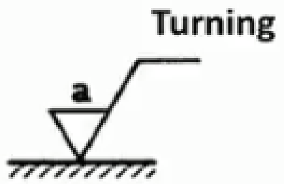




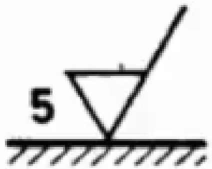


⊥	Lay approximately perpendicular to the line representing the surface to which the symbol is applied.	
X	Lay angular in both directions to line representing the surface to which the symbol is applied.	

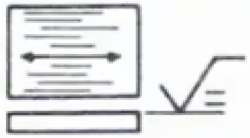
- If it is required that the **surface texture** be produced by a **particular production method**, this method is indicated in plain language on the extension of the longer arm of the symbol

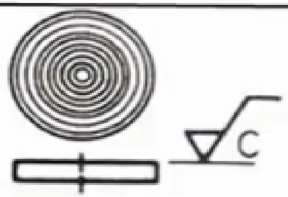
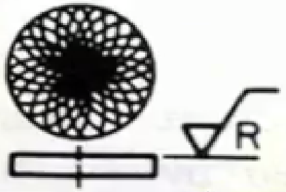
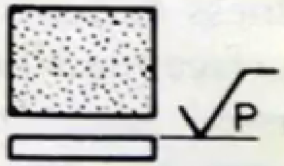


- **Indication of machining allowance:** Where it is necessary to specify the value of the machining allowance, this is indicated on the **left of the symbol**. This value shall be expressed in **millimeters**.

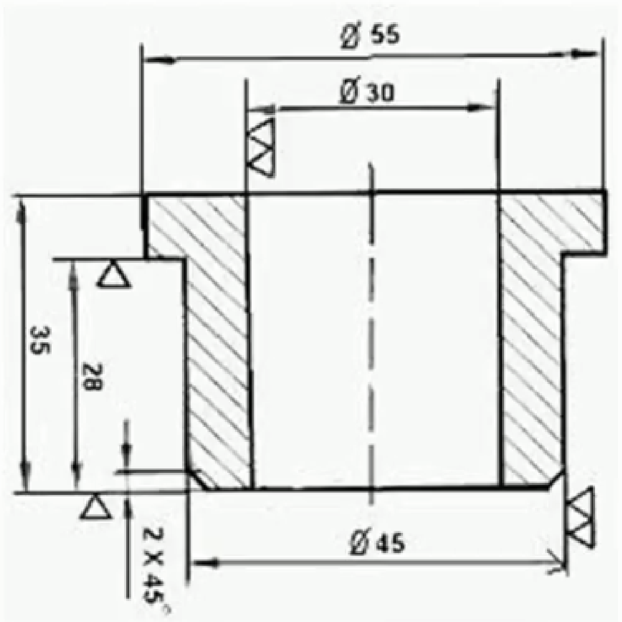


Surface texture symbols

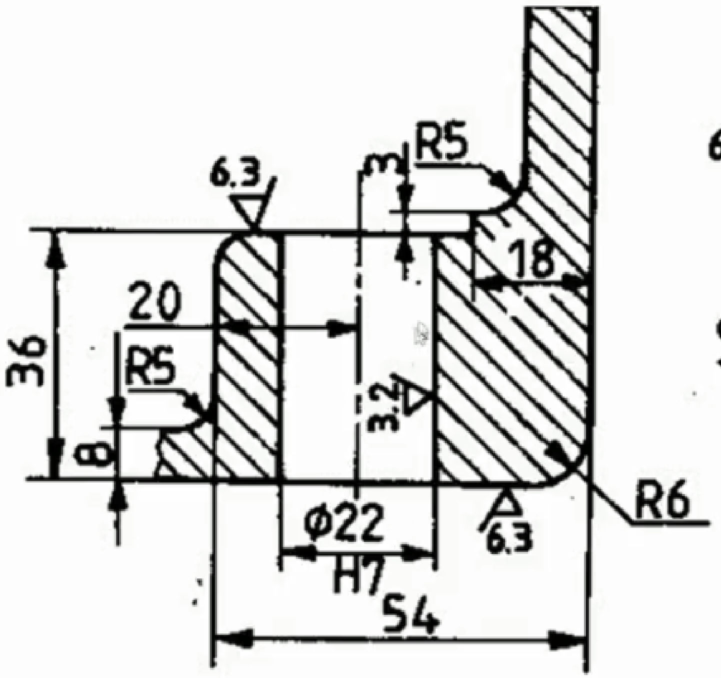
Lay Symbol	Meaning	Example Showing Direction of Tool Marks
=	Lay approximately parallel to the line representing the surface to which the symbol is applied.	
⊥	Lay approximately perpendicular to the line representing the surface to which the symbol is applied.	
X	Lay angular in both directions to line representing the surface to which the symbol is applied.	
M	Lay multidirectional.	

Lay Symbol	Meaning	Example Showing Direction of Tool Marks
C	Lay approximately circular relative to the center of the surface to which the symbol is applied.	
R	Lay approximately radial relative to the center of the surface to which the symbol is applied.	
P[3]	Lay particulate, non-directional, or protuberant.	

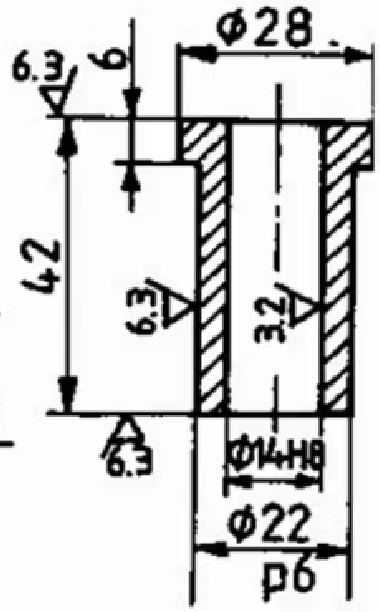
INDICATION OF SURFACE TEXTURE ON DRAWINGS



BUSH

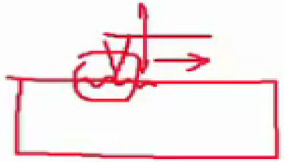


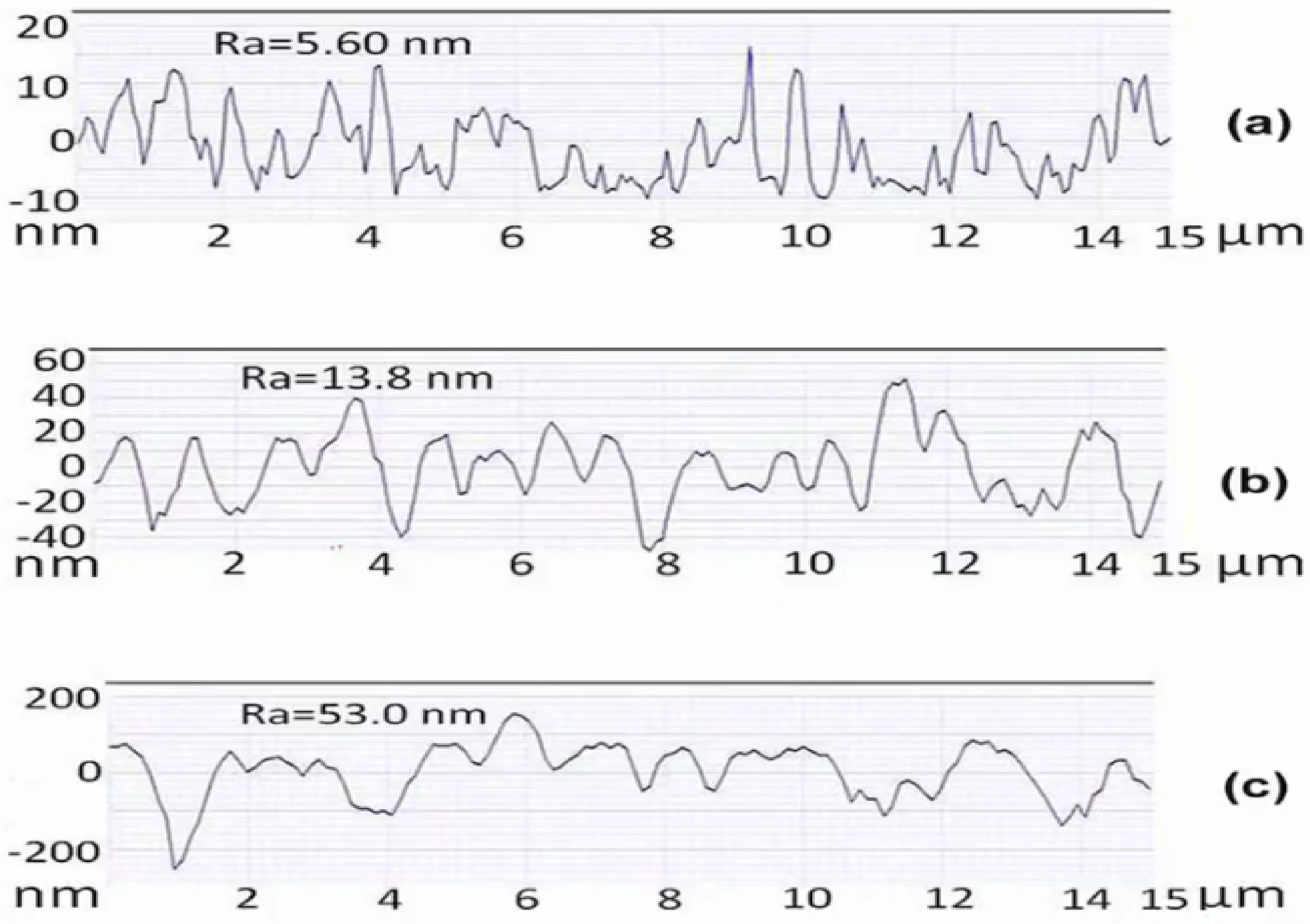
BODY



BUSH

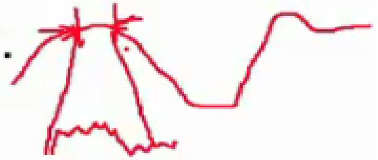
Roughness profiles





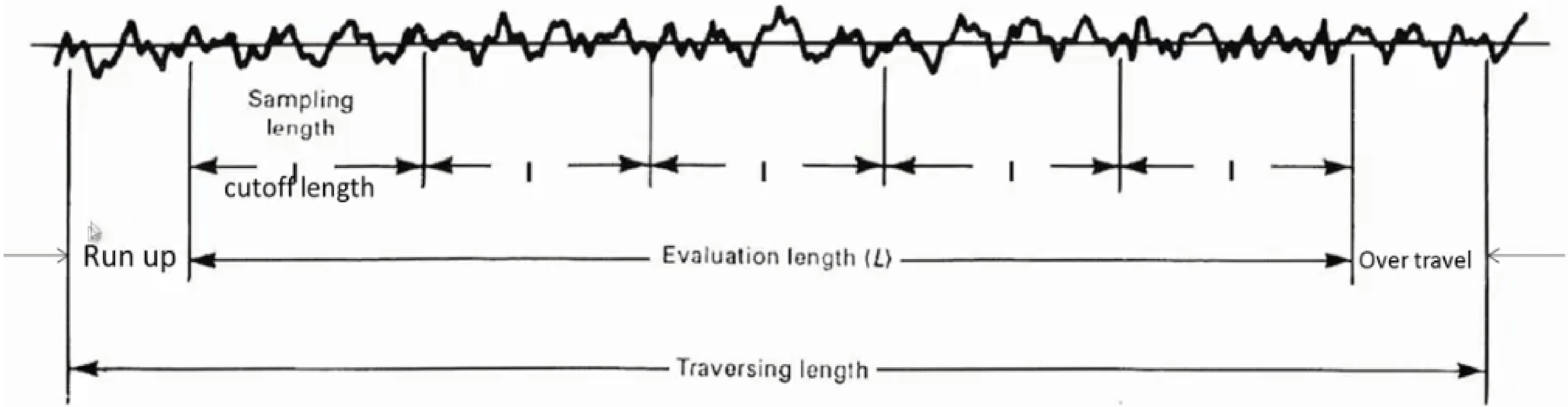
Roughness parameters

- **Mean Line** - A straight line that is generated on the profile resulting in equal areas above and below the line. Also known as **centre line**.
- **Profile** - A two dimensional slice through an area.
- **Roughness Parameters** - The non-periodic finer irregularities in the surface texture which are inherent in the production process. These are a measure of the vertical characteristics of the surface.



- **Sampling Length** - The area selected for assessment and evaluation of the roughness parameter having the cutoff wavelength. Any surface irregularities spaced farther apart than the sampling length are considered waviness. Also known as **cutoff length**.

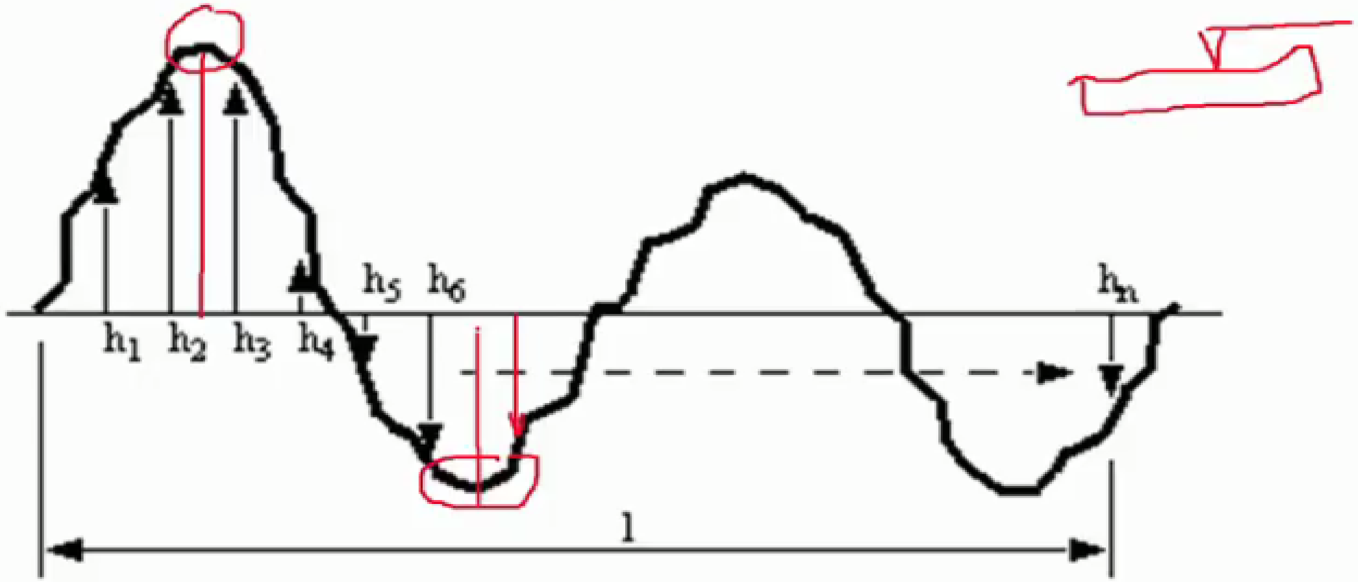
Surface Profile Measurement Lengths



CONTENTS

- Roughness parameters
- Methods of surface finish measurement : contact and non-contact
- Elements of stylus instruments: skid, stylus, out-of –phase of skid
- Selection of measuring parameters: cut off length
- Experiments

Ra –Roughness average (CLA)

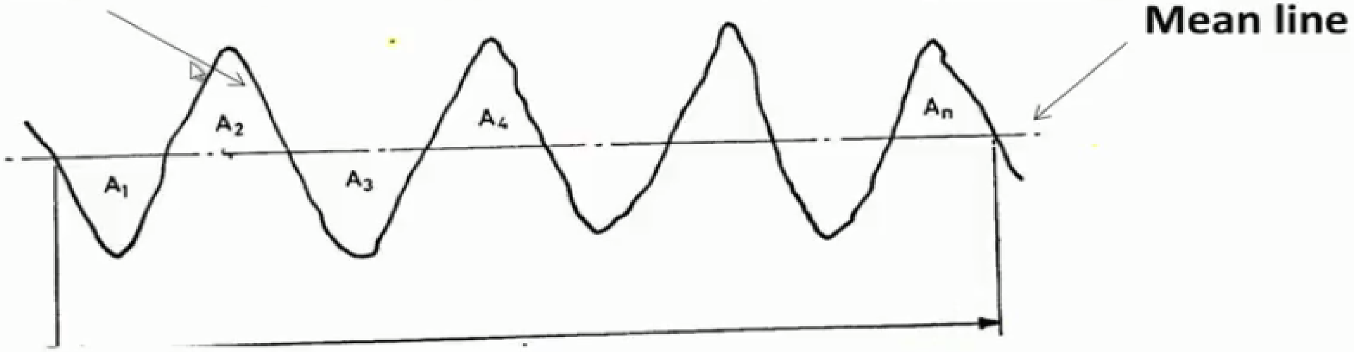


Roughness average Ra is the arithmetic average of the absolute values of the roughness profile ordinates.

Ra = Σh/n

Ra –Roughness average (CLA)

Areas can be measured using **planimeter**



$$R_a = \frac{A_1 + A_2 + A_3 + \ldots + A_n}{L}$$

$$= \frac{\Sigma A}{L}$$

Advantages of Ra

- The most commonly used parameter to monitor a production process.
- Default parameter on a drawing if not otherwise specified.
- Available even in the least sophisticated instruments.
- Statistically a very stable, repeatable parameter.
- Good for random type surfaces, such as grinding.
- A good parameter where a process is under control and where the conditions are always same, e.g. cutting tips, speeds, feeds, lubricant

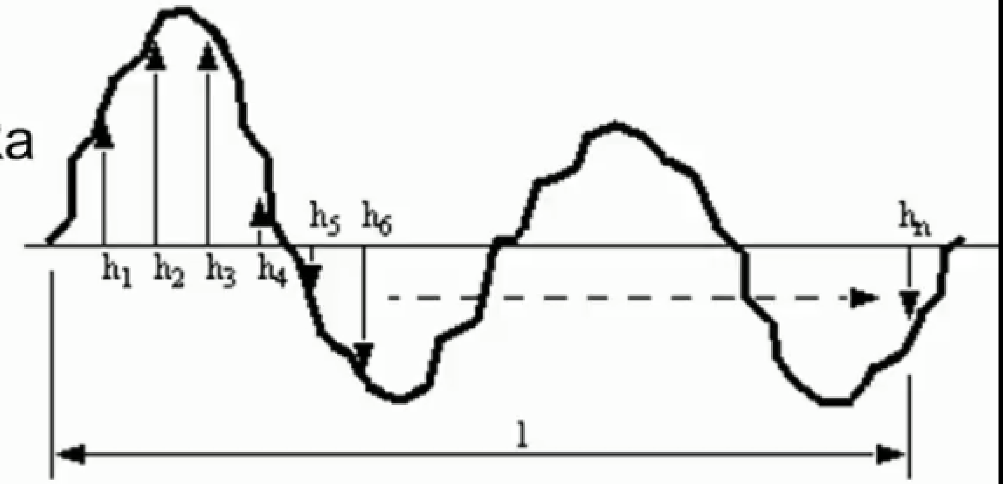
Disadvantage of Ra

- Not a good discriminator for different types of surfaces (no distinction is made between peaks and valleys).

Rq - Root Mean Square Roughness

Rq is typically 11% higher than Ra

Rq is more sensitive to peaks and valleys than Ra, because the amplitudes are squared.

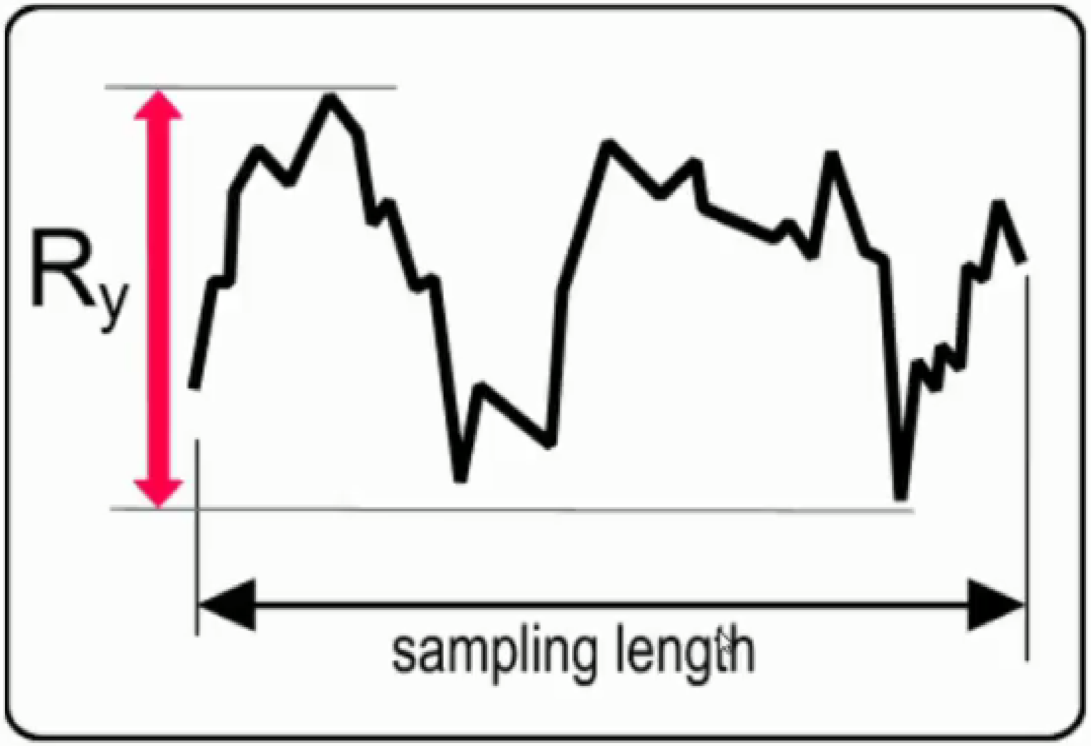


$$RMS = R_q = \sqrt{\frac{h_1^2 + h_2^2 + h_3^2 + \ldots + h_n^2}{n}}$$

Rq is used to control very fine surfaces in scientific measurements and statistical evaluations.

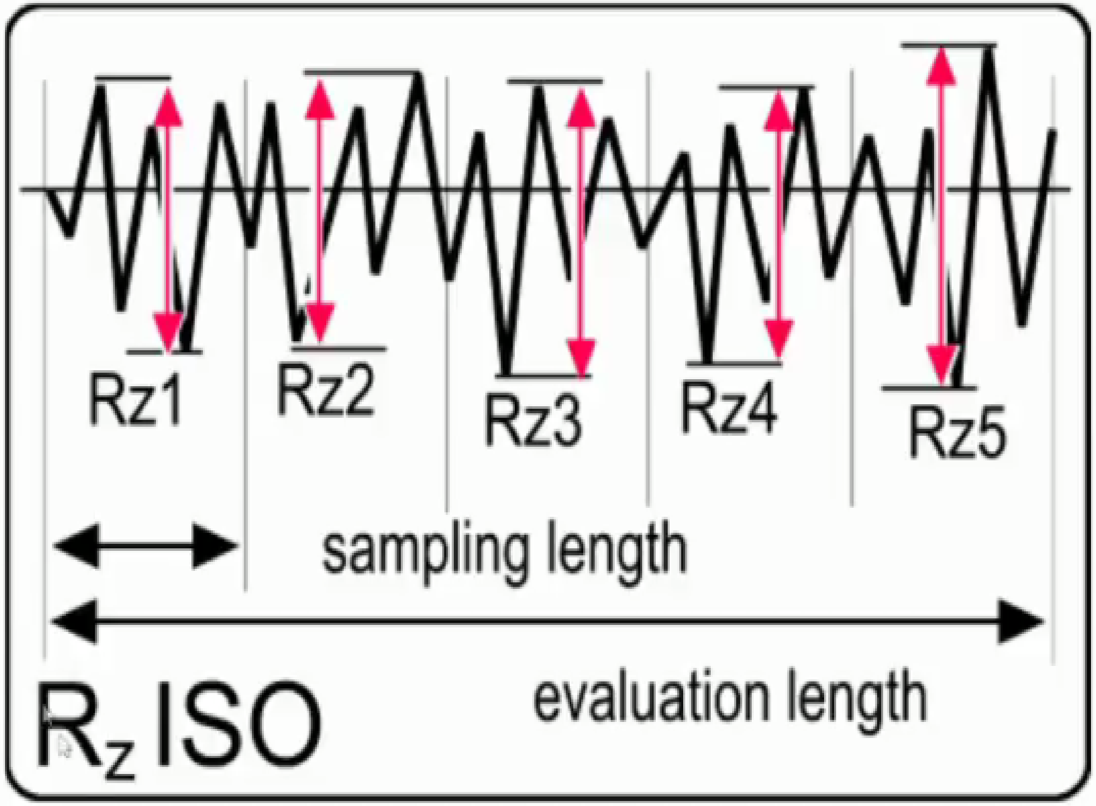
Ry (Rmax)

Maximum peak-to-valley distance. The vertical distance between the top of the highest peak and the bottom of the deepest valley within the sampling length. It is the maximum of all the peak-to-valley values.

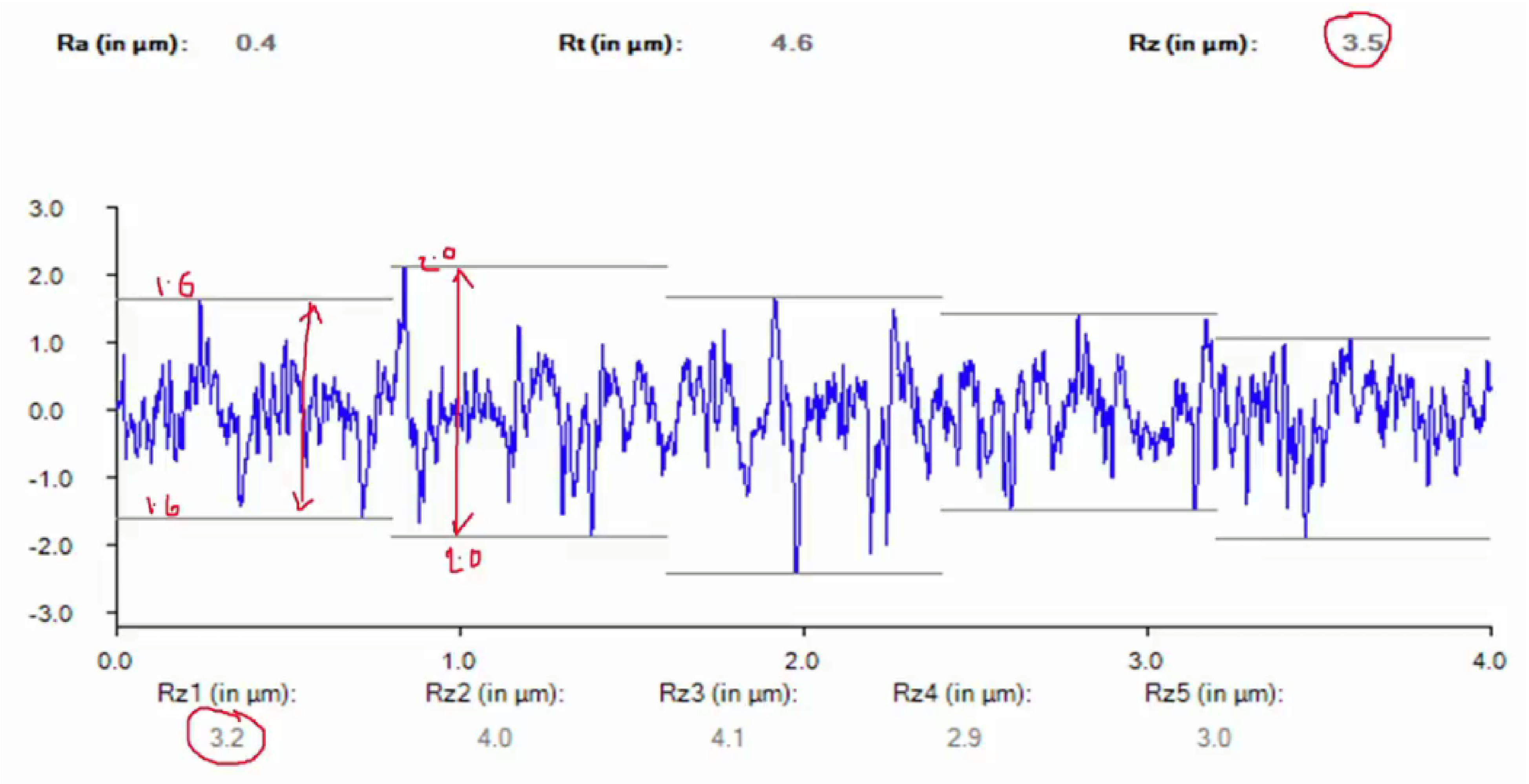


Rz ISO

Average peak-to-valley profile roughness. The average peak-to-valley roughness based on one peak and one valley per sampling length. The single largest deviation is found in five sampling lengths and then averaged.



- Rz is more sensitive than Ra to changes in surface finish as maximum profile heights and not averages are being examined.
- Rmax is useful for surfaces where a single defect is not permissible, e.g. a seal with a single scratch.
- Rz and Rmax are used together to monitor the variations of surface finish in a production process. Similar values of Rz and Rmax indicate a consistent surface finish, while a significant difference indicates a surface defect in an otherwise consistent surface.



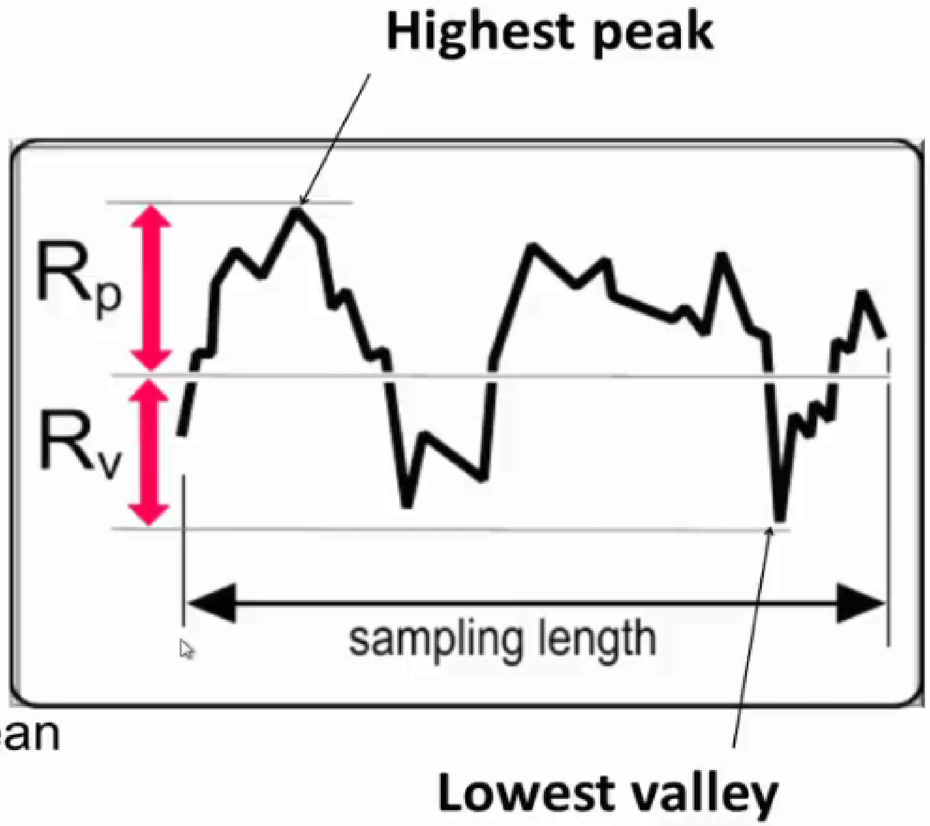
Ra (in µm): 0.4
Rt (in µm): 4.6
Rz (in µm): 3.5
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0.0
1.0
2.0
3.0
4.0
1.6
1.6
2.0
2.0
Rz1 (in µm): 3.2
Rz2 (in µm): 4.0
Rz3 (in µm): 4.1
Rz4 (in µm): 2.9
Rz5 (in µm): 3.0

Rp (Peak)

Highest peak. The maximum distance between the mean line and the highest point within the sample. It is the maximum data point height above the mean line through the entire data set.

Rv (Valley)

Lowest valley. The maximum distance between the mean line and the lowest point within the sample. It is the maximum data point height below the mean line through the entire data set



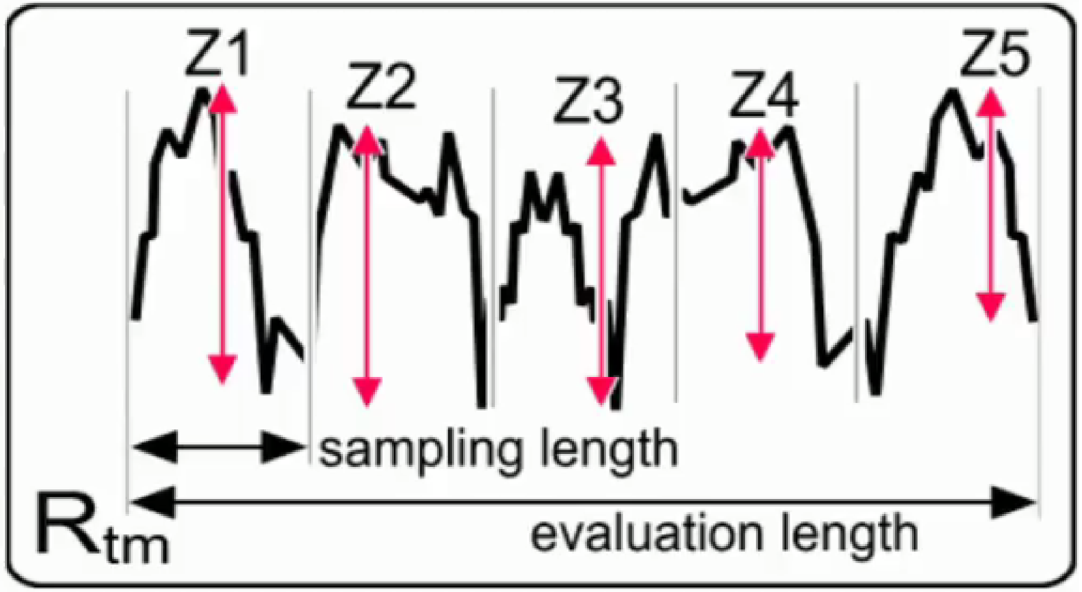
Rt (PV)

Maximum peak-to-valley height. The absolute value between the highest and lowest peaks.

$$R_t = R_p + R_v$$

Rtm

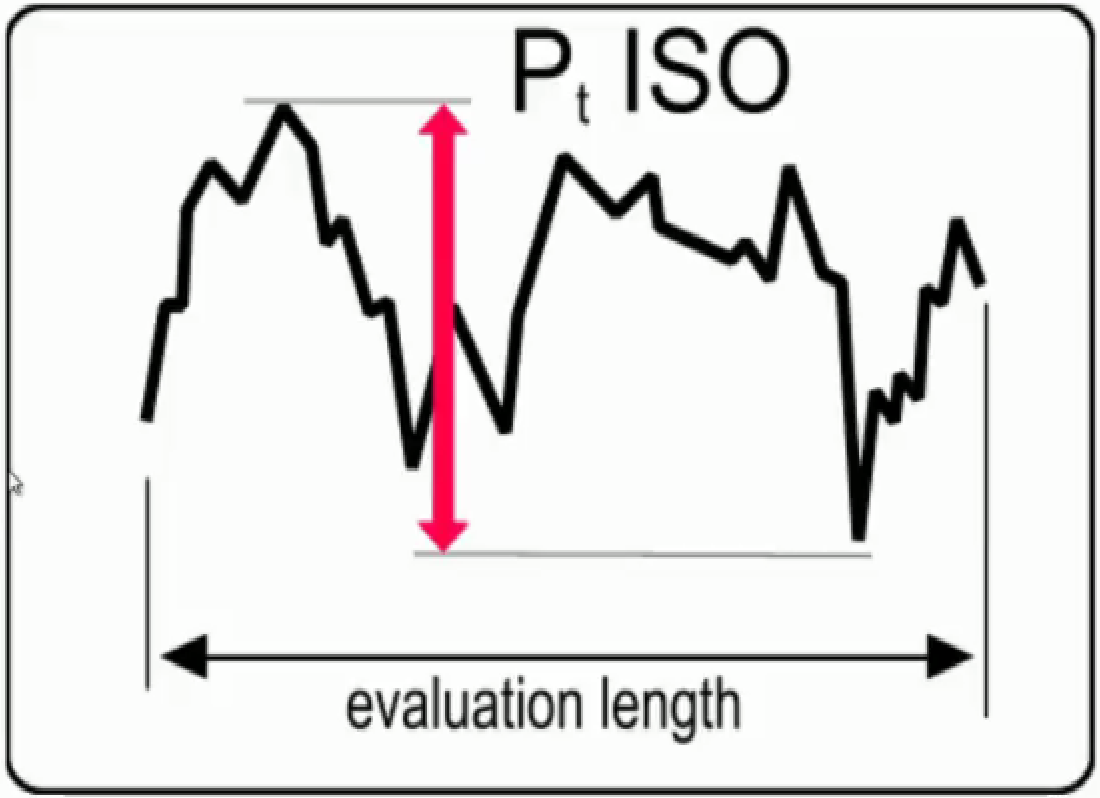
Mean peak-to-valley roughness. It is determined by the difference between the highest peak and the lowest valley within multiple samples in the evaluation length. For profile data it is based on five sample lengths.



$$R_{tm} = \frac{Z1 + Z2 ... + Zn}{n}$$

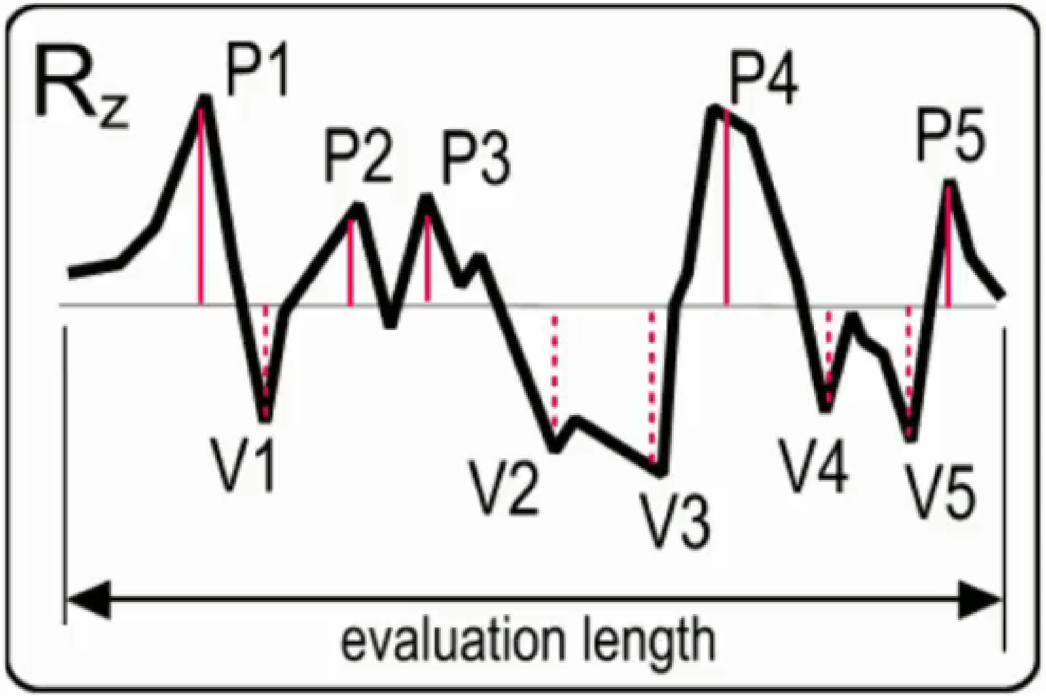
Pt ISO

Total peak-to-valley profile height. The distance between the highest peak and the deepest valley over the entire evaluation length.



10 point height average (Rz)

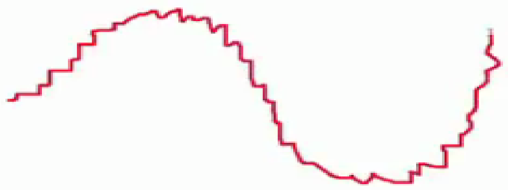
The average absolute value of the five highest peaks and the five lowest valleys over the evaluation length.



$$R_z = \frac{(P1 + P2 \ldots P5) - (V1 + V2 \ldots V5)}{5}$$

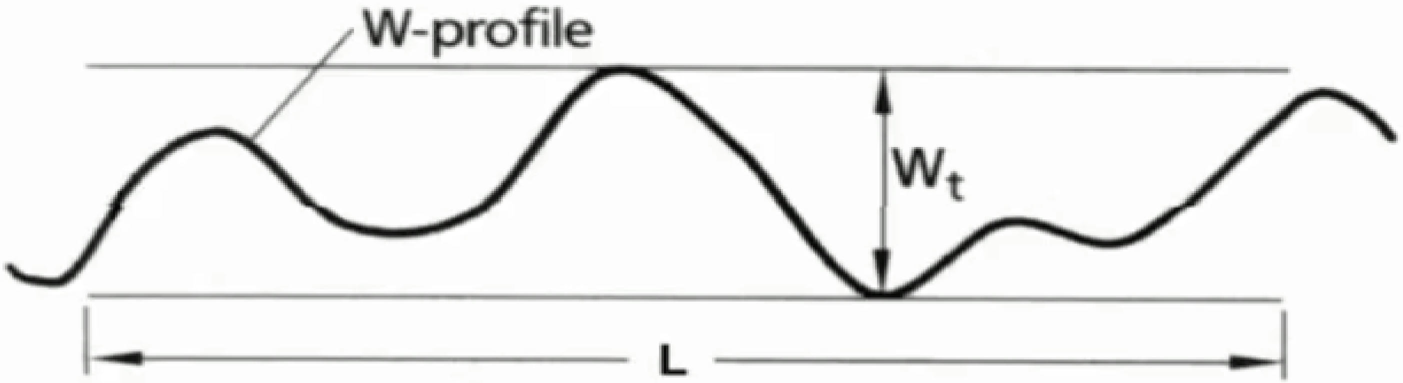
Waviness Parameters

Waviness is a larger component of surface texture upon which roughness is superimposed.



Waviness Height - Wt

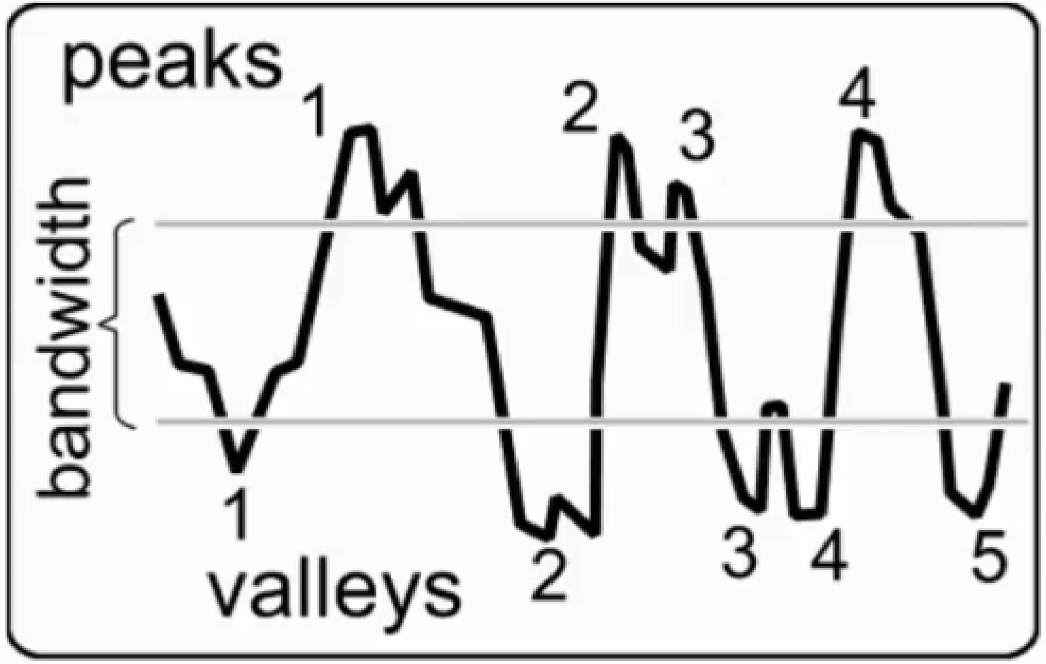
The maximum height of the waviness data, within evaluation length L



To monitor processes where in addition to roughness, waviness, possibly caused by vibrations (both within the machine and external), is also critical.

Spacing Parameters

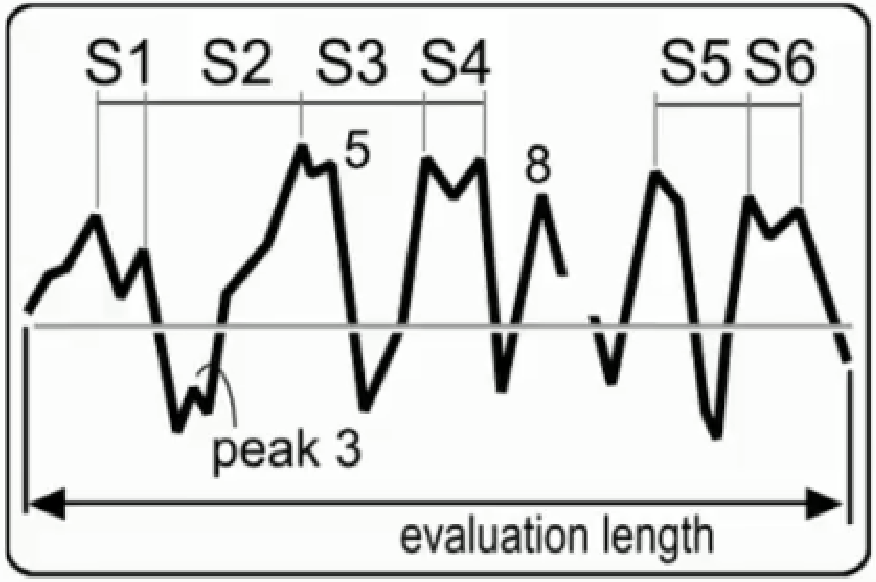
Pc
Peak count or the number of peaks included in the analysis. A peak is defined as a data point whose height is above a software selected bandwidth.



Peak density: The number of peaks per unit area.

S

The average spacing between local peaks over the evaluation length. The average spacing for the example shown is: $S = (S1+S2+\ldots+S6)/6$



Measurement of surface roughness

The roughness may be measured, using any of the following :

Off-line methods:

Contact type

1. Stylus probes
2. Mecrin 3

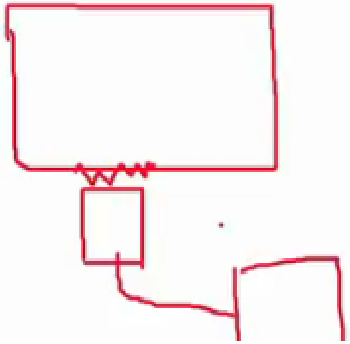
- **Non-contact type:**
  - Optical system:
    - Tool marker's microscope
    - Laser based system (Reflected light intensity)
    - Image processing system
  - Visual and tactile examination (comparison standards)
    - Rubert standard set

In-process measurement

Many methods are used to measure surface roughness in process.

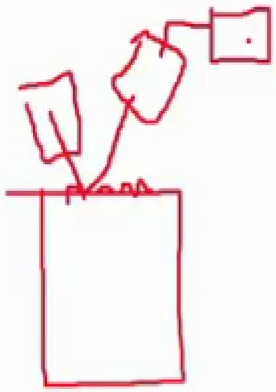
a. Machine vision: In this technique, a light source is used to illuminate the surface with a digital system to view the surface and the data being sent to a computer for analysis. The digitized data is then used with a correlation chart to get actual roughness values.

b. Inductance method: An inductance pickup is used to measure the distance between the surface and the pickup. This measurement gives a parametric value that may be used to give a comparative roughness. However, this method is limited to measuring magnetic materials.



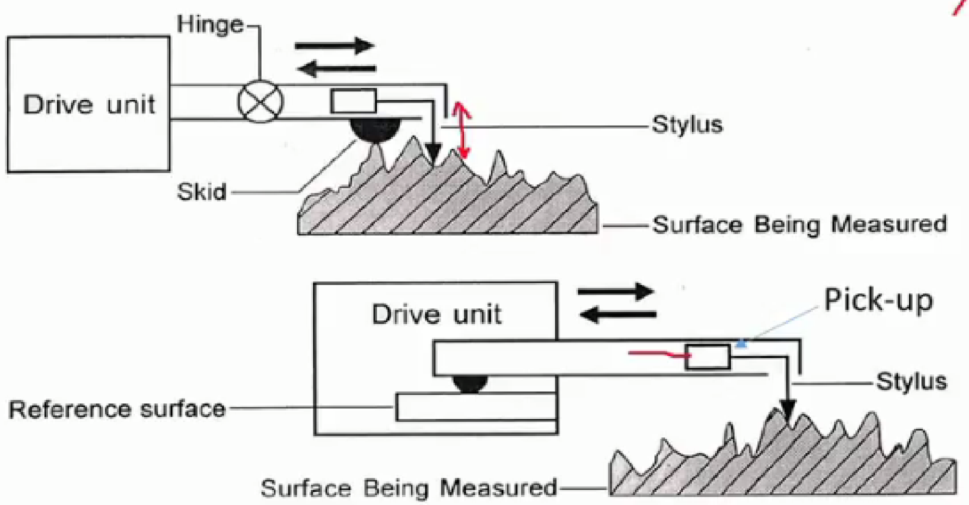
c. Ultrasound: A spherically focused ultrasonic sensor is positioned with a non normal incidence angle above the surface. The sensor sends out an ultrasonic pulse to the personal computer for analysis and calculation of roughness parameters.

d. Pneumatic method : Variation of back pressure in the nozzle is the measure of surface finish.

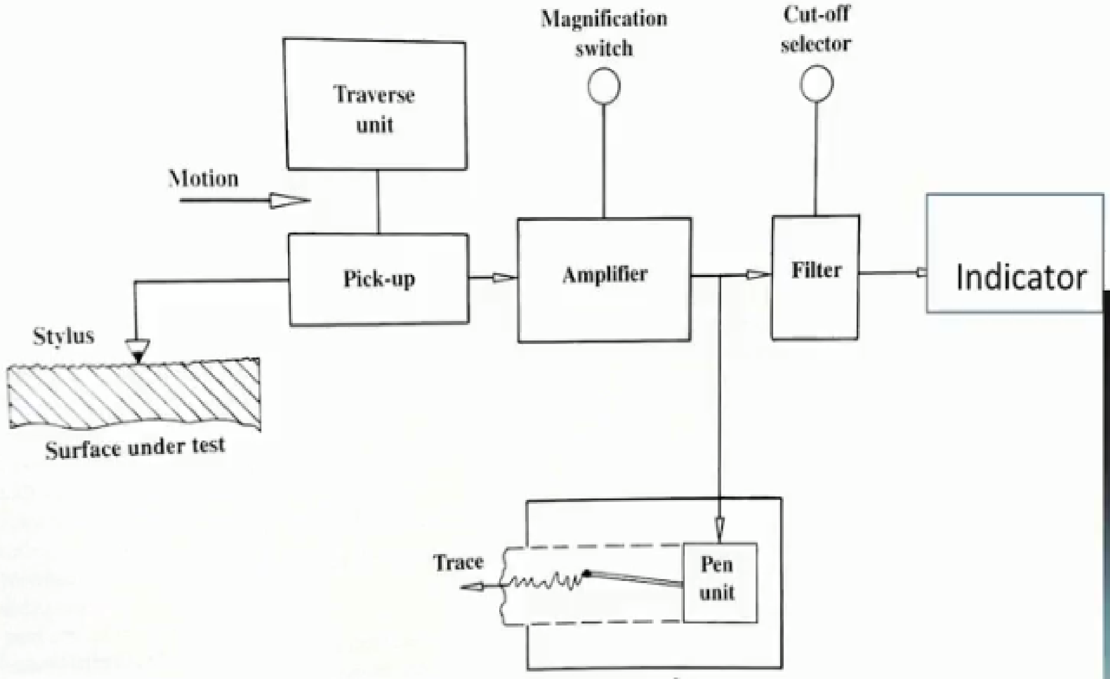


Stylus probe instruments

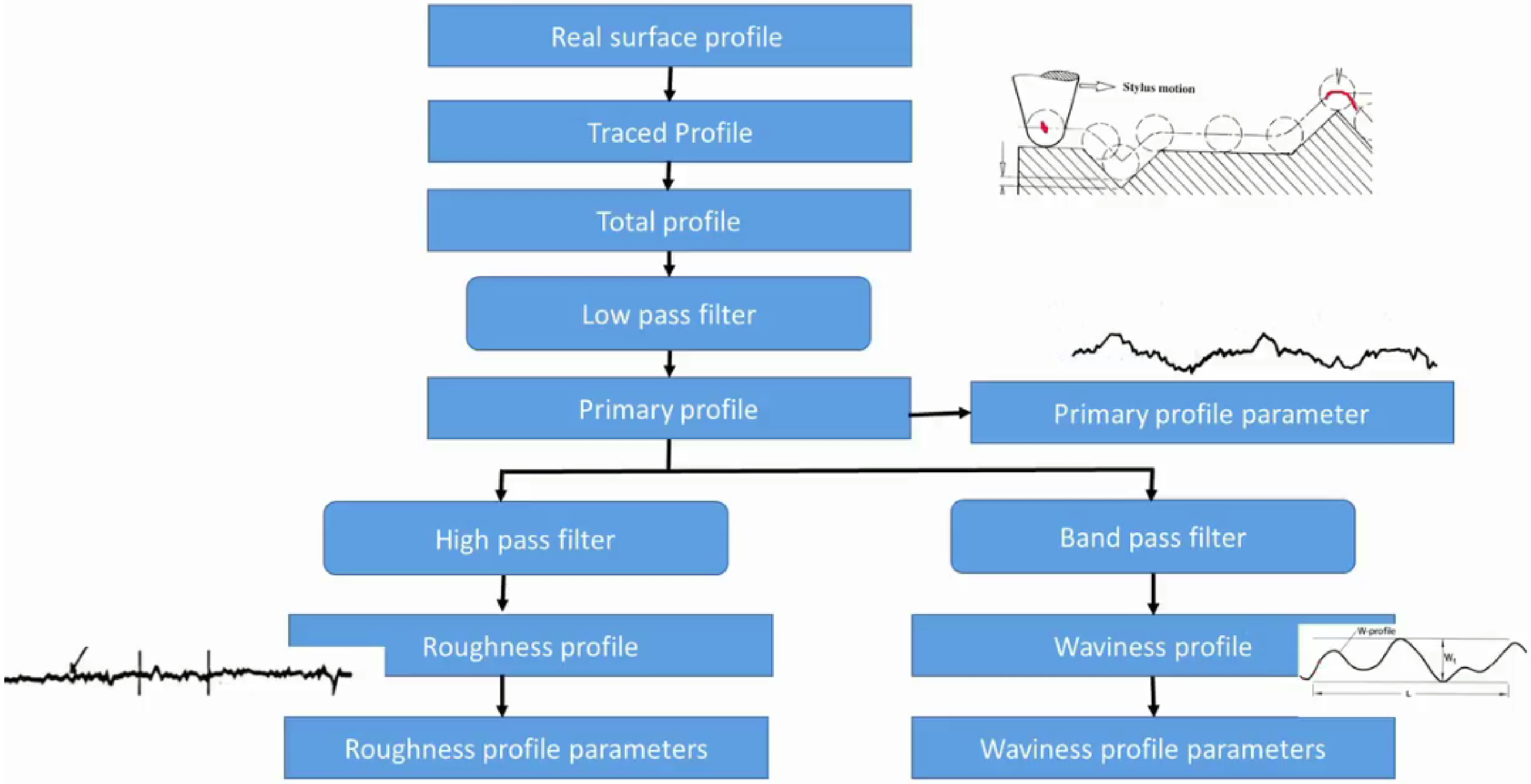
- Movement of stylus due to surface irregularities is used to compute roughness
- Stylus tip – 5 to10 micro meter radius, diamond
- Pointed probe drawn slowly over surface
- Magnification switch and cut-off selector, display and recorder



Elements of stylus type instrument



Data Processing



SURFACE ROUGHNESS MEASURING INSTRUMENTS

Measurement of surface finish:-

- The methods used for measuring surface finish are classified in to two groups

1. Inspection by comparison
2. Direct instrument measurement

Inspection by comparison

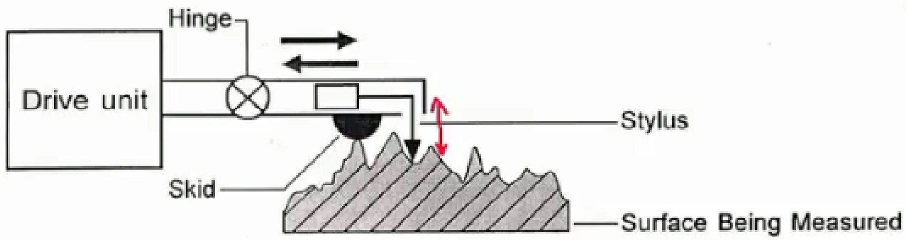
- Visual inspection
- Touch inspection
- Scratch inspection
- Microscopic inspection
- Surface photographs
- Micro interferometer
- Wallace surface dynamometer
- Reflected light intensity

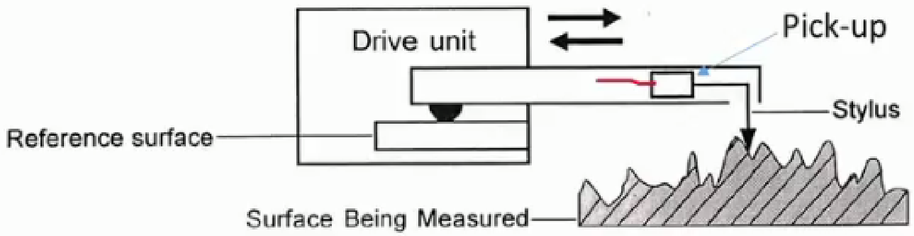
Direct instrument measurement

- These are the methods of quantitative analysis.
- These methods determine the numerical value of surface finish of any surface by stylus probe type instruments operating on electrical principles.
- In these instruments the output is amplified and is used to operate recording and indicating instrument.

Stylus probe instruments

- Movement of stylus due to surface irregularities is used to compute roughness
- Stylus tip – 5 to10 micro meter radius, diamond
- Pointed probe drawn slowly over surface
- Magnification switch and cut-off selector, display and recorder





Stylus probe instruments generally consist the fallowing instruments:-

- Skid or shoe
- Finely pointed stylus or probe
- An amplifying device for magnifying the stylus movement and indicator
- Recording device to produce a trace
- Means for analysing the trace

- Skid is drawn slowly over the surface by hand or motor drive. It fallows general contours of the surface and provides datum for measurements.
- The stylus moves over the surface with the skid. It moves vertically up and down due to surface irregularities and records the micro geometrical form of the surface.
- The stylus movements are magnified by an amplified device and recorded to produce the trace. The trace is then analysed by some automatic device incorporated in the instrument.

Advantages

- The available electrical signal can be processed to get any desired roughness parameter and it can be recorded for display or subsequent analysis.

Disadvantages

- These instruments are bulky and complex
- They are relatively fragile
- Initial cost is high
- need skilled operators for measurements
- Measurements limited to section of a surface.

Disadvantages contd…

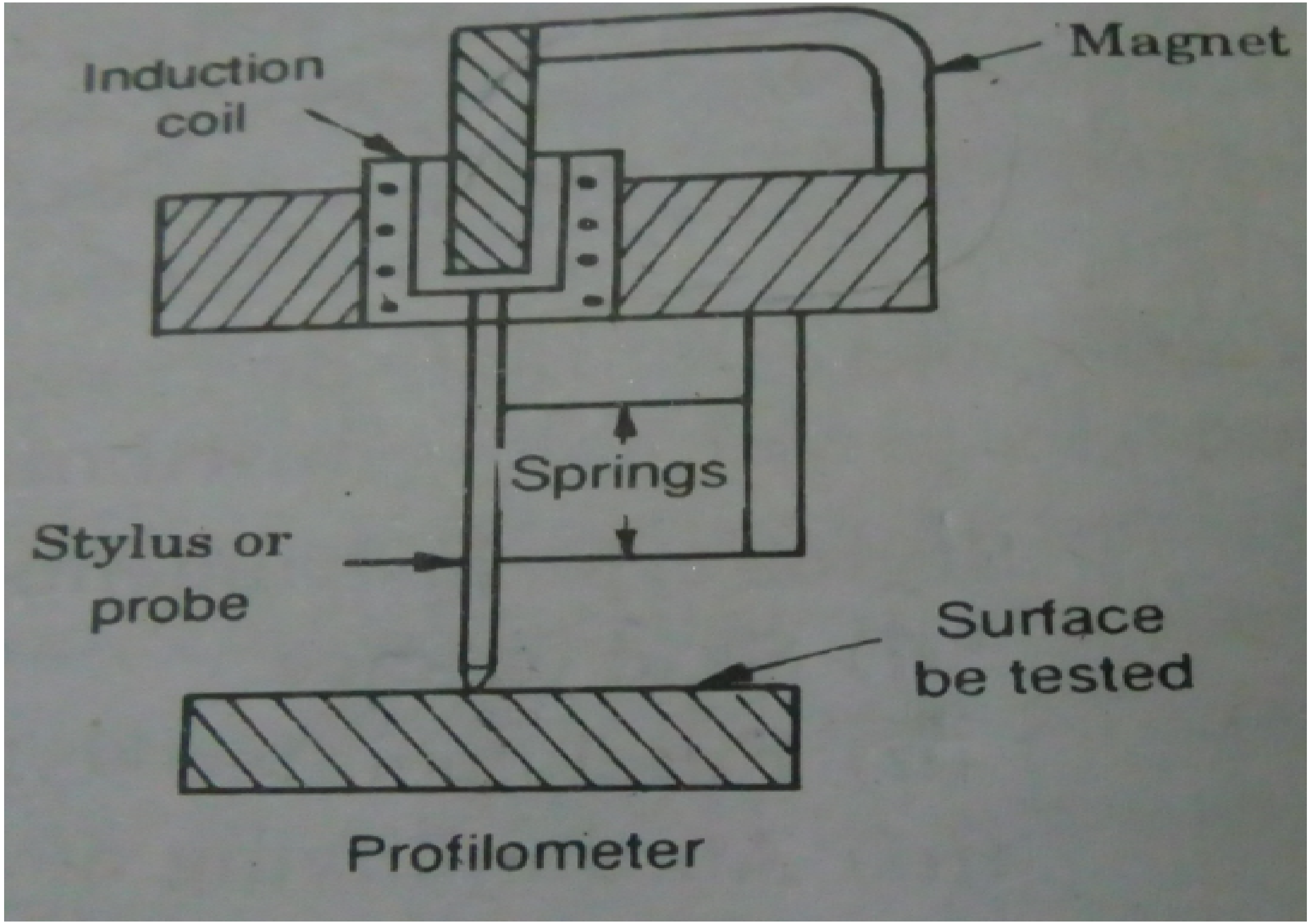
- Distance between stylus and skid and the shape of the skid introduce errors in measurement for wavy surfaces.
- **The stylus probe instruments currently in use for surface finish measurement**:-
- Profilometer
- The Tomlinson surface meter
- The Taylor Hobson Talysurf
- The sigma microtest

Contd…

- The Rubert Mecrin Roughness Indicator
- **Other methods for evaluating surface finish:-**
- profilograph

Profilometer

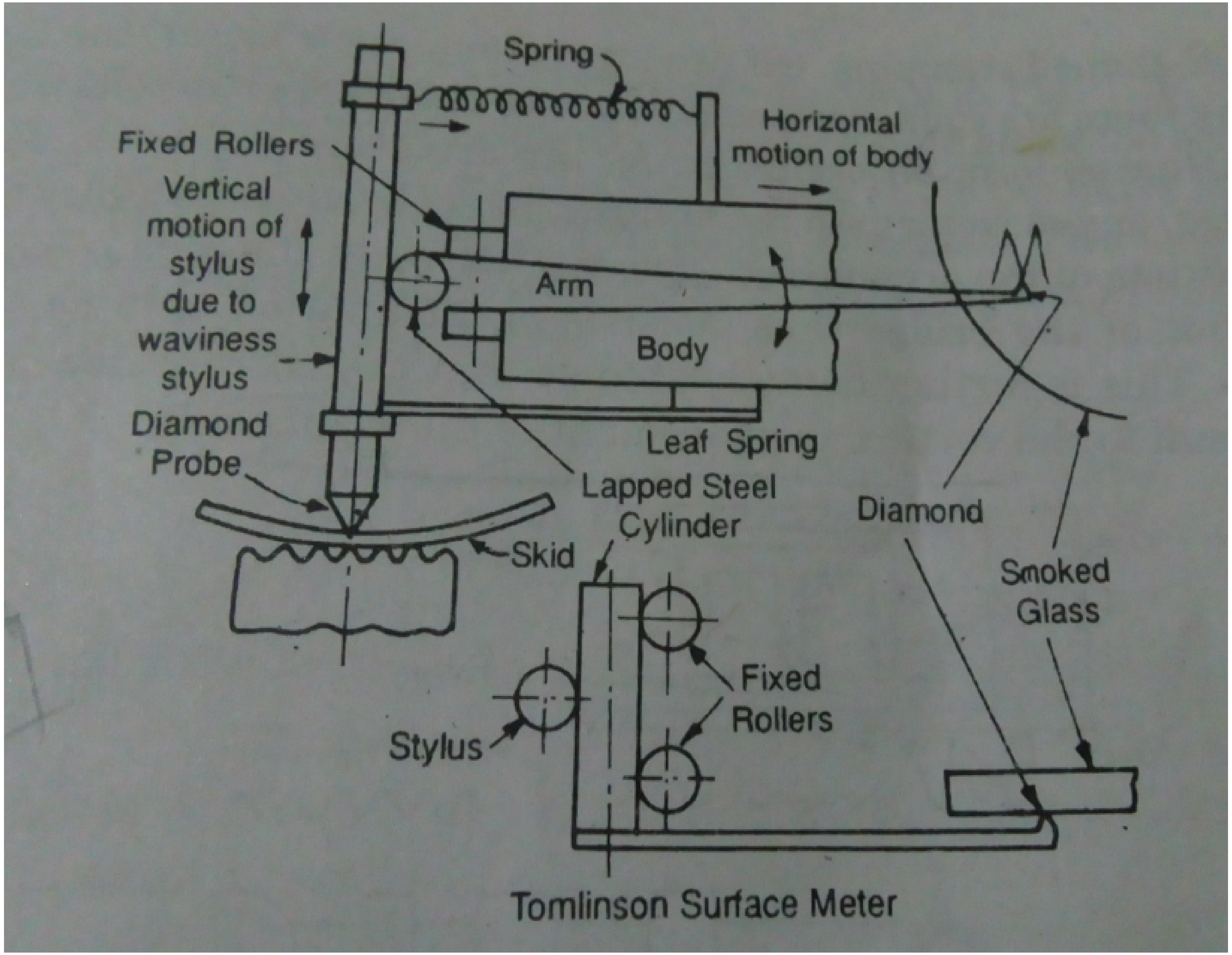
- Profilometer is an indicating and recording instrument to measure roughness in microns.
- The principle of the instrument is similar to gramophone pickup.
- It consists of two principle units: a tracer and amplifier
- Tracer is a finely pointed stylus. It is mounted in the pick up unit which consists of induction coil located in the field of permanent magnet.
- When the tracer moved across the surface to be tested, it is displaced vertically up and down due to the surface irregularities.
- This causes the induction coil to move in the field of permanent magnet and induces voltage. The induced voltage is amplified and recorded.
- This instrument suited for measuring surface finish of deep bores.


Magnet
Induction
coil
Springs
Stylus or
probe
Surface
be tested
Profilometer

The Tomlinson surface meter

- It consists of a diamond probe(stylus) held by spring pressure against surface of a lapped cylinder and is attached to the body of instrument by a leaf spring.
- The lapped cylinder is supported on one side by the probe and the other side by fixed rollers.
- A light spring steel arm attached to the lapped cylinder.
- It carries at its tip a diamond scriber which rests against smoked glass
- The motions of stylus in all the directions except the vertical one are prevented by the forces exerted by the springs.

- For measuring the surface finish the body of instrument is moved across the surface finish by screw rotated by a synchronous motor.
- The vertical movement of the probe caused by surface irregularities makes the horizontal lapped cylinder to roll.
- This causes the movement of the arm attached to the lapped cylinder.
- A magnified vertical movement of the diamond scriber on smoked glass is obtained by the movement of arm.
- This vertical movement of the scriber along with horizontal movement produces a trace on the smoked glass plate. This trace is further magnified by X50 SND X100 by an optical projector for examination.


Spring
Fixed Rollers
Horizontal motion of body
Vertical motion of stylus due to waviness stylus
Arm
Body
Diamond Probe
Leaf Spring
Lapped Steel Cylinder
Diamond
Skid
Smoked Glass
Fixed Rollers
Stylus
Tomlinson Surface Meter

The Taylor Hobson Talysurf

- Taylor – Hobson Talysurf is a stylus and skid type instrument working on carrier modulating principle. Its response is more rapid and accurate as compared to Tomlinson surface meter.
- The measuring head of this instrument consists of a sharply pointed diamond stylus of about 0.002mm tip radius and skid which is drawn across the surface by a motorised driving unit.
- In this instrument the stylus moves across the surface due to irregularities on surface causes the oscillatory movement of the stylus and it is converted in to changes in electrical current by the arrangement.

- The arm carrying the stylus forms the armature which pivots the centre piece of E shaped stamping . On other two legs of the E shaped stamping there are coils carrying a.c current.
- These two coils with two resistors forms a oscillator. As the armature pivoted to the central leg, so any movement of the stylus causes to vary air gap and thus causes changes in amplitude a.c flows through coils.
- The output of this bridge is carried through carrier signal and passes through the amplifier and generates modulated carrier signal.
- Then this signal passes through the Demodulator then we get demodulated and smoothened signal then it is stored in the recorder for future use.
- The demodulated output passes through the filter then we get filtered wave form and based on that the meter to give numerical values of roughness parameters.

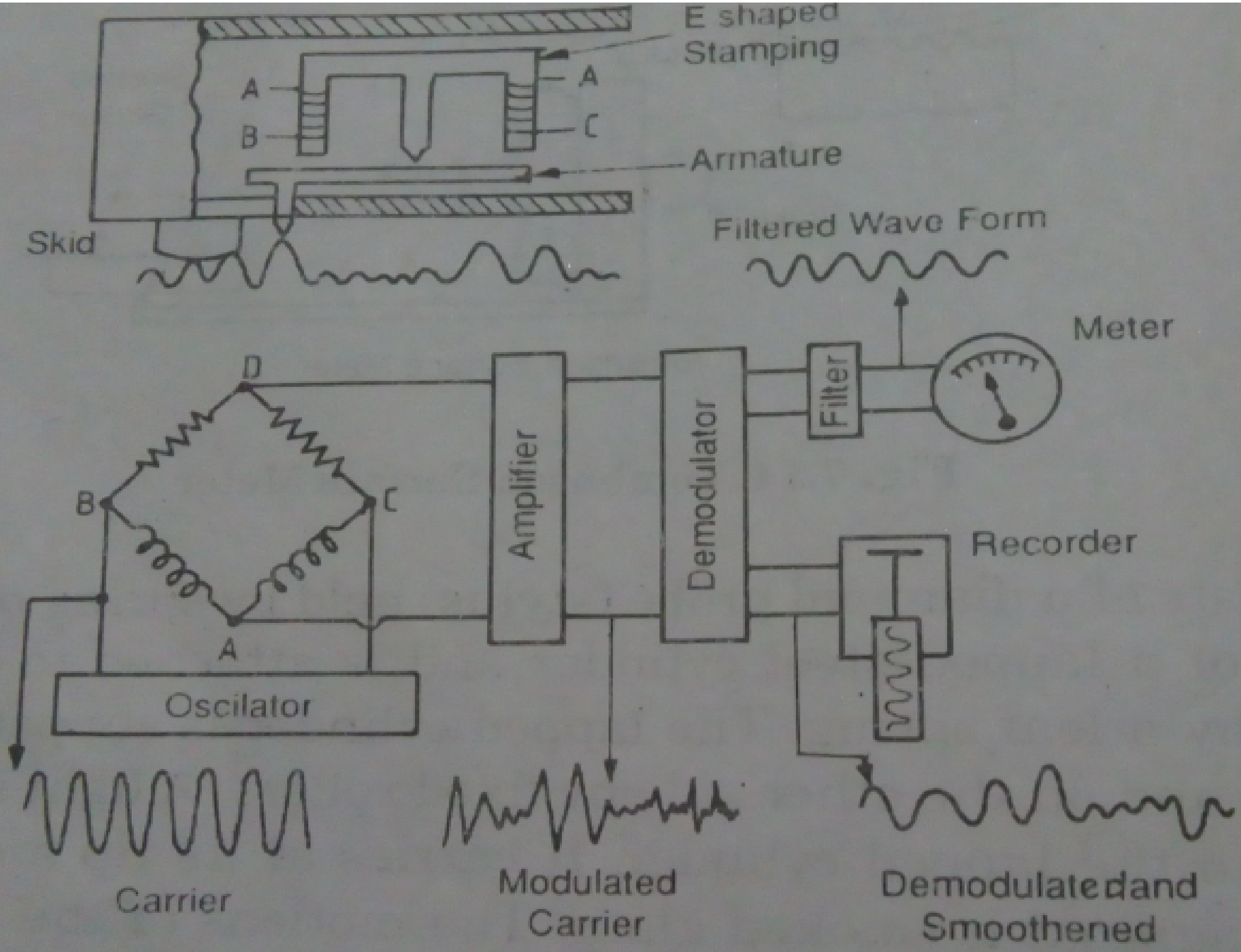


Fig. 7.15. Talyor-Hobson-Talysurf

profilograph

- The workpiece to be tested is placed over the table of the instrument. The table and the workpiece are moved with the help of lead screw.
- The stylus is moved across the surface and is pivoted to the mirror. The oscillations of the stylus are transmitted to the mirror. A light source sends a beam of light through lens and precision slit to the oscillating mirror.
- The reflected beam directed towards the revolving drum, upon which a sensitised film is arranged. This drum is rotated with the help of bevel gears from the same lead screw that moves the table of the instrument.
- A profilogram will be obtained form the sensitised film, that may subsequently analysed to determine the values of roughness parameters.

screw.

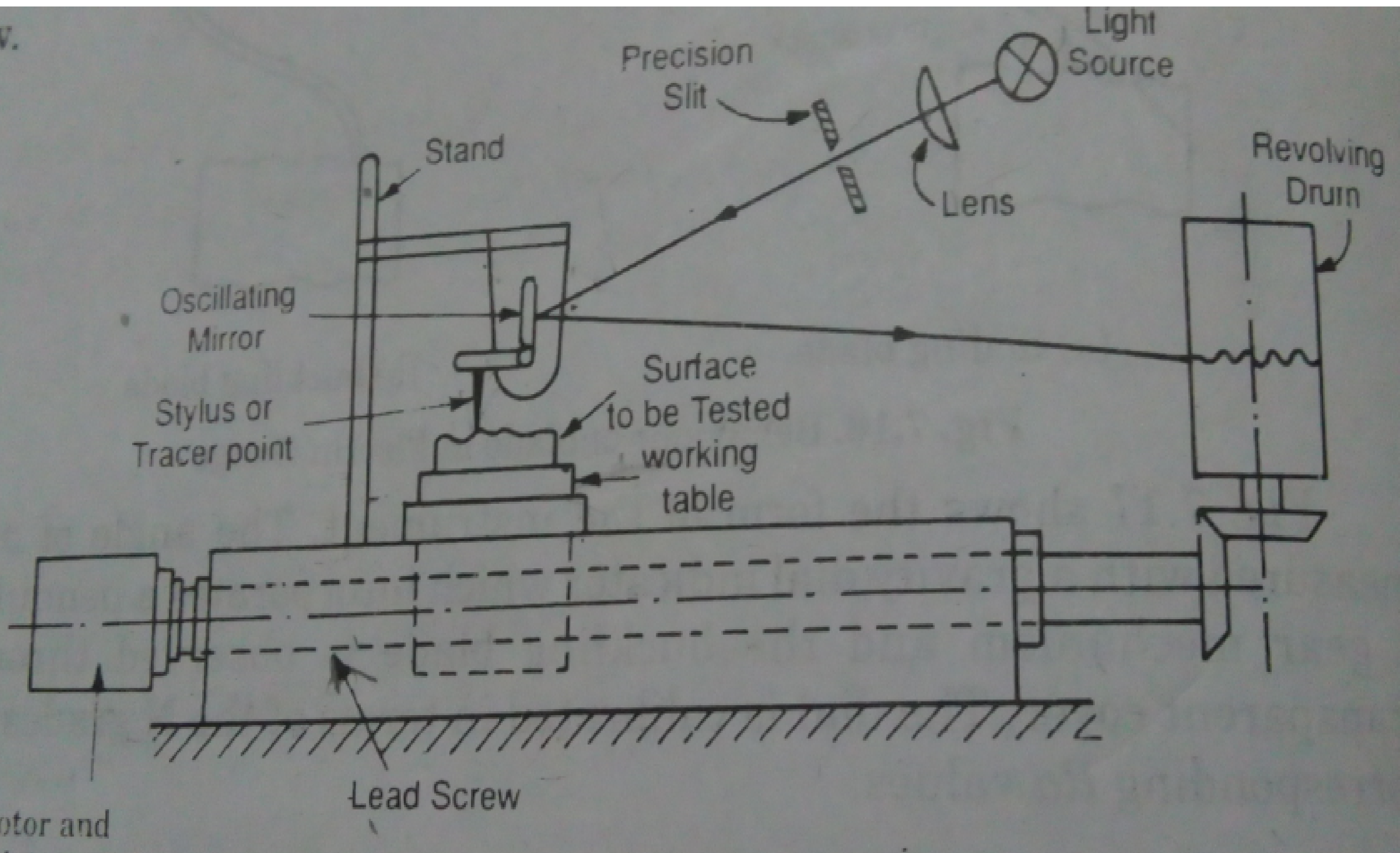


Fig. 7.18. Principle of the tracer-type profilogram